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ÖZET BİLDİRİLER/ ABSTRACT PRESENTATIONS

Sürdürülebilir Çevre Teknolojileri Kapsamında Atık Bitki Tabanlı CeO_2 Nanopartikül Sentezi

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Özet

Bu çalışma, bitki atıkları kullanılarak çevre dostu, hızlı ve ucuz bir yöntem olan yeşil sentez aracılığıyla seryum oksit (CeO_2) nanopartiküllerinin (CeO_2 NP) elde edilmesi ve spektroskopik yöntemlerle karakterizasyonunu içermektedir. Kimyasal veya fiziksel yöntemlerle nanopartikül sentezlenmesi yerine bitki atıklarından hazırlanan su ekstraktı doğal indirgeme ve stabilize edici ajanlar olarak kullanılmıştır. Çünkü bitki materyalleri sekonder metabolitler dediğimiz biyoaktif bileşenler içermektedir. Sentezlenen nanopartiküllerin yapısal ve morfolojik özellikleri UV-Vis spektroskopisi, X-ışını difraksiyonu (XRD), Fourier dönüşümlü kızılötesi spektroskopi (FTIR) ve taramalı elektron mikroskobu (SEM)ile karakterize edilmiştir. Bu yöntemlerin ortaya koyduğu sonuçlar, CeO_2 NP'lerin başarılı bir şekilde sentezlendiğini ve bitki atıklarının bu süreçte etkili bir rol oynadığını göstermiştir. Tüm dünyada ekonomik ve çevre temizliği açısından sürdürülebilir kavramı önem kazanırken çalışmamız bu yönden de önem arz etmektedir. Elde edilen CeO_2 NP'ler tıp (antioksidan, anti kanser ve ilaç taşıma), çevre çalışmaları (atık su iyileştirilmesi), enerji sistemleri ve elektronik alanlarında, tarım sektöründe yaygın kullanılmalarıyla dikkat çekmektedir. Elde edilen sonuçlar, CeO_2 NP'lerin başarıyla sentezlendiğini ve atık bitkilerin çevre dostu nanoteknolojik uygulamalarda değerlendirilebileceğini ortaya koymuştur. Bu çalışma, çevre teknolojileri ve sürdürülebilir nanomalzeme üretimi alanlarına katkı sunmayı amaçlamaktadır.

Anahtar Kelimeler: *Seryum oksit nanopartikül, Yeşil sentez, Bitki atıkları, Karakterizasyon, Sürdürülebilir nanoteknoloji*

Formaldehit Kullanılan Tıbbi Laboratuvarlarda Maruziyet Tespit Etkinliğinin TWA, STEL, VOC Yöntemleri ile İncelenmesi

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Abstract

Tıbbi laboratuvar tanımı güncel mevzuatta; insan sağlığının değerlendirilmesi, hastalıkların önlenmesi, tanı ve tedavi sürecinin izlenmesi ile prognoz öngörüsü amacı ile biyolojik materyallerin incelendiği, sonuçların raporlandığı, gerektiğinde yorumlandığı ve ileri incelemeler için önerileri de içeren hizmetlerin sunulduğu laboratuvar olarak tanımlanmaktadır. Eğer tıbbi laboratuvarda formaldehit gibi buharının solunması ile toksik etkilerinin ortaya çıktığı WHO tarafından kabul edilmiş bir kimyasal kullanılması halinde laboratuvarda; çalışanların soluduğu hava düzeyine ve laboratuvar ortamında çalışanları formaldehit buharı gazından menfi etkilenmesini engelleyen havalandırma sistemlerin kurulması ve tıbbi laboratuvar alanına uygun, kalibre edilmiş ve sertifikalı formaldehit buharı varlığı ve gaz düzeyini dedekte edecek ölçüm cihazı ile veya yaka kartı ile solunum düzeyinde ölçüm yapılarak maruziyet düzeyi belirlenir. Çalışanların maruziyeti halinde formaldehit metabolitlerinin kan veya idrarda tespit edilmez ancak dedektör ile gaz ölçümü kullanıcıya ortamda bulunan anlık maruziyet hakkında kalitatif bilgi verirken solunum düzeyinde yaka kartı ile ölçüm ise kişisel maruziyet düzey miktarı hakkında kantitatif bilgi vermektedir.
Anabilim Dalımızda; 2013-2023 yılları arasında farklı zaman aralıklarında, aynı çalışma alanlarında solunum düzeyinde yaka kartı ile TWA(sekiz saatlik), stel(15 dakikalık), VOC (Volatile Organic Compounds ; Uçucu Organik Bileşikler) tespit cihazı ile momentary (anlık) 23 farklı ölçüm yapılmıştır. Aynı teknik alanda yer alan farklı noktalarda; 22 ölçüm TWA, STEL ve VOC ölçümlerinde kabul edilebilir değerlerde bulunmuştur. İki noktada yapılan ölçümde elde edilen değerlerde en az bir ölçüm değerinin kabul edilebilir nitelikte diğer iki değerin ise kabul edilebilir değerin üzerinde olduğu görülmüş bu noktalarda düzenleyici önleyici faaliyet raporu hazırlanmıştır. Bu noktalarda; STEL değerlerin kabul edilebilir sınırlarda olmasına rağmen VOC değerlerin limit üzerinde kaldığı anlaşılmaktadır.
Tüm sonuçlar toplu halde incelendiğinde, TWA ve STEL değerlerinin çalışma alanı ve görev niteliklerine uygun olduğu, VOC değerlerinin ise STEL solunum düzeyi değerlerinin % 0,1 ile % 0,8 arasında yüksek değer almakla birlikte yakın değerler almıştır. Kabul edilebilir limit üzerinde kalan ölçümler ayrıca incelendiğinde TWA ve STEL değerler kabul edilebilir limitlerde kalmasına karşın VOC değerlerin limit üzeri kalması; formaldehit gazı buharının solunum düzeyinde yaka kartı ile tespit mesafesinden daha hızlı yayıldığı, anlık ölçümlerde anlamlı fark olmamasına rağmen VOC ölçüm etkinliğinin yaka kartı ölçümlerinden ancak % 10'a kadar yüksek olduğunu göstermektedir.

Key words: *Formaldehyde, TWA, STEL, VOC, OSHA*

Graph Neural Network-Based HCV Diagnosis Using Transductive Learning on Biochemical Features

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Abstract

Hepatitis C Virus (HCV), a widespread bloodborne pathogen, plays a major role in the global prevalence of chronic liver disorders, particularly cirrhosis and hepatocellular carcinoma. Timely and accurate detection of HCV is essential for preventing disease progression and improving patient outcomes. Traditional diagnostic methods, while effective, can be invasive and expensive, emphasizing the need for more accessible, non-invasive alternatives. In this context, machine learning (ML), and more recently Graph Neural Networks (GNNs), have gained prominence for their ability to model complex relationships within biomedical data. This study investigates the classification of HCV using a biochemical dataset comprising features such as age, sex, ALB, ALP, ALT, AST, BIL, CHE, CHOL, CREA, GGT, and PROT. SMOTE-NC (Synthetic Minority Over-sampling Technique for Nominal and Continuous features) was applied to balance the class distribution. A graph was constructed using the k-nearest neighbors algorithm with k=14, forming edges based on feature similarity in a transductive setting. Although GraphSAGE is primarily designed for large-scale graphs with dense relational structure, our experiments demonstrate that it performs remarkably well even on tabular biomedical datasets like HCV. The model architecture includes four graph convolutional layers with residual connections, Leaky ReLU activations, dropout, and was optimized using AdamW over 1000 epochs. Performance was validated across 10 independent train-test splits. The GraphSAGE model achieved robust and consistent results with accuracy and F1-score of 99.29% ± 0.28. Additionally, classical ML models such as random forest, gradient boosting, k-nearest neighbors, support vector machine, and decision tree yielded F1-scores and accuracy values ranging from 95.72% to 99.29%, with standard deviations between 0.28 and 0.85. These findings suggest that while both approaches are viable, GraphSAGE provides a robust and flexible alternative to traditional ML, especially with better feature selection and parameter tuning. Its adaptability to a variety of parameter configurations makes it a promising tool in biomedical diagnosis setting.

Keywords: *HCV, Graph Neural Networks, Machine Learning, Biochemical Data, Diagnosis*

Meta-Learning for Stock Price Forecasting: An Ensemble Component Based Approach with STL Decomposition

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Abstract

The stock market is highly arduous to predict due to its nature. As a result of market noise, volatility, and external influences such as economic indicators, geopolitical events, and investor sentiment, stock price prediction is inherently challenging. It's observed in the existing literature that when a single univariate model is used to model stock prices, the models have difficulty fully detecting price movements. For this reason, we developed a daily forecasting framework applied to the BIST30 index, focusing on the THYAO stock. We decomposed the data into components using STL and predicted each component individually by selecting an appropriate modeling approach based on its characteristics. The trend component is modeled by Ridge Regression thanks to its capability of applying regularization to prevent overfitting, and the seasonal component is modeled using TCN, a CNN-based architecture. The residual component which captures irregular and volatile fluctuations, is modeled using an ensemble approach This component is handled through a sophisticated ensemble method that combines XGBoost, GARCH, and spike detection techniques as input to XGBoost meta model. Finally, we combined their predictions into a meta-learner based on Lineer Regression to generate the final forecast. Empirical evaluations demonstrate significant improvements on stock price prediction accuracy, with evaluation metrics of MAE: 1.5574 and MAPE: 0.53%. The study found that ensemble meta-learning techniques and decomposed component based predictions significantly increased the accuracy of stock price predictions.

Key words: *Price Forecasting, Data Decomposition Machine Learning, Deep Learning, Meta-Learning*

Assessment of Commercial and CTAB-Based DNA Extraction Protocols for Microbial Profiling in Bread

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Abstract

Isolating high-quality DNA from fermented bread products presents a significant difficulty due to the presence of complex carbohydrates, inhibitors, and a diverse microbial life within the matrix. This study aimed to assess the efficacy of two commercial DNA extraction kits, GeneSpin and NucleoSpin in isolating genomic DNA from bread derived from Triticum monococcum. A manually tailored CTAB-based extraction process was concurrently employed to evaluate its effectiveness as an alternate method for DNA recovery from starch-rich, fermented food samples.

DNA was extracted using the commercial kits as well as the manually optimized CTAB protocol. The performance of each extraction method was comprehensively evaluated by measuring DNA yield (expressed in ng/µL) and assessing purity ratios (A260/A280 and A260/A230) using a NanoDrop™ spectrophotometer. These metrics provided insight into nucleic acid concentration and the presence of potential contaminants such as proteins, phenolic compounds, or polysaccharides, which are particularly relevant in starch-rich, fermented matrices like sourdough bread.

The comparison investigation indicated that NucleoSpin provided the best yield and most consistent quality DNA, closely followed by GeneSpin, both designed for complex food matrices. Despite its labor-intensive nature, the CTAB method yielded high-molecular-weight DNA with minimal fragmentation and superior purity. This made it a promising candidate for downstream applications such as PCR and metagenomics. However, for successful application in high-throughput sequencing workflows, the CTAB method requires additional optimization steps to effectively remove inhibitors and improve performance. Its success is critically dependent on precise execution, reagent freshness, and the incorporation of specific purification modifications tailored for starch-heavy substrates like bread.

Following extraction, the DNA samples have been undergoing 16S rRNA gene sequencing and metagenomic analysis, further confirming the effectiveness of the optimized methods in studying fermented food microbiomes.

Key words: *DNA extraction, Microbiome , Fermented food*

Üniversite Öğrencilerinin Yapay Zeka Okuryazarlık Düzeylerinin Farklı Demografik Değişkenler Açısından İncelenmesi

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Özet

Günümüzde yapay zekâ (YZ) teknolojileri; eğitimden sağlığa, ekonomiden sosyal yaşama kadar birçok alanda hızla yaygınlaşmakta ve bireylerin yaşam biçimlerini doğrudan etkilemektedir. Bu gelişmeler, bireylerin YZ teknolojilerini anlayabilme, yorumlayabilme ve bilinçli bir şekilde kullanabilme becerilerini ifade eden yapay zekâ okuryazarlığını önemli bir yeterlilik haline getirmiştir.

Bu doğrultuda, çalışmanın amacı üniversite öğrencilerinin yapay zekâ okuryazarlık düzeylerini belirlemek ve çeşitli demografik değişkenlere göre anlamlı farklılık gösterip göstermediğini incelemektir. Nicel araştırma yöntemlerinden tarama modeli kullanılarak gerçekleştirilen çalışmanın örneklemini, 2024-2025 akademik yılında Tokat Gaziosmanpaşa Üniversitesi Erbaa Meslek Yüksekokulunda öğrenim gören toplam 421 öğrenci oluşturmaktadır. Katılımcılar, kolayda örnekleme yöntemiyle belirlenmiştir. Veriler, Wang ve arkadaşları (2022) tarafından geliştirilen ve Çelebi ve arkadaşları (2023) tarafından Türkçeye uyarlanan, bireylerin yapay zekâ okuryazarlık düzeylerini ölçmeye yönelik ifadeler içeren "Yapay Zekâ Okuryazarlığı Ölçeği" aracılığıyla toplanmıştır. Elde edilen veriler, SPSS 22 programı kullanılarak analiz edilmiş; analiz sürecinde betimsel istatistikler, bağımsız örneklemler için t-testi ve tek yönlü varyans analizi (ANOVA) uygulanmıştır.

Araştırma sonuçlarına göre öğrencilerin yapay zekâ okuryazarlık düzeyleri yüksek bulunmuştur. Katılımcıların YZ okuryazarlık düzeyleri; cinsiyet, YZ eğitimi alma durumu ve öğrenim görülen program türü (teknik veya sosyal) değişkenlerine göre anlamlı farklılık göstermektedir. Bununla birlikte, öğrenim görülen sınıf düzeyi ile günlük bilgisayar (internet) kullanımı süresi değişkenlerine göre yapay zekâ okuryazarlık düzeylerinde anlamlı bir fark tespit edilmemiştir. Bu sonuçlar, yapay zekâ okuryazarlığının teknolojiyi kullanım süresinden ziyade, alınan eğitim ve öğrenim görülen alanla daha yakından ilişkili olduğunu ortaya koymaktadır.

Anahtar Kelimeler: *Yapay Zeka, Yapay Zeka Okuryazarlığı, Üniversite Öğrencileri*

IoT Cihazlarında DDoS ve Mirai Ataklarında Yeni Bir Saldırı Tespit Sistemi

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Özet

CIC-IoT2023 veri setinin bu çalışmada kullanılan versiyonu, çeşitli DDoS ve Mirai tabanlı saldırı türlerinin yanı sıra normal (Benign) trafiği de içerecek şekilde yapılandırılmıştır. LSTM, BiLSTM ve CNN-BiLSTM+Transformer modelleri ile çok sınıflı (multi-class) çalışılmıştır. Veri setindeki eksik ve anlamsız verilerin temizlenerek model eğitimdeki sapmalar minimize edilmiştir. Özellikle modelde ezberlemeye neden olan sütunların veri setinden çıkarılması, overfitting riskini önemli ölçüde azaltmıştır. Çalışmada, özelliklerin değer aralıklarını normalize etmek amacıyla RobustScaler ve MinMaxScaler birlikte kullanılmıştır. Yüksek boyutlu veriyle çalışıldığı için SelectKBest yöntemiyle chi² testi uygulanmış ve en iyi 15 özellik seçilmiştir.

LSTM ve BiLSTM modelleri %98'lik başarım değerleri ile birbirine oldukça yakın sonuçlar verirken, CNN-BiLSTM + Transformer mimarisi, özellikle Mirai-Greeths ve Mirai-Greips sınıflarında daha düşük performans sergilemiştir. Model performansının sınıf bazlı detaylı analizini yapabilmek adına, ROC (Receiver Operating Characteristic) ve PR (Precision-Recall) eğrileri değerlendirilmiştir.

LSTM modeline ait ROC eğrisi, modelin genel anlamda oldukça başarılı bir ayırt etme kapasitesine sahip olduğunu ortaya koymaktadır. Benign, DDoS-SYN, DDoS-TCPs, DDoS-UDP ve Mirai-udpplains gibi sınıflar için AUC = 1.00 seviyesinde değerler elde edilmiş, Mirai-Greeths ve Mirai-Greips gibi örüntüleri benzeşen alt sınıflarda ise AUC = 0.99 değerleri gözlemlenmiştir.

BiLSTM modeli, çift yönlü öğrenme kapasitesi sayesinde özellikle zaman bağımlı örüntülerde daha derin bağlamları kavrayabilmektedir. BiLSTM modeli için ROC eğrilerinde model, Benign ve DDoS türlerinde AUC = 1.00 düzeyinde bir başarıya ulaşmıştır. Ancak Mirai-Greeths sınıfı için AUC = 0.97, Greips için ise AUC = 0.98 değerleri gözlemlenmiştir.

CNN-BiLSTM + Transformer modeli Precision-Recall (PR) eğrileri, özellikle dengesiz veri yapılarında sınıf bazlı doğruluğu ölçmek açısından kritiktir. Bu modelde Benign ve DDoS sınıflarında AP (Average Precision) değeri 1.00 olarak ölçülmüş olsa da, Mirai-Greeths sınıfı için AP = 0.84 ve Mirai-Greips için AP = 0.87 değeri elde edilmiştir.

Üç modelin confusion matrix sonuçları birlikte değerlendirildiğinde Benign, DDoS-SYN, DDoS-TCPs ve DDoS-UDP gibi temel sınıflarda modellerin yüksek doğrulukta tahmin yaptığı anlaşılmaktadır. Ancak Mirai alt sınıflarında, benzer davranış desenleri sebebiyle modeller için daha zorlayıcı olmuştur. Bu durum, model mimarisi seçiminde sınıf yapısının ayrıştırılabilirliğinin göz önünde bulundurulması gerektiğini ortaya koymaktadır (Gueriani et al., 2024).

Anahtar kelimeler: *IoT Güvenliği, Saldırı Tespit Sistemleri, Derin Öğrenme*

Examination of Digital Game Addiction Levels in Children Living in Rural Areas: The Case of Çat Martyr Lieutenant Ragıp Yılmaz Secondary School

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Abstract

The main purpose of this study is to examine the relationship between digital game addiction and learning responsibilities among secondary school students living in rural areas. A review of the literature shows that most studies on digital game addiction have focused on urban settings, while studies specific to rural areas remain limited. In this context, the research was conducted using the relational survey model. The sample consists of 131 students from 5th, 6th, 7th, and 8th grades at a secondary school in the town of Çat, located in the central district of Tokat province, Turkey. As data collection tools, a Personal Information Form developed by the researchers and the "Digital Game Addiction Scale for Children" developed by Hazar and Hazar (2017) were used. This 12-item scale, designed for children aged 10–14, is structured as a 5-point Likert-type scale. The scale includes four sub-dimensions: "postponement of individual and social responsibilities," "excessive focus on and conflict over digital games," "tolerance development during gameplay and the value attributed to games," and "psychological-physiological reflections of deprivation and immersion in games." The data were analyzed using the SPSS software package. The Cronbach's alpha coefficient of the scale was calculated as .737, indicating an acceptable level of internal consistency. Skewness and kurtosis values showed that the data were normally distributed. According to the analysis results, there was no significant difference in digital game addiction levels between male and female students ($p > .001$). However, a significant difference was found in the sub-dimension of "psychological-physiological reflections of deprivation and immersion in games" in favor of students aged 10 and 13 ($p < .001$). Based on these findings, it is recommended that similar studies be conducted with larger samples, and that intervention programs be developed to raise awareness, particularly regarding the fourth sub-dimension.

Key words: *Digital game addiction, Addiction symptoms, Excessive focus on digital games, Rural children, gameplay duration.*

Examining Relationship Between Middle School Students' Online Gaming Motivations and Their Metacognitions: The Case of Atatürk Middle School

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Abstract

With the rapid advancement of digital technologies, online games have become a significant part of the daily lives of middle school students (Griffiths, 2010). This age group is drawn to games for both cognitive and emotional reasons, motivated by factors such as achievement, entertainment, and socialization (Varanok & Şahin, 2024). Additionally, metacognitive awareness related to gaming processes provides important insights into how individuals regulate their gaming behaviors (Nazlıgül & Süsen, 2021). The aim of this study is to examine the relationship between middle school students' motivations for participating in online games and their metacognitive beliefs regarding gaming. The study analyzed data collected from 365 middle school students. Two data collection tools were used: the 16-item "Online Gaming Motivation Scale (ÇOKAÖ)" and the 12-item "Metacognitions about Online Gaming Scale (MOGS-T)." The ÇOKAÖ, developed by Korkın-Varanok and Şahin (2024), consists of three subscales: achievement, entertainment, and socialization. Reliability coefficients for the scale are as follows: Fleiss' Kappa = .91, McDonald's Omega = .93, test-retest correlation = .80, and Cronbach's alpha values are .87 (achievement), .83 (entertainment), and .81 (socialization). The MOGS-T, adapted by Denizci-Nazlıgül and Süsen (2021), measures students' metacognitive beliefs regarding gaming and includes two subscales: positive and negative metacognitions. In the current study, the Cronbach's alpha value for the MOGS-T was calculated as .883. Skewness and kurtosis values indicated that the data met the assumption of normality. Findings revealed that male students had significantly higher scores in both gaming motivations and metacognitive beliefs compared to female students. While grade level did not result in significant differences in gaming motivations, it did have a significant effect on metacognitive beliefs. Specifically, 8th-grade students exhibited lower metacognitive awareness compared to those in 5th and 6th grades. Furthermore, a moderate, positive, and statistically significant correlation was found between gaming motivations and metacognitive beliefs ($r = .481$, $p < .001$). In conclusion, as students' motivations for playing online games increase, their cognitive awareness regarding the gaming process also tends to increase. Based on the findings, it is recommended that educational programs be developed to raise awareness among students about their gaming behaviors through the lens of their motivations and metacognitive beliefs.

Key words: *Digital gaming in adolescence, Gaming addiction, Metacognitions about online gaming, Online gaming motivations, Problematic gaming behavior*

Metal Nanopartiküllerin Sentezinde Yapay Zeka

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Özet

Yapay zekâ ve metal nanopartiküllerin (MN) sentezi, modern bilim ve teknolojinin kesişiminde önemli bir alan olarak karşımıza çıkmaktadır. MN, yüksek yüzey alanları, kimyasal aktivite ve optik özellikleri sayesinde birçok endüstri sektöründe özellikle elektronik, tıp ve çevre mühendisliğinde kullanımları bulunmaktadır. MN sentezinde geleneksel yöntemler uzun zaman alırken, maliyet ve kontrol zorlukları içermektedir. Yapay zekâ devreye girdiğinde bu süreçlerin optimize edilmesine katkı sağlamaktadır. Yapay zekâ algoritmaları, büyük veri analizi, modelleme ve simülasyon gibi tekniklerle, nanopartikül sentezini daha hızlı, daha etkili ve daha az maliyetli hale getirmektedir.

Yapay zekanın MN sentezindeki rolü, bu malzemelerin özelliklerini etkileyen parametrelerin belirlenmesi açısından önemlidir. Geleneksel deneysel yöntemler, optimum şartların belirlenmesi için zaman alıcı olabilirken, yapay zekâ sistemleri, makine öğrenimi temelli yaklaşımlar ile parametrelerin otomatik olarak analizini sağlayarak, en uygun koşulları belirleyebilmektedir. Bu süreçte, veriye dayalı yaklaşımlar, nanopartikül boyutu, şekli, dağılımı ve yüzey modifikasyonları gibi özelliklerin kontrolünü kolaylaştırır. Bu durum, yalnızca materyal mühendisliğinde değil, aynı zamanda biyomedikal uygulamalarda da nanopartiküllerin spesifik işlevselliğini artırmaktadır.

Sonuç olarak, yapay zekâ ile MN sentezi, yenilikçi bir yaklaşım sunmakta ve araştırmacıların malzeme tasarımı süreçlerini yeniden şekillendirmektedir. Bu disiplinler arası entegrasyon, nanopartikül araştırmalarında daha önce mümkün olmayan hız, doğruluk ve verimlilik elde edilmesine olanak tanımaktadır. Yapay zekâ destekli bu yeni yöntemler, bilimsel keşifleri hızlandırırken, aynı zamanda ticari uygulamalar için de potansiyel faydalar sunmaktadır.

Anahtar Kelimeler: *Yapay zeka, Metal nanopartikül, Sentez, Karakterizasyon.*

A Wildlife-Tick Interface: A Mini-Surveillance of Babesia Parasites in Türkiye

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Abstract

The genus Babesia, belonging to the phylum Apicomplexa, comprises protozoan parasites that are transmitted by ticks and are known to infect the red blood cells of mammals, including humans. In this study, a total of 112 ticks collected from 80 wild mammals representing 23 species across 17 provinces in Türkiye were screened for Babesia using PCR targeting the 411–452 bp region of the 18S rRNA gene. The sequences obtained were analyzed and aligned using BioEdit Sequence Alignment Editor, version 7.0.5, while MEGA 12 software was employed for phylogenetic analysis based on the maximum likelihood method. The analysis revealed Babesia DNA in 7 ticks (6.25%). NCBI Blastn comparisons and phylogenetic inference confirmed the presence of Babesia microti in Ixodes acuminatus ticks from Edirne, Balıkesir, and Tokat provinces, and Babesia caballi in a Hyalomma sp. tick from Kars province of Türkiye. The study provides insights into the diversity and distribution of Babesia species in wildlife-associated ticks in Türkiye and contributes to the broader understanding of tick-borne disease ecology through molecular and phylogenetic approaches.

Key words: *Babesia, Ticks, Ectoparasites, Zoonoses, Diseases*

Lineer Derin Öğrenme Algoritmalarıyla Bıldırcınlarda Büyüme Eğrisinin Tahmini

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Özet

Bıldırcın yetiştiriciliği, son yıllarda artan talep ve ekonomik potansiyeli nedeniyle önemli bir tarımsal faaliyet haline gelmiştir. Bıldırcınların büyüme eğrilerinin doğru bir şekilde tahmin edilmesi, yem maliyetlerinin optimizasyonu, kesim zamanının belirlenmesi ve genel verimliliğin artırılması açısından kritik öneme sahiptir. Geleneksel yöntemlerin yanı sıra büyük veri topluluğunda daha hassas yaklaşımlara ihtiyaç duyulmaktadır. Bu bağlamda, lineer derin öğrenme algoritmaları, bıldırcınların büyüme eğrilerini tahmin etmek için umut vadeden bir yöntem olarak ortaya çıkmaktadır. Derin öğrenme, yapay sinir ağları (YSA) üzerine kurulu bir makine öğrenimi alt dalıdır. Lineer derin öğrenme, YSA'ların en temel türlerinden biridir ve genellikle verilerin lineer bir ilişki sergilediği durumlarda kullanılır. Bu algoritmalar, girdi katmanı, bir veya daha fazla gizli katman ve bir çıktı katmanından oluşur. Her bir katman, bir dizi düğümden (nöron) oluşur ve bu düğümler arasındaki bağlantılar, ağırlıklar aracılığıyla temsil edilir. Lineer derin öğrenme algoritmaları, bıldırcınların büyüme eğrilerini modellemek için kullanılabilir. Bu modeller, yaş, yem tüketimi, genetik faktörler ve çevresel koşullar gibi çeşitli girdileri kullanarak, bıldırcınların ağırlıklarını tahmin edebilir. Bu tahminler, yetiştiricilere önemli bilgiler sağlayarak, daha bilinçli kararlar almalarına yardımcı olabilir.

Anahtar Kelimeler: *Lineer Derin Öğrenme, Büyüme Eğrisi Bıldırcın*

Özel Yetenekli Bireyler için Fen Eğitiminde Yapay Zeka Kullanımı Üzerine Bir İnceleme

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Özet

Bu çalışma, özel yetenekli bireylerin fen eğitiminde yapay zeka (YZ) tabanlı uygulamalara yönelik son on yılda (2014–2024) yapılmış akademik çalışmaları sistematik biçimde incelemeyi amaçlamaktadır. Alan yazını taraması yöntemiyle yürütülen bu araştırmada, örneklem özellikleri, yayın yeri (uluslararası/ulusal), kullanılan araştırma desenleri, çalışılan konu başlıkları, kullanılan YZ araçları ve veri analizi yöntemleri temel inceleme kriterleri olarak belirlenmiştir. Çalışma kapsamında, "gifted students", "science education", "artificial intelligence", "AI in gifted education" gibi anahtar kelimelerle ulusal ve uluslararası veri tabanlarında (ERIC, Scopus, Web of Science, ULAKBİM vb.) tarama yapılmış; dâhil edilme ölçütlerini karşılayan çalışmalar detaylı olarak incelenmiştir. Çalışmanın sonunda, elde edilen veriler doğrultusunda özel yetenekli bireylerin fen eğitiminde yapay zeka kullanımına ilişkin eğilimler, odaklanılan temalar ve metodolojik özellikler sistematik bir biçimde sunulacaktır. Bu inceleme, alanda yapılan çalışmaların genel eğilimlerini ve boşluklarını ortaya koyarak, gelecekte özel yetenekli bireylere yönelik fen öğretiminde yapay zeka kullanımını daha etkili ve hedefe yönelik planlamak isteyen araştırmacılar ve uygulayıcılar için yol gösterici olmayı amaçlamaktadır.

Anahtar Kelimeler: *Özel yetenekli öğrenciler, Fen eğitimi, Yapay zeka, Doküman inceleme*

Generative AI Applications

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Abstract

In this study, the concept of generative artificial intelligence (generative AI) is introduced. Also, current applications in areas such as text, image, audio, code, and educational content generation are examined through specific examples. In the field of text generation, large language models such as ChatGPT and DeepSeek stand out. For image generation, systems like DALL·E and Stable Diffusion are prominent. For audio generation, platforms such as ElevenLabs are noteworthy. In software development processes, tools like GitHub Copilot and ChatGPT are widely used; and in educational material production, platforms like Curipod have gained attention. The common feature of these technologies is their ability to produce original and usable content based on human input. These AI tools, each serving different purposes in their respective domains, accelerate learning processes, support creative production, and contribute to democratizing access to information.

Key words: *Generative AI, Artificial Intelligence, Large Language Models*

Analysis of Financial Network Dynamics Using Hybrid Graph Convolutional Networks: An Application on BIST-30 Portfolio Optimization

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Abstract

Understanding stock market dynamics plays a crucial role in achieving both risk management goals and effective investment decision-making. Standard financial models have limitations when it comes to understanding complex stock relationships which results in subpar portfolio strategies. This research examines the application of Hybrid Graph Convolutional Network (Hybrid GCN) to analyze stock price relationships found within the Borsa İstanbul 30 (BIST 30) index. The use of graph-based deep learning aims to improve financial network analysis while developing an investment framework that provides stronger data-driven solutions to enhance portfolio performance. The analysis used Yahoo Finance historical stock price data spanning a decade to accomplish this research. The calculation of stock return correlations produced a matrix which defined significant relationships between stocks through edge connections. The Hybrid GCN model received training to optimize portfolio allocation through its ability to learn about stock dependencies and price movements. The model's effectiveness was evaluated through testing against Minimum Variance Portfolio and Risk Parity Portfolio and Market Capitalization-Weighted Portfolio which represent common risk-based approaches in financial markets. The Hybrid GCN model delivers superior results than benchmark portfolios when it comes to risk-adjusted returns and overall profitability. The Hybrid GCN model achieved a Sharpe ratio of 1.0047 which outperformed all benchmark portfolios since the Minimum Variance and Risk Parity portfolios reached 0.3830 and the Market Cap-weighted portfolio achieved 0.3393. The Hybrid GCN model produced a cumulative return of 1.0938 which exceeded the benchmark portfolios' returns of 1.0260 for Minimum Variance and Risk Parity and 1.0217 for the Market Cap-weighted portfolio. The Hybrid GCN model demonstrated better downside risk control, with a maximum drawdown (MDD) of -7.94%, compared to the benchmark models, which reached -9.02% and -9.05% for the Minimum Variance and Risk Parity portfolios, respectively, and the Market Cap-weighted portfolio. The Sortino ratio of the Hybrid GCN model reached 1.8342, whereas the Minimum Variance, Risk Parity, and Market Cap-weighted portfolios achieved 0.6835 and 0.5978, respectively. These results indicate Hybrid GCN financial models deliver superior portfolio performance through their ability to analyze stock dependencies for risk-adjusted return optimization. This research demonstrates how Hybrid GCN can optimize portfolio allocation more effectively than traditional methods through financial modeling applications. The study demonstrates an adaptable financial forecasting and portfolio construction method that scales through graph-based learning. Research should validate this model by applying it to broader stock indices, utilizing different data sources in real-world investment strategies.

Keywords: *Graph convolutional networks, Portfolio optimization, Financial network analysis, Stock market prediction, Deep learning*

Predictive AI for Disruption Management in Global Supply Chains: From Geopolitical Risk to Port Congestion

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Abstract

In an increasingly volatile geopolitical and environmental landscape, global supply chains are under constant threat from a myriad of disruptions, ranging from political conflicts and trade restrictions to natural disasters and port congestion. This paper investigates the integration of predictive Artificial Intelligence (AI) models into international logistics systems as a proactive mechanism to anticipate, evaluate, and mitigate such disruptions. Utilizing a multidisciplinary approach, this study synthesizes advancements in machine learning, network optimization, and real-time data analytics to demonstrate how AI is revolutionizing supply chain risk management. Through comparative analysis and empirical examples, it is shown that predictive AI not only enhances operational resilience but also offers economic advantages by minimizing downtime and rerouting logistics in near-real-time. The paper presents a framework for implementing AI-driven predictive systems within global logistics operations, emphasizing ethical considerations, data governance, and international policy harmonization. Ultimately, this research highlights AI's transformative potential in shaping a more adaptive, secure, and efficient global trade network.

Keywords: *Predictive AI, Supply Chain Disruption, Geopolitical Risk, Port Congestion, Logistics Optimization.*

Strategies and models of digital transformation of business processes in the trade sector

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Abstract

A breakthrough in the development of information technology is the most relevant expression of future social development. Today, digital transformation is one of the most important directions in international economic development policy.

The main prerequisites for digital transformation are new technologies: mobile Internet, social networks, Artificial Intelligence (AI), BigData, cloud technologies, new generation robots, virtual and augmented reality, Internet of Things, blockchain. Obviously, they appeared a long time ago, but the conditions for their widespread use have developed only in the last decade. First of all, this was influenced by the increased functionality and lower cost of technology.

Considering the current stage of development of society and the economy, it can be argued that today we are witnessing a complete transition to a digital society, after many years of industrial development. The digital transformation of the economy is taking place all over the world, at the level of individual companies. Studying this process is especially relevant now, when we observe how international companies create strong competitive advantages through the digital transformation of business processes, which gives them leading positions on a global scale and great superiority in the technological development of other organizations.

At the present stage, the digital transformation of business processes is an essential component in the activities of trading companies, which occurs gradually and can last for years. The use of new technologies in the activities of trading companies will be effective if the technologies, models and competence of personnel meet the conditions for using the company's digital development strategy.
Digital transformation strategies and models are based on the use of digital technologies to change business processes and create a competitive business, which makes it possible to obtain financial benefits in the short term.

Key words: *Digital transformation, Business processes, Trading companies, Digital strategies, Business models*

Simultaneous Representation of Observations and Variables: Biplot Method

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Abstract

This study investigates the theoretical and practical aspects of the biplot method, an important visualization technique in the field of multivariate data analysis. Biplot makes multidimensional data structures comprehensible through two-dimensional graphs by representing both observation units (samples) and variables on the same plane.

Biplot is a way of providing an interpretation of a common graph of row and column points. This is based on using scalar products among row vectors and column vectors, linked to the lengths of the vectors and the angles between them, not the distances between the points. In a biplot, just one of the sets of features, rows or columns, is depicted in the base coordinates. This feature allows researchers to simultaneously analyze the relationships between variables, the similarities between observations, and which variables affect which observations more.

In the study, the mathematical foundations of biplot analysis are explained and its relationship with principal component analysis is evaluated. Following the theoretical part, an applied biplot analysis was performed on a multivariate data set from agricultural sciences; the orientation of variable vectors, distribution of observation points and clustering tendencies were interpreted in detail.

The findings show that the biplot method not only supports statistical analyses, but is also an effective visualization tool in decision support processes. The research underlines the need for biplot analysis, especially in interdisciplinary studies that seek to make sense of complex data structures.

Key words: *Biplot, Principal Components, Multivariate Analysis, Visualization, Data Exploration*

The Problem of Algorithmic Transparency and Accountability: An Examination of the Auditability of Artificial Intelligence Systems in Public Administration

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Abstract

The increasing use of artificial intelligence (AI) and algorithm-based decision support systems in public administration raises significant concerns regarding transparency and accountability in the context of governance principles. As digitalization accelerates, the proliferation of algorithmic systems in public services reduces the role of human agency in decision-making processes. However, the lack of clarity in the functioning of these systems presents critical challenges for both citizens and oversight mechanisms in terms of transparency and auditability. In particular, the opacity of so-called "black box" algorithms undermines public trust and contradicts the principles of democratic accountability. This study adopts a qualitative methodology, drawing on literature review, legislative analysis, and the examination of policy documents. Key regulatory frameworks such as the General Data Protection Regulation (GDPR) of the European Union, the Turkish Personal Data Protection Law (KVKK), the OECD Principles on AI, and the proposed AI Act are analyzed with respect to algorithmic transparency. Case examples from Turkey—such as algorithmic applications in social assistance distribution and e-government services—are discussed. International practices from the EU, Canada, and the United States concerning the use of algorithms in public services are also reviewed.
The findings reveal that the legal framework governing public algorithms in Turkey remains inadequate, public awareness is limited, and algorithms are implemented without sufficient oversight mechanisms. The study emphasizes the necessity for a comprehensive transparency mechanism supported by explainable AI systems, algorithmic impact assessments, and improved levels of digital literacy among citizens.

Key words: *Algorithmic Transparency, Artificial Intelligence in Public Administration, Accountability*

Biyopsi Tip ve Yük Artışının Atık Yönetimi Üzerine Etkileri

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Abstract

Tıbbi Patoloji Laboratuvarı rutin işlemleri; pre analitik, analitik ve post analitik süreçler olarak ayrılması ardından analitik aşamada tanı alması hedeflenen doku veya hücre gruplarının farklı aşamalardan geçirilerek dokuya ait ön bilgi ve elde edilen veriler eşliğinde incelenmesi talep edilen doku ve hücre grubunun tanı alma süreci olarak tanımlanabilir. Tanı alma sürecinde olan doku veya hücre grubu; makroskopi, doku takip, doku gömme, trimming, kesit alma, basit ve kapsamlı boyama ile İHC, İF, FİSH, İSH gibi daha kapsamlı iş ve işlemleri kapsayan uzun bir süreçtir. Bu süreç aşama aşama devam eder, her aşamada farklı unsurlar, sarf malzemeler, teknik araç ve gereçler kullanılması zorunludur. Üretim amacın ve vasfını yitirmiş olan tüm malzeme atık olarak tanımlanmıştır. Atıklar, yerinde ve türüne göre farklı alanlarda farklı unsurlar kullanılarak toplanmış ve geçici atık depolama biriminde atık bertaraf yüklenicisine süreç teslim sürecinin tamamlanması ile teslim edilmiştir.
Analitik süreç sonunda; 2013-2024 yılları arasında teknik alanında üretilen biyopsi sayısı ve zorluğu ile üretilen atık profil miktarı arasındaki değişim ve değişime etki eden teknik unsurlar değerlendirilmiştir. 2013 yılından başlayan ve 2020 yılına kadar aralıksız devam eden süreçte biyopsi başına yük miktarında artışın ortalama tehlikeli, patolojik atık üretim profili biyopsi başına dikkate değer artış göstermediği ancak 2020 yılında evsel ve kesici delici atık miktarında önceki yıllara göre belirgin bir atış meydana geldiği ve artış eğiliminin azalarak 2023 yılına kadar sürdüğü 2024 yılı başından itibaren ise rutin atık üretim profiline uygun devam ettiği anlaşılmıştır.
Dönem olarak, 2020 yılı başından başlamak üzere biyopsi sayısında anlamlı düşme görülmesine rağmen evsel ve kesici delici atık üretim miktarında görülen ciddi yükseliş 17.11.2019 tarihinde Çin'de ilk Covid-19 vaka sonrası 11.03.2020 tarihinde ülkemizde ilk vakanınn tespit edilmesi ile kişisel koruma önlemlerindeki yüksek artışın neden olabileceğini düşündürmektedir. Covid-19 vakaları ve 14.01.2021 tarihinde aşılama uygulamasının başlaması ile evsel ve kesici delici atık üretim miktarında anlamlı azalma görülmüş, 05.05.2023 tarihinde, WHO direktörü T. Ghebreyesus 15. Acil durum toplantısında; küresel halk sağlığı acil durumuna son vermeyi tavsiye etmiştir. Bu nedenle Covid-19 küresel acil durumunun bittiği açıklaması ile 2024 yılından itibaren 2013-2019 seyrine geri döndüğü anlaşılmıştır. Analitik süreç işlemleri sonucu ortaya çıkan evsel, patolojik, tehlikeli, kesici delici atık miktarı ile biyopsi sayısı oranı covid-19 süreci 2020-2021 yılları üretimi ile karşılaştırıldığında ($p>0,78$)istatistiksel olarak anlamlı bulunmamıştır. Ancak pandemi dönemini kapsayan küresel sağlık sorununun yoğun yaşandığı ve biyopsi sayısının bir önceki yıla göre en az %34 oranında azaldığı, 2020 ve 2021 pandemi yıllarında kişisel korunma önlemleri ve evsel atık üretiminde %42, kesici delici atık üretiminde %250 oranında artış görülmüş, istatistiksel olarak anlamlı görülmüştür ($P<0,05$). (WHO) Dünya Sağlık Örgütü'nün 05.05.2023 tarihinde küresel halk sağlığı acil durumuna son vermesi ile birlikte evsel ve kesici delici atık üretim oranı 2013-2019 dönemi rakamlarına geri dönmüştür. Post pandemi sürecinde ise rutin atık üretim miktarlarına geri dönüldüğünü, pandemi gibi küresel etkilerin klasik doku takip, rutin laboratuvar süreçlerinde atık üretimine etkisinin anlamlı düzeyde olmadığını göstermektedir.
Key words: *Covid-19, Medical waste, Domestic waste.*

Dijital Tehditler ve Ekonomik Kırılganlık: Siber Saldırıların Makroekonomik Etkileri

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Özet

Bu çalışma, dijitalleşmenin hız kazandığı günümüz ekonomik ortamında siber güvenliğin makroekonomik politika ile olan ilişkisini incelemeyi amaçlamaktadır. Finansal sistemlerin dijital altyapılara bağımlılığı arttıkça, siber güvenlik riskleri yalnızca teknik düzeyde değil, ekonomik karar alma süreçlerinde de önem kazanmaktadır. Siber saldırıların finansal piyasalarda dalgalanmalara neden olabileceği, kamu maliyesi üzerinde baskı oluşturabileceği ve yatırımcı güvenini etkileyebileceği literatürde giderek daha fazla tartışılmaktadır. Çalışmada, siber tehditlerin ekonomi üzerindeki potansiyel etkileri dört önemli vaka (Colonial Pipeline, SWIFT saldırısı, Norsk Hydro ve NotPetya) aracılığıyla değerlendirilmiş; bu olayların kısa vadeli ekonomik sonuçlarının yanı sıra politika yanıtları da incelenmiştir. Ayrıca uluslararası düzenlemeler ve merkez bankalarının yaklaşım biçimleri ışığında, siber güvenliğin ekonomi politikası içindeki yeri tartışılmıştır. Elde edilen bulgular, siber güvenliğe yönelik tehditlerin ekonomik yönünün giderek daha görünür hâle geldiğini ve özellikle finansal istikrarın sürdürülebilirliği açısından dikkate alınması gerektiğini göstermektedir. Bu doğrultuda, dijital altyapıların korunması için merkez bankalarının ve kamu otoritelerinin daha bütüncül bir yaklaşım geliştirmesi önerilmektedir.

Anahtar Kelimeler: *Siber güvenlik, Makroekonomi, Finansal istikrar, Siber saldırılar, Dijital dönüşüm*

Yapay Zeka ve Ekonomi: Küresel Gelişim, Toplumsal Etkiler ve Türkiye Üzerine Bir Analiz

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Özet

Bu çalışma, yapay zeka teknolojilerinin tarihsel gelişim süreci, temel sınıflamaları ve güncel uygulama alanlarını inceleyerek, söz konusu teknolojilerin ekonomik yapı, toplumsal düzen ve bilimsel üretim üzerindeki çok katmanlı etkilerini analiz etmeyi amaçlamaktadır. Yapay zekanın sanayi, sağlık, eğitim, savunma ve hizmet sektörlerinde sunduğu verimlilik artışı, maliyet azaltımı ve hizmet kalitesi gibi katkıların yanında; iş gücü piyasası, gelir dağılımı, etik normlar ve veri mahremiyeti bağlamında ortaya çıkardığı riskler, bütüncül bir yaklaşımla değerlendirilmiştir. Küresel ölçekte Çin, ABD, Japonya, Güney Kore ve Almanya'nın öncülüğünde şekillenen yapay zeka ve robotik yatırımları, Türkiye örneği üzerinden karşılaştırmalı olarak incelenmiş; Türkiye'nin bu teknolojik dönüşüme sanayi, hizmet ve kamu sektörleri düzeyinde verdiği tepkiler sistematik biçimde analiz edilmiştir. Çalışma sonucunda, yapay zeka teknolojilerinin yalnızca ekonomik büyüme ve bilimsel ilerleme açısından değil, aynı zamanda toplumsal refah, sosyal adalet ve yönetişim ilkeleri bakımından da dönüştürücü bir rol üstlendiği ortaya konulmuştur.

Anahtar Kelimeler: *Yapay Zeka, Robot Teknolojisi, Yapay Zekanın Ekonomiye Etkisi*

Big Data in Business: A Systematic Review of Methods and Application Areas

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Abstract

This study aims to systematically examine the recent academic literature on big data use in businesses, focusing on the most commonly applied data analysis methods, functional business areas where big data is utilized, and the benefits and challenges encountered in its implementation. Following the PRISMA methodology, a total of 185 peer-reviewed articles from the last five years were selected from the Web of Science database. Thematic analysis revealed that the most frequently used methods are data mining and big data analytics (40.8%), artificial intelligence and machine learning techniques (34.2%), and statistical analysis and modeling approaches (25.0%). Big data is most intensively employed in strategic management (52.2%), information technologies and digital transformation (47.8%), and marketing and customer relationship management (32.1%). The primary challenges identified in the literature include data integration and siloed systems (40.2%), complexity due to data volume and variety (33.7%), and technological infrastructure and cost barriers (31.5%). In contrast, benefits of big data use were reported less frequently, with only 3.8% of studies mentioning improved decision quality and 1.6% reporting competitive advantages. These findings suggest that although big data holds substantial potential for organizational value creation, businesses face considerable technical and managerial obstacles in realizing these benefits effectively.

Key words: *Big Data, Data Analytics, Digitalization in Business, Systematic Review, Thematic Analysis*

Application of Image Processing Methods in Identifying Wood Structure

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Abstract

Wood is a heterogeneous, complex material consisting of various cell types. These cells form special arrangements and have different shapes depending on the tree species. However, their shapes and arrangements may change due to defects in the natural structure. A classical method for identifying wood is to examine wood sections with a microscope. Various image processing techniques developed today facilitate faster and more accurate determination of the cellular structure of wood. The method allows in-depth analysis of cells to evaluate wood quality and technological properties. Sections taken from a piece of wood are identified using image processing algorithms. Image processing: are methods that enable the digitization of images and conversion into data sets with various techniques. Using microscopic images in the wood section, they are processed and analyzed with computer programs. There are different computer programs and algorithms prepared for this purpose. Images are obtained with various image acquisition methods, including surface images, wood anatomical micro sections, micro-CT tomograms or X-ray computerized micro tomography. These images allow the software to detect important wood anatomical features such as cell shape and size. Cell quantities and percentages are extracted from the image. Comparisons of commonly used image analysis methods have shown agreement between the methods. There is high success in species identification, determination of defect rates and agreement with microscopic data.

Key words: *Image analysis, Image processing, Morphological operations, Wood anatomy*

Acid-Sensing Ion Channels as Potential Therapeutic Targets in The Peripheral and Central Nervous System Diseases

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Abstract

Acid-sensing ion channels (ASICs) are widely expressed in the peripheral and central nervous systems. ASICs act as pH sensors leading to neuronal excitation. These channels are a family of proton-sensing channels that are voltage-insensitive, mostly permeable to Na^+, and nonspecifically blocked by amiloride. At least seven ASIC subunits encoded by five genes (ASIC1-ASIC5) have been identified in the peripheral and central nervous system: ASIC1a, ASIC1b, ASIC2a, ASIC2b, ASIC3, ASIC4, ASIC5. Acid-sensing ion channels play an important role as pharmacological targets due to their involvement in various pathophysiological conditions. These channels are important pharmacological targets in various pathophysiological processes affecting the peripheral nervous system, such as neuropathic pain and diabetic neuropathy, and the central nervous system, including epilepsy, stroke, migraine, anxiety, depression, neurodegenerative diseases, and other neurological disorders. This review focuses on recent advances that have helped us to better understand the role played by ASICs in different pathologies related to peripheral and central nervous systems diseases. The role played by ASICs in different pathologies and pharmacological agents that act on ASICs and may represent promising drugs are discussed. In the near future, ASIC antagonists and modulators may also be considered as potential pharmacological targets in peripheral and central nervous system diseases.

Key words: *Acid-sensitive ion channels, Acidosis, Peripheral and central nervous system diseases*

Aspects regarding the empirical behavior of manufacturing systems accessing Industry 4.0 and Industry 5.0

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Abstract

The starting point for the choice of the theme is that Industry 4.0 has been dramatically affected by artificial intelligence technology, which has led to both positive and negative results. Increased productivity and better optimization processes have allowed factories to be more efficient, but due to the capabilities offered by artificial intelligence, professions that are at risk of automation are identified on the market. Industry 4.0 is characterized by the integration of digital technologies and automation in production

The paper deals with the concept of Industry 4.0, highlighting key technologies such as cloud manufacturing, the Internet of Things (IoT), artificial intelligence (AI) and big data analysis that have a decisive role in reshaping industrial processes. The paper explores the perception of Industry 4.0, highlighting its impact on production efficiency, the analysis of the manufacturing process in general.

Industry 5.0 has emerged as an entity that leads to a coherent, resilient and stable society. This paper attempts to present an empirical projection of current artificial intelligence systems and the possible impact on industries and societies. Industry 5.0 analyzes the changing dynamics of the workforce, emphasizing the need for improvement and adaptability in the face of automation and technological advances.

An important role in the development of the paper is played by the idea that Industry 4.0 is considered to be technology-based, while Industry 5.0 is value-based. The transition from one industrial revolution to another raises several questions, which in turn require discussion and clarification.

This paper provides an overview of the conception and perception of Industry 4.0, while anticipating the paradigm shift towards Industry 5.0. It emphasizes the importance of rethinking the entire system in the context of evolving technologies, emphasizing technological innovation.

In order to highlight the basic components for Industry 4.0 and Industry 5.0, we used Petri nets to simulate an empirical model, because the advantages and disadvantages of manufacturing systems can be observed in real time and the decision-making system can intervene from the design phase.

Key words: *Industry 4.0, Industry 5.0, Cloud manufacturing, Internet Of Things*

Türkiye ve Avrupa Birliği'nde Sağlık Politikaları ve Harcamaları

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Özet

En temel yaşam hakkı olan sağlık, genel olarak hastalığın baştan engellenmesi ve hastalık halinde teşhis ve tedavinin gerçekleştirilmesi olarak tanımlanmaktadır. Ancak bunlara ek olarak bireyin fiziksel, zihinsel, duygusal veya sosyal açıdan tam işlevsel hale gelmesini destekleyen rehabilitasyon süreci de sağlığın kapsamına girmektedir. Bu sebeplerden dolayı sağlık yalnızca hastalık öncesi ya da tedavisi süreciyle kısıtlanamayacak, bireyin yaşam kalitesini artırmaya yönelik çok yönlü bir süreci ifade etmektedir. Bu yönüyle sağlık, sosyal devlet ilkesi gereği devlet tarafından sunulması ya da regüle edilmesi gereken kamusal bir mal olarak nitelendirilebilir.

Diğer yandan, toplumların varlığını devam ettirebilmeleri için sağlığın temel şart olması toplumun kalkınmışlık düzeyi ile sağlık arasında ayrılmaz bir bağ oluşturmaktadır. Bu yüzden sağlık, dünya genelinde olduğu gibi Türkiye ve Avrupa Birliği'nde (AB) de sunulan başat kamusal hizmetlerdendir. Kalkınma süreciyle birlikte toplumsal beklentilerin değişmesi, nüfus artışı, demografik yapının değişmesi ve teknolojik gelişmeler, sağlık harcamalarında artışa neden olmuş ve Türkiye ve AB'de sağlık politikalarının yapılandırmasını gerektirmiştir. Yapılan reformlar ile sağlıkta dönüşüm çalışmaları başlamış ve bu çalışmalarda sadece bireysel arz ve talep dengesi değil hastalığın topluma ve ekonomiye yükü de ele alınmıştır. Tercih edilen sağlık sistemleri ve uygulama şekillerinin yanı sıra bu sistemlerin özellikleri de sağlık harcamalarına yön vermektedir. Bu çalışmada, Türkiye ve AB sağlık politikaları ve harcamaları karşılaştırmalı olarak tartışılmıştır.

Anahtar Kelimeler: *Sağlık Politikası, Sağlık Harcaması, Kamusal Mal.*

Ruh Sağlığında Yapay Zekânın Rolü: Avantajlar, Etik Tartışmalar ve Gelecek Perspektifi

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Özet

Psikoterapi, bireylerin ruh sağlığına yönelik sorunları anlamalarını ve çözmelerini destekleyen bilimsel bir tedavi yöntemidir (APA, 2016). Stresli yaşam olayları, hastalıklarla baş etme, travma sonrası etkiler ve yas sürecinin yanı sıra depresyon ve anksiyete gibi psikiyatrik rahatsızlıkların tedavisinde yaygın olarak kullanılmaktadır. Son yıllarda yapay zekâ (YZ) teknolojilerinin gelişmesiyle, psikoterapi alanında dijital uygulamaların kullanımı önemli ölçüde artmıştır. YZ'nın insan duygularını ve düşüncelerini analiz edebilme yeteneği, psikoterapötik müdahaleleri destekleyici imkanlar sunmaktadır.

YZ tabanlı terapötik uygulamalar, terapistleri destekleyici sistemler olarak veya doğrudan danışanlarla etkileşime giren sanal terapistler ve chatbotlar şeklinde kullanılmaktadır. Tess, Woebot, Wysa ve Youper gibi uygulamalar; depresyon ve anksiyete gibi yaygın ruhsal sorunların yönetiminde bilişsel yeniden yapılandırma, psiko-eğitim ve farkındalık geliştirme işlevleri üstlenmektedir. Sanal gerçeklik tabanlı avatar terapisi, şizofreni gibi bozukluklarda işitsel halüsinasyonları azaltma potansiyeli taşırken; gençler için geliştirilen SPARX gibi dijital BDT (bilişsel davranışçı terapi) programları, duygu düzenleme becerilerini geliştirmeye yardımcı olmaktadır. Yapay zekanın doğal dil işleme yetenekleri sayesinde, bireylerin ifadeleri analiz edilerek ruhsal rahatsızlık belirtileri erken aşamada tespit edilebilmektedir. Bu teknolojiler, kişiye özel terapi planları oluşturmak, olumsuz düşünceleri sorgulamak ve duygusal dayanıklılığı artırmak için etkili şekilde kullanılabilmektedir. YZ temelli terapötik sistemler arasında robot terapisi de dikkat çekmektedir. Yaşlılar ve demans hastaları için geliştirilen Paro gibi sosyal robotlar, bireylerin sosyal etkileşimlerini güçlendirerek yalnızlık ve stres düzeylerini azaltmaya yardımcı olmaktadır.

YZ destekli sistemler, düşük maliyet, geniş erişim, anında müdahale ve kişiselleştirilmiş tedavi gibi avantajlar sunmaktadır. Ancak etik, güvenlik ve veri gizliliği konularında tartışmalara yol açmaktadır. Empatik ilişkinin ve insan temasının önemli olduğu psikoterapi süreçlerinde, yapay zekânın sınırlılıkları göz önünde bulundurulmalıdır. Sonuç olarak, YZ'nin psikoterapiye entegrasyonu önemli bir dönüşüm sürecini beraberinde getirmektedir. İnsan terapistlerin yerini tamamen alması mümkün görünmese de en etkili yaklaşımın insan-YZ iş birliği olduğu düşünülmektedir. Etik ilkelere uygun geliştirilen YZ sistemlerinin, ruh sağlığı hizmetlerini daha erişilebilir ve etkili hale getirmesi beklenmektedir. Bu derleme, YZ'nin psikoterapideki kullanımını, etik tartışmaları ve gelecekteki olası dönüşümleri değerlendirmektedir.

Anahtar Sözcükler: *Ruh Sağlığı, Yapay Zeka, Psikoterapi.*

Dijital Pazarlama Sürecinde Sosyal Medyanın Sağlık Sektöründeki Rolü

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Özet

Pazarlama, hanehalkı, iş ortakları ve tüm toplum için değer taşıyan teklifleri yaratma, iletme, sunma ve değiştirme faaliyetine ilişkin süreçler bütünü olarak ifade edilebilir. Uzun yıllar boyunca geleneksel yöntemlere yürütülen pazarlama süreci sosyal medya ve dijital dünyanın hızlı gelişimi sonucunda evrimleşerek daha etkili organize edilmeye başlanmıştır. Söz konusu dijitalleşme ve sosyal medyanın hızla ve büyüyerek yayılımı modern dünyada markaların müşterilere ulaşma yöntemlerinin kökten değişmesine neden olmuştur. Geleneksel pazarlama yöntemlerine kıyasla daha hızlı, ölçülebilir ve etkileşimli olan dijital pazarlama, bu yöntemi etkili kullanan işletmelerin rekabet avantajı elde etmesini sağlamıştır. Dijital pazarlamada ortaya çıkan son yöntem ise sosyal medya pazarlaması olmuştur. Bireylerin, toplulukların ve markaların dijital platformlar aracılığıyla içerik paylaşmasını, etkileşimde bulunmasını ve iletişim kurmasını sağlayan çevrimiçi ağların genel adı olan sosyal medya, kullanıcıları tarafından oluşturulan içeriklerin ön planda olduğu, etkileşim ve katılımın esas alındığı bir medya türüdür. 2025 yılı itibariyle dünya genelinde yaklaşık 5,5 milyar insanın sosyal medya kullandığı ve bu insanların günlük ortalama 2,5 saatlerini sosyal medyada geçirdikleri varsayımı altında sosyal medya bir numaralı pazarlama yöntemi halini almıştır. Sonuçta marka bilinirliğinin artırılması, hedef kitleyle doğrudan iletişim kurulması ve satışların artırılması için sosyal medya vazgeçilmez bir kanal haline gelmiştir. Dijital pazarlama ve sosyal medyanın hızla geleneksel pazarlama yöntemlerinin yerini almasının temelinde daha düşük maliyetli olması, ölçülebilir ve hedeflenebilir olması, kişiselleştirme imkanı sunması, gerçek zamanlı veri analizleriyle anlık strateji değişikliklerine izin vermesi, satışları artırmada, marka sadakati ve müşteri ilişkileri geliştirmede etkili olması gibi birçok neden yatmaktadır. Sağlık sektörü açısından ise, sağlık hizmeti sağlayıcılarının tanıtılması başta olmak üzere hasta bilgilendirme ve eğitim, hasta deneyimi ve değerlendirme, sağlık turizmi gibi birçok alanda dijital pazarlama ve sosyal medyaya başvurulması söz konusudur. Bu kapsamda, hiper kişiselleştirilmiş sağlık reklamları, tele sağlık ve sanal hizmetleri, büyük veri ve yapay zeka entegrasyonu dijital pazarlama ve sosyal medyanın sağlık sektöründeki trendlerini oluşturmaktadır.

Anahtar Kelimeler: *Sağlık, Pazarlama, Kamusal Mal.*

Hybrid Portfolio Optimization Using Fuzzy Logic and Genetic Algorithms: A Comparative Study

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Abstract

This research evaluates the potential of using a Fuzzy Logic-based Genetic Algorithm (Fuzzy-GA) as an alternative to traditional portfolio optimization methods such as Markowitz, Minimum Variance, and Equal Weight. The goal is to create more balanced and efficient investment portfolios by integrating multi-criteria decision-making using fuzzy logic. We analyzed the daily closing prices of the 30 large-cap companies listed in the Dow Jones Industrial Average (DJIA) spanning from January 1, 2020, to March 10, 2025. The optimization process utilized daily logarithmic returns as input data. The Fuzzy-GA model incorporates genetic algorithm core mechanics for individual generation and crossover and mutation but includes a fuzzy inference system to evaluate portfolios. This system evaluates risk and return and diversification using fuzzy rules to give each portfolio a fitness score. This method allows for multi-objective optimization while avoiding weight combinations which makes decisions more practical. According to our findings, the Fuzzy-GA model produced the highest annual return of 12% and kept risk at a relatively low level of 15%. The combination produced the best Sharpe ratio at 1.20. The model delivered strong results in terms of maximum drawdown at 25% while attaining the highest diversification score at 1.5. The model received the highest fuzzy score (0.85) which indicated its balanced nature. The Markowitz portfolio generated a 10% return with 18% risk and achieved a Sharpe ratio of 1.00. The Equal Weight strategy generated a 9% return with 20% risk and produced a Sharpe ratio of 0.80. The Minimum Variance strategy generated the minimum risk level of 12% but produced the smallest return rate of 7%. The study demonstrates how evolutionary algorithms with fuzzy logic integration provide new solutions for managing investment challenges in real-world market conditions. Fuzzy-GA proves to be a valuable instrument for investors because it generates both significant profits and sustainable risk management, especially when markets remain unclear. Future research could explore how this method performs under varying market conditions and further investigate the potential of adaptive fuzzy rule systems to enhance their flexibility and robustness.

Keywords: *Fuzzy Logic, Genetic Algorithm, Hybrid Optimization, Portfolio Management, Multi-Criteria Decision Making*

Virtual Reality Intervention for Fear of Flying: Software Development and Effectiveness Study

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Abstract

Fear of flying (aerophobia) is a common type of specific phobia in which individuals experience intense anxiety, panic, and avoidance behaviors at the thought of traveling by airplane. This condition can significantly reduce a person's quality of life by interfering with business, vacation, or emergency travel plans. In recent years, virtual reality (VR)-based interventions have emerged as an innovative treatment approach for this phobia. Virtual reality therapy exposes the individual to a simulated flight experience in a controlled environment, teaching them how to cope with situations similar to actual air travel. This method aims to gradually reduce fear by simulating triggering scenarios such as sitting inside the airplane, takeoff, and turbulence. The developed software is an intervention visual aimed at reducing anxiety during a flight. The goal is to reduce the anxiety of individuals with fear of flying through exposure therapy. During the software development process, modeling was first done in Blender 3D. The models were transferred to Unity 3D, where necessary coding was performed, and a build was created. The build was then loaded onto the Meta Quest 3 headset in APK format. In the study, a demographic information form and the Flight Anxiety Situations Survey, specifically the Flıght-Related Anxıety Scale and General Flight Anxity Scale, were used. The analysis will be conducted using dependent sample T-tests or the nonparametric counterpart, the Wilcoxon Signed-Rank test. The implementation of the study is ongoing. All stages of the study will be completed by the presentation date and the final manuscript submission deadline.

Key words: *Aerophobia, Virtual Reality, Exposure Therapy, Software Development, Effectiveness*

Empirical analysis aspects of sustainable management for Industry 4.0

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Abstract

The emergence of the fourth industrial revolution, known as Industry 4.0, and its applications in the manufacturing sector have ushered in a new era for business entities. It not only promises to improve operational efficiency, but also to enhance sustainable operational practices. This current paper provides an empirical analysis of management and highlights the benefits in favor of the sustainability dimension in the Industry 4.0 paradigm.
By definition, Industry 4.0 is an initiative that aims to create a smart factory that integrates emerging and future technologies such as big data analytics, industrial IoT, additive manufacturing, virtual reality, cloud technology, and industrial robotics to create a cyber-physical system to produce intelligent manufacturing systems that are efficient in terms of decision-making.
This paper presents an empirical analysis of management for a case study involving the integration of several currently available emerging technologies that lead to a sustainable decision-making system. The modeling contains a manufacturing system with big data analysis, industrial IoT and a cloud system that communicates with the outside world in order to improve accessibility, communication and ensure security through Internet networks. The analysis highlights, following the simulation, through graphic representations obtained in real time, the occurrence of possible errors, delays, or possible interruptions that may occur during a complete and complex manufacturing process.

Key words: *Industry 4.0, Cloud Manufacturıng, Internet Of Thıngs, Sustaınable Management*

From Transactional Systems to Decision Support: Embedding Analytics into SME-Oriented ERP Platforms

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Abstract

Enterprise Resource Planning (ERP) systems are essential tools for managing and integrating business operations. However, most ERP platforms are designed with large enterprises in mind, leading to high implementation costs, technical complexity, and limited adaptability for small and medium-sized enterprises (SMEs). These challenges are compounded by the lack of embedded analytical capabilities, which restricts the potential of ERP systems to serve as effective decision-support tools.

This study presents the design and development of a lightweight, modular ERP system that integrates descriptive, diagnostic, and predictive analytics directly within its core operational modules—Projects, Employees, Employee Payments, Vehicles, and Inventory. Tailored specifically for SMEs, the system emphasizes modularity, ease of use, cost-efficiency, and the ability to deliver actionable, real-time insights without the need for external business intelligence tools. The architecture supports flexible deployment and scalability, making it suitable for a range of SME use cases.

The system was developed using real operational data from a manufacturing SME and validated through iterative testing and user feedback. Results demonstrate that embedding analytics within ERP workflows enhances operational transparency, supports proactive decision-making, and improves overall business agility. This research contributes a practical framework for ERP design that redefines analytics as an integral component of business operations, offering a sustainable pathway for SMEs to become more data-driven in their day-to-day processes.

Key words: *ERP Systems, Business Analytics, Small and Medium Enterprises, Data-Driven Decision Making*

A Bibliometric Analysis of Publications on the Use of Virtual Reality Technology in Medical Education

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Abstract

Virtual reality (VR) technology offers medical students interactive, risk-free learning environments that closely resemble real-life situations. In fields such as anatomy, surgical practices, and clinical scenarios, VR enhances experiential learning and improves knowledge retention. This technology, especially in simulation-based education, encourages learning without the fear of making mistakes, thereby improving the quality of training. This study aims to analyze the scientific literature on the use of virtual reality (VR) technology in medical education through a bibliometric approach. By identifying publication trends, key authors, institutions, and countries, the study highlights the main research themes and collaboration networks. The study aims to map the intellectual structure of the field, providing insights into the current state and potential future directions. For the research, 6816 publications were retrieved from the Web of Science database. After applying inclusion and exclusion criteria, 4377 publications were analyzed. The first publication on the topic was made in 1994. The included publications were published in a total of 1432 sources. The annual growth rate of the topic is 15.5%. 24.29% of the publications were produced through international collaboration. The average number of citations per publication is 22.39. The most prolific journal in the field is BMC Medical Education (140), followed by the Journal of Surgical Education (115) and Surgical Endoscopy and Other Interventional Tech. (100). Publications from the top 10 most prolific journals account for 16% of the total publications. The top three most influential authors in the field are Konge L. (84), Aggarwal R. (30), and Fan YB. (28). The top 10 authors in the field have produced 7% of the total publications. The most research-intensive institution in the field is the University of Toronto (265), followed by the University of Copenhagen (213) and Harvard University (209). The top 10 institutions in the field account for 42% of the total research. The most cited work globally on this topic is Issenberg et al. (2005), "Features and Uses of High-Fidelity Medical Simulations that Lead to Effective Learning: A BEME Systematic Review", which systematically analyzed 109 papers examining the contributions of high-fidelity medical simulations to effective learning. The research identified the conditions under which simulation-based medical education is most effective, emphasizing factors such as feedback provision, repeated practice, integration into the curriculum, diversity in task difficulty levels, use of multiple learning strategies, reflection of clinical variations, controlled learning environments, personalized learning experiences, clearly defined learning outcomes, and simulation validity. When analyzing keyword trends over the years, early studies focused on topics such as virtual reality and laparoscopic skill measurement, along with the structural validity of psychomotor performance. In the mid-2010s, the research focus shifted to integrating VR simulations into medical education curricula and demonstrating the educational validity and reliability of these applications. From 2017 to 2019, publication volume significantly increased, and the contribution of VR to learning outcomes was empirically examined under the concepts of 'impact' and 'performance'. In recent years, themes such as augmented reality, user acceptance, anxiety, and patient experience have emerged, and the multilayered effects of XR technologies on clinical education and practice have started to be explored.

Key words: *virtual reality, healthcare management, medical education, health Technologies*

A Review of Studies on Digital Media in the Preschool Period in Turkey: The Case of 2014-2024

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Abstract

This study is structured based on a document analysis of research published between 2014 and 2024 on digital media in the preschool period in Turkey. To collect data, searches were conducted using the keywords "digital media" and "preschool period" in online databases such as the National Thesis Center of the Council of Higher Education, Google Scholar, DergiPark, and the National Academic Network and Information Center (ULAKBIM). A total of 89 studies were included in the research, consisting of 46 articles, 35 master's theses, 3 doctoral dissertations, 3 conference papers, and 2 specialist theses, all of which were open-access and published in Turkish. The studies were evaluated based on criteria determined by the researchers using the "Study Review Form on Digital Media." The collected data were analyzed using the descriptive content analysis method. As a result of the study, it was found that the highest number of publications on digital media occurred in 2022 (f=15), and most of them were in the format of journal articles (f=46). It was observed that the majority of the studies were conducted using a quantitative research design (f=49) and employed convenience sampling methods (f=28). Moreover, the primary target groups in these studies were mainly parents (f=30) and children (f=30), and scales were the most frequently used data collection tools (f=45). The most commonly used scale was the Digital Game Addiction Scale (f=15). Based on the findings, it is suggested that future studies should adopt more comprehensive approaches to examine the effects of digital media use in the preschool period, support research with qualitative and mixed-method designs, and enrich studies with diversified data collection tools. Additionally, it is recommended to develop family- and child-centered intervention programs regarding digital media use, evaluate the effectiveness of these programs through experimental studies, and identify regional differences by conducting research in various regions of Turkey.

Key words: *Preschool period, Document analysis, Digital media, Technology*

Examining Early Childhood Education Teacher Candidates' Experiences in Using Artificial Intelligence Tools to Create Digital Educational Games

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Abstract

Digital game-based learning is becoming increasingly common in early childhood education, and artificial intelligence (AI) tools are more accessible than ever. Particularly in digital game-based teaching, AI tools facilitate the creation of effective, efficient, and engaging digital games for children aged 3-8. Using generative AI tools, tasks such as developing game ideas and scenarios, creating game mechanics, designing characters, and coding can be accomplished swiftly and effectively. Despite their growing availability, research remains limited on how pre-service teachers perceive and interact with these AI technologies during the educational game design process, particularly within early childhood education contexts. This research aimed to examine the experiences of pre-service early childhood teachers in developing digital games using AI tools. A qualitative case study approach was selected to allow detailed exploration of participants' authentic experiences and perceptions. The participants included 10 second-year pre-service teachers from the Early Childhood Education program at Tokat Gaziosmanpaşa University. These pre-service teachers engaged in digital game development activities using AI tools as part of their "Instructional Technologies" course. Data was collected via a semi-structured focus group interview form designed by theresearchers. Two sessions of focus group interviews were audio-recorded, transcribed, and analyzed through content analysis. Initially, pre-service teachers perceived AI tools as complex and difficult to use, resulting in low self-confidence and significant hesitation. However, practical classroom experiences significantly improved these perceptions, enhancing their confidence and enthusiasm. Participants reported enjoying the AI-supported digital game design process, emphasizing that creating tangible educational materials positively influenced their views of the teaching profession. Moreover, they noted that the experience promoted essential 21st-century skills such as problem-solving, analysis, collaborative learning, creativity, and critical thinking. Ultimately, the pre-service teachers expressed strong intentions to integrate AI tools into their future teaching practices, recognizing the need to align with the technology-rich environment familiar to Alpha-generation learners. The findings underscore the importance of embedding hands-on AI-based digital game development activities within teacher education programs. Such integration can significantly enhance digital literacy and pedagogical skills, effectively preparing future teachers to meet the evolving demands of contemporary educational settings.

Key words: *Early Childhood Education, Artificial Intelligent, Digital Educational Game*

Üretken Yapay Zekânın Eğitimde Kullanılması: Bibliyometrik Bir Araştırma

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Özet

Bu araştırmanın amacı, üretken yapay zekâ ve eğitim alanlarında yapılan araştırmaların bibliyometrik analiz yöntemiyle incelenmesidir. Yapay zekânın sunmuş olduğu yeniliklerden olan üretken yapay zekâ kullanıcılara bireyselleştirilmiş araçlar sunmaktadır. Yapay zekâ ve hesaplama teknolojileri üzerine yapılan çalışmalar yapay zekâ teknolojilerinin sağlık, adalet ve eğitim dahil birçok alanda kullanılmasına neden olmuştur. Yapay sinir ağlarının ve derin öğrenmenin getirmiş olduğu yenilikler yapay zekâ teknolojilerinin bireysel kullanımına olanak sağlamış ve kişiye özel içerik sunulmasını beraberinde getirmiştir. Bu gelişmelerle birlikte eğitim ortamlarında bireysel farklılıklardan dolayı öğrencilerin farklı öğrenme stillerine, hızlarına ve yöntemlerine yönelik geliştirilen yapay zekâ destekli araçların sayılarında artış meydana gelmiştir. Üretken yapay zekâ bireylere resim, ses, metin, ders vb. alanlarda orijinal içerikler sunmaktadır. Üretken yapay zekânın sunmuş olduğu bu hizmetler eğitim araştırmalarına da konu olmuştur ve araştırmacılar tarafından eğitim üzerine etkileri incelenmiştir. Araştırma yöntemi olarak bibliyometrik analiz kullanılmıştır. Bibliyometrik analiz yöntemi belirlenen alanlarda yapılan araştırmaların yayın yılı, kullanılan anahtar kelimeler, yayın yapılan dergiler gibi alanlardaki eğilimleri ortaya koymayı ve yapılan araştırmalar hakkında bilgi sahibi olmayı sağlar. Üretken yapay zekâ ve eğitim alanında yapılan araştırmaların incelenmesi için araştırmacılar tarafından tercih edilen ve farklı disiplinler arası araştırmaların yer aldığı veri tabanlarından biri olan Web of Science (WoS) veri tabanı kullanılmıştır. WoS üzerinde yapılan araştırmada "Generative Artificial Intelliegence (Üretken Yapay Zekâ)" ve "Education (Eğitim)" anahtar kelimeleri kullanılarak inceleme yapılmıştır. Araştırma sonucuna göre 1333 makaleye erişilmiştir. Araştırmaların 2022 yılında başladığı, araştırmalarda 4671 yazarın yer aldığı, araştırmalara 49.399 atıf yapıldığı, araştırmalarda 3818 anahtar kelime yer aldığı görülmüştür. Yapılan araştırmaların en fazla Education and Information Technologies ve Education Science dergilerinde yayılandığı görülmüştür. Eğitimde üretken yapay zekânın kullanılması üzerine yapılan araştırmaların yıllar geçtikçe arttığı da tespit edilmiştir. Elde edilen sonuçlara göre farklı derslere yönelik üretken yapay zekâ kullanılarak geliştirilen eğitim materyallerinin artacağı ve bu alanda yapılan çalışmaların yaygınlaşacağı ifade edilebilir.

Anahtar Kelimeler: Üretken Yapay Zekâ, Eğitim, Bibliyometrik Analiz.

Hibrit Makine Öğrenimi ile Çoklu Hastalık Risk Tahmini: XGBoost ve Çok Katmanlı Yapay Sinir Ağı Entegrasyonu

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Özet

Diyabet, kalp hastalığı ve inme günümüzde yaygın olarak görülen kronik hastalıklardandır. Çalışmada bu hastalıklar için için risk tahmini yapan yenilikçi bir hibrit makine öğrenimi platformu sunulmaktadır. Geliştirilen model ile gradient boosting algoritmalarından olan XGBoost ile çok katmanlı yapay sinir ağlarının avantajları birleştirilerek, hem yüksek doğruluk hem de yorumlanabilirlik hedeflenmiştir. Veri ön işleme aşamasında, her bir hastalık veri setinden ortak klinik parametreler (yaş, vücut kitle indeksi, kan basıncı, glukoz düzeyleri gibi) standartlaştırılmış ve eksik veriler medyan değerlerle tamamlanmıştır. Kategorik değişkenler one-hot encoding yöntemiyle sayısallaştırılarak model eğitimi için uygun hale getirilmiştir. Geliştirilen hibrit model, XGBoost'un özellik önem sıralama yeteneği ile çok katmanlı yapay sinir ağlarının karmaşık ilişkileri yakalama kapasitesini bir arada kullanmaktadır. Model performans değerlendirmesi kapsamında, doğruluk (accuracy), kesinlik (precision), duyarlılık (recall) ve F1-skor metrikleri kullanılmış olup çapraz doğrulama (cross-validation) sonuçları, modelin genelleme yeteneğini göstermektedir. Sistem, özellikle birinci basamak sağlık hizmetlerinde, hastaların çoklu kronik hastalık risklerinin erken belirlenmesi ve kişiselleştirilmiş önlem stratejileri geliştirilmesi amacıyla kullanılabilecek güçlü bir klinik karar destek aracı olarak tasarlanmıştır. Kullanıcı dostu arayüzü sayesinde tıp uzmanları, hasta parametrelerini girerek anında risk tahminleri hakkında bilgi alabilmektedir. Çalışma, makine öğreniminin klinik uygulamalardaki potansiyelini göstermekle kalmayıp, özellikle farklı kaynaklardan gelen tıbbi verilerin entegrasyonu ve yorumlanabilir yapay zeka modellerinin geliştirilmesi konularında metodolojik bir referans sunmaktadır. Gelecekteki çalışmalarda, daha fazla hastalık türünün ve daha geniş hasta popülasyonlarının modele dahil edilmesi planlanmaktadır.

Anahtar Kelimeler: *Makine Öğrenmesi, XGBoost, Hastalık Tahmini*

InsurTech: Transforming the Insurance Industry Through Technological Innovation and Digital Adaptation

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Abstract

InsurTech represents the integration of technology into the insurance industry, aiming to transform the sector through innovative business models and digital applications. This paper explores the global impacts of InsurTech on the insurance sector, analyzing current trends and future potentials.

InsurTech applications leverage advanced technologies such as artificial intelligence, machine learning, blockchain, big data analytics, and the Internet of Things (IoT) to enhance operational efficiency, improve customer experience, and optimize risk management. Particularly, digitalization in claims management, underwriting processes, and distribution channels has significantly reshaped the traditional structures of the insurance industry.

The study evaluates international case studies to illustrate how InsurTech startups interact with existing insurance ecosystems and addresses emerging regulatory challenges. Additionally, the current status, opportunities, and obstacles faced by InsurTech initiatives in Turkey are examined, providing strategic recommendations tailored to the national context.

In conclusion, the positive contributions of InsurTech to the digital transformation of the insurance sector and its sustainability are highlighted, emphasizing that adaptation to these changes has become a critical competitive advantage for insurance companies. The paper suggests future research should particularly focus on regulation and technological adaptation processes due to their significance for the industry's future.

Keywords: *InsurTech, Insurance Innovation, Digital Transformation*

Türkiye'de 2024 Yılında Uygulanan Maarif Modeli Kapsamında Öğretmenlerin Dijital Okuryazarlık Konusundaki Yeterliklerinin İncelenmesi

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Özet

Dijital okuryazarlık, içinde bulunduğumuz çağda giderek daha önemli hale gelmektedir ve Türkiye'deki son öğretim programı değişikliği, bu becerinin tüm derslere entegrasyonunu zorunlu kılmıştır. 2024-2025 eğitim-öğretim yılından itibaren Türkiye'de uygulanmaya başlanan yeni ulusal öğretim programı içerisinde dijital okuryazarlık becerisi, dijital çağa etkin katılım için gerekli temel beceri olarak kabul edilmektedir. Böylelikle uygulanan öğretim programı ile yalnızca dijital araçları yetkin bir şekilde kullanabilen değil, aynı zamanda bilim ve yenilikçi teknolojinin üreticisi ve yöneticisi olan, güçlü dijital yetkinliklere, hayat boyu öğrenme kültürüne ve 21. yüzyıl becerilerine sahip bireylerin yetiştirilmesi amaçlanmaktadır. Bunun için özellikle öğretmenlerin sınıf içi ve dışı öğretim uygulamalarında öğrencilerin dijital okuryazarlık becerilerini geliştirecek yenilikçi etkinlikler gerçekleştirmeleri beklenmektedir. Dijital okuryazarlığın eğitim bağlamındaki stratejik önemi göz önüne alındığında, ulusal öğretim programının etkili bir şekilde uygulanması ve geliştirilebilmesi için öğretmenlerin bakış açılarını anlamak araştırmanın odaklandığı temel noktadır. Bu bağlamda araştırmada, Türkiye'nin yeni ulusal öğretim programı kapsamında görev başındaki öğretmenlerin öğrencilerine dijital okuryazarlık becerilerinin kazandırılması konusundaki deneyimlerini, süreçte karşılaştıkları engelleri ve iyileştirme önerilerini ortaya çıkarmak amaçlanmıştır. Araştırmada nitel bir durum çalışması deseni kullanılarak öğretmenlerin deneyimleri derinlemesine incelenmiştir. Araştırmanın çalışma grubunu, Türkiye genelinde farklı alanlardaki gönüllü öğretmenler oluşturmaktadır. Araştırmaya 2024-2025 ulusal öğretim programı kapsamında öğretmenlere verilen eğitimlere katılmış 20 öğretmen dahil edilmiştir. Veriler, araştırmacılar tarafından geliştirilen açık uçlu anket yardımıyla toplanmıştır. Çevrimiçi toplanan veriler içerik analizi kullanılarak analiz edilmiştir. Araştırma sonucunda katılımcılar, öğrencilerinin dijital becerilerini dikkate alarak derslerini şekillendirdiklerini belirtmelerine rağmen, yoğun olarak okullarda sunulan teknolojik imkanları sınırlı düzeyde kullanabildiklerini göstermektedir. Buna karşın yenilikçi teknolojilerin dijital okuryazarlık başta olmak üzere 21. yüzyıl becerilerini kazandırılmaya yönelik iyi uygulama örneklerinin sınırlı düzeyde kaldığı belirlenmiştir. Özellikle üst düzey bilişsel beceriler gerektirecek yapay zeka araçları gibi yenilikçi teknolojilerden yeterli biçimde yararlanmadıkları görülmüştür. Ayrıca katılımcılar, öğretim sürecinde etkileşimli ve oyunlaştırılmış dijital araçlar kullanmanın, öğrenci motivasyonu ve sınıf katılımı üzerinde önemli olumlu etkisinin olduğunu vurgulamışlardır. Dijital okuryazarlık becerisinin kazandırılmasına yönelik karşılaşılan en önemli engelin güvenilir internet bağlantısı ve yeterli sayıda bilgisayar/tabletin olmaması gibi altyapı sorunları olduğunu belirtmişlerdir. Bu durum herkesin dijital kaynaklara eşit şekilde ulaşamaması nedeniyle öğrenciler arasındaki dijital uçurumu artırdığını da belirtmişlerdir. Öğretmenler karşılaşılan sorunların aşılması için altyapı iyileştirmeleri, yönetici desteği, düzenli zorunlu mesleki gelişim, güncel kaynaklara erişim ve kolayca ulaşılabilir teknik yardım gibi sistematik destek ihtiyacını güçlü bir şekilde vurgulamışlardır.

Anahtar Kelimeler: *Dijital Okuryazarlık, Eğitim Teknolojileri, Öğretmen Deneyimleri, Öğretim Programları*

Bingöl İli İçin Penman-Monteith Yöntemine Göre Standartlaştırılmış Yağış Evapotranspirasyon İndisi (SPEI) Hesaplama Algoritmasına Teorik Olasılık Dağılımın Etkisi

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Abstract

Küresel ısınma, günümüzde dünyanın karşı karşıya olduğu en kritik çevresel tehditlerden biri olarak, farklı coğrafi bölgelerde çeşitli sosyo-ekonomik ve ekolojik etkilerle kendini göstermektedir. Türkiye, yarı kurak iklim kuşağında konumlanmış olması nedeniyle, özellikle İç Anadolu ve Güneydoğu Anadolu bölgelerinde kuraklık olgusunu daha yoğun bir şekilde deneyimlemektedir. Bu bölgelerde yıllık ortalama yağış miktarlarının yetersizliği ve su kaynaklarının sınırlılığı, tarımsal üretim üzerinde sürdürülebilirliği tehdit eden ciddi bir baskı unsuru oluşturmaktadır. Bu çalışma kapsamında, Bingöl ili kuraklık analizi, Standartlaştırılmış Yağış-Evapotranspirasyon İndeksi (SPEI) kullanılarak gerçekleştirilmiştir. Kuraklık analizinde Bingöl ili tercih edilmiştir; çünkü bu il, Fırat Havzası'nın üst kesimlerinde yer almasıyla hidrolojik açıdan stratejik bir konuma sahip olup, aynı zamanda tarımsal faaliyetlerin büyük ölçüde iklim koşullarına bağımlı olduğu kırsal bir yapıya sahiptir. Araştırma için gerekli olan iklim verileri (yağış, rüzgâr hızı, maksimum ve minimum hava sıcaklığı, güneşlenme süresi ve nispi nem), Devlet Meteoroloji Genel Müdürlüğü (MGM) tarafından işletilen Bingöl Meteoroloji İstasyonu'ndan temin edilmiştir. SPEI hesaplamasında ihtiyaç duyulan bitki su tüketimi, Penman-Monteith yöntemi ile tahmin edilmiştir. SPEI hesaplamaları yalnızca geleneksel yöntem olan Genelleştirilmiş Log-Logistik (GLOG) dağılımı ile sınırlı kalmamış; aynı zamanda yağış ile bitki su tüketimi farklarına en uygun teorik olasılık dağılım biçimleri de değerlendirilmiştir. Bu dağılımların parametrelerinin hesaplanmasında ise momentler, maksimum olabilirlik (ML) ve L-momentler yöntemleri kullanılmıştır. Farklı zaman ölçekleri (3, 6, 9, 12 ve 24 aylık periyotlar) için yapılan analizlerde, en uygun dağılım biçimlerinin çoğunlukla GLOG ve Genelleştirilmiş Ekstrem Değer (GEV) dağılımları olduğu tespit edilmiştir. Bu durum, tek bir dağılım biçimine bağlı kalarak yapılan SPEI tahminlerinin güvenilirliğini sorgulatmakta ve bu tür analizlerde dağılım seçiminin ne denli kritik olduğunu ortaya koymaktadır. Elde edilen bulgular, Bingöl'de GEV ve GLOG dağılımları arasında geçişlerin yaşandığını göstermektedir. Buna dayanarak, SPEI ile yapılan kuraklık analizlerinde hem zaman ölçeğinin hem de seçilen teorik olasılık dağılımının sonuçlar üzerinde önemli bir etkisinin bulunduğu sonucuna ulaşılmıştır. Ayrıca, parametre tahmininde kullanılan yöntemlerin farklılığı da analiz sonuçlarını önemli ölçüde etkilemektedir Sonuç olarak bu çalışma, Bingöl ilindeki kuraklık risklerinin belirlenmesine katkı sağlamakta ve su kaynaklarının sürdürülebilir yönetimi açısından bilimsel bir temel oluşturmaktadır

Key words: *Kuraklık, SPEI, Penman-Monteith Yöntemi, GEV, GLOG*

The Role of Smart City Theories in Enhancing Traffic Flow: The Case of Tirana

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Abstract

Urban traffic congestion poses growing challenges to mobility, environmental quality, and public health, particularly in rapidly expanding cities like Tirana. This paper presents a theory-based literature review of smart city frameworks, namely the Internet of Things (IoT), Intelligent Transportation Systems (ITS), data-driven urbanism, AI-driven traffic control, and sustainable urban mobility theory as applied to traffic management. Drawing on global case studies, the review highlights how these frameworks improve traffic efficiency, integrate public transportation, and reduce emissions. The paper contextualizes these theories within Tirana's traffic landscape, marked by high car dependency, limited transit alternatives, and rising air pollution. It discusses the applicability of interventions such as adaptive signal control, real-time traffic monitoring, and integration of electric bus rapid transit (e-BRT). The study concludes that while technology is essential, it must be coupled with sustainability-oriented policies to transform Tirana's transport system. Recommendations include prioritizing data collection via IoT, deploying adaptive signals and transit signal priority, and using AI for predictive traffic control. Challenges such as funding, technical capacity, and public acceptance are noted. A phased approach starting with smart pilot corridors, expanding through evidence-based planning, and supported by citizen engagement is proposed. The findings emphasize that a combined strategy leveraging smart city technologies and sustainable mobility principles can help Tirana build a smarter, cleaner, and more efficient urban transport network.

Keywords: (*AI Traffic Management, Intelligent Transportation Systems (ITS), Smart City Frameworks, Sustainable Urban Mobility, Traffic Flow Optimization)*

Analysis of the Effects of Chemical Applications on Quality Parameters of Cherry Fruit Using the Decision Tree Method

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Abstract

In this study, the effects of different chemical applications on fruit quality parameters (fruit firmness, fruit weight, fruit size, TMA, and pH) were evaluated using CHAID (Chi-squared Automatic Interaction Detection) decision tree analysis. The results revealed that the most influential variable was fruit firmness (Improvement = 0.044). Among the groups separated based on fruit firmness, fruit weight emerged as the second most important variable (Improvements = 0.074 and 0.058). In groups with fruit weight less than or equal to 6.315 g, the third separation was made according to fruit size, with a critical threshold identified at 21.04 mm. In groups with fruit weight greater than 6.315 g, TMA was the distinguishing variable, with 1.67 identified as a critical threshold value. On the other hand, for samples with fruit firmness greater than 74.35 N, separations were again based on fruit weight, followed by pH value as a determining factor. Notably, the effects of chemical applications varied in samples with a pH greater than 3.485. The results demonstrated that chemical applications caused significant differences in fruit quality parameters. Specifically, the control group was associated with firmer and heavier fruits, whereas the ABA1 and AVG-ABA2 applications were more prominent in fruits with relatively lower firmness and weight. This study highlights that the effects of chemical applications on fruit quality in agricultural production can be thoroughly assessed using multivariate data analysis methods.

Key words: *CHAID, Fruit Quality, Chemical Applications, Decision Tree Analysis, Fruit Firmness, TMA*

An integration of the multi-choice best-worst method to multi-criteria decision-making based Z-Numbers

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Abstract

Best Worst Method (BWM) is quite functional for Multi-Criteria Decision Making (MCDM) to handle uncertain decision processes. Classical BWM determines the priority order by comparing the best and worst criteria in pairs. Multiple-choice best-worst method (MCBWM) is a new extension of BWM developed by addressing various reasons such as incomplete information in expert opinions, lack of knowledge, ambiguity in linguistic terms, etc. Unlike BWM, MCBWM uses multiple-choice parameters instead of single-parameter values for pairwise comparisons. Also, compared to fuzzy numbers, Z-numbers have more ability to describe human knowledge. In this study, we develop the Z-MCBWM method that is a strong integration of MCBWM with Z-numbers. Its comparative analysis is presented to show the superior aspects of the proposed method over classical decision-making techniques. This approach provides a new perspective on MCDM approaches to solve real-life problems.

Keywords: *Z-numbers, BWM, MCBWM, Z-MCBWM, Decision making.*

Startup Ventures in the Insurance Sector: Digitalization and Future Perspectives

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Abstract

The concept of a startup is defined as an initiative that aims to grow by developing a new product or service, primarily through the use of technology and digital platforms. Startups in the field of insurance are referred to as InsurTech ventures, and they not only restructure insurance sector processes using digital technologies but also offer technology-based solutions to the challenges faced by traditional insurance, thereby providing foresight to the future of the industry..

The insurance sector has been reluctant to innovate for the past 300 years due to its complex structure, strict regulations, and the profitability of existing companies. However, the rapid advancement of digital technologies in recent years has compelled the insurance industry to undergo change and has enabled the emergence and growth of startup ventures in the sector. This study discusses the innovations offered by InsurTech startups operating in the insurance industry and the benefits they bring to the sector.

Since 2012, startup ventures in the insurance sector have been rapidly increasing. InsurTech startups utilize technologies such as artificial intelligence, big data, blockchain, the Internet of Things (IoT), cloud computing, mobile applications, and chatbots to make insurance processes more efficient and customer-centric. Compared to traditional insurance companies, these startups offer more flexible and customer-friendly solutions, thereby increasing competition in the market.

While InsurTech startups bring major innovations to the sector, they also face some fundamental challenges. The first is regulations and legal barriers. While InsurTech startups generally aim to transform insurance processes by using innovative technologies, current regulations may be insufficient to accommodate these innovations. Second, trust is very important for the insurance sector. The fact that new generation digital startups are not as well-known as traditional insurance companies makes it difficult for consumers to develop trust in these companies. Third, it becomes even more difficult for InsurTechs to gain market share due to the digitalization moves of traditional insurance companies.

In the coming years, startup ventures in the insurance sector are expected to grow in harmony with technological advancements. The first of these areas is artificial intelligence–based automation, which is increasingly being used to simplify claims processes, detect fraud, reduce manual operations and costs, and support various other functions. Secondly, the Internet of Things (IoT) enables the development of personalized insurance products—for example, the use of telematics devices in vehicle insurance or wearable technologies in health insurance. The third area is microinsurance products, which have significant growth potential in providing health, life, or agricultural insurance to low-income individuals through low-premium offerings. Another emerging field is embedded insurance, which aims to deliver integrated insurance solutions. For instance, automatically offering a policy during the purchase of a travel ticket is considered a leading example of next-generation InsurTech models. Lastly, the area of sustainability-focused insurance (green insurance) is open to further development, with green insurance products and sustainable business models becoming increasingly popular.

InsurTech startups play a crucial role in helping the insurance industry adapt to the modern age. However, their continued success is expected to be more sustainable if they focus on collaboration with traditional insurance companies rather than competition, and if they deliver customer-centric innovations..

Keywords: *Insurance, InsurTech, Digitalization, Artificial intelligence*

Using information technology in conducting and analyzing field research

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Abstract

It is necessary to summarize the long-term data collected during the implementation of field research and process analysis, prepare a theoretical model, study the data and provide certain conclusions and forecasts. In this regard, the important role of information technologies and advantages have been investigated for the article discusses the effective organization of scientific research. About application programs (Excel, Math CAD, Auto CAD) used to solve various problems, examples of the use of systems are reflected. Soil diagnostics and assessment of the land reclamation condition were carried out using GIS programs. A distribution curve was constructed for the 0-100 cm soil layer, statistical analysis of the variation indicator (based on the law of 3σ, etc.) the dynamics of desalination was studied by conducting using the Excel spreadsheet program soil samples located in the study area on the basis of laboratory analysis data covering different years. During the investigation of the research data, the hypothesis of the homogeneity of the sample was tested using the Simirnov-Grabbs method, when "suspicious" values were excluded from the report. The values of the correlation coefficient for hydrocarbons were obtained in the intervals of $-0{,}107 \leq r_{hydro} \leq -0{,}004$*, for sulfates* $0{,}570 \leq r_{sulfate} \leq 0{,}757$*, for chlorine* $0{,}685 \leq r_{chlorine} \leq 0{,}948$ *and for dry residue* $0{,}634 \leq r_{dry\ residue} \leq 0{,}768$*. The study of the results obtained on the corresponding mineralization indicators of dry residue, chlorine, hydrocarbonate, sulfate, groundwater showed that, unlike chlorine and sulfate, hydrocarbonate is weakly and inversely correlated. The main goal of regression analysis is to identify a model and study the relationship between variables. During the study, measurements taken in the field and in the laboratory were compared with data obtained from satellite images, for the purpose of studying soil and plant objects, accordingly. For comparative analysis and digital image processing the study of satellite images was mainly carried out using various index indicators (NDVI, MSAVI, etc.) with ArcMap 10.3 was used to carry out the research.*

Key words: *İnformation Technology, Application Software, Mathematical Statistics, Satellite Images, Distribution Function.*

Automation of Transit Declarations in International Road Transport with Artificial Intelligence: BARBOT System

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Abstract

In international road transport of goods, preparation of correct and legally compliant transit declarations is of critical importance for the smooth operation of border crossings. With the NCTS 5th Version, which will be put into effect throughout Europe as of 2024, a separate declaration obligation has been introduced for each export item, which has made the declaration process both time-consuming and open to error risk. As a solution to these difficulties, BARBOT, an artificial intelligence-supported automation system has been developed. Equipped with OCR (Optical Character Recognition) technology and intelligent error correction algorithms, BARBOT has a structure that automatically reads the load and voyage information and foreign trade documents created by users, detects errors, corrects them and creates the declaration within minutes. With this developed system, it works in integration with SGS TransitNet, which provides transit guarantee services in 23 European countries, and transmits the declarations to the relevant country customs authorities electronically. With this artificial intelligence-supported solution, which reduces the currently hour-long manual processes to minutes and minimizes human error, customs-approved transit declarations are produced. BARBOT's modular structure is not limited to SGS TransitNet alone but is flexible enough to integrate with other collateral providers and official customs systems in Europe. In this study, the architecture of the BARBOT system, its application processes and the transformational effects it creates in foreign trade logistics are discussed.

Key words: *AI-Powered Automation, BARBOT, Transit Declaration, Digital Customs Integration, Knowledge Management*

Analysis of Patient Feedback: An Interactive Tool for Sentiment and Topic Modeling with Multi-Format Support and Turkish Language Processing

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Abstract

Important markers that inspire the need for ongoing development and a patient-centered approach are patient experience, quality of healthcare services, and satisfaction. Although patient comments offer perceptive analysis, the abundance of text data from many sources—including polls, online reviews, and scanned papers—offers a major analytical difficulty. Often resource-intensive and time-consuming, manual processing of such massive, unstructured, multi-format datasets limits healthcare institutions' capacity to extract timely and actionable intelligence. This stduy presents "SentimHasta Pro", an interactive R Shiny-based analysis tool meant to handle these problems. Focusing especially on the Turkish language, SentimHasta Pro offers a strong and automatic framework for carefully analyzing written patient comments, thereby supporting hospital management and quality improvement teams. Beginning with flexible data collecting, this tool supports standard structured file formats including CSV and Excel in addition to processing text from PDF documents. One significant benefit of this data acquisition compatibility is that it enables SentimHasta Pro's central analytical tools, which include topic modeling and sentiment analysis. Currently, the sentiment analysis tool uses a dictionary-based approach to rapidly and consistently rank emotions as either positive, negative, or neutral by utilizing a specialized Turkish dictionary. Additionally included in the application is a conceptual framework that shows how future machine learning models might be combined for sentiment prediction and acts as a placeholder for continuous research in this direction. Using Latent Dirichlet Allocation (LDA) for topic modeling, this method also identifies hidden themes and key discussion topics from the feedback data. One of the most important advantages of SentimHasta Pro's interactive user interface is how simply it converts complicated analytical outputs into understandable visualizations. Users can investigate department-specific sentiment scores, review broad sentiment distributions, track sentiment changes over time, and find often discussed subjects by their most often occurring keywords. Word frequency counts, N-gram (bigram and trigram) analysis, word co-occurrence network visualization, and a comparative analysis module that letss one study several feedback subsets side-by-side all help to improve the analysis. You can export every produced table and selected visualization for offline study and reporting assistance. SentimHasta Pro can greatly improve healthcare organizations' capacity to grasp patient perspectives, pinpoint particular areas for service development, and generate more informed, data-driven decisions by automating the extraction of insights from various patient feedback sources. Apart from sorting and assessing patient comments, this tool supports applied NLP in health informatics in languages including Turkish, so fostering a culture of ongoing quality improvement motivated by the voice of the patient.

Key words: *Patient feedback, Sentiment analysis, NLP, Interactive analysis tool, Healthcare organizations*

Otizm Spektrum Bozukluğu Olan Çocuklarda Gyrus Precentralis ve Gyrus Postcentralis'in Volümetrik İncelenmesi

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Özet

Otizm Spektrum Bozukluğu (OSB), erken gelişimsel dönemde başlayan ve bireyin yaşamı boyunca devam eden; sosyal iletişim ve etkileşimde kalıcı yetersizlikler ile sınırlı, tekrarlayıcı davranışlar ve ilgi alanlarıyla karakterize edilen nörogelişimsel bir bozukluktur. OSB, primer motor ve duyu kortekslerde yapısal ve işlevsel değişikliklere yol açabilmektedir. Çalışmamızda, OSB'nin motor fonksiyonun kontrol merkezi olan gyrus precentralis ile duyuların algılanmasında fonksiyon gören gyrus postcentralis hacimlerine etki edip etmediğini sağlıklı kontrol grubu ile karşılaştırarak değerlendirmeyi amaçladık. Çalışmamızda, Tokat Gaziosmanpaşa Üniversitesi Sağlık Uygulama ve Araştırma Hastanesi'ne başvuran ve OSB tanısı koyulan 33 çocuğun beyin manyetik rezonans (MR) görüntüleri incelendi. Kontrol grubu olarak baş ağrısı nedeniyle MR çekilen ve herhangi bir tanı konmayan sağlıklı 33 çocuğun görüntüleri analiz edildi. Çalışmamız retrospektif olarak yapıldı. Hacimsel analizler için beyin MR görüntülerini ücretsiz işleyen çevrimiçi web tabanlı volBrain (v.1.0, http://volbrain.upv.es) sistemi kullanıldı. İstatistiksel analiz için IBM SPSS Statistics 25 kullanıldı. Sonuçlarımız OSB tanısı konulan çocukların gyrus postcentralis hacimlerinde sağlıklı kontrol grubuna kıyasla istatistiksel olarak anlamlı bir artış ($p < 0,05$) olduğunu, gyrus precentralis hacimleri açısından gruplar arasında anlamlı bir fark olmadığını ($p > 0,05$) gösterdi. Çalışmamız, OSB'de kortikal duyu hacimlerinin motor hacimlere kıyasla daha belirgin şekilde etkilendiğini göstermiştir.

Anahtar Kelimeler: *Otizm spektrum bozukluğu, Hacim, Gyrus precentralis, Gyrus postcenralis*

Classification of Sugar Beet Farmers Based on the Purified Sugar Rates with Machine Learning Techniques

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Abstract

Sugar beet, which is the raw material of the sugar industry, contributes to the agricultural and industrial sectors in many respects. Thanks to the sugar they produce, sugar factories are suppliers for the beverage, food, pharmaceutical and sweetener sectors. Industrial companies are carrying out studies to reduce costs without compromising efficiency in order to minimize the impact of recent economic problems and strengthen their competitiveness in the global market.

The sugar beet price determined at the beginning of the harvest period is explained based on a ton of sugar beets with a sugar content of 16% by mass. Although a pricing based on a certain parameter, sugar beets with the same sugar ratio cannot obtain the same amount of sugar due to differences in other quality parameters (potassium content, sodium content, α-amino nitrogen content, etc.). This situation causes the fairness of the raw material prices paid to the producers to be questioned and the need for a new payment model in which all sugar beet quality parameters are evaluated in order to protect the interests of the sugar companies.

In this study, in order to adopt a more realistic pricing model for sugar beet, a pricing model based on the purified sugar rate, which includes all quality parameters of sugar beet, was tried to be established. In the establishment of the model, supervised machine learning models based on the purified sugar rate were created using real data from the sugar factory operating in our region, and producer classification was made. After pre-processing, approximately fifty-five thousand data obtained were divided into 10 different classes by characterizing the producers with class numbers between 1 and 10. Of the sugar beets delivered to the factory, those with the highest quality were taken to the 1st class, while those with the lowest quality were taken to the 10th class. Also, intermediate classes are identified in the same way. Six different supervised machine learning techniques (Support Vector Machines, K-Nearest Neighbor, Decision Trees, Logistic Regression, Naive Bayes, Random Forest) were applied to the data set and the results were compared. According to these results, the best accuracy rate was obtained from Support Vector Machines (SVM) with 0.99, while the technique with the highest f1 score was determined as Random Forest (RF) with

0.86. When the parameters used to evaluate the machine learning results are examined, it is seen that all models classify sugar beet producers quite well.Finally, a function group was created that was rewarding for the best class and punishing for the worst class. Thanks to the function group, the data of the classes within each other are parsed and it is prevented that there is data belonging to another class in the range representing the classes. In this way, it is ensured that high quality sugar beets are paid more than low quality sugar beets. The fairness problem in the payment system has been resolved and the payment amount realized according to the current situation and the proposed function group in the study can be compared. With new payment model, although the unit price paid to producers for sugar beet was 0.3% less, fairness was established among producers.

Key words: Supervised Machine Learning, Classification Techniques on Machine Learning, Sugar Beet Quality Parameters

Yenilikçi Teknolojiler ile Müşteri Deneyimlerinin İyileştirmesi ve DEMATEL Yöntemi ile Faktörlerin Değerlendirilmesi

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Özet

Dijital ortamlarda müşteri deneyimi, gelişen teknolojilerle birlikte daha da önemli hale gelmiştir. Yenilikçi teknolojilerle müşteri deneyimi, şirketlerin veya kurumların müşterilere daha iyi, daha hızlı, daha kişiselleştirilmiş ve daha tatmin edici hizmetler sunmak amacıyla teknolojik yenilikleri kullanma çabasıdır. Ancak tüm müşteri segmentleri teknolojiye eşit düzeyde erişememektedir ve yanlış öneriler, adaletsiz fiyatlandırmalar, eğitim eksikliğinden kaynaklanan platform ve yanıt sistemlerinin verimsizliği ile sistemlerin siber güvenlik riskleri gibi sorunlar marka sadakatini azaltabilmektedir. Dijital platformlarda etkili bir müşteri deneyimi sunabilmek için, işletmelerin müşteri deneyimine etki eden çeşitli faktörleri doğru şekilde belirlemesi ve analiz etmesi gerekmektedir. Bu çalışmada, müşteri deneyimini iyileştirmeye yönelik faktörlerin etkileşimleri, DEMATEL (Karar Verme ve Çok Kriterli Değerlendirme) yöntemi ile incelenmiştir. Araştırma, altı ana kriteri ele almıştır: K1 (Optimum kullanıcı deneyimi), K2 (Kesintisiz alışveriş deneyimi), K3 (Doğru ve alakalı öneriler), K4 (Hızlı ihtiyaç cevaplama), K5 (Kullanım zorlukları) ve K6 (Siber güvenlik riskleri). Yapılan analizler sonucunda, K3 (Doğru ve alakalı öneriler) sistemdeki en etkili faktör olarak belirlenmişken, K6 (Siber güvenlik riskleri) en fazla etkilenen faktör olarak öne çıkmıştır. Ayrıca, K1 (Optimum kullanıcı deneyimi) hem yüksek etkiye sahip hem de diğer faktörlerden güçlü bir şekilde etkilenmiş, bu da onu sistemin merkezi bir faktörü haline getirmiştir. Bu bulgular, dijital müşteri deneyimi üzerindeki faktörlerin etkileşimini daha iyi anlamaya yardımcı olmuş ve stratejik önceliklerin belirlenmesinde önemli bir rol oynamıştır. Sonuç olarak, bu analiz, dijital platformlarda müşteri deneyiminin iyileştirilmesine yönelik kaynak tahsisinde ve iyileştirme çabalarında rehberlik edecek değerli bir yol haritası sunmuştur.

Anahtar kelime: *Müşteri deneyim, Dijital dönüşüm, Yenilik teknolojiler, Dematel*

Community Detection and Social Network Analysis with Hierarchical Clustering

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Abstract

Community detection is an important analysis process that aims to determine tightly related groups of nodes in complex networks that represent interacting objects as nodes and their relationships through links (edges). As one of the basic subfields of social network analysis, this method is widely applied in many disciplines such as biology, computer science, engineering, economics, social sciences and politics. With the increasing digitalization and diversification of online interactions, the volume of data in social networks has grown significantly; analysis of networks containing millions or even billions of nodes have become a necessity. This growth significantly limits the scalability and efficiency of existing community detection algorithms, which reveals the need for new and fast algorithms. Although classical algorithms such as Girvan-Newman provide effective results in smaller-scale networks, they lose their practicality due to high computational costs when working with large data sets. In this context, modularity-based approaches stand out as an important evaluation criterion; they are used to evaluate how well a network is divided into clusters. High modularity means that nodes within clusters have dense connections, while connections between clusters are limited. Alternative algorithms such as hierarchical clustering and spectral clustering have been developed to detect community structures more quickly and effectively in large and complex networks.

In this study, we evaluate how different algorithms for community detection in social networks work in the context of structural network analysis; a comparative view is presented, especially in terms of criteria such as modularity and computation time. Community detection is not only limited to modeling graphical relationships but also forms the basis for many advanced applications such as understanding user behavior, system optimization, and data mining. The effectiveness of the developed methods directly affects the quality of decision support mechanisms in social network analysis.

Key words: *Community Detection, Social Network Analysis, Data Analysis, Clustering Algorithms*

Oyun Motorları ve Oyun Geliştirme Araçlarının Programlama Öğretiminde Kullanımına İlişkin Sistematik İnceleme

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Özet

Günümüzde programlama eğitiminin niteliğini artırmak amacıyla yenilikçi pedagojik yaklaşımlara duyulan ihtiyaç, oyun tabanlı öğrenme araçlarına yönelik ilgiyi artırmaktadır. Bu bağlamda, öğrencilerin motivasyonunu artırma, algoritmik düşünme ve problem çözme becerilerini geliştirme potansiyeline sahip oyun geliştirme uygulamaları öne çıkmaktadır. Bu çalışma, oyun motorları ve oyun geliştirme amacıyla kullanılan araç ve kütüphanelerin programlama öğretiminde nasıl kullanıldığını ortaya koymayı ve bu alandaki bilimsel araştırmaların bulgularını sistematik biçimde analiz ederek alana katkı sunmayı amaçlamaktadır. Bu doğrultuda, Web of Science (WoS) veri tabanında 2015–2025 yılları arasında belirlenen anahtar kelimelerle gerçekleştirilen sistematik tarama sonucunda 475 çalışma incelenmiş ve içerik açısından konu ile doğrudan ilişkili 41 çalışma değerlendirmeye alınmıştır. Makale seçim sürecinde PRISMA protokolü temel alınmış, analizlerde ise derinlemesine içerik analizi yöntemi kullanılmıştır. Analiz sonuçlarına göre, bu çalışmaların oldukça az bir kısmı üç boyutlu (3B) oyun motorlarını (örneğin Unity 3D) kullanarak programlama öğretimine odaklanmıştır. Geriye kalan büyük çoğunlukta ise Scratch, Code.org gibi blok tabanlı görsel programlama araçlarının, basit oyun kütüphanelerinin (örneğin Pygame) veya oyun benzeri simülasyonlar oluşturmak için geliştirilmiş modelleme araçlarının (örneğin StarLogo) tercih edildiği görülmüştür. Oyun motoru kullanılan sınırlı sayıdaki çalışmalarda, öğrencilerin yalnızca teknik becerilerinin değil, aynı zamanda bilişsel farkındalık, problem çözme, öz-yeterlik ve öğrenme motivasyonu gibi duyuşsal ve bilişsel boyutlarda da gelişim gösterdiği rapor edilmiştir. Ayrıca, oyun motorlarının sunduğu sanal ortamların gerçek dünya koşullarını modellemesi ve öğrenciyi aktif öğrenme sürecine dahil etmesi, öğretimsel açıdan öne çıkan unsurlar arasında yer almaktadır. Bununla birlikte, bu tür araçların yaygın olarak kullanılmamasının arkasında erişim kısıtlılıkları, eğitmen yeterlikleri ve teknik altyapı eksiklikleri gibi faktörlerin etkili olduğu görülmektedir. Araştırma bulguları, oyun motoru temelli uygulamaların programlama öğretiminde yüksek pedagojik potansiyel taşımasına karşın, mevcut literatürde bu potansiyelin yeterince temsil edilmediğini ortaya koymaktadır. Literatürde daha çok Scratch ve benzeri blok temelli araçlarla gerçekleştirilen çalışmaların ağırlıkta olduğu görülmektedir. Oysa oyun motorlarıyla gerçekleştirilen oyun geliştirme süreçleri, öğrencilere yalnızca programlama becerileri kazandırmakla kalmamakta, aynı zamanda yaratıcı düşünme, proje tabanlı öğrenme ve dijital üretkenlik gibi üst düzey becerilerin gelişimine de katkı sunmaktadır. Bu bağlamda hem programlama hem de oyun geliştirme yetkinliklerinin bütüncül şekilde ele alındığı, özellikle öğretim tasarımı ve öğrenci çıktıları bakımından karşılaştırmalı ampirik araştırmalara ihtiyaç duyulduğu düşünülmektedir.

Anahtar Kelimeler: *Oyun Tabanlı Öğrenme, Programlama Öğretimi, Oyun Motoru, Oyun Geliştirme Araçları*

Derin Öğrenme ile El Görüntülerinden Cinsiyet Tahmininin Değerlendirilmesi: Bir Ön Çalışma

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Özet

Bu çalışmanın amacı, derin öğrenme modelleri ile el fotoğraflarını kullanarak cinsiyet tahmin etme başarısını değerlendirmektir. Bu doğrultuda, biyometrik tanımlama ve adli tıp bilimlerinde destekleyici bir analiz aracı olarak yapay zekâ kullanımının potansiyel katkıları araştırılmıştır.

Çalışmada, standart bir A4 kağıdı üzerinde konumlandırılmış 100 farklı kişiye ait el fotoğraflarından oluşan veri seti kullanılmıştır. Katılımcılardan 50'sı erkek, 50'u kadındır. Veri setinin %80 i eğitim %20'si test için ayrılmıştır. Veri seti derin öğrenme modellerinden AlexNet, VGG16 ve ResNet50 ile eğitilerek cinsiyet tahmininde bulunmuştur.

Elde edilen tahmin sonuçları, çeşitli performans metrikleri ile değerlendirilerek modellerin performansları karşılaştırılmıştır. Deneysel sonuçlara göre en yüksek tahmin başarısı ResNet50 ağı kullanılarak elde edilmiştir.

Çalışmada el görüntüleri üzerinden cinsiyet tahminine yönelik sınırlı sayıda görüntü kullanılmasına rağmen anlamlı sonuçlar elde edilmiştir. İleriki çalışmalarda veri setinde bulunan görüntü sayısının artırılması ve yeni derin öğrenme modelleri tasarlanarak mevcut modeller ile performans karşılaştırması yapılması planlanmaktadır.

Anahtar kelimeler: *Derin öğrenme, El, Cinsiyet, Görüntü*

Cinsiyete Bağlı Yüz Açılarının Makine Öğrenmesi Yaklaşımıyla İncelenmesi: Morfometrik Ön Araştırma

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Özet

Bu çalışmanın amacı, yüz morfometrisinde önemli yer tutan frontonasal, nasolabial ve mentolabial açıların cinsiyetler arasındaki varyasyonlarını değerlendirmek ve bu açıların cinsiyet tahmininde kullanılabilirliğini istatistiksel olarak incelemektir.

Çalışma kapsamında 20 erkek ve 20 kadın bireye ait toplam 40 olgunun yüz açıları değerlendirilmiştir. Ölçülen parametreler frontonasal açı, nasolabial açı ve mentolabial açıdan oluşmaktadır. Öncelikle her açı için Shapiro-Wilk testi ile normal dağılım analizi yapılmıştır. Normal dağılım gösteren değişkenlerde bağımsız örneklem t-testi, normal dağılmayan değişkenlerde ise Mann-Whitney U testi kullanılarak cinsiyetler arası karşılaştırmalar gerçekleştirilmiştir. Anlamlılık düzeyi $p<0.05$ olarak belirlenmiştir.

Toplam veri incelendiğinde frontonasal ve mentolabial açıların normal dağılım göstermediği, yalnızca nasolabial açının normal dağıldığı belirlenmiştir. Cinsiyete göre karşılaştırmalarda:

Frontonasal açı: Mann-Whitney U testi, $p = 0.1556$

Nasolabial açı: Bağımsız örneklem t-testi, $p = 0.0573$

Mentolabial açı: Mann-Whitney U testi, $p = 0.4735$

Tüm parametreler için cinsiyetler arasında istatistiksel olarak anlamlı fark bulunmamıştır ($p>0.05$).

Yüz açılarının cinsiyet tayininde ayırt edici bir unsur olarak kullanılabilirliğini araştıran bu ön çalışmada, istatistiksel olarak anlamlı fark saptanamamıştır. Ancak örneklem sayısının sınırlı oluşu, bu bulguların genellenebilirliğini kısıtlamaktadır. Daha geniş örneklem gruplarıyla yapılacak ileri düzey morfometrik ve yapay zeka tabanlı çalışmalar, yüz morfolojisinin cinsiyet ayrımı konusundaki potansiyelini daha net ortaya koyabilir.

Anahtar kelimeler: *Yüz, Cinsiyet, Morfometri, Açı*

Determining the Effect of Waiting Time in the Sugar Beet Silos on Quality Parameters

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Abstract

Sugar beets are transported to factories for sugar production and are stored in silos to prevent interruptions during production. However, environmental factors such as air, humidity, and temperature accelerate biological activity within these silos, causing sugar beet spoilage and resulting in various losses. To quantify these losses, the effect of waiting times in sugar beet silos on quality parameters was investigated. Understanding how the quality of beets in silos changes with storage time is crucial for the efficiency of sugar factories. In the study, four different silos, each containing approximately 500 tons of sugar beet, were created and kept for 5, 10, 15, and 20 days, respectively. The quality parameters of the sugar beets were measured before they were placed in the silo and after the waiting period, allowing the changes in the parameters to be observed.

The quality parameters evaluated in this study include sugar content (polar value), α-amino nitrogen content, and mass change. The average polar value indicates the sugar content of the sugar beet, while α-amino nitrogen measures the harmful nitrogen in the root, which complicates sugar production for factories. The change in mass reveals how much weight the sugar beets lose during the storage period.

Upon reviewing the trial results, it was found that keeping sugar beets in the silo caused significant changes in the quality parameters. The amount of change in these parameters was directly proportional to the waiting time in the silo. The greatest economic loss for the factories occurred when the sugar beets were removed from the silo after 20 days of storage. In the 20-day silo, 5.34% mass loss, 24.82% increase in α-amino nitrogen content, and less than 1% increase in polar value were observed.

For factories operating in the Central Anatolian region of Türkiye, it was noted that losses did not increase significantly within the first 8 days of storage, but losses grew exponentially in silos removed after the 8th day. While the economic loss in the silo held for 5 days was 0.8% of the price paid for 1 ton of sugar beets, this loss reached 11.5% in the silo held for 20 days. Based on the results, it was concluded that raw material stock should be kept to a minimum by planning harvests in accordance with the daily processing capacities of the sugar factories.

Key words: *Sugar Beet, Quality Parameters, Silo Losses, Alpha Amino Nitrogen*

Biostatistical Assessment of the Relationship of Immune Checkpoint Genes with Vital Status in Ovarian Cancer

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Abstract

Ovarian cancer has the highest mortality rate among gynecological malignancies in women and constitutes a significant health problem worldwide. Immune checkpoints are among the mechanisms that allow tumor cells to escape the immune system. Molecules such as PD-L1, PD-L2, CTLA-4, LAG-3 and VISTA support tumor immune escape by suppressing T cell activity. In this study, the relationship between the expression of PD-L1, PD-L2, CTLA-4, LAG-3 and VISTA genes in ovarian cancer patients and the vital status of the patients was evaluated using biostatistical methods. In the study, the relationship between the expression levels of immune checkpoint genes PD-L1 (CD274), PD-L2 (PDCD1LG2), CTLA-4 and LAG-3 in ovarian cancer and the vital status and survival of the patients was found to be statistically significant. Better survival rates were detected in patients with high levels of expression of these genes. This finding suggests that these genes can be used as immunotherapeutic targets and prognostic markers in ovarian cancer. On the other hand, no significant difference was observed between the expression level of the VISTA gene and patient survival or survival status. This suggests that the prognostic role of VISTA in ovarian cancer may be limited. These findings emphasize the importance of personalizing treatment strategies to be developed for immune checkpoint targets by considering the patient's genetic profile. The therapeutic potential of these genes can be more clearly demonstrated with large-scale and functional studies to be conducted in the future.

Key words: *Gene, Ovarian cancer, Immune control, Vital status*

Optimizing Trade Signals in Algorithmic Trading with Entropy-Based Filtering

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Abstract

This study investigates the integration of Shannon entropy as a filtering mechanism to refine trading signals generated by the Learning Vector Quantization (LVQ) machine learning algorithm in algorithmic trading. The primary objective is to enhance trade entry accuracy by mitigating market noise and identifying more robust trends. To evaluate this approach, a fully automated trading bot was developed and tested on Bitcoin using a three-minute timeframe on the TradingView platform. Backtesting was conducted between February 1 and February 18, 2025, employing a capital allocation strategy that reinvested profits for compounding. Trades were executed with 100% of available capital and closed upon the emergence of an opposite signal. Com-parative analysis demonstrated that the incorporation of Shannon entropy improved trade selection and prof-itability relative to a baseline LVQ strategy. These results suggest that entropy-based filtering can enhance algorithmic trading performance by increasing signal reliability and trend accuracy, highlighting its potential for broader adoption in quantitative finance.

Key words: *Shannon Entropy, Machine Learning, Algorithmic Trading, Trend Detection, Bitcoin Trading*

Digital Transformation in Logistics and Customs Operations with Robotic Process Automation

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Abstract

In today's business world, data-based decision-making processes have become the key to operational success. Especially in dynamic areas such as logistics, supply chain management, international transportation and customs transactions, instant access to accurate and up-to-date data is of critical importance. However, since many companies do not support modern API-based system integrations, data flow is still provided by manual methods, which negatively affects operational efficiency. In this study, a Robotic Process Automation (RPA)-based digital transformation model is proposed as a solution to time losses, human error risk and data standardization difficulties caused by manually executed processes. Within the scope of the proposed model, it is aimed to automate data entry and collection processes end-to-end, increase speed and accuracy in processes, minimize human errors and integrate companies with legacy system infrastructures into digital transformation. The examples presented in the study show that processes such as container status inquiry and customs data processing can be completed in seconds thanks to RPA applications. This not only provides operational speed gain but also provides the opportunity to work uninterruptedly 24/7. In addition, it becomes possible to direct employees who are freed from repetitive tasks with RPA to more strategic and creative areas; This both increases workforce efficiency and supports individual competence and motivation. As a result, this study reveals that digitalization in logistics and customs operations provides permanent benefits not only in technical but also in organizational and human dimensions. The RPA-supported digital transformation model offers a holistic solution that offers sustainable competitive advantage to businesses.

Key words: *Robotic Process Automation, RPA, Data Management, Digital Transformation, Logistics Operations*

A Comparative Benchmark of Biclustering Algorithms for Livestock Transcriptomic Data Analysis

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Abstract

Biclustering algorithms are commonly employed to identify co-expression patterns in high-dimensional transcriptomic datasets. The performance of these algorithms varies depending on the biological structures inherent in the datasets. The objective of this study is to compare the performances of Spectral Biclustering, Factor Analysis for Bicluster Acquisition (FABIA), and Non-negative Matrix Factorization (NMF) algorithms using three publicly available bovine transcriptomic datasets representing distinct biological processes. The datasets utilized include GSE131607, which encompasses inflammation associated with mastitis; GSE116775, containing liver transcriptomes related to nutritional intervention; and GSE62938, comprising transcriptomic changes linked to nutrition in muscle and adipose tissues. During the preprocessing phase of each dataset, the top 1000 genes exhibiting the highest variance were selected. The algorithms were evaluated based on the number of valid biclusters, bicluster size, average mean squared residue (MSR), computational time, and biological interpretability. The results indicated that, within the GSE131607 dataset, Spectral Biclustering demonstrated the highest discovery capacity with 16 valid biclusters, whereas NMF yielded the lowest MSR values. For the GSE116775 dataset, the FABIA algorithm achieved the lowest average MSR, while in the GSE62938 dataset, all algorithms produced low MSR values; however, NMF was distinguished by the shortest computational time. Functional enrichment analyses revealed significant enrichment of the "Cornified envelope formation" pathway in the GSE131607_Spectral_BC8 bicluster and the "Growth hormone synthesis, secretion and action" pathway in the GSE116775_FABIA_BC1 bicluster. In conclusion, the findings suggest that no single algorithm is superior across different datasets and performance metrics. It is therefore recommended that algorithm selection be guided by the research objectives, data structure, and anticipated biological outcomes. This study provides a comprehensive evaluation of biclustering methods applied to livestock transcriptomic data and establishes a methodological reference for future bioinformatics benchmarking studies.

Key words: *Biclustering algorithms, Transcriptomics, Gene expression, Livestock bioinformatics, RNA-seq*

Görüntü İşleme Destekli Engelli Araçları için Yol İzleme Asistanı

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Abstract

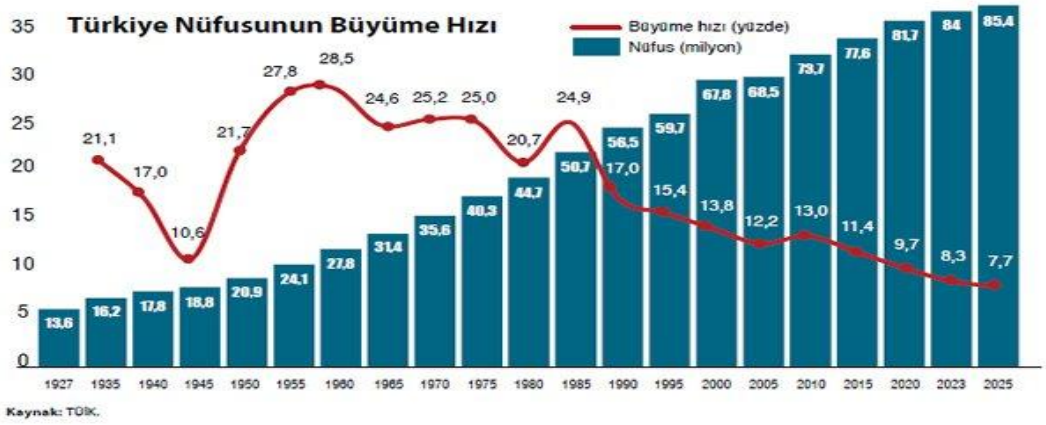
Günümüzde elektrikli engelli araçları ve scooterler, bireylerin hareket etme, kabiliyetini ve bağımsızlıklarını artırarak günlük yaşamlarını kolaylaştırmada büyük bir öneme sahiptir ve şehir içi ulaşımda pratik bir çözüm sunmaktadır. Yavaş ama stabil ilerleme kabiliyetleri sayesinde, engelli bireyler kalabalık alanlarda bile bu araçlarla hareket edebilmektedirler. Ancak bazı uygunsuz yol koşulları ve önlerine çıkan ani istenmeyen engeller, onların hareket kabiliyeti ve konforlarını zorlaştırmaktadır. En çok karşılaştıkları zorlu engellerden biri önlerine ani çıkan çukurlardır. Bu istenmeyen engeller, engelli bireylerin genelde sahip oldukları zayıf refleks ve ani manevra yapma kabiliyetlerinin kısıtlı olması, durumu zorlaştırmakta ve onlara bazı zamanlarda büyük zorluklar getirebilmektedir. Bu istenmeyen durumu minimize etmek ve onlara ayrı bir manevra kabiliyeti kazandırmak için bu çalışmada görüntü işleme destekli yol izle asistanı geliştirilmiştir. Geliştirilen çalışmada kinetik sensör destekli bilgisayar görme modeli olan YOLOv8, Open CV, Raspberry Pi üzerinde çalışan PWM tekniği ve sistemin kodlamasında Python dili kullanılmıştır. Geliştirilen yol izleme asistanı sayesinde ani çıkan çukurlar algılanmakta ve engelli aracın otonom şekilde çukurun boyutuna ve yayılımına göre, yavaşlama, duraklama veya yön değiştirme gibi tepki vermektedir. Bu şekilde oluşan ani durum için engelli bireyin kendi müdahalesi olmadan ani oluşumdan sıyrılması sağlanmaktadır.

Keywords: *YOLOv8, Open CV, Görüntü İşleme, Pyhton, Raspberry Pi*

GİRİŞ

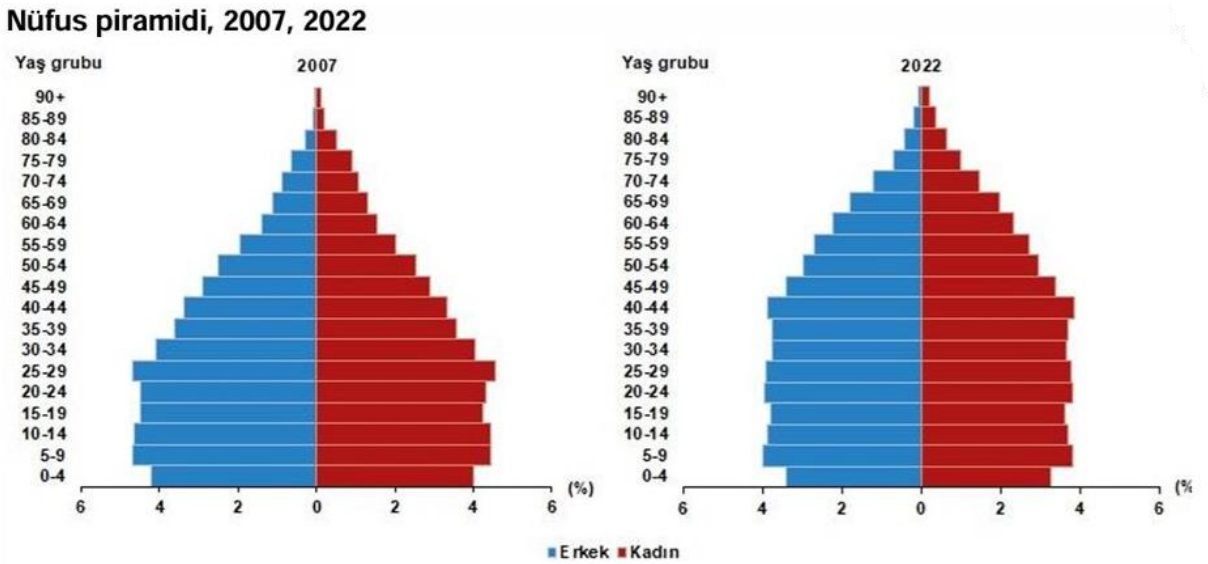
Engelli bireylerin yaş ortalamaları her geçen yıl artmaktadır. Yaş ortalamanın artması engelli vatandaşların engelli araç kullanım has hasiyetlerinin zayıflaması anlamına gelmektedir. Günümüzde kullanılan engelli araçları çoğunlukla kullanıcın kendi yönetiminde olan araçlardır. Ancak engelli sürücülerin refleks kabiliyetlerinin zayıf olması, özellikle gelişmekte olan ülkelerde yolların genelde bozuk ve engelli vatandaşlar için uygun tasarlanmamış olması onlara birçok zorluk getirmektedir. Bu bağlamda engelli vatandaşlar araçlarını kullanırken aniden önlerine çıkan çukur, tümsek gibi istenmeyen engellere takılmakta ve son derece konforsuz yolculuklar yaşamaktadırlar. Hatta bazı durumlarda bu tip durmalar, yaralanma hatta ölümle bile sonuçlanabilmektedir. Kaynaklara göre Türkiye'de engelli nüfusun toplam nüfus içindeki oranı %12,29'dur. Ayrıca, Dünya Sağlık Örgütü'nün tahminine göre, dünya nüfusunun yaklaşık %15'i yani bir milyardan fazla insan bir tür engellilik ile yaşamaktadır (Tıraş H.H, 2020), Genel verilere göre yılı, Türkiye'de 2023 2.511.950 erkek ve 1.097.307 kadın olmak üzere toplam 3.609.257 engelli vatandaş olduğu belirtilmiştir.

Türkiye'de nüfus yıldan yıla artmaktadır. Bunun başlıca sebeplerin başında insan ömrünün tıp ve ilaç teknolojilerin de yaşanan gelişmelerdir (Tıraş H.H, 2020).



Şekil 1. Türkiye nüfusunun büğüme hızı.

Yukarıdaki şekilde Türkiye'de yıllara göre büğüme hızı görülmektedir. Aşağıda şekilde ise Engelli vatandaşların Türkiye'de 2022 yılı için yaşlara göre kadın ve erkek, Tüik, Adrese Dayalı Nüfus Kayıt Sistemi Sonuçları görülmektedir. Engelli vatandaşların Türkiye'de yaşlara göre kadın ve erkek yüzdeler erkekler için mavi alan, kadınlar için kırmızı alan olarak verilmiştir.



Şekil 2. Engelli vatandaşların Türkiye'de yaşlara göre kadın ve erkek yüzdeleri.

Engelli araç sürücülerin karşılaştıkları zorluklar şu alt başlıklar altında toplanabilir; Erişilebilirlik Sorunları: Kamusal alanlarda uygun rampalar ve asfalt yolların olmaması kullanıcılarının güvenli bir şekilde hareket etmelerini engeller. Toplu Taşıma: Birçok toplu taşıma sisteminin erişilebilirlik seçeneklerinin yetersiz olması seyahati zorlaştırır. Güvenlik Kaygıları: Kalabalık alanlarda çarpışma riskleri, hava koşullarının olumsuz etkileri (yağmur, kar, buz) ve yetersiz eğitim, yaralanmalara ve kazalara yol açabilir. Sosyal Damgalama: Scooter kullanımının sosyal olarak damgalanması, kullanıcıları duygusal ve sosyal olarak etkileyebilir. Teknik Sorunlar: El kontrol sistemleri ve rampalarda yaşanan arızalar gibi teknik problemler, kullanıcıların yaşamını zorlaştırabilir.

YÖNTEM VE METOTLAR

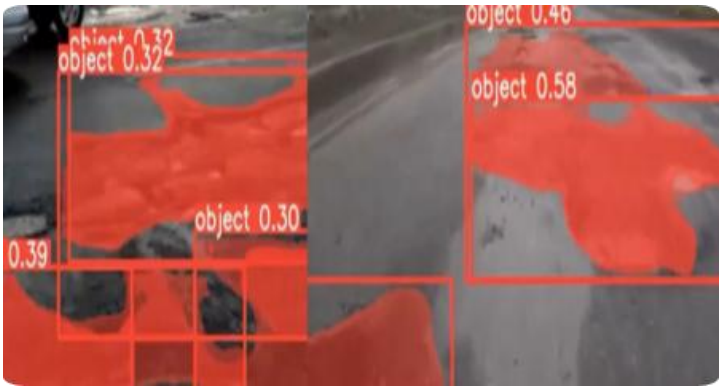
Yukarıda anlatılan engelli araçlarda kazaların önlenmesi ve engelli vatandaşların daha konforlu seyahat etmelerini sağlamak için bu çalışmada Raspberry Pi yönetimli, görüntü işleme tekniği kullanılarak bir yol asistanı geliştirilmiştir. Sistemin simülasyonun Kullanılan teknolojiler arasında OpenCV ve onun geniş nesne algılama kütüphanelerinden olan YoloV8 kullanılmıştır. Görüntü işleme sistemlerinin algoritmik temelinde genellikle gri tonlama dönüşümü, eşikleme, kenar tespiti (örneğin Canny veya Sobel), kontur bulma (OpenCV'de findContours gibi), merkez koordinat hesaplama ve ardından bu konumun servo motorlara aktarılması gibi aşamalar yer almaktadır.

Yol üzerindeki Çukurların YOLOv8 ile Algılanması

Sadece bir kez bak anlamına gelen YOLOv8 (You Only Look Once), algoritmasının sekizinci versiyonu olup, nesne tespitinde hızlı ve doğru sonuçlar sunan bir bilgisayarla görme modelidir. Bundan önce ilk sürümü olan YOLOv1 2016 yılında yayınlandı. Tek bir evrimsel sinir ağı (CNN) kullanarak tüm işlemleri gerçekleştirmekteydi (Karakazan.E, Ceyhan.E.B, 2024). Son sürümü olan YOLOv8'in teknik özellikleri aşağıdaki gibi sıralanabilir [6].

YOLOv8 Teknik Özelikleri

Anchor-Free Tespit: YOLOv8, çapasız bir tespit yaklaşımı kullanır, bu da modelin nesneleri doğrudan merkez noktalarından tahmin etmesini sağlar. Veri Artırma: Mosaic ve mixup gibi gelişmiş veri artırma teknikleri kullanılmaktadır. Focal Loss Fonksiyonu: Sınıflandırma görevlerinde, zor sınıflandırılan örneklere daha fazla ağırlık veren bir focal loss fonksiyonu bulunmaktadır ve kullanılmaktadır. IoU Kaybı: Sınırlayıcı kutu tahminlerinin doğruluğunu artırmak için Intersection over Union (IoU) kaybı kullanılmaktadır. Nesne Odaklılık: Model, nesnelere odaklanma olasılığını artıran bir nesnellik kaybı içermektedir. Optimizasyon: Eğitim ve çıkarım süreçlerini hızlandırmak için karma hassasiyetli eğitim kullanılmaktadır. Çeşitli Model sürümleri: YOLOv8, YOLOv8n, YOLOv8s, YOLOv8m, YOLOv8l ve YOLOv8x gibi farklı parametre sayılarına sahip model varyantları bulunmaktadır. Aşağıdaki şekilde YOLOv8 çukur tespit kullanıcı arayüzü görülmektedir.



Şekil 3. YOLOv8 ile çukur algılama.

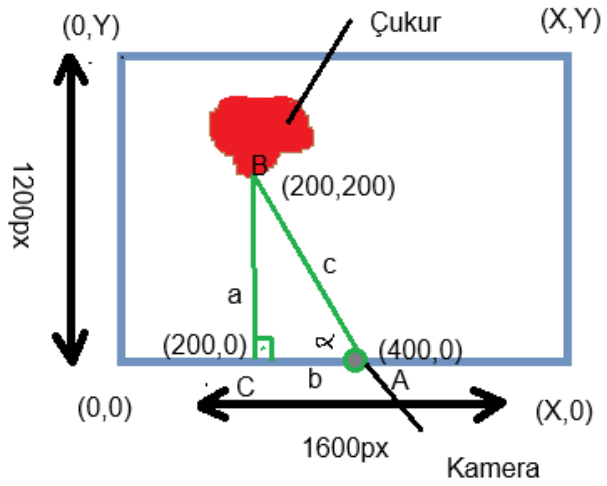
Yol Asistanın Gömülü Sistem üzerinde Çalışması

YOLOv8, Raspberry Pi ile uyumlu bir şekilde çalışmakta olup, kolaylıkla üzerine yüklenip faaliyete geçirilebilmektedir. Kurulum süreci için "pip3 install ultralytics" komutu aracılığıyla Ultralytics paketi ve OpenCV kütüphanesi kurulmalıdır. Raspberry Pi'nin sınırlı işlem gücü göz önüne alındığında, YOLOv8 modelinin etkili bir biçimde çalışabilmesi için optimizasyon yapılması gerekebilmektedir.

Çukurların YOLOv8 ile Tespiti için Uygulanacak Adımlar

Veri Toplama ve Etiketleme: Yol çukurlarının bulunduğu görüntüler toplanır ve bu görüntüler YOLO etiketi ile etiketlenir. Model Eğitimi: YOLOv8 modeli, PyTorch framework üzerinde eğitilir. Eğitim

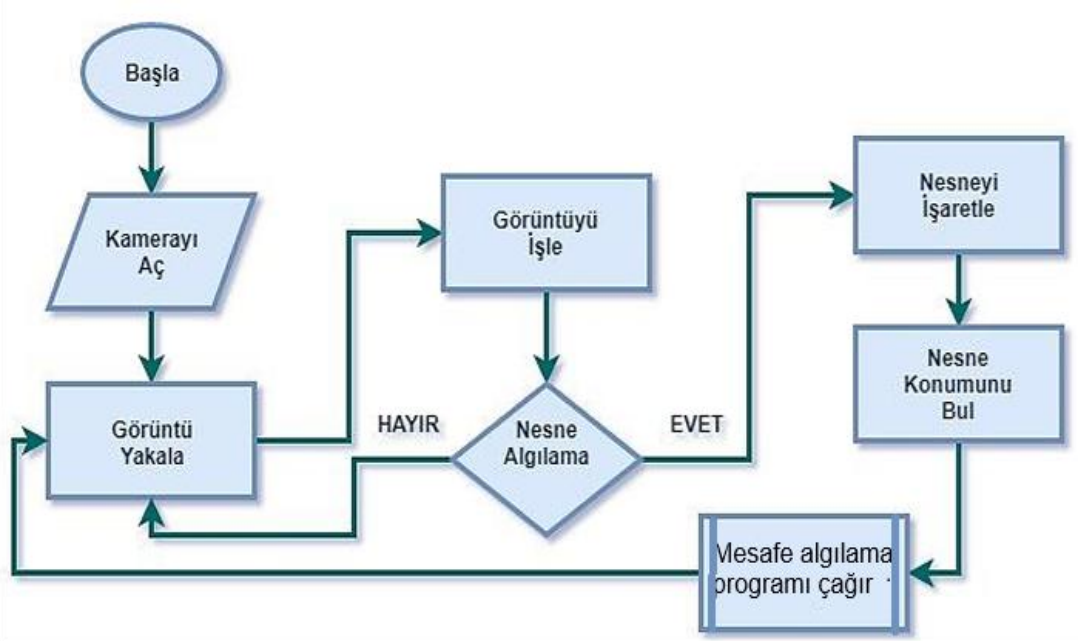
için train.py komut satırı kullanılır ve gerekli parametreler (görüntü boyutu, batch boyutu, epoch sayısı vb.) ayarlanır.



Şekil 4. Görüntü üzerinde mesafe tespiti

Yukarıdaki şekilde OpenCV ve YOLOv8 tarafından algılana sistem üzerinde açı ve mesafe değerleri ayıklanarak, geliştirilen phyton programı tarafından hangi direksiyon açı değeri ve hız ile engelli aracının manevra hangi hız ve direksiyon açısı ile manevra yapacağı belirlenmektedir. Normal bir USB kamera ile alınan görüntü sayesinde iki boyutlu olarak görüntü geliştirilen phyton kodu ile analiz edilmektedir. Raspberry Pi üzerinde çalışan ve phyton kodları ile geliştirilmiş yol asistanı çukura olan mesafe ve açısal sapması hesaplanmaktadır. Direksiyon hareketi tekerlerin hızlanması veya yavaşlatılması servo motor ile sağlanmaktadır. Pulse Width Modulation (Nabız Genişlik Modülasyonu) PWM ile Raspberry Pi üzerinde servo motorların kontrolü sağlanmaktadır. Sistemin akış şeması aşağıdaki şekilde verilmiştir.

Aşağıda sistemin çalışmasını gösteren akış diyagramı görülmektedir. Buna göre kamera görüntü almaktadır. Alınan görüntü USB kamera üzerinden gerçekleşmektedir. Görüntü Raspberry Pi tarafından işlenerek nesnenin boyutuna, mesafesine ve açısal pozisyonuna göre direksiyon ve motorların servo motorlarını yönetmektedir.



Şekil 5. Yol asistanın çalışmasını gösteren akış diyagramı.

SONUÇ

Sistem için geliştirilen simülasyon çalışmasında elde edilen görüntüye bağılı servo motorların çalışması test edilmiştir. Testler sonucunda motorların elde edilen görüntüye bağılı gerekli hızlanmaları ve manevraları yapmalarını tespit edilmiştir. Bu sistem IOT üzerinden desteklenip, Rag sunucuların kullanımı ile bulut üzerinde çok sayıda engelli aracın yönetilmesi sağlanabilir. Ayrıca daha iyi konfor ve kesinlik için derin öğrenme eklenebilir. Derin öğrenme bulut üzerinde çalıştırılıp gömülü sistem şekilinde Raspberry Pİ üzerinden haberleşmesi ve yönetimi sağlanabilir.

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Intelligent Urban Micro-Mobility: Personalized Electric Scooter Configuration Based on User Profile

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Abstract

The demand for individual transportation has greatly grown with population and urbanization, which has in turn raised the use of fossil fuel-powered vehicles and aggravated environmental problems. Apart from the negative effects including greenhouse gas emissions, air and noise pollution, the running of these vehicles in spatially limited surroundings poses great challenges regarding parking and maneuverability. As a result, consumers are looking to micro-mobility solutions including electric scooters and bicycles, which provide quiet, small, energy-efficient substitutes with environmentally friendly impact. Personalized technical solutions are becoming more and more necessary, though, given the different physical traits of users, geographic locations, and use contexts. This work has developed a MATLAB-based simulation tool in order to meet this need and ascertain the most appropriate motor output power and battery capacity catered to the user profile. Input for the system is user-specific parameters including height, weight, average daily travel distance, speed preference, and route gradient; artificial intelligence-supported algorithms then help to determine the necessary motor output power and battery capacity. This helps users avoid unnecessarily high-powered configurations that lead to excess energy consumption as well as away from underperforming systems that fail their needs. This helps one to make decisions with more efficiency, economy, and environmental conscience. Apart from maximizing personal consumption, the suggested strategy helps micro-mobility systems to be effectively incorporated into urban design. Finally, this work marks a major step towards guaranteeing technological sustainability by means of user-centered engineering solutions and so fostering environmentally friendly personal transportation choices.

Keywords: Electric scooter, Sustainable transportation, Artificial intelligence, User profile, Energy efficiency

INTRODUCTION

Rising demand for individual transportation and fast urbanization in today's environment have resulted in the general use of fossil fuel-powered vehicles (Tolu, 2022). This situation raises different issues concerning urban usability as well as environmental impact. Particularly in short-distance travel, their parking and maneuvering restrictions make these vehicles ineffective (UK Parliament Transport Committee, 2022). Moreover compromising the long-term viability of urban mobility are the emissions, noise pollution, and high energy consumption linked with certain vehicles (Özbek and Paköz, 2025; European Environment Agency, 2023).

Micro-Mobility solutions such as electric scooters offer reasonably priced and environmentally friendly substitutes to these challenges by low energy consumption, zero emissions, and small design (Smith and Liu, 2024). Still, these systems do not offer every user the same performance. Standardized vehicle designs often produce either underperformance or unnecessary resource consumption since users vary in terms of physical traits, geographical conditions, use patterns, and budget (Hieu et al., 2024).

This work intends to find a customized electric scooter configuration depending on individual user profiles. We developed a MATLAB-based simulation tool to reach at this. The system inputs route slope, average use duration, body weight range, riding mode preference, and budget level. It finds the optimal motor output power and battery capacity by means of AI-supported algorithms. Especially with regard to short-distance, localized transportation, the system seeks to maximize technical performance and economy.

This report consists of 4 main sections. First, in section INTRODUCTION, information about the designed simulation was provided, along with examples of literature review. In section MATERIAL AND METHODS, information about the materials and working system used in the creation of the designed simulation is provided. In section RESULTS, the impact of the obtained outputs on the objectives has been interpreted. In section DISCUSSION AND CONCLUSION, the relationship between the created simulation and other literature studies has been examined.

Related Work and Literature Review

Amin et al. (2023) proposed a machine learning-based system for estimating, more especially for e-scooters and e-bikes, the remaining range of electric two-wheelers without depending on exact onboard technical specifications. The authors developed a mobile app that systematically compiled real-world data including user riding behavior, environmental conditions (including road surface and weather), and vehicle performance measures. Next a predictive analytics cloud-based Support Vector Machine (SVM) model was trained using this dataset. The proposed method showed great predictive accuracy with a mean absolute error of almost 150 meters for travel distances averaging 7.5 kilometers, so validating the dependability of the model for practical range estimation conditions.

In order to develop and validate a simulation model meant to examine the energy consumption of electric scooters, Yuniarto et al. (2022) conducted a thorough investigation. Built in the MATLAB/Simulink environment using a longitudinal dynamics approach, the model combines important design parameters to estimate important performance metrics including range, energy use, and power demand. The researchers ran dynamometer tests as well as real-world road tests to evaluate the accuracy and practicality of the model. The dependability of the model was confirmed by the great degree of consistency between the experimental data and simulation results. This validated tool is unique in terms of a useful basis for next development in the performance optimization and design of electric two- wheelers.

Ting et al. (2009) presented a technique to estimate the Remaining Travel Distance (RTD) of electric scooters using an Adaptive Neuro-Fuzzy Inference System (ANFIS). To forecast how far the scooter can travel before the battery is fully depleted, the proposed model integrates multiple input parameters such as battery terminal voltage, discharge current, battery temperature, vehicle speed, and total distance traveled. The ANFIS-based approach greatly beats conventional voltage-based estimation techniques by considering battery aging's effects and nonlinear discharge characteristics. With a prediction accuracy

of almost 91%, the model shows a strong and flexible structure for real-time range estimation in electric micro-mobility uses.

Bui et al. (2022), using physics-based modeling combined with machine learning methods, developed a hybrid method for approximating the remaining range of electric motorcycles—technically similar to high-performance electric scooters. The proposed architecture comprises a Support Vector Machine (SVM) classifier intended to detect riding cycle types based on real-time speed and acceleration profiles, coupled with a linear range estimation model. The classified riding cycle then informs the range estimate module, allowing context-aware and adaptive forecasts. Combining dynamic vehicle modeling with historical behavioral data improves the real-time range forecasting in the system. Under mixed daily use conditions, performance assessments confirmed the effectiveness of the model in enhancing energy management strategies for two-wheeled electric vehicles.

Combining real-world sensor data with machine learning, Rincón-Maya et al. (2025) devised a hybrid architecture to replicate battery behavior and predict state-of-charge (SOC) and remaining range in electric bicycles. Data from instrumented e-bikes on a 15-km urban path over a 28-day period allowed the authors to compile operational, environmental, and route-specific variables. Among other machine learning models, LSTM, SVR, AdaBoost, and Gradient Boost help to estimate Remaining Useful Life (RUL). Recent developments show how well preprocessing raw sensor data using a CNN improves prediction accuracy by itself. Particularly adding test case data inside a 95% confidence interval greatly improved the accuracy of generated Remaining Useful Life (RUL) estimates for the LSTM model. These findings underline how urgently real-time energy management in electric micro-mobility systems depends on hybrid, data-driven approaches.

Lee et al. (2007) addressed the difficult task of exactly ascertaining the state-of- charge (SoC) in electric scooter batteries running under dynamic load conditions. To properly address the nonlinear and time- variant properties of battery discharge behavior, the authors developed an intelligent battery management system including fuzzy neural networks and cerebellar model articulations controllers (CMACs).

Hung et al. (2018) designed and tested a MATLAB/Simulink-based semi-automatic transmission electric bicycle to optimize motor power demand. By modeling various gear ratios, frontal areas, and slope conditions, their study demonstrated how selecting appropriate gear settings can significantly reduce motor load and enhance energy efficiency. Real-world road tests showed strong agreement with simulation outcomes, thereby validating these findings. In addition to this, the proposed system enhanced SoC estimation accuracy and provided riders with valuable decision-support tools beyond what traditional linear models offer. These included predicting the remaining travel distance at a specific speed and determining the maximum safe speed to reach a destination. By reducing the risk of unexpected battery depletion during operation, the integration of AI-driven estimators not only strengthened the predictive accuracy of the system but also significantly improved the reliability and usability of electric scooters.

MATERIAL AND METHODS

Material

Developed in MATLAB/Simulink environment (Yuniarto et al., 2022), this work mostly consists on a user-centered electric scooter configuration system. The model is designed to find technical parameters depending on user profiles and usage conditions including motor output power and battery capacity. Key user inputs are average usage time, budget level, road gradient, body weight

range, and preferred speed mode—eco or performance. An AI-supported decision mechanism handles these inputs and suggests an ideal configuration in terms of both technical performance and cost economy (Hieu and Lim, 2024). Fixed inside the simulation structure, several environmental and mechanical parameters are set to ensure consistency across several user scenarios. Then included into the model, general engineering standards define values including battery voltage, wheel dimensions, acceleration and deceleration durations, and energy economy.

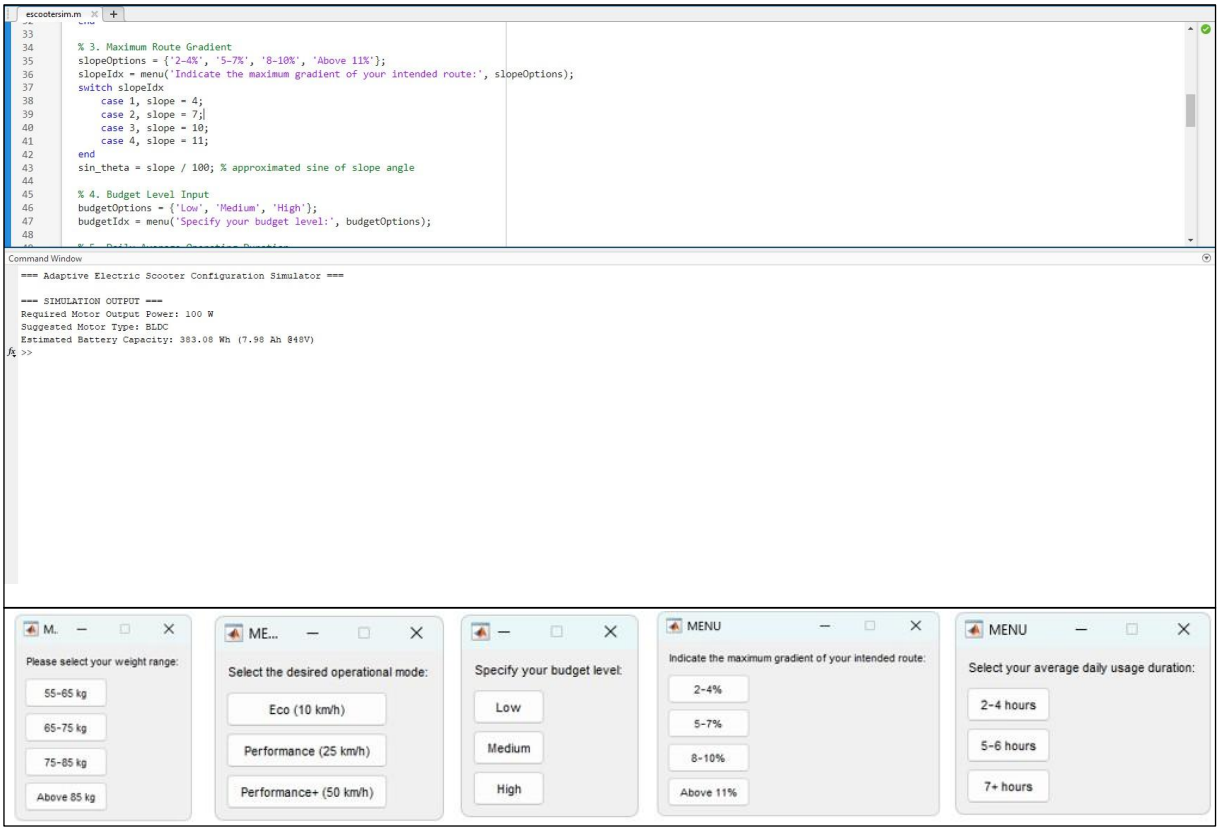


Figure 1. MATLAB System Interface

This figure shows a sample interface derived from the MATLAB-based simulation environment intended for user-adaptive electric scooter configuration. The simulation architecture generates system outputs by processing user-defined parameters acting as a decision-support tool. Five interactive menu windows in the bottom part of the screen each reflect a user input field needed by the system. The user loads their weight range, preferred speed mode, budget level, maximum route gradient, and average usage duration using these interface components.

Dominant the figure is the Command Window, where the technical outputs calculated depending on user inputs are displayed. Among these outputs are the needed motor power, the recommended motor type, and the expected battery capacity. The system dynamically adjusts the configuration depending on personal needs and environmental conditions, so preventing both underperformance and too powerful configurations (Shah et al., 2024). The results of the simulation guide direct design of electric scooters and support sustainable, user-specific micro-Mobility solutions based on informed decision-making.

Methods

This work generates user-specific electric scooter configurations using artificial intelligence-supported rule-based simulation methodology. The simulation computes important performance parameters by running a predefined set of user inputs under mechanical and environmental constant application.

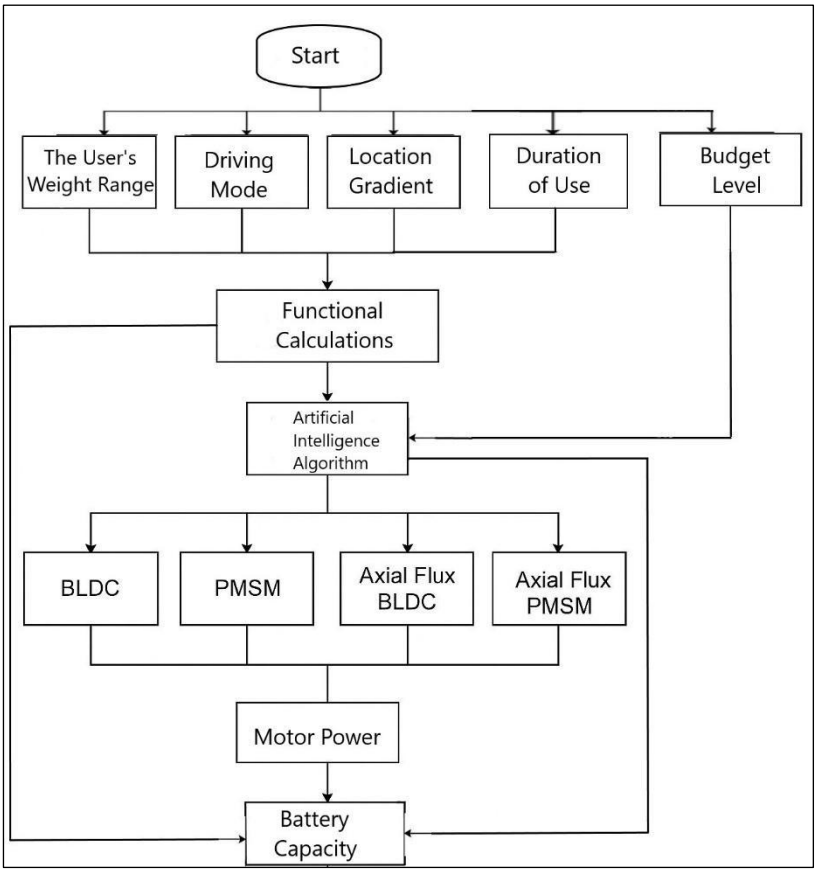


Figure 2. System Flow Diagram

The process flow of the AI-supported decision algorithm created for the configuration of an electric scooter is shown in the diagram Five main user inputs—weight range, driving mode, location gradient, daily usage length, and budget level start the simulation (Korzilius et al., 2021). Of these, the first four parameters directly relate to the functional calculations meant to project the necessary motor output power. The budget level is evaluated just by the artificial intelligence algorithm, thus it is not numerically handled in the functional calculations.

After the technical calculations, the AI module uses the user's budget level and the computed power needs to choose the most suitable motor type. Moreover, the AI algorithm affects the final battery capacity recommendation, so influencing factors other than motor selection. This lets the system offer a technically sound but financially flexible scooter configuration fit for the user.

As demonstrated, the final motor power—along with the AI output—directly affects battery size, so guaranteeing an optimal balance between cost and performance.

The approach comprises several phases. User data are first gathered within the MATLAB script using menu-driven inputs so that the user may specify their weight, preferred speed mode, budget range, route slope, and average usage duration. These inputs directly influence the calculations of the model for needed motor output power and energy consumption. The simulation uses predefined physical constants

applied following data input to preserve constant conditions. The computed power needs and budget category then guide a dynamic choice of motor type and battery capacity. Optimized for the particular user profile, the final output consists in suggested motor specifications and battery size.

Table 1. Dependent and Independent Variable Data

Independent Variables (Inputs)	Dependent Variables (Outputs)
User Weight	Max. Motor Power
Driving Mode	Recommended Motor Type
Location Gradient	Battery Capacity
Daily Usage Duration	Motor Efficiency
Budget Level	Torque (T)

This table compiled the independent (input) and dependent (output) variables applied in the developed electric scooter simulation system. User-related physical characteristics and tastes are input variables; technical parameters computed depending on these inputs reflect the outputs of the model. The simulation dynamically manages these inputs in a user-adaptive way to find required engineering specs including motor power, battery capacity, and recommended motor type.

Regarding artificial intelligence application, the system uses a rule-based decision logic instead of a machine learning paradigm. The AI module is meant to map budget categories to reasonable motor and battery configurations by means of pre-defined conditional rules derived from engineering constraints and performance-cost trade-offs. Low-budget users, for example, are algorithmically limited to standard BLDC motors and moderate battery capacities; high-budget users have access to more advanced motor types including Axial Flux PMSMs. Without a data training phase, this knowledge-driven rule structure lets one make deterministic, transparent, repeatable decisions. Acting as a contextual decision layer, the AI component thus improves technical outputs computationally efficiently based on user constraints.

RESULTS

Results of the simulation-based evaluation of user-specific electric scooter configurations show that the model efficiently computes optimal motor output power and battery capacity depending on changing user inputs and predefined system parameters. Results of simulation show that the necessary motor power is much influenced by changes in user weight and route slope. For instance, higher body mass and steeper terrain conditions call for more torque, which drives more powerful motors and larger battery capacity. Conversely, lighter users working in flat areas with eco mode require much less energy, which lowers system demand generally. Budget level greatly affects the type of motor to use. Usually matched with users with limited budgets, standard BLDC motors are assigned more effective or high-performance options including PMSM or axial flux motors depending on more financial flexibility. This approach keeps the system from oversizing, so lowering unnecessary energy use and cost. The simulation also dynamically varies wheel radius in response to torque needs to maximize traction and energy transmission. Including daily use time into battery size computations guarantees more reasonable energy consumption estimates. The great consistency between expected performance over test environments and simulated outputs guarantees both the dependability of the model and its possible scalability in urban mobility planning.

DISCUSSION AND CONCLUSION

While conventional research in the field mostly address energy demand estimate or nominal battery sizing under standard operational scenarios (Lee et al., 2007; Hung et al., 2018), the proposed framework introduces a notable improvement by including mechanical parameters and user-specific economic constraints into the configuration logic. For instance, while earlier studies including Ting et al. (2009) and Bui et al. (2022) concentrated on improving range estimation or battery management systems using machine learning or fuzzy logic approaches, often times budget-aware component selection was overlooked. Similarly, the Yuniarto et al. (2022) study makes presumptions on fixed motor and battery types for simulation even if it provides a validated energy consumption model for electric scooters.

Conversely, by combining deterministic engineering rules with an AI-driven decision layer, the proposed system presents a cost-adaptive and performance-oriented solution tailored to every user. While data-driven approaches needing massive training datasets (Amin et al., 2023; Rincón-Maya et al., 2025) the rule-based AI logic used here guarantees quick, repeatable decisions while preserving technical validity. Moreover, the choice of motor types among BLDC, PMSM, and axial flux machines reveals a special integration of financial variables into the mobility optimization process — a characteristic not particularly observed in the current literature — advised by torque demands.

The proposed architecture so presents a special perspective to the micro-mobility field by aggregating user diversity, environmental factors, and financial constraints into a single decision-support model. This all-encompassing approach fits rather nicely with the growing emphasis on intelligent, sustainable, and customized transportation design.

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Natural Language Processing (NLP) for Advanced Data Analysis in Flight Operations Decision Support Systems (DSS)

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Abstract

Integrating Natural Language Processing (NLP) into Decision Support Systems (DSS) has considerable potential to transform flight operation-based accident data analysis. This research presents the potential of NLP techniques to be applied to DDS data through an integrated approach. The primary objective of this approach is to facilitate a more profound comprehension of the underlying causes of accidents, to unveil latent patterns and trends, and to enhance the precision with which risk factors can be identified. While sentiment analysis provides insight into pilots' mental states and subjective factors, topic modeling also enables the discovery of recurring themes and hidden patterns of accidents from large volumes of reports. Text classification facilitates targeted risk analysis by segmenting accident reports into meaningful subcategories. NLP can also identify specific risk factors (e.g., mobile phone use, Foreign Object Damage (FOD), cognitive fatigue) that are not coded in standard forms in accident reports. Consequently, the enriched data will serve as the foundation for more comprehensive risk modeling and comparative analyses (regional, temporal differences) by the DSS. This will contribute significantly to the development of targeted accident prevention strategies and to maintaining and increasing the level of operational safety at the desired level. This integrated approach is also aimed at facilitating the transformation of the DSS from a reactive data warehouse into a proactive safety risk management tool.

Key words: *Decision Support Systems, Flight Operations, Natural Language Processing, Risk Identification, DSS.*

INTRODUCTION

Ensuring safety in the aviation sector is possible not only through technological investments but also through the accurate and in-depth analysis of operational data. Every year, thousands of flight safety reports are prepared worldwide, containing valuable information regarding the causes of accidents or near-miss incidents. However, most of this data is in free-text (unstructured data) format, and existing

Decision Support Systems (DSS) are inadequate in analyzing such texts. This situation particularly leads to overlooking implicit risks based on human factors and perpetuates a reactive approach in safety management. However, in recent years, the use of decision support systems during the decision-making phase has become quite widespread. Developed decision support systems enable end-users to easily access data from within or outside their organizations or institutions. Consequently, quick and timely access to needed information aids in timely decision-making in institutions, thereby increasing efficiency and the quality of decisions made (Aslan & Yılmaz, 2010). In determining the most suitable technologies to employ, it is imperative to consider the particular applications and requirements of the project. In the context of Industry 4.0 and smart cities, a self-learning model that utilises natural language processing (NLP) and knowledge graphs has the potential to facilitate machine-to-machine communication and ontology alignment (Javed et al., 2023). Decision support systems have been shown to facilitate timely and high-quality decision-making by providing rapid access to pertinent information. Integrating NLP into decision support systems can accelerate decision-making processes by optimising data flow and facilitating seamless machine-to-machine communication. The enhancement of these decision-making processes has the potential to contribute to a favourable decline in accident statistics, thereby facilitating more precise and expeditious interventions, particularly in crisis situations.

Natural Language Processing (NLP) and Decision Support Systems (DSS) can be integrated to enhance decision-making processes and improve the effectiveness of information retrieval and analysis. Natural language processing (NLP) decodes and contextualizes textual data to decision support systems and enables context-aware decision-making, supporting managers to interpret data and make decisions more effectively (Seymen & Demirci, 2023). Furthermore, utilizing NLP techniques facilitates the identification of emergent accident trends and risk factors through the meticulous analysis of textual elements inherent within accident reports. This enables the implementation of timely preventive measures. Furthermore, training programmes focusing on risky behaviours identified by NLP analyses can be more effective by increasing employee awareness. The continuous analysis of accident data has been demonstrated to enhance safety protocols and business processes. For example, (Pereira et al., 2013), (Grigorev et al., 2024). The application of NLP techniques enabled the analysis and classification of traffic accident reports according to the severity of the incidents. This approach has contributed to the enhancement of incident management processes.

The objective of this study is twofold: firstly, to conduct a more in-depth analysis of flight safety reports using natural language processing (NLP) techniques, and secondly, to increase the effectiveness of decision support systems by evaluating the findings through comparative analysis. The present study undertakes a comparative analysis of the various methods proffered by NLP, with a view to ascertaining the strategic contributions these methods can provide in aviation safety. This approach paves the way for a more holistic and forward-looking safety management framework within the sector.

1. Background

1.1. Decision Support Systems (DSS) in Aviation

A significant proportion of Decision Support Systems (DSS) research employs one of the fundamental conceptual approaches, although this is not explicitly articulated. The initial approach involves the delineation of DSSs within the framework of the structural features of the task they are tasked with handling. Secondly, the design of DSS necessitates a bespoke strategy grounded in evolutionary development and "medium-focused" techniques. The third approach emphasises the role of DSSs in supporting the cognitive processes of individual decision-makers. In this context, the field of decision research provides explanatory information to the managerial problem-solving process and develops

normative theories with the objective of increasing the effectiveness of such problem-solving (Keen, 1980). In addition to the aforementioned elements, DSS constitutes a computer-aided information system that furnishes interactive information support to managers in the decision-making process. The utilisation of analytical models, specialised databases, the decision maker's own opinions and judgements, and an interactive computer-based modelling process is a hallmark of these systems in supporting semi-structured or unstructured business decisions (Aslan & Yılmaz, 2010).

Decision support systems (DSS) in aviation have been identified as a factor that can improve operational efficiency, safety, and decision-making. These systems use automation technologies and artificial intelligence to assist human operators in complex aerospace environments (Cummings, 2004; Yiu et al., 2021). In air traffic management, DSS is being developed to cope with increasing air traffic densities and support autonomous operations (Ballin et al., 2002; Xie et al., 2021). However, interestingly, while automation can improve efficiency, it also presents challenges. In time-critical environments, such as air traffic control, higher levels of automation are not always advisable due to the complexity and potential risks involved (Cummings, 2004). However, there is a need to balance automation with human involvement to maintain situational awareness and flexibility in decision-making. Also, the opacity of AI algorithms has led to the integration of Explainable AI (XAI) into ATM decision support systems to improve interpretability and build trust among human operators (Xie et al., 2021). As a result, decision support systems in aviation are evolving to incorporate advanced technologies such as artificial intelligence of things (AIoT) and machine learning algorithms (Kabashkin & Shoshin, 2024). The objective of these systems is to enhance predictive accuracy, operational efficiency, and safety while optimising maintenance strategies. The integration of DSS in aviation signifies a paradigm shift within the industry towards a proactive health management framework and data-driven decision-making processes.

1.2 NLP Practices in the field of Aviation

Natural Language Processing (NLP) is a field of study that aims to analyse and comprehend written and spoken language by applying machine learning and cognitive computing techniques. NLP is a linguistic analysis tool that enables computers to comprehend human languages (Jothilakshmi & Gudivada, 2016). This discipline focuses on managing complex natural language factors, such as ambiguity and context, bridging the communication gap between humans and computers (Chopra et al., 2013). This technology facilitates the processing and analysis of substantial volumes of unstructured data, including but not limited to social media posts, newspaper articles, customer reviews, and emails. In this manner, NLP facilitates the acquisition of human-like language capabilities in machines, thereby enabling businesses to glean insights from data, automate processes, and enhance decision-making methodologies (Ghosh, 2024). NLP has a wide range of applications, including in the fields of chatbots, language translation, and sentiment analysis, and has a significant impact on business and technology. In this manner, machines have the capacity to effectively execute a variety of beneficial tasks by means of text data (Singh, 2018).

NLP has a role in improving communication between pilots, air traffic control, and ground staff. The aviation industry generates high volumes of data from various sources, including voice communications, operational reports, and real-time flight data interactions. NLP facilitates the extraction and interpretation of valuable insights from this unstructured data, enabling timely decisions to support flight safety and efficiency. By implementing NLP algorithms, aviation stakeholders can increase situational awareness (SA), which is vital for reducing risks associated with human error and improving response times during critical scenarios (Degas et al., 2022; Kabashkin et al., 2023). These developments may contribute to minimizing incidents and accidents, especially those based on communication errors, and

support the formation of a positive downward trend in accident statistics in the long term. The real-time analysis and alerts provided by NLP-powered systems can be used to detect potential hazards at an earlier stage. Thus, both preventive security measures are strengthened, and emergency response processes become faster and more effective. The use of NLP in the aviation industry is one of the primary areas of analysis in safety reports. According to Amin et al. (2022), NLP contributes to more effective risk management and decision-making processes in aviation maintenance and air traffic control by facilitating the extraction of meaningful insights from large amounts of safety data. In aviation maintenance, NLP has not only been able to predict predictable component failures by analyzing maintenance logbooks, but it has also facilitated MRO technicians' access to technical resources. In air traffic control, NLP is often used to detect or mitigate communication errors and improve the clarity of verbal messages exchanged with pilots. The number of NLP software that automates text and speech analysis is growing and is widely used in the aerospace industry (Amin et al., 2022). Furthermore, NLP is instrumental in the sentiment analysis of airline customer feedback. These analyses are utilised to formulate strategies that are aimed at enhancing service quality and customer satisfaction. Li's research reveals how airlines can apply Natural Language Processing (NLP) techniques, such as Bidirectional Encoder Representations from Transformers (BERT), to analyse both customer reviews and social media feedback effectively. This form of analysis assists airlines in making more informed decisions regarding operational improvements and strategic planning, thereby contributing to an enhancement in the customer experience. (Li et al., 2023).

Another important application of NLP in aviation is incident report analysis. The research by Jiao et al. (2022) presents a system that uses NLP techniques to classify and identify the causes of incidents occurring in Chinese civil aviation. This approach can contribute to developing more effective safety measures and strategies to prevent incidents (Jiao et al., 2022). In addition, the integration of NLP with machine learning techniques to predict human factors in aviation incidents has also been discussed. Madeira et al. (2021) highlight that the combination of these two technologies can improve predictive capabilities regarding safety incidents, thereby contributing to the formation of a more proactive safety culture in the aviation industry. With a better understanding of human factors, this approach can help prevent incidents and strengthen security measures (Madeira et al., 2021).

Despite the considerable progress made by NLP, there are still several challenges that must be addressed, including issues such as data bias, interpretability, domain-specific language understanding, and multilingual support. Notwithstanding the aforementioned challenges, NLP persists in its development and the identification of applications in numerous domains, including but not limited to healthcare, finance, education, and customer service (Gour, 2020). As research progresses, further innovation and refinement in NLP technologies can be expected; This, in turn, could lead to more natural and intuitive human-computer interactions (Mihalcea et al., 2006).

1.3 NLP Techniques Used in Aviation

Natural Language Processing (NLP) techniques are being adopted in greater numbers within the aviation industry, with a view to enhancing safety, efficiency, and operational understanding by analysing the vast quantities of textual data that are now being generated. These techniques facilitate the automated processing and derivation of insights from various reports and documents.

1.3.1 Text Classification

Text classification in aviation is primarily utilized for the automatic categorization of safety reports, such as Aviation Safety Reporting System (ASRS) reports. Algorithms/Models Used: Common

algorithms include Term Frequency-Inverse Document Frequency (TF-IDF) combined with Support Vector Machines (SVM), Long Short-Term Memory (LSTM) networks, Random Forest, and XGBoost. Example Application: In a study, 425 ASRS reports from a university flight training program were classified into three categories, achieving an F1-score exceeding 0.90. This system was designed to operate exclusively within an institutional infrastructure (New & Wallace, 2025).

1.3.2 Topic Modeling

Topic modeling is applied in aviation to discover dominant themes within aviation safety reports. Algorithms/Models Used: Techniques such as Latent Dirichlet Allocation (LDA), Non-negative Matrix Factorization (NMF), and BERTopic (which combines BERT with HDBSCAN) are employed. Example Application: Human factors and technical failures in accident scenarios were automatically identified from NTSB and ASRS reports using LDA and the transformer-based BERTopic (Jonk et al., 2023).

1.3.3 Named Entity Recognition (NER)

NER techniques are used to convert critical terms found in flight safety reports into structured data. Algorithms/Models Used: Fine-tuning of transformer-based models like Aviation-BERT is a common approach. Example Application: Entities such as aircraft types, manufacturers, and error factors were identified with over 90% accuracy using the BERT-based Aviation-BERT-NER model, as demonstrated in a 2024 study using real and synthetic aviation safety reports (Chandra et al., 2024).

1.3.4 Deep Learning-Based Classification

Deep learning models are utilized for tasks such as the phase classification of aviation incident reports. Algorithms/Models Used: LSTM, Bidirectional LSTM (BI-LSTM), Gated Recurrent Unit (GRU), and Simple Recurrent Neural Networks (SimpleRNN) are frequently used. Example Application: A comparative study presented on arXiv found that LSTM provided the best results for classifying flight phases in ATSB safety reports, achieving 87% accuracy and a similar F1-score (Nanyonga, et al., 2025).

1.3.5 Safety Audit Report Classification

This application focuses on the automatic categorization of civil aviation audit reports. Algorithms/Models Used: BERTopic, combined with transformer-based classification methods, is utilized. Example Application: In the study published in MDPI, a new classification method was proposed on the reports of the China Civil Aviation Supervision Directorate, statistically outpacing the existing techniques (Xu et al., 2024).

1.3.6 Phase-of-Flight Classification

This technique is crucial for determining the specific phase of flight (e.g., takeoff, cruise, landing) in air accident or incident reports. Algorithms/Models Used: Models include ResNet (a derivative of text-CNN) and SimpleRNN. Example Application: A study comparing ResNet and sRNN on 27,000 NTSB reports found that sRNN achieved over 68% accuracy, showing superiority in phase classification (Nanyonga, et al., 2025).

1.3.7 Supervised Machine Learning Applications

Supervised ML is applied to categorize flight occurrences, such as distinguishing between "incident" and "serious incident". Algorithms/Models Used: A range of algorithms, including SVM, Logistic Regression, Random Forest, XGBoost, and K-Nearest Neighbors (KNN), are tested. Example Application: A web-based application developed by Siow (2025) demonstrated that Random Forest achieved the best results with an accuracy of 0.77 and an F1-score of 0.7 for classifying aviation safety occurrences.

1.3.8 Knowledge Graph Creation

Knowledge graphs are used to present the model's causal and temporal relationships between different accident reports. Algorithms/Models Used: Techniques involve Open Information Extraction (OpenIE), RDF triplet extraction, and integration with graph databases like Neo4j. Example Application: The prototype, developed in collaboration with Tanguy et al. (2016) produced an infographic by extracting RDF triplets from ASRS incident reports.

1.3.9 Hybrid Rule-Based & Machine Learning Approaches

These approaches combine expert-defined rules with ML models for tasks like detecting critical procedures' non-compliance. Algorithms/Models Used: Combinations include Regex with Random Forest, and Rule Terrier with transformer models. Example Application: Combining rule-based reasoning with machine learning enhances risk detection accuracy while maintaining the interpretability and expert knowledge integration crucial for critical decision-making (García et al., 2016).

1.3.10 Explainable AI (XAI) & Active Learning

XAI and active learning techniques are employed to present the rationale behind model recommendations and to enable effective learning from sparsely labeled datasets in aviation. Algorithms/Models Used: Techniques include LIME (Local Interpretable Model-agnostic Explanations), SHAP (SHapley Additive exPlanations), and Uncertainty Sampling combined with transformer models. Example Application: Explainable AI techniques like SHAP facilitate expert feedback during active learning, accelerating model approval and reducing labeling costs, particularly in safety-critical applications, though the quality of explanations depends on the model used (Lundberg & Lee, 2017; Holzinger et al., 2019).

1.4 NLP and DDS Integration

The integration of natural language processing (NLP) with decision support systems facilitates the development of sophisticated systems capable of producing more accurate and expeditious decisions by extracting meaning from user inputs. The implementation of such systems has been demonstrated to enhance the accuracy of decision-making processes by minimising the impact of human error, thereby facilitating enhanced operational efficiency. A comparable integration within the domain of aviation holds the potential to contribute to the mitigation of accidents that are precipitated by miscommunication or delay, thereby resulting in an enhancement of accident statistics. The combination of neuro-linguistic programming (NLP) and decision support systems (DSS) is a recent development in the field of information systems. This could lead to more advanced systems, such as the CUDoctor telehealth system, which is described in Omoregbe's 2020 paper. This system uses NLP techniques to recognize

user inputs and fuzzy logic rules for decision support in diagnosing tropical diseases. Similarly, Szlosek & Ferrett, (2016), in their research, tried to automate the evaluation of clinical decision support systems (CDSS) in electronic medical record (EMR) systems using machine learning and natural language processing (NLP) techniques. Thus, the use of machine learning and NLP techniques to improve clinical decision support systems offers a solution that can increase efficiency by both maintaining the accuracy rate and reducing the need for human resources. The 2023 study by Marqas et al. provides a comprehensive review of contemporary decision support systems (DSS) and advanced optimization methods. In this study, the evolution of DSS, its current application areas, and the main challenges encountered in the development of these systems are discussed. In particular, the integration of advanced technologies such as artificial intelligence and machine learning into decision support systems was emphasized, and the positive effects of this integration on the effectiveness of decision-making processes were discussed. In addition, the various optimization techniques such as linear programming, genetic algorithms, and heuristics used in DSS systems are analyzed. The decisive role of factors such as data quality, system flexibility, and user acceptance in system success is also emphasized. At the end of the study, suggestions for the future, such as making DSSs more user-friendly, increasing data security, and strengthening system flexibility, are included. Integrating decision support systems with advanced technologies such as artificial intelligence and machine learning increases the effectiveness of decision-making processes. The inclusion of NLP in this integration can strengthen system flexibility and data analysis capability, supporting faster and more accurate decisions. These developments can have a positive impact on accident statistics by contributing to the improvement of critical moment-to-moment decisions, especially in-flight operations.

The study presented by Han, (2017) proposes a new method that can be used in intelligent decision support systems (IDSS) to improve decision-making processes under uncertainty. In this method, a decision is made by comparing a new object with these rules and calculating the weight of each outcome, using the minimum set of decision rules obtained by simplifying the decision tables. In the decision-making process, subjective factors representing user preferences and objective factors such as the degree of support of decision rules are evaluated together, and the ratio of these factors can be adjusted. This approach supports decision-making processes in both specific and uncertain environments, resulting in results that better reflect user needs. In intelligent decision support systems, it is critical to evaluate subjective and objective factors together in order to make effective decisions even under uncertainty. NLP can more accurately interpret users' needs and expectations, increasing the precision and accuracy of decisions in such systems. Such integration offers the potential for a reduction in accident statistics, enabling more accurate and faster decisions to be made even in uncertain situations. The integration of NLP and DSS is not limited to traditional decision-making contexts. (Nikiforos et al., 2020), By investigating the use of NLP techniques in virtual learning communities to detect and modify bullying behavior, it showcases the potential of NLP-powered decision support in educational and social contexts. (Bahja, 2020), It also highlights the broader applications of NLP integration in various industries, highlighting its potential to improve human-computer interaction and increase operational efficiency through better decision-making. This integration, which contributes to faster and more accurate decisions by improving human-computer interaction, can also increase operational efficiency in time and safety-oriented sectors such as aviation. Thus, it has the potential to have a positive impact on accident statistics by reducing communication errors and decision delays.

In the study conducted by Maderina et al. in (2021), they used machine learning (ML) and natural language processing (NLP) techniques to detect human factors in aviation incident reports. In the study, pre-processing steps were performed on text data obtained from incident reports, and these data were

applied to various machine learning algorithms (e.g., support vector machines, decision trees, artificial neural networks) for classifying human factors. Model performances were evaluated on criteria such as accuracy, sensitivity, and specificity. By reducing the reliance on manual analysis of incident reports, the study aims to detect elements of human error in a faster, systematic, and automated way. This approach contributes to the development of a decision support mechanism based on data analytics in the field of aviation safety. This approach lays a strong foundation for integrating NLP technology into decision support systems. In particular, NLP models that can automatically extract meaning from incident reports can speed up the data collection and analysis processes of decision support systems, thus enabling decision-makers to make accurate and timely interventions. Detecting complex factors such as human error at an early stage allows for proactive security measures to be taken. This integration makes it possible to understand the root causes of aviation accidents better and to monitor risk factors systematically. Therefore, the use of NLP-powered decision systems can contribute to more effective management of pre-accident risks, helping to change overall accident statistics over time positively. Xie et al. (2021), on the other hand, carried out a study to increase the explainability of machine learning solutions in the field of air traffic management (ATM). In the research, it is emphasized that the "black box" nature of machine learning models poses a serious problem, especially in security-critical decision support systems. In an attempt to overcome this problem, the integration of Explainable Artificial Intelligence (XAI) techniques has been proposed. In the study, it has been shown that the outputs of machine learning-based decision support systems can be made more transparent and understandable by users by using methods such as SHAP (Shapley Additive exPlanations) and LIME (Local Interpretable Model-agnostic Explanations). According to the research results, XAI techniques enable air traffic controllers and other users to understand decisions from machine learning systems better, thereby increasing the reliability of the systems. This study reveals that the development of the explainability dimension of artificial intelligence applications in air traffic management is a critical element in terms of supporting operational safety.

MATERIAL AND METHODS

This study is based on a comparative analysis of Natural Language Processing (NLP) techniques used in the aviation industry. In the study, the qualitative comparative analysis (QCA) method was adopted, and it was aimed to evaluate the selected NLP techniques in terms of their usage areas, functionality, and effectiveness. The research was structured by adopting a descriptive and analytical method. Examples of application of NLP techniques in the field of aviation and their use in the literature were examined, and the extent to which each technique contributed to certain problem types was analyzed. In this context, a comparative analysis was made based on both academic and sectoral sources. The data were obtained through a systematic literature review.

RESULTS

In this section, examples of natural language processing (NLP) techniques applied in the aviation industry and the comparative evaluation results of these techniques are presented. Table 1 presents an overview of the applications made in different fields with various techniques, together with the results obtained and their limits. The diversity of the fields and sectors in which NLP is employed has been found to facilitate a comprehensive understanding of the potential areas of benefit and the limitations of NLP in a holistic manner. Based on Table 1, text classification techniques play a critical role in the automatic analysis of unstructured safety reports. These techniques are instrumental in distinguishing between different types of incidents and in facilitating the development of rapid decision support systems. However, they also present disadvantages such as the need for labeled data and limited

generalization capabilities. Named Entity Recognition (NER) stands out in maintenance and fault analysis by enabling the extraction of specific information (e.g., aircraft type, fault codes) from technical documents. However, to accurately identify aviation-specific terminology, training models with domain-specific data are essential. Topic modeling is well-suited for uncovering recurring themes in maintenance logs and passenger complaint records; however, the interpretive nature of the topics generated often requires human input. Sentiment analysis is helpful for quickly assessing passenger satisfaction, but it may introduce distortions in meaning when applied to technical texts. Text summarization enables the meaningful condensation of lengthy reports, thereby supporting decision-makers who face time constraints. Nonetheless, due to the high risk of semantic loss, more sophisticated and aviation-specific models are required. In conclusion, the effective development of decision support systems in the aviation sector depends on evaluating each NLP technique based on specific operational needs and applying it in a contextually appropriate manner.

ileTables should be listed by number with Latin letters where they are used in the text and should be arranged according to the example as given below. Tables should be fit on the page, justified. Tables that do not fit on one page should be divided into two and indicated as "Table 1. continued". It should be cited the tables before the tables in the text. The titles of the tables should be justified and the first letter should be written in uppercase and all letters except for proper names should be written in lowercase. The abbreviations and statistical criteria in the table should be explained below the table as given in the example.

Table 1. Comparison of Major NLP Techniques Used in the Aviation Industry

NLP TECHNIQUE	**Aviation Application Area**	**Advantages**	**Limitations**	**Case Study (in Aviation)**	**Reference**
Text Classification	Automatic classification of ASRS reports	High classification accuracy; Demonstrated applicability in operational environments.	Requires big data with good labeling; an imbalance between classes may degrade performance	425 ASRS reports in a university flight training program were divided into three categories, and an F_1 score of over 0.90% was obtained (working only within the institutional infrastructure)	(New & Wallace, 2025)

Topic Modeling	Exploration of dominant themes in aviation safety reports	Extracting thematic structures from extensive collections, quickly identifying general trends without the need for human labeling	Hyperparameter setting (number of themes k) is challenging; Meaningful theme production may be limited in very short texts	Using LDA and transformer-based BERTopic on NTSB and ASRS reports, human factors and technical fault themes were automatically discovered in accident scenarios.	(Jonk et al., 2023)
Named Entity Recognition (NER)	Conversion of critical terms in flight safety reports into structured data	Automatic extraction of critical equipment, procedures, weather conditions, etc. It facilitates the further steps of information extraction.	General NER models are not flight-dome compatible; Fine-tuning large language models requires high computational resources.	Entities such as aircraft types, manufacturers , and error factors were identified with over 90% accuracy using the BERT-based Aviation-BERT-NER model, as demonstrated in a 2024 study using real and synthetic aviation safety reports.	(Chandra et al., 2024)

Deep Learning-Based Classification	Phase classification of aviation incident reports	High achievement in complex language patterns by capturing long dependencies; Automatic feature learning.	Large dataset for education; Computational and memory costs are high	In the study presented in arXiv, LSTM, Bi-LSTM, GRU, and SimpleRNN were compared; LSTM gave the best result with an accuracy of 87% and a similar F_1 score.	(Nanyonga, Wasswa, Wild, 2025)
Safety Audit Report Classification	Automatic categorization of civil aviation inspection reports	Free audit reports from manual workload; Reduces the need for attribute engineering.	The problem of explainability of model components, and Data privacy concerns	In the study published in MDPI, a new classification method was proposed on the reports of the China Civil Aviation Supervision Directorate, statistically outpacing the existing techniques.	(Xu et al., 2024)

Phase-of-Flight Classification	Determination of flight phase in air accident/incident reports	Flight phase extraction with high accuracy; He went directly into decision support systems.	Errors in cases of semantic ambiguity; Uneven phase distribution can affect performance	ResNet and sRNN were compared on 27,000 NTSB reports; sRNN achieved an accuracy of over 68%, providing superiority in phase classification.	(Nanyonga, Wasswa, Molloy et al., 2025)
Supervised ML	Categorization of flight incidents as "incidents" vs "serious incidents"	A comparison of different classical ML algorithms and imbalanced data techniques, such as SMOTE, was tested.	The SMOTE application may reduce performance on some models; Accuracy is still around 80%	In the web-based application developed by Siow (2025), Random Forest gave the best results with an accuracy of 0.77% and F_1=0.78.	(Siow, 2025)
Knowledge Graphs	Modeling of causal and temporal connections between accident reports	It presents complex accident chains in a visual and questionable structure, and singles out multiple report links.	Relationship labeled data requirement, Graphics scalability	The prototype, developed in collaboration with Tanguy et al. (2016) produced an infographic by extracting RDF triplets from ASRS incident reports.	(Tanguy et al, 2016)

Hybrid Rule-Based & ML	Critical procedure non-compliance determinations	Scalability of ML without missing expert rules; ML remediation if it applies a bad rule.	The automated ASRS processing system, published in SAGE Publications, uses a combination of rules and ML components to provide high-accuracy risk detection.	Combining rule-based reasoning with machine learning enhances risk detection accuracy while maintaining the interpretability and expert knowledge integration crucial for critical decision-making.	(García, S., Luengo, J., & Herrera, F., 2016)
XAI & Active Learning	Presenting the reasons for model proposals: Efficient learning from low-label data.	Accelerates expert approval; reduces the cost of labeling; Acceptance is high in safety-critical areas.	Increases human surveillance; XAI output quality may fluctuate depending on the model.	Explainable AI techniques like SHAP facilitate expert feedback during active learning, accelerating model approval and reducing labeling costs, particularly in safety-critical applications, though the quality of explanations depends on the model used.	(Lundberg & Lee, 2017; Holzinger et al., 2019)

Text Classification: Structured Categorization with High Accuracy

Text classification provides high accuracy in the automatic analysis of unstructured safety reports and forms the basis of decision support systems. For example, F1 scores exceeding 0.90 in ASRS report

classification demonstrate the operational reliability of this technique. However, the heavy reliance on labeled data and class imbalance issues may limit the model's generalizability. Therefore, data quality and diversity are of critical importance.

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Named Entity Recognition (NER): Domain-Specific Information Extraction

NER is effective in transforming aviation safety and maintenance reports into structured data by extracting key entities such as aircraft type, manufacturer, and cause of failure. The success of models like Aviation-BERT-NER, exceeding 90%, shows their potential in aviation-specific contexts. However, general NER models lack sensitivity to aviation terminology, requiring fine-tuning with sector-specific datasets.

Topic Modeling: Discovering Latent Themes in Unstructured Reports

Topic modeling techniques help identify recurring themes in large volumes of maintenance logs or incident reports. The automatic extraction of human factors and technical fault themes from ASRS and NTSB data exemplifies its usefulness in trend analysis and strategic planning. However, the interpretability of the generated topics relies on human input, and the classifications are not always definitive.

Sentiment Analysis: Passenger Feedback with Ambiguity Risk

Although not explicitly listed in Table 1, sentiment analysis is commonly used in DSS applications to evaluate passenger complaints and satisfaction. This technique offers quick insights but may lead to misinterpretations when applied to technical texts, especially due to neutral or domain-specific language.

Text Summarization: Enhancing Efficiency for Time-Critical Decisions

Text summarization supports decision-makers under time constraints by condensing lengthy reports. However, the risk of semantic loss and contextual inaccuracies requires support from more sophisticated and domain-adapted models. Alignment with aviation-specific vocabulary is crucial.

Deep Learning Models: High Performance with Computational Demands

Deep learning-based classification approaches, such as LSTM variants, perform well in capturing complex linguistic patterns. However, they demand large datasets and computational resources. Additionally, the lack of explainability can limit their use in safety-critical environments.

XAI and Active Learning: Interpretability and Expert Interaction

Explainable AI techniques provide insight into the reasoning behind model outputs, increasing acceptability in high-stakes environments. Active learning reduces labeling costs by leveraging unlabeled data. However, these systems require human supervision, and the quality of the outputs varies depending on the model.

In conclusion, each NLP technique has specific advantages and limitations depending on the data types and operational context in aviation. Thus, technique selection for decision support systems should be context-sensitive. In the future, hybrid approaches that integrate multiple techniques may offer more holistic and reliable analysis capabilities.

DISCUSSION AND CONCLUSION

This study has explored the integration of Natural Language Processing (NLP) techniques into Decision Support Systems (DSS) in the context of flight operations and aviation safety. Through a comparative analysis of diverse NLP techniques—ranging from text classification and named entity recognition to topic modeling and deep learning models—it has become evident that each method has unique strengths and constraints depending on the nature of the data and operational needs.

The findings highlight that text classification and named entity recognition (NER) are particularly effective in transforming unstructured safety reports into actionable intelligence. Topic modeling and text summarization techniques further support strategic decision-making by revealing latent patterns and condensing complex data. However, successfully implementing these methods depends on access to domain-specific datasets, high-quality labeling, and computational resources. In light of these insights, the following recommendations are proposed:

1. Context-Specific Technique Selection: Aviation organizations should match NLP techniques to their operational needs—for instance, using NER for maintenance logs and text classification for incident reporting systems.
2. Hybrid Model Development: Combining rule-based and machine learning approaches (e.g., Hybrid NER or XAI-supported classification) can balance accuracy and interpretability in safety-critical applications.
3. Investment in Domain-Specific Data: Building or accessing annotated aviation corpora will enhance the effectiveness of NLP models tailored to aviation terminology and context.
4. XAI Integration for Transparency: Explainable AI (XAI) components should be embedded in DSS to ensure human operators understand and trust model outputs, especially in safety-sensitive contexts.
5. Scalable System Design: DSS architectures should be flexible enough to incorporate evolving NLP tools without compromising data integrity, speed, or reliability.

Ultimately, this study affirms the transformative potential of NLP-based DSS in advancing proactive risk management, enhancing operational safety, and enabling data-driven decision-making in aviation. Future research may focus on real-time NLP integration with flight data monitoring systems and validating hybrid models in live operational settings.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Comparative Evaluation of Flight Planning Software Used in Pilot Training Organizations

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Abstract

Developing proficient flight planning skills constitutes a cornerstone of comprehensive pilot training. Modern flight schools are increasingly leveraging specialized software to impart critical competencies. However, selecting tools that align with teaching objectives poses a distinct challenge. This research presents a comparative analysis of contemporary flight planning software, focusing on assessing its suitability and effectiveness within the context of flight school training curricula. The study introduces a set of criteria deemed essential for an educational environment and utilizes this set to assess a selection of software applications. These include the following: academic value in demonstrating fundamental planning principles, ease of use for novice pilots, accuracy of aircraft performance calculations, integration of data (weather, NOTAMs) for instructional integrity, relevance to typical training aircraft fleets, and licensing models suitable for educational institutions. The analysis focuses on how these software tools facilitate the learning and practical application of flight planning processes by ab-initio pilots. The research examined these parameters to identify the software features and functionalities that support student learning outcomes. This study aims to furnish flight schools with evidence-based guidance to facilitate the selection and integration of software that has been demonstrated to significantly enhance the quality and efficacy of pilot education in flight planning.

Key words: *Flight Planning Software, Pilot Training, Aviation Education, Flight Schools, Pilot Training Organizations.*

INTRODUCTION

The development of proficient flight planning skills constitutes a cornerstone of comprehensive pilot training, equipping student pilots with the foundational abilities to ensure safe and efficient flight operations (Federal Aviation Administration, 2016; International Civil Aviation Organization, 2012). Historically, this intricate process was taught through manual calculations and paper-based charting, methods that, while fundamental, are increasingly supplemented and, in some cases, replaced by digital solutions. Modern flight schools are progressively leveraging specialized software to impart these critical competencies, recognizing the potential of technology to enhance the learning experience and operational efficiency (Salas et al., 2012). However, the proliferation of such tools presents a distinct challenge: selecting software that reflects contemporary aviation practice and aligns seamlessly with established teaching objectives and the learning trajectory of ab-initio pilots.

The complexity of choosing the right software stems from the diverse educational and technical demands placed upon it. Flight planning is a core skill in pilot education, and the digital tools adopted must provide robust support for its instruction. This study addresses the critical need for a systematic evaluation of contemporary flight planning software, focusing specifically on its suitability and effectiveness within flight school training curricula. The primary aim is to compare available software applications by examining their educational value in demonstrating fundamental planning principles, alongside their technical features, such as the accuracy of aircraft performance calculations and the integration of essential real-time data, including weather and Notices to Airmen (NOTAMs). This research is particularly concerned with aligning these tools with the needs of ab-initio pilots, who require intuitive interfaces and clear pedagogical pathways. By emphasizing the software's practical benefits, this study aims to reassure flight schools and administrators of the value of their investment and instill confidence in their decision-making process.

Integrating educational technology, such as flight planning software, offers significant potential for enabling experiential learning environments. Such environments are crucial in aviation training, where the practical application of theoretical knowledge is paramount. Simulations and interactive digital tools have been demonstrated to foster deeper learning and enhance the retention of complex procedures (Kolb, 2015; Mayer, 2017). From a pedagogical standpoint, Cognitive Load Theory (CLT) suggests that instructional tools must be designed to avoid overwhelming learners with excessive or poorly presented information, allowing them to focus on mastering core concepts (Sweller, 1988). Furthermore, constructivist learning paradigms advocate for scenario-based planning, which allows students to actively construct their understanding by engaging with realistic problems, a feature that well-designed software can facilitate (Piaget, 1970; Vygotsky, 1978).

The significance of this study lies in its potential to furnish flight schools with evidence-based guidance, supporting informed software adoption and integration strategies. By identifying software features and functionalities that demonstrably enhance student learning outcomes in flight planning, this research aims to contribute to the overall quality and efficacy of pilot education. The scope of this investigation is centered on tools applicable to the initial phases of pilot training, specifically for aircraft fleets typically utilized by flight schools. A recognized limitation of this research is its evaluation of software tools anticipated to be available and relevant in the 2025 timeframe, acknowledging the dynamic nature of software development. This study seeks to provide a timely and pertinent analysis to aid educational institutions in navigating the evolving landscape of flight planning technology. However, it is important to note that the findings and recommendations of this study may not fully apply to future software developments beyond the 2025 timeframe.

Literature Review

The integration of digital tools and software into pilot training has become increasingly prevalent, especially for tasks such as flight planning. Modern flight schools now leverage a range of technologies to enhance educational outcomes and operational proficiency. This review synthesizes recent studies on flight planning software and related digital solutions in aviation education, highlighting their pedagogical effectiveness, technological capabilities, and, most importantly, the crucial role of evidence-based software selection in aligning with training goals.

Inan and Gunes (2024) explored the promising use of virtual reality (VR) technology in pilotage training and compared it with real flight performance. Their findings demonstrate that VR environments can effectively mimic real flight scenarios, suggesting that immersive technologies hold great potential

as valuable complements to traditional flight planning exercises by strengthening spatial and procedural understanding.

Guevarra et al. (2022) introduced an AI-driven flight instructor system designed to teach student pilots through behavioral cloning. This system analyzes student errors and offers corrective feedback, underlining the potential for intelligent software to support flight planning education through adaptive learning mechanisms.

Volz and Dorneich (2020) delved into the delicate balance between automated flight planning tools and the preservation of pilots' manual planning and cognitive skills. Their research underscores the importance of maintaining a balance, reassuring flight training organizations about the crucial consideration of preserving foundational skill development when selecting educational software.

Zhu et al. (2024) conducted a comparative study on Chinese pilot training practices both domestically and abroad. Their analysis, which included software use in curriculum design, found that exposure to diverse digital platforms enriched trainees' adaptability and competence in real-world operations.

Wei, Fang, and Liu (2022) developed a six-degree-of-freedom training simulator aimed at increasing realism in pilot training. While not focused exclusively on planning, the simulator's integration of flight data and scenario-based tasks reflects broader trends toward incorporating real-time data, an essential criterion for evaluating flight planning software.

Kelemen, Polishchuk, Kelemen, and Sabo(2023) proposed a hybrid assessment model using fuzzy logic and expert systems to evaluate student pilots' outcomes. This model emphasizes objectivity and alignment with didactic systems, supporting the notion that flight planning tools should align with clear educational performance metrics.

Lastly, Prayitno et al. (2023) developed a web-based flight simulator management system to support instructional oversight. Their system's user-friendliness and data integration capabilities reflect characteristics that flight planning software should possess to be suitable for educational settings.

Collectively, these studies underscore the multifaceted nature of evaluating flight planning tools for pilot education. Key themes include usability, accuracy, instructional relevance, and the capacity to reinforce essential skills without over-reliance on automation. As flight schools increasingly rely on technology to deliver their curriculum, the evidence-based selection of planning software remains critical to ensuring pedagogical integrity and student competency.

MATERIAL and METHODS

This study employed a comparative descriptive analysis design to systematically evaluate and compare contemporary flight planning software applications based on their suitability for ab-initio pilot training curricula. The aim was to assess how effectively these tools support student pilots' learning and practical application of flight planning processes. The thoroughness of the evaluation process, which included hands-on testing by evaluators familiar with flight planning principles and ab-initio training requirements, ensures the reliability and trustworthiness of the research's conclusions, providing flight schools with a secure foundation for their decision-making.

A purposive sampling strategy was utilized to select five prominent flight planning software applications for evaluation: ForeFlight, SkyDemon, RocketRoute, Garmin FltPlan, and Jeppesen FliteDeck. These applications were chosen based on their widespread availability, established presence within the general aviation community, and comprehensive feature sets relevant to flight school

operations as of 2025. The selection aimed to represent a range of popular tools currently utilized or considered for integration into pilot training programs.

Data collection involved hands-on testing of each selected software application by evaluators familiar with flight planning principles and ab-initio training requirements. A standardized flight planning scenario was developed to ensure consistency and comparability across the evaluations. This scenario simulated a typical Visual Flight Rules (VFR) cross-country training flight, a common exercise for student pilots. The parameters for this scenario, including aircraft performance characteristics, were based on a ubiquitous training aircraft, the Cessna 172, to reflect its everyday use in flight school fleets.

An evaluation rubric was meticulously developed to guide the hands-on testing and ensure a structured, consistent assessment of each software application against predefined criteria. These criteria were deemed essential for an effective educational environment and included:

1- Academic Value: This criterion evaluated the software's instructional clarity, its effectiveness in demonstrating fundamental flight planning principles such as route selection, fuel calculation, and weight and balance, as well as its capacity to support the pedagogical objectives inherent in ab-initio training.

2- Ease of Use: Emphasizing the intuitiveness of the user interface, the systematic progression of planning processes integrated into the software, and the comprehensive learning curve for novice pilots with minimal prior exposure to digital flight planning tools.

3- Accuracy: This involved evaluating the accuracy of the software's aircraft performance calculations (e.g., time en route, fuel consumption, takeoff and landing distances) against established aircraft data and manual computation methods.

4- Integrated Data: This criterion rigorously evaluated the coherence, timeliness, and presentation quality of integrated aeronautical data, with a particular emphasis on real-time meteorological information such as METARs, TAFs, and graphical weather representations, alongside Notices to Airmen (NOTAMs). These elements are deemed essential for maintaining instructional integrity and fostering realistic scenario-based learning environments.

5- Relevance to Trainer Aircraft: This study evaluated the comprehensiveness of the software's aircraft database, with a particular emphasis on its capability to support standard training aircraft fleets beyond the Cessna 172, as well as the ease with which users can customize aircraft profiles.

6- Educational Licensing Model: This assesses the availability, suitability, and affordability of licensing options for educational institutions, including student licenses, bulk subscriptions, and specific academic programs provided by software vendors.

The qualitative and quantitative data collected through the rubric-based, scenario-driven assessments were subsequently analyzed through a comparative descriptive approach. This analysis concentrated on discerning the strengths and weaknesses of each software application in accordance with the predetermined evaluation criteria. The primary aim was to underscore particular features and functionalities that substantially bolster or may impede student learning outcomes in flight planning, thereby offering flight schools evidence-based insights to inform their software selection process.

RESULTS

An evaluative comparison of five flight planning software platforms, ForeFlight, SkyDemon, RocketRoute, Garmin FltPlan, and Jeppesen FliteDeck, was conducted based on scholarly value, ease

of use, accuracy, data integration, aircraft relevance, and the availability of educational licensing (see Table 1).

ForeFlight and SkyDemon emerged as the most suitable platforms for educational contexts. ForeFlight demonstrated high educational value, accuracy, and strong relevance to aircraft operations. It was the only software rated "Excellent" for data integration and also offers educational licensing, making it highly viable for institutional use. SkyDemon, while slightly less comprehensive in integration capabilities, excelled in ease of use, marked as "Very High" and maintained high ratings across other categories, particularly beneficial for new learners due to its user-friendly interface and accessible learning curve.

RocketRoute presented moderate performance in nearly all categories, representing a mid-tier solution. While it does not outperform in any specific domain, it offers a balanced profile with moderate educational value, usability, and integration.

Garmin FltPlan received the lowest scores in academic value and data integration. Although it has high relevance for aircraft and educational licensing availability, its limitations in accuracy, particularly regarding real-time NOTAM and weather information, make it a less effective tool in educational environments.

Jeppesen FliteDeck demonstrated a high degree of accuracy and effective data integration, effectively aligning with the requirements of Instrument Flight Rules (IFR) training. Nevertheless, it encountered challenges related to ease of use and restrictions in educational licensing. While its advanced features are ideally suited for proficient users, the substantial learning curve and barriers to accessibility reduce its applicability within educational settings.

Overall, the findings underscore ForeFlight as the most robust and pedagogically valuable tool, followed closely by SkyDemon. The analysis reveals a clear correlation between ease of use, data integration, and educational suitability, highlighting the need for transparent and accessible institutional licensing across all platforms evaluated.

Table 1. Comparative Evaluation of Flight Planning Software for Pilot Training Contexts

Software	Academic Value	Ease of Use	Accuracy	Data Integration	Aircraft Relevance	Educational Licensing
ForeFlight	High	High	Very High	Excellent	High	Available
SkyDemon	High	Very High	High	Good	High	Available
RocketRoute	Moderate	Moderate	Moderate	Moderate	Moderate	Limited
Garmin FltPlan	Low	Moderate	Moderate	Low	High	Available
Jeppesen FliteDeck	Moderate	Low	High	High	Moderate	Limited

DISCUSSION and CONCLUSION

The findings of this study suggest that ForeFlight and SkyDemon are the most pedagogically aligned flight planning tools for ab-initio aviation training programs. Their high scholarly value, ease of use, and strong data integration capabilities position them as effective platforms for enhancing learning outcomes (see Table 1). In particular, ForeFlight's exceptional data integration and real-time accuracy features make it especially suitable for structured aviation education. At the same time, SkyDemon's intuitive design lowers the entry barrier for novice learners, contributing to a steeper early learning curve.

A key insight from the evaluation is that effective educational software must strike a balance between technical precision and usability. While platforms such as Jeppesen FliteDeck offer advanced IFR features and high data fidelity, their limited ease of use and restricted educational licensing significantly hinder their effectiveness in entry-level training. Similarly, tools like Garmin FltPlan, though highly relevant to aircraft operations, fall short in academic utility due to limited integration and lower data reliability.

The discourse additionally underscores the paramount significance of curriculum integration. Even the most proficient software will exhibit suboptimal performance if it is not incorporated within a well-structured syllabus. Early and consistent engagement with digital planning tools enhances competency-oriented learning and cultivates operational familiarity among students. Consequently, the pedagogical advantage lies not solely in the selection of appropriate software but also in its practical implementation within instructional frameworks.

Recommendations

To maximize student outcomes and align with training objectives, the following recommendations are proposed:

1- Adopt ForeFlight or SkyDemon as the primary software platforms for ab-initio flight training, based on their educational effectiveness and licensing availability.

2- Partner with vendors to negotiate tailored educational licensing agreements supporting institutional access and long-term scalability.

3- Integrate software training directly into the curriculum, ensuring students gain practical exposure from the outset of their aviation education.

4- Implement regular evaluations of digital tools as technology and regulatory standards evolve, maintaining alignment with both industry needs and educational goals.

In conclusion, flight planning software should not be viewed as ancillary, but as an integral part of modern pilot education. When properly selected and embedded, tools like ForeFlight and SkyDemon can meaningfully enhance both technical understanding and operational readiness of future aviators.

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Mixed Data Types in Measurement Models: A Simulation Study

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Abstract

The use of both continuous and categorical observed variables in a measurement model as mixed data types is becoming increasingly important, especially in medical, social and behavioral sciences. Simulation studies generally address whether the observed variables are categorical or continuous variables. Bayesian simulation studies for both continuous and categorical observed variables have made significant contributions to this field. However, the performance of estimation techniques used in classical statistics is unknown. In the current study, it is aimed to investigate the performance of the Robust Maximum Likelihood-MLR estimation technique, which has robust corrections. The entire structure of the measurement model and the sample size were determined by considering the literature findings. The model has three latent variables, and the factor loadings are between 0.8 and 0.6, and the correlation coefficient of the latent variables is pre-assigned as 0.3. Four observed variables are determined for each latent variable, and it is ensured that the categorical and continuous variables are included in a latent variable together. The sample size is determined as 200, 500 and 1000 units. Data generation process was carried out by means of Mplus 8.3 program. Bias, mean absolute bias (MAB) and relative bias (RB) were used in determining MLR performance. According to the findings, in the sample size of 200 units, there were RB values exceeding 5-6% in some factor loadings, while in 500 units, bias values decreased and RB values fell below 3%. In the sample size of 1000 units, it was observed that all bias values approached zero. In the correlation between factors, a bias of 6.7-6.9% was observed in 200 units, while this value decreased to around 3% in 500 units. In the sample size of 1000 units, all biases also approached zero in correlation. According to these findings, it can be interpreted that a medium level and above sample size of 500 units is required for the use of MLR in a measurement model with a mixed variable structure.

Key words: *Measurement Models, Mixed Data Types, MLR, Monte Carlo Simulation.*

INTRODUCTION

In Structural Equation Model (SEM) studies, more than one model is put forward by practitioners and then data is collected to estimate and compare these models. Thus, the one that provides the best consistency with the theory is selected from the available findings. Practitioners generally do not only look for a good fit between the model and the data, but also are interested in the estimation of the parameters that the model has. The reason for this situation is that parameter estimates are directly related to the content of the theory of interest. Whether the consistency in the theory is achieved with the estimation results is very important for the research (Lali, 2018).

SEM has become the most frequently used technique with the long-term use of practitioner research in terms of evaluating the consistencies in the theory and developing important hypotheses. Despite the years, the default Most Likely -ML method is still used in frequently used package programs (e.g., AMOS). By ensuring multivariate normality in the light of continuous data, ML gives the expected information matrix and the standard errors of the parameter estimates and the model's fit values with the

likelihood ratio test (Bollen, 1989). This situation was first studied by Sattora and Bentler in 1994, and many studies were carried out in the following period (Bentler & Yuan, 1999; Yuan & Bentler, 1997, 2000). Now, some SEM packages (e.g., Mplus; Muthén & Muthén, 2016) calculate standard errors using the observed information matrix instead of the expected information matrix.

The data of many researchers generally consist of categorical data, provided that it is not the majority. In general, the data is of 5-7 Likert type. In this case, although the use of estimation techniques used in the case of continuous variables (e.g., ML) is not recommended, they are still used (Rhemtulla et al., 2012). Estimation techniques recommended for the use of continuous variables perform as well as estimation techniques recommended for the presence of categorical variables (e.g., Diagonally Weighted Least Squares- DWLS) when the number of categories decreases (Savalei, 2021).

Many researchers are not only unaware of current developments but also obtain their findings with inappropriate techniques regardless of the type of data and model structure at hand. This situation causes the doors that will contribute to the existing hypotheses in theory to be closed. For example, in many branches of science that frequently use the concept of latent variables, the measurement model does not have to be either categorical or continuous. For example, in measuring the concept of job embeddedness (Hom et al., 2009; Mitchell et al., 2001), both continuous and categorical observed variables should be used. While the number of years an individual has worked can be given as a continuous variable, the frequency of customer contact can be given as a categorical variable in a five-point Likert type. A similar situation can be seen in the treatment of substance addiction in psychology. In measuring alcohol addiction, the age of first use, the amount of alcohol consumed in a week can be given as continuous variables; and the frequency of weekly alcohol consumption can be given as categorical variables. Again, a similar situation can be seen in the measurement of political economic risk structure (Quinn, 2004). While gross domestic product is treated as a continuous variable, judicial independence and poverty can be given as ordinal categorical variables. Many applications in medical and social sciences use both categorical and continuous variables together in measurement models (Diemer & Li, 2012; Lee & Xu, 2003; Li, 2021; Song et al., 2007; Zhou et al., 2014).

In addition to the importance of using mixed variables in measurement models, there is not much simulation or application on which estimation technique is a better technique. Because most of the studies are either for categorical variables or for continuous variables (Maydeu-Olivares, 2017; Li, 2016a, 2016b). There are simulation studies using the Bayesian approach on this subject (Lee & Zhu, 2000; Fahrmeir & Raach, 2007; Quinn, 2004; Samani & Ganjali, 2011; Song & Lee, 2001). However, this issue has not yet been clarified as a result of intensive studies in classical statistics (Li, 2021).

The current study aims to measure the performance of the MLR technique, which is a robust version of the ML technique that practitioners often use, in the case of mixed observed variables in measurement models. The reasons why techniques used for ordinal variables are not selected instead of MLR are as follows. The first is to introduce practitioners to the robust version of a technique they are mostly familiar with. In fact, while MLR is applied for continuous variables and cases where there is no normality, there are simulation studies that state that it gives good results when there is a deviation from normality and is resistant to this situation. The last is that it is seen as a good alternative to DWLS, which uses polycritical correlation when the number of response categories of the observed variable is more than 5 to 7 (Li, 2021; Rhemtulla et al., 2012; Yang-Wallentin et al., 2010).

MATERIAL AND METHODS

Material

The measurement model in the study has three latent variables and for this structure, the number of categorical and continuous variables, sample size, and factor loadings were used in all selection processes from Li (2021). Li (2021) explained all selection processes by supporting them with literature findings in his study. There is a similar use in this study and the selection processes are as follows (Li, 2021):

Number of Categorical Variables: When we look at the studies that have been conducted, it is seen that categorical observed variables have five or more answers. In this case, there is a suitable ground to use MLR.

Selection in the Number of Continuous and Categorical Variables: Here, when a medium-sized scale development phase is considered, a total of 4 observed variables belonging to three latent variables are given in the CFA model. However, the ratio of continuous variables to categorical variables is determined as follows. In the first latent variable, there are three continuous variables and one categorical variable. In the second, this ratio is two. In the third latent variable, there are three categorical variables and one continuous variable.

Determining Factor Loadings and Correlations: In simulation studies (e.g., Forero and Maydeu-Olivares, 2009), a homogeneous selection process is usually used in factor loadings, but it is very difficult to meet this situation with real data. At this point, factor loadings for both continuous and categorical observed variables were selected between 0.8 and 0.6. Correlations between factors were determined as 0.3.

Sample Size: As in many other simulation studies, the small sample size in the current study was considered as 200 units, while the medium size was determined as 500 units and the large sample size as 1000.

The path diagram of the study model is given in Figure 1.

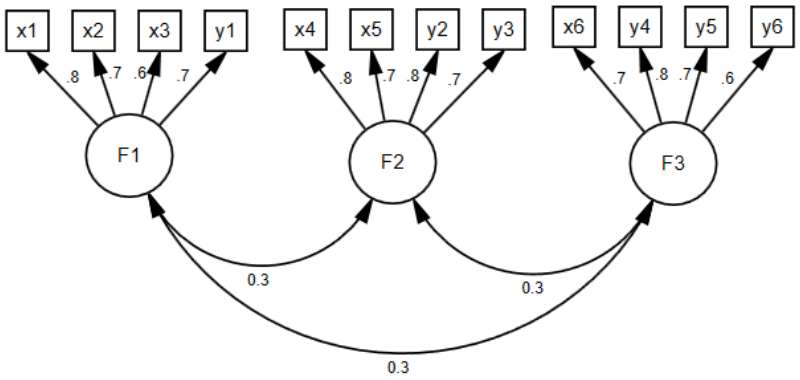


Figure 1. Path diagram of the model

Methods

The Collection of the Data

Data generation process was produced with the help of Mplus 8.3 for 200, 500 and 1000 samples with Monte Carlo method and 1000 replications. Data is symmetric and there is no missing data. In line with the purpose of the study, 6 of the 12 observed variables were considered continuous and 6 were considered categorical and production was provided.

Statistical Analysis

In measuring MLR performance, the factor loadings and the closeness of the correlation values between the factors to the previously assigned values were of interest. In measuring this closeness, bias, mean absolute bias (MAB) and relative bias (RB) values were examined.

RESULTS

With Monte Carlo simulation of sample sizes of small (N = 200), medium (N = 500) and large (N = 1000) using Mplus 8.3, a power of 0.80 was obtained during the data generation phase and the subsequent analysis phase, including factor loadings and correlations. The model fit values were as follows.

Table 1. Model fit values according to sample sizes

Sample	Estimator	χ^2/df (sd)	CFI (sd)	TLI (sd)	SRMR (sd)	RMSEA (sd)
200	MLR	53.723/51 (10.860)	0.990 (0.014)	0.994 (0.026)	0.043 (0.005)	0.017 (0.017)
500	MLR	52.413/51 (10.219)	0.997 (0.005)	0.999 (0.010)	0.027 (0.003)	0.009 (0.010)
1000	MLR	52.246/51 (10.022)	0.998 (0.002)	0.999 (0.005)	0.019 (0.002)	0.006 (0.007)

The fit values of the model in each sample size appear to be quite good (Schermelleh-Engel et al., 2003). With this result, factor loadings and correlation findings between factors were passed. The findings are given in Tables 2 and 3. For the evaluation of the information in these tables where biases are discussed, based on previous simulation studies (Bandalos, 2002; Curran et al., 1996; Flora & Curran, 2004; Kaplan, 1989; Yang-Wallentin et al., 2010), it was considered that a relative bias of less than 5% is insignificant, a bias between 5-10% indicates a moderate level of bias, and a bias greater than 10% indicates a significant bias.

Table 3. Factor loadings bias mab and rb

Indicator	Sample Size	Bias	RB	MAB
X1	200	-0.05	-0.06250	0.05
X1	500	-0.02	-0.02500	0.02
X1	1000	0.00	0.00000	0.00
X2	200	-0.02	-0.02857	0.02
X2	500	-0.01	-0.01429	0.01
X2	1000	0.00	0.00000	0.00
X3	200	-0.02	-0.03333	0.02
X3	500	-0.01	-0.01667	0.01
X3	1000	0.00	0.00000	0.00
Y1	200	-0.01	-0.01786	0.01
Y1	500	0.00	0.00000	0.00
Y1	1000	0.00	0.00000	0.00
X4	200	-0.04	-0.05000	0.04

Table 3. Continued

Indicator	Sample Size	Bias	RB	MAB
X4	500	-0.02	-0.02500	0.02
X4	1000	-0.01	0.00000	0.01
X5	200	-0.03	-0.04286	0.03
X5	500	-0.01	-0.01429	0.01
X5	1000	0.00	0.00000	0.00
Y2	200	-0.02	-0.03077	0.02
Y2	500	-0.01	-0.01538	0.01
Y2	1000	0.00	0.00000	0.00
Y3	200	-0.03	-0.05263	0.03
Y3	500	-0.01	-0.01754	0.01
Y3	1000	0.00	0.00000	0.00
X6	200	-0.04	-0.05797	0.04
X6	500	-0.02	-0.02899	0.02
X6	1000	0.00	0.00000	0.00
Y4	200	-0.03	-0.04615	0.03
Y4	500	-0.02	-0.03077	0.02
Y4	1000	0.00	0.00000	0.00
Y5	200	-0.02	-0.03509	0.02
Y5	500	-0.01	-0.01754	0.01
Y5	1000	0.00	0.00000	0.00
Y6	200	-0.02	-0.04082	0.02
Y6	500	-0.01	-0.02041	0.01
Y6	1000	0.00	0.00000	0.00

The biases for factor loadings decreased as the sample size increased and approached zero. This showed that a biased estimation was made in small sample sizes, while in large sizes (N=1000) the bias almost approached zero. In particular, it is seen that the relative bias of the x1 variable in the 200-unit sample size is 6.25%, while this bias is 0.000 in the 1000-unit volume.

Table 4. Factor correlations bias mab and rb

Correlation	Sample Size	Bias	RB	MAB
F1_F2	200	-0.02	-0.06667	0.02
F1_F2	500	-0.01	-0.03333	0.01
F1_F2	1000	0.00	0.00000	0.00
F1_F3	200	-0.02	-0.06667	0.02
F1_F3	500	-0.01	-0.03333	0.01
F1_F3	1000	0.00	0.00000	0.00
F2_F3	200	-0.02	-0.06897	0.02
F2_F3	500	-0.01	-0.03448	0.01
F2_F3	1000	0.00	0.00000	0.00

The correlation values between the factors also resulted in a similar way to the factor loadings. In small samples, RB had the highest value of 6.89%. Even this result is below the 10% bias. Visual outputs for the correlations between factors and factor loadings were also obtained according to the sample sizes. Figures 2. 3. 4. 5. are given.

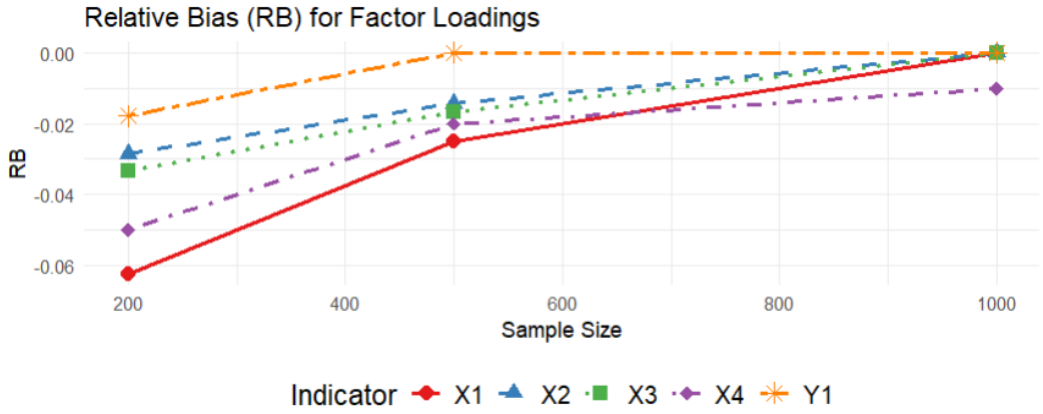


Figure 2. Relative bias for indicator x1 x2 x3 x4 and y1

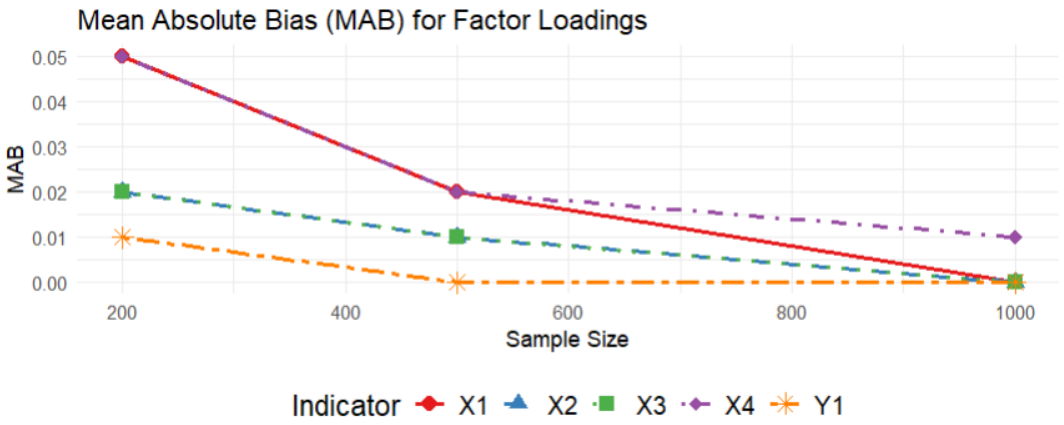


Figure 3. Mean absolute bias for indicator x1 x2 x3 x4 and y1

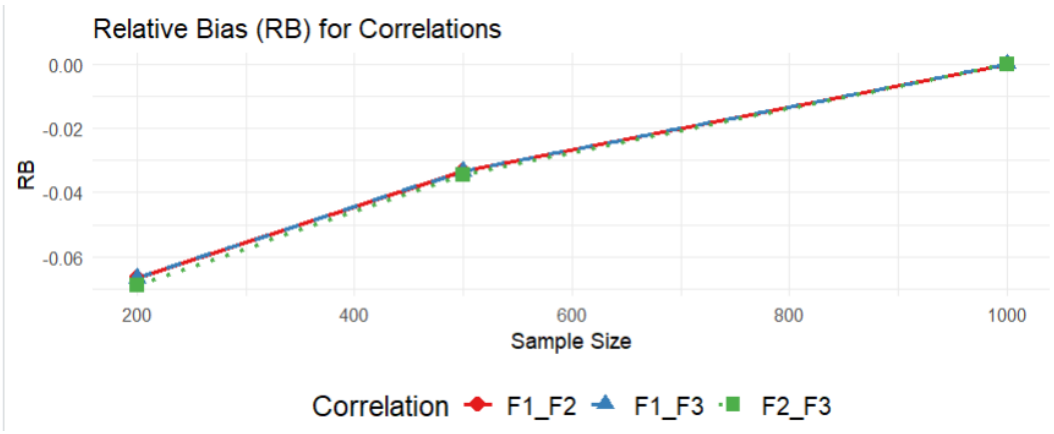


Figure 4. Relative bias for correlations

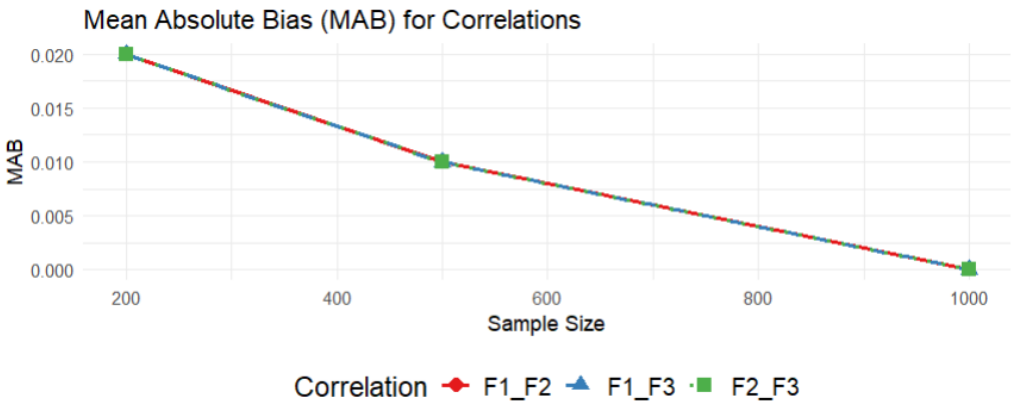


Figure 5. Mean absolute bias for correlations

Only the visuals of some variables are given for the factor loadings. When these visuals and the data belonging to the tables are examined, it is seen that a sample size of more than 500 units is actually sufficient. A similar situation is seen in the correlation between the factors. When it is desired to display the situation against sample size with a single visual for MAB and RB, Figure 6 and Figure 7 will be sufficient.

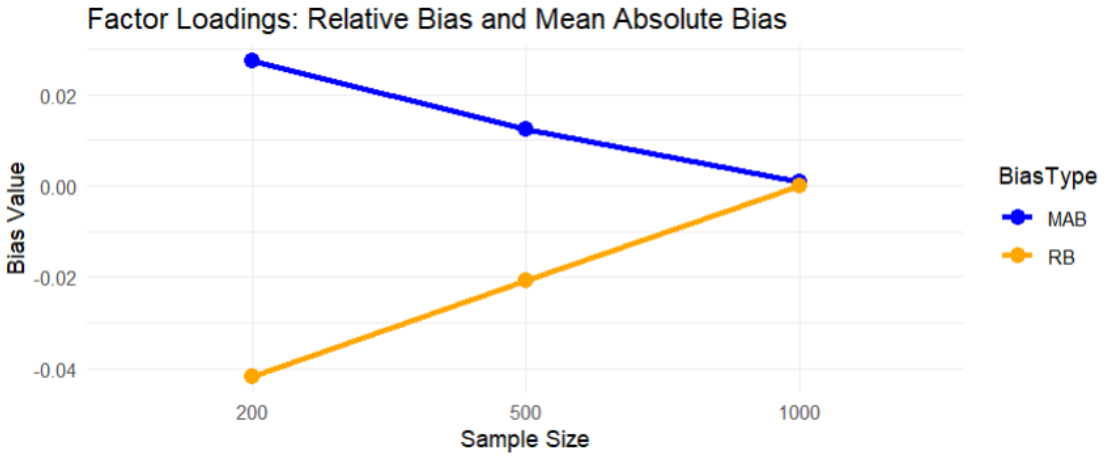


Figure 6. MAB and RB in factor loadings

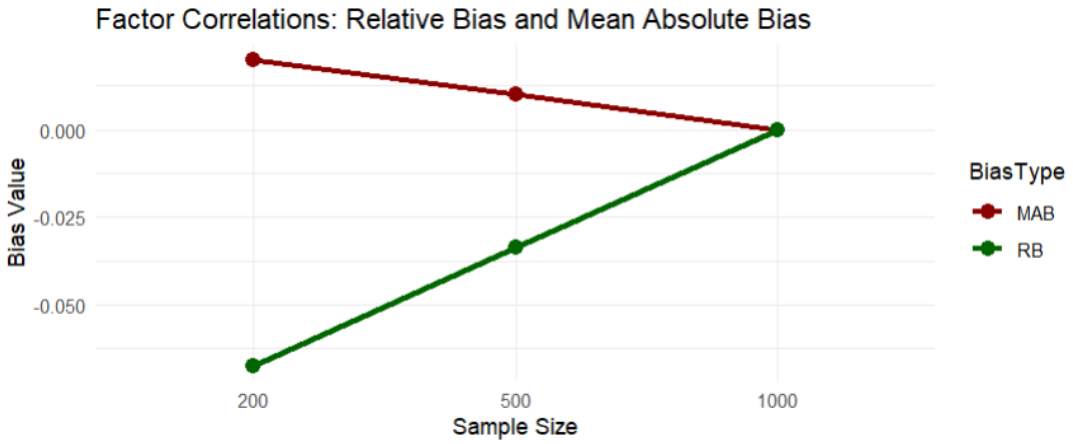


Figure 7. MAB and RB in factor correlations

DISCUSSION AND CONCLUSION

There is a use of mixed variables in many measurement models in social sciences. DWLS, developed for categorical variables in the literature, has begun to become popular with its very robust corrections in applications. At this point, MLR, which is a strong method against deviation from normality, is also expected to perform well in mixed variables. The analysis performed in the current study addressed the performance of MLR in measurement models where both categorical and continuously observed variables are present only from the perspective of sample size. The study has limitations in many points in this respect. These are many deficiencies such as not addressing standard error estimates, chi-square fit statistics, deviation from normality and missing data. In this respect, the study only focused on the bias values of MLR against the sample size. However, the fact that the biases in this study have small values makes MLR attractive for SEM applications. When the bias findings obtained are examined, it is seen that they have similar results to Li (2021), who conducted a more comprehensive study.

If the limitations of the current study are taken into account in future studies, the performance of MLR can be observed better. In addition, the established model consists of only a measurement model.

At this point, if the model structures frequently used by SEM practitioners are considered, more attractive and useful research findings can be revealed.

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Conflict of Interest

The study is a single author and has declared that there is no conflict of interest.

Author Contributions

The study is a single author and all contributions belong to the author.

Deep Recurrent Models for Carbon Emission Forecasting: A Case Study on Canadian Vehicle Data

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Abstract

The increase in global carbon dioxide (CO2) emissions represents a significant threat to climate change and environmental sustainability. It is evident that emissions originating from the transportation sector, in particular, contribute significantly to greenhouse gas emissions. Consequently, the development of decision support systems that can accurately estimate the amount of CO2 emissions based on technical and structural vehicle data is imperative. In this study, the open dataset consisting of 7,385 samples of passenger vehicles registered in Canada was utilised to estimate the CO2 emission per kilometer by means of three different deep learning models. The models examined are Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU) and Simple Recurrent Neural Network (RNN) architectures. Each model was trained and tested on the same dataset, utilising both the 70-15-15 fixed data splitting method and 5-fold cross-validation. R^2, Mean Square Error (MSE) and Root Mean Square Error (RMSE) metrics were utilised in performance evaluation. The findings indicated that all models demonstrated the capacity to make predictions with a high degree of accuracy; however, the LSTM model exhibited superior performance with regard to overall success, generalizability, and error rates. The findings demonstrate the efficacy of recurrent neural networks in processing structured data that is devoid of time series, thereby underscoring their potential for generating data-driven insights that inform sustainable transportation policies.

Key words: *Deep learning, CO_2 emission prediction, LSTM, GRU, RNN*

INTRODUCTION

Global climate change is triggering environmental and socioeconomic crises worldwide due to increasing greenhouse gas emissions. In this context, carbon dioxide (CO_2) emissions have an important share especially in the transport sector and have become one of the focal points of climate policies (Guo, Kou, & He, 2024; Abdulmalik & Srivastava, 2023). Motor vehicles emit significant amounts of CO_2 to the atmosphere through the direct consumption of fossil fuels, which not only increases environmental pollution but also poses serious threats to energy efficiency and sustainable transport systems (Verma et al., 2024).

In recent years, artificial intelligence and data science-based approaches have been increasingly used to analyse and predict environmental variables. These methods have the potential to produce successful predictions, especially in high-dimensional and non-linear data structures (Goodfellow, Bengio, & Courville, 2016). Deep learning techniques have stronger generalisation capability compared to

traditional machine learning algorithms thanks to their multi-layered structure and can successfully model complex patterns (He et al., 2024; Khalid et al., 2024).

In the literature, classical regression models or conventional machine learning algorithms are generally preferred in studies that estimate CO_2 emissions using technical data of vehicles (Kumar, Sinha & Ranjan, 2022). However, recurrent neural network (RNN)-based models stand out with their powerful learning capabilities even for data that do not contain time dependence or sequential structure. In particular, architectures such as Long Short Term Memory (LSTM) and Gated Recurrent Unit (GRU) can learn long-term dependencies more efficiently by minimizing problems such as gradient fading (Hochreiter & Schmidhuber, 1997; Cho et al., 2014).

This study aims to develop deep learning models that predict CO_2 emissions per kilometer from the technical characteristics of vehicles using an open dataset of vehicles registered in Canada. In this context, three different recurrent architectures-RNN, LSTM and GRU-were evaluated and their performance was compared by training each model with both fixed data splitting (70-15-15) and 5-fold cross-validation methods. The performance of the models was analyzed through regression metrics such as coefficient of determination (R^2), Mean Square Error (MSE) and Root Mean Square Error (RMSE). This study reveals how effective deep learning models can be in environmental data analysis such as CO_2 emission estimation and presents a data-driven approach that can contribute to sustainable transportation policies (Khalid et al., 2024; Kohavi, 1995).

MATERIAL AND METHODS

This study aims to estimate the amount of CO_2 emissions per kilometer using technical data of passenger vehicles registered in Canada. The dataset used was obtained from the Canadian government's open data sources and published on the Kaggle platform. This dataset, which includes various vehicle models produced between 2014-2020, contains a total of 7385 observations and 12 variables.

Data Characteristics and Preprocessing

The target variable to be estimated is “CO2 Emissions (g/km)”. The independent variables include technical variables such as engine displacement (L), number of cylinders, transmission type, vehicle class, fuel type and urban/highway/combined fuel consumption (L/100 km). The “Fuel Consumption Comb (mpg)” column was excluded from the analysis as it was found to contain incorrect conversions (Patel, 2024; Wang, Zhang & Chen, 2024).

Prior to modeling, categorical variables were converted into numerical form using one-hot encoding. All numerical attributes were normalized in the range [0,1] using the MinMaxScaler technique. The dataset was randomly divided into 70% training, 15% validation and 15% testing subsets.

Model Architectures

The same basic architecture is used in all models. In the three-layer sequential structure, the first recurrent layer consists of 512 units and the time dimension is preserved with the return_sequences=True parameter. The subsequent layers contain 256 and 128 units. To prevent overfitting, a 20% dropout is applied after each recurrent layer. Then, two dense layers with 64 and 32 neurons respectively are added and the model is completed with a single neuron regression output. The ReLU activation function was used in all models and only the recurrent layer type was changed to obtain the LSTM, GRU and RNN variants.

Three different deep learning architectures are evaluated in the study: Simple RNN, LSTM and GRU. The models are trained under the same data processing and architectural structure and a comparative performance analysis is performed.

Simple Recurrent Neural Network (RNN)

The Simple Recurrent Neural Network is the basic recurrent neural network developed to model short-term dependencies in sequential data. It produces a new output at each time step, taking into account the previous output. Although this structure is effective in capturing short correlations, it may be insufficient for learning long-term dependencies due to problems such as gradient disappearance (Goodfellow, Bengio & Courville, 2016). Although the RNN architecture is characterized by its computational simplicity, its limited memory capacity can be a performance disadvantage for more complex data patterns.

Long Short Term Memory (LSTM)

LSTM was developed to overcome the inability of the RNN structure to model long-term relations. LSTM cells can control the flow of information through input, forget and output gates, allowing the network to decide which information to keep and which to forget. This mechanism increases the stability of the learning process by preventing the loss of gradients over time (Hochreiter & Schmidhuber, 1997). LSTM is a prominent model in terms of accuracy and generalizability, especially in high-dimensional and complex data sets.

Gated Recurrent Unit (GRU)

GRU has a time-dependent learning mechanism similar to the LSTM architecture, but with a simplified structure with fewer parameters. By organizing the flow of information through update and forget gates, GRU can offer similar performance with a lower computational load compared to LSTM. It can provide effective results with fast training and low error, especially for small and medium-sized data sets (Cho et al., 2014).

Common Architecture and Training Details

The same network structure is adopted in all three models. There are three recurrent layers with 512, 256 and 128 units, followed by dense layers with 64 and 32 neurons and a single regression output. A 20% dropout was applied after each recurrent layer to avoid overfitting. In all layers, ReLU was used as the activation function and Adam as the optimization algorithm. Mean Squared Error (MSE) was used as the loss function and the training process was controlled with an early stopping strategy based on validation loss.

Since the data structure does not include time series, the model input format was converted into a three-dimensional tensor (number of samples, time step, number of attributes) to ensure the applicability of sequential models.

Evaluation Method

In order to evaluate the performance of the models developed in this study, two different validation strategies were applied: fixed data splitting method and 5-fold cross-validation.

In the first method, the dataset was randomly divided into 70% training, 15% validation and 15% testing subsets. The training process was performed with only training and validation data, while the overall performance of the model was evaluated on independent test data. This method was used to measure the performance on a single test set of the model on a specific data split.

As the second method, 5-Fold Cross-Validation was applied. In this method, the data set is divided into five equal parts; in each layer, a different part is used as test data, while the remaining four parts are reserved for training. In each round, the model was retrained and the test performances were calculated. The results were averaged to determine the overall model performance. This approach provided a more objective measure of the generalizability and stability of the model across different data splits (Kohavi, 1995).

In both evaluation strategies, four basic regression metrics were used to compare model performance: R^2, MAE, MSE, RMSE. The combination of these two methods provided more reliable results by observing both the performance on a single test set on a specific data split and the overall generalizability of the model.

RESULTS

In this study, three different deep learning models consisting of RNN, LSTM and GRU architectures were developed to predict the carbon dioxide (CO_2) emission value per kilometer from the technical specifications of vehicles. To ensure a fair comparison, all models shared an identical architectural configuration, varying only in the type of recurrent unit employed. In this way, the performance of the models is comparable under equal conditions.

The training process was performed according to two different evaluation strategies. First, the dataset was divided into training, validation and test sets with a fixed proportion (70%-15%-15%) and the classical splitting method was applied. Secondly, the 5-Fold Cross-Validation method was used to evaluate model generalizability more reliably.

In both strategies, the predictive success of the models was evaluated using regression performance metrics: R^2, MSE and RMSE. The test results based on the fixed data split are summarized in Table 1 and the cross-validation results are summarized in Table 2.

Table 1. Regression performance comparison of LSTM, GRU and RNN models on fixed test set

Model	R^2	RMSE	MSE
LSTM	0.9804	8.2203	67.5732
RNN	0.9846	7.2859	53.0841
GRU	0.9855	7.0679	49.9547

Table 2. 5-fold cross-validation results of LSTM, GRU and RNN

Model	R^2	RMSE	MSE
LSTM	0.9766	8.928	80.044
RNN	0.9725	9.68	93.94
GRU	0.9691	10.2637	105.7944

Figures 1 to 3 illustrate the comparative alignment between actual and predicted CO_2 emissions across the three architectures. These figures show the distribution between the actual and predicted CO_2 emission values of the LSTM, GRU and RNN models, respectively.

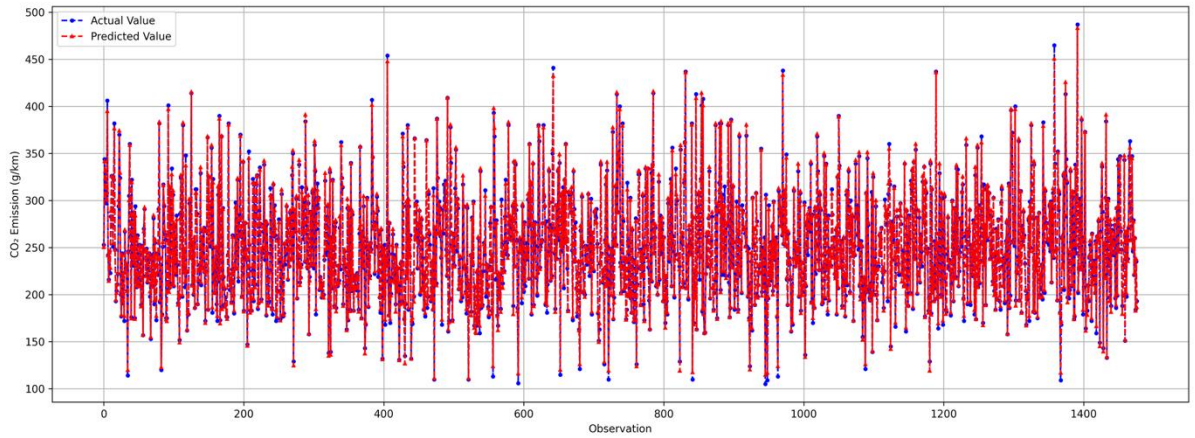


Figure 1. Actual vs. Predicted CO_2 Emissions using the LSTM Model

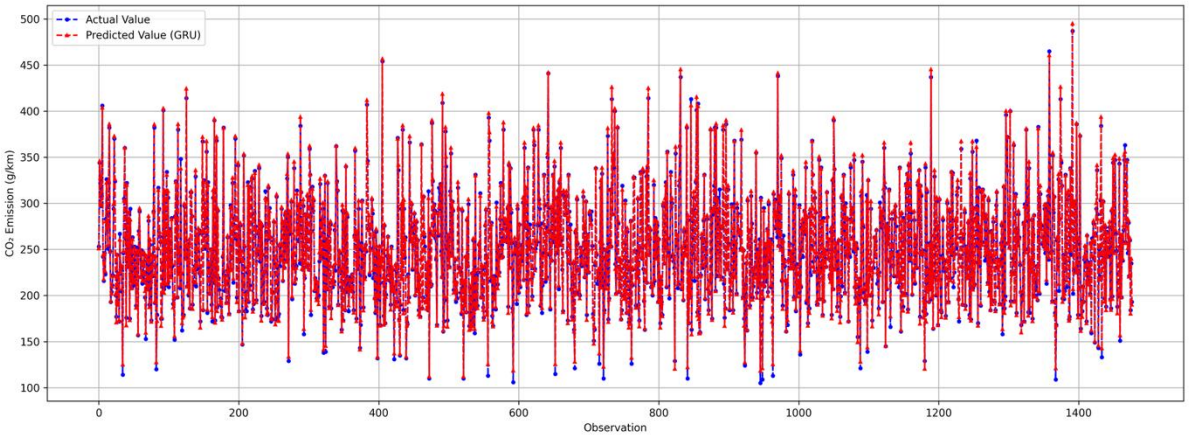


Figure 2. Actual vs. Predicted CO_2 Emissions using the GRU Model

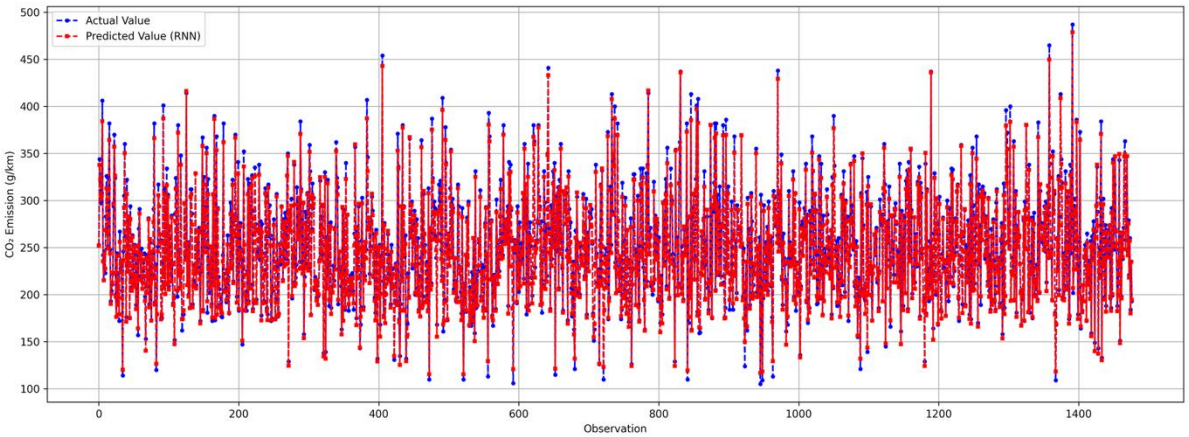


Figure 3. Actual vs. Predicted CO_2 Emissions using the RNN Model

DISCUSSION AND CONCLUSION

In this study, RNN, LSTM and GRU based deep learning models designed to predict CO_2 emissions based on the technical characteristics of vehicles are evaluated. All models were designed in the same network structure and only the recurrent layer type was changed, thus providing an objective basis for

model comparisons. Performance measurements were performed using both fixed data partition and 5-fold cross-validation methods, thus observing both immediate and generalizable performance.

According to the results, the LSTM and GRU models outperformed the classical RNN structure. In particular, the LSTM model produced more stable results with lower errors in cross-validation scenarios. This is directly related to the ability of LSTM and GRU to capture more complex intrinsic dependencies.

Although the dataset used does not contain time series in the classical sense, the structural and sequential relationships embedded between attributes (e.g. engine displacement, fuel type, number of cylinders, fuel consumption, etc.) make sequential information processing advantageous. In this context, recurrent neural network architectures are considered more suitable for learning hidden dependencies in such data. Convolutional architectures, on the other hand, are more prone to learning spatial patterns, resulting in limited impact on such tabular and non-sequential data structures. Therefore, structures such as LSTM and GRU are better suited for modeling correlations between features and improving prediction accuracy.

Moreover, the high success rates obtained with fixed data partitioning are slightly reduced compared to cross-validation, suggesting that reliance on individual data partitions may be misleading and that model performance should be consistently tested on different subsets of data.

As a result of this study, it was observed that LSTM and GRU architectures can provide high accuracy not only in time series data but also in non-sequential data with structural relationships. In this context, recurrent neural networks can be considered as powerful tools in different application areas such as environmental impact analysis, sustainable transportation modeling and emission estimation in the automotive industry. Future improvements may include the integration of broader datasets and interpretability techniques.

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Is Manual Feature Filtering Still Necessary After Automated Extraction? A Comparative Study

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Abstract

This study investigates whether manual dimensionality reduction techniques (in particular VarianceThreshold (VT)) applied to features automatically extracted by unsupervised methods such as Autoencoder and UMAP can improve classification performance. The experiments are performed on two structurally different datasets: the low-dimensional and regularised Dry Bean dataset and the high-dimensional and artificially generated Madelon dataset. Five modelling scenarios were evaluated for each dataset: classification with raw data, dimensionality reduction with Autoencoder and UMAP, and versions with VT applied to these representations. The results show that in the Dry Bean dataset, automatic feature extraction preserves the classification performance, and the application of VT does not contribute significantly. In contrast, in the Madelon dataset, automatic feature extraction significantly reduced accuracy and subsequent VT filtering could not compensate for this loss. These findings suggest that interventions such as VT are not universally beneficial and are highly dependent on the structure of the dataset and the quality of the learnt representations. The study highlights that post-inference filtering should be applied in a way that is sensitive to the data context and not rote learning.

Keywords: *Automated Feature Extraction, Dimensionality Reduction, Variance Threshold, Autoencoder, Classification Performance*

INTRODUCTION

With the proliferation of deep learning-based models, automated feature extraction approaches have become an essential component of machine learning applications. These approaches generate model inputs by deriving abstractions from data without manualisation, thus automating the traditional feature engineering process. However, in many cases where these automatically extracted features have high dimensionality and information redundancy, they can adversely affect classification performance.

Therefore, in recent studies, it has been stated that applying techniques such as dimensionality reduction or feature selection after automatic feature extraction can increase the classification performance and make the model more interpretable. For example, Gil-Rios et al. (2024) showed that 89% success was achieved with only 4 features by filtering 473 image-based automatically extracted features with evolutionary algorithms, which revealed that high-dimensional automatic representations can be optimized with aggressive reduction. Moslemi & Jamshidi (2025) reported that the feature selection they applied by preserving manifold structures in Autoencoder-based automatic feature extraction significantly improved both the classification accuracy and the NMI score. Wang et al. (2023) stated that they achieved significant dimensionality reductions without loss of accuracy by combining transformation and selection in multidimensional automatic features with SUP/GOSUP approaches. The

GB-AFS method presented by Levin & Singer (2023) was able to achieve full accuracy with only a 7–30% feature subset without any parametric adjustments and provided resource savings. Biglari et al. (2020) reported that 92% accuracy was achieved with a dimensionality reduction of up to 99% with progressive feature selection in the small sample-high dimensionality scenario. Wang et al. (2022) stated that selecting only meaningful features in deep learning-based recommendation systems increases performance. Meepaganithage & Nicolescu (2025) showed that feature selection with decision trees in RNN, GRU and LSTM-based systems provides maximum performance in the 70% subset. Padilha et al. (2021) pointed out that multidimensional automatic feature filtering with Boruta algorithm provides a significant contribution to model performance.

On the other hand, there are also studies that argue that intervention after automatic feature extraction is unnecessary. Biharie (2020) stated that feature selection becomes meaningless in deep learning models, especially in architectures such as RNN, and only provides limited contribution in feedforward structures. Bosch (2021) reported that automatic feature filtering can reduce the explanatory ability of the model in the absence of user intervention and is ineffective.

Considering all these studies, the question of the extent to which dimensionality reduction or feature selection applications after automatic feature extraction are meaningful is still controversial, depending on the size of the dataset, the feature distribution structure, and the nature of the automatic extraction method. This study experimentally evaluates the effect of manual filtering intervention with VarianceThreshold (VT) after automatic feature extraction with Autoencoder and UMAP on two different datasets and questions the contribution of this intervention to the classification performance.

MATERIAL AND METHODS

Datasets

In this study, two different datasets were used to evaluate the effectiveness of manual filtering interventions after automatic feature extraction. The datasets were obtained from the UCI Machine Learning Repository, which is widely used and accepted for comparative analyses in the literature:

- **Dry Bean Dataset:** It is a medium-sized and balanced dataset consisting of 16 numerical features and 7 classes. It allows multi-class classification based on the physical properties of agricultural products.
- **Madelon Dataset:** It is a high-dimensional and artificially generated dataset consisting of 500 numerical features and 2 classes. Due to its complex structure, it is frequently used to test the performance effects of methods such as dimensionality reduction and feature selection.

These two datasets were specifically selected to observe how the intervention after automatic feature extraction produces results on different data types.

Preprocessing and Representation Transformations

Five basic scenarios were considered for each dataset:

1. Direct classification with raw data (reference model)
2. Automatic dimensionality reduction with Autoencoder (AE)
3. Manual filtering with VarianceThreshold (VT) after AE
4. Dimensionality reduction with UMAP
5. Manual filtering with VT after UMAP

Since there were no missing values in the data preprocessing stage, direct normalization was applied. All features were subjected to z-score scaling with `StandardScaler()`. Class labels coded as ±1 in the Madelon dataset were relabeled as 0 and 1.

The remaining feature numbers after the dimensionality reduction steps are summarized in the table below:

Table 3. Feature dimensionality before and after reduction for each dataset and method.

Dataset	Rae	AE	AE + VT	UMAP	UMAP + VT
Dry Bean	16	8	8	8	8
Madelon	500	32	31	32	32

Autoencoder architecture was created with Keras library and coding was performed with layers such as input dimension → 256 → 128 → 32. Decoder has a symmetric structure. Transformation was performed for UMAP using `umap-learn` library with `n_components=8` (Dry Bean) and `n_components=32` (Madelon) parameters. VT process was applied with `sklearn.feature_selection.VarianceThreshold` function using `threshold=0.01` threshold value. This threshold is aimed at eliminating features with almost zero variance.

Classification and Evaluation Method

The XGBoost model was preferred for classification in all scenarios. This model was especially preferred due to its low training time and high success in small-medium sized data sets. It can also provide performance on low-dimensional representations resulting from VT without being prone to over-learning.

XGBoost classifiers were created with use_label_encoder=False and eval_metric='logloss' parameters, and for each scenario, the data was divided into 80% training - 20% test, preserving the class balance (stratify=y).

The model performance was evaluated with the following two basic metrics:

- **Accuracy:** The overall accuracy rate reflects the overall success of the model on all classes.
- **F1-score:** It is the harmonic average of the precision and recall values, and is particularly sensitive to the possibility of class imbalance.

A macro average F1-score was calculated for the Dry Bean data set, and a binary F1-score was calculated for the Madelon.

Thanks to this methodological structure, classification performance in different dimensionality reduction and filtering scenarios can be compared directly by following the same experimental protocol on both datasets.

RESULTS

In this section, the classification performances of five different modeling scenarios applied on the Dry Bean and Madelon datasets are presented and evaluated comparatively. Accuracy and F1-score are used as performance criteria, and the effectiveness of the dimensionality reduction steps for each scenario is also interpreted in terms of the number of features and classification success.

Dry Bean Dataset Results

Classification performances of five scenarios applied on the Dry Bean dataset are as shown in Table 2:

Table 4. Classification performance on the Dry Bean dataset across five feature processing scenarios. Dimensionality is preserved post-VT

Scenario	Feature Count	Accuracy	F1-score
Raw (XGBoost)	16	**0.9225**	**0.9225**
Autoencoder	8	0.9218	0.9219
Autoencoder + VT	8	0.9148	0.9148
UMAP	8	0.9104	0.9103
UMAP + VT	8	0.9104	0.9103

These results show that automatic dimensionality reduction methods such as AE and UMAP can preserve the classification performance with very little loss. However, VT intervention did not cause a change in the number of features and did not affect the performance since the variance of the selected features was sufficient in this data. This indicates that intervention on automatically extracted representations may be unnecessary in data with medium size and regular distribution in statistical terms.

Madelon Dataset Results

The results for the Madelon dataset, which consists of high-dimensional and artificial features, are given in Table 3:

Table 3. Classification performance on the Madelon dataset. AE and UMAP significantly reduce performance, and VT filtering has no measurable benefit.

Scenario	Feature Count	Accuracy	F1-score
Raw (XGBoost)	500	**0.8000**	**0.8104**
Autoencoder	32	0.5725	0.5778
Autoencoder + VT	31	0.5725	0.5778
UMAP	32	0.5300	0.5459
UMAP + VT	32	0.5300	0.5459

In this scenario, automatic feature extraction methods caused significant information loss, and classification performance decreased dramatically. AE and UMAP outputs were insufficient, and VT filtering could not provide any improvement on these outputs. This situation reveals that in some cases, automatic feature extraction already produces scattered and meaningless representations, and traditional interventions on them may be ineffective. The results of both datasets and scenarios are visualized in the graph in Figure 1. As seen in Figure 1, the Madelon dataset shows a significant decrease in accuracy after AE and UMAP transformations.

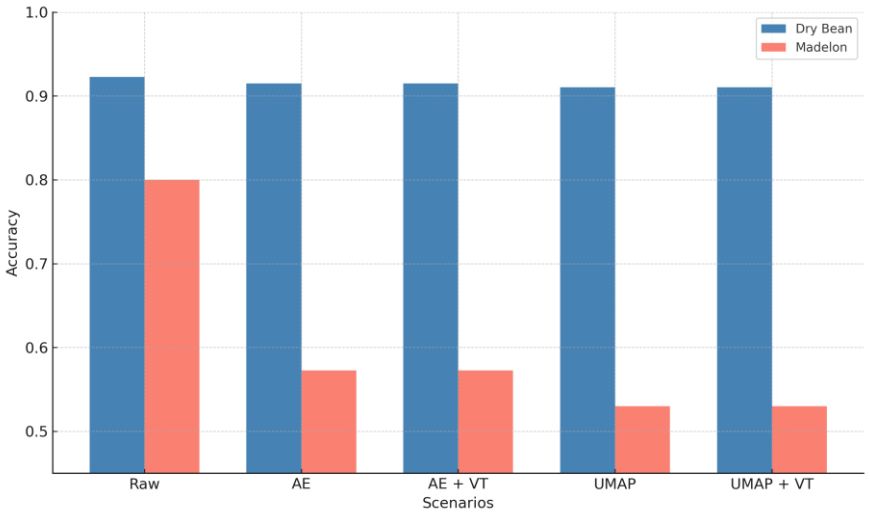


Figure 4. Comparison of classification accuracy across five dimensionality reduction strategies for both datasets.

DISCUSSION AND CONCLUSION

This study systematically evaluated the effects of manual dimensionality reduction interventions applied after automatic feature extraction on classification performance on two different datasets. The results of five scenarios applied to the Dry Bean and Madelon datasets show that data structure and dimensionality play a decisive role in the effectiveness of the intervention.

In the experiments conducted on the Dry Bean dataset, automatic dimensionality reduction techniques such as Autoencoder and UMAP yielded results very close to the original accuracy level, and it was observed that VT filtering did not contribute to these representation forms. At first glance, applying automatic feature extraction on such a dataset may seem unnecessary. However, the inclusion of such datasets in the study is important in terms of experimentally demonstrating not only successful interventions but also unnecessary interventions. Since Dry Bean has high data quality and a balanced distribution, it has been shown that unnecessary transformations applied on such structures do not contribute to performance, but may also create additional burden in terms of model simplicity and computational cost. This scenario was evaluated as a reference to question whether the intervention is really necessary.

The situation is quite different in the Madelon dataset. Automatically extracted representations significantly reduced the classification success and the VT application could not compensate for this loss. This result reveals that models such as Autoencoder and UMAP may not be able to obtain sufficiently informative features in high-dimensional and artificially derived data and that in this case, traditional filtering methods may not make a meaningful contribution. In other words, the reason for the decrease in success may not be only the ineffectiveness of VT but also the inadequacy of the automatic inference process itself.

In this context, it should be kept in mind that automatic feature extraction models are designed not only for dimension reduction but also to enrich data representations. However, if the extracted representations are not meaningful enough, the reduction processes applied on them also become inefficient. Therefore, especially in high-dimensional and noisy data such as Madelon that do not carry

information, filtrations performed without evaluating the quality of the extracted representations may be ineffective.

In general, the findings obtained show that the effectiveness of the interventions made after automatic inference depends on the characteristics of the data set, the information carrying power of the representations and the sensitivity of the target classification model. This study experimentally demonstrates that intervention strategies such as “post-autoencoder VT” or “post-UMAP filtering”, which are widely suggested in the literature, are not valid for every data structure. As a result, this study suggests that a cautious and data-driven approach should be adopted against generalizing statements in the literature regarding the benefits of intervention after automatic feature extraction. Especially in medium-sized structures where model performance is stable, unnecessary filtering steps can have negative consequences in terms of both processing load and model simplicity. On the other hand, whether the decrease in success is due to the weakness of automatic extraction or the inappropriateness of the intervention method should be evaluated separately, and further studies should reveal this distinction methodologically.

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Using Biometric Visualization for Multivariate Agricultural Data in Decision Support: A Practical Approach with Milk Quality

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Abstract

Quality control processes play a pivotal role in the agricultural industry. The precision and efficiency with which these processes are executed have a direct impact on the success of production systems. Open-source dataset from Kaggle.com featuring various milk quality attributes was utilized in this research. The dataset encompasses both physical and sensory quality indicators including pH, temperature, taste, odor, fat content, color, and density ratio. A combination of simple graphical tools and advanced multivariate visualization techniques was applied for statistical analysis of data. Missing values were identified during the data preprocessing phase and outliers were flagged, therefore data was standardized. Several biometric visualization techniques were employed, such as Principal Component Analysis (PCA), dendrograms with heatmaps, boxplots and radar charts. PCA was instrumental in examining the relationships between samples and variables in a two-dimensional format. Meanwhile, dendrograms and heatmaps helped uncover clusters of samples that shared similar quality characteristics. Radar charts offered a comprehensive representation of the quality profiles for individual samples. In conclusion, the study illustrates that visualization is not only a method for presenting data but also serves as a powerful component of decision support systems. The study evaluates the practicality, clarity, and usefulness of multivariate data analysis techniques using milk quality parameters. The strategic use of biometric visualization tools for analyzing complex agricultural products stands out as a strategic contribution toward the digital advancement of agriculture.

Key words: *Biometric analysis, Visualization, Milk quality, PCA, Clustering, Heatmap*

INTRODUCTION

In recent years, the rapid increase in data volumes and information sources, along with the fact that this data has become more processable, has significantly elevated the importance and usage of data-driven approaches. The formation of large data sets in the agriculture and livestock sectors and the growth of analyzable quantitative and qualitative data have led to a greater need for such approaches in decision-making processes. Challenges faced in agriculture, the declining number of farmers able to address these issues, and the increase in production have made it harder to closely monitor activities. As a result, the presence of decision support systems has become essential (Parisa et al., 2021; Gargiuolo et al., 2018).

Biometric data obtained from living organisms, which reveal differences between observations, are widely used in decision support systems. A significant amount of biometric data is collected in various fields such as agriculture, livestock, health, and engineering. Visualizing this data supports rapid and effective information exchange among decision-makers and significantly enhances the efficiency of these systems.

Accordingly, Ghazali et al. (2022) emphasized that the visualization techniques of decision support systems play an important role in facilitating information communication between researchers and decision-makers. Visual decision support systems help to better understand complex and multivariate

data structures through visual techniques such as color codes, graphics, and network maps. This provides a new perspective in agriculture and livestock. The technique combines the processing power of modern computers with visual capabilities to better support analyses. Interactive visualizations make it easier to understand different data structures and volumes. They synthesize the information within data structures and make the analysis process more efficient.

In agriculture, visualization tools are highly beneficial in processes such as effectively presenting forecasts in different areas, tracking new products, managing pests, and applying irrigation and fertilizers. Agricultural visualization tools play a crucial role in supporting decision-making processes in precision agriculture. Numerous studies in the literature have demonstrated the benefits of visualization in agricultural practices, such as color coding, network mapping, and pest management (Htun et al., 2022). According to Meng and colleagues (2025), biometric data are personal and harmless. These biometric data can be digitally recorded and processed using computer vision techniques. Consequently, although this study does not directly use animal structures, it aims to interpret biometric indicators such as milk quality data in a digital environment.

MATERIAL AND METHODS

Material

In this study, a multivariate dataset related to milk quality parameters was utilized. The dataset, obtained from Kaggle.com, consists of a total of 1,059 observations, each representing an individual milk sample (Cpluzshrijayan, 2020). The dataset includes the following variables: pH – the pH level of the milk, Temperature (°C) – the temperature of the sample, Taste – taste evaluation score (0 = bad, 1 = good), Odor – odor evaluation score (0 = bad, 1 = good), Fat (%) – fat content, Turbidity – turbidity score, Colour – color scale value, and Grade – overall quality classification (Low, Medium, High). There are no missing observations in the dataset. Therefore, no data preprocessing was conducted to handle missing values.

Methods

The Collection of the Data

Each row in the dataset represents a milk sample, for which physicochemical (pH, temperature, fat content, turbidity, color) and sensory (taste, odor) properties have been measured. In addition, an overall quality assessment has been conducted for each sample, and this evaluation has been classified as a nominal variable (Grade: Low, Medium, High).

Statistical Analysis

In this study, various biometric data visualization techniques were applied to explore patterns in the dataset, identify, group, and interpret quality classes. The methods used in this study include: PCA Biplot (Principal Component Analysis), which visualizes the relationships between variables and the distribution of samples in a reduced two-dimensional space from the original multivariate space; Heatmap and Dendrogram, which visually represent the influence of variables on samples through color intensity and group milk samples with similar characteristics; Radar Chart, which enables comparative analysis of quality classes based on variables; and Boxplot, which compares the central tendency and dispersion characteristics of distributions across classes. In total, four methods were utilized. All analyses were conducted using R version 4.5.0, with the help of popular R packages such as ggplot2, pheatmap, cluster, fmsb, and dplyr. Numerical variables were transformed into a standard normal distribution (z-score standardization) before analysis, while categorical variables were converted into factor type (R Core Team, 2024).

RESULTS

In this study, a multivariate milk quality dataset was evaluated using biometric data visualization techniques. By exploring the patterns within the dataset, the distinction between milk quality classes was statistically demonstrated.

1. Principal Component Analysis (PCA)

As a result of the principal component analysis (PCA) applied to milk quality parameters, it was determined that the first two principal components explained 45.6% of the variance. Thus, the multidimensional dataset was summarized and visualized in two dimensions.

Figure 1 presents the PCA Biplot graph of the dataset. Upon examining the graph, it is observed that the variables Fat, Odor, Taste, and Colour have a negative influence along Dim1, while Temperature and pH have a positive influence along Dim2. High-quality samples showed a strong correlation with the Fat, Odor, and Taste parameters. Medium-quality samples exhibited a moderate correlation with Colour and pH. Low-quality samples demonstrated a positive correlation with pH and Temperature parameters. In light of this information, it is evident that milk quality classes exhibit distinct patterns, and these differences can be clearly identified through PCA analysis.

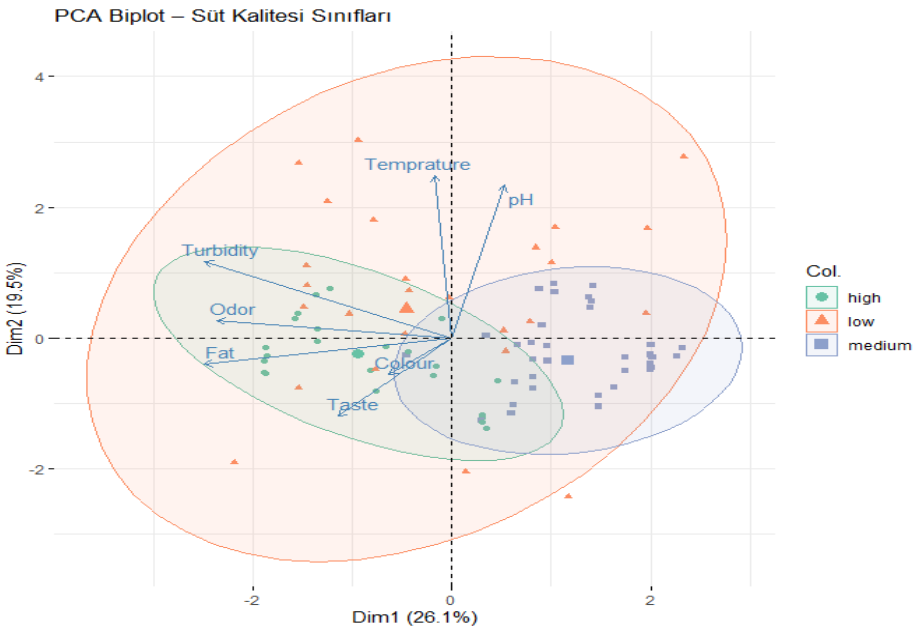


Figure 1. Biplot graphic of Milk Quality Parameters

In Table 1, Principal Component Analysis (PCA) was applied to generate the biplot graph. Numerical variables were scaled using z-score standardization and reduced to two principal components using the prcomp() function. The resulting components were visualized with a biplot graph using the fviz_pca_biplot() function. In the graph, both the samples (observations) and variables are represented in a two-dimensional plane. Quality classes are distinguished by colors, and ellipses were added to better illustrate the distribution of each class. The code was executed using R version 4.5.0 (R Core Team, 2024) with the help of the factoextra and ggplot2 packages.

Table 1. R Code for Generating a Biplot Graphic of Milk Quality Parameters

```
milk <- read.csv
head(milk)
install.packages("factoextra")
install.packages("ggplot2")
library(factoextra)
library(ggplot2)
milk <- read.csv("C:/data/milknew.csv")
milk$Grade <- as.factor(milk$Grade)
num_data <- milk[, c("pH", "Temperature", "Taste", "Odor", "Fat", "Turbidity", "Colour")]
scaled_data <- scale(num_data)
pca_result <- prcomp(scaled_data, center = TRUE, scale. = TRUE)
group <- milk$Grade
p <- fviz_pca_biplot(pca_result,
                     geom.ind = "point",
                     col.ind = group,
                     palette = "Set2",
                     addEllipses = TRUE,
                     label = "var",
                     repel = TRUE,
                     title = "PCA Biplot – Milk quality grade")
windows()
print(p)   (R Core Team, 2024)
```

2. Heatmap

The heatmap created based on standardized Z-scores of milk quality parameters is shown in Figure 2. Hierarchical clustering was applied to both samples and variables to reveal similarities.

The orange, green, and purple colored bands in Figure 2 indicate the classes to which the samples belong. Orange represents the low-quality class, purple indicates the medium-quality class, and green corresponds to the high-quality class. From the figure, it is observed that most of the low-quality group samples are clustered at the bottom of the heatmap. These samples have high scores in terms of pH and Temperature, but low scores in Fat, Odor, and Taste parameters. Additionally, the heterogeneous clustering structure of this group suggests a high level of internal variation. Fat, Odor, and Taste parameters are observed to have high values in high-quality samples. The presence of dark blue colors in these parameters indicates that this quality group is distinctly and consistently separated. When examining the medium-quality group samples, it is seen that they are spread over a wider area compared to both the low- and high-quality groups. An examination of the variables related to milk quality parameters in the heatmap shows that they have an impact on quality classification. The variables Fat, Taste, and Odor are not only high in high-quality samples but also cluster closely together, indicating similar variance values. Among the samples, these three variables tend to increase and decrease together.

From a modeling perspective, using these three variables together enhances predictive power. pH and Temperature cluster in a different group and have high scores in low-quality classes.

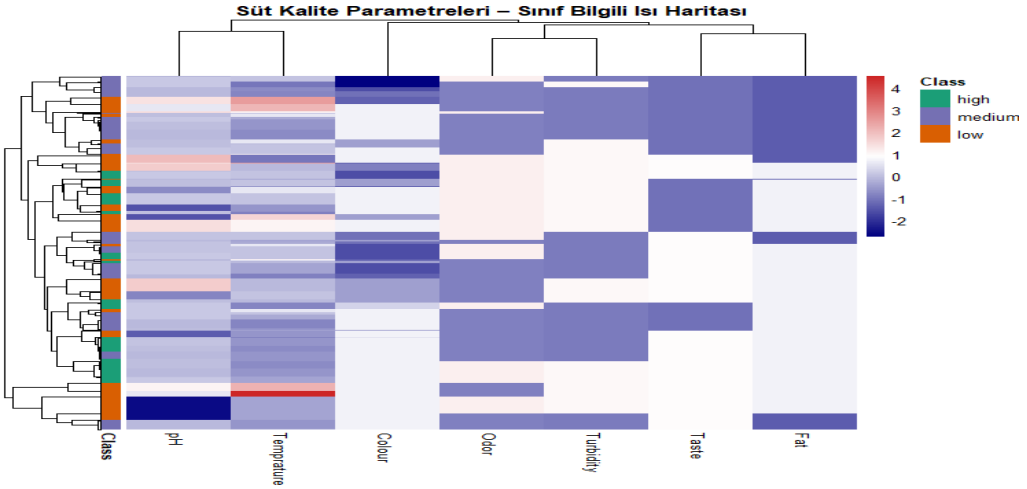


Figure 2. The heatmap related to milk quality parameters.

The R code presented in Table 2 was used to standardize the numerical data related to milk quality parameters and to visualize it through a heatmap. Using the pheatmap package, hierarchical clustering was applied to both the samples (rows) and the variables (columns), allowing structural similarities and distinctions among quality classes to be displayed through color intensity. The code was implemented in R version 4.5.0 (R Core Team, 2024).

Table 2. R Code for Generating a Heatmap of Milk Quality Parameters

```
install.packages("pheatmap")
library(pheatmap)
num_data <- milk[, c("pH", "Temperature", "Taste", "Odor", "Fat", "Turbidity", "Colour")]
scaled_data <- scale(num_data)
ı<-pheatmap(scaled_data,
        cluster_rows = TRUE,
        cluster_cols = TRUE,
        show_rownames = FALSE,
        show_colnames = TRUE,
        main = "Heatmap graphic for milk quality parameters",
        color = colorRampPalette(c("navy", "white", "firebrick3"))(50))
windows()
print(ı)    (R Core Team, 2024)
```

3. Radar chart

Radar charts are an effective tool for comparing different classes on the same scale and for visually representing multidimensional data. The chart features a circular axis, around which variables are displayed without the need for a fixed order. This allows structural differences between classes to be easily observed. Radar charts enable the simultaneous comparison of variables within a single graph. Moreover, they offer the ability to summarize high-dimensional data within a compact visual space. They are particularly effective compared to traditional charts when a holistic examination of similarities and differences between classes is required (Seide et al., 2022).

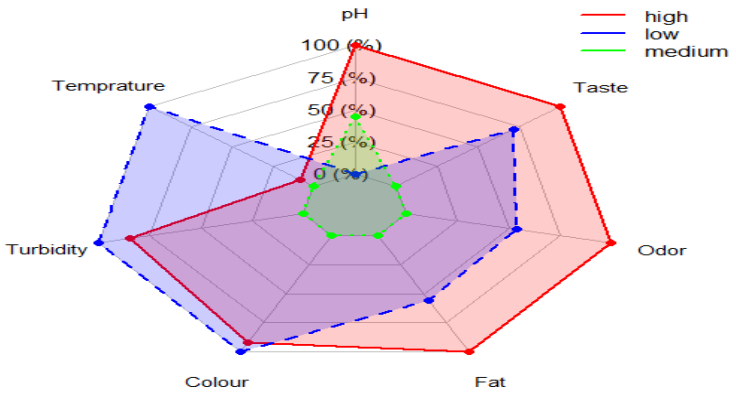


Figure 3. Radar chart for the milk quality dataset

The R code presented in Table 3 was used to create a radar chart aimed at comparing the average values of milk quality parameters across different quality classes. The data was visualized using the fmsb package, and the averages of seven quality variables (pH, Temperature, Turbidity, Colour, Fat, Odor, Taste) were calculated for each quality class (High, Medium, Low). Then, the radarchart() function was employed to generate a multidimensional visual profile of the classes based on the variables. The code was executed using R version 4.5.0 (R Core Team, 2024) and the fmsb package.

Table 3. R Code for Generating a radar graphics of Milk Quality Parameters

```
install.packages("fmsb")
library(fmsb)
milk <- read.csv("C:/data/milknew.csv")
head(milk)
radar_data <- aggregate(cbind(pH, Temperature, Turbidity, Colour, Fat, Odor, Taste) ~ Grade,
data = milk, FUN = mean)
rownames(radar_data) <- radar_data$Grade
radar_data$Grade <- NULL
max_values <- apply(radar_data, 2, max)
min_values <- apply(radar_data, 2, min)
radar_plot_data <- rbind(max_values, min_values, radar_data)
radarchart(radar_plot_data,
        axistype = 1,
        pcol = c("red", "blue", "green"),
        pfcol = c(rgb(1,0,0,0.2), rgb(0,0,1,0.2), rgb(0,1,0,0.2)),
        plwd = 2, cglcol = "grey", cglty = 1, axislabcol = "black",
        vlcex = 0.9
)
legend("topright", legend = rownames(radar_data), col = c("red", "blue", "green"),
      lty = 1, lwd = 2, bty = "n")  (R Core Team, 2024)
```

Figure 3 presents a radar chart depicting the milk quality parameters. This chart enables the comparison of quality classes (High, Medium, Low) in terms of quality parameters. It is constructed based on the average values of each quality class, which are displayed after being normalized according

to the standard Z-scores. On the right side of the chart, the quality classes are indicated using four different colors. In this chart, red represents the high-quality class, while the green line denotes the medium-quality class. The high-quality class exhibits the highest values for the variables Taste, Odor, Fat, and Colour, suggesting that these milk samples possess superior profiles in terms of taste, smell, fat content, and color. Conversely, milk samples in the low-quality class have high values in Temperature, Turbidity, and Colour. The elevated Temperature and Turbidity indicate that this group is defined by negative quality parameters. The medium-quality class displays intermediate values across all variables and presents a balanced distribution. This suggests that the medium class serves as a transitional group between the two extremes.

Radar charts clearly illustrate the distinction among quality classes based on milk quality parameters. Specifically, Taste, Odor, and Fat stand out as key indicators in distinguishing the high-quality class. Meanwhile, parameters such as Temperature, pH, and Turbidity are indicative of the low-quality class. This multidimensional visualization allows differences between classes to be discerned not only numerically but also visually. Additionally, the chart contributes to identifying meaningful patterns that can be used in predictive models. Such multivariate visualizations serve a preliminary role, particularly in evaluating variable selection and class separation power for machine learning-based classification models.
Radar charts are particularly effective tools for visualizing and interpreting inter-class patterns in multivariate data (Jolliffe & Cadima, 2016; Seide et al., 2022). These charts reveal the overall structure of classes at a glance, facilitating pattern recognition. The radar chart used in this study, alongside other multivariate visualization techniques such as biplots, boxplots, and heatmaps, offers diverse perspectives on the same dataset, supporting decision-making systems. Similarly, the concept of integrating multiple data sources proposed by Javadi and Farina (2020) in the context of signal processing and data fusion in radar networks is realized in this study through the joint interpretation of different graphical representations.

Radar systems emphasize sensor management and knowledge-driven inference mechanisms for efficient utilization of limited resources (Javadi & Farina, 2020). Likewise, the simultaneous use of various graphical summaries in this study aims to extract maximum information from limited observations and provide decision-makers with enhanced visual insight. The radar chart effectively visualizes the structural differences among quality classes based on variables. To further support these findings and explore variable distributions in more detail, boxplots depicting the parametric distribution by quality class were also utilized.

1. Boxplot

The chart visualizes the distributions of seven different quality parameters (Colour, Fat, Odor, pH, Taste, Temperature, Turbidity) across milk quality classes (high, medium, low) using boxplots. It provides a comparative presentation of how each variable's values are distributed among the quality classes. Figure 4 displays the boxplot chart of the milk quality parameters.

Upon examining Figure 4, the Colour parameter is higher in the high-quality class, while it is lower in the low and medium classes. The Fat content appears to be similar across all classes, showing no significant distinguishing differences. The Odor variable is elevated in the low-quality class but remains lower in the other classes. The pH level is higher in the low-quality class compared to the other quality classes. The Taste parameter is consistent across all classes, with no observable distinctive differences. Temperature is notably higher in the low-quality class. Turbidity shows high levels in both the low and high-quality classes, whereas it is significantly lower in the medium-quality class.

The chart illustrates that the low-quality group tends to have higher values in terms of pH, temperature, and odor, while the high-quality group displays a more homogeneous and consistent distribution in terms of color, taste, and fat. The medium-quality class, on the other hand, occupies intermediate values for many variables, serving as a transitional category.

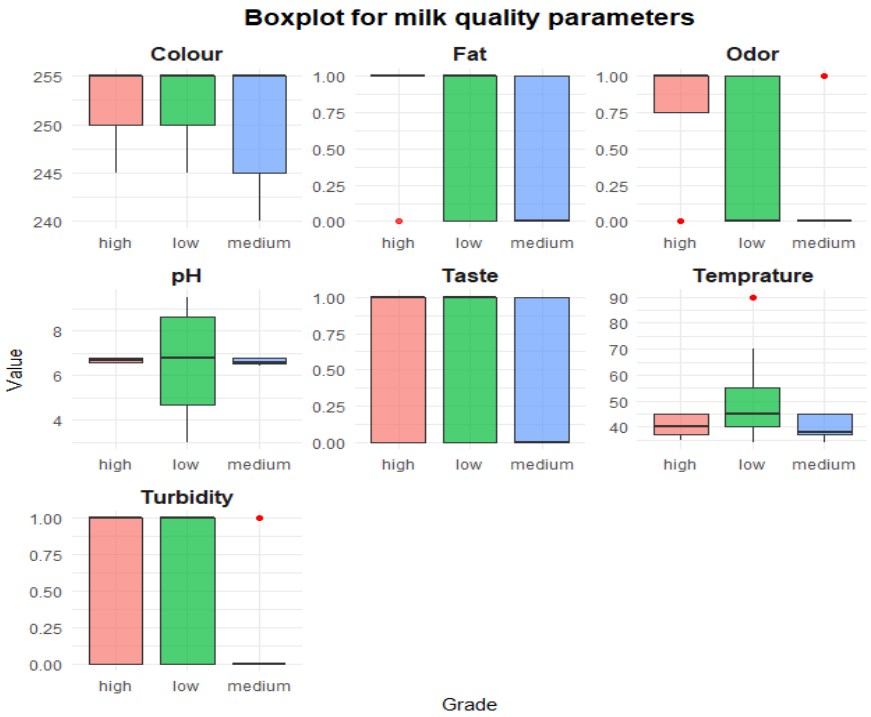


Figure 4. Boxplot graphic for milk quality parameters

The R code provided in Table 4 generates boxplots to visually compare the distribution of variables in the milk quality dataset across quality classes (High, Medium, Low). The code was implemented using R version 4.5.0 (R Core Team, 2024) along with the ggplot2 and tidyr libraries.

Table 4. R Code for Generating a Boxplot Graphic of Milk Quality Parameters

```
# install.packages("ggplot2")
library(ggplot2)
milk <- read.csv("C:/data/milknew.csv")
library(tidyr)
milk_long <- pivot_longer(milk,
                          cols = c(pH, Temperature, Turbidity, Colour, Fat, Odor, Taste),
                          names_to = "Parameter",
                          values_to = "Value")
ggplot(milk_long, aes(x = Grade, y = Value, fill = Grade)) +
  geom_boxplot(alpha = 0.7, outlier.color = "red", outlier.size = 1.5) +
  facet_wrap(~Parameter, scales = "free", ncol = 3) +
  labs(title = "Boxplot for milk quality parameters",
       x = "Grade", y = "Value") +
  theme_minimal() +
  theme(legend.position = "none",
        strip.text = element_text(size = 12, face = "bold"),
        plot.title = element_text(hjust = 0.5, size = 14, face = "bold"))  (R Core Team, 2024)
```

DISCUSSION AND CONCLUSION

In this study, various biometric visualization techniques such as radar charts, biplots, boxplots, and heatmaps were used to enable a comprehensive analysis of milk quality data. The selection of these techniques is supported by literature findings suggesting that they enhance users' ability to perceive cluster structures more effectively (Ventocilla and Riveiro, 2020).
While the radar chart clarifies visual distinctions among quality classes, the heatmap successfully highlights within-class variations. The results align with PCA and hierarchical clustering analyses, indicating that the quality classes separate in harmony with the natural patterns within the data. Notably, the variables Fat, Odor, and Taste serve as the most distinctive parameters for identifying the high-quality class, while pH and Temperature are strongly associated with low quality. The medium-quality class exhibits a hybrid structure, functioning as a transition between low and high-quality groups. These findings show that biometric visualization methods not only contribute to data analysis but also function as effective tools that can be integrated with classification algorithms and decision support systems. Additionally, they strengthen the flow of information by offering clear, understandable, and interpretable analysis outputs to users.

In light of these findings, future dairy processing facilities and quality control laboratories could develop rapid evaluation systems based on such visual analyses. Visualization outputs of this kind can be used in machine learning models to enhance model explainability and increase user trust. These approaches can be incorporated into mobile agricultural applications or web-based decision support systems to provide simplified decision-making support for farmers.

Testing similar multivariate visualization techniques on different animal-based products (e.g., meat, eggs, dairy derivatives) would improve the generalizability of the method. New dimensionality reduction techniques could be comparatively evaluated against traditional methods. Visualizing uncertainties (e.g., confidence intervals, fuzzy classification) would enhance the robustness of decision support systems.

In conclusion, biometric visualization techniques have the potential not only to serve as analytical tools but also as integral components of educational, operational, and strategic decision-making processes..

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Author Contributions

All stages of this study including conceptualization, methodology, data collection, analysis, visualization, writing, and editing were carried out collaboratively by Figen Ceritoğlu and Nazire Mikail.

Eğitimde İçgörü Üretimi: Büyük Veri ve Veri Madenciliğinin Eğitim Paradigmalarına Yönelik Kuramsal Bir Yeniden Yapılandırması

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Özet

Eğitimde yıllardır süregelen geleneksel yaklaşımlar, çoğu zaman öğrenci başarısını sınav puanları ve hazırbulunuşluk düzeyleriyle sınırlı çerçevelerde değerlendirmiştir. Ancak günümüzde hem sınıf içi gözlemler hem de dijital öğrenme platformları sayesinde elde edilen veri çeşitliliği, artık öğretmenlerin sadece "ne öğretildiği"ne değil, "öğrencinin nasıl öğrendiği"ne dair daha derin bir farkındalık geliştirmesini gerektiriyor. Bu çalışma, büyük veri ve veri madenciliği gibi araçlarla bu farkındalığın nasıl sistematik bir içgörüye dönüştürülebileceğini kuramsal bir çerçeve içinde tartışmayı amaçlamaktadır.

Geleneksel yöntemlerin önemli bir kısıtı, öğrencinin bireysel öğrenme sürecine dair dinamikleri göz ardı etmesi ve öğretim sürecini genellemeler üzerinden şekillendirmesidir. Oysa içgörü dediğimiz şey, sadece veri analizinden çıkan sonuçlar değil, aynı zamanda insan davranışlarını, duygularını ve karar alma mekanizmalarını anlamlandırmaya yönelik derinlemesine bir kavrayıştır. Psikolojik araştırmalar, bireyin kendi öğrenme sürecine dair farkındalık kazandıkça motivasyonunun ve öğrenme kalitesinin arttığını göstermektedir. Bu durum, eğitimde içgörü üretiminin yalnızca teknik bir kazanım değil, aynı zamanda pedagojik bir zorunluluk olduğunu ortaya koymaktadır.

Bu bağlamda, öğretmenin rolü de dönüşmektedir. İçgörü temelli bir eğitim anlayışında öğretmenin yalnızca bilgi aktarıcı değil, veriyi anlamlandırabilen, öğrenci davranışlarını yorumlayabilen ve bireysel farklılıklara göre strateji geliştirebilen bir rehber olması beklenir. Bu da öğretmen yeterliliklerinin veri okuryazarlığı, dijital analiz ve etik değerlendirme gibi yeni boyutlarla yeniden tanımlanmasını gerektirir.

Sonuç olarak bu bildiri, büyük veri ve veri madenciliğinin sunduğu teknik imkânların eğitim sistemlerinde yüzeysel analizlerin ötesine geçerek nasıl anlamlı içgörülere dönüştürülebileceğini tartışmakta; bu dönüşümün hem öğrenci başarısı hem de öğretmen yeterliliği açısından nasıl bir paradigma değişimine işaret ettiğini kuramsal bir bakış açısıyla ortaya koymaktadır.

Anahtar Kelimeler: *İçgörü tabanlı eğitim, Öğretmen yeterlilikleri, Büyük veri, Veri madenciliği*

1. GİRİŞ

21. yüzyılda eğitimin en belirgin özelliği, bilgiyi ezberlemekten ziyade bilgiden anlam çıkarabilme, yani içgörü üretebilme becerisidir. İçgörü, sadece gözlem ya da veriye dayalı bir anlayış değil; aynı zamanda eğitim süreçlerine dair karmaşık örüntüleri fark edebilme ve geleceğe dair anlamlı çıkarımlarda bulunabilme yetisidir (Siemens, 2005). Bu bağlamda, eğitimde içgörü üretimi, bireysel öğrenmeyi derinleştiren ve kurumsal gelişimi yönlendiren temel bir dinamik haline gelmiştir.

Geleneksel eğitim paradigmaları, genellikle öğretmenin bilgi aktarıcı rolüne odaklanmakta, öğrenciyi ise pasif bilgi alıcısı konumuna yerleştirmektedir (Freire, 1970). Oysa, dijital çağın gereksinimleri, öğrenmenin çok daha etkileşimli, kişiselleştirilmiş ve veriye dayalı bir şekilde yapılandırılmasını zorunlu kılmaktadır. Bu dönüşümün merkezinde büyük veri (big data) ve veri madenciliği (data mining) kavramları yer almaktadır. Eğitim ortamlarında üretilen dijital verilerin analiz edilmesiyle, hem öğrenci başarısı hem de öğretim tasarımı açısından anlamlı içgörüler geliştirilebilmektedir (Bienkowski, Feng & Means, 2012).

Ancak bu teknolojik araçların etkili kullanılabilmesi, yalnızca teknik yeterlilikle değil, aynı zamanda sağlam bir kuramsal çerçeve ile mümkündür. Bugüne dek yapılan birçok çalışmada, veri madenciliğinin eğitimsel bağlamda kullanımı, çoğunlukla istatistiksel başarı tahminleriyle sınırlı kalmıştır (Romero & Ventura, 2020). Oysa, veriden içgörüye geçiş için, eğitim paradigmasının da yapısal olarak yeniden düşünülmesi gerekmektedir. Bu çalışma, söz konusu yeniden yapılanmayı kuramsal düzlemde ele almayı amaçlamaktadır.

Aşağıda verilen **Tablo 1**, eğitimde veri akışının geleneksel ve çağdaş yaklaşımlardaki yerini görselleştirmektedir:

Tablo 1. Geleneksel ve Veri Tabanlı Eğitim Paradigmalarının Karşılaştırılması

Paradigma	**Bilgi kaynağı**	**Öğretmen rolü**	**Öğrenci rolü**	**İçgörü kaynağı**
Geleneksel	Kitap/ Öğretmen	Bilgi aktarıcı	Pasif alıcı	Gözleme dayalı
Veri tabanlı	Dijital öğrenme verisi	Analist/ Rehber	Aktif katılımcı	Algoritmik/ Kavramsal

Bu çalışmada, öncelikle eğitimde içgörü üretiminin kuramsal temelleri incelenecek, ardından büyük veri ve veri madenciliği araçlarının bu süreci nasıl dönüştürdüğü ortaya konacaktır. Son olarak, mevcut eğitim paradigmalarının sınırları tartışılarak, veri temelli içgörü üretimini merkeze alan alternatif bir **kuramsal yeniden yapılandırma** önerilecektir.

2. KURAMSAL ARKA PLAN VE LİTERATÜR TARAMASI

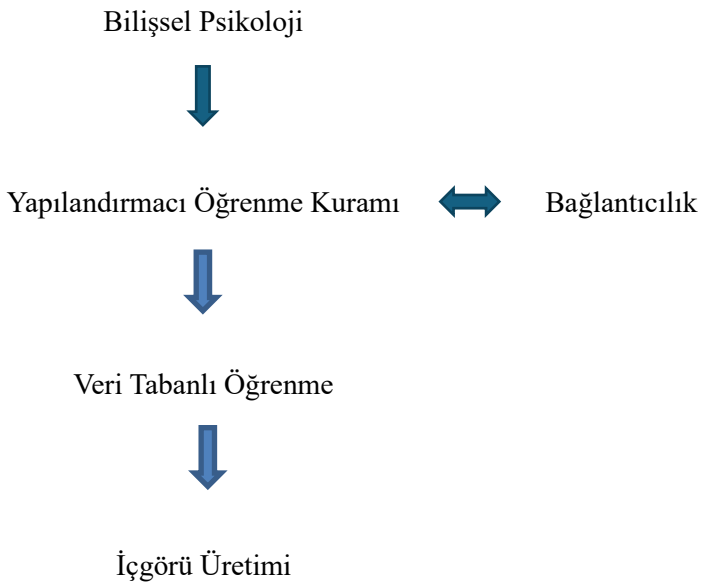
Eğitimde içgörü üretimi, sadece bilişsel süreçlerle açıklanamayacak kadar çok katmanlı ve sistemik bir yapıya sahiptir. İçgörü, klasik bilgi edinme süreçlerinden farklı olarak, bireyin yeni durumlarla karşılaştığında mevcut bilgi yapılarını dönüştürmesini sağlayan bir bilişsel yeniden yapılanma sürecidir (Sternberg, 1985). Bu bağlamda, eğitimde içgörü üretiminin temellendirileceği kuramsal çerçeveler, bilişsel psikoloji, yapılandırmacı öğrenme kuramı ve bağlantıcılık (connectivism) gibi çağdaş yaklaşımları içermelidir.

Öncelikle, yapılandırmacı öğrenme kuramı, bireyin bilgiyi pasif olarak almak yerine, aktif olarak yapılandırdığını savunur. Piaget (1970) ve Vygotsky (1978) gibi kuramcıların öncülüğünde gelişen bu yaklaşım, öğrenmenin bireyin deneyimleri üzerinden inşa edildiğini öne sürer. Vygotsky'nin "yakınsal gelişim alanı" kavramı, özellikle veriyle zenginleşen öğrenme ortamlarında öğrenciye uygun rehberlik sağlandığında içgörü üretiminin nasıl tetiklenebileceğini göstermektedir.

Bununla birlikte, dijital çağda öğrenme süreçlerini anlamak için bağlantıcılık kuramı önemli bir kuramsal temel sunar. Siemens (2005) tarafından geliştirilen bu kuram, bilginin artık bireysel hafızada

değil, ağlar ve veri sistemleri aracılığıyla erişilen bir yapıda olduğunu savunur. Bu bağlamda, içgörü üretimi, veriler arasında bağlantı kurma ve örüntüleri tanıma becerisiyle doğrudan ilişkilidir.

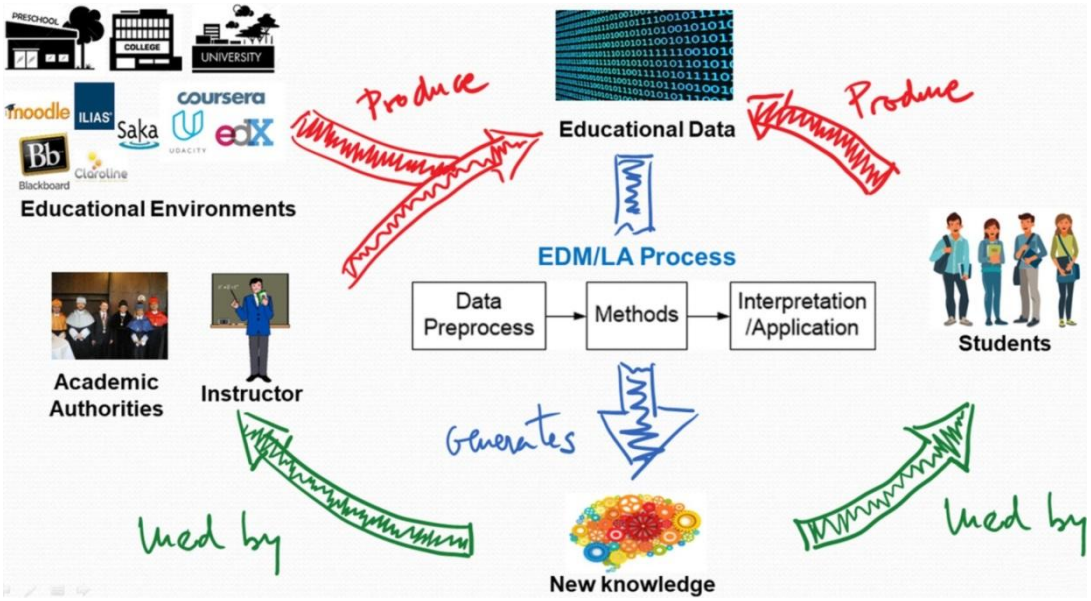
Aşağıda verilen Şekil 1, eğitimde içgörü üretimini etkileyen başlıca kuramsal alanları ve veriyle olan etkileşimlerini özetlemektedir:



Şekil 1. Eğitimde İçgörü Üretimini Şekillendiren Kuramsal Temeller

Veri madenciliği tekniklerinin eğitim ortamlarına entegrasyonu ise, bu kuramsal çerçevelerle birlikte anlam kazanır. Romero ve Ventura (2020), eğitimsel veri madenciliği alanındaki uygulamaların yalnızca tahminleme modellerine odaklanmaması gerektiğini, aynı zamanda öğrenme süreçlerinin derinlemesine anlaşılması için yorumlayıcı modellerin de geliştirilmesi gerektiğini vurgular.

Bununla birlikte, aşağıdaki görsel, eğitimsel veri madenciliği ve öğrenme analitiği (EDM/LA) süreçlerinin işleyişini, verinin nasıl üretildiğini ve hangi aktörler tarafından nasıl kullanıldığını detaylı biçimde özetlemektedir. Bu yapı, önerilen kuramsal modelin işlemesini mümkün kılan temel mekanizmaları da temsil etmektedir.



Şekil 2. Eğitimsel veri üretimi, işlenmesi ve bilgiye dönüşüm sürecinin genel akışı. (Romero, C., & Ventura, S., 2020)

Benzer şekilde, Baker ve Inventado (2014), içgörü üretimini mümkün kılan öğrenme analitiği modellerinin, eğitsel karar mekanizmalarını dönüştürdüğünü ifade etmektedir.

Aşağıda verilen Tablo 2, literatürde öne çıkan veri madenciliği yaklaşımlarını ve içgörü üretimiyle olan ilişkilerini özetlemektedir:

Tablo 2. Veri Madenciliği Yöntemlerinin İçgörü Üretimine Katkısı

Yöntem	**Temel kullanım alanı**	**İçgörüye katkısı**
Kümelenme (Clustering)	Öğrenci profillemesi	Örüntü Tespiti
Sınıflandırma (Classification)	Başarı tahmini	Riskli grupların belirlenmesi
Regresyon	Not tahmini, süre analizi	Öğrenme davranışlarının zamanla analizi
Metin madenciliği	Açık uçlu yanıtların analizi	Kavramsal anlayışın izlenmesi

İçgörü kavramı, sadece eğitimde değil; pazarlama, reklamcılık ve davranışsal ikna gibi alanlarda da etkili biçimde kullanılmaktadır. Özellikle tüketici davranışlarını anlamaya ve dönüştürmeye yönelik stratejilerde, içgörüler duygusal bağ kurma, farkındalık yaratma ve uzun süreli marka sadakati oluşturma amacıyla öne çıkmaktadır (Duncan & Moriarty, 1998). Örneğin, Dove'un "Gerçek Güzellik" kampanyası, kadınların toplumsal güzellik algısıyla kurduğu duygusal ilişkiyi hedef alarak, marka mesajını toplumsal bir içgörüye yaslamıştır. Benzer şekilde, OMO'nun "Kirlenmek Güzeldir" sloganı, çocukların özgürce oynama hakkı üzerinden ebeveynlerle bağ kurarken; Darüşşafaka'nın "Olmasa da

Olur" kampanyası, bağışçıların tüketim alışkanlıklarıyla vicdani sorumluluklarını buluşturan güçlü bir içgörüyü kullanmaktadır. Bu örnekler, içgörünün sadece bilgiye değil, derin **insanlık haline dair bir anlayışa** dayandığını ve bu yönüyle eğitimin de temel yapı taşlarından biri olabileceğini göstermektedir.

Bu bulgular doğrultusunda, içgörü üretimi yalnızca bireysel bir zihinsel süreç değil, aynı zamanda **veriye dayalı, çok boyutlu ve kuramsal olarak desteklenmiş bir yeniden yapılanma süreci** olarak değerlendirilmelidir. Bu da eğitimde yeni bir paradigmanın inşasını zorunlu kılmaktadır.

3. KURAMSAL YAKLAŞIM VE MODEL ÖNERİSİ

Eğitimde içgörü üretimini merkeze alan kuramsal yeniden yapılandırma, yalnızca pedagojik ilkelerle değil; aynı zamanda verinin anlamlandırılması sürecine dair sistemik bir anlayışla inşa edilmelidir. Bu bağlamda, önerilen yaklaşım üç temel eksen üzerine oturtulmaktadır: **(1) Bilişsel İnşa, (2) Veri Tabanlı Gözlem ve (3) Sistemik Yorumlama**. Bu eksenler, birlikte işlediğinde, hem öğrenci merkezli hem de veriyle beslenen bir içgörü ekosistemi oluşturur.

3.1. BİLİŞSEL İNŞA

Bilişsel kuramlar, özellikle yapılandırmacı öğrenme ve yakınsak gelişim modeli, bireyin bilgiyi çevresiyle etkileşime girerek dönüştürdüğünü savunur (Bruner, 1996; Vygotsky, 1978). Bu bağlamda içgörü, öğrenenin daha önceki bilgi örüntülerini yeniden örgütlemesiyle oluşur. Bu sürecin tetiklenebilmesi için, öğrenme ortamlarının esnek, veriyle zenginleştirilmiş ve anlamlandırmaya açık olması gerekir.

3.2. VERİTABANLI GÖZLEM

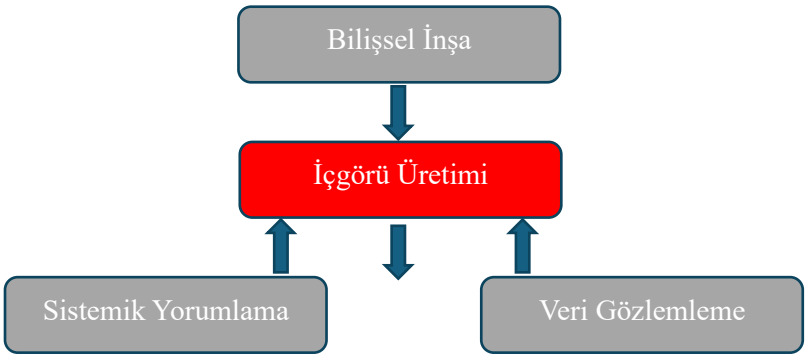
Bilişsel süreçlerin yalnızca gözleme ya da sınavlara dayalı değil, dijital izler (log kayıtları, yanıt süreleri, kaynak kullanımı gibi) üzerinden analiz edilmesi, öğrenme davranışlarını çok katmanlı şekilde değerlendirmeyi mümkün kılar (Siemens & Long, 2011). Bu analizler, veri madenciliği ve öğrenme analitiği teknikleriyle desteklendiğinde, yalnızca neyin öğrenildiği değil, nasıl öğrenildiği ve ne zaman içgörüye dönüştüğü de izlenebilir hâle gelir (Clow, 2013).

3.3. SİSTEMİK YORUMLAMA

Veri analizinin anlamlı içgörülere dönüşmesi, yorumlama sürecinin **pedagojik, etik ve sosyal bağlamlarla birlikte** değerlendirilmesiyle mümkündür. Salt veri odaklı kararlar, öğrenme sürecini indirgemeci kılabilir. Bu nedenle önerilen model, yorumlama süreçlerinin çok disiplinli ve çok katmanlı bir yapı içerisinde ele alınmasını savunur (Buckingham Shum & Ferguson, 2012).

3.4. MODELİN GÖRSEL TEMSİLİ

Aşağıda sunulan model, içgörü üretimini merkezde konumlandırmakta ve üç temel bileşenin etkileşimli yapısını yansıtmaktadır:



Şekil 3. Eğitimde İçgörü Üretimine Dayalı Kuramsal Model

Bu modelin öne çıkardığı nokta, **içgörünün ne yalnızca bireysel ne de yalnızca algoritmik** bir çıktı olmadığı; aksine bilişsel süreçler ile veri analitiği arasındaki etkileşimden doğan dinamik bir yapı olduğudur. Öğretim tasarımcıları, politika yapıcılar ve araştırmacılar açısından bu model, içgörü odaklı bir eğitim sistemi tasarımı için referans çerçevesi sunmaktadır.

4. TARTIŞMA VE DEĞERLENDİRME

Önerilen kuramsal model, içgörü üretimini eğitim sisteminin merkezine yerleştirerek, geleneksel bilgi aktarıcı yaklaşımı sorgulamakta ve veri destekli, bilişsel derinliği olan bir öğrenme anlayışını savunmaktadır. Bu yönüyle model, klasik eğitim paradigmalarından önemli ölçüde ayrılmaktadır. Özellikle öğretmen-öğrenci ilişkisinde gözlemlenen otorite merkezli yapı, bu modelde yerini veriye dayalı rehberlik ve katılımcı öğrenme dinamiklerine bırakmaktadır.

Siemens (2005) tarafından geliştirilen bağlantıcılık kuramı da benzer biçimde, öğrenmenin artık bireyin zihinsel kapasitesine değil, ağlar üzerinden erişilen bilgiye bağlı olduğunu savunur. Ancak bağlantıcılık kuramı çoğunlukla bilgiye erişim yollarına odaklanırken, bu çalışmada önerilen model, bilginin zihinde nasıl yapılandığı ve veriyle nasıl yeniden üretildiğine dair daha bütüncül bir yaklaşım sunmaktadır.

Baker ve Inventado (2014), öğrenme analitiği uygulamalarının çoğunlukla başarı tahmini ve riskli öğrenci tespiti gibi yansal (reactive) kullanım alanlarına odaklandığını ifade etmektedir. Bu durum, veriye dayalı sistemlerin potansiyelini sınırlamaktadır. Bu bağlamda, önerilen modelin temel katkılarından biri, öğrenme verilerinin yalnızca ölçüm ve denetim amaçlı değil, aynı zamanda bilişsel gelişimi yönlendiren içgörüler üretme amacıyla kullanılabileceğini göstermesidir.

Ancak bu modelin uygulanabilirliği bazı koşullara bağlıdır. İlk olarak, okullarda veri okuryazarlığı seviyesinin artırılması gereklidir. Öğretmenlerin yalnızca pedagojik değil, aynı zamanda temel veri analizi ve yorumlama becerilerine de sahip olması beklenmektedir (Williamson, 2017). İkincisi, içgörü üretimini destekleyecek dijital altyapılar ve etik veri politikaları geliştirilmeli; öğrenci mahremiyeti ve veri güvenliği ön planda tutulmalıdır (Slade & Prinsloo, 2013).

Aşağıdaki tablo, önerilen modelin geleneksel öğretim anlayışı ve mevcut veri tabanlı modellerle karşılaştırmalı olarak güçlü ve sınırlı yönlerini özetlemektedir:

Tablo 3. Önerilen Modelin Diğer Yaklaşımlarla Karşılaştırmalı Değerlendirmesi

Kriter	Geleneksel Model	Öğrenme Analitiği (mevcut)	Önerilen İçgörü Modeli
Öğrenen rolü	Pasif	Tepkisel	Aktif- Yorumlayıcı
Veri kullanımı	Yok	Tanısal-Tahminsel	Yorumlayıcı- Üretici
Kuramsal dayanak	Davranışçılık	Bilişsel+ Nicel	Yapılandırmacılık+ Sistemik
İçgörü üretimi	Gözleme Dayalı	Otomatik çıkarım	Kavramsal- Anlamlı
Uygulama sınırlılıkları	Pedagojik Dogmalar	Teknik yetersizlik	Veri okuryazarlığı- Etik

Sonuç olarak, bu modelin başarıyla uygulanabilmesi hem teknolojik altyapının hem de insan kaynağının bu dönüşüme hazır olmasına bağlıdır. İçgörü odaklı bir yaklaşım, sadece sistemleri değil, aynı zamanda eğitimcilerin düşünme biçimini de dönüştürmeyi gerektirir. Bu noktada, veriyle şekillenen yeni eğitim paradigmalarının hem **teknolojik hem de felsefi bir yeniden yapılanmayı** zorunlu kıldığı söylenebilir.

5. SONUÇ VE ÖNERİLER

Bu çalışma, eğitimde içgörü üretimini veri temelli öğrenme ortamlarıyla ilişkilendiren özgün bir kuramsal model önermiştir. Giriş bölümünde vurgulandığı üzere, dijitalleşen öğrenme ortamları, yalnızca bilgiye erişimi değil; bu bilgiden anlam üretimini de merkezî bir beceri haline getirmiştir. Bu bağlamda, içgörü üretimi; bilişsel inşa süreçleri, veri gözlemi ve sistemik yorumlamanın etkileşimli yapısında ortaya çıkan, çok boyutlu bir öğrenme çıktısı olarak ele alınmıştır.

Kuramsal arka planda yapılandırmacı öğrenme, bağlantıcılık ve veri okuryazarlığı gibi temel kavramlar üzerinden modelin dayandığı çerçeve ortaya konmuş; ardından bu modelin, geleneksel eğitim paradigmalarına alternatif oluşturacak biçimde nasıl yapılandığı şekil ve tablolarla görselleştirilmiştir. Tartışma bölümünde ise, mevcut veri analitiği uygulamalarıyla karşılaştırmalı analiz yapılmış, önerilen modelin güçlü yönleri ve sınırlılıkları somut biçimde değerlendirilmiştir.

Bu doğrultuda aşağıdaki öneriler hem politika geliştiriciler hem de uygulayıcılar için yol gösterici niteliktedir:

5.1. UYGULAYICILAR İÇİN ÖNERİLER

- Öğretmen eğitimi programlarında veri okuryazarlığı ve temel öğrenme analitiği becerileri yer almalıdır. Öğretmenlerin, öğrencilerin davranışsal verilerini sadece raporlama amacıyla değil, pedagojik kararlar almak için kullanabilmeleri desteklenmelidir (Williamson, 2017).
- İçgörü üretimini teşvik eden öğrenme ortamları tasarlanmalıdır. Bu ortamlar; öğrencinin anlam kurma sürecini destekleyen, sorgulama temelli, dijital veriye erişimi kolay ve öğretmen rehberliğini içeren yapılarda olmalıdır (Bruner, 1996).

5.2. POLİTİKA GELİŞTİRİCİLER İÇİN ÖNERİLER

- Ulusal eğitim sistemlerine veri temelli karar alma kültürü kazandırılmalı, okullarda dijital öğrenme verilerinin anlamlı biçimde toplanması ve yorumlanması için güvenli ve etik çerçeveler oluşturulmalıdır (Slade & Prinsloo, 2013).
- Öğrenme analitiği sistemlerinin ticarileştirilmiş değil, eğitimsel olarak anlamlı kullanımı teşvik edilmelidir. Sistemler sadece başarı sıralaması üretmek yerine, öğrencilerin düşünme biçimlerini ve kavramsal gelişimlerini izleyebilmelidir (Ferguson, 2012).

5.3. ARAŞTIRMACILAR İÇİN ÖNERİLER

- Önerilen kuramsal modelin farklı eğitim düzeylerinde (ilkokul, lise, yükseköğretim) uygulamalı araştırmalarla test edilmesi gereklidir. Bu tür çalışmalar, modelin geçerliliğini ve etkililiğini ortaya koyarak kuramsal çerçevenin güçlendirilmesini sağlar.
- İçgörü üretiminin ölçülebilir göstergelerinin belirlenmesi, eğitim verisinin sadece nicel değil, nitel boyutlarının da kapsanmasını sağlayacaktır. Bu noktada karma yöntem (mixed-methods) yaklaşımlarına ihtiyaç duyulmaktadır.

Sonuç olarak, bu çalışma, eğitimde içgörü üretimini dijital veri çağının gereklilikleriyle uyumlu biçimde yeniden kuramsallaştırmayı hedeflemiştir. Teknolojik araçların anlamlı pedagojik süreçlerle bütünleşmesi sayesinde, yalnızca daha başarılı değil; aynı zamanda daha **eleştirel düşünen, anlam kurabilen ve farkındalığı yüksek bireyler** yetiştirmek mümkün olacaktır.

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Phylogenetic Inference of the Genus *Cortinarius* (Basidiomycota, Agaricales) Based on Nuclear Internal Transcribed Spacer (nrITS) Region

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Abstract

Cortinarius (Pers.) Gray is the largest and taxonomically most complex genus in the order Agaricales, comprising nearly 5,000 species worldwide. Cortinarius species form ectomycorrhizal associations with coniferous, deciduous trees as well as herbaceous plants from various families. The species are named Cortinarius due to the initial development of the basidiocarp surrounded by a cortina, which is short-lived and initially covers all the gills that gradually disappear as the fruiting body develops. The morphological similarities and cryptic species within the genus cause species delimitation problems. Thus, molecular methods are very crucial in species identification and nomenclature. Nuclear Internal Transcribed Spacer (nrITS) gene region is a universal DNA barcoding region due to its high evolutionary rates and effectively used for Cortinarius species identification. Additional barcoding regions, such as the subunits of RNA polymerase II (RPB1, RPB2) and the large subunit of ribosomal RNA (nLSU) are used especially in distinguishing closely related species. With the advent of molecular studies, taxonomic classification of fungal species has become more reliable and phylogenetic relationships of many species have been resolved within the genus Cortinarius.

Key words: *Cortinarius phylogeny, DNA barcode, nrITS, Molecular phylogenetic analysis*

Nükleer İç Transkripsiyonel Boşluk (nrITS) Bölgesine Dayalı *Cortinarius* (Basidiomycota, Agaricales) Cinsinin Filogenetik Çıkarımı

Özet

Cortinarius (Pers.) Gray, Agaricales takımının en büyük ve taksonomik olarak en karmaşık cinsidir ve dünyada yaklaşık 5.000 türü kapsamaktadır. Cortinarius türleri iğne yapraklı, yaprak döken ağaçlar ile otsu bitkileri de barındıran birçok familyaya ait bitkilerle ektomikorizal ilişki kurarlar. Cortinarius olarak isimlendirilme, bu cinse ait türlerin gelişimin ilk evresinde tüm lamelleri kaplayan, kısa ömürlü bir kortina ile çevrili bazidiokarba sahip olmalarından kaynaklanır. Türler arası morfolojik benzerlikler ve kriptik türlerin varlığı bu cinse ait türlerin tanımlanmasını zorlaştırmaktadır. Bu nedenle, moleküler yöntemlere dayalı tür teşhisi ve adlandırmasında büyük önem arz etmektedir. Çekirdek Nükleer İç Transkripsiyonel Boşluk (nrITS) gen bölgeleri, yüksek evrimsel hızlarından dolayı evrensel bir barkod olarak kabul edilmekte ve Cortinarius türlerinin belirlenmesinde etkili bir şekilde kullanılmaktadır. Ek olarak, RNA polimeraz II alt birimleri (RPB1, RPB2) ve ribozomal RNA'nın büyük alt birimi (nLSU) gibi barkod bölgeleri özellikle birbirine yakın türlerin ayrımında kullanılmaktadır. Moleküler çalışmaların gelişmesiyle birlikte, mantar türlerinin taksonomik sınıflandırması daha güvenilir hale gelmiştir ve Cortinarius'a ait birçok türün filogenetik ilişkileri ortaya konmuştur.

Anahtar Kelime: *Cortinarius filogenesi, DNA barkodu, nrITS, Moleküler filogenetik analiz*

GİRİŞ

Cortinarius (Pers.) Gray, Basidiomycota şubesine bağlı, Agaricales takımı, Cortinariaceae familyasının bir üyesi olan, en büyük ve en fazla sinonime sahip mantar cinsidir (Kalichman ve ark., 2020). Kuzey ve güney yarım kürede yayılım gösteren ve dünyada yaklaşık 5000'den fazla türe sahip olduğu ifade edilmektedir (Index Fungorum, 2025). Özellikle son yıllarda ivme kazanan moleküler çalışmalar ile bu cinse ait yaklaşık 3000'i geçerli tür olarak kabul görmektedir (Liimatainen ve ark., 2022). Önceleri, Cortinariaceae familyası altında *Cortinarius* (Pers.) Gray tek bir cins olarak kabul edilmekteydi. Ancak Cortinariaceae familyasının moleküler revizyonu ve yeni sınıflandırılması ile bu familya günümüzde 10 cins ile temsil edilmektedir; *Cortinarius* (Pers.) Gray, *Phlegmacium* (Fr.) Wünsche, *Thaxterogaster* Singer, *Calonarius* Niskanen & Liimat., *Aureonarius* Niskanen & Liimat., *Cystinarius* Niskanen & Liimat., *Volvanarius* Niskanen & Liimat., *Hygronarius* Niskanen & Liimat., *Mystinarius* Niskanen & Liimat. ve *Austrocortinarius* Niskanen & Liimat. (Liimatainen ve ark., 2022). Ayrıca, *Cortinarius* (Pers.) Gray cinsi 11 alt cinse ayrılmaktadır; *Cortinarius*, Camphorati Liimat., Niskanen & Ammirati, *Dermocybe* (Fr.) Trog, *Illumini* Liimat., Niskanen & Kytöv., *Infracti* Niskanen & Liimat., *Iodolentes* Niskanen & Liimat., *Leprocybe* M.M. Moser, Myxacium (Fr.) Trog, *Orellani* (M.M. Moser) Gasparini, *Paramyxacium* M.M. Moser & E. Horak ve *Telamonia* (Fr.) Trog.

Cortinarius cinsi mantarlar ektomikorizal olup Cistaceae, Caesalpiniaceae, Dipterocarpaceae, Fagaceae, Malvaceae, Myrtaceae, Nothofagaceae, Pinaceae, Rhamnaceae, Rosaceaea ve Salicaceae familyalarına ait bitkiler ile birlikte bulunmaktadırlar (Frøslev ve ark., 2005, 2006; Garnica ve ark., 2005; Brandrud ve ark., 2018; Soop ve ark., 2019; Liimatainen ve ark., 2022, Liu ve ark., 2024). Çoğu tür zehirli olmakla birlikte bazıları kötü kokulu, jelatinimsi bir yüzeye sahip olmaları nedeniyle beslenme amacıyla tercih edilmezler. Bu cins türlerinin genç örneklerinde şapka ile sap arasında, lamellerini örten "kortina" olarak adlandırılan ve zamanla bazidiyokarp genişledikçe kaybolan perdeye sahip olmaları nedeniyle cinsin ismi "perdeli" anlamına gelen *Cortinarius* olarak adlandırılmış ve ilk defa Fries (1836-1838) tarafından kullanılmıştır. Kortina özelliği dışında, paslı kahverengi spor izlerine sahip olmaları, sporlarında filizlenme gözeneklerinin olmaması veya gevşek perisporyum yapısına sahip olmaları *Cortinarius* cinsine ait en temel özelliklerdir (Peintner ve ark., 2004). Şapkaları genellikle konveks, yüzeyleri kuru, ipeksi, fibrilöz veya yapışkan, sapları silindrik veya çomak şeklinde ve tabanlarında şişkinlik görülmektedir. Bu belirtilen özellikler, Cortinarius mantarlarını diğerlerinden ayırmak ve tanımlamak için kullanılan en karateristik makroskobik özelliklerdir. Ancak türleri arasında morfolojik ve mikroskobik özelliklerin çok benzer olması, kriptik türlerin bulunması, bu cinse ait türlerin tanımlanmasını zorlaştırmaktadır. Bu yüzden, sadece morfolojik özelliklere dayanarak *Cortinarius* cinsi mantar tür tanımlamasının yapılması, aynı isimlerin farklı türler için kullanılmasına ve yanlış isimlendirmelerin yapılmasına, dolayısıyla, bu cinse ait tür sayısında artışa neden olmaktadır.

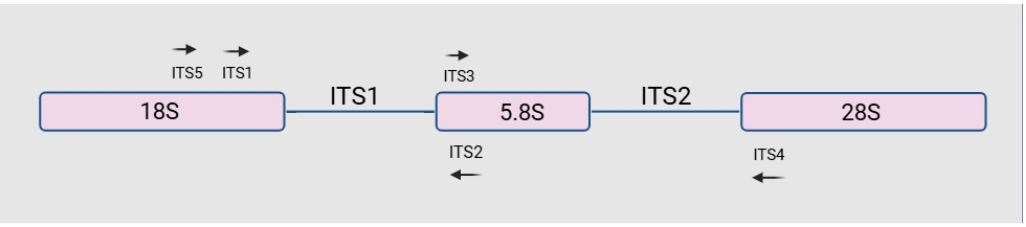
Son yıllarda moleküler yöntemlerin kullanılmasıyla birlikte moleküler mantar taksonomisi çalışmaları hız kazanmıştır. Belirli gen dizileri, DNA barkodu olarak kulllanılarak, mantar türlerinin tanımlanmasına ve filogenetik ilişkilerinin anlaşılmasına yardımcı olmaktadır. Şu anda tür düzeyinde taksonomide en yaygın kullanılan gen bölgesi, mantarlar için evrensel bir barkod belirteci olarak önerilen nükleer iç transkripsiyonel boşluk (nrITS) bölgesidir (Schoch ve ark., 2012). Klasik taksonominin bir tamamlayıcısı olarak, nrITS gen bölgesine ait moleküler veriler, *Cortinarius* türlerinin filogenetik ilişkileri tahmin etmek kullanılmaktadır.

Moleküler Yöntemlere Dayali Mantar Tür Teşhisi

Cortinarius cinsi, yüksek tür çeşitliliği ve morfolojik benzerlikler nedeniyle taksonomik açıdan oldukça karmaşık bir gruptur. Bu nedenle, moleküler belirteçlerin kullanımı, bu cinsin tür düzeyinde ayrımı ve

filogenetik sınıflandırılması açısından büyük önem taşımaktadır. (Liimatainen ve ark., 2014; Liimatainen ve ark., 2022). 2012 yılına kadar mantar taksonomisine yönelik moleküler çalışmalar yapılmış olsa da, Schoch ve ark. (2012)'nın, yaklaşık 700 mantar numunesinin çalışıldığı kapsamlı bir araştırmada, altı gen bölgesini DNA barkodlama için kullanmış, bunlardan özellikle nükleer iç transkripsiyonel boşluk (nrITS) bölgesinin, farklı mantar taksonlarında tür içi ve türler arası varyasyonları belirleyebilen en başarılı barkod olarak belirlemişlerdir. Bu çalışma sonucunda, nrITS gen bölgesinin, diğer mitokondriyal gen bölgelerine (örnek: sitokrom c oksidaz altbirim 1) de alternatif olabilecek ve mantar taksonomik çalışmaları için daha güvenilir bir barkod olduğu ortaya konmuştur. Böylelikle, nrITS gen bölgesine dayalı mantar taksonomik ilişkilerin ve genetik varyasyonun belirlenmesi çalışmaları oldukça önem kazanmıştır.

ITS gen bölgesi, 5.8S geni tarafından ayrılmış olan ITS1 ve ITS2 bölgelerini içerir ve nrDNA tekrar birimindeki 18S (SSU) ve 28S (LSU) genleri arasında yer alır (Şekil 1). ITS bölgelerinin uç bölgelerinde 18S ve 28S genleri oldukça korunmuştur ve bu korunmuş bölgelere karşılık gelen dizilerden primerler dizayn edilmektedir (White ve ark., 1990).



Şekil 1. ITS gen bölgesi ve sıklıkla kullanılan primerlerin gen üzerindeki pozisyonları

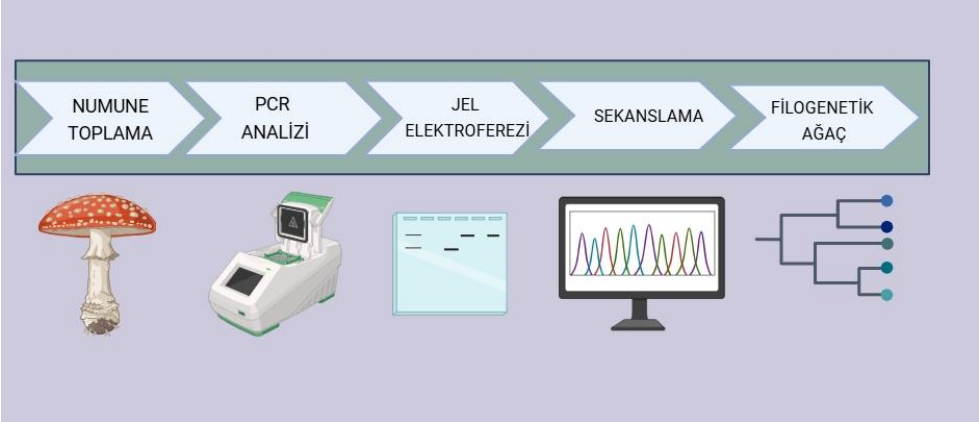
ITS bölgesine dayalı tür teşhisi için sıklıkla kullanılan primerler Tablo1'de verilmiştir. Bu primer çiftleri yaklaşık 450-700 baz çifti arasında dizi elde edilmesini sağlar. ITS gen bölgesinin nispeten küçük olması Polimeraz Zincir Reaksiyonu (PZR) ile çoğaltılmasında kolaylık sağlar.

Tablo 1. Mantar DNA barkodlama çalışmalarında kullanılan ITS gen bölgesine ait primer dizileri

Gen Bölgesi	Primer Adı	Primer Sekansı	Referans
ITS	ITS1 (Forward)	TCCGTAGGTGAACCTGCGG	White ve ark., 1990
	ITS5 (Forward)	GGAAGTAAAAGTCGTAACAAGG	
	ITS2 (Reverse)	GCTGCGTTCTTCATCGATGC	
	ITS3 (Forward)	GCATCGATGAAGAACGCAGC	
	ITS4 (Reverse)	TCCTCCGCTTATTGATATGC	

Moleküler yöntemlere tür teşhisinde izlenilecek adımlar Şekil 2'de verilmektedir. Buna göre tür teşhisinde ilk adım mantar örneklerinin toplanmasıdır. Doğal habitatlarında toplanan mantarlar mikroskobik ve moleküler çalışmalarda kullanılmak üzere muhafaza edilmeleri gerekir. Laboratuvar ortamında mantar numunesinden DNA ekstraksiyonu gerçekleştirilir. Bu aşamada genellikle mantar için DNA izolasyon kitleri kullanılmaktadır. Elde edilen genomik DNA, yukarıda belirtilen primer

çiftlerinin kullanıldığı Polimeraz Zincir Reaksiyonu (PZR) ile çoğaltılarak ürün elde edilmektedir. PZR ürün varlığı teyit edildikten sonra Sanger sekanslama ile ürünün DNA dizisi elde edilir. Biyoinformatik analizlerin ilk aşamasında, elde edilen PZR ürün dizisinin National Center for Biotechnology Information (NCBI) veritabanlarında BLASTn ile araştırılır. Çalışılan mantar türü ile veritabanlarında bugüne kadar çalışılan mantar türlerine ait barkod dizileri karşılaştırılarak en benzer olanlar belirlenir. Türler arasındaki akrabalık ilşkisinin ortaya konması için filogenetik ağaç çizimi gereklidir. Bir türe ait elde edilen DNA dizisinin doğruluğu, genetik ilişksinin anlaşılması ancak filogenetik analizlerin desteğiyle sağlanır.



Şekil 2. Mantar tür tanımlamasında izlenecek moleküler adımlar

Cortinarius cinsi mantar tür teşhisinde nrITS gen bölgesine dayalı filogenetik ayırım çoğu tür için yeterli sonuçların elde edilmesine olanak sağlamaktadır (Fajarningsih, 2016; Garnica ve ark., 2016; Soop ve ark., 2019; Şengül Demirak ve Türkekul, 2021; Liimatainen ve ark., 2020, 2022; Kaygusuz, 2022; Zhang ve ark., 2023; Şengül Demirak ve ark., 2024). Daha önce mofolojik olarak belirlenmiş birçok *Cortinarius* türün moleküler yöntemler ile revizyonu gerçekleştirilmektedir (Liimatainen ve ark., 2022). Dünyada birçok mantar türünün yeni kayıt olarak verilmesinde moleküler destekli tür teşhisinin yapılması gerekmektedir.

Bazı durumlarda, mantar taksonomik çalışması için ikili barkodlama sistemlerinin de kullanılması önerilmektedir (Schoch ve ark., 2012). Kapsamlı taksonomik bir çalışmada veya morfolojik ve ekolojik benzerliği fazla olan türlerde, iki gen bölgesine dayalı teşhis yapmak en doğrusudur. Özellikle, nrITS ve ribozomal büyük alt birim rRNA (LSU) gen bölgelerinin birlikte kullanılması, türler arası düşük nrITS değişkenliğine sahip taksonlarda genetik çeşitliliği doğru belirleyebilmek için oldukça önemlidir. Çoklu gen bölgesine dayalı filogenetik çıkarımların yapılması hem teşhisin güvenirliliğini artırmakta hem de ileride yapılacak çalışmalar için önemli moleküler veri sağlamaktadır.

Türkiye'de *Cortinarius* Tür Teşhisine Yönelik Moleküler Çalişmalar

Yaptığımız literatür taramasına göre, Türkiye'de bu zamana kadar 81 ilin 46'sinde 170'e yakın *Cortinarius* cinsi mantar keşfedilmiştir. Bu mantarların en yoğun bulunduğu bölge Karadeniz bölgesi, an az bulunduğu bölge ise Ege ve Güneydoğu Anadolu bölgesidir. Türkiye'de *Cortinarius* türlerinin çoğu liste olarak verilmiştir, herhangi morfolojik ve moleküler veri sunulmamıştır. Bugüne kadar çalışılan *Cortinarius* cinsi mantarların yaklaşık %70'i sadece liste olarak, %23'e yakını sadece morfolojik teşhise dayalı ve %7'e yakını moleküler ve morfolojik çalışmaların sonucunda teşhis edilmiştir. Bu sonuçlar, Türkiye'de sadece liste olarak sunulan veya morfolojik olarak tanımlanan çoğu *Cortinarius* türünün doğruluğunun teyit edilmesi gerekliliğini ortaya koymaktadır. Kısıtlı olmakla birlikte, moleküler yöntemlere dayalı yeni kayıt *Cortinarius* cinsi mantar türleri çoğunlukla Trabzon ve

Tokat illerinden sunulmuştur (Tablo 2). Türkiye'de *Cortinarius*'a yönelik moleküler çalışmaların yetersiz olduğu görülmektedir. Bu sebeplerden dolayı Türkiye'deki *Cortinarius* cinsi mantarların teşhisinde moleküler tanımlama yöntemlerinin kullanılması oldukça önemlidir.

Tablo 2. Türkiye'de moleküler yöntemlerle incelenen *Cortinarius* cinsi mantarlar

Cortinarius Türü	**Bulunduğu Bölge**	**İl**	**Referans**
C. bulliardi	Karadeniz Bölgesi	Tokat	(Şengül Demirak ve Türkekul, 2021)
C. caerulescens	Doğu Anadolu	Hakkari	(Kalmer ve ark., 2019)
C. caninus	Karadeniz Bölgesi	Trabzon	(Sesli, 2020)
C. cinnamoviolaceus	Karadeniz Bölgesi	Trabzon	(Sesli ve Örtücü, 2020)
C. conicoumbonatus	Karadeniz Bölgesi	Trabzon	(Sesli ve Liimatainen, 2018)
C. dibaphus	Marmara Bölgesi	Bursa	(Kaygusuz, 2022)
C. eucaeruleus	Karadeniz Bölgesi	Tokat	(Şengül Demirak ve ark., 2022)
C. lilacinovelatus	Karadeniz Bölgesi	Tokat	(Şengül Demirak ve Türkekul, 2021)
C. rapaceodies	Karadeniz Bölgesi	Tokat	(Şengül Demirak ve Işık, 2020b)
C. rufo-olivaceus	Karadeniz Bölgesi	Tokat	(Şengül Demirak ve ark., 2020a)
C. strenuipes	Karadeniz Bölgesi	Tokat	(Şengül Demirak ve ark., 2024)
C.variegatus	Karadenzi Bölgesi	Trabzon	(Sesli ve Örtücü, 2020)

TARTIŞMA VE SONUÇ

Mantarlar aleminde türlerin belirlenmesi oldukça karmaşık ve hatta imkânsız olabilmektedir. Makro- ve mikro-morfolojik özelliklerin tür ayırımında yetersiz olması, hatta farklı araştırmacıların mantarın morfolojik özelliklerini farklı yorumlaması, bazı türlerin farklı isimler altında birden fazla adlandırılmasına ve mantarların sınıflandırılmasında karmaşıklığa yol açmaktadır. Taksonomide her cinse ait tip materyal olması, tür tanımlamaların daha doğru ve kolay yapılmasını sağlarken, tip materyal olmayan durumlarda türü belirlemek oldukça zordur. Mantar taksonomik çalışmalarda geleneksel yöntemlerin (morfolojik, ekolojik ve kimyasal) yetersiz kalmasındaki olumsuzluk, teknolojik gelişmelerin etkisiyle azalmakla birlikte, daha doğru ve güvenilir yaklaşımların geliştirilmesine neden olmuştur.

Moleküler yaklaşımların kullanılmasıyla birlikte yüksek seviyeli taksonomik grupların ve büyük evrimsel soyların belirlenmesi, düşük taksonomik seviyelerde ise türlerin, kısmi popülasyonların ve bireylerin teşhisi daha güvenilir hale gelmiştir (Kılıçoğlu ve Özkoç, 2008). Moleküler yöntemlerde kullanılan "DNA barkodu", bir türden elde edilen küçük bir DNA dizisi olup o türe özgül bir DNA verisidir. Dolayısıyla, türe özgül bu dizilerin veri tabanlarındaki tüm verilerle karşılaştırılması ile hangi tür olduğu hakkında bilgi edinilmektedir. Bu yüzden seçilen barkod genlerinin güvenirliliği oldukça önemlidir. Mantarlar için polimorfik DNA dizilerinden en yaygın olarak kullanılan nrITS gen bölgesi, mantar türlerinin doğru teşhisinde en güvenilir barkod olarak kabul edilmiştir.

Cortinarius, dünyada kozmopolit dağılıma sahip, tür açısından oldukça zengin, türlerinde ortak morfolojik karakterlerin bulunması nedeniyle tür ayırımı bakımından zorlu bir cinstir. Son yıllarda yapılan çalışmalar, moleküler yöntemler ile morfolojik tanımlamaların birlikte kullanıldığı tür teşhisinin daha güvenilir olduğunu ortaya koymaktadır (Şengül Demirak ve Türkekul, 2021; Liimatainen ve ark., 2020, 2022). nrITS gen bölgesine dayalı filogenetik analizler, Cortinarius cinsinin monofiletik olduğunu

göstermektedir (Peintner ve ark., 2004; Garnica ve ark., 2006; Şengül Demirak ve Türkekul, 2021; Liimatainen ve ark., 2022; Şengül Demirak ve ark., 2024). Geleneksel yöntemlerin moleküler verilerle desteklenmesi, *Cortinarius* taksonomisinin doğruluğunu ve güvenirliliğini artırmaktadır.

Dünyada hala keşfedilmemiş *Cortinarius* cinsi ve farklı mantar türleri oldukça fazladır ve çalışılmamış birçok lokasyon bulunmaktadır. Farklı ekolojik ortamlardan toplanan mantarların çalışılması, daha fazla moleküler verilerin paylaşılmasına ve taksonomik bilgilerimizin daha güvenilir olmasına katkıda bulunacaktır. Sonuç olarak, DNA barkodlama ile gerçekleştirilen moleküler çalışmalar binlerce yeni türün daha hızlı, güvenilir ve doğru şekilde tanımlanmasına katkıda bulunmaktadır.

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Çıkar Çatışması

Yazarlar çıkar çatışması olmadığını beyan etmişlerdir.

Design and Implementation of Digital Butterworth IIR Filter Using Xilinx System Generator on FPGA

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Abstract

In modern Digital Signal Processing (DSP) systems, achieving efficient real-time filtering remains a critical challenge, especially in applications requiring high accuracy, low power consumption, and optimized hardware utilization. Traditional software-based approaches often fall short when it comes to meeting performance and energy constraints. Field-programmable gate arrays (FPGAs) offer a promising alternative due to their inherent parallelism, reconfigurability, and energy efficiency. However, translating complex DSP algorithms into efficient FPGA implementations requires careful design considerations and robust development tools. This research addresses these challenges by designing and implementing a Digital Butterworth Infinite Impulse Response (IIR) filter on an FPGA platform using the Xilinx System Generator. The Butterworth IIR filter is selected for its maximally flat magnitude response in the passband, making it ideal for applications that demand smooth frequency characteristics with minimal ripple. Leveraging the Xilinx System Generator enables high-level hardware modeling and rapid prototyping, significantly reducing development time while ensuring hardware compatibility. The filter is deployed on an ARTIX-7 FPGA, and its performance is evaluated in terms of resource utilization, specifically, lookup tables (LUTs), slices, and other fundamental FPGA components, as well as dynamic power consumption. The implementation results demonstrate not only the feasibility of deploying sophisticated DSP algorithms on FPGA hardware but also provide empirical insights into design trade-offs related to resource efficiency and power consumption. This work contributes to the growing body of research in FPGA-based DSP by offering a practical methodology for developing power- and resource-efficient filtering solutions.

Key words: *Digital Butterworth Infinite Impulse Response, Field-Programmable Gate Arrays, Xilinx System Generator, Digital Signal Processing*

INTRODUCTION

This study investigates the design and implementation of a Digital Butterworth Infinite Impulse Response (IIR) filter on a Field-Programmable Gate Array (FPGA) platform using the Xilinx System Generator. With growing demands in real-time signal processing applications, such as biomedical monitoring and communication systems, there is a significant interest in realizing efficient digital filtering techniques that balance performance, resource usage, and power consumption.

Digital filters play a central role in modern signal processing systems by allowing for the extraction, modification, and enhancement of information from discrete-time signals. Among these, IIR filters are known for their computational efficiency and ability to model complex frequency responses using fewer coefficients compared to FIR filters. The Butterworth IIR filter, in particular, is prized for its maximally flat passband response and is frequently applied where signal integrity in the passband is critical.

The aim of this research is to explore the theoretical foundation and practical realization of a second-order Butterworth IIR low-pass filter using a Direct Form II structure. The filter was designed using MATLAB's FDA Toolbox and implemented on an Artix-7 FPGA board via Xilinx System Generator. The study provides a comprehensive analysis of resource usage, including Look-Up Tables (LUTs), slices, and power consumption. Furthermore, real-time noise reduction for ECG signals was used as a practical application to demonstrate system efficiency and reliability.

This paper contributes to the advancement of FPGA-based digital signal processing by presenting a well-rounded implementation pipeline from filter design to real-world application. Emphasis is placed on system optimization, hardware efficiency, and the synergy between academic theory and practical engineering.

MATERIAL AND METHODS

This section outlines the materials, tools, and procedural methodology employed for the design and implementation of a Digital Butterworth IIR Filter using Xilinx System Generator on an FPGA platform. The process includes filter design using MATLAB tools, simulation in Simulink, integration via Xilinx System Generator, and deployment on an Artix-7 FPGA board.

Material

The core hardware component used in this study was the Xilinx Artix-7 FPGA development board, which is widely recognized for its low power consumption, compact size, and suitability for digital signal processing (DSP) applications. In addition to this, the following software environments and tools were utilized:

- MATLAB R2021a with Simulink: For designing and simulating the digital filter.
- Filter Design and Analysis (FDA) Toolbox: To develop and analyze the filter structure, coefficients, and performance parameters.
- Xilinx System Generator (XSG): A high-level tool integrated with Simulink for translating filter designs into FPGA-synthesizable blocks.
- Xilinx ISE Design Suite 14.7: For bitstream generation, synthesis, and FPGA programming.

All simulations and implementations were carried out on a standard computing workstation running Windows OS with sufficient computational capacity for HDL simulation and FPGA compilation.

Methods

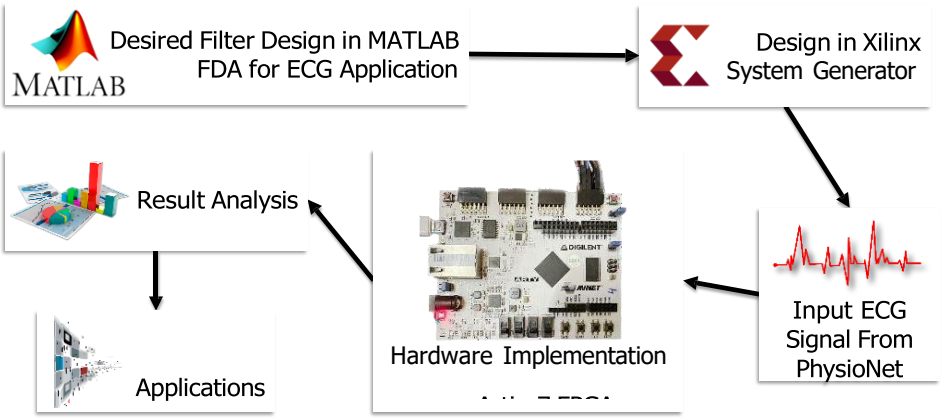


Figure 1. Workflow

Filter Design and Analysis

The Butterworth filter is essential due to its flat frequency response in the passband. Important for adjusting filters to uses, filter design specifications spell out the intended behavior by establishing criteria such as passband and stopband frequencies, ripples, and attenuation. A second-order Butterworth IIR low-pass filter was designed using the FDA toolbox. The primary design and the parameters are shown below:

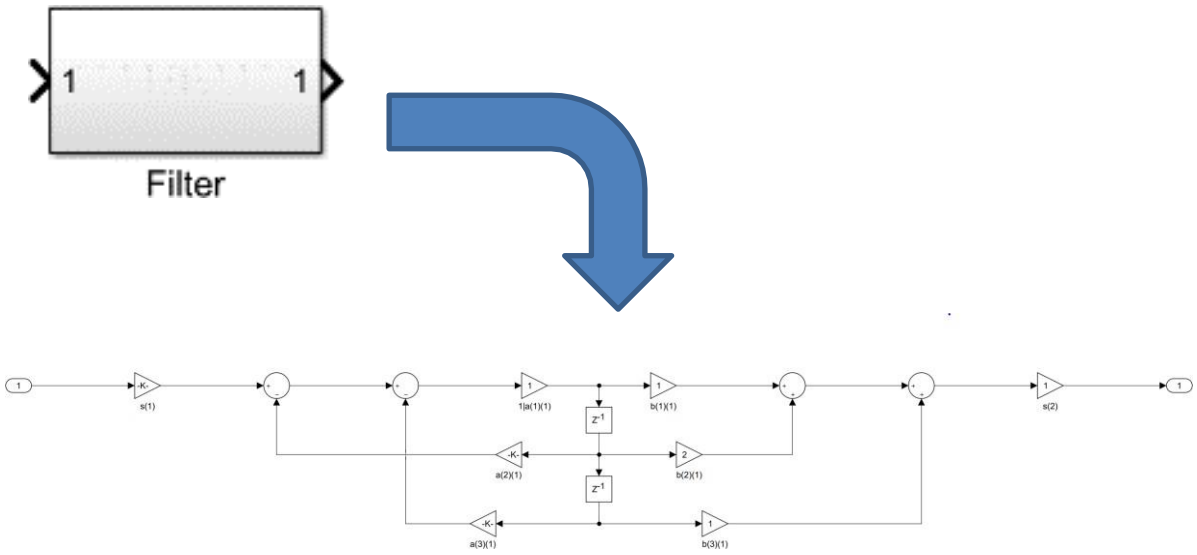


Figure 2. Filter Realization in FDA

Table 1. Filter Design Specifications

Sampling Frequency Fs	1000Hz
Filter Response	Low Pass
Filter order	2
F cut-off	0.2
3db point	0.2
6db point	0.25725

Table 2. Filter Parameters

Filter Structure	Direct form II
Number of sections	1
Filter Stability	Stable
Linear Phase	No
Design Algorithm	Butter

The filter specs must be normalized with respect to the Nyquist frequency before they can be used in the design process. The frequency at which it experience a decrease in volume by 3 dB is 200 Hz (0.2 * 1000 Hz / 2). We convert this frequency to a normalized 3 dB frequency of 0.4 by dividing it by the Nyquist frequency (500 Hz). Designing a stable filter is essential. All of the poles of a stable IIR filter are within the complicated unit circle. In the complex plane, the poles of the Butterworth filter lie on a circle of radius 1. This innate quality guarantees steadiness.

Z-Transform of Filter

We investigate the mathematical transformation that connects the input and output sequences of a 2nd order Butterworth IIR (Infinite Impulse Response) filter by way of the Z-Transform (a useful tool for analyzing and representing discrete-time systems like digital filters). Its transfer function may be expressed in the Z-domain using the Z-Transform. The poles and zeros of the filter are encoded in its transfer function, which governs its operation in the frequency and time domains. We examine the filter's frequency response, stability, and transient response, thus having insight into the filter's future behavior, allowing us to foresee how it will process incoming signals and how their output will change over time.

Transfer Function Equation

The polynomial in the Z-domain representing the filter's output is divided by polynomial in the Z-domain representing the filter's input to arrive at the expression for the gain.

$$H_{(z)} = \frac{0.067(1 + 2z^{-1} + z^{-2})}{1 - 1.12z^{-1} + 0.4162z^{-2}}$$

For Poles and Zeros

Multiply & Dividing by Z square (eq. 4-1)

$$H(z) = \frac{0.067(z^2 + 2z + 1)}{z^2 - 1.12z + 0.4162}$$

$$Now\ to\ find\ Zeroes$$

$$z^2 + 2z + 1 = 0$$

$$Z1 = -1 \quad Z2 = -1$$

$$Now\ to\ find\ Poles$$

$$z^2 - 1.12z + 0.4162 = 0$$

$$Z1 = 0.571 + j0.299 \quad Z2 = 0.571 - j0.299$$

Magnitude and Angle for Conjugate poles

A set of following equations represent the magnitude and angle of conjugate poles.

$$Now\ to\ find$$

$$Magnitude\ |Z| = \sqrt{x^2} + y^2$$

$$|Z| = 0.64454$$

$$Now\ to\ find\ Angle$$

$$\tan\theta = -\frac{y}{x}$$

$$\theta_1 = +0.4818$$

$$\theta_1 = -0.4818$$

The filter coefficients were generated using MATLAB's butter function. The designed filter's stability was verified using a pole-zero plot, ensuring all poles were located within the unit circle.

These difference equation coefficients are the filter coefficients:

- Section #1
- ----------
- Numerator:
- 1
- 2
- 1
- Denominator:
- 1
- -1.998222847291841741679263577680103480816
- ----------
- 0.998224425026400519200819871912244707346
- Gain:

Figure 3. Filter Coefficients

System Generator Implementation

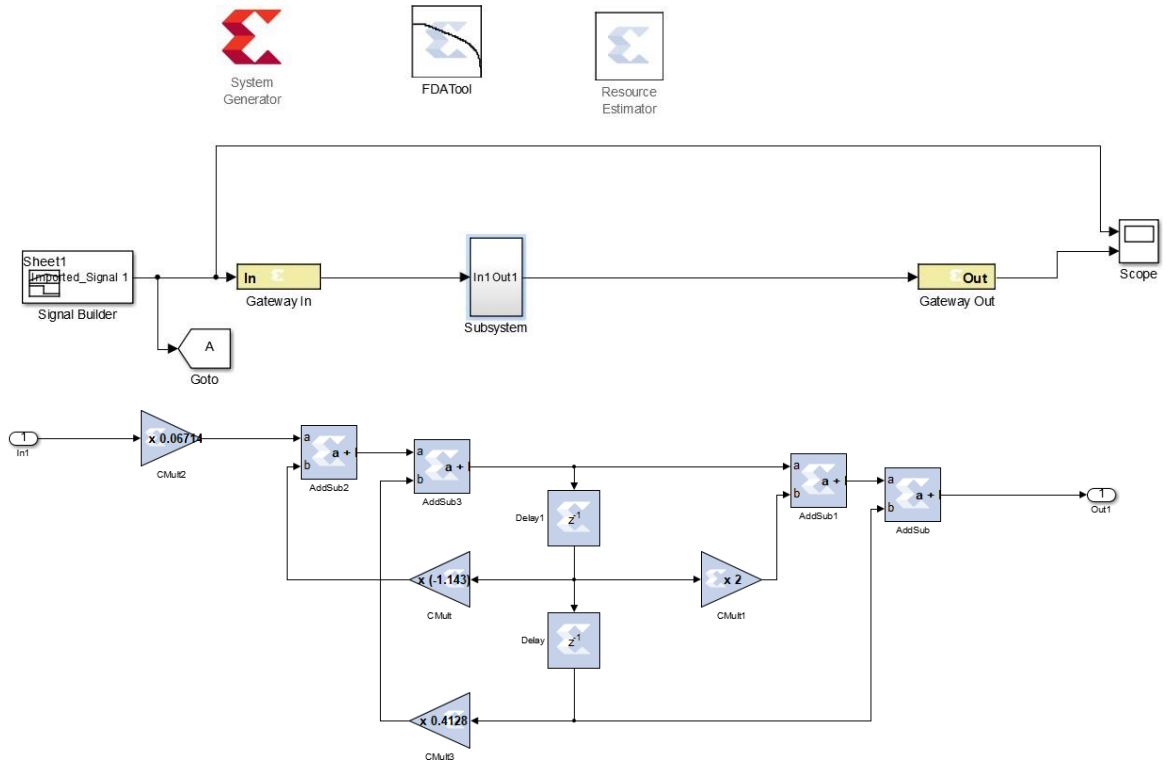


Figure 4. Low Pass IIR Butterworth Filter in Xilinx System Generator and Sub-systems

After filter design, the implementation proceeded using Xilinx System Generator blocks in Simulink. The system was constructed using the following XSG modules:

- Gateway In: To convert floating-point Simulink data into fixed-point format for FPGA synthesis.
- Delay: To manage signal synchronization within the feedback loop.
- Add/Subtract: Arithmetic blocks to implement the recursive nature of the IIR filter.
- CMult (Constant Multiplier): Used to apply coefficient multiplication in both feedback and feedforward paths.
- Gateway Out: Converts processed fixed-point signal back to Simulink format for analysis.

Each block corresponds to specific elements in the Direct Form II IIR structure. The coefficient values were manually inserted based on the FDA-generated results.

ECG Signal Acquisition and Noise Reduction

To validate the filter in a practical context, an ECG signal was processed using the designed Butterworth filter. Data was obtained from the PhysioNet (PhysioBank ATM) database. The signal was first imported into MATLAB Signal Builder via Excel. Key processing steps included:

- Signal Import from Excel.
- Real-time Simulation in Simulink.
- Filtering using XSG-implemented.
- IIR filter Comparison of pre- and post-filtered ECG signals.

The major range of interest is between around 0.5 Hz and 40 Hz. The ECG's P-wave, QRS complex, and T-wave all fall within this region. Atrial depolarization is represented by the P-wave, ventricular depolarization by the QRS complex, and ventricular repolarization by the T-wave in a standard electrocardiogram. To guarantee correct ECG interpretation, high-frequency noise over 40 Hz, such as muscular artifacts and electrical interference, must be filtered away. Overall, it is vital for correct signal processing and significant clinical insights to comprehend the frequency range of ECG data.

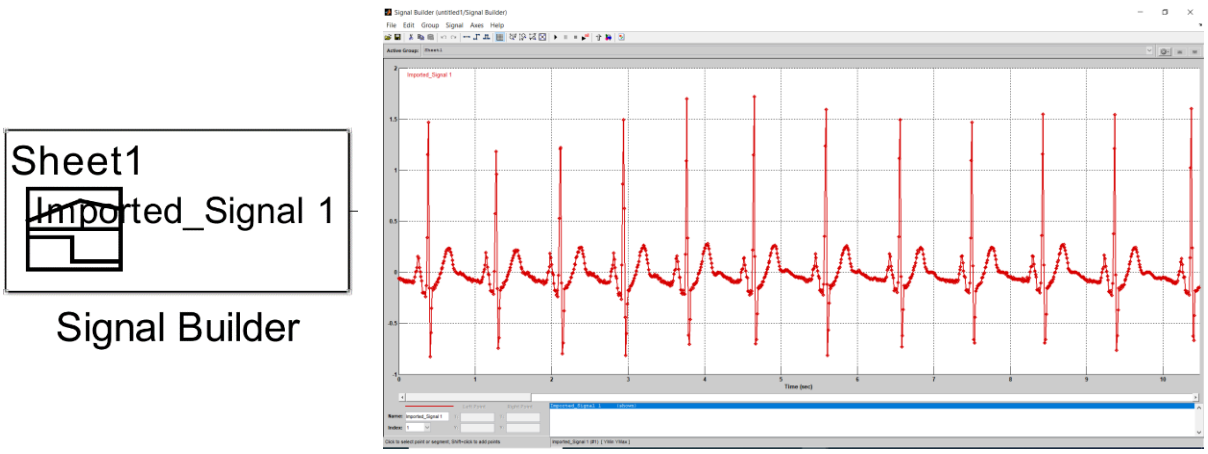


Figure 5. Input ECG Signal in Signal Builder

Hardware Implementation

The complete system was synthesized and deployed on the FPGA Artix-7 board using Xilinx ISE 14.7. After synthesis, resource utilization was measured in terms of Look-Up Tables (LUTs), Slices: Flip-Flops, Clock Cycles and Power Consumption (mW). The "Resource Estimator" block from XSG was used during simulation, and on-chip FPGA reports were retrieved post-implementation.

To optimize performance and reduce power consumption, design refinements were applied:

- Direct Form II structure was preferred for its memory efficiency.
- Pipelining was avoided due to the low order of the filter.
- Clock gating techniques were explored in Xilinx ISE 14.7 power analysis tool.

RESULTS

The designed second-order Butterworth IIR filter was successfully synthesized and implemented on the Xilinx Artix-7 FPGA board using Xilinx System Generator. This section presents the key performance outcomes of the filter implementation, including simulation results, ECG signal processing outputs, device utilization statistics, timing performance, and power consumption metrics.

Simulation Results and Filter Response

The filter exhibited a maximally flat magnitude response in the passband and a smooth roll-off in the stopband. The phase response was consistent and showed minimal distortion in the passband, which is critical for applications like ECG signal filtering.

The pole-zero diagram confirmed the filter’s stability, with all poles located within the unit circle. Frequency and time-domain analyses were conducted using MATLAB, and the group delay remained largely constant across the passband, confirming the preservation of phase relationships.

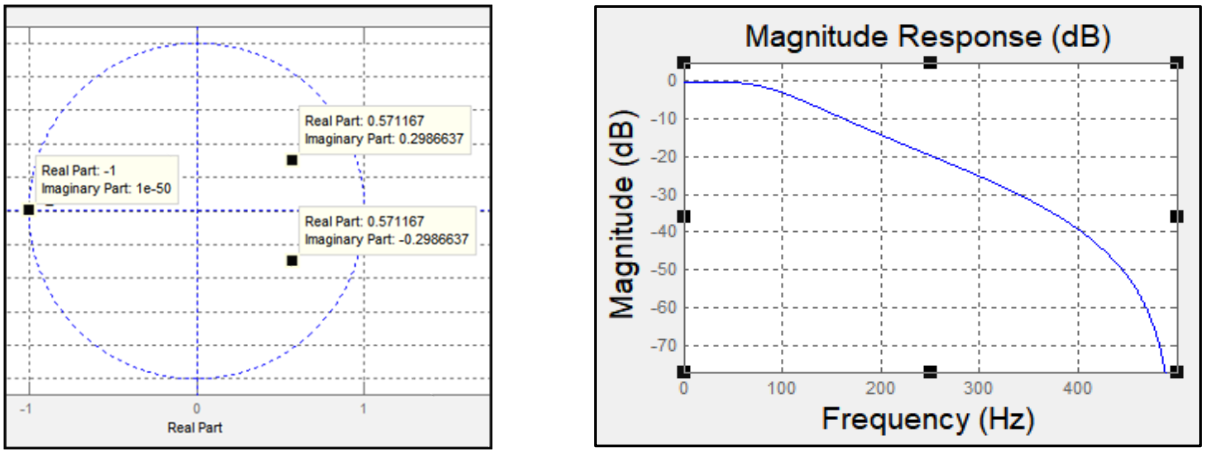


Figure 6. Pole-Zero Plot and Magnitude Response of the Filter

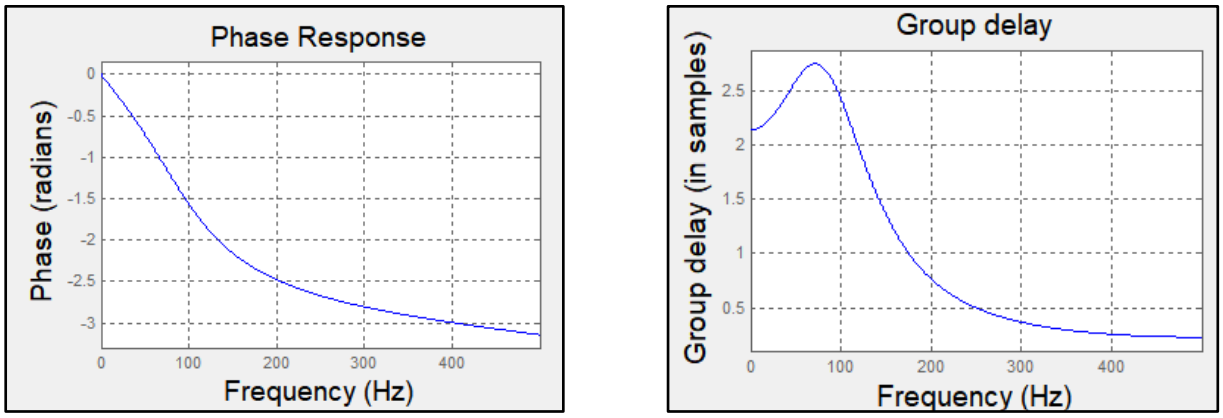


Figure 7. Phase Response and Grouup Delay of the Filter

We can tell if a filter is stable by looking at whether its poles are within or outside the unit circle. The magnitude response gradually decreases as the frequency rises, illustrating the filter's efficient attenuation of higher frequencies.

We can see how the phase shift of the filter varies with frequency by plotting the phase response. When it comes to the time domain, distortion is kept to a minimum because of the Butterworth filter's characteristically maximum flat magnitude response in the passband, which translates to a smooth and consistent phase response. The group delay of a filter is revealed by its phase response analysis. Since a 2nd order Butterworth IIR filter has a maximum flat magnitude response, the group delay should remain essentially constant across the passband.

ECG Signal Filtering

To validate the filter in a biomedical context, ECG signal data obtained from PhysioBank ATM was processed. The original signal contained high-frequency noise, which was significantly reduced after passing through the implemented Butterworth filter. The filtered ECG waveform retained all significant features (P-wave, QRS complex, T-wave) while effectively suppressing noise above the cutoff frequency.

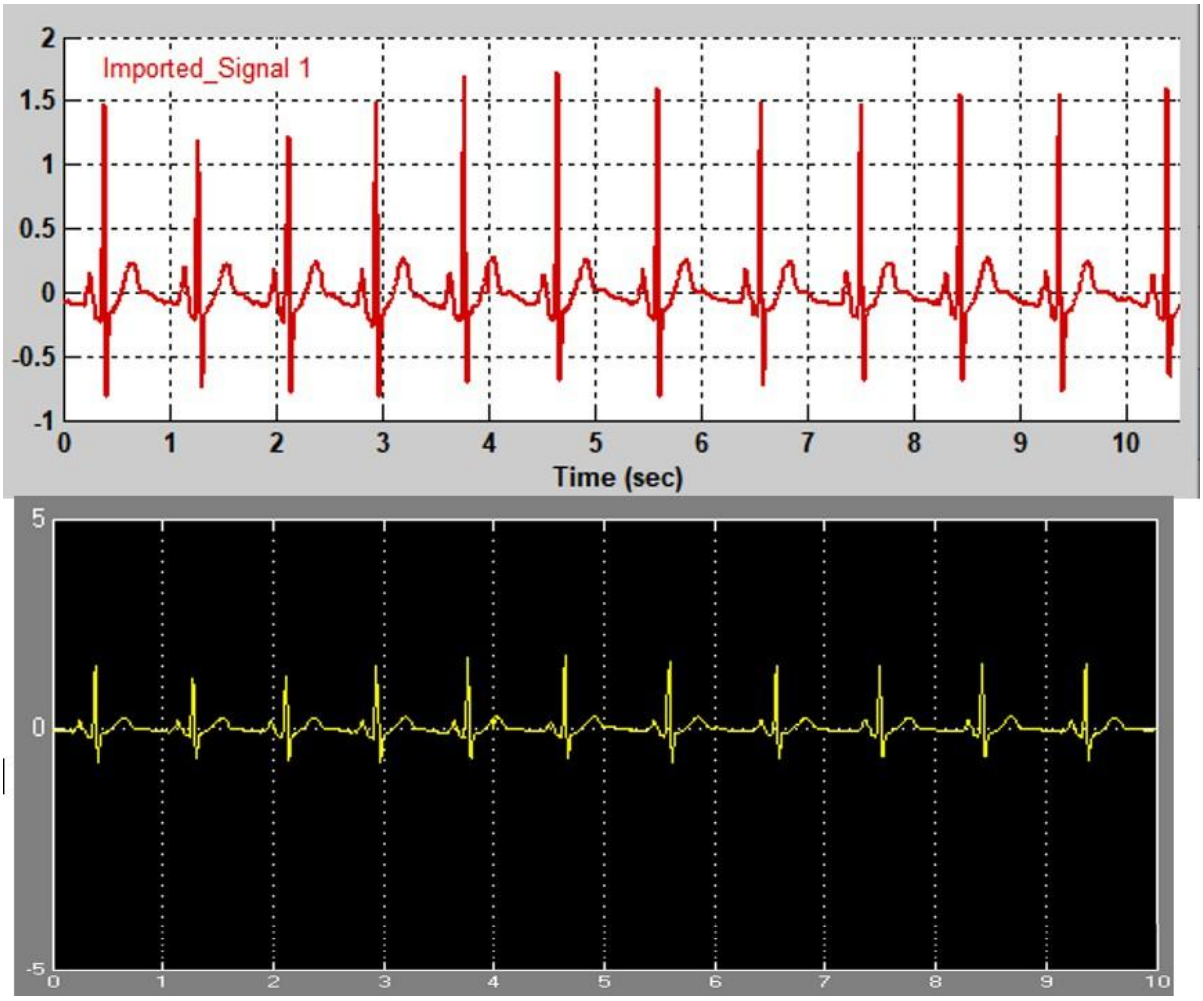


Figure 8. Input ECG Signal VS Output Filtered ECG signal

Resource Utilization on FPGA

Once the design was synthesized in Xilinx ISE 14.7 and implemented on the Artix-7 FPGA, a comprehensive report of resource consumption was generated. The following summarizes the utilization:

Table 3. Filter Implementation Cost

Number of Multipliers	4
Number of adders	4
Number of states	2
Multiplication per input sample	4
Addition per input sample	4

Area in Terms of LUTs

As illustrated in Figure 9, the FPGA implementation utilized 3,239 out of 63,400 available LUTs, which corresponds to only 5.1% usage. This efficient utilization confirms that the filter architecture is highly optimized for hardware deployment. It also suggests that the design is scalable and can accommodate additional logic or parallel processing paths within the same device.

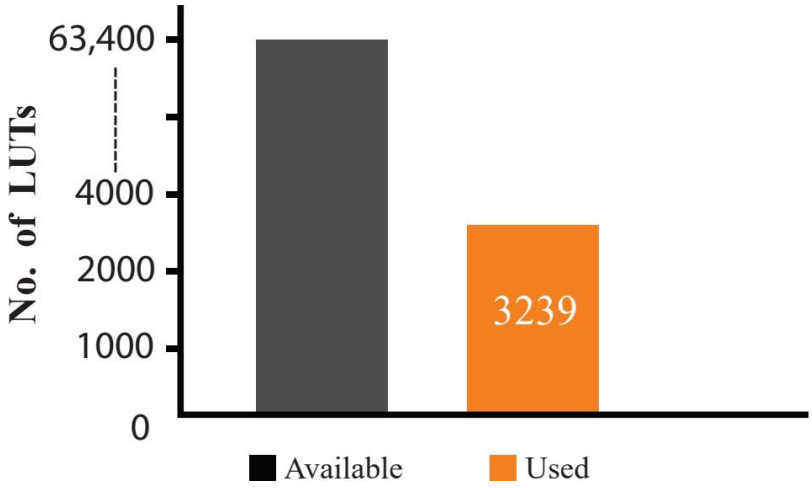


Figure 9. Area in Terms of LUTs

Area in Terms of Slices

As shown in Figure 10, the implemented filter utilized only 78 slices out of 126,800 available, which translates to a remarkably low 0.06% slice usage. This result highlights the efficiency of the filter architecture, allowing room for significant design expansion or integration with additional signal processing components. The minimal use of slice resources directly contributes to reduced power consumption and makes the implementation ideal for low-power, real-time systems.

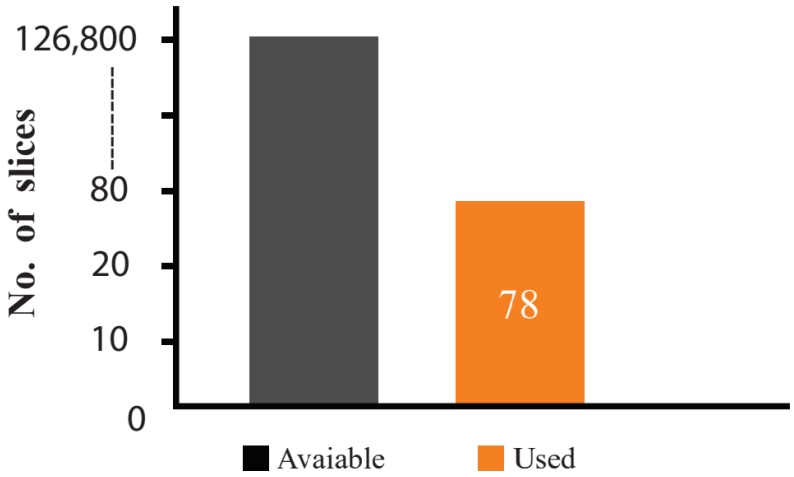


Figure 10. Area in Terms of Slices

Time In terms of Clock Cycles

The timing report, shown in Figure 11, demonstrates that the designed filter achieved a maximum propagation delay of only 1.388 ns and a net skew of 0.166 ns. These values are indicative of an efficiently routed design with excellent synchronization across logic elements. The low delay and minimal skew confirm that the implemented filter is suitable for high-frequency operation and real-time processing, comfortably meeting the constraints of the Artix-7 FPGA.

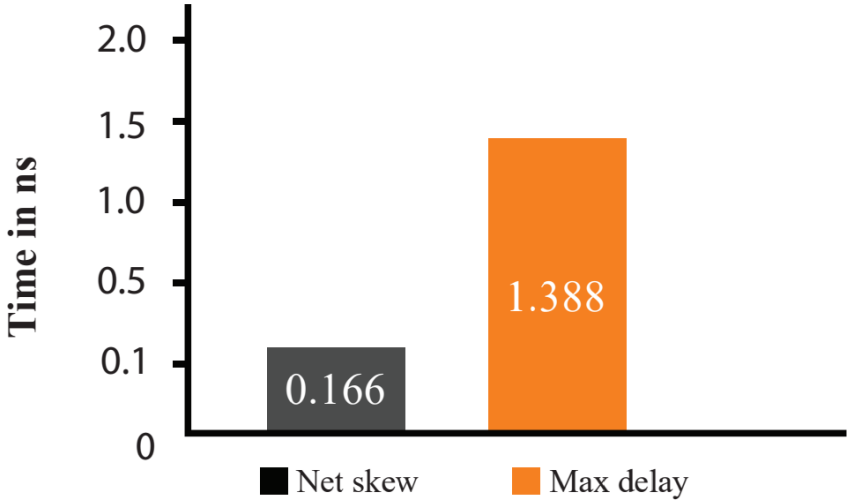


Figure 11. Time In terms of Clock Cycles

Power in mWatts

The power analysis, as shown in Figure 12, revealed that the total power consumption of the implemented filter design was approximately 130.60 mW, which includes 48.28 mW of dynamic power and 82.32 mW of static power. This level of consumption is acceptable for real-time signal processing applications such as ECG filtering and reflects efficient design choices made in terms of structure, timing, and resource allocation.

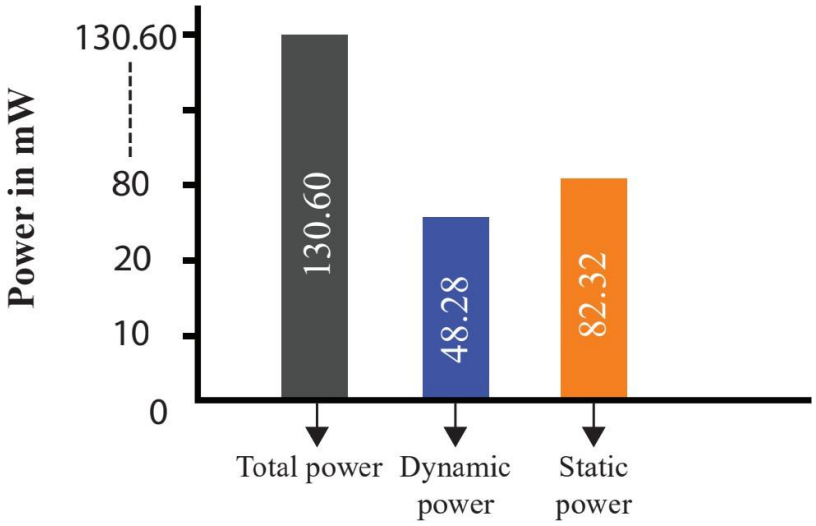


Figure 12. Power in mWatts

RTL Schematic Views

To visualize the hardware structure, RTL (Register Transfer Level) schematics were extracted. The top module and submodules clearly represented the architecture developed in System Generator, including the feedback paths and coefficient multipliers.

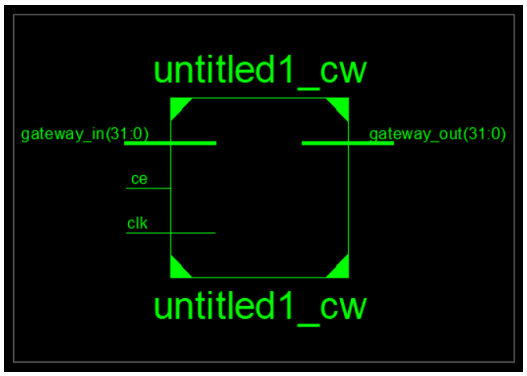


Figure 13.1. Top Module RTL Schematic

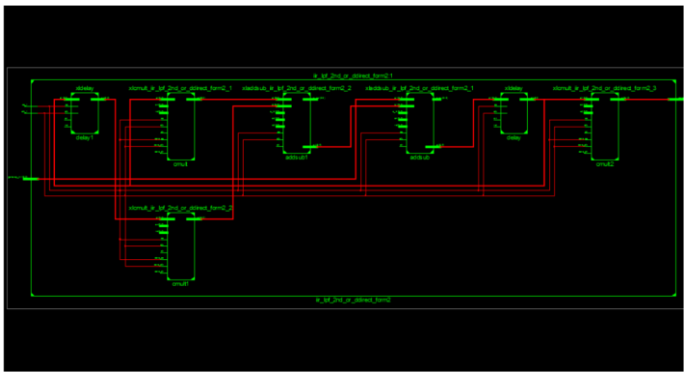


Figure 13.2. Sub Module RTL Schematic

DISCUSSION AND CONCLUSION

The design and implementation of a Digital Butterworth IIR filter using Xilinx System Generator on an Artix-7 FPGA platform have demonstrated significant efficiency in both resource utilization and real- time signal processing performance. The primary goal of developing a power-conscious, low-resource, and high-speed filter architecture was successfully achieved.

Discussion

The second-order Butterworth IIR filter was designed with a focus on achieving a flat passband response and gradual roll-off in the stopband, making it highly suitable for biomedical applications such as ECG signal denoising. The frequency response, phase characteristics, and group delay confirmed the expected theoretical behavior, with minimal distortion and excellent time-domain integrity.

From a hardware implementation perspective, the Direct Form II structure proved highly efficient. Only 5.1% of LUTs (3,239 out of 63,400) and 0.06% of slices (78 out of 126,800) were utilized, which confirms that the system was implemented with optimal use of FPGA fabric. The extremely low net skew of 0.166 ns and maximum propagation delay of 1.388 ns ensured that the design operated comfortably under real-time constraints, allowing for high-frequency clock support and reliable synchronous behavior.

Moreover, the measured total power consumption of 130.60 mW with 48.28 mW dynamic and 82.32 mW static, reflects the design's energy efficiency. These metrics indicate the system's suitability for deployment in portable or wearable health monitoring devices, where battery life and thermal performance are critical.

The practical application using ECG signal data from PhysioBank further validated the filter's effectiveness. The filtered signal preserved essential waveform components (P-wave, QRS complex, T-wave) while successfully attenuating high-frequency noise, thereby meeting medical-grade filtering standards.

Conclusion

This work successfully bridges the gap between theoretical DSP filter design and real-time hardware implementation. By utilizing MATLAB, Simulink, and Xilinx System Generator, the project illustrates a high-level yet hardware-optimized design flow that translates seamlessly into efficient FPGA deployment.

- The following key contributions were made:
- A practical demonstration of Butterworth IIR filter design using FDA tools.
- Efficient resource mapping to FPGA hardware via Xilinx System Generator.
- Real-world signal processing validated through ECG denoising.
- Detailed analysis of power, timing, and utilization metrics confirming design excellence.

These results contribute to the growing body of research in low-power, high-performance FPGA-based digital signal processing. The techniques and methodology presented are extendable to higher-order filters, multi-channel systems, or adaptive filtering frameworks in future projects.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Author Contributions

The lead author Syed Hassan Ali and the co-authors Ayesha Jamshaid and Danish Muhammad, contributed collectively to the conceptualization, design, simulation, and hardware implementation of the digital filter system. The lead author was primarily responsible for system modeling, FPGA deployment, and result analysis. Ayesha Jamshaid contributed to MATLAB/Simulink integration and documentation, while Danish Muhammad supported the FPGA synthesis and testing stages. All authors reviewed and approved the final manuscript.

Consumer Perception on Traceability of Food Products.A case study in Albania

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Abstract

Food traceability has become one of the key topics in today's world. It has gained importance because consumers are increasingly demanding food quality and safety. But how well do consumers in Albania understand the concept of food traceability? This article provides a questionnaire conducted with consumers in Albania, divided into 3 parts. Through this questionnaire, we gather information about consumers' perception of food traceability, how well they understand it, and how important it is to them. Each result obtained is also evaluated using SPSS. In addition to consumers, we will also focus on some of the most well-known businesses in Albania. For each of them, information is provided on what they are what traceability they use, and the safety certifications they possess.

Keywords: *Food traceability, Consumer perception, QR code, Food safety, SPSS analysis.*

INTRODUCTION

Traceability has emerged as a fundamental component of modern agricultural supply chains, facilitating the systematic tracking of products across each stage of production, processing, and distribution. Agricultural traceability systems are designed to document critical data throughout the lifecycle of a product—from farm to consumer. These systems enhance transparency by providing consumers with verifiable information regarding the origin and handling of the food they consume. Moreover, they serve a crucial role in regulatory oversight by enabling authorities to swiftly identify points of failure within the supply chain, assign responsibility, initiate targeted recalls, and effectively mitigate economic and public health risks.The process of traceability also brings benefits to consumers, but it depends on the perception they have of the concept of traceability. The concept of traceability is often complex and not easily comprehended by consumers.Researchers have tried to give a broad description to consumers , focusing mostly on the outcomes that traceability provides (Hobbs et al., 2005; Dickinson & Bailey, 2002).Researchers such as Hobbs et al. (2005) and Dickinson and Bailey (2002) describe traceability as "identity preservation" and as being associated with quality and safety assurance schemes. Gellynck and Verbeke (2001) defined traceability from the viewpoint of providing information to consumers. Wilson and Clarke (1998) defined traceability as the information necessary to describe the production history of a food crop and any subsequent transformations or processes that the crop might undergo on its journey from the grower to the consumer's plate. Finally, other researchers described traceability as a system able to identify a product and trace its movement through its processing stages till the final

consumer (Timon & O'Reilly, 1998; Opara & Mazaud, 2001). Consumers seem not to value traceability information per se (Hobbs et al., 2005; Verbeke & Ward, 2005), and if provided alone does little to reduce consumer information asymmetry with respect to credence quality attributes (Hobbs et al.,2005). The main purpose of the study is to assess consumers' perception of food traceability, their level of awareness, and their interest in the subject. The study aims to identify significant differences in the perception of food traceability among respondents from the study areaas based on gender, education level , and age. In addition to consumers, the study will also focus on several well-known businesses in Albania. For each business, information will be provided regarding their nature, the traceability systems they employ, and the food safety certifications they hold.

MATERIAL AND METHODS

To assess consumer perception of food traceability in Albania, a questionnaire was conducted to gather data. The main purpose of the study is to assess consumer awareness levels and perceptions of food traceability. A total of 128 consumers participated in the survey which took place in outdoor markets and squares with randomly selected consumers. The questionnaire was distributed using a hard copy. Participation in the survey was voluntary. To achieve the particular goals, a researcher-designed questionnaire was used in conjunction with the descriptive method for data collection. The data were analyzed using the Statistical Package for Social Sciences (SPSS) software. The questionnaire was structured into three distinct sections:

(i) Socio-demographic data of the participants

(ii) Knowledge about food traceability

(iii) Food product inspection before purchase by consumers

Questions concerning the respondents' sociodemographic traits were asked in the first section. Three questions in the second section were intended to evaluate the familiarity with the concept of food traceability and the level of trust in traceability systems and food safety information. The third part included 9 questions focused on the participant‘s control of food products before purchase. The data were analyzed using SPSS 20. The designed survey contained 17 questions, from which 9 contained a 5-point Likert-type questionnaire that ranges from "SD-Strongly Disagree to SA-Strongly Agree.

RESULTS

Using the Statistical Package for Social Sciences (SPSS) software, descriptive statistics were used to examine data acquired via administrative questionnaires. These included mean, standard deviation, T-test, and one-way ANOVA. The questionnaire's primary goal was to find out how consumers felt about food traceability.

Table 1. Sociodemographic characterization of the sample

Variable	Groups	(%)
Gender	Male	54.7
	Female	45.3
Age	=<30	22.7
	31-59	57
	>=60	20.3
Level of education	Basic to middle school	0
	High school	33.6
	Higher education, university	66.4
Monthly income(€)	<500	25
	500-1000	46.875
	>1000	28.125
Nr.in family(people)	1-2	26.7
	3-4	34.7
	5+	38.7

From the 128 participants, male respondents made up 54.7% of the sample, and female respondents made up 45.3%. Regarding the age of respondents, 22.7 % of the respondents were less than or equal to 30 years, 57 % of the respondents were between 31 and 59 years, and 20.3 % were greater than or equal to 60 years old. The majority of the respondents had higher education (66.4%), 0% of respondents belonged to basic to middle school, whereas 33.6% of respondents belonged to high school. Regarding the monthly income, 25% of participants in the questionnaire earned less than 500 euros per month, 46.875 % earned 500-1000 euros per month, while only 28.125% earned more than 1000 euros. The majority of the participants came from families with more than 5 members (38.7%), 34.7% came from families with 3 to 4 members, while only 26.7% came from families with 1 to 2 members.

Hypotheses:

H1: There is no significant difference in the level of trust in traceability systems and food safety information based on gender.

Reliability Statistics

Cronbach's Alpha	N of Items
.923	3

First, we measured the internal consistency of a set of three questions in the survey, and we found Cronbach's alpha. These questions are meant to measure the same concept. The value of Cronbach's alpha is 0.924, which means that the three items in our questionnaire show excellent internal consistency and respondents answered these items in a highly consistent way.

Group Statistics

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Consumer's trust level when they perceive food traceability systems and food safety	male	70	11.30	2.510	.300
	female	58	13.29	1.965	.258

Before performing a t-test, we calculated the mean, standard deviation, and standard error mean to give an overview of how the groups compare.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Consumer's trust level when they perceive food traceability systems and food safety	Equal variances assumed	.698	.405	-4.924	126	.000	-1.993	.405	-2.794	-1.192
	Equal variances not assumed			-5.037	125.623	.000	-1.993	.396	-2.776	-1.210

At the 0.05 level, significant

t=-4.924 ;df= 126 ; $p<0.05$

We choose the alternative hypothesis over the null hypothesis because $p<0.05$. The hypothesis is not validated. The study found that there is a statistically significant gender difference in the consumer's trust perception level on food traceability systems and food safety.

The second hypothesis:

H2: There is no significant difference in consumers' perception of food traceability based on gender, education, and age.

Then we tested the effect of three independent variables, gender, education level, and age, on consumers' perception. Since we tested multiple independent variables not at once, we used one-way ANOVA.

ANOVA

Consumer's perception of food traceability based on gender

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	414.796	1	414.796	18.882	.000
Within Groups	2767.946	126	21.968		
Total	3182.742	127			

At the 0.05 level, significant.

F=18.882; df=1&126; p<0.05, Sig=.000

First, we tested a single factor, the effect of gender. Since p<0.05, the result is statistically significant. There is a statistically significant difference in consumers' perception of food traceability based on gender. This indicates that consumers' perceptions of food traceability vary significantly depending on their gender. Consumers of different genders think differently about food traceability.

ANOVA

Consumer's perception of food traceability based on education

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	242.940	1	242.940	10.412	.002
Within Groups	2939.802	126	23.332		
Total	3182.742	127			

At the 0.05 level, significant.

F=10.412; df=1&126; p<0.05 Sig.=0.002

Then we tested the second variable, education level. Based on education level, a one-way ANOVA showed a statistically significant variation in how consumers perceived food traceability.

ANOVA

Consumers' perception of food traceability based on age

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.959	2	1.980	.078	.925
Within Groups	3178.783	125	25.430		

Total	3182.742	127			

At the 0.05 level, significant.

F=0.078; df=2&125; p>0.05

When we tested the third independent variable, age, the test showed the result p value (Sig.=0925)>0.05, which means that the result is not statistically significant. Therefore, consumers' perceptions of food traceability do not differ significantly according to statistical data, dependent on age.

From the results obtained using ANOVA, there is a statistically significant difference based on gender and education level in consumers' perception of food traceability, but there is no statistically significant difference based on age in consumers' perception of food traceability.

BUSINESSES IN ALBANIA

Businesses in Albania generally use traceability systems and are equipped with safety certifications, but they have not implemented technologies such as blockchain, RFID, or IoT. For this reason, businesses need to take initiatives to apply these technologies to build trust among consumers and provide quality and food safety.

We will develop a functional model, tailored to the reality and needs of our country. The model will take into account the legal, technological, and operational limitations that exist within the Albanian context (adaptation to local constraints). Coordination and interconnection with already functional and mandatory systems in the country, such as fiscalization, AKU, etc. We will integrate it with existing systems. Based on the chosen model and the planned integrations, a complete functional and sustainable system for food traceability will be built.

1.KRACO:

"Capital Resources" sh.p. k, known by its brand name KRACO, is a manufacturing and distribution company, leader in Albania in the production of teas of different formats and flavors, infusions, instant powders for preparations of hot and cold drinks, preparations for cakes, mashed potatoes, coffee in pods, packed sugar, etc. The start of its activity, dates back in 1997, becoming one of the pioneer Albanian companies in the food production industry. The first product offered in 1997, when its activity started, was packed sugar. Nowadays, Kraco branded products and private labels count for more than 130 different SKU-s which are widely used in all Albanian families, local Horeca, offices, luxury resorts, and are also distributed in Europe, Middle East, etc. Every day nearly 600,000 KRACO products are consumed in the Albanian & European market (Kraco,n.d.-a). Traceability, as a risk management tool, enables us to recall products that are not fully compliant with their standards, thereby minimizing all types of risks or dissatisfactions to our customers. The traceability system is based on four pillars: product identification, data to trace, product routing, and traceability tools. When a safety or product misalignment with our standards is suspected or identified, we have the cability to trace the problem back to its source, swiftly isolate it, and prevent additional non-compliant products from reaching the consumers. Our traceability information is based on PO (purchase orders) and lots. We are using the traceability function based on POs for raw materials intake and lots in the actual production process. Various data collection points are used to link all these elements together into our traceability chain. The traceability system we have managed build, is the key to us for reassuring our customers about the quality and safety of our products. Real-time traceability of individual units helps the complete sequencing control throughout production lines (Kraco, n.d.-b).

2.Erzeni:

We are committed to providing a high-quality level of products and food safety services for the PRODUCTION, STORAGE, and DISTRIBUTION of milk-based products.These products comply with Albanian food legislation and meet the quality and food safety standards demanded by our consumers (Erzeni, n.d.).

Production Process of "Erzeni" Products

- Collection: We collect milk every day from around 50 villages. The areas where we collect milk include : Berat, Kuçovë, Dumre-Elbasan, Fier, Lushnjë, Rrogozhinë, Lezhë, Vlorë (Novoselë, Vlorë River), Mallakastër, Memaliaj, Tepelenë. The new addition is the milk collection point in Gjirokastër, where we gather milk from goats and sheep in the southern pastures of Albania. The quantity of collected milk in these areas is increasing year after year." (Erzeni, n.d.)

- Production Process: After the initial check, the milk proceeds to the acceptance department, where it is filtered, weighed, cooled to 2ºC, and directed to the acceptance warehouses according to its destination (Erzeni, n.d)

3.Lufra:

The dairy company "Lufra" started in 1992, and our work has been improving since then. "Lufra" started as a simple improvised workshop in one of the rooms of the house, with the limited capacity equipment (up to 1000 liters of milk per day). Now Lufra processes over 60 tons of milk per day and is the leading company in Albania. (Lufra, n.d.)

Milk Way

- Food: Our farmers feed the cows with natural food. This improves the milk quality, and makes it healthy and full of nutritional values. (Lufra, n.d.)

- Farm: Farmers clean and disinfect the cow's breasts before milking. The stables are equipped with milking rooms of modern equipment . (Lufra, n.d.)

- Transportation: The fresh milk immediately after milking is filtered and cooled to 4 ° C. This temperature stays constant during transport by special trucks of the factory. (Lufra, n.d.)

- Factory: In the factory, the milk goes through a pasteurization process which kills pathogenic bacteria. This is where the sterilization and the standardization of fat takes place. (Lufra, n.d.)

- Grocery Store: Pasteurized milk and its sub-products come from the farm to the factory and then to the grocery store within 24 hours, through a well-organized logistics network. (Lufra, n.d.)

4.Beata:Company Beata Ltd. was established in 2009 in Koplik amidst the clean air of the field with Sherebelë and fresh water flowing from the Bjeshkët in the Malësia e Koplikut. The poultry capacity is 150,000 chicken heads for production and 80,000 chicks for breeding. The production is 140,000 eggs per day or, in other words, 51,000,000 eggs per year.

Quality: Beata eggs are a product of healthy chickens, raised on natural grains, without antibiotics and artificial growth enhancers, enriched with omega-3, proteins, etc.

Control : Every Beata product is analyzed at the Noval laboratory, the only accredited laboratory in Albania with the highest European standards (Beata Ltd., n.d.)

5.Aiba : Company Aiba owns the largest poultry farm in Albania for egg production with 500,000 chicken heads and an average annual production of 110 million eggs. Established in 1994, Aiba has gained experience and reputation in terms of quality and safety. The final product of Aiba company is chicken eggs, for human consumption and processing in the industry. Egg production is a biological process carried out through the breeding of chickens for eggs, ensuring food supply, providing all necessary technical conditions, in accordance with breed, age, productivity level, etc(Aiba, n.d.) Aiba Egg has the advantage of a 20-year experience in egg production and packaging.Aiba holds the ISO 9001:2000 quality certificate, guaranteeing consumers for our products (Aiba, n.d.)

6.Hako:

Its main activity is meat processing in over 70 types of sausages, ham and marinated products. The company factory with a capacity of over 4000 tons of production per year employs over 200 employees and is present with its products all over Albania. The supply of raw materials is done by domestic distributions or by European companies. Certification related to the quality management system: ISO 9001: 2008, ISO 22000: 2005, ISO 14001: 2004, OHSAS 18001: 2007 and the HACCP food safety system has been certified by the international company IQNET.(HAKO sh.p.k., n.d.)Today the company has increased the range of services and is present with subsidiaries throughout Albania making customers have the opportunity to find HAKO products at any time and as fresh as possible.(HAKO sh.p.k., n.d.)

DISCUSSION AND CONCLUSION

Our survey indicates that the majority of Albanian consumers lack familiarity with the concept of food traceability. Only a small percentage could accurately define it, and there is a general lack of proactive behavior among consumers when selecting food products. This highlights an urgent need for consumer education to foster greater awareness about the characteristics and safety of food products.

While Albanian businesses generally employ traceability systems and hold safety certifications, they have yet to adopt emerging technologies such as blockchain, RFID, IoT, etc. The integration of these technologies is crucial for enhancing transparency, building consumer trust, and ensuring higher standards of food quality and safety.

In response, we recommend the development of a functional traceability model tailored to Albania's context. This model should respect local legal and operational constraints while enabling seamless integration with mandatory systems such as fiscalization, AKU, etc. By implementing such a system, Albanian businesses can advance towards a more reliable and sustainable food traceability framework that meets both domestic and international demands.

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Exploring the Role of ZNF518A in Gastric Adenocarcinoma via In Silico Analyses

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Abstract

Gastric cancer is characterized by high incidence and mortality rates worldwide, as well as low survival rates due to its aggressive biological behavior and tumor heterogeneity. Among all cancer types, it ranks fifth globally in both incidence and mortality. Approximately 95% of gastric cancers are adenocarcinomas, with the most common subtypes being intestinal and diffuse adenocarcinomas. Helicobacter pylori (H. pylori) infection is one of the main risk factors for gastric cancer and is considered responsible for nearly 90% of distal gastric cancer cases globally. Gastric cancer is often diagnosed at advanced stages due to the late onset of noticeable symptoms; however, it can be treated with surgical resection if detected early.

ZNF518A is a member of the zinc finger protein family and plays a role in the transcriptional regulation of various genes. While studies on ZNF518A have indicated critical functions in cell proliferation and gene expression regulation, its roles in gastric cancer remain unclear.

In this study, the expression and methylation profiles of the ZNF518A gene in stomach adenocarcinoma (STAD) were analyzed using TCGA patient data through online bioinformatics databases such as GEPIA, TIMER, UALCAN, and SMART. Analyses conducted on both normal and tumor tissues revealed that ZNF518A was significantly overexpressed in tumor tissues and exhibited pronounced hypomethylation in the promoter region. These findings suggest that ZNF518A may play a potential role in the development of gastric cancer through epigenetic mechanisms.

Keywords**:** *ZNF518A gene, gastric cancer, epigenetics, methylation*

INTRODUCTION

Gastric cancer is one of the most common malignant tumors of the digestive system (Song et al., 2017). Globally, it ranks as the fifth most frequently diagnosed malignancy and the third leading cause of cancer-related mortality. Although a decline in the overall incidence of gastric cancer has been observed in recent years, an alarming increase in its occurrence among younger age groups has been reported (Wu et al., 2025).

According to data from GLOBOCAN 2020, gastric cancer accounted for approximately 800,000 deaths worldwide (Ilic and Ilic, 2022). Histopathologically, gastric neoplasms are classified into three main subtypes: intestinal, diffuse, and indeterminate. The majority of stomach adenocarcinomas (STAD) are of the intestinal type, typically localized in the antrum of the stomach and commonly associated with

Helicobacter pylori infection. These subtypes generally arise sporadically and exhibit significant differences in terms of tumor etiology and prognosis (Santos et al., 2025).

Gastric cancer has a multifactorial etiology and is closely associated with lifestyle and environmental factors. Major risk factors include Helicobacter pylori (H. pylori) infection, low socioeconomic status, high consumption of salted and smoked foods, inadequate intake of fruits, vegetables, and dietary fiber, tobacco and alcohol use, physical inactivity, obesity, radiation exposure, gastroesophageal reflux disease, a positive family history, and hereditary predisposition. Despite these known associations, the molecular etiology of gastric cancer remains incompletely understood (Ilic and Ilic, 2022).

Patients with stomach adenocarcinoma (STAD) are often diagnosed at advanced stages due to the presence of non-specific clinical symptoms and the lack of effective screening programs. Consequently, the average overall survival (OS) time in individuals with metastatic disease is limited to approximately 12 months (Santos et al., 2025).

In recent years, advancements in surgical techniques, along with improvements in conventional radiotherapy, chemotherapy, and neoadjuvant treatment approaches, have increased five-year survival rates to over 95% in patients diagnosed with gastric cancer at an early stage. However, the low rates of early detection lead to the majority of cases being diagnosed at advanced stages, resulting in the loss of the optimal window for curative surgical intervention. In this context, although current treatment strategies for advanced-stage gastric cancer have shifted toward multimodal approaches—including combinations of neoadjuvant chemoradiotherapy, molecularly targeted agents, and immunotherapeutic strategies (Song et al., 2017) the limited survival rates in advanced-stage gastric cancer cases highlight the necessity of a deeper understanding of the molecular basis of the disease. In this context, transcription factors (TFs) are proteins that bind to DNA and play a fundamental role in regulating gene expression. Numerous transcription factors, particularly pro-inflammatory TFs and hypoxia-inducible factors (HIFs), have been shown to play critical roles in the regulation of tumor initiation and progression across various cancer types (Cheng et al., 2022).

ZNF518A (Zinc Finger Protein 518A) is a nuclear transcriptional regulator that contains five zinc finger motifs. This protein has the potential to mediate interactions with molecules involved in gene expression mechanisms that play a critical role in the development and maintenance of cellular identity (Cheng et al., 2022). ZNF518A has also been recently reported to play a role in the formation of heterochromatin in pericentromeric regions, which is essential for proper chromosome segregation during mitosis and meiosis. Although its exact role in cancer remains unclear, some studies have shown that it is associated with cell proliferation and gene regulation. In recent years, studies have demonstrated that, in addition to genetic mutations, epigenetic alterations also play a significant role in tumor development. Chromatin-modifying complexes are key regulators of epigenetic processes. Two major histone methyltransferase complexes—Polycomb Repressive Complex 2 (PRC2) and the histone-lysine N-methyltransferases EHMT2 (G9A) and EHMT1 (GLP)—promote cell type-specific gene silencing by adding repressive post-translational modifications to histone tails at the promoters of target genes. ZNF518A has been reported to participate in this interaction (Maier et al., 2015).

In this study, we aimed to investigate whether the ZNF518A gene could serve as a prognostic biomarker in stomach adenocarcinoma (STAD) by analyzing its expression levels, DNA methylation status, and association with survival outcomes using bioinformatic analysis methods.

MATERIAL AND METHODS

Gene Expression Analysis

The TIMER 2.0 database was utilized to visualize gene expression levels across various types of cancer. The UALCAN database was employed to explore the expression of the ZNF518A gene in stomach adenocarcinoma under different clinical and pathological parameters.

Correlation Between ZNF518A Expression and Methylation in Gastric Cancer

The SMART database was used to analyze the correlation between gene expression and DNA methylation. Specific CpG islands were examined, and the significance of the relationship between expression and methylation was evaluated.

Gene Methylation Analysis

The SMART database was used to compare the methylation levels of the ZNF518A gene at specific CpG islands between normal and tumor tissues.

Survival Analyses

Kaplan-Meier curves were used to visualize survival outcomes, and log-rank tests were conducted to determine statistical significance (KM plotter).

Statistical Analysis

The student t-test was used to analyze the expression differences in normal and tumor tissues of TCGA samples. The Logrank test was used to compare KM survival curves and prognostic graphs of genetic changes. Statistically significant values were considered as: ****: $p \leq 0.0001$, ***: $p \leq 0.001$, **: $p \leq 0.01$, *: $p \leq 0.05$.

RESULTS

Our results revealed that the ZNF518A gene is significantly differentially expressed in various tumor tissues compared to normal tissues, as analyzed using the TIMER 2.0 database. In cancer types such as invasive breast carcinoma (BRCA), cholangiocarcinoma (CHOL), liver hepatocellular carcinoma (LIHC), stomach adenocarcinoma (STAD), thyroid carcinoma (THCA), and uterine corpus endometrial carcinoma (UCEC), ZNF518A expression was significantly upregulated in tumor tissues compared to normal tissues ($p < 0.001$). On the other hand, no statistically significant difference in ZNF518A expression was observed between tumor and normal tissues in prostate adenocarcinoma (PRAD), lung squamous cell carcinoma (LUSC), and several other cancer types ($p > 0.05$).

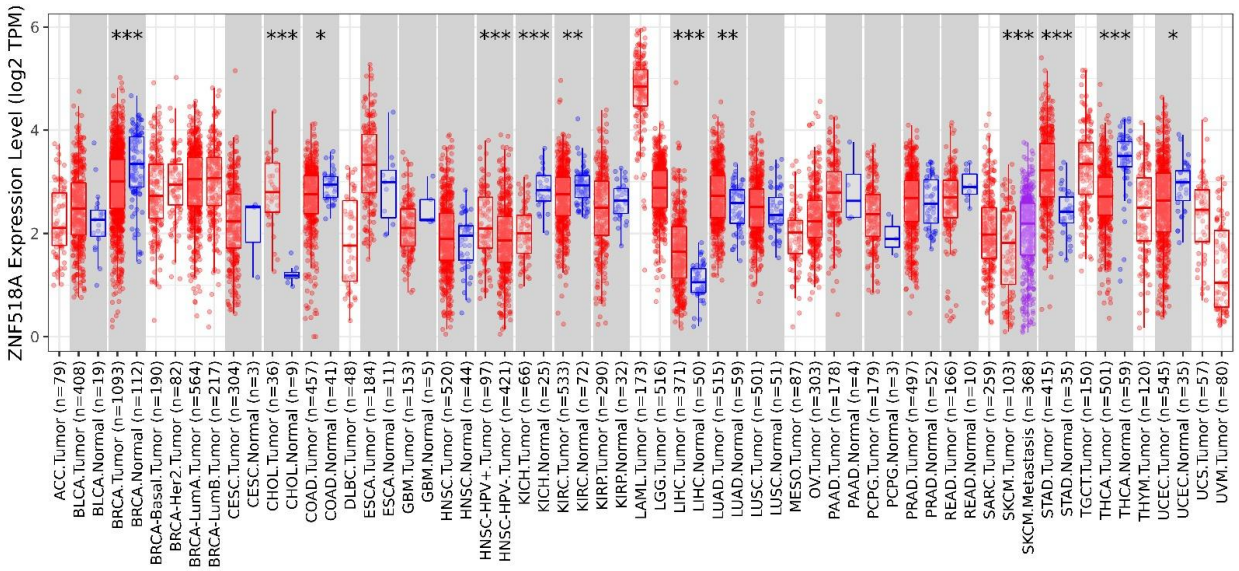


Figure1: Relative expression of ZNF518A in tumor and normal tissues. TIMER 2.0 (http://timer.compgenomics.org/timer) was used to visualize ZNF518A expression across all cancer types.

Red boxes represent ZNF518A expression levels in tumor tissues, while blue boxes indicate expression levels in normal tissues. Statistical significance was indicated as follows: ****: $p \leq 0.0001$, ***: $p \leq 0.001$, **: $p \leq 0.01$, *: $p \leq 0.05$.

Expression of the ZNF518A Gene in Normal and Tumor Tissues in Stomach Adenocarcinoma (STAD) and Its Expression According to Tumor Grade

Analysis using the UALCAN database revealed that the expression of the ZNF518A gene is significantly elevated in stomach adenocarcinoma (STAD) tissues compared to normal gastric tissues. The markedly higher average transcript levels in tumor tissues indicate that this gene is overexpressed in gastric tumors. This finding suggests that ZNF518A may play a potential role in the pathogenesis of gastric cancer (Figure 2).

When comparing the expression levels of the ZNF518A gene across different tumor grades (Grade 1–3) in stomach adenocarcinoma, a general trend of increased gene expression with higher tumor grade was observed. Notably, transcript levels of ZNF518A were significantly elevated in Grade 2 and Grade 3 tumors compared to normal tissue (Figure 3).

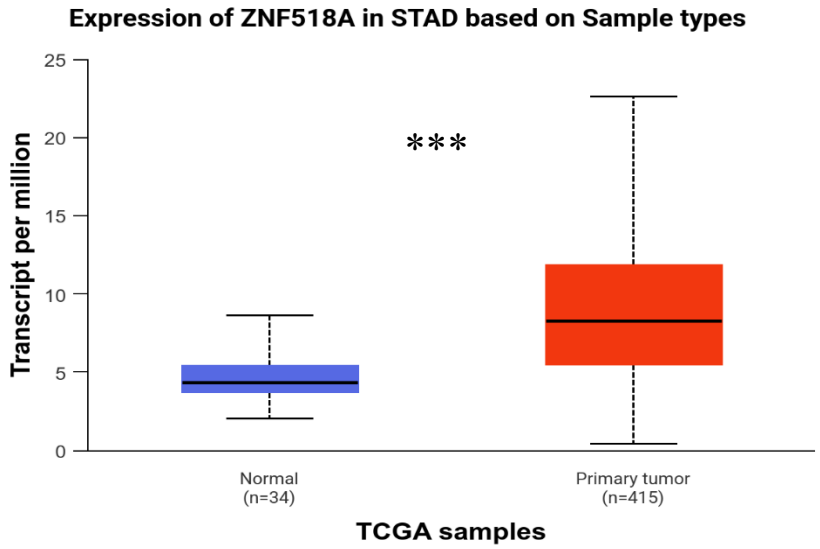


Figure 2: Comparison of ZNF518A Expression Levels in STAD Tissues Using the UALCAN Database (P <1E-12)

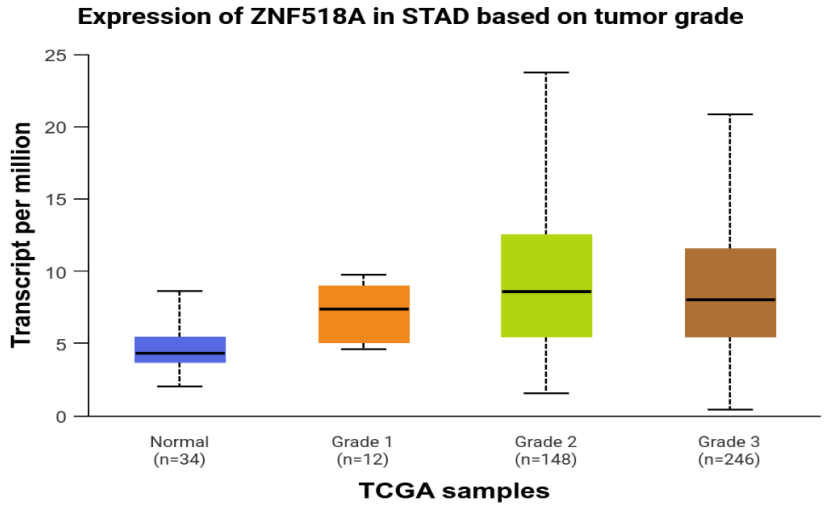


Figure 3: Analysis of ZNF518A Gene Transcript Levels According to Tumor Grade

Survival Analysis

Kaplan–Meier survival curves were analyzed to evaluate the potential impact of ZNF518A gene expression on overall survival in patients with stomach adenocarcinoma (STAD). The analysis was conducted using two different ZNF518A probe sets (215644_at and 244132_x_at). According to the results obtained, patients exhibiting high levels of ZNF518A expression showed significantly poorer overall survival, whereas individuals with low ZNF518A expression had better survival outcomes (Figure 4).

These findings suggest that high expression of the ZNF518A gene may be associated with poor prognosis and potentially play a significant role in tumor biology.

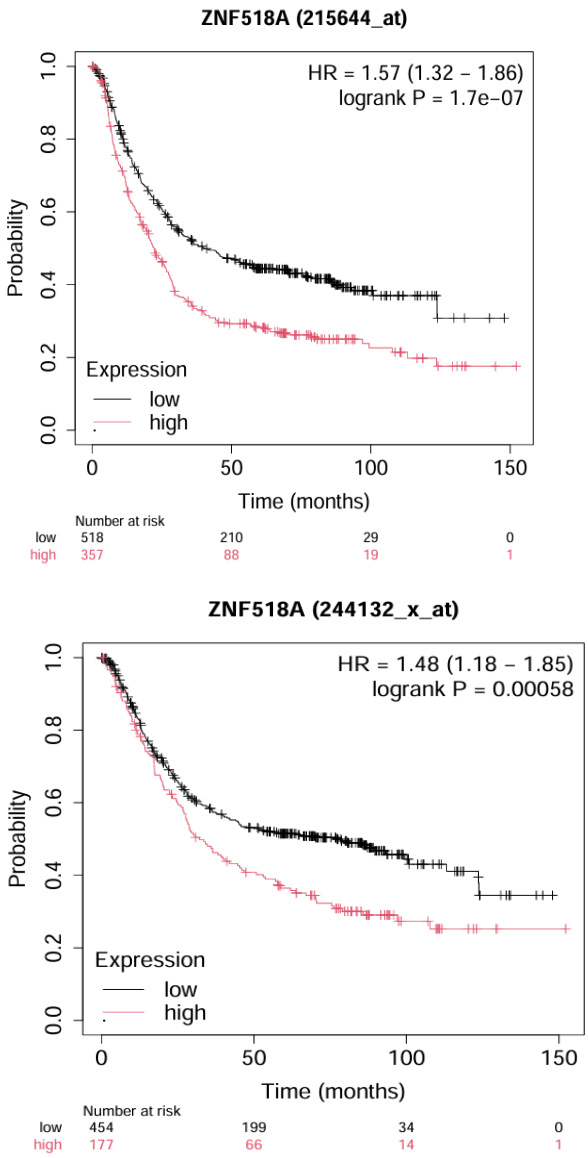


Figure 4: Survival Analysis of ZNF518A in STAD Tissues.

Correlation between ZNF518A gene expression and methylation in sthomac cancer

Correlation analyses revealed statistically significant negative correlations between ZNF518A gene expression and several CpG methylation sites. Notably, at CpG sites cg05953028, cg17330833, cg01457986, and cg19623264, increased methylation levels were associated with a marked decrease in ZNF518A expression (Figure 5.)

These results suggest that the expression level of the ZNF518A gene may be suppressed through epigenetic mechanisms, particularly via DNA methylation. Furthermore, the "Aggregation" analysis also revealed a significant negative relationship between overall CpG methylation levels and ZNF518A expression.

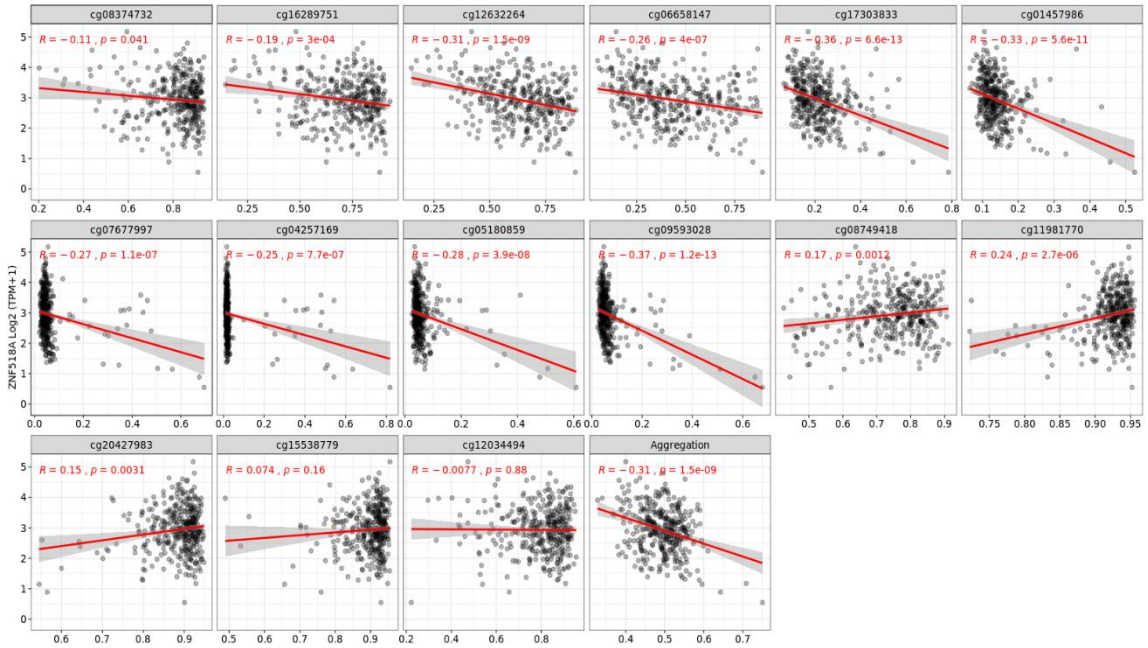


Figure 5: Correlation analysis of gene expression and methylation at specific CpG sites of the ZNF518A gene.

Comparison of Methylation Levels of ZNF518A Across Normal and Tumor Tissues in STAD

Based on the obtained results, the methylation levels of specific CpG sites associated with the ZNF518A gene were compared between stomach adenocarcinoma (STAD) tissues and normal tissues. The analysis revealed that methylation levels at cg20427983 and cg15538779 were significantly decreased in tumor tissues compared to normal tissues, indicating hypomethylation. Additionally, several CpG sites showed p-values approaching statistical significance (e.g., cg09658147; aggregation, p = 0.051).

These findings indicate that tumor-specific hypomethylation patterns exist at certain CpG sites of the ZNF518A gene, and that these epigenetic alterations may be associated with its overexpression.

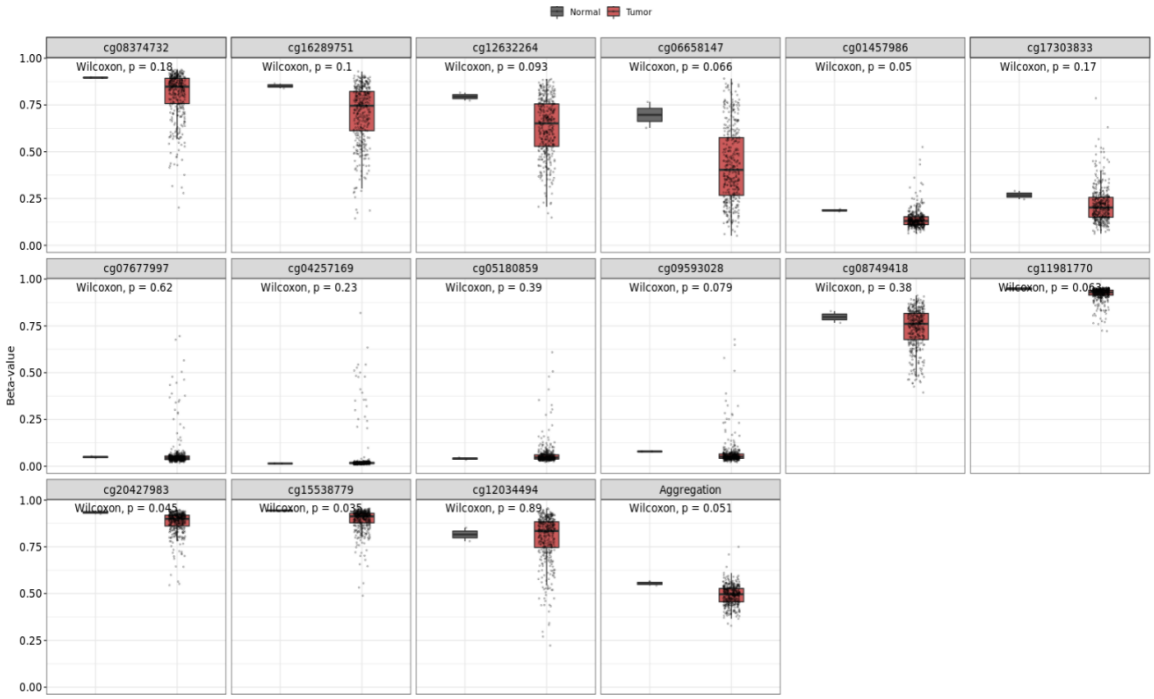


Figure 6: Comparison of methylation levels at CpG sites.

DISCUSSION AND CONCLUSION

In this study, the potential role of the ZNF518A gene in stomach adenocarcinoma (STAD) was evaluated through bioinformatics-based in silico analyses, focusing on gene expression, DNA methylation, and survival data**.** Analyses conducted using the TIMER 2.0 and UALCAN databases demonstrated that ZNF518A gene expression is significantly elevated in gastric tumor tissues compared to normal gastric tissues. This finding suggests that ZNF518A may be transcriptionally active in tumor cells and potentially involved in tumor development.

Kaplan–Meier analyses revealed that stomach adenocarcinoma (STAD) patients with high ZNF518A expression exhibited significantly reduced overall survival. These findings support the potential of ZNF518A as a negative prognostic biomarker. Epigenetic analyses identified hypomethylation at several CpG sites associated with the ZNF518A gene, and negative correlations were observed between gene expression and methylation levels.

Although ZNF518A has not been extensively studied in the context of cancer-related mechanisms, the present findings suggest that it may serve as a potential biomarker and an epigenetically regulated target gene in stomach adenocarcinoma.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Prediction of ballistic properties of alumina ceramic armor under cylindrical projectile impact with artificial neural networks

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Abstract

In this study, numerical simulation and machine learning based analyses were performed to determine the ballistic properties of alumina ceramic armors. Ballistic analyses were performed at high speeds with cylindrical bullets of different sizes on ceramic armors using Ansys autodyn software. As a result of numerical simulations, a data set was created for the residual velocities that occur depending on the ceramic thickness and bullet velocity. The obtained data was used to train the Multi-Layer Perceptron (MLP) model. It was aimed to estimate the residual velocity values that occur after the bullet impact. Bullet model, bullet velocity and ceramic thickness were selected as input parameters. The residual velocity was evaluated as the output parameter. 70% of the data was used for training and 30% for testing. As a result of the study, it was emphasized that MLP algorithms are an effective method in determining the ballistic properties of ceramic armors.
Key words: *(Ballistic, Artificial neural networks, Finite element method, Ansys autodyn)*

INTRODUCTION

Protection against ballistic threats is of great importance in military and security fields. Traditional metal armors are increasingly being replaced by lighter and more effective materials. In this context, ceramics stand out in ballistic protection systems due to their high hardness, fracture toughness and low density (Crouch, 2006). These materials are widely used especially in personal protective equipment (body armor), armored vehicles and aviation applications. Unlike metals and polymers, ceramics are inorganic, crystalline or amorphous materials consisting of atoms bonded together by ionic and/or covalent bonds. These properties provide them with advantages such as high hardness, high melting point, chemical resistance and low thermal conductivity (Richerson, 1992). However, since they are also brittle, they can be broken without undergoing plastic deformation. The most commonly used ceramic materials in ballistic applications are alumina, silicon carbide and boron carbide ceramics. Ceramics are used as part of "hard-faced armor systems" to protect against kinetic energy munitions. Typically, a ceramic layer is combined with an energy-absorbing composite or metal backing. When the ammunition shots the ceramic, the high hardness causes the bullet core to shatter, then the energy is dissipated by the ceramic breaking (Chen et al., 2009).

Hazell et al. (2007) analyzed the resistance of 99% pure monolithic alumina sheets against 7.62 mm AP (armor-piercing) ammunition in their study. Their findings showed that pure alumina can destroy the bullet core, but its effectiveness decreases if the ceramic does not have a support to limit crack propagation after breaking.

Crouch (2006) also evaluated the performance of alumina sheets alone and stated that despite the high hardness, the tendency to brittle fracture limits ballistic performance. In this study, it was emphasized that resistance against penetrating bullets increased significantly as the thickness was increased, but the optimum design in terms of weight/protection balance was important.

Ben-Dor et al. (2005) studied 10 mm thick SiC sheets in a monolithic structure, and in the tests conducted against 5.56 mm and 7.62 mm ammunition, it was observed that SiC eroded the bullet core by erosion and then the sheet was broken into pieces with a crack network. The study showed that the hardness of the ceramic was effective in the first stage of deformation due to the pressure it created on the bullet.

Muscatelli et al. (2010) tested monolithic SiC sheets produced at different sintering temperatures comparatively and reported that high density, low porosity samples provided more successful energy absorption.

Hazen et al. (2012), in his study on boron carbide plates, stated that ceramics performed successfully against 7.62 mm NATO ammunition thanks to their ultra-hard structure, but crack formation spread rapidly throughout the plate after impact. The study revealed that monolithic B_4C not only fragmented the core, but also had a deflecting effect on the bullet.

Gupta et al. (2016), in his study examining the relationship between microstructure properties and ballistic resistance of B_4C ceramic plates, showed that samples with smaller grain sizes had higher crack initiation resistance, but the progressive fracture behavior was directly related to porosity.

In this study, the effects of parameters such as ceramic thickness, bullet type and bullet velocity on the ballistic performance of alumina material used in ceramic armor systems were investigated comprehensively. Machine learning-based modeling techniques such as artificial neural networks (ANN) were used to estimate the residual velocity data obtained as a result of ballistic tests and numerical analyzes. In this way, the effects of different parameter combinations on ballistic performance were made predictable.

MATERIAL AND METHODS

In this study, the ballistic properties of 3 different cylindrical bullets and 6 different thicknesses of alumina ceramic armors were analyzed with the Ansys/autodyn module. Bullets used in numerical analysis studies in the literature were used in the analyses. Bullets and armors are given in Figure 1. Alumina material properties were assigned from the Ansys library for the ceramic material. Steel4340 material in the Ansys library was selected for the bullet. The properties of both materials are given in Figure 2 and Figure 3.

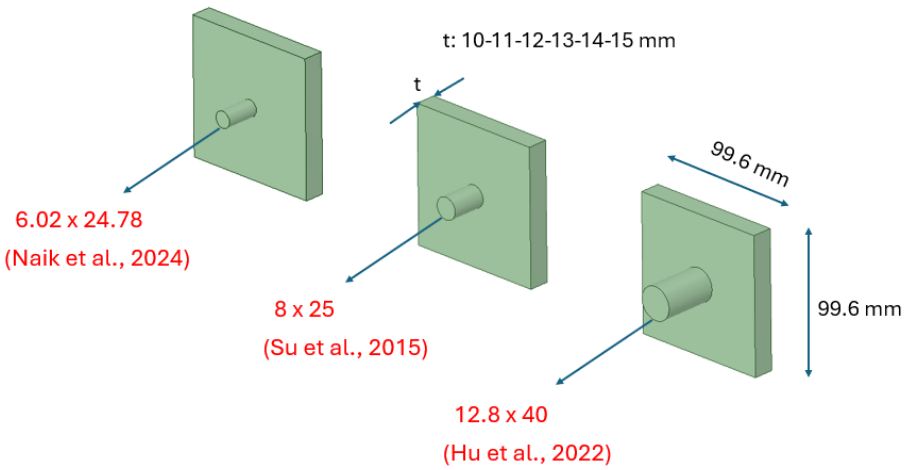


Figure 1. 3D models of bullets and ceramic armor

Properties of Outline Row 5: STEEL 4340

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7830	kg m^-3		
4	Specific Heat, C_p	477	J kg^-1...		
5	Johnson Cook Strength				
6	Strain Rate Correction	First-Order			
7	Initial Yield Stress	7,92E+08	Pa		
8	Hardening Constant	5,1E+08	Pa		
9	Hardening Exponent	0,26			
10	Strain Rate Constant	0,014			
11	Thermal Softening Exponent	1,03			
12	Melting Temperature	1519,9	C		
13	Reference Strain Rate (/sec)	1			
14	Bulk Modulus	1,59E+11	Pa		
15	Shear Modulus	8,18E+10	Pa		

Figure 2. Steel4340 material properties

Properties of Outline Row 3: AL203-99.7

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	3800	kg m^-3		
4	Johnson-Holmquist Strength Continuous				
5	Failure Type	Gradual			
6	Hugoniot Elastic Limit HEL	5,9E+09	Pa		
7	Intact Strength Constant A	0,989			
8	Intact Strength Exponent N	0,3755			
9	Strain Rate Constant C	0			
10	Fracture Strength Constant B	0,77			
11	Fracture Strength Exponent m	1			
12	Maximum Fracture Strength Ratio SFMAX	0,5			
13	Damage Constant D1	0,01			
14	Damage Constant D2	1			
15	Bulking Constant B	1			
16	Hydrodynamic Tensile Limit T	-2,9E+07	Pa		
17	Bulk Modulus	2E+11	Pa		
18	Shear Modulus	1,35E+11	Pa		

Figure 3. Alumina material properties

A friction coefficient of 0.2 was assigned between the bullet and the armor. The ceramic armor was supported by fixed support from all corners. The bullets shot the ceramics with velocities of 800, 900 and 1000 m/s. Residual velocities were obtained as a result of the analysis. The interface of the Autodyn module where the analyses were performed is given in Figure 4.

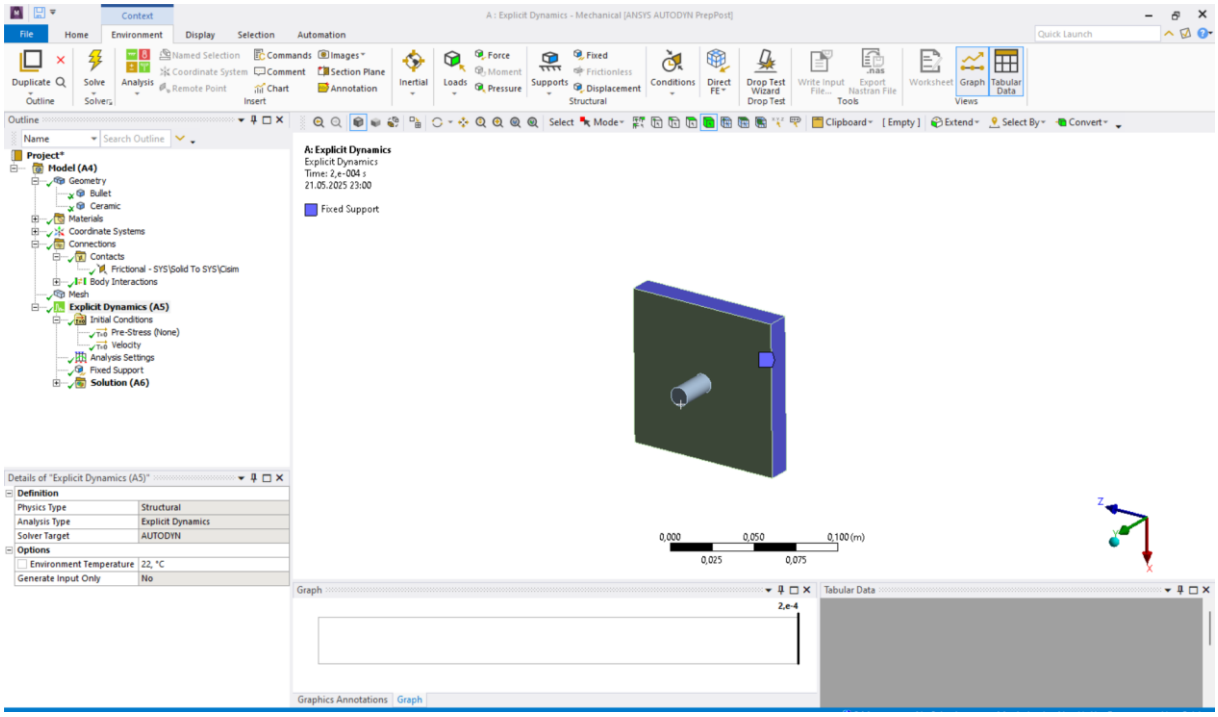


Figure 4. Ballistic analysis interface

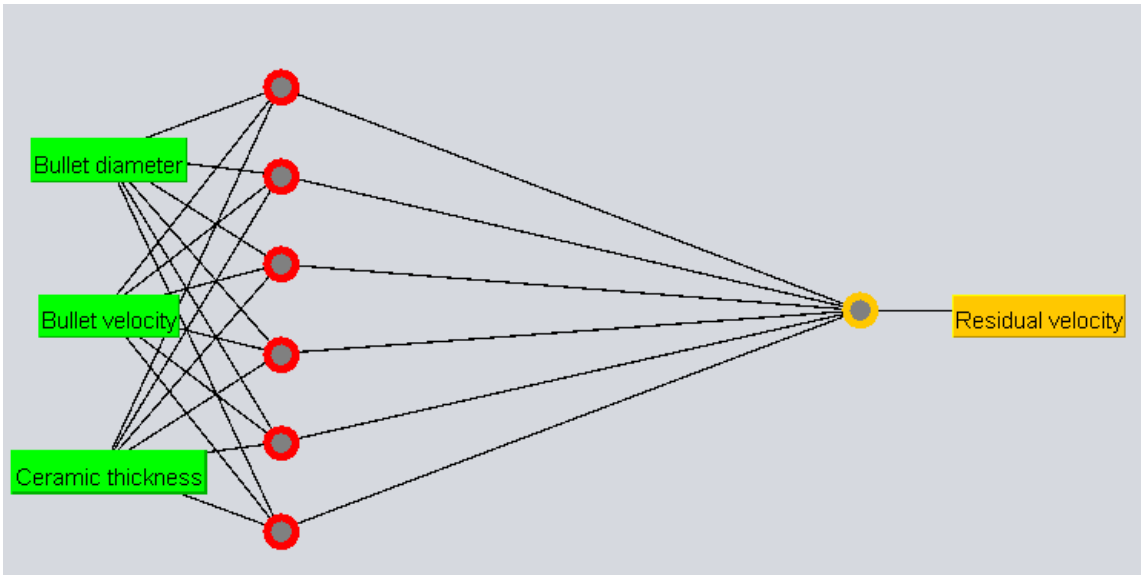


Figure 5. ANN network structure

ANN modeling was performed using WEKA software with the obtained residual velocity values. Bullet diameter, bullet velocity and ceramic thickness were used as input parameters in ANN. Different hidden layer variations were tried. And residual velocity was selected as the output parameter. ANN network structure is given in Figure 5.

RESULTS

Shots were fired at 3 different speeds with 3 different cylindrical bullets against 10, 11, 12, 13, 14 and 15 mm thick alumina ceramic armor. As a result of the analysis performed with the Ansys autodyn module, full penetration was observed for all armors for all speeds and bullets. The full penetration and deformation in the armor are seen in Figure 6.

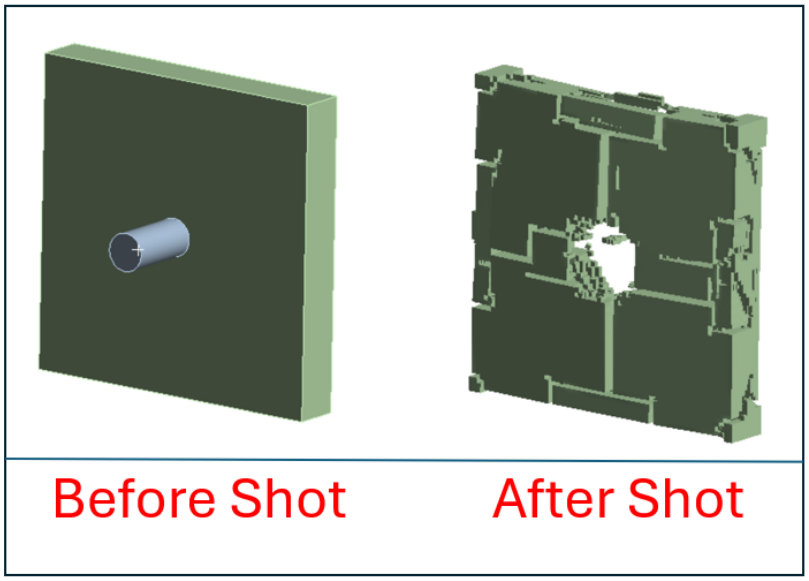


Figure 6. Views before and after shot

Table 1. ANN network structure and results for residual velocity estimation.

Model No	Learning Rate	Momentum	Network Structure	Training Set			Testing Set		
				R	MAE	RMSE	R	MAE	RMSE
1	0.05	0.05	3-2-1-1	0.9973	13.8072	16.9420	0.9924	24.1212	29.3373
2	0.05	0.05	3-3-1-1	0.9975	13.7789	16.4736	0.9928	24.5884	29.1680
3	0.05	0.05	3-4-1-1	0.9972	13.8175	16.9586	0.9926	24.7382	29.1946
4	0.05	0.05	3-5-1-1	0.9969	13.9286	16.9654	0.9927	24.0157	29.6293
5	0.05	0.05	3-6-1-1	0.9968	13.8175	16.9586	0.9925	24.9831	29.4027
6	0.05	0.05	3-7-1-1	0.9965	13.8175	16.9586	0.9924	24.2268	29.9105
7	0.1	0.1	3-2-1-1	0.9977	13.6341	16.8200	0.9932	23.7571	28.8534
8	0.1	0.1	3-3-1-1	0.9975	13.6229	16.7372	0.9939	23.6262	28.8796
9	0.1	0.1	3-4-1-1	0.9976	13.5371	16.8182	0.9932	23.6018	28.8271
10	0.1	0.1	3-5-1-1	0.9976	13.5825	16.7778	0.9933	23.5589	28.7811
11	0.1	0.1	3-6-1-1	0.9979	13.4448	16.7098	0.9937	23.2923	28.7752
12	0.1	0.1	3-7-1-1	0.9975	13.5885	16.8544	0.9935	23.6554	28.9654

Table 1 presents twelve separate MLP models developed as part of the ANN optimization process. Each model was built using WEKA software with varying parameter configurations. These parameters include the learning rate, momentum value, and the basic components of the network structure. While the learning rate controls the learning rate of the model, the momentum value affects the update rate of the weights, and the network structure determines the depth and complexity of the model. During the optimization process, the performance of each model was evaluated on the test dataset. This evaluation was made based on important error metrics such as linear correlation coefficient (R), mean absolute error (MAE), and root mean square error (RMSE). These metrics measure the differences between the predicted values of the model and the actual values and reveal the accuracy of the model. As a result of the tests, it was observed that Model 13 exhibited lower error rates in terms of MAE, MAPE, and RMSE values compared to the other models. As a result, Model 13 was determined as the most suitable model for the MLP approach. This optimization process increased the accuracy of ballistic analyses and contributed to improved efficiency and faster computations. The superior performance of Model 13 further highlights the potential of the MLP method in advancing ballistic analysis. Figure 7 shows the interface of the WEKA software, where the machine learning method is implemented.

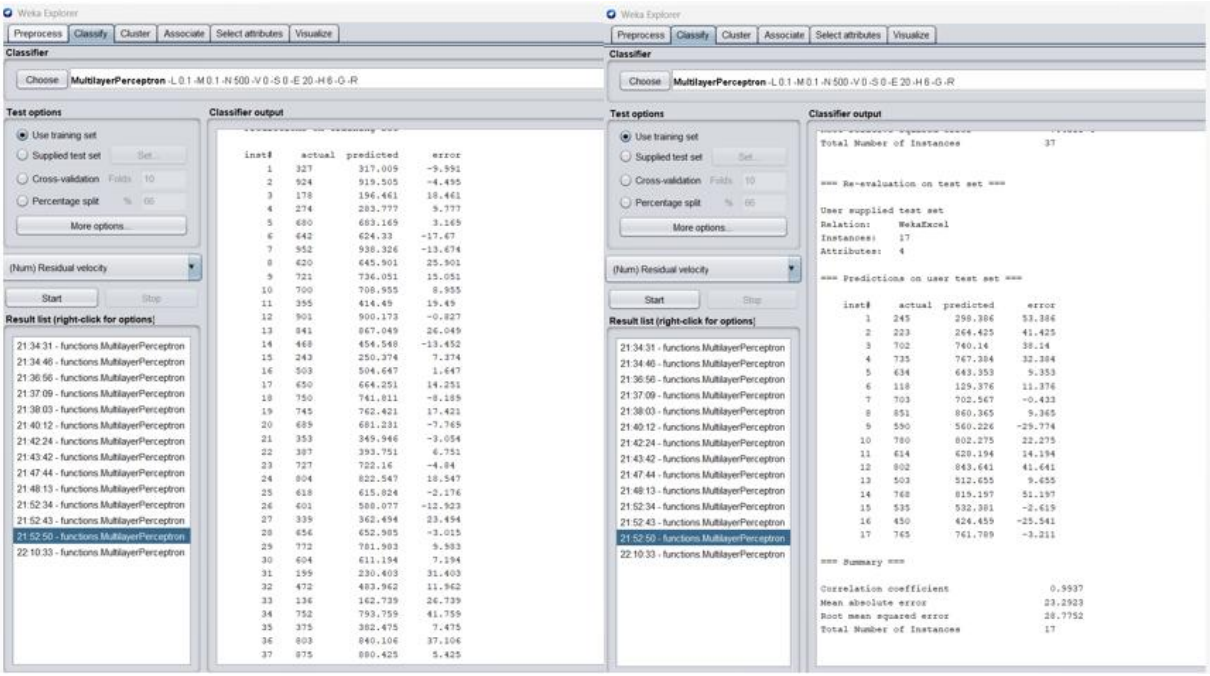


Figure 7. WEKA Software interface

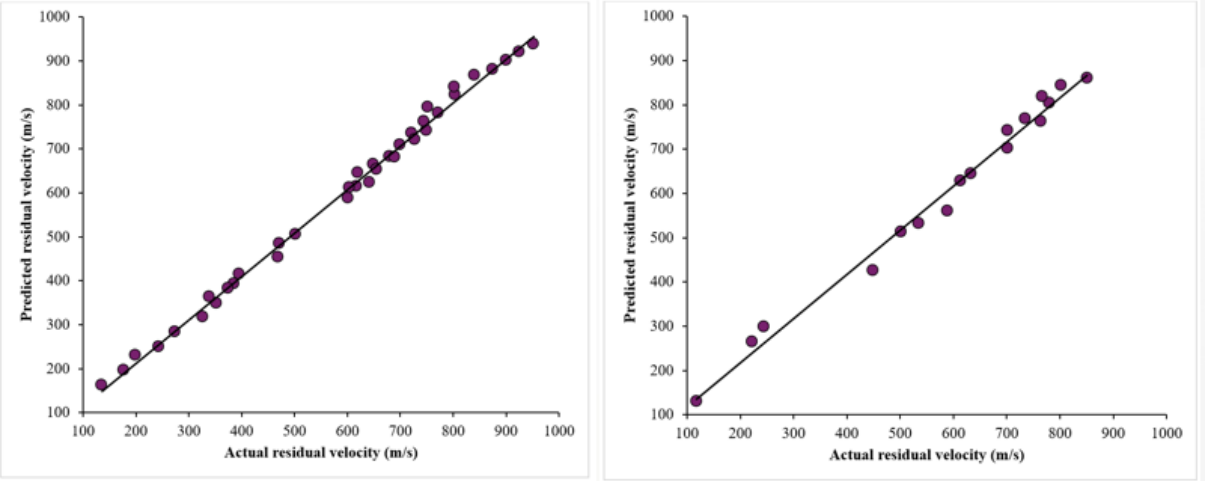


Figure 8. Residual velocity estimation results with ANN method

Figure 8 presents the residual velocity estimation results for both training and testing sets using the ANN method. From Figure 8, it can be seen that the ANN method achieved an R value of 0.9979, a MAE of 13.4448, and a RMSE of 16.7098 for the training set. For the testing set, the MLP method produced an R value of 0.9937, a MAE of 23.2923, and a RMSE of 28.7752.

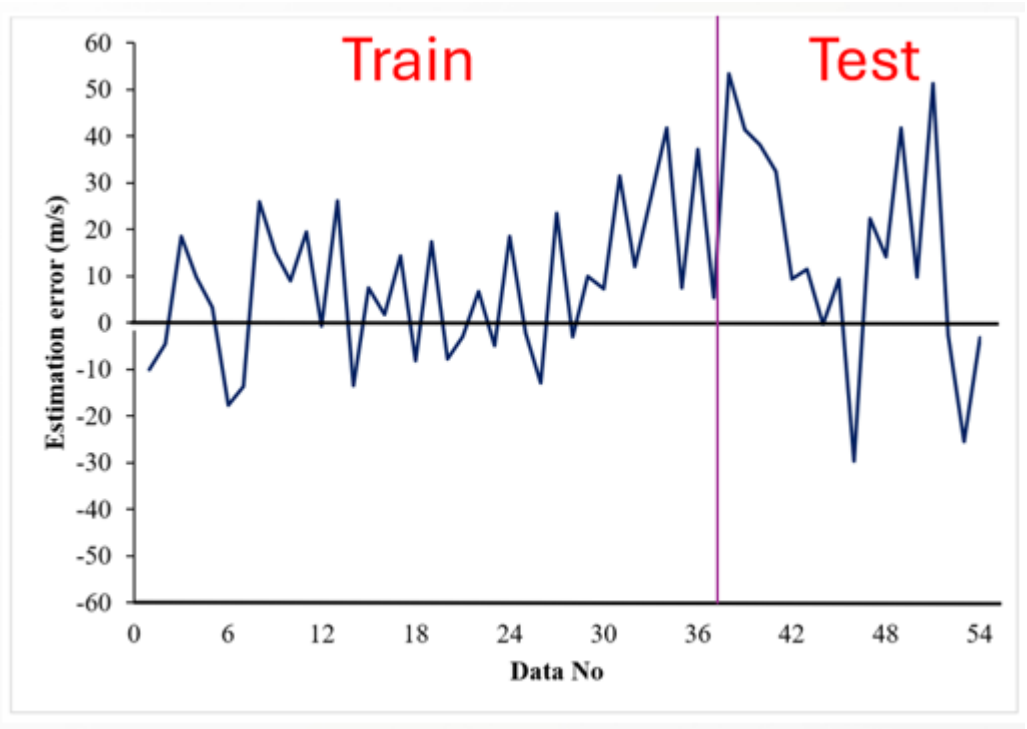


Figure 9. Estimation errors

Figure 9 shows the residual speed estimation errors obtained using the ANN method. The error values on the Y-axis represent the difference between the predicted and FEA residual speed values. A larger deviation from the zero point on the Y-axis indicates poorer estimation performance, while a smaller deviation indicates superior estimation accuracy.

DISCUSSION AND CONCLUSION

In this study, the effects of ceramic thickness, bullet type and bullet velocity on the ballistic properties of alumina armors were investigated. ANN, one of the machine learning methods, was also used to estimate the residual velocity values obtained from the analyses. According to the results obtained from the analyses:

• Full penetration was observed in all armors.

• Radial fractures occurred in ceramic armors.

• Mushrooming effect was observed in bullets.

• As the bullet diameter increases, the residual velocity value increases.

• As the bullet impact speed increases, the residual velocity value increases.

• ANN gave good results in residual velocity estimation.

• ANN optimization reduced the estimation error rate.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Biomechanical Analysis of Tibial Fractures Using Finite Element Method

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Abstract

In this study, static structural analyses were performed with the implant design made in the Ansys Workbench program by creating a fracture model with 3 different thicknesses in the middle of the tibia shaft. 316L SS and Ti–6Al–4V alloy materials were used as implant and screw materials. All materials were assumed to be isotropic and linear elastic in the analysis. Axial loads from 500 N to 1000 N simulating an adult standing on one leg were applied to the fractured tibia model to represent the body weights of people with different kilograms. As a result of finite element analysis (FEA), the mechanical behaviors of different implant and biomaterial combinations were compared by considering the maximum stress values occurring in the implants and screws. It was found that the maximum stress value in implants with 316L SS material properties was higher than the maximum stress value in Ti-6Al-4V alloy implants.

Key words: *(Biomedicine, Ansys, Finite element analysis, Static structural analyses)*

INTRODUCTION

Tibial shaft fractures represent one of the most prevalent long bone injuries in adult populations, accounting for approximately 15% of all adult fractures (Economedes et al., 2014). These injuries frequently result from high-energy trauma, such as motor vehicle collisions or falls from significant heights, and are associated with complex soft tissue involvement and substantial biomechanical disruption. Due to the nature of these mechanisms, tibial diaphyseal fractures pose significant clinical challenges not only during the acute phase but also throughout the long-term rehabilitation period. Prolonged hospitalization, risk of delayed union or non-union, permanent functional impairment, and elevated healthcare costs render these fractures a major concern for orthopedic trauma management.

The treatment of tibial shaft fractures involves a spectrum of both surgical and conservative modalities. Selection of the appropriate method is highly dependent on fracture characteristics (e.g., pattern, location, and whether the fracture is open or closed), as well as patient-specific factors such as age, bone quality, comorbidities, and surgeon expertise. The most commonly employed surgical interventions include intramedullary (IM) nailing, plate and screw fixation, and external fixation. In select low-energy, minimally displaced fracture cases, conservative management through long-leg casting or functional bracing may be appropriate (Li et al., 2014; Beardi et al., 2008).

Plate osteosynthesis requires careful consideration of several biomechanical variables that influence construct stability: plate positioning (e.g., medial vs. lateral), plate span length, the number and type of screws (locking vs. cortical, unicortical vs. bicortical), screw placement strategy, and overall implant stiffness. These parameters collectively determine the load-sharing behavior and interfragmentary motion at the fracture site, which are critical to the biological healing process.

In addition to experimental studies, computational approaches such as Finite Element Analysis (FEA) have become increasingly valuable for evaluating the mechanical performance of different fixation configurations. FEA enables detailed assessment of stress distribution, deformation, and micromotion under physiological loading conditions, thereby providing insights into optimal implant designs and placement strategies that are difficult to capture in vivo or through cadaveric studies (Olçar et al., 2024).

In this study, internal fixation via plate and screw constructs was employed using two widely investigated biomaterials: Ti–6Al–4V titanium alloy and 316L stainless steel. Both materials are extensively used in orthopedic implantology due to their favorable biomechanical and biocompatibility properties, yet they exhibit distinct differences in elastic modulus, corrosion resistance, and osseointegration potential.

MATERIAL AND METHODS

In this study, 3D modeling of tibia, implants and cortical screws was performed with Ansys/SpaceClaim module and static structural analysis was performed in Ansys Workbench. All materials were assumed to be isotropic and linearly elastic in the analysis. Two different biomaterials, Ti–6Al–4V and 316L stainless steel, were defined for implants and cortical screws. Ti–6Al–4V alloy and 316L stainless steel were selected as implant materials in this study because they are widely used in biomedical applications due to their superior mechanical properties and proven biocompatibility. Ti–6Al–4V has a Young's modulus of 114 GPa, a Poisson's ratio of 0.34 and a yield stress of 830 MPa (Oken et al., 2011). 316L SS has a Young's modulus of 193 GPa, a Poisson's ratio of 0.28 and a yield stress of 332 MPa (Oken et al., 2011; Mohammad et al., 2013). Tibial Cortical Bone has a Young modulus of 20 GPa, a Poisson ratio of 0.3, and a yield stress of 120 MPa (Benli et al., 2008; Beillas et al., 2001). The mechanical properties of all materials are shown in Table 1. Three different fractures were defined in the tibial shaft as 2, 4, and 6 mm. The implant was placed centered at the fracture center. The visual of the three different fractures and implant placement is given in Figure 1 and the implant and cortical screw are given in Figure 2.

Table 1. Mechanical properties of materials.

Materials	Young's modulus (GPa)	Poisson ratio	Yield strength (MPa)
Tibia Cortical Bone	20	0.3	120
Ti–6Al–4V	114	0.34	830
316L SS	193	0.28	332

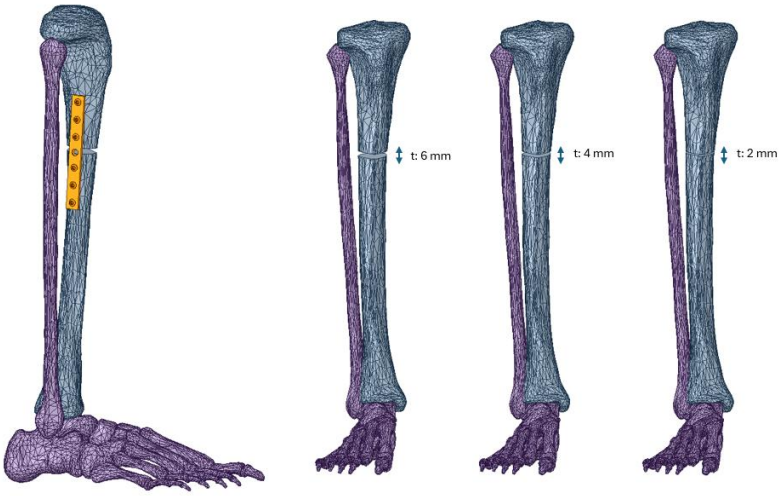


Figure 1. Different fracture values



Figure 2. View of implant

Figure 3 shows the loading status and support types applied to the Tibia shaft. A total of 6 different human weights were taken as reference, increasing by 10 kg from 50 kg to 100 kg. Structural analyzes were performed to measure the stress values occurring in the implant by applying forces between 500 N and 1000 N.

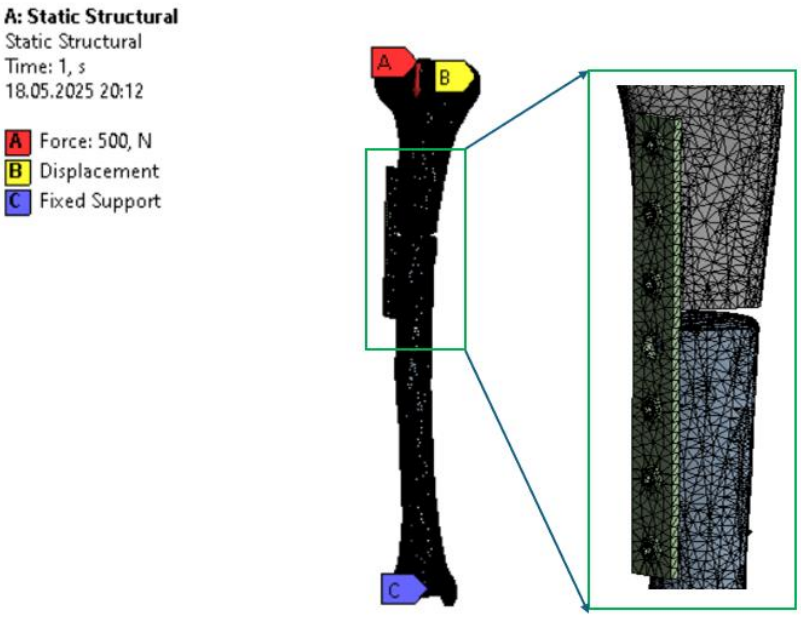


Figure 3. Alumina material properties

RESULTS

This study was performed using Ansys/Workbench, a powerful software for engineering simulations and analyses. The stresses developed in the implants were investigated by applying axial compressive forces of 500 N, 600 N, 700 N, 800 N, 900 N and 1000 N to the apex of the distal tibia in full extension. Figure 4 shows the stress values for 6 different loading conditions in 316 L implants for a 2 mm fracture gap. Figure 5 shows the stress values for 6 different loading conditions in Ti6Al4V implants for a 2 mm fracture gap. Figure 6 shows the stress values for 6 different loading conditions in 316 L implants for a 4 mm fracture gap. Figure 7 shows the stress values for 6 different loading conditions in Ti6Al4V implants for a 4 mm fracture gap. Figure 8 shows the stress values for 6 different loading conditions in 316 L implants for a 6 mm fracture gap. Figure 9 shows the stress values for 6 different loading conditions in Ti6Al4V implants for a 6 mm fracture gap.

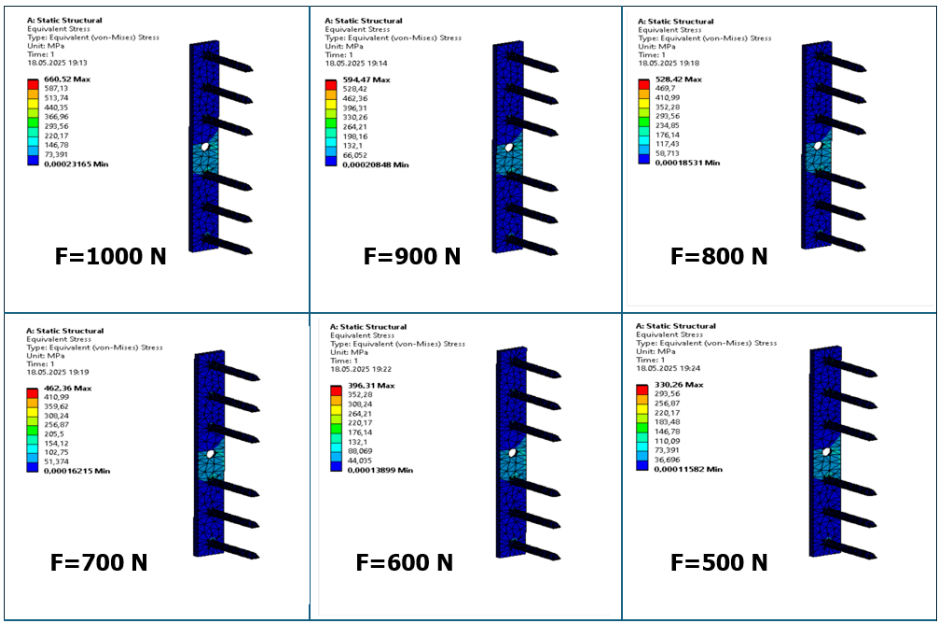


Figure 4. Maximum stress values for 316 L (t=2 mm)

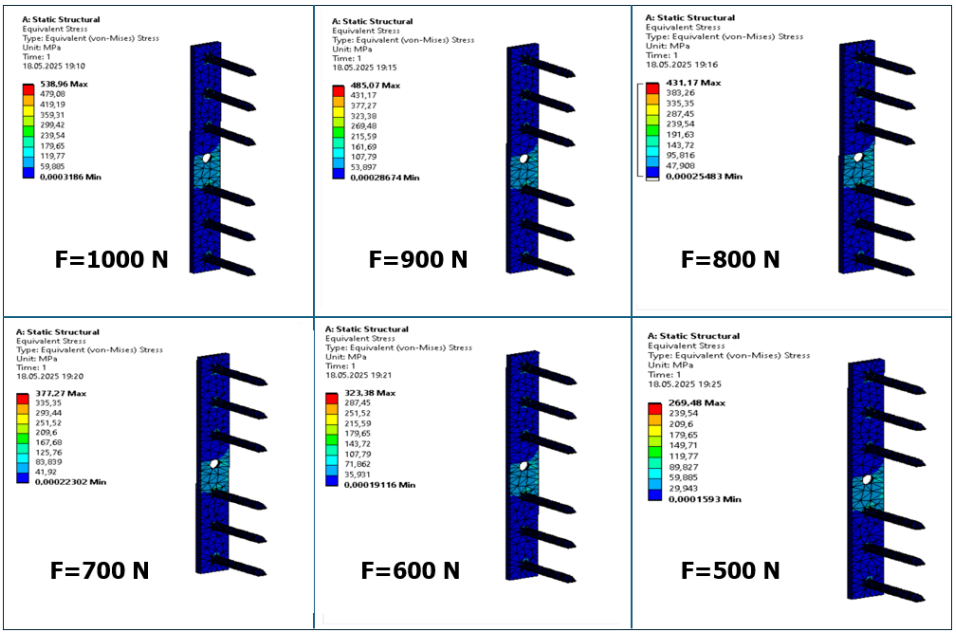


Figure 5. Maximum stress values for Ti6Al4V (t=2 mm)

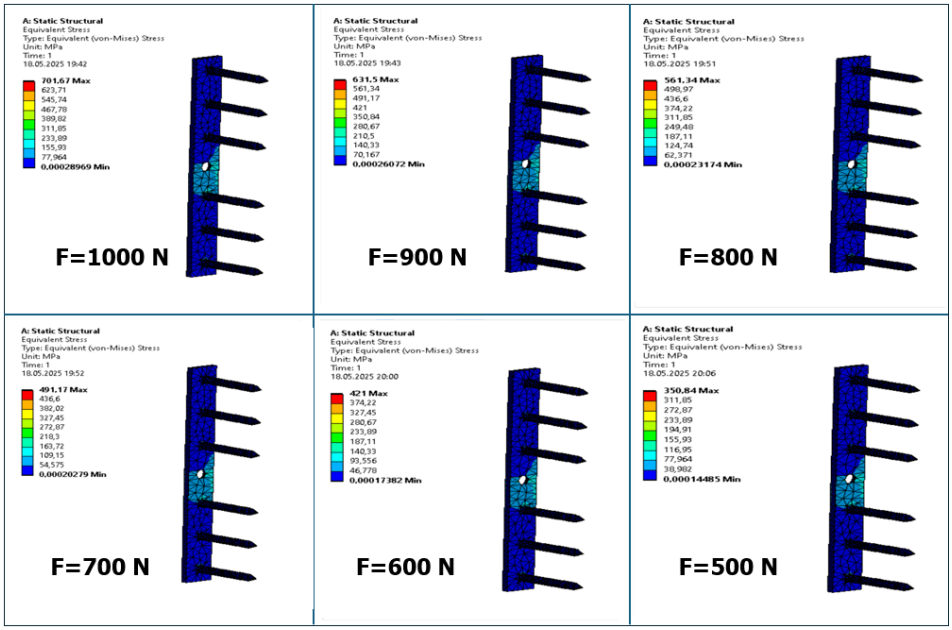


Figure 6. Maximum stress values for 316 L (t=4 mm)

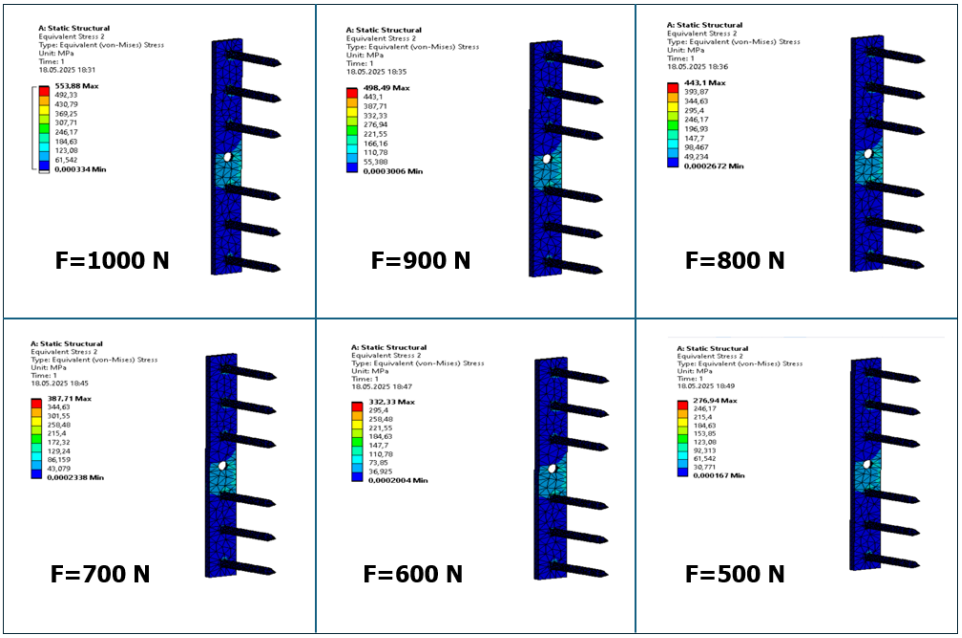


Figure 7. Maximum stress values for Ti6Al4V (t=4 mm)

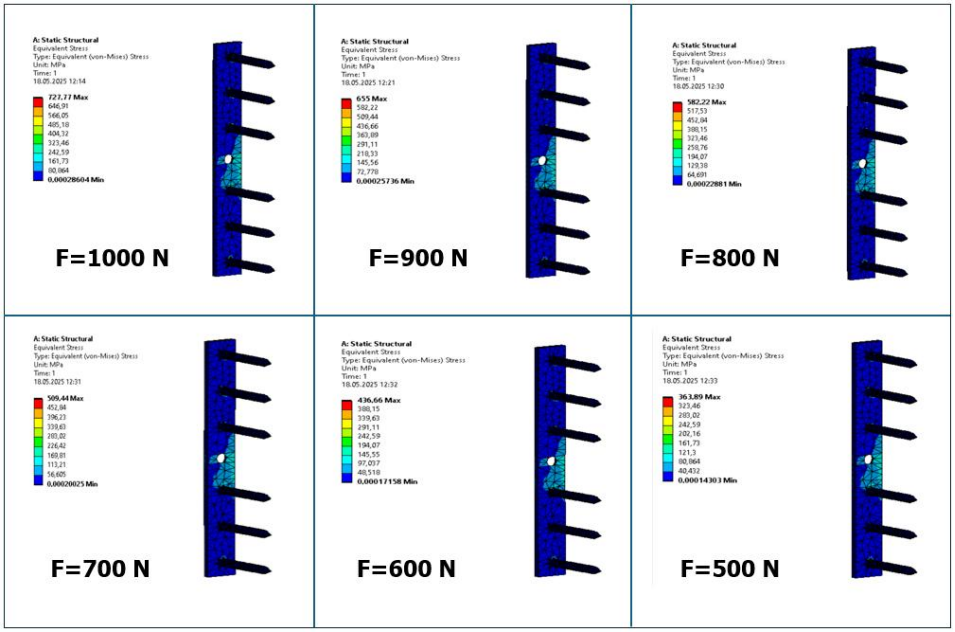


Figure 8. Maximum stress values for 316 L (t=6 mm)

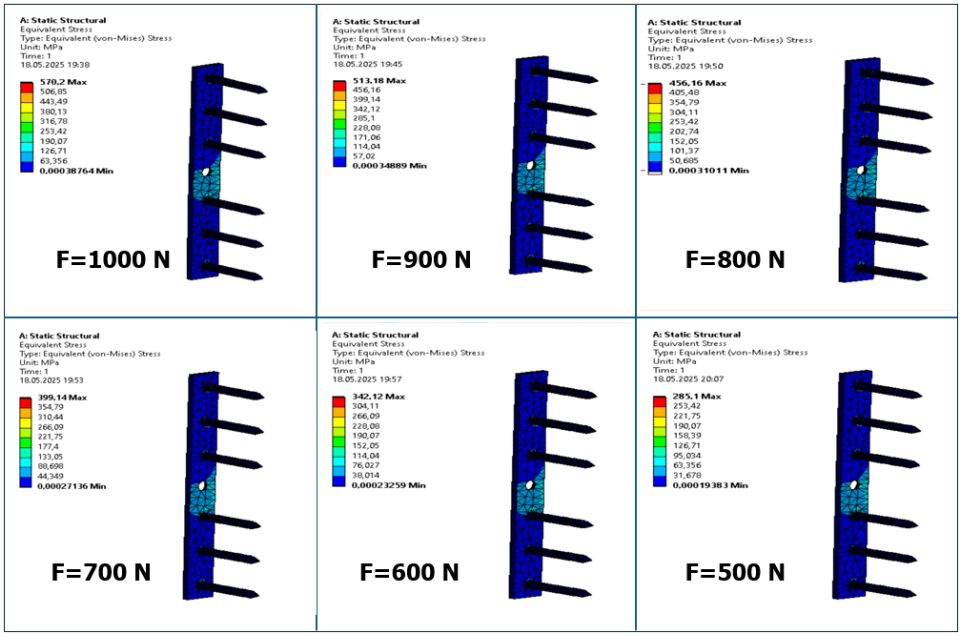


Figure 9. Maximum stress values for Ti6Al4V (t=6 mm)

In FEM analyses, stress concentration was observed around the hole in the center of the plate, that is, in the tibial fracture region. Table 2 shows the stress values for implants in 3 different fracture gaps and 6 different loading conditions for both material groups. The lowest stress occurred in the Ti6Al4V alloy where the fracture gap was 2 mm at 500 N loading. The highest stress occurred in the 316 L material implant where the fracture gap was 6 mm at 1000 N loading.

Table 2. Stress values for implants

Material / Force	316 L			Ti6Al4V		
	t=2 mm	t=4 mm	t=6 mm	t=2 mm	t=4 mm	t=6 mm
500 N	330 MPa	350 MPa	363 MPa	269 MPa	276 MPa	285 MPa
600 N	396 MPa	421 MPa	436 MPa	323 MPa	332 MPa	342 MPa
700 N	462 MPa	491 MPa	509 MPa	377 MPa	387 MPa	399 MPa
800 N	528 MPa	561 MPa	582 MPa	431 MPa	443 MPa	456 MPa
900 N	594 MPa	631 MPa	655 MPa	485 MPa	498 MPa	513 MPa
1000 N	660 MPa	701 MPa	727 MPa	538 MPa	553 MPa	570 MPa

DISCUSSION AND CONCLUSION

In this study, Ti-–6Al-–4V alloy and 316L stainless steel material implants were used in 3 different fracture intervals, and forces were applied from 500 N to 1000 N, increasing by 100, and the stress values in the implants were examined.

Tümer et al. (2020) found the maximum stress value in 316L stainless steel to be higher in the finite element analysis they conducted with Ti-–6Al-–4V alloy and 316L stainless steel material implants. They observed an increase in the maximum stress value as the force applied to the tibia increased. El-Desouky et al. (2022) observed that the stress values on the implant increased as the fracture interval increased. Titanium implants exhibited better mechanical performance than stainless steel implants. The current study supports both studies.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

The Importance for Disaster and Emergency Management of Early Warning Systems Based on Artificial Intelligence

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Abstract

A disaster is a serious disruption that occurs suddenly and causes damage to people, infrastructure, the environment, and the economy, having a profound impact on society. Turkey faces disasters of varying types and severity every year due to its geographical and geological characteristics. Since the location, time, size, and severity of disasters cannot be predicted with certainty, effective disaster management requires a proactive approach and a rapid, coordinated, and comprehensive response. A multidimensional approach is needed to reduce the damage caused by disasters, mitigate their effects, and eliminate disaster risks. Today, the increasing frequency of natural and man-made disasters and the disorganization of infrastructure warn us that we need to develop more flexible, safe, and resilient emergency response systems. This situation suggests the development of early warning systems that provide information as alerts or warnings to vulnerable communities before or during disasters so that effective and coordinated action can be taken in time to prevent and reduce losses and damage caused by disasters. In disaster management, the emergence of secondary disasters increases the need for technological solutions and early warning systems. These technologies include machine-learning algorithms that can predict floods, which can be a secondary disaster, and drones that can be used to transport the needs of people affected by disasters. In addition, artificial intelligence (AI) has made significant progress in developing models for disaster prediction and early warning. The aim of this research is to touch upon the importance of early warning systems based on artificial intelligence in the management of disasters and emergencies, which are essential for our country, in the light of the literature.

Keywords: *AI-Based Emergency Response, Disaster management, Early warning system*

INTRODUCTION

Disasters cause physical, socio-economic, and psychological losses, disrupting normal life and preventing development and progress. Disasters highlight the inadequacy of society's ability to react to and adapt to events. In our country, the most common disasters recently have been earthquakes, floods, landslides, rockfalls, avalanches, forest fires, droughts, technological disasters, transport accidents, environmental pollution, and migration. In addition, global epidemics, cyber threats, and climate change can create new disaster risks in our country. The concept of disaster management includes pre-disaster mitigation and preparation, disaster response, and post-disaster recovery efforts, as well as a wide range of activities such as risk assessment, disaster and emergency planning, resource management, and communication, cooperation, and coordination. Disaster management is a strategic and comprehensive

process involving mitigation, preparation, intervention, rescue, and recovery, with the aim of protecting vulnerable communities from potential disasters and reducing the damage they cause. Important aspects of disaster management include reducing the risk of disaster, creating preparation plans, and taking proactive steps before disaster strikes. From this perspective, the use of artificial intelligence in disaster management is crucial for safeguarding the lives and property of those affected by disasters, and it will undoubtedly be the future of disaster management (Abid et al., 2021). Our country is frequently exposed to disasters that challenge infrastructure and development, such as mass population movements, due to its international and geographical location. Disasters that cause serious damage should be managed using risk-focused technologies that take into account the characteristics of the age we live in. AI-based systems have emerged as critical enablers of smart infrastructure security, facilitating decision-making processes in various areas such as risk assessment and disaster mitigation strategies (Bajwa, 2025). The accurate results of AI predictions facilitate the swift identification of hazards and risks, enable a faster response to disasters and minimise human error. Artificial intelligence-driven models facilitate risk reduction and proactive disaster preparation by activating early warning systems for earthquakes, forest fires, and floods (Bajwa, 2025). AI technologies help with the early detection of disasters and emergencies, thus enabling immediate intervention. They also facilitate the rapid delivery of urgent supplies and logistics to disaster-affected areas.

One of the main objectives of disaster and emergency management is to reduce or prevent loss of life and property. Technological tools and applications provide effective, comprehensive, and modern support in humanity's fight against natural and man-made disasters. Notable developments, particularly in artificial intelligence (AI), have brought about radical changes in disaster and emergency management (Kocaman, 2025). The use of artificial intelligence-based technologies at different stages is increasing day by day in the fight against various disasters, such as earthquakes, floods, landslides, inundations, hurricanes, tornadoes, tsunamis, migration, epidemics, and droughts. These technologies have become an important tool for protecting life, property, and information in disaster management. These technologies have been widely adopted in many areas, including trade, business, education, and health, as part of the efforts to combat the outbreak of the SARS-CoV-2 virus (Shamman et al., 2023). Traditional disaster and emergency response mechanisms, which mostly rely on human intervention and require urgent decisions, often result in delays, ineffective interventions, and incorrect decisions. Artificial intelligence-based technologies such as machine learning (ML), the Internet of Things (IoT), deep learning (DL) and computer vision have demonstrated their potential to improve disaster preparedness and enhance the performance of disaster and emergency responses (Kong & Woods, 2018). They have been shown to significantly reduce infrastructure damage, loss of life and property by facilitating better decision-making, improving situational awareness, and enabling automatic hazard detection in disaster and emergency situations (Leszczynski, 2016). Earthquake prediction models based on deep learning technology, for example, have successfully analysed seismic activity and provided early warnings, thereby minimising negative impacts on human life and infrastructure (Smigiel, 2018). Similarly, flood monitoring systems integrated with artificial intelligence use hydrological models and remote sensing data to predict and mitigate flood risks (Yao and Wang, 2020). Such systems have greatly enhanced the capacity of institutions responsible for disaster and emergency management to respond proactively, thereby reducing the damage associated with disasters resulting in significant loss of life and property (Evgrafova et al., 2022). Examining artificial intelligence-based emergency response systems reveals significant developments in disaster prediction, industrial hazard prevention, cybersecurity, intelligent traffic control, incident prediction and detection, and healthcare emergency management (Bajwa, 2025).

The Role of Artificial Intelligence in Disaster Management

Disasters and emergencies usually occur suddenly and unexpectedly. They can cause significant damage and loss, and have adverse consequences for victims, including physical, social, emotional, and psychological problems (Velev and Zlateva, 2023). In recent years, disasters have become more frequent and severe all over the world. This means that disaster interventions need to be carried out more effectively and appropriately than in previous years (Kankanamge et al., 2021). Effective management of disasters and emergencies is crucial in reducing their negative impact on communities (Fares et al., 2021). If rapid and effective responses to disasters cannot be provided, however, existing risks will increase exponentially (Lee et al., 2023). In this advanced age, accurate information collected from various sources and past disasters must be used in disaster management, especially in the risk management phase. Recently, attempts have been made to integrate disaster management applications with digital tools and new information technology solutions, most commonly artificial intelligence-based applications (Tan et al., 2020). Artificial intelligence (AI) is a major innovation in the fields of computers, electronics and information and communication technology. There is no universally accepted definition of AI; different researchers define it in different ways (Rahmatizadeh and Kohzadi, 2024). Artificial intelligence (AI) refers to computers or machines designed to mimic the learning, problem-solving, and cognitive abilities usually associated with the human brain. Another definition describes artificial intelligence as a technology that uses data with complex properties and applies various techniques to achieve specific objectives (Wang, 2008).

The use of artificial intelligence in disaster management is expanding today. In many cases, people benefit directly or indirectly from AI. Examples of this include using artificial intelligence-based methods to analyse disaster-related information on social media, using artificial intelligence to encourage information sharing in disasters, and using public cooperation and artificial intelligence-supported game programs and simulations to increase public disaster awareness (Sun et al., 2020). Historical disasters often reveal that emergency responses are slow and inadequate. Human capabilities may be insufficient for processing large amounts of environmental data and using it to inform rapid responses. Artificial intelligence is now emerging as a powerful resource for such situations. Many organizations are researching AI to enable them to respond quickly and effectively to emergencies (Rahmatizadeh and Kohzadi, 2024). Recent advances in artificial intelligence have given researchers and scientists access to significantly larger and more diverse data sets. AI makes it possible to predict natural disasters and their potential risks, offering proactive strategies for effective disaster management (Aboualola et al., 2023). Studies on fire risk show that hybrid models excel at identifying areas at risk of fire. Designing special programs and using machine learning models to predict evacuation times can increase preparedness for and response to fire events (Wu et al., 2021).

Disasters have the potential to cause significant damage and socio-economic loss. Therefore, disaster managers must proactively protect society by developing effective management strategies. Studies on disaster management and artificial intelligence focus on using artificial intelligence to perform disaster management quickly and effectively during the four phases of disaster management: damage reduction and preparation, response, rescue, and recovery (Sun et al., 2020; Gupta & Roy, 2024). Gupta and Roy (2024) conducted a review of 72 studies on the application of AI at various stages of disaster management, including simulation, prediction, detection, and post-disaster management. The studies suggest that AI-based systems can enhance early warning systems, optimize relief logistics, facilitate risk communication, and support evacuation planning. The analysis focuses on the transformative potential of AI in all phases of disaster management, from mitigation and prevention to preparedness,

response, and recovery. As Figure 1 shows, 60% of the reviewed studies recommend using AI methods to improve preparedness for different types of disasters. A quarter of the studies focus on the response phase, while the remainder focus on disaster mitigation and recovery.

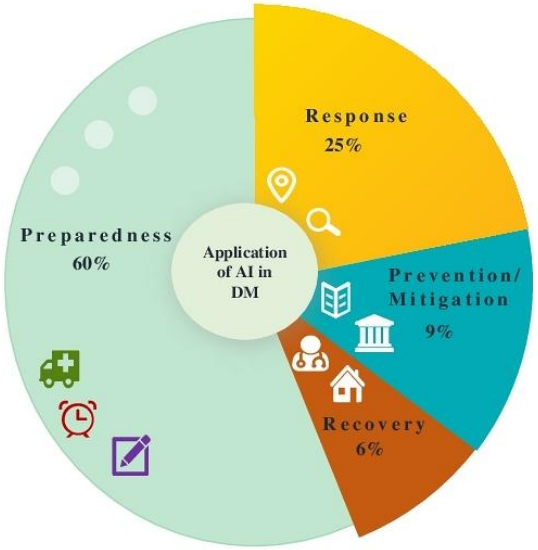


Figure 1. Percentage use of AI Techniques in different phases of disaster management.

Bajwa (2025) conducted a systematic review of 424 studies and revealed significant advances in AI-supported emergency response systems. Notable developments were observed in several areas, including disaster prediction, instantaneous incident detection, health emergency management, industrial hazard prevention, cybersecurity frameworks, and intelligent traffic control, as illustrated in Figure 2. AI-powered traffic control and congestion management systems have played a vital role in optimizing the routing of emergency vehicles, reducing transportation delays, and enhancing urban mobility during crises. Compared to traditional emergency response models, AI-powered frameworks have increased efficiency, automation, and decision-making accuracy significantly in many areas by shifting from static, rule-based approaches to dynamic, real-time, adaptive systems.

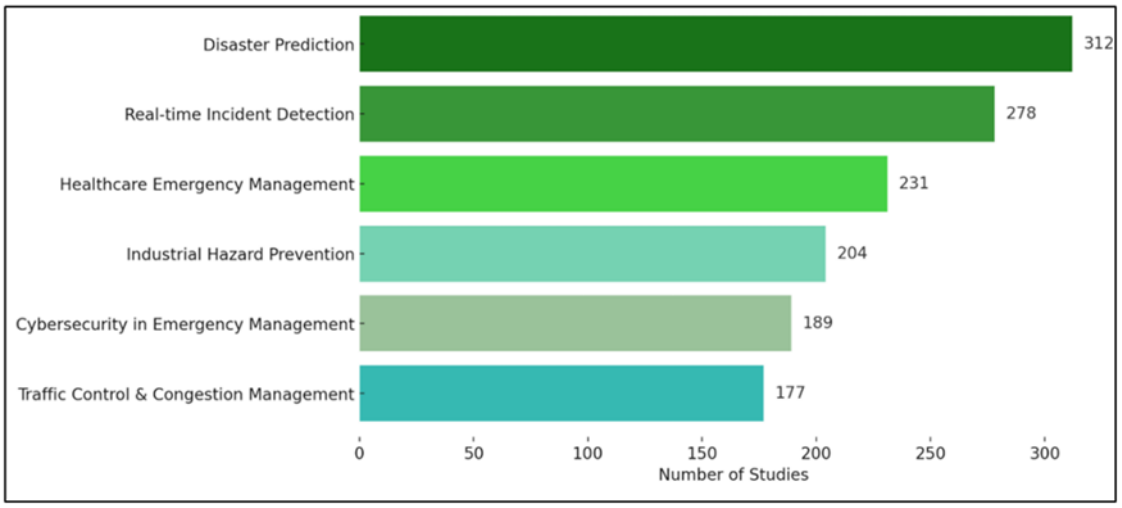


Figure 2. Applications of AI in emergency management.

Studies of Literature on Artificial Intelligence and Disaster Conducted in Turkey

Disasters cause serious physical and economic damage to communities by destroying natural resources. To reduce these impacts and ensure sustainable development, countries must implement strategic disaster management supported by the latest technological developments. In the world of technology, artificial intelligence can be used for disaster management, including predicting and preventing risks, identifying the negative effects of possible disasters, minimizing these effects by taking the necessary precautions, and effectively intervening in disasters. In recent years, the number of studies on artificial intelligence and disasters has also increased in Turkey. This section of the study includes some of these studies.

A comprehensive framework must be developed to protect against and combat disasters. Using artificial intelligence technologies when developing and implementing the framework is important for the efficient use of resources. Karaca (2023) aims to contribute to the process of combating disasters by analyzing data obtained through literature reviews and archive research techniques. The research has revealed that artificial intelligence-based technologies have significant potential in predicting disasters and emergencies, protecting against them, and responding to disasters. It has also been concluded that utilizing this potential would contribute greatly to the strategic disaster management process.

As time goes by and technology advances, new methods, approaches, and techniques are being developed in disaster management. Artificial intelligence, which has many applications, is also being used in disaster management. The aim of the study by Angın (2024) is to reveal the importance and potential of artificial intelligence in disaster management, using examples and current global developments. The study suggests that there is a shift from traditional disaster management approaches to artificial intelligence-based technological disaster management. As a result, it has emerged that artificial intelligence (AI) has great potential in disaster management. AI can be adapted to all stages of the disaster management process, and its use is increasing, providing an up-to-date perspective on disaster management.

Traditional methods are not sufficient to address the increasingly complex problems caused by urban activities, which have been exacerbated by intense population growth and urbanization driven by globalisation (Abhijeet and Samir, 2015). The increase in disasters due to global climate change has caused problems in fundamental areas such as health, security, infrastructure, and education in urban areas over time (Tan et al., 2020). Therefore, information technology has become essential for the sustainable development and effective management of disasters, enabling societies to live in healthier and safer environments. Partigöç (2022) highlights the importance of using artificial intelligence-based technologies to reduce or eliminate potential losses in risk management during the pre-disaster period. The study used a qualitative research method and found that one of the fundamental building blocks of the Modern Integrated Disaster Management system is the use of Information and Communication Technologies (ICT). This system is sustainable, multi-stakeholder, and interdisciplinary, and yields effective results in the long term. Additionally, artificial intelligence-based applications play a significant role in enhancing urban resilience.

Artificial intelligence tools are used for tasks such as predicting natural disaster risks and estimating damage, providing humanitarian aid and logistics support, analyzing social media, assessing risks, creating disaster recovery plans, and estimating recovery costs. Significant results are obtained (Pi et al., 2020). Thus, artificial intelligence technologies resolve the various difficulties encountered when

implementing traditional systems. Kocaman (2025) employed qualitative research methods in his study to examine the use of artificial intelligence applications in disaster management, investigating the advantages these applications offer to stakeholders and actors involved in disaster and emergency management. It was concluded that, without the necessary legal regulations at a global level supported by various legal and criminal sanctions, most artificial intelligence applications developed for disaster and emergency management could lead to new human-induced disasters.

Cities in Turkey with high rates of vertical construction and large populations are at risk of natural disasters, especially earthquakes. After disasters and emergencies, it is difficult to quickly and accurately determine the location of damaged houses. The system proposed by Tarhan et al. (2022) aims to quickly and effectively detect damage using an artificial intelligence-based application. Thus, the location of damaged structures caused by the disaster will be shared and recorded in the database, supporting all subsequent activities.

Artificial intelligence (AI)-based technologies offer innovative solutions for countries frequently exposed to and struggling with disasters, enabling rapid and effective action. The study by Şimşek et al. (2023) aims to reveal the role of AI-based systems and their application methods in disaster management processes through a systematic literature review. The effectiveness and adequacy of these roles and methods are also discussed, particularly in Turkey. The study revealed that AI systems can effectively manage natural disasters and minimise logistical problems in disaster response. The systematic review found that most disaster-related AI applications focused on earthquakes, with only a limited number of studies addressing the prevention and management of other potential disasters.

CONCLUSION

Disasters of various types and severities occur around the world every year. These disasters have negative physical, social, and psychological effects. As the time, place, and magnitude of disasters cannot be predicted with certainty beforehand, it is often impossible to prevent them and their negative effects. In this context, an approach involving rapid, comprehensive, and coordinated intervention within the framework of pre-made plans is required for the effective management of disasters and emergencies. Disaster management is an ongoing process involving activities such as risk analysis and assessment, disaster and emergency planning, communication, resource management, and cooperation and coordination. This includes damage reduction and preparation during the pre-disaster period, intervention during the disaster itself, and recovery during the post-disaster period. Researchers and scientists have demonstrated that artificial intelligence can be utilized for swift and efficient disaster management, minimizing damage during the preparation phase and ensuring preparedness for disasters and emergencies. AI can potentially enhance our disaster management capabilities in many ways, from prediction, warning, and detection to situational assessment and monitoring of the recovery process. AI-based early warning systems have become a critical technological component, strengthening decision-making processes, reducing risks, and increasing the effectiveness of responses at every stage of disaster and emergency management. They provide institutions and society with vital information by using big data analytics, machine learning algorithms, and real-time sensor data to make predictions in advance about the timing, magnitude, and potential impact of disasters. In a world where natural disasters are becoming more frequent and severe, the accuracy and prevalence of early warning systems are key to disaster preparedness. The research has revealed the transformative effect of artificial intelligence-supported systems in disaster and emergency response. Significant improvements have been observed in disaster prediction, emergency response management, real-time incident detection, intelligent traffic control, hazard prevention, and cyber security. Researchers and policymakers should prioritise studies

of disasters and emergencies that cause significant human losses and damage, and provide adequate incentives to overcome existing barriers and improve the process.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Yenilikçi Teknolojiler ile Müşteri Deneyimlerinin İyileştirmesi ve DEMATEL Yöntemi ile Faktörlerin Değerlendirilmesi

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Özet

Dijital ortamlarda müşteri deneyimi, gelişen teknolojilerle birlikte daha da önemli hale gelmiştir. Yenilikçi teknolojilerle müşteri deneyimi, şirketlerin veya kurumların müşterilere daha iyi, daha hızlı, daha kişiselleştirilmiş ve daha tatmin edici hizmetler sunmak amacıyla teknolojik yenilikleri kullanma çabasıdır. Ancak tüm müşteri segmentleri teknolojiye eşit düzeyde erişememektedir ve yanlış öneriler, adaletsiz fiyatlandırmalar, eğitim eksikliğinden kaynaklanan platform ve yanıt sistemlerinin verimsizliği ile sistemlerin siber güvenlik riskleri gibi sorunlar marka sadakatini azaltabilmektedir. Dijital platformlarda etkili bir müşteri deneyimi sunabilmek için, işletmelerin müşteri deneyimine etki eden çeşitli faktörleri doğru şekilde belirlemesi ve analiz etmesi gerekmektedir. Bu çalışmada, müşteri deneyimini iyileştirmeye yönelik faktörlerin etkileşimleri, DEMATEL (Karar Verme ve Çok Kriterli Değerlendirme) yöntemi ile incelenmiştir. Araştırma, altı ana kriteri ele almıştır: K1 (Optimum kullanıcı deneyimi), K2 (Kesintisiz alışveriş deneyimi), K3 (Doğru ve alakalı öneriler), K4 (Hızlı ihtiyaç cevaplama), K5 (Kullanım zorlukları) ve K6 (Siber güvenlik riskleri). Yapılan analizler sonucunda, K3 (Doğru ve alakalı öneriler) sistemdeki en etkili faktör olarak belirlenmişken, K6 (Siber güvenlik riskleri) en fazla etkilenen faktör olarak öne çıkmıştır. Ayrıca, K1 (Optimum kullanıcı deneyimi) hem yüksek etkiye sahip hem de diğer faktörlerden güçlü bir şekilde etkilenmiş, bu da onu sistemin merkezi bir faktörü haline getirmiştir. Bu bulgular, dijital müşteri deneyimi üzerindeki faktörlerin etkileşimini daha iyi anlamaya yardımcı olmuş ve stratejik önceliklerin belirlenmesinde önemli bir rol oynamıştır. Sonuç olarak, bu analiz, dijital platformlarda müşteri deneyiminin iyileştirilmesine yönelik kaynak tahsisinde ve iyileştirme çabalarında rehberlik edecek değerli bir yol haritası sunmuştur.

Anahtar kelime: *Müşteri deneyim, Dijital dönüşüm, Yenilik teknolojiler, Dematel*

GİRİŞ

Son zamanlarda, Dördüncü Endüstriyel Devrim (Endüstri 4.0) teknolojilerinin, büyük veri, yapay zeka (AI), dijital ikiz, Nesnelerin İnterneti (IoT) ve siber-fiziksel sistemler (CPS) gibi unsurlarının ortaya çıkması, insanlar, sistemler, hizmetler, ürünler ve şirketler arasındaki bağlantıyı güçlendirmiştir. Bu nedenle, yeni iş yapma yöntemleri tanıtılmakta ve özellikle imalat şirketleri üzerinde güçlü bir etki yaratabilir (Benitez, 2020). Bu teknolojiler, cihazlar, makineler, hizmetler ve ürünler arasında etkileşimlere olanak tanıyarak dijital bir dönüşüm tetikler ve böylece şirketlerin pazarlarındaki değişimlere uyum sağlama hızlarını artırır (Kim, 2023). Dijital dönüşüm (DT), dijital teknolojileri iş süreçlerine entegre ederek verimliliği, bilgi paylaşımını ve stratejik çevikliği artırır (Verhoef, 2021).

Ancak, DT'nin stratejik karmaşıklığı, mevcut teknolojilerin kullanımı (exploitative innovation) ile yeni teknolojilerin keşfi (exploratory innovation) arasında bir gerilim yaratabilir. Başarılı organizasyonlar, hem aşamalı hem de devrimsel değişimlerle başa çıkma anlamına gelen ambidexterity (çift yönlü yenilik yeteneği) geliştirmelidir (Li, 2025). Dijital dönüşüm, şirketlerin iş yapma biçimlerinde köklü değişimlere neden olmakta; bu da ürün yerine hizmet odaklı modellere yönelmelerine yol açmaktadır. Dijital ve fiziksel dünyaların birleşmesi, dijital dönüşüm yolunda dijital bir girişim ile gerçek organizasyonel değişim arasındaki sınırları belirsizleştirir. Örneğin, Apple ve Google gibi bilgisayar çözümü sağlayıcıları şimdi sağlık ürünleri ve hizmetleri sunuyor; Qualcomm, bir yarı iletken şirketi, bağlı bir sağlık platformu geliştirdi; ve Tesla, bir otomobil üreticisi, enerji işine girdi (Szalavetz, 2022). Ancak, dijital dönüşüm sadece teknoloji ile ilgili değildir; dijital olarak daha olgunlaşmış sanayi işletmeleri, dijital teknolojilerden daha iyi yararlanmak için gerekli becerilere ve organizasyonel yapıya sahip olma eğilimindedir (Ghosh, 2025). Günümüzün rekabetçi ortamında, firmalar; müşteri taleplerindeki sık değişimler, ürün kalitesinin artırılması, operasyonların çevikliği ve verimliliği gibi birçok zorlukla karşı karşıyadır. Ayrıca, müşteriler sürekli teknolojik gelişmelerin farkındadır ve bu durum beklentilerini artırmıştır. Buna bağlı olarak, müşteriler daha kısa teslimat süreleriyle birlikte yüksek kaliteli, özelleştirilmiş ve yenilikçi ürünler talep etmektedir (Gillani, 2020). İnovasyon yeteneğine sahip olan işletmeler, değer yaratma faaliyetlerinde rakiplerine göre daha başarılıdır. Bu nedenle İnovasyon yeteneği, rekabet avantajı elde etmenin önemli önkoşullarından biridir (Gangwani, 2024). Yenilik kavramı, Aslam (2020) tarafından; yeni ya da önemli derecede iyileştirilmiş ürün, süreç, pazarlama yaklaşımı ya da organizasyonel yöntemin kullanımına başlanması olarak tanımlanmıştır. İnovasyon performansı hem verimlilik hem de etkinlik açısından değerlendirilir. Bu nedenle, yeni ürünlerin zamanında piyasaya sunulması büyük önem taşır. Rekabetçi pazarlarda öne çıkabilmek adına, inovasyonun stratejik bir zorunluluk haline geldiği görülmektedir (Aslam, 2020). Son yıllarda yapay zeka (YZ) markalarla müşteri etkileşimini dönüştürerek kişiselleştirilmiş pazarlama, programatik reklamcılık ve çok kanallı pazarlama gibi yeni uygulamaların önünü açmaktadır. Özellikle 1:1 pazarlama stratejisi ile müşterilerin ilgi alanlarına dayalı özelleştirilmiş reklamlar sunulmakta, bu da müşteri sadakatini artırmakta ve pazarlama yatırımından yüksek geri dönüş sağlamaktadır. Ayrıca dijital reklam alanlarında programatik reklamcılık, gerçek zamanlı açık artırmalarla reklamların otomatik satın alınmasını ve yerleştirilmesini sağlamaktadır. Bu teknolojilerin entegrasyonu, markaların müşteri deneyimini daha akıllı ve verimli hale getirmelerine olanak tanımaktadır (Tekin, 2024). DEMATEL (Decision Making Trial and Evaluation Laboratory), çok kriterli karar verme ortamlarında kararları etkileyen değişkenler arasındaki etkileşimleri belirlemek amacıyla Cenevre Battelle Memorial Enstitüsü tarafından geliştirilmiştir. Bu yöntem, özellikle dolaylı ilişkileri bir sebep-sonuç ilişkisiyle değerlendirerek, sistem bileşenleri arasındaki yapıyı ve ilişkileri incelemeye yardımcı olur. DEMATEL yönteminin en önemli avantajı, karmaşık sistemlerin analizini yaparak karar alma süreçlerinde öncelikleri belirlemeyi mümkün kılmasıdır ve bu, onu diğer çok kriterli karar verme tekniklerinden ayıran önemli bir özelliktir (Bulğurcu, 2022). Bu çalışmada, yenilikçi teknolojilerin müşteri deneyimlerine olan etkileri ele alınacak ve DEMATEL yöntemi kullanılarak bu teknolojilerin hangi faktörlerle ilişkilendirilebileceği değerlendirilecektir. Çalışmanın amacı, işletmelere teknolojik yeniliklerin müşteri deneyimini iyileştirmedeki potansiyelini anlamaları ve doğru stratejileri belirlemeleri konusunda yol gösterecek bir analiz sağlamaktır.

LİTERATÜR ARAŞTIRMASI

2.1. Müşteri Deneyimi Tanımı ve önemi

Müşteri deneyimi, bir müşterinin bir firma ya da marka hakkında ne hissettiğine odaklanan öznel bir bakış açısıdır (Gounaris, 2024). Müşteri deneyimlerini oluştururken, müşteriler sahip oldukları tüm temas noktalarını ve firma hakkındaki izlenimlerini dikkate alırlar (Kranzbühler, 2018). Müşteri deneyimi, B2B ilişki literatüründen ayrışır; zira bu kavram, ilişkilerin sonuçlarını geliştiren dinamik bir süreç olarak değerlendirilmektedir (Schmitt, 2025). Müşteri kaybının belirli bir ürün veya hizmete dair bilgiye dayandığını öne süren statik bir bakış açısını vurgulamıştır. Elde edilen bilginin beklentileri karşılamaması durumunda, tüketiciler hayal kırıklığı yaşayabilir ve bu da onları hizmeti bırakmaya ya da başka seçenekler aramaya yönlendirebilir. Yani, müşteri kaybı yalnızca statik bir perspektiften gerçekleşmeyebilir. (Zhang, 2025). Gelişmiş ekonomilerde ürün ve hizmetlerin bireysel ihtiyaçlara göre uyarlanması, "deneyim ekonomisi" anlayışını ortaya çıkarmış; bu tür kişiselleştirmenin tanıtımı ise "deneyim pazarlaması" şeklinde adlandırılmıştır. Deneyim ekonomisinin yaşandığı ortamda tüketiciler daha fazla kişiselleştirilmiş ürün ve daha fazla hizmet tüketmektedirler. Schmitt'in (1999) bir nevi geleneksel pazarlama eleştirisi olarak ilgili makalesinde, geleneksel pazarlamanın, tüketicileri yalnızca ürün hizmetin fayda ve özellikleriyle ilgilenerek karar verme aşamasında rasyonel faydayı gözeten bireyler olarak ele almasının bir yanılgı olduğunu belirtmektedir. İleri sürdüğü deneyimsel pazarlamada ise tüketicileri, ürün-hizmet alımı sürecinde keyif verici deneyimleri önemseyen rasyonel ve duygusal bireyler olarak tanımlamaktadır. (Orak, 2022).

Dijital Müşteri Deneyiminin ve Önemi

Web 4.0 gelişmiş teknolojilerle, nesnelerin interneti, yapay zekâ ve kuantum bilişimi içermektedir. Bu dijital dönüşüm süreci, iş dünyasında, toplumda ve kişisel yaşamda büyük değişimlere yol açarken, aynı zamanda güvenlik, gizlilik ve dijital eşitsizlik gibi yeni zorlukları da beraberinde getirmiştir. Bu nedenle, dijitalleşme sürecini anlayarak bu teknolojilerden en iyi şekilde yararlanmak önemlidir (Varol, 2024). Web 5.0, aşırı kişiselleştirme, bağlama duyarlı anlayış, semantik internet yapıları, doğal dil işleme teknolojileri, akıllı otomasyon sistemleri, sanal ve artırılmış gerçekliğin bütünleşmesi ve dağıtık yapay zekâ gibi özelliklerle öne çıkmaktadır. Bu yeni aşama, gelişmiş veri analizi, yapay zekâ algoritmaları ve makine öğrenme sayesinde her kullanıcıya özel içerik ve hizmet sunmayı hedeflemektedir (Sindhu, 2016). Teknolojinin hızlı ilerlemesiyle birlikte, Web 5.0 büyük değişiklikler yaşamıştır ve teknolojik ürünler, statik yapılardan akıllı etkileşimlere sahip yapılara dönüşmüştür. Nesnelerin interneti (IoT), yapay zekâ, sanal ve artırılmış gerçeklik (VR/AR), otonom nesneler, blok zinciri ve 5G gibi yenilikçi teknolojilerle donatılmış ürün ve hizmetler, daha insan odaklı yapılara dönüşmektedir. (Kavak, 2023).

Müşteri Deneyim ile Müşteri Sadakat Arasındaki İlişki

Müşteri sadakatinin alanyazında pek çok tanımı yapılmıştır. Müşteri sadakati; bireylerin belirli bir markayı yeniden tercih etmesi, çevresine tavsiye etmesi ve genel olarak markaya karşı olumlu yaklaşım sergilemesiyle tanımlanabilir. Müşteri sadakati yönetimi konusunda başarılı olan bir işletme, tıpkı bir mıknatıs gibi müşterilerini kendisine çekebilmektedir. Sadakatı yüksek olan müşteriler, bir yandan da reklam aracı olarak işletmeye yeni müşteriler kazandırmaktadır. Müşteri beklentileri memnuniyet seviyesini belirlerken, aynı firmayı tercih etmeye devam etmeleri onların bağlılığının bir göstergesidir. Bütün sadık müşterilerin tatmin düzeylerinin yüksek olduğu, bunun yanında her tatmin olan müşterinin sadakatinin yüksek olmayabileceği belirtilmektedir. Hizmet kalitesinin yüksek seviyede korunması, müşteri memnuniyetine ulaşmak açısından büyük önem taşır ve bu durum sadakatin oluşumuna doğrudan katkı sağlar (Aydın, 2020).

Müşteri Deneyiminin Kişiselleştirme ve Hiper KişiselleştirmeTanımı

"Çoğu zaman insanlar siz onlara gösterene kadar ne istediklerini bilmezler" Bu sözüyle Steve Jobs, 1998 yılında Business Week dergisinde, müşterilerin isteklerini ve ihtiyaçlarını anlamanın zorluklarını vurgulamıştır. Dolayısıyla kişiselleştirme, müşteriyle kurulan etkileşimlerde merkezi bir rol üstlenmektedir. Kişiselleştirme ürünlerin ve alışveriş deneyiminin, bireysel tüketicilerin tercihlerine dayalı olarak uyarlanmasıdır. Bu, iki faktöre bağlıdır: birincisi, satıcıların tüketici bilgilerini toplama ve işleme yeteneği; ikincisi ise tüketicilerin bilgilerini paylaşma ve kişiselleştirme hizmetlerini kullanma istekliliğidir (Chellappa, 2005). Hiper kişiselleştirme bire bir pazarlama, özelleştirme, müşterileştirme ve özellik-le de kişiselleştirme gibi bir dizi ilişkisel dijital pazarlamanın yapay zekâ tabanlı yeni bir evresidir. Bu bağlamda Hiper kişiselleştirme kavramı, Todd Lebo'nun tanımıyla, kişiselleştirilmiş pazarlamanın ötesine geçilerek kullanıcıya daha uygun içerik ve ürünlerin sunulması amacıyla yapay zekâ ve anlık verilere dayalı bir strateji olarak görülmektedir. Bu bağlamda, Kullanıcılara bağlamsal olarak yüksek oranda hedeflenmiş ve kişiselleştirilmiş ürünler-hizmetler, indi-rimler, teklifler ve alakalı içerikler sunulur ve tüm bunlar, doğru kanalda doğru içerikle doğru zamanda doğru kullanıcıya ulaştırılır (Zengin, 2021).

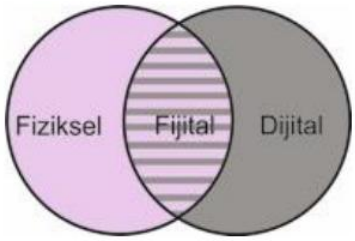
Yeni Teknolojilerin Müşteri Çekmede Rölü

Metaverse Kavramı

1992 yılında Neal Stevenson'ın Snow Crash adlı eseri, Metaverse kavramını edebiyata kazandırmıştır; bu yapıt, insanların sanal gerçeklik teknolojileriyle dijital avatarlar aracılığıyla sanal bir ortamda yaşadığı bir dünyayı tasvir eder. Son zamanlarda, özellikle Web 5.0 devrimiyle birlikte, Metaverse'in gelecekte yeni bir yaşam formu yaratacağına dair görüşler yaygınlaşmaktadır (Paçacı, 2024). Metaverse, fiziksel gerçekliği dijital teknolojiyle birleştiren, Yapay Zekâ (AI) ve Genişletilmiş Gerçeklik (XR) teknolojilerinden yararlanarak birbirine bağlı ve kapsayıcı ortamların oluşturulduğu sanal bir dünyayı ifade eder. Sanal Gerçeklik (VR) ve Artırılmış Gerçeklik (AR) teknolojilerini harmanlayarak kullanıcıların sanal nesneler, insanlar ve çevrelerle çoklu-duyusal etkileşimlerde bulunmalarına olanak tanır (Cheng, 2022). Metaverse kavramı toplumda daha yaygın hale geldikçe, metaverse geliştiricileri ve platformları tarafından kullanıcıların konumu, tarama geçmişi, kişisel tercihleri gibi ayrıntılı kişisel bilgilerin toplanması ve kullanılmasıyla ilgili gizlilik endişeleri önemli bir hâl almaktadır (Alkaeed, 2024).

Fijital (Phygital) Kavramı

Fijital kavramı kullanıcılar ve ürün arasında pazarlama iletişimini oluşturan fiziksel ve dijital ortamın yeniliklerini kullanan bir sistem oluşturmaktadır. "Fijital (phygital)" sözcüğü, Amerikan Reklam Ajansları Birliği Başkanı tarafından 2007 yılının ilk kez kullanılmıştır. Fijital terimi, iki kavramın birleşiminden türemiş olup, özellikle son yıllarda artan bir şekilde kullanılmakta ve dikkat çekmektedir. Fijital dünya, birbirlerinden katı sınırlarla ayrılan iki farklı uzama ait (fiziksel ve dijital) iletişim kanallarını, pazarlama içeriklerini, toplulukları birleştirerek, onları birbirleriyle etkileşime girmeye ve ortak hareket etmeye zorlamaktadır. Fijital, çok kanallı yapısıyla tüketicilere hem dijital hem de fiziksel ortamlarda bütüncül bir deneyim sunar. Bu yaklaşım, markaların dijital platformlarla geleneksel temas noktalarını bir araya getirerek etkili bir pazarlama stratejisi geliştirmelerine olanak tanımıştır. Böylece, tüketicilerle daha sık temas kurulmuş ve marka etkisi artırılmıştır (Çakın, 2020).



Kaynak: Moravcikova, D. ve Kliestikova, J.(2017: 150).

Şekil1: Fijital

RFID Teknologisi

Çevrimiçi mağazalarda müşteri alışveriş kalıplarını anlamak nispeten kolay olsa da fiziksel perakende mağazalarında bu durum, özellikle kasa öncesi müşteri davranışlarını izlemek karmaşık bir süreç olduğundan zorluk yaratmaktadır. RFID'den elde edilen faz ölçümleri, müşteri aktivitelerini tespit etmek amacıyla kullanılmış ve dikkat çekici sonuçlar elde edilmiştir. Zhou ve ark 2017'de fiziksel alışveriş mağazaları için etkili pazarlama stratejileri geliştirmek amacıyla, RFID etiketleri ve okuyuculardan oluşan siber-fiziksel bir sistem kullanarak müşteri alışveriş davranışlarını incelemiştir. Liu ve ark. göre, standart raf tipi RFID cihazlarını (Commercial Off-The-Shelf- COTS) kullanarak ürün hareketlerini tespit eden ve müşteri davranışlarını ortaya çıkaran yenilikçi bir sistem olan TagBooth'u sunmuştur (Alfian, 2023).

Müşteri Deneyimlerini Şekillendiren Yeni Teknolojilerin Rolü

Yapay Zekâ (AI) Kavramı ve Müşteri Kişiselleştirme

Yapay zekâ, bir sistemin dış verileri doğru bir şekilde yorumlama, bu verilerden öğrenme ve bu öğrenmeleri esnek adaptasyon yoluyla belirli hedeflere ve görevlere ulaşmak için kullanma yeteneği olarak tanımlanabilir.Yapay zekâ, insan bilişsel görevlerini, çevreden gelen belirli bir girdi anlayışına dayalı eylemler gerçekleştiren akıllı ajan olarak hareket eden bir yapay yapı şeklinde taklit edebilir (Gür, 2022). İşletmeler, çeşitli veri kaynaklarını; müşteri bilgileri, satış verileri, web trafiği ve sosyal medya etkileşimlerini etkin bir şekilde yönetmektedir. Yapay Zekâ ile Müşteri İlişkileri Platformları (CRM) entegrasyonu önemli bir role sahip. Bu entegrasyon, işletmelere veri odaklı kararlar almanın yanı sıra, müşteri deneyimini özelleştirme, pazarlama faaliyetlerini optimize etme ve daha pek çok işlevi yerine getirme imkânı sunmaktadır. Ancak günümüz iş dünyasında, yalnızca veri toplamak ve saklamak yeterli değildir. İşletmeler, bu verileri çözümlemek, müşteri davranışlarını öngörmek ve hizmet kalitesini artırmak için daha fazla bilgiye ihtiyaç duyar. İşte bu noktada Yapay Zeka'nın (AI) CRM yazılımlarıyla entegrasyonu devreye girer (Çakır, 2024).

Sanal Gerçeklik (VR), Artırılmış Gerçeklik (AR) ve Karmaşık Gerçekilik (MR) Genel Bakış

Dünyaya bakış açımızı geliştiren veya değiştiren teknolojiye Genişletilmiş Gerçeklik (XR) adı verilir ve bu genellikle bilgisayar metni ve grafiklerinin gerçek ya da sanal ortamlara bindirilmesi veya bu ortamlara daldırılmasıyla gerçekleşir. Sanal içeriğin gerçek dünyaya eklenip eklenmediğine veya gerçek dünyanın dijital içeriğe yansıtılıp yansıtılmadığına bağlı olarak, fiziksel çevre kullanıcı deneyiminin bir parçasıysa bu AR'dır; değilse VR'dır. Sanal gerçeklik (VR) ve artırılmış gerçeklik (AR) teknolojilerinin pazarlama, eğitim ve müşteri hizmetlerinde kullanımı birçok avantaj sunmaktadır (Wedel, 2020). Sanal gerçeklik teknolojisinin dahil olduğu pazarlama kampanyalarına VR pazarlama denir. Sosyal medya kullanımı, bir kitleyle etkileşim kurmanıza ve daha güçlü bir marka oluşturmanıza yardımcı olabilir. Bu

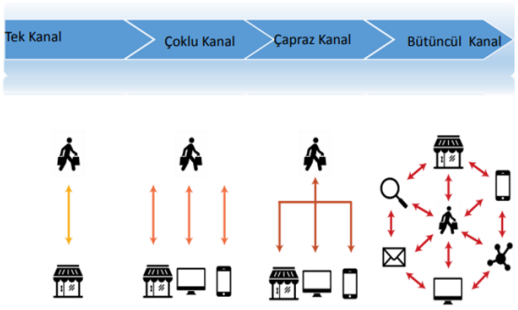
teknoloji ile markalar, müşterilerine mobil cihazları aracılığıyla benzersiz deneyimler sunabilir (Jayawardena, 2023). Sanal gerçeklik, kullanıcının bilgisayar tarafından simüle edilmiş bir dünyada hareket ettiği, duyusal etkilerle etkileşime girdiği bir ortamdır. Sanal gerçeklik, 3D görüntüler ve sesler gibi teknolojilerle kullanıcıyı bir sanal dünyaya daldırmayı amaçlar. Bu dünyada kullanıcı, fiziksel gerçeklikten bağımsız bir şekilde etkileşimde bulunabilir (Güleç, 2020). Karmaşık Gerçeklik (MR) deneyimi, kullanıcıların gerçek dünya ile etkileşimde bulunan sanal nesnelerle çevrelerini birleştirmesine olanak tanır. Yani, kullanıcılar gerçek dünyayı görmeye devam ederken, aynı zamanda sanal nesneleri bu gerçek dünyada varmış gibi görebilirler. MR ve VR arasındaki temel fark, VR'da kullanıcıların tamamen sanal bir ortamda bulunması, ancak MR'da gerçek dünya ile etkileşimin sürmesidir (Özdal, 2020).

Nesnelerin İnterneti (IoT) ve Müşteri Etkileşimi Arasındaki İlişki

İnternetin Nesneleri (IoT) kavramı ilk kez 1999 yılında MIT Auto-ID merkezinin kurucu ortaklarından Kevin Ashton tarafından P&G firmasında yapılan bir sunumda ortaya atılmıştır. Ashton, bu sunumda Radyo Frekansı Tanımlama (RFID) teknolojisinin tedarik zincirinde kullanılmasıyla cihazlar arasında kurulacak iletişimin potansiyel faydalarına dikkat çekmiştir. İnsanlar, nesneler ve internet arasında iletişim kurulmasını mümkün kılan Nesnelerin İnterneti, etkin kullanımı durumunda birçok sektörde önemli avantajlar sağlar. Özellikle perakende sektöründe, üretim süreçleri ve tedarik zincirlerinde; maliyetlerin düşürülmesi, yüksek kalite, zaman verimliliği, hata payının azaltılması, çeviklik ve daha iyi koordinasyon gibi birçok fayda sunar. Gregory'ye (2015) göre, Nesnelerin İnterneti teknolojisinin perakende sektöründe kullanımı; müşteri deneyimini geliştirme, tedarik zincirinin optimizasyonu ve yeni gelir kaynaklarının oluşturulması gibi konularda önemli fırsatlar sunmaktadır (Kaya, 2022).

Çok Kanallı Deneyim (Omni-channel)

Latince kökenli olan "omni" kelimesi, Türkçe "tüm", "bütüncül", "hep", "bütün", "her şey" anlamına gelmektedir. İnternet kullanımının artması ve dağıtım stratejilerindeki değişiklikler ile birlikte, tek kanal yerine çok kanallı stratejilerin kullanımı, işletmeler için bir zorunluluk haline gelmiştir. Bu strateji, fiziksel mağazalar, televizyon ve web siteleri gibi çeşitli satış kanallarının kullanımını içermektedir. Bu yöntemde, kanallar birbirinden bağımsız olarak yönetilmektedir (Avşar, 2023).



Şekil 5: Omni-channel

Her kanalın kendine özgü avantajları olduğundan perakendeciler, birden fazla dağıtım kanalını kullanarak son kullanıcılara ulaşmayı amaçlar. Ancak, günümüzde kullanıcılar yalnızca birden fazla kanaldan erişim sağlamakla kalmayıp, bu kanallar arasında sorunsuz alışveriş yapabilmek de istemektedirler. Dijital kanalların yükselmesi, özellikle mobil internetin yaygınlaşması, kullanıcıların kesintisiz alışveriş deneyimi arayışında önemli bir faktördür (Burton, 2011). Bu değişimle birlikte, çoklu kanal stratejisinden entegre bir kanal yönetimine geçişin gözlemlendiği söylenebilir. Entegre kanal

yönetimi, kanallar arasındaki sinerjiyi güçlendirerek kullanıcı deneyimini en üst düzeye çıkarmayı amaçlar (Hüseyinoğlu, 2017).

Sanal Mağaza Deneyimi

Sanal mağaza deneyiminin başarılı örnekleri arasında Trendyol, LC Waikiki, IKEA ve Nike gibi büyük markalar yer almaktadır. Bu platformlar, kullanıcı dostu arayüzler, etkileyici görsel içerikler ve özel promosyonlarla müşteri deneyimini iyileştirmeyi hedeflemektedir. Örneğin, IKEA'nın sanal mağaza tasarımı, kullanıcıların ürünleri farklı açılardan görmelerine ve deneyimlemelerine olanak tanırken, Nike ve LC Waikiki de özel kampanya ve indirimlerle kullanıcıların ilgisini çekmeyi başarmaktadır. Bu markaların tasarımları, tüketicilerin mağaza atmosferine daha fazla dahil olmalarını ve daha uzun süre siteyi ziyaret etmelerini sağlamak için optimize edilmiştir. Günümüzde otomotiv endüstrisi, sanal gerçeklik (VR) teknolojisini hem müşterilere hem de çalışanlara yönelik kullanmaktadır. Örneğin, SEAT, tasarımda VR kullanarak üretim sürecinde zaman tasarrufu sağlamış, üretim hatalarını azaltmış ve prototip üretim süresini %30 oranında kısaltmıştır. Toyota, CHR modelinin tanıtımını VR teknolojisi kullanarak gerçekleştirmiş ve böylece müşterilerine aracı dijital ortamda kişiselleştirme ve keşfetme fırsatı sunmuştur. Sanal showroomlar, markaların araçlarını her yerden sergileyebilmesine, müşterilerin 7/24 erişim sağlamasına ve showroomları 360 derece görmelerine olanak tanır (Akın, 2022). Amazon Go, geleneksel ödeme süreçlerinden geçmek yerine sırada beklemeden doğrudan çıkış yaparak alışveriş sürecini nasıl kolaylaştırabileceğini teknoloji aracılığıyla en iyi şekilde örneklemektedir. Walmart ve Target, hırsızlıkları azaltmak için yapay zekâ destekli gözetim sistemlerinden faydalanırken, Carrefour ve Lowe's ise RFID ve robotik teknolojilerini envanter yönetimini iyileştirmek ve kayıpları önlemek amacıyla kullanmaktadır. Diğer yaygın temalar arasında, çalışanların teknolojiyle eğitilmesi yer almakta; Best Buy ve Sephora, hizmet kalitesini ve müşteri deneyimini artırmak için yapay zekâ destekli asistanlar kullanmaktadır (Kalyanam, 2023). Tumi, 2021'de sanal mağazasında artırılmış gerçeklik (AR) teknolojisi kullanarak, alışveriş yapanların evlerine gerçek boyutlu ürün görselleri yerleştirmelerine imkân tanımaktadır (Sucu, 2022).

Yenilikçi Teknolojilerin Müşteriler Üzerindeki Etkileri

Optimum kullanıcı deneyimi

Öneri sistemleri, kişiselleştirme süreçlerinin en güçlü araçlarındandır. Bu sistemler, kullanıcıların ilgi alanlarına uygun, ancak kendi başlarına keşfetmeleri zor olan içerikleri sunar ve doğru zamanda, doğru sayfada ilgili öğelerle ziyaretçi deneyimini iyileştirir. Öneri sistemleri, kullanıcı profilleri ve davranışsal verilerle çalışarak, verilerin farklı kaynaklardan toplanıp filtrelendiği, kalıpların keşfedildiği bir süreçle kişiselleştirmeyi sağlar (Arora, 2016). E-ticaret siteleri, mobil uygulamalar ve sosyal medya platformlarında yaygın olarak kullanılan bu sistemler, özellikle video akış platformlarında popüler hale gelmiştir. Örneği, Netflix'in tavsiye sistemi, kişiselleştirme stratejilerinin nasıl işlediğini anlamak için dikkate değer bir örnektir. Shabana Arora'ya (2016) göre, Netflix, en iyi öneri motoruna sahip olmanın önemini kavrayarak algoritmalarını optimize etmek için büyük yatırımlar yapmaktadır. 2009 yılında, algoritmalarının verimliliğini artırmak amacıyla bir milyon dolarlık ödül veren bir yarışma düzenlemiş ve bu yarışma, içerik keşif sistemlerinin geliştirilmesinde önemli bir rol oynamıştır. Netflix'in tavsiye sistemi, kişiselleştirme stratejilerinin nasıl işlediğini anlamak için dikkate değer bir örnektir. (Zengin, 2021).

Kesintisiz alışveriş deneyimi

Çok kanallı bölümünde bahsedildiği gibi, kişiselleştirmenin olumlu yanlarından biri de kesintisiz alışveriştir. Çevrimiçi ve çevrimdışı birçok kanal sunulması ve tüketicilerin bu kanallar arasında geçiş

yapabilmesi, alışverişi kolaylaştırmaktadır. Tüketiciler, fiziksel veya sanal mağazalardan ürünler hakkında bilgi alabilir, fiyat farklarını karşılaştırabilir ve ardından bu kanallardan birini kullanarak alışveriş yapabilirler. Bu tür pazarlama, "çok kanallı" veya "kanallar arası" pazarlama biçimi olarak anılmaktadır (Nie, 2019). Tüketiciler, alışveriş yolculukları boyunca tüm kanallardan, fiziksel mağazalar, çevrimiçi mağazalar, sosyal medya platformları ve mobil uygulamalar gibi kanallardan yararlanma imkânına sahiptir. Entegre kanal yapıları sayesinde, tüketicilere her aşamada kesintisiz bir alışveriş deneyimi sunulması hedeflenir. Mağazalar, web siteleri ve mobil uygulamalar düzenli olarak birbirleriyle iletişim kurarak müşterilere entegre bir alışveriş deneyimi sunmaktadır (Avşar, 2023).

Doğru ve alakalı öneriler

Yapay zekâ destekli hiper kişiselleştirme, her bireyin verilerini inceleyerek ona özel içerikler üretmeyi sağlar. Bu süreç, geçmiş ve gerçek zamanlı verilerle beslenen algoritmalar aracılığıyla gerçekleşir. Yapay zekâ, kullanıcıların ihtiyaçlarını öğrenir ve onları doğru zamanda, doğru içeriklerle hedefler. Bu yöntem, kullanıcıların ürün ve hizmet seçimlerinde rehberlik eden görünmeyen bir satış görevlisi gibi işlev görür. Öneri sistemleri, kişiselleştirme sürecinin temel araçlarından biridir. Bu sistemler, zor ulaşılan içerikleri öne çıkararak ve doğru anda doğru bilgiyi sunarak kullanıcı deneyimini olumlu yönde etkiler. Kullanıcı profilleri ve davranışsal veriler kullanılarak yapılan bu kişiselleştirme, farklı kaynaklardan toplanan verilerle beslenir, en alakalı bilgiler filtrelenir ve kullanıcılara sunulacak içerikler belirli kalıplar doğrultusunda şekillendirilir. Bu tür öneri motorları, e-ticaret siteleri, sosyal medya platformları, mobil uygulamalar ve özellikle video akış platformlarında yaygın olarak kullanılmaktadır. (Zengin, 2021).

Özelleştirilmesi ve Hızlı İhtiyaç Cevaplama

Hızlı yanıt verme genellikle CRM (Müşteri İlişkileri Yönetimi) sistemleri aracılığıyla yapılır. Birçok CRM sistemi, müşterilerin iletişimlerini ve taleplerini takip edip yönetmek için tasarlanmıştır. Ancak, hızlı yanıt verme özelliklerinden bazıları, müşteri destek sistemleri (örneğin, sohbet botları veya çevrimiçi destek yazılımları gibi) aracılığıyla da sağlanabilir. Sohbet robotları, hızlı bir şekilde sorulara yanıt verebilme ve kullanıcıların amacını anlayarak sorunları çözme yeteneğine sahiptir. Bu, sohbet robotlarının teknolojiyi insan benzeri bir şekilde yansıtarak insanlaşmasına yol açmaktadır. Mevcut verileri kullanarak, sohbet robotları çok çeşitli soruları yanıtlayabilir, ürünleri, hizmetleri ve etkinlikleri tanıtarak potansiyel müşteriler elde edebilir, konuşmaları planlayabilir ve değerli geri bildirimler alabilir. Markaların sosyal medya faaliyetlerinde de faydalı olan bu robotlar, sosyal medya profillerinin güncellenmesi, müşteri iletişimi ve uygun içeriklerin tespiti için kullanılmaktadır. Ayrıca, veriye dayalı sohbet robotları, müşterilerin satın alma kararlarına etki ederek markanın imajını olumlu yönde etkileyebilir (Kuruca, 2022).

Müşteri kullanma Eğitimi ve Müşteri Destek ve Teknik Hizmetler

İçerik tabanlı eğitim (İçerik Tabanlı Eğitim- WTE), müşterilere dijital içerik ve çevrimiçi platformlar aracılığıyla eğitim süreçlerinin gerçekleştirildiği bir öğrenme yöntemidir. Bu yöntem, işletmelere ve organizasyonlara, müşterilerini zaman ve mekân sınırlamaları olmadan çevrimiçi kaynaklarla eğitme imkânı sunar. Bu eğitim modelinde içerik, bilgisayar ağları aracılığıyla paylaşılır ve öğrenme süreci dijital ortamda gerçekleşir. WTE sistemleri, eğitim içeriklerine 7 gün 24 saat erişim sağlayarak, müşterilerin eğitmenlerle etkileşimde bulunmalarına ve aktif bir şekilde öğrenmelerine olanak tanır. İşletmeler ve eğitmenler için, içerik tabanlı eğitim pek çok avantaj sunar. (Saraç, 2011). Diğer yandan, chatbotları 7/24 kesintisiz destek sunarak, sık sorulan soruları hızlı bir şekilde yanıtlayabilmekte ve teknik sorunları çözme süreçlerini hızlandırmaktadır. Bu yapay zekâ tabanlı araçlar, müşteri taleplerine anında yanıt vererek, müşteri memnuniyetini artırırken, destek ekiplerinin üzerindeki yükü de

azaltmaktadır. Konuşmaya dayalı yapay zekâ teknolojileri sayesinde, iletişim süreçleri otomatik hale getirilmiş ve çok sayıda kullanıcıya özel deneyimler sunulabilmiştir. Bu teknoloji, metin ya da ses aracılığıyla müşterilerle uzun süreli etkileşim imkânı sunmakta, aynı zamanda etkileşimleri iki yönlü hale getirecek şekilde yönlendirilebilir (Kuruca, 2022).

Müşteri Bilgi ve Siber Güvenliği Riskleri

Blockchain (blok zincir) teknolojisi, bir dizi bilgiyi, dijital işlemleri veya var-lıkları güvenli ve şeffaf bir şekilde kaydetmek, doğrulamak ve işlemek için kullanılan bir dağıtık kayıt defteri (distributed ladger) teknolojisidir. Merkezi bir yapıya ihtiyaç duymayan bu sistem, kullanıcılar arasında veri paylaşımını, onayını ve güncellenmesini mümkün kılar. Blockchain kavramı, ilk olarak Satoshi Nakamoto adında bir yazarın ilk kripto para birimi olan Bitcoin tanıt-tığı Bitcoin: A Peer-to-Peer Electronic Cash System adlı makale ile ortaya çık-mıştır (Treibimaier, 2020). Nakamoto (2008) tarafından önerilen Blockchain teknolojisi, Bitcoin işlemlerinin onaylanması ve ağ üzerindeki defterlere kaydedilmesi için kullanılması amaçlanıyordu. Kavram içinde geçen block ifadesi bir işlem havuzunu, işlem blok'unu tarif etmekle birlikte, yine adında geçen chain ifa-desi, zincirleme bir model olarak inşa edilen, takip edilebilen ama kırılama-yan, değiştirilemeyen bir yapıyı tarif eder (Yıldız, 2023).

MATERYAL VE YÖNTEM

Amacı, Kapsamı ve önemi

Bu araştırmanın amacı, yenilikçi teknolojilerin müşteri deneyimini geliştirmedeki etkilerini incelemek ve bu süreci etkileyen temel faktörleri belirlemektir. DEMATEL yöntemi kullanılarak; optimum kullanıcı deneyimi, kesintisiz alışveriş, doğru öneriler, kişiselleştirme, hızlı yanıt, kullanım zorlukları ve siber güvenlik riskleri gibi faktörler arasındaki ilişkiler analiz edilecektir. Araştırmanın kapsamı hem literatür taraması hem de uzman görüşlerine dayalı veri analizlerini içermektedir. Bu çalışmanın önemi, mevcut literatürdeki boşlukları doldurarak müşteri deneyimi konusunda daha derin bir anlayış sunması ve işletmelere yenilikçi teknolojileri etkin kullanarak müşteri memnuniyetini artırmaya yönelik stratejiler geliştirme konusunda katkı sağlamasıdır.

Tablo1: Kaynak Literatür İncelemesi

	Optimum kullanıcı deneyimi	Kesintisiz alışveriş deneyimi	Doğru ve alakalı öneriler	Özelleştirilmesi ve hızlı ihtiyaç cevaplama	Kullanım zorlukları	Siber güvenliği riskleri
(İlgen, 2024)		*		*		*
(Simit, 2023)	*		*		*	
(Koyuncuoglu, 2023)	*	*				
(Tarık Yolcu, 2024)	*			*		*
(Belhadj, 2022)	*		*	*		
(Huseynli, 2021)	*	*		*		*
(Durum, 2018)			*		*	
(Orak, 2022)	*	*	*			
(KURTARAN, 2022)	*		*	*	*	*
(Kolukırık, 2020)					*	*
(HUSEYNLİ, 2021)	*	*		*	*	
(Agamyradova, 2024)	*	*		*		*

(Sönmez Karapınar, 2024)	*		*	*		
(Mesele, 2024)	*		*	*	*	
(Aksoy, 2023)	*				*	*
(Agamyradova, 2024)	*	*		*	*	*
(Subaşı, 2023)			*	*	*	*
(TUTSAL, 2022)	*			*	*	
(Ediş, 2024)	*			*		*
(Aytekin, 2022)	*	*				

Tablo2: Konu ve Kullanılan Tekniği Göre Makalelerin Sınıflandırılması

Yazar(lar)	Konu	Kullanılan Teknik					
		AHP	ANP	TOPSIS	VIKTOR	ELECTRE	DEMATEL
(Diwan, 2025)	Optimizing guest experience in smart hospitality: Integrated fuzzy-AHP and machine learning for centralized hotel operations with IoT	*					
(Potra, 2024)	Refining the HWWP model by merging the Kano model's customer requirements with AHP's specialist hierarchy for new product design	*					
(Karasan, 2022)	Customer-oriented product design using an integrated neutrosophic AHP & DEMATEL & QFD methodology	*					*
(Lin, 2008)	Using AHP and TOPSIS approaches in customer-driven product design process	*		*			
(Zhou, 2023)	Smart experience-oriented customer requirement analysis for smart product service system: A novel hesitant fuzzy linguistic cloud DEMATEL method						*
(Karasan, 2022)	Customer-oriented product design using an integrated neutrosophic AHP & DEMATEL & QFD methodology	*					*
(Zhao, 2024)	Blockchain technology in omnichannel retailing: A novel fuzzy large-scale group-DEMATEL & Ordinal Priority approach						*
(Büyükselçuk, 2024)	Evaluation of Industrial IoT Service Providers with TOPSIS Based on Circular Intuitionistic Fuzzy Sets			*			
(Nebati, 2024)	Bankacılıkta dijital dönüşüm performanslarının karşılaştırılması: müşteri perspektifinden bir değerlendirme						*
(Nebati, 2024)	Lojistik taşimaciliğinda anp ve codas yöntemleri ile kargo firmasi seçimi		*				
(Nebati, 2022)	Çok Kriterli Karar Verme Yaklaşımı ile E-Ticarette Strateji Seçimi: Perakende Sektöründe Bir Araştırma		*	*	*	*	
(Özüdoğru, 2024)	Sigortacılık Sektöründe Hizmet Kalitesinin Değerlendirilmesi: AHP ve TOPSIS Yöntemi	*		*			
(Nepomuceno, 2024)	A knowledge-based directional multicriteria framework with defuzzified subset of preferences for sustainable banking strategy analysis			*			

(Zhou, 2023)	Smart experience-oriented customer requirement analysis for smart product service system: A novel hesitant fuzzy linguistic cloud DEMATEL method						*

Yöntem

DEMATEL (Decision Making Trial and Evaluation Laboratory) yöntemi, özellikle karmaşık sorunlarda neden-sonuç ilişkilerini belirlemek ve faktörler arasındaki ilişkileri analiz etmek için kullanılan bir yöntemdir. Bu yöntem, faktörlerin birbiri üzerindeki etkilerini değerlendirmek ve bu etkilerden bir neden-sonuç diyagramı oluşturmak amacıyla kullanılır (Fontela, 1976). Yöntem 6 adımdan oluşmaktadır. The Decision Making Trial and Evaluation Laboratory (DEMATEL) Metodu; araştırmada karmaşık ve birbirine girmiş problem gruplarının çözümünde kullanılması amacıyla 1972 ve 1976 yılları arasında Cenevre Battelle Memorial Enstitüsü, Bilim ve İnsan İlişkileri programı tarafından geliştirilmiştir.

DEMATEL, özel problematiklerin kavrayışını geliştirmek, birbirine geçmiş problem kümelerini ve hiyerarşik yapıda uygulanabilir çözümlerin tanımlanmasına katkıda bulunmak için uygun bilimsel araştırma yöntemlerinin kullanılmasına öncülük etme ümidiyle geliştirilmiştir. Graf teori temelli DEMATEL metodu nedensel ilişkiyi daha iyi anlamamızı sağlayacak ilgili faktörleri sebep ve sonuç gruplarına bölerek, problemleri taslak olarak planlama ve çözme imkânı verir. DEMATEL metodunun başlıca avantajı uzlaşmacı sebep-sonuç modeli içeren dolaylı ilişkileri kapsamasıdır. DEMATEL metodu sistem bileşenleri arasındaki yapı ve ilişkileri veya geçerli sayıda alternatifleri inceleyen etkili bir yöntemdir. DEMATEL kriterleri ilişkilerin cinsi ve birbirleri üzerindeki etkilerinin önemi yönünden öncelik sırasına göre düzenleyebilir. Diğer kriterler üstünde daha çok etkisi olan ve yüksek önceliği olduğu farz edilen kriterler, sebep kriterleri, daha çok etki altında kalan ve düşük önceliği olduğu faz edilen kriterler ise sonuç kriterleri olarak adlandırılır. DEMATEL metodu birbirini takip eden 6 adımdan oluşmaktadır. 6. Adım sonunda elde edilen etki-yönlü graf diyagramı ile çözüme ulaşılır.

Başlangıç İçin Doğrudan İlişki Matrisi Oluşturma

Karar vericiler, faktörlerin birbirleri üzerindeki etkilerini değerlendirmek için bir puanlama yaparlar (genellikle 0 ile 4 arasında: 0 = hiç etkisi yok, 4 = çok güçlü etki). Bu değerlendirmeler sonucunda, n x n boyutunda bir Doğrudan İlişki Matrisi (X) oluşturulur.

X = [[0, x12, x13, ..., x1n], [x21, 0, x23, ..., x2n], [x31, x32, 0, ..., x3n], ..., [xn1, xn2, xn3, ..., 0]]

Sayısal Değer	Tanım
0	Etkisiz
1	Düşük etki
2	Orta etki
3	Yüksek etki
4	Çok yüksek etki

Normalizasyon Matrisi Hesaplama

Doğrudan ilişki matrisi (X) normalize edilir. Normalizasyon için en büyük satır toplamı veya sütun toplamı kullanılır:

$$M = k \times A \tag{3.2.1}$$

$$k = Min\left\{ \frac{1}{\max\limits_{1\le i\le n}\sum\limits_{j=1}^{n}\left|a_{ij}\right|}, \frac{1}{\max\limits_{1\le i\le n}\sum\limits_{j=1}^{n}\left|a_{ij}\right|} \right\} \tag{3.2.2}$$

Toplam İlişki Matrisi Hesaplama

Toplam ilişki matrisi (T), normalize edilmiş matrisin tersinin kullanılmasıyla hesaplanır: Toplam İlişki Matrisi T T, DEMATEL'in hem doğrudan hem de dolaylı etkileşimleri bir arada değerlendiren, faktörlerin sistem içindeki etki ağırlıklarını ortaya koyan ve bunları analizine dönüştüren adımdır.

$$S = M + M^2 + M^3 + \ldots = \sum_{i=1}^{\infty \leftarrow} M^i \\ = M(I - M)^{-1} \tag{3.2.3}$$

Etki ve Tepki Değerlerini Hesaplama

Her faktörün toplam neden (Di) ve toplam etki (Ri) değerleri hesaplanır:

Gönderici grubu ve alıcı grubu hesaplanması matrisindeki sütunlar toplamı (R), matrisindeki satırlar toplamı (D) olmakla beraber D-R ve D+R değerlerini kullanarak, her bir kriterin diğerlerine olan etki seviyesi ve diğerleriyle ilişki seviyesi belirlenir. Bazı kriterler D-R değeri için pozitif değerlere sahiptir. Bu kriterler diğerleri üzerinde daha yüksek etkiye sahiptirler ve daha yüksek önceliğe sahip oldukları kabul edilir. Bu tip kriterler gönderici olarak adlandırılır. D-R değeri için negatif değere sahip olan kriterler ise diğer kriterlerden daha fazla etkilenirler. Daha düşük önceliğe sahip olduğu kabul edilen bu kriterler alıcı olarak adlandırılır. Diğer taraftan D+R değerleri her bir kriterin diğer kriterlerle arasındaki ilişkiyi gösterir ve D+R değeri yüksek olan kriterler diğer kriterler ile daha çok ilişkilidir, düşük olanların ise diğerleriyle ilişkisi azdır.

$$S = \left[s_{i,j}\right]_{n\times n},\ i,j \in \{1,2,3,\ldots,n\} \tag{3.2.4}$$

$$D = \sum_{j=1}^{n} s_{i,j} \tag{3.2.5}$$

$$R = \sum_{j=1}^{n} s_{i,j} \tag{3.2.6}$$

Neden-Sonuç Diyagramı Oluşturma

Neden ve sonuçlar arasındaki ilişkiyi belirlemek için $(Di + Ri) ve (Di - Ri)$ değerleri kullanılır (Tseng, M. L., & Lin, Y. H. 2009).

Toplam ilişki matrisi $T = [t_{ij}]$ elde edildikten sonra, $r_i = \sum_{j=1}^{n} t_{ij}$ ve $c_i = \sum_{j=1}^{n} t_{ji}$ ile her faktörün 'etki gücü' ve 'etkilenme gücü' hesaplanır.

Prominence ve Relation değerleri hesaplanır: $P_i = r_i + c_i$(Prominence) ve $N_i = r_i - c_i$(Relation).

Eşik değeri (α) belirlenir. Örneğin ortalama değer yaklaşımı: $\alpha = (1/n^2) \sum_{i=1}^{n} \sum_{j=1}^{n} t_{ij}$

Önemli ilişkiler $t_\{ij\} \geq \alpha$ koşuluna göre seçilir, diğerleri elenir.

Her faktör, $x_i = P_i$ ve $y_i = N_i$ koordinatlarına yerleştirilerek koordinat düzlemine aktarılır. $N_i > 0$ olanlar 'neden', $N_i < 0$ olanlar 'sonuç' grubuna ayrılır.

Koordinatlardaki faktörler arasındaki önemli ilişkiler oklarla bağlanır. Ok kalınlığı veya yoğunluğu t_{ij} değerine orantılı olarak ayarlanabilir.

Diyagram renk veya sembollerle görsel olarak düzenlenir ve yorumlanır; sebep ve sonuç grupları vurgulanarak sunuma hazır hale getirilir.

(Di + Ri): Faktörün toplam etki derecesi (hem neden hem de etki olarak).

(Di- Ri): Pozitif ise faktör neden, negatif ise faktör sonuç olarak değerlendirilir.

Kriter ağırlıkları w_i = (Di + Ri) / Σ (Dk + Rk)

Neden-Sonuç Haritası Çizimi

Faktörler, (Di- Ri) ve (Di + Ri) eksenlerinde bir grafikte gösterilir. Bu harita, faktörlerin birbirleri üzerindeki neden ve sonuç ilişkilerini net bir şekilde görselleştirir.

Uygulama

Adayların belirlenmesi

Çalışmada seçim süreci modeli oluşturulduktan sonra üniversite ve danışman firmanın yönetici düzeyindeki çalışanlarından oluşan adaylar belirlenmiştir. Bir vakıf üniversitesinde yapılan çalışmada, İktisadi, İdari ve Sosyal Bilimler Fakültesinden uzmanları uygulama ve çalışmaları yapan danışman firmaların görüşleri alınarak oluşturulmuştur.

	Görev	Görev tanımı	Tecrübe	Çalışma Alını
1	Öğretim Üyesi	Doç.Dr.	30	Yönetim Bileşim
2	Öğretim Üyesi	Dr. Öğretim Üyesi	25	İşletme
3	Öğretim Üyesi	Dr. Öğretim Üyesi	35	İşletme
4	Danışman	Genel Müdür-Kurucu	37	Operasyon
5	Danışman	Genel Müdür - Kurucu	40	Operasyon

Kritik faktörlerin **Değerlendirme ortalamaları**

K1 (Optimum kullanıcı deneyimi), K2 (Kesintisiz alışveriş deneyimi), K3 (Doğru ve alakalı öneriler), K4 (Hızlı ihtiyaç cevaplama), K5 (Kullanım zorlukları) ve K6 (Siber güvenlik riskleri). Yapılan analizler sonucunda, K3 (Doğru ve alakalı öneriler) sistemdeki en etkili faktör olarak belirlenmişken, K6 (Siber güvenlik riskleri tanımlanmıştır.

	K1	K2	K3	K4	K5	K6
K1 (Optimum kullanıcı deneyim)	0.0	3.0	2.8	3.7	3.9	1.5
K2 (Kesintisiz alışveriş deneyimi)	3.8	0.0	2.2	1.8	2.1	1.8
K3 (Doğru ve alakalı öneriler)	3.8	3.4	0.0	2.0	2.0	2.0
K4 (Hızlı ihtiyaç Cevaplama)	3.0	2.8	2.0	0.0	2.0	2.0
K5 (Kullanım Zorlukları)	2.2	2.0	1.2	1.2	0.0	2.0
K6 (Siber Güvenliği riskleri)	1.0	1.2	1.2	1.0	2.8	0.0

Normalizasyon Matrisi Hesaplama

	K1	K2	K3	K4	K5	K6		TOPLAM
K1	0,0000	0.2013	0.1879	0.2483	0.2617	0.1007		0.9999
K2	0.2550	0,0000	0.1477	0.1208	0.1409	0.1208		0.7852
K3	0.2550	0.2282	0,0000	0.1342	0.1342	0.1342		0.8858
K4	0.2013	0.1879	0.1342	0,0000	0.1342	0.1342		0.7918
K5	0.1477	0.1342	0.0805	0.0805	0,0000	0.1342		0.5771
K6	0.0671	0.0805	0.0805	0.0671	0.1879	0,0000		0.4831
							Maksimum	0.4831
TOPLAM	0.9261	0.8321	0.6308	0.6509	0.8589	0.6241	Maksimum	0.9261
Normalleştirme								0.067114

Toplam İlişki Matrisi

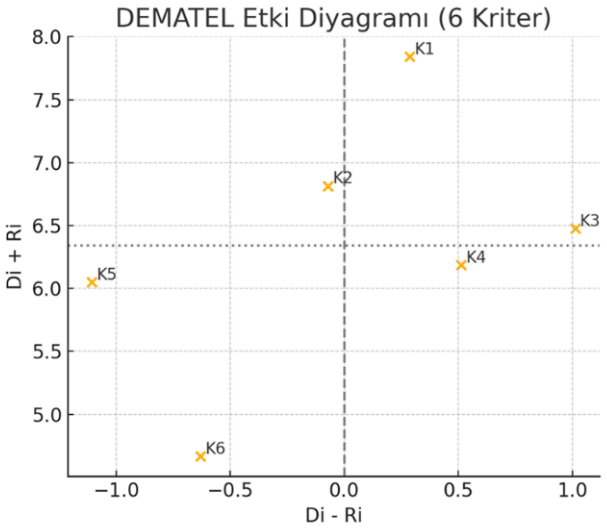
	K1	K2	K3	K4	K5	K6
K1	0.6458	0.7550	0.6220	0.6853	0.8145	0.5417
K2	0.7406	0.4875	0.5174	0.5160	0.6320	0.4778
K3	0.8022	0.7295	0.4324	0.5699	0.6810	0.5291
K4	0.6980	0.6409	0.5029	0.4008	0.6200	0.4864
K5	0.5140	0.4699	0.3574	0.3690	0.3716	0.3901
K6	0.3781	0.3605	0.2997	0.2968	0.4598	0.2234

Neden-Sonuç Diyagramı Oluşturma

	Di	Ri	Di+Ri	Di-Ri
K1	4.0642	3.7786	7.8428	0.2856
K2	3.3714	3.4434	6.8147	-0.0720
K3	3.7440	2.7318	6.4758	1.0122
K4	3.3491	2.8380	6.1870	0.5111
K5	2.4720	3.5787	6.0507	-1.1068
K6	2.0183	2.6485	4.6669	-0.6302

	Wi	**Ağırlık (Wi)**
K1	7,848	0,205
K2	6,815	0,178
K3	6,554	0,171
K4	6,208	0,162
K5	6,151	0,161
K6	4,709	0,123

Bulgular



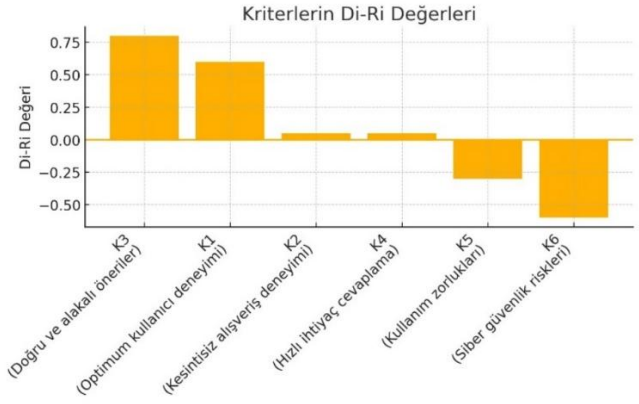
K3 (Doğru ve alakalı öneriler), Di-Ri değeri en yüksek olan kriterdir. Bu durum, K3'ün sistemdeki en güçlü etkileyici faktör olduğunu ve diğer kriterler üzerinde yönlendirici bir rol üstlendiğini ortaya koymaktadır. Kullanıcılara zamanında ve ilgili öneriler sunulması, yalnızca kullanıcı memnuniyetini değil, aynı zamanda genel dijital deneyimi iyileştirmede de doğrudan etkili olmaktadır. Bu nedenle, K3 kriterine yönelik stratejik yatırımlar ve iyileştirmeler, sistemin geneline yayılan bir pozitif etki yaratacaktır. K1 (Optimum kullanıcı deneyimi) de pozitif Di-Ri değeriyle etkileyici bir faktör olarak öne çıkmaktadır. Ancak bu etkileyicilik, K3 kadar baskın değildir. Yine de kullanıcı deneyiminin doğrudan ve dolaylı yollarla diğer kriterleri etkilediği göz önünde bulundurulduğunda, K1'in sistemdeki merkezi rolü yadsınamaz. K6 (Siber güvenlik riskleri), Di-Ri değeri en düşük olan kriterdir. Bu durum, K6'nın sistemde en fazla etkilenen ve dış faktörlere en duyarlı unsur olduğunu göstermektedir. Güvenlik

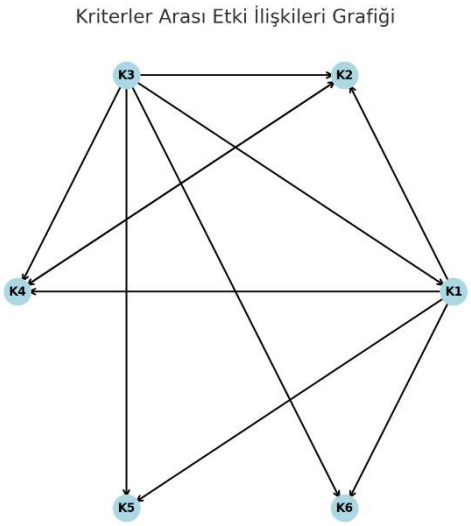
açıkları, genellikle sistemdeki diğer zayıflıklardan kaynaklanmakta ve doğrudan kontrol altına alınmadan iyileştirilememektedir. Benzer şekilde K5 (Kullanım zorlukları) da negatif Di-Ri değeriyle sistemin pasif ve dışsal etkilerden daha çok etkilenen kriterlerinden biri olarak değerlendirilmektedir. K2 (Kesintisiz alışveriş deneyimi) ve K4 (Hızlı ihtiyaç cevaplama), Di-Ri değerleri sıfıra yakın olup, sistemde hem etkileyen hem de etkilenen bir denge içinde rol almaktadır. Bu denge, bu iki kriterin sistemde daha stabil ve destekleyici işlevler gördüğünü göstermektedir. Sonuç olarak, K3 ve K1 gibi güçlü etkileyici kriterlerin önceliklendirilmesi, özellikle K5 ve K6 gibi kırılgan kriterler üzerinde iyileştirici etkiler sağlayacaktır. Sistem içi dengelerin sürdürülebilir şekilde korunması için etki-tepki zincirinin dikkatle yönetilmesi gerekmektedir.

SONUÇ

K3 (Doğru ve alakalı öneriler), Di Ri değeri pozitif ve oldukça yüksek olduğundan, sistem üzerinde en güçlü etkileyici faktörlerden biri olarak öne çıkmaktadır. Bu durum, önerilerin doğruluğunun ve alaka düzeyinin, kullanıcı deneyimini doğrudan iyileştiren kritik bir etken olduğunu göstermektedir. K3'ün güçlendirilmesi, diğer kriterlere olumlu yönde yansıyacaktır. Özellikle K1 (Optimum kullanıcı deneyimi) ve K4 (Hızlı ihtiyaç cevaplama) gibi faktörler, doğru önerilerin sağlanmasıyla doğrudan etkilenecektir. Bu nedenle, öneri sistemlerinin geliştirilmesi ve kullanıcı verilerine dayalı daha doğru öneriler sunulması stratejik bir öneme sahiptir. K1 (Optimum kullanıcı deneyimi), sistemdeki önemli etkenlerden biridir ve K3 gibi etkileyici faktörlerin iyileştirilmesi, kullanıcı deneyimini hızla artıracaktır. Aynı şekilde, K4 (Hızlı ihtiyaç cevaplama) ve K2 (Kesintisiz alışveriş deneyimi) gibi destekleyici faktörler, K1'in etkisini güçlendirecek ve genel sistem performansına katkı sağlayacaktır. Diğer taraftan, K6 (Siber güvenlik riskleri) ve K5 (Kullanım zorlukları), sistemin zayıf noktaları arasında yer almakta olup, bu faktörler daha düşük etki değerlerine sahiptir. Ancak, bu faktörler sistemdeki aksaklıkları tetikleyen kritik unsurlar olduğu için, K3 ve K1 gibi etkili faktörlerin iyileştirilmesi, K5 ve K6'daki riskleri azaltacaktır.

Grafikte, kriterler arasındaki etkileri görselleştiren diyagramda, K3 (Doğru ve alakalı öneriler) ve K1 (Optimum kullanıcı deneyimi) gibi güçlü etkenlerin sistemdeki genel performansı doğrudan etkilediği, K6 (Siber güvenlik riskleri) ve K5 (Kullanım zorlukları) gibi faktörlerin ise dışarıdan gelen etkilere daha fazla bağımlı olduğu görülmektedir. K3 ve K1 gibi faktörlerin iyileştirilmesi, sistemin tüm yönlerine pozitif bir geri bildirim yaratacaktır.





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The Impact of Digital Technologies on Legal Awareness among Middle School Students

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Abstract

This study explores the impact of digital technologies on middle school students' understanding of human rights and their legal awareness. The primary aim is to identify the effectiveness of digital educational tools in shaping legal consciousness and to evaluate their pedagogical value. A questionnaire survey method was employed, involving 5th and 6th grade students from schools in Bishkek. The results revealed that social platforms were the main sources of legal information, and that visual and interactive formats were more effective in fostering legal awareness compared to traditional methods. The study concludes by emphasizing the necessity of systematically integrating digital educational tools into human rights education.

Key words: *Dıgıtal technologies, Legal awareness, Human rights, middle school students, educational tools*

INTRODUCTION

Digital technologies, as a hallmark of the 21st century, have profoundly permeated all facets of human life, including education, healthcare, economy, and the legal sphere. Particularly in the educational context, these technologies have significantly reshaped the ways in which youth access information, perceive the world, develop consciousness, and form civic attitudes. Modern students increasingly rely on smartphones, tablets, and social media rather than traditional information sources, necessitating a transformation in the methods used for delivering legal education (Filippov, 2021).

Human rights education plays a pivotal role in fostering an active and informed citizenry. Effective citizenship develops when individuals clearly understand their rights, responsibilities, and societal roles, a process ideally initiated in early schooling. However, traditional approaches to legal education often rely on formal, monotonous methods that fail to engage young learners, leading to superficial legal consciousness limited to mere legal definitions (Sydykova, 2022).

Digital technologies offer significant potential to revolutionize both the content and delivery methods of legal education. Formats such as YouTube videos, TikTok-style clips, interactive applications, and educational games generate interest among youth, making the legal concepts "lively" and practically relatable. Methods such as gamification, case-based scenarios, and quizzes can deepen legal understanding through emotional engagement, sensory experiences, and practical activities, surpassing traditional textbooks and lectures in efficacy (Nazarova & Toktogulov, 2023).

Nevertheless, the vast abundance of online content presents both opportunities and risks. Digital content related to legal education can vary significantly in quality, reliability, and pedagogical appropriateness. Platforms such as social media often simplify legal concepts, presenting them in populist or manipulative forms that can distort students' perceptions and understanding (Niyazalieva,

2022). Therefore, ensuring high-quality, credible, and methodologically sound content becomes critical in digitally-mediated legal education.

Previous studies highlight that young people seek easily accessible, engaging legal information. When conventional teaching methods fail to capture students' attention, interactive formats like short videos or digital games can significantly enhance their engagement and comprehension (Holmes et al., 2023; Jongsermtrakoon & Nasongkhla, 2015). Consequently, utilizing digital platforms for delivering legal education is not merely an innovation but an essential adaptation to contemporary educational realities.

This research addresses precisely this context, aiming to examine how digital technologies impact legal consciousness among middle school students, identify the most effective digital tools, and clarify necessary pedagogical conditions. Empirical data collected via questionnaire surveys among 5th and 6th-grade students provide direct insights into their attitudes towards legal content, information retrieval methods, and interest in digital tools. Ultimately, this study aims to produce concrete recommendations for integrating digital technologies effectively into legal education practices.

Thus, understanding the intersection between digital technology and legal education is vital for developing strategies that enhance students' legal awareness and critical thinking, ensuring they become informed and active participants in a digital and democratic society.

MATERIAL AND METHODS

Material

The primary materials used for this study consisted of educational digital content, including interactive videos, animations, mobile applications, and online platforms commonly accessed by middle school students. Specific digital platforms analyzed in the study included YouTube, TikTok, Instagram, and various educational mobile apps dedicated to legal education and human rights topics. Additionally, official textbooks and teaching guidelines from Kyrgyzstan's Ministry of Education were reviewed to provide a comparative framework against digital educational tools.

Relevant theoretical and empirical literature was also extensively reviewed to build a comprehensive conceptual basis for the study. Primary sources included research papers and reports examining digital technologies' effectiveness in educational contexts, specifically in legal awareness and human rights education. Key sources included studies by Filippov (2021), Sydykova (2022), Nazarova and Toktogulov (2023), Holmes et al. (2023), Niyazalieva (2022), Jongsermtrakoon and Nasongkhla (2015), Corradini and Nardelli (2020), and Poblet and Kolieb (2018).

The Collection of the Data

The data collection was carried out using a structured questionnaire designed specifically for this research. The survey was administered in February 2025 to a total of 30 middle school students (15 boys and 15 girls) from 5th and 6th grades at selected schools in Bishkek, Kyrgyzstan. Prior to data collection, written consent was obtained from parents or legal guardians to ensure ethical compliance. Students' anonymity and confidentiality were strictly maintained throughout the study.

The questionnaire comprised four thematic blocks:

- Legal awareness level: Students' understanding of the concepts of "rights" and "human rights," including their ability to provide relevant examples.

- Sources of legal information: Where students typically obtained their information about human rights and legal topics, including options like teachers, family, internet sources, social media, YouTube, and TikTok.
- Frequency and purpose of digital tools usage: How often students utilized digital technologies and their motivations for accessing legal information through these platforms.
- Response to digital legal content: Students' reactions and attitudes towards digital educational tools such as animations, interactive games, and case-based methods for legal education.

Questions were structured to suit the developmental and cognitive abilities of middle school students, employing simple and clear language. The survey consisted of multiple-choice questions, "yes/no" options, and open-ended questions designed to capture qualitative responses reflecting students' genuine opinions and experiences.

Statistical Analysis

The collected data were analyzed using a combination of quantitative and qualitative methods. Quantitative data were processed using descriptive statistical methods, providing frequency distributions, percentages, and graphical visualizations such as bar charts and pie diagrams to illustrate clearly how students responded to each survey item.

For qualitative data analysis, thematic content analysis was employed to categorize open-ended responses and highlight common themes, attitudes, and perceptions regarding digital legal education content. This analysis aimed to identify underlying patterns in students' preferences and critical views on digital tools, contributing nuanced insights to complement quantitative findings.

The statistical package SPSS (Statistical Package for Social Sciences, version 26.0) was used for processing quantitative data, ensuring accuracy and reliability in the presentation of results. Triangulation of quantitative and qualitative findings was applied to enhance the robustness and credibility of the study outcomes.

Through these comprehensive methodological approaches, the research aimed to clearly delineate the effectiveness and practical implications of digital educational technologies in shaping legal consciousness among middle school students.

RESULTS

The findings of the study reveal significant insights into the role of digital technologies in shaping legal awareness among middle school students. The results are presented thematically, based on the structure of the questionnaire, and supported by descriptive statistics and qualitative observations.

1. Sources of Legal Information

Students were asked where they primarily obtain legal or human rights-related information. The responses were distributed as follows:

Source of Information	Number of Students	Percentage (%)
TikTok / YouTube	14	46.7%
Teachers / School Lessons	8	26.7%
Family Members	5	16.7%

Source of Information	Number of Students	Percentage (%)
No Interest / No Knowledge	3	10.0%

Interpretation:
These results confirm that nearly half of the students rely on informal video-based platforms such as TikTok and YouTube as their primary source of legal knowledge. In contrast, only a quarter of students cited teachers as their main source. This reflects the growing dominance of digital platforms in youth information culture, aligning with findings by Filippov (2021) and Niyazalieva (2022).

2. Level of Awareness of Human Rights Concepts

Students' understanding of human rights was assessed through self-evaluation and definition-based questions.

Level of Understanding	Number of Students	Percentage (%)
Good Understanding	10	33.3%
General but Limited Knowledge	12	40.0%
Poor or No Understanding	8	26.7%

Interpretation:
Only one-third of the students demonstrated a solid understanding of human rights, while the remaining students either had vague knowledge or none at all. These results underscore the importance of adapting legal education content to students' cognitive levels and media preferences, as also argued by Sydykova (2022) and Nazarova & Toktogulov (2023).

3. Frequency of Using Digital Tools

The survey also explored how frequently students engage with digital technologies, which correlates with their exposure to legal information in digital formats.

Frequency of Use	Number of Students	Percentage (%)
Daily	18	60.0%
Occasionally	9	30.0%
Rarely / Never	3	10.0%

Interpretation:
The majority (60%) of students reported using digital tools daily. This finding supports the practical potential of reaching students through digital platforms for legal education and further validates the use of media-based content such as games, quizzes, and short videos.

4. Reactions to Digital Legal Content

Qualitative responses from open-ended questions highlighted the students' preferences and motivations. Notable observations included:

- A preference for **short, story-based legal videos**, especially those using animation and relatable characters.
- Positive feedback on **interactive games and quizzes**, often described as "fun" and "easy to understand."
- Students expressed that visual formats helped them remember the material better than reading or listening to lectures.

Interpretation:
These responses resonate with the claims made by Jongsermtrakoon & Nasongkhla (2015) and Corradini & Nardelli (2020), who emphasized the emotional and cognitive benefits of gamified and visual learning in legal and civic education.

DISCUSSION AND CONCLUSION

The findings of this study underscore the growing influence of digital technologies in shaping students' legal awareness and highlight both the opportunities and challenges associated with integrating these technologies into human rights education.

First, the **dominance of digital platforms** such as TikTok and YouTube as primary sources of legal information among students confirms the urgent need to reconsider traditional educational models. Nearly half of the surveyed students indicated that they receive their legal knowledge from these platforms rather than from school or family. This aligns with the findings of Filippov (2021), who argued that digital transformation fosters new forms of civic identity and legal consciousness, particularly through visual and interactive channels.

Second, **the limited depth of students' understanding** of human rights—only 33.3% demonstrating good comprehension—suggests that legal education, while present in curriculum, often fails to engage students meaningfully. As noted by Sydykova (2022), legal knowledge transmitted through conventional means tends to be too abstract, formal, or irrelevant to students' daily lives. Thus, effective legal education must be relevant, interactive, and responsive to the digital realities that define students' information consumption habits.

Third, the **high frequency of digital technology usage** (60% daily) confirms the practical feasibility of delivering legal education through digital channels. However, Niyazalieva (2022) and Poblet & Kolieb (2018) warn of the risks: misinformation, manipulative content, and unverified claims often dominate online spaces. Therefore, while digital tools offer potential, their use must be accompanied by **rigorous content quality control** and **pedagogical supervision**.

Students' qualitative feedback reveals strong preferences for **short, animated, story-based videos** and **interactive formats** like games and quizzes. This supports the frameworks proposed by Jongsermtrakoon & Nasongkhla (2015), who emphasized that gamification and visual learning enhance both comprehension and retention. Holmes et al. (2023) further extend this argument by showing that artificial intelligence and digital personalization tools can be leveraged to tailor legal education to individual student needs, offering adaptive content delivery.

The implications of these findings are significant for educators, policymakers, and content developers. Legal education must not only move toward digitalization, but also adapt in form, tone, and

method to meet the learning styles of the digital generation. Ignoring this shift risks further alienating students from civic learning and undermining the broader goals of democratic education.

Practical Recommendations

Based on the results and discussion, the following recommendations are proposed for stakeholders involved in legal education:

1. **Develop National or Institutional Legal Education Platforms**: These platforms should host animated, interactive, and age-appropriate content on legal rights and responsibilities.
2. **Train Teachers in Digital Pedagogy**: Professional development programs should include modules on how to integrate digital tools and legal topics effectively in classroom settings.
3. **Establish Youth Media Clubs for Legal Content Analysis**: These clubs can cultivate critical thinking skills and help students evaluate the accuracy and bias of online legal information.
4. **Create an Expert Panel to Vet Legal Content**: Ministries of education should collaborate with legal professionals to ensure that digital content aligns with legal standards and pedagogical ethics.
5. **Expand Research and Monitoring**: Future studies should explore how legal education varies across regions, age groups, and delivery formats, with a view to refining national strategies.

Conclusion

In conclusion, digital technologies have emerged not only as supplementary tools but as essential elements of modern legal education. They reshape the way young people acquire, interpret, and apply knowledge about human rights. However, their effective integration requires a deliberate, strategic, and ethically guided approach. Legal awareness is not merely about knowing the law; it is about forming a conscious, engaged, and critically minded generation capable of navigating a digitalized civic world.

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Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this study.

Author Contributions

The author solely conceived, designed, and conducted the research, including literature review, data collection, analysis, and manuscript writing. All stages of the study were completed independently by the author as part of doctoral academic work at I. Arabaev Kyrgyz State University.

Smart Charging Locker for Personal Electronics Using Solar-Powered ESP32 with Real-Time Usage Analytics

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Abstract

The increasing demand for accessible and sustainable charging solutions for personal electronic devices has prompted the development of intelligent public infrastructure. This paper presents the design and implementation of a solar-powered intelligent charging locker system integrated with ESP32 microcontrollers for real-time monitoring and usage analytics. Each locker unit is equipped with USB and wireless charging interfaces powered by photovoltaic panels, with the ESP32 managing energy usage, access control, and data collection. The system monitors key metrics, including charging time, energy consumption per user, and slot availability, and transmits data via MQTT to a cloud-based dashboard for visualization and analytics. The locker supports user interaction through a touchscreen interface and mobile app, enabling QR-based access and reservation features. Performance evaluations demonstrate practical power autonomy under varying sunlight conditions and robust user analytics for facility optimization. The proposed solution contributes to sustainable smart infrastructure by promoting renewable energy usage, intelligent control, and user-centric service delivery.

Key words: *Smart Charging Systems with ESP32, Solar Energy and Public Infrastructure, MQTT and IoT Analytics, Energy Monitoring and Sustainable Design, Embedded IoT Applications and Real-Time Usage Tracking*

INTRODUCTION

The increasing reliance on personal electronic devices has amplified the demand for accessible and sustainable charging solutions in public spaces (Holte & Richard Ferraro, 2021). Traditional charging stations often depend on grid electricity, raising concerns about energy consumption and environmental impact (Ghasemi-Marzbali, 2022). Integrating renewable energy sources, such as solar power, with smart charging infrastructures presents a viable solution to these challenges (Sachan, Deb, & Singh, 2020).

The ESP32 microcontroller (El-Khozondar et al., 2024), known for its low power consumption and integrated Wi-Fi and Bluetooth capabilities, has been widely adopted in IoT applications. Its versatility allows for real-time monitoring and control of various systems (Yin, Rodriguez-Andina, & Jiang, 2019), including solar-powered devices. Previous implementations have demonstrated the ESP32's efficacy in solar power monitoring systems, enabling users to track energy generation and consumption remotely (Al Mamun et al., 2024).

Moreover, advancements in solar charging technologies have facilitated the development of autonomous IoT devices capable of operating indefinitely without external power sources (Lei et al., 2020). These innovations underscore the potential of integrating solar energy (Kabir, Kumar, Kumar,

Adelodun, & Kim, 2018) with innovative charging solutions to promote sustainability and energy efficiency.

This paper presents the design and implementation of a solar-powered intelligent charging locker system (Huo et al., 2023) with ESP32-based usage analytics. The system aims to provide an eco-friendly charging solution for personal electronics while offering real-time monitoring and data analysis capabilities through IoT integration (Sahoo, Ratha, Rout, & Nayak, 2022). The proposed solution contributes to sustainable smart infrastructure by promoting renewable energy usage, intelligent control, and user-centric service delivery.

Main Contributions:

1. Design and development of a solar-powered smart charging locker system utilizing ESP32 microcontrollers for real-time monitoring and control.
2. Integration of renewable energy sources with intelligent charging infrastructures to promote sustainability and energy efficiency.
3. Implementation of usage analytics and data visualization capabilities through IoT integration, enhancing user experience and system management.
4. Evaluation of system performance under varying environmental conditions, demonstrating its reliability and practicality for public spaces.
5. Contribution to advancing sustainable smart infrastructure by providing an eco-friendly charging solution for personal electronic devices.

The remainder of this paper is structured as follows: Section 2 presents related works on solar-powered IoT charging systems, ESP32-based energy monitoring, and MQTT communication. Section 3 describes the materials and methods, including the system design, hardware, and software components. Section 4 details the application scenario, deployment, and operation flow. Section 5 presents the experimental results covering responsiveness, energy performance, slot usage analytics, and system autonomy. Finally, Section 6 discusses the findings, compares the system with existing solutions, and outlines future work directions.

RELATED WORKS

The increasing demand for sustainable public infrastructure has led to widespread interest in intelligent energy management and off-grid IoT-powered solutions (Bibri, 2020; Zach, Kretschmer, & Stoeglehner, 2019). Numerous studies have explored integrating renewable energy with embedded systems to support green urban technologies (Hsu et al., 2022; Mishra & Singh, 2023).

ESP32 microcontrollers have gained popularity in such applications due to their low power consumption, built-in Wi-Fi/Bluetooth, and compatibility with MQTT for lightweight data communication. For example, Han, Zhang, Ping, and Yan (2020) developed a decentralized energy trading platform based on ESP32 and MQTT, highlighting the device's viability for edge computing and real-time monitoring. Similarly, Bharudin et al. (2024) demonstrated ESP32's dual-protocol capabilities in controlling BLE-based systems with extended autonomy in outdoor deployments.

The incorporation of solar energy into IoT charging systems has also been investigated. Li, Lin, Young, Dai, and Wang (2019) applied hybrid solar energy systems in rural environments, confirming their operational reliability under variable solar irradiance. Such findings support the feasibility of using solar panels to power charging lockers in public areas. Complementary studies by (Alabi et al., 2022); Mostafa, Ramadan, and Elfarouk (2022) reviewed the integration of machine learning and energy analytics in smart cities, emphasizing the role of data-driven usage optimization.

Modern solutions increasingly adopt QR-based and app-driven interfaces regarding innovative locker systems and access control. While many commercial systems still rely on grid power, recent academic prototypes focus on integrating solar harvesting, embedded user analytics, and cloud dashboards (Nath et al., 2024). The MQTT protocol remains the preferred backbone for these applications due to its efficiency in low-bandwidth, low-power environments (Silva, Carvalho, Soares, & Sofia, 2021).

Despite these advances, current literature often isolates energy monitoring from user-side analytics or lacks integration between solar harvesting and intelligent usage dashboards. The present work addresses this gap by delivering a fully autonomous, solar-powered, ESP32-based intelligent charging locker system with real-time usage tracking, user interaction, and MQTT-based data services, making it a novel and applicable contribution to sustainable urban infrastructure.

While previous studies have addressed individual aspects of smart charging, solar integration, or MQTT-based IoT systems, a unified solution that combines solar-powered charging, ESP32-driven monitoring, user analytics, and real-time cloud integration within a modular public locker system remains largely unexplored. This study introduces a cost-effective, off-grid smart locker platform that powers itself through photovoltaic energy and provides real-time usage insights and user interaction features, bridging a practical gap in sustainable and intelligent public infrastructure design.

MATERIAL AND METHODS

System Overview

The proposed system is a solar-powered smart charging locker designed for public use in schools, libraries, parks, and transit hubs. It provides secure, independent charging compartments for personal electronic devices such as smartphones, tablets, and earbuds. The system comprises four compartments, each with USB-A and wireless charging outputs. The locker unit is powered by a photovoltaic (PV) panel mounted on top, which charges a 12V Li-ion battery pack via a solar charge controller. At the system's core lies an ESP32 microcontroller, responsible for monitoring charging duration, voltage/current levels, and compartment availability. The ESP32 also handles user authentication (via a QR code or keypad interface), sends real-time usage data over MQTT, and displays feedback through a small TFT screen or LED indicators mounted per slot.

The system is fully autonomous in energy operation and modular in design, allowing more compartments to be added with minimal changes to the power and communication infrastructure. Each locker's status is published periodically to a central cloud dashboard, which provides system administrators with usage statistics, fault notifications, and occupancy history.

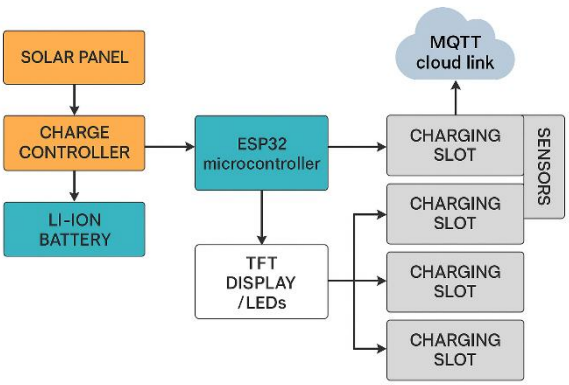


Figure 5. System Architecture of the Solar-Powered Smart Charging Locker

Figure 5 shows how the solar panel powers the system through a charge controller and Li-ion battery. The ESP32 microcontroller manages four charging slots, user display/LEDs, sensors, and real-time MQTT communication.

Hardware Components

The core controller of the smart charging locker is the ESP32-WROOM-32 module, chosen for its dual-core processing capability, integrated Wi-Fi/Bluetooth support, and low-power operation. In versions requiring extended memory or graphical interface support, the ESP32-WROVER variant may be used. The system is powered by a 30W solar panel, which charges a 12V 10Ah Li-ion battery pack through a TP4056-based charge controller or an MPPT module for higher efficiency. This setup provides complete off-grid operation, enabling continuous service even in environments with intermittent sunlight.

Each charging slot is monitored using current and voltage sensors, such as the INA219 or MAX471, which track energy delivered per user. Outputs include 5V USB charging ports and optional Qi-standard wireless charging pads, making the system compatible with most modern devices. User interaction is managed through a TFT touchscreen or a 4x4 matrix keypad, enabling access authentication and status feedback. Status LEDs or icons on the TFT interface guide the user during operation.

A relay module or N-channel MOSFETs are used between the ESP32 and charging outputs for controlled power switching and safety. These allow individual slot activation/deactivation based on user presence, energy availability, or fault detection, further improving energy efficiency and system control.

An overview of the solar-powered intelligent charging locker system's key components and their functions is provided in Table 5. The ESP32 microcontroller is the central unit, coordinating all sensor data acquisition, user interface updates, and MQTT communication. With a charge controller and Li-ion battery, the solar panel supplies off-grid renewable power to the entire system, enabling autonomous operation.

Table 5. Locker System Components Overview

Component	Description
ESP32 MCU	Core controller; handles logic and MQTT comms
Solar Panel (30W)	Powers battery charging during daylight
Li-Ion Battery (12V, 10Ah)	Stores solar energy for night use
TP4056/MPPT Controller	Manages solar input and battery health
USB Charging Ports	5V regulated outputs per compartment
Wireless Charging Coil	Optional Qi-compatible charging pad
TFT Display / LEDs	Shows slot status and user prompts
Voltage/Current Sensors	Monitor per-slot power usage (e.g., INA219)

Software Environment

The firmware for the ESP32 microcontroller was developed using the Arduino IDE, utilizing libraries such as *WiFi.h, PubSubClient.h, Adafruit_GFX, and TFT_eSPI* for wireless communication, MQTT messaging, and user interface rendering. These open-source libraries ensured compatibility with various sensors and displays while maintaining low memory usage, which is critical in microcontroller-based systems.

The MQTT protocol was adopted for data communication due to its lightweight publish-subscribe model. The system connects to a Mosquitto MQTT broker, hosted locally (e.g., on a Raspberry Pi) or

remotely via a cloud platform. Through this broker, the ESP32 publishes real-time usage metrics such as charging slot status, energy consumption, and user session logs to designated topics (e.g., *locker/slot1/status, locker/slot2/power*). It also subscribes to control messages for remote configuration or firmware updates.

A web-based mobile interface was designed to enable user access and slot reservation. This interface supports QR code scanning for authentication and displays real-time locker availability. A dashboard backend was developed using Node-RED for visual logic flows and Blynk (or optionally ThingsBoard) for mobile visualization. These platforms allowed seamless data display, control logic implementation, and notification features without requiring deep backend programming.

This software stack provides flexibility, real-time responsiveness, and expandability—key attributes for deploying scalable, innovative locker systems in public environments.

Communication and Data Flow Architecture

The intelligent charging locker system is built around a modular, event-driven communication structure. Sensor data—such as voltage, current, and occupancy status—is periodically read by the ESP32 and processed locally. Each ESP32 node publishes structured MQTT messages to a broker using predefined topics (e.g., locker/slot1/energy, locker/slot3/status), allowing seamless integration with dashboards, databases, or notification systems.

The data flow begins with real-time sensing during an active charging session. Upon user interaction (e.g., via touchscreen or keypad), the ESP32 initializes a session, activates the appropriate charging relay, and starts recording voltage and current. These values are sent to a remote server or cloud service via MQTT at defined intervals (e.g., every 10 seconds). Node-RED or Blynk interprets and logs the data into databases or visualizes it for administrators.

Meanwhile, local feedback is provided through a TFT touchscreen or LCD, which shows messages like “Charging Started,” “Slot In Use,” or “Session Complete.” The process ensures usability even if MQTT/cloud services are temporarily unavailable. Status LEDs next to each slot further assist users by displaying real-time availability (e.g., green for free, red for occupied).

The architecture ensures a non-blocking, fault-tolerant workflow: all MQTT communications are queued and retried in case of connectivity issues, while local control continues autonomously to avoid user disruption.

Energy Management Strategy

The intelligent charging locker system is built around a modular, event-driven communication structure. Sensor data—such as voltage, current, and occupancy status—is periodically read by the ESP32 and processed locally. Each ESP32 node publishes structured MQTT messages to a broker using predefined topics (e.g., locker/slot1/energy, locker/slot3/status), allowing seamless integration with dashboards, databases, or notification systems.

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The architecture ensures a non-blocking, fault-tolerant workflow: all MQTT communications are queued and retried in case of connectivity issues, while local control continues autonomously to avoid user disruption.

Equation (1) represents the dynamic energy balance of the intelligent charging locker system. This balance allows the system to adaptively manage slot activation adaptively, ensuring that charging operations are only enabled when sufficient surplus energy is available, thereby protecting the battery from deep discharge and optimizing energy utilization under variable solar conditions.

$$E_{\text{available}} = E_{\text{generated}} - E_{\text{consumed}} - E_{\text{reserve}} \quad (1)$$

The flowchart in Figure 6 clearly shows the energy management logic. After charging the battery, the system evaluates the battery level. If sufficient, it enables charging slots based on ESP32 priority logic. If the battery is critically low and no available capacity exists, the system initiates automatic power cutoff to protect the system.

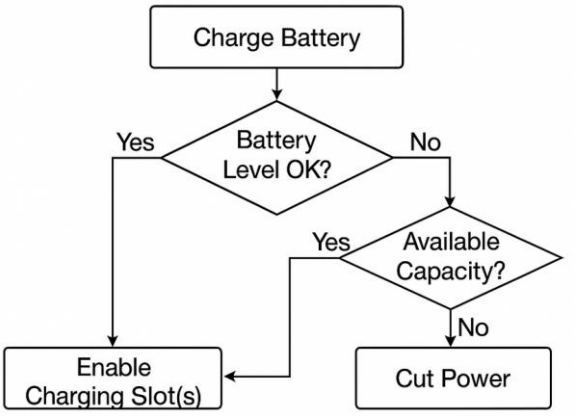


Figure 6. Simplified Energy Management Flowchart

APPLICATION

Scenario Definition and Objectives

The intelligent charging locker system was designed for deployment in public outdoor spaces such as university campuses, parks, or transport hubs, where users often need convenient, sustainable device charging. The locker was installed in a semi-outdoor area with moderate sunlight exposure, ensuring optimal photovoltaic panel performance while maintaining user accessibility.

The primary objectives of the system include:

- Sustainability: Operate entirely on solar power without dependency on grid electricity.
- Autonomy: Manage charging operations and energy management independently through onboard ESP32 logic.
- User-Friendliness: Offer an intuitive interface for slot reservation, real-time status display, and seamless QR code-based access.

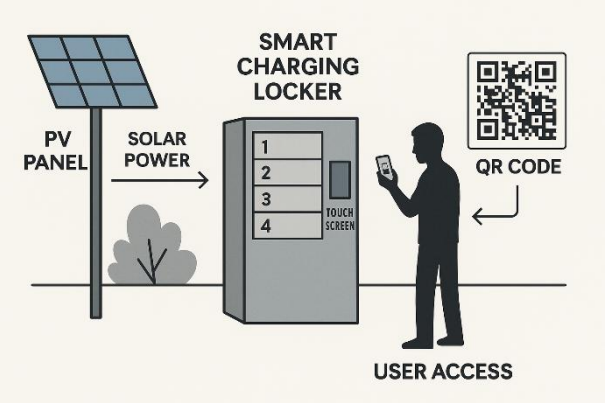


Figure 7. Smart Charging Locker Deployment Scenario

Figure 7 illustrates the outdoor deployment of the smart charging locker system. The PV panel charges the system, while users interact through a touchscreen or QR code using their mobile devices. The layout shows the self-contained, user-friendly, and autonomous design of the system.

System Deployment and Setup

The prototype system was deployed in a semi-outdoor area on a university campus, providing moderate sunlight exposure throughout the day. The solar panel was installed facing south at a 35-degree tilt to maximize solar energy harvesting. The locker unit had four compartments, each with USB-A ports and optional wireless charging pads.

A 4.3-inch TFT touchscreen was installed on the locker front panel for user interaction. The interface displayed available slots, charging progress, and system messages. A QR code reader and dynamic QR codes were integrated, enabling users to initiate sessions, authenticate access, and monitor their charging status via mobile devices. This setup ensured ease of use, autonomous power operation, and accessibility for multiple users simultaneously.

System Operation Flow

The system operation begins when the user scans the locker's QR code using their mobile device or interacts directly via the touchscreen interface. After authentication, the system checks the available slots and battery status.

The user selects a free slot if sufficient energy is available, which the ESP32 activates via relay or MOSFET switching. The charging session is monitored in real-time, with usage data logged locally and sent via MQTT to the cloud dashboard. At the end of the session or when the device is removed, the ESP32 deactivates the slot, updates the occupancy status, and logs the energy delivered during the session.

Figure 8 illustrates the typical user journey and system operation, from QR code scanning or touchscreen use, checking slot availability and battery status, selecting a free slot, monitoring charging progress, and ending the session with automatic slot deactivation. The clear, step-by-step flow ensures a user-friendly and autonomous process.

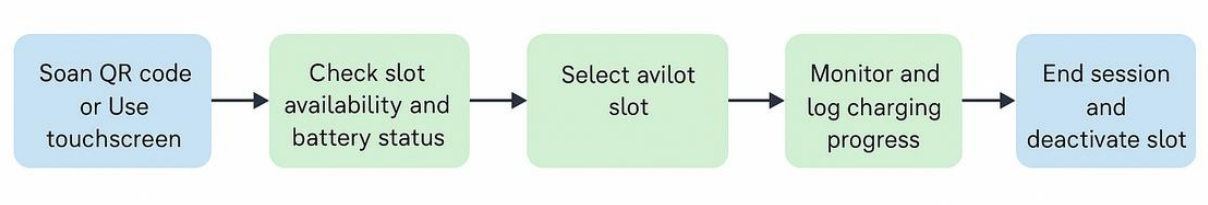


Figure 8. User Interaction and System Operation Flowchart

Real-Time Monitoring and User Interaction Features

The system offers real-time monitoring and user interaction capabilities via a cloud-based dashboard developed using Node-RED and Blynk platforms. Users and administrators can view:

- Slot availability in real time, with visual icons indicating free, in-use, or fault conditions.
- Battery status and solar input are displayed as gauges and graphs.
- Energy usage per session, including historical logs for each compartment.

Users receive notifications on their mobile devices when:

- Their session starts or ends.
- The slot is nearing a timeout or session limit.
- The system enters low battery mode, suspending new sessions.

The locker's touchscreen interface also mirrors key information locally, ensuring that even without network access, users can interact smoothly and receive feedback on slot status and charging progress.

This dashboard in Figure 9 displays real-time information including slot status, battery level, solar input, and historical energy usage. Users can see active slots, receive session notifications, and track the system's energy performance through intuitive visuals.

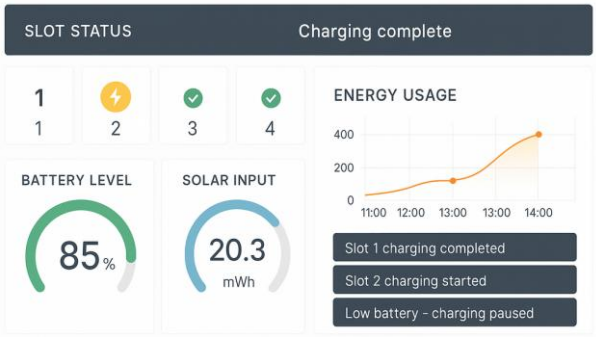


Figure 9. Smart Charging Locker Monitoring Dashboard Example

Summary of Application Behavior

During typical daytime use, the smart charging locker operated with consistent autonomy, relying solely on solar input without requiring external power. The system successfully managed user sessions across all four slots, with automatic slot activation and deactivation occurring reliably via ESP32 control logic.

Response time from QR code scan to slot unlocking averaged under 2 seconds, and real-time feedback on the TFT screen minimized user confusion. In overcast conditions, the system's power management logic effectively disabled low-priority slots while maintaining operation in at least one active slot, demonstrating adaptive slot prioritization based on battery availability.

MQTT-based data reporting remained stable throughout the testing period, with no missed session logs and accurate energy usage reporting on the dashboard. These observations confirm the system's practical viability for real-world deployment in semi-public outdoor environments.

RESULTS

System Responsiveness Evaluation

The system's responsiveness was evaluated across three key metrics:

- **User interaction latency**: Time from QR code scan to slot activation
- **Charging session response**: Time from user confirmation to actual charging start
- **MQTT data transmission delay**: Time from ESP32 data publish to cloud dashboard visualization

Table 6. Average System Latency Metrics

Metric	Average Time (s)	Standard Deviation (s)
QR to Slot Activation	1.8	0.2
Charging Start Response	0.9	0.1
MQTT Transmission Delay	0.5	0.05

The measurements were averaged over **50 user interactions** under standard conditions. The results are summarized in Table 6.

Figure 10 presents the latency metrics as a bar chart. User-to-slot activation latency remained under 2 seconds, ensuring an acceptable user experience. Charging session start was consistently fast (~0.9s), while MQTT data transmission was the fastest (~0.5s), confirming the system's capability to provide near real-time reporting and control.

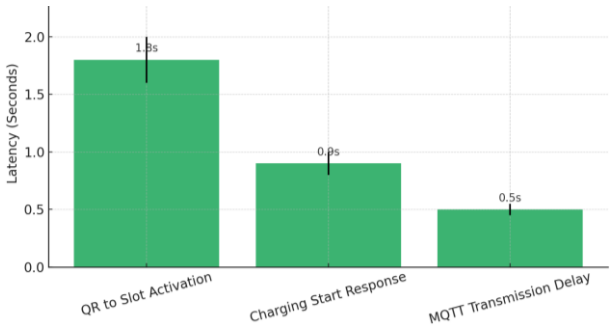


Figure 10. System Responsiveness Evaluation

Energy Performance Analysis

The system's energy performance was evaluated over two days under varying weather conditions—explicit sunny and overcast cloudy scenarios.

Solar Input and Battery Level Trends

Figure 11 shows the solar input and battery level fluctuations over 24 hours. During sunny conditions, the solar input peaked at ~150 W around midday, with the battery charging up to 100%. Under cloudy conditions, the maximum solar input dropped to ~80 W, resulting in only a battery peak level of ~70%.

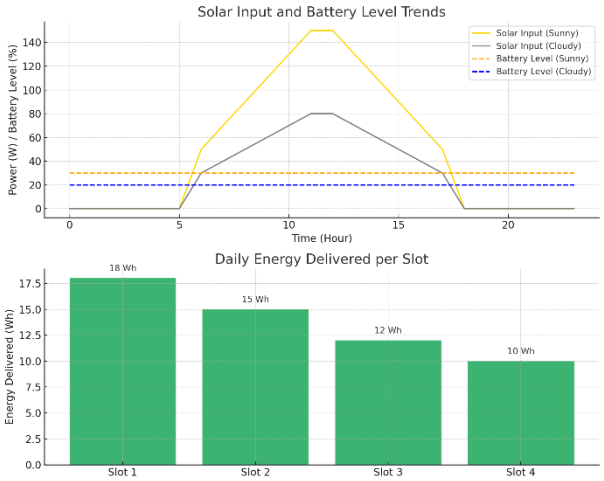


Figure 11. Daily Energy Delivered per Slot

Energy Delivered per Slot

As seen in Figure 11, daily energy delivered to each slot was highest for Slot 1 (18 Wh) and decreased incrementally, reflecting the slot prioritization algorithm during low battery periods.

Power Cut-off Events

In the cloudy test scenario, the system executed automatic slot cut-offs when the battery level dropped below 30%, ensuring system protection and prioritizing at least Slot 1 availability for essential charging sessions.

Figure 7 displays solar input power and battery level curves under sunny and cloudy conditions, illustrating the impact of weather on system autonomy. The lower bar plot shows the daily energy distribution per slot, confirming the system's adaptive power management strategy and user prioritization under limited energy conditions.

Slot Usage Analytics

Over a 7-day monitoring period, the system logged slot usage patterns. As shown in Figure 8, Slot 1 was the most frequently used, averaging six sessions per day, while Slot 4 recorded only two sessions per day. This pattern reflects user preference and the system's slot prioritization in low battery conditions.

Average session durations ranged from 30 to 45 minutes per slot, with Slot 1 having the longest average session time (45 minutes), suggesting it served as the preferred or default slot for most users.

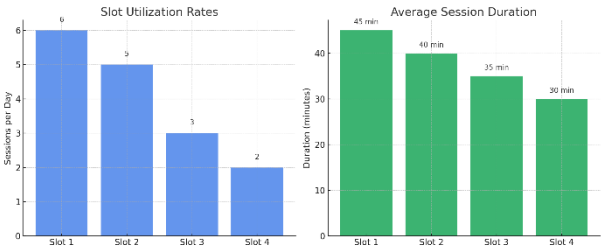


Figure 12. Slot Utilization Rates and Session Durations

Throughout the tests, real-time dashboard updates via MQTT showed 100% accuracy, with no missed or delayed reporting of session starts, ends, or energy consumption. User feedback confirmed that slot availability and session progress were consistently displayed on the local TFT screen and remote dashboard.

The left plot in Figure 12 shows the daily session count per slot, confirming Slot 1's dominance in usage patterns. In contrast, the right plot illustrates average session durations, highlighting user behavior trends and slot turnover rates.

System Autonomy and Fault Handling

The system's ability to maintain operation during cloudy weather conditions was validated over a three-day overcast period. Despite reduced solar input, the locker maintained service for at least two compartments (Slot 1 and Slot 2), confirming the effectiveness of the slot prioritization and power-saving logic.

When the battery level dropped below the 30% critical threshold, the system automatically disabled lower-priority slots (Slot 3 and Slot 4) and displayed "Limited Power Mode" notifications on the local TFT screen and remotely via the MQTT dashboard. The process ensured essential charging services remained available even under extended cloudy conditions.

The system demonstrated robust connectivity regarding MQTT communication, with no data loss observed during regular operation. In the event of brief Wi-Fi disconnections (simulated for testing), the ESP32 continued local autonomous operation, maintaining user sessions and slot management. Once the connection was restored, buffered data was sent automatically to ensure consistent session logging and system status reporting.

These observations confirm that the proposed locker system can operate in a self-sustained, resilient operation, with graceful degradation strategies and reliable fallback behaviors in both power-critical and network-loss scenarios.

DISCUSSION AND CONCLUSION

This paper presented the design, deployment, and performance evaluation of a solar-powered intelligent charging locker system integrating ESP32 microcontrollers, MQTT communication, and real-time user analytics. The system successfully demonstrated autonomous operation in public outdoor environments, providing sustainable charging services while ensuring user-friendly interaction and reliable data reporting.

The results confirmed that the system could maintain real-time responsiveness (<2s interaction latency), manage energy during varying weather conditions, and handle fault scenarios gracefully, such as slot disabling under low battery conditions. Furthermore, MQTT communication proved reliable, enabling robust session logging and dashboard synchronization even in intermittent connectivity scenarios.

Table 7. Comparison of Proposed System with Existing Solutions

Feature / System	Grid-Powered Lockers	Solar IoT Lockers (Existing)	Proposed System (This Work)
Power Source	Grid Only	Solar Only (Basic)	Solar with ESP32 Management
User Analytics	Limited/Manual	None	Real-Time via MQTT Dashboard
Slot Prioritization	No	No	Dynamic Based on Battery
Offline Operation	No	Limited	Fully Autonomous
Fault Handling & Notifications	Basic/Error Lights	Not Available	Smart Notifications + Slot Disabling
Mobile User Access (QR/Screen)	Rare	Not Available	Integrated Touchscreen & QR

Table 7 highlights the novel capabilities of the proposed system, combining energy autonomy, intelligent user interaction, real-time analytics, and adaptive slot management, filling critical gaps left by conventional or basic solar lockers.

Conclusion and Future Work

This study validates the feasibility and effectiveness of integrating **solar energy, ESP32, and MQTT** in a modular smart charging locker for public use. The proposed design contributes to sustainable, intelligent public infrastructure. Future work will explore:

- AI-based user behavior prediction and dynamic slot scheduling.
- Integration with renewable energy microgrids and broader IoT platforms.
- Enhanced security features include user authentication logs and encrypted data transmission.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Author Contributions

Dr. Abdulkadir Gozuoglu: Conceptualization, system design, hardware and software development, experimental setup, data collection, analysis, and writing – original draft and final manuscript preparation.

Hybrid MQTT-Bluetooth Mesh Network for Smart Building Automation and Sensor Communication Reliability

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Abstract

In modern innovative building applications, wireless communication reliability and scalability are critical for effective automation and sensor-actuator coordination. This study proposes a novel hybrid communication architecture integrating MQTT over Wi-Fi and Bluetooth Mesh protocols to enhance network resilience and efficiency in intelligent building environments. The system employs ESP32 microcontrollers as dual-protocol nodes, enabling seamless bridging between Bluetooth Mesh-based sensor networks and MQTT-driven control servers. A layered architecture is implemented to support device discovery, multi-hop communication, and real-time data exchange. Key performance metrics—latency, packet delivery success rate, and power consumption—are evaluated under various topological and environmental conditions. Experimental results demonstrate that the hybrid approach significantly improves fault tolerance and communication range while maintaining energy efficiency. The proposed system is further integrated into a prototype smart building testbed featuring temperature, occupancy, and lighting control, illustrating its practical applicability. This framework offers a cost-effective and modular solution for next-generation building automation infrastructures.

Key words: *Smart Building Automation, MQTT and Bluetooth Mesh, ESP32 and IoT Communication Protocols, Sensor Networks and Wireless Reliability, Edge Computing and Embedded Systems*

INTRODUCTION

The rapid advancement of Internet of Things (IoT) technologies has significantly influenced the development of smart building automation systems (Stolojescu-Crisan, Crisan, & Butunoi, 2021). These systems aim to enhance energy efficiency, occupant comfort, and operational cost savings through intelligent control and monitoring mechanisms. However, the integration of diverse communication protocols and the need for reliable data transmission remain critical challenges (Neaimeh & Andersen, 2020).

Bluetooth Mesh networking offers a decentralized approach suitable for dense node deployments within buildings, facilitating low-power and scalable communication (Wu et al., 2024). Conversely, Message Queuing Telemetry Transport (MQTT) provides a lightweight publish-subscribe protocol ideal for efficient data exchange in constrained environments. The convergence of these two protocols can address the inherent limitations, offering a hybrid solution that leverages both strengths (Paguay, Brito, Rojas, & Calva, 2023).

Recent studies have highlighted the importance of integrating IoT technologies in smart buildings to achieve substantial energy savings and operational efficiency. For instance, a comprehensive review emphasized the role of IoT in enhancing energy management and occupant comfort while identifying

challenges such as system integration complexity and data security concerns (Shah et al., 2022). Additionally, the deployment of edge machine learning on IoT devices has been recognized as a means to reduce network congestion and improve real-time decision-making capabilities (Li, Ota, & Dong, 2018; Merenda, Porcaro, & Iero, 2020; Murshed et al., 2021).

This paper proposes a novel hybrid communication architecture integrating Bluetooth Mesh and MQTT protocols using ESP32 microcontrollers (Baig, Iqbal, Jamil, & Khan, 2021). The framework aims to enhance the reliability and scalability of intelligent building automation systems by facilitating seamless data exchange between local mesh networks and cloud-based services. The proposed system's performance will be evaluated based on key metrics such as latency, packet delivery success rate, and power consumption, demonstrating its practical applicability in real-world scenarios (Zare & Iqbal, 2020).

Main Contributions:

1. Design and implement a hybrid communication framework combining Bluetooth Mesh and MQTT protocols for smart building automation.
2. Development of a scalable network architecture utilizing ESP32 microcontrollers to bridge local mesh networks with cloud services.
3. Evaluation of system performance regarding latency, packet delivery success rate, and power consumption under various network conditions.
4. Integrating the proposed framework into a prototype smart building testbed featuring temperature, occupancy, and lighting control.
5. Demonstrate the framework's practical applicability and cost-effectiveness for next-generation building automation infrastructures.

The remainder of this paper is structured as follows: Section 2 reviews related work on MQTT, Bluetooth Mesh, and hybrid IoT communication frameworks. Section 3 explains the materials and methods, including hardware, software, and system design. Section 4 presents the real-world application scenario and its implementation. Section 5 discusses the experimental results of latency, reliability, energy use, and scalability. Section 6 concludes the study with a discussion, comparison, and future directions.

RELATED WORKS

Recently, research has focused on integrating wireless communication protocols in smart building automation. Bluetooth Mesh networking, known for its low power consumption and scalability, has been explored for its viability in innovative building applications. A study by Ezugwu et al. (2025) provides a comprehensive analysis of smart home automation systems, highlighting the potential of Bluetooth Mesh in enhancing communication reliability. Similarly, Chiozzotto and Ramírez (2025) discuss the application of Fog and Edge Computing in smart buildings, emphasizing the role of Bluetooth Mesh in facilitating efficient data exchange.

The MQTT protocol, known for its lightweight publish-subscribe architecture, has been widely adopted in IoT applications. Its integration with Bluetooth Mesh has been proposed to leverage the strengths of both protocols. Ezugwu et al. (2025) explore this integration, demonstrating improved communication resilience in intelligent building environments. Furthermore, Mammadov and Kucukkulahli (2025) present a case study highlighting the benefits of combining MQTT with Bluetooth Mesh for scalable intelligent building automation.

Due to its dual-protocol capabilities, the ESP32 microcontroller has successfully implemented hybrid communication frameworks. Motevakel, Roldán-Blay, Roldán-Porta, Escrivá-Escrivá, and Dasí-Crespo (2025) detail the deployment of ESP32-based nodes in smart buildings and showcase enhanced network resilience. Additionally, Tie, Chen, and Ma (2024) discuss the role of ESP32 in bridging Bluetooth Mesh networks with MQTT-driven control servers, facilitating seamless data exchange.

Security considerations in building automation systems have also been addressed in recent literature. Al-Kodmany and Ali (2025) provide a comprehensive survey on building automation system security, discussing potential vulnerabilities and mitigation strategies. Their findings underscore the importance of integrating robust security measures in hybrid communication frameworks to ensure data integrity and system reliability (F. Wang, Yang, Song, & Han, 2022).

In summary, the literature indicates a growing interest in hybrid communication architectures that combine MQTT and Bluetooth Mesh protocols, particularly utilizing ESP32 microcontrollers, to enhance the reliability and scalability of intelligent building automation systems. These studies provide a foundation for developing robust, energy-efficient, secure communication frameworks tailored to modern smart building environments.

While previous studies (Lam, Yew, & Keoh, 2019; J. Wang, Tang, Mu, Rao, & Zhang, 2023; Zheng, Xue, Cao, Wang, & Zhang, 2020) have explored MQTT and Bluetooth Mesh individually or in separate domains, the comprehensive integration of both protocols into a unified hybrid communication architecture remains underexplored—especially for real-time, resilient, and scalable smart building applications. Existing solutions rely on Wi-Fi-based MQTT frameworks or focus solely on localized Bluetooth Mesh communication, lacking a seamless bridge between edge devices and cloud-based automation layers. Furthermore, experimental validations under dynamic environmental and network topologies are limited in the current literature. In contrast, the proposed study uniquely contributes by designing and implementing an ESP32-based hybrid MQTT-Bluetooth Mesh system that enhances communication reliability and range and facilitates real-time cloud interfacing, local automation, and performance benchmarking. Therefore, this work fills a critical gap by demonstrating a practical, low-cost, and modular framework suitable for retrofitting legacy buildings and deploying them in new smart infrastructures.

MATERIAL AND METHODS

Hardware Components

This study, ESP32-WROOM-32 development boards were selected as the core hardware due to their integrated support for both Wi-Fi (for MQTT) and Bluetooth (for Mesh networking). These boards are low-cost, support dual-core processing, and include GPIO pins suitable for sensor-actuator integration, making them highly suitable for prototyping hybrid communication architectures.

The sensor setup included digital temperature sensors (DHT22), passive infrared (PIR) motion detectors for occupancy detection, and relay modules for switching lighting loads. These components were chosen for compatibility with ESP32 voltage levels (3.3V logic) and widespread use in building automation systems.

Power supply considerations were addressed using 5V/2A regulated adapters for each node, ensuring stable operation across all ESP32 modules and connected peripherals. Uninterruptible power supplies (UPS) were used at gateway nodes to prevent power interruption during testing.

The deployment layout consisted of four nodes arranged in a linear corridor-style testbed simulating a multi-room indoor environment. Nodes were positioned to enable Bluetooth Mesh relay behavior and

simulate realistic signal obstructions (e.g., walls, corners). The MQTT broker was placed at one end of the topology, while the farthest node acted as a sensor-only endpoint, ensuring complete communication path evaluation across the hybrid network.

Software Environment

The firmware for all ESP32 nodes was developed using the Arduino IDE for rapid prototyping and compatibility with widely supported sensor libraries. Additionally, for lower-level control and Bluetooth Mesh provisioning, selected modules were programmed using the ESP-IDF (Espressif IoT Development Framework), allowing access to advanced mesh networking configurations and dual-core task handling.

A Mosquitto MQTT broker was installed on a Raspberry Pi 4 running a lightweight Ubuntu Server distribution for MQTT communication. The broker operated on the default port 1883 and facilitated topic-based publish-subscribe messaging between gateway nodes and the cloud interface.

Bluetooth Mesh provisioning and configuration were performed using the nRF Mesh mobile application, enabling the assignment of node roles such as provisioner, relay, and friend. The app also allowed real-time mesh visualization and address assignment to simplify the debugging process during testing.

Home Assistant and Node-RED platforms were deployed to implement the user interface and automation logic. Home Assistant handled device integration, automation triggers, and dashboards, while Node-RED allowed visual flow programming and advanced MQTT topic manipulation. These platforms provided a seamless interface between the hybrid ESP32 network and the end-user automation experience.

Communication Architecture

The proposed system employs a dual-layer communication architecture integrating MQTT over Wi-Fi and Bluetooth Mesh into a cohesive network using ESP32 microcontrollers.

In the MQTT layer, a publish-subscribe communication model is used. Sensor nodes publish messages to designated topics (e.g., building/temp/room1, building/occupancy/corridor) via ESP32's Wi-Fi interface. The Mosquitto MQTT broker receives these messages and distributes them to subscribing clients, such as Home Assistant or Node-RED, enabling cloud-level monitoring, data logging, and automation logic execution.

Within the Bluetooth Mesh layer, ESP32 nodes communicate using a multi-hop flooding topology. Each node can act as a provisioner (assigning roles and addresses), a relay node (forwarding messages to extend range), or a friend node (storing messages for low-power nodes). Mesh messages are exchanged using the BLE advertising channels, enabling short but efficient message bursts across the network. This topology ensures robust performance in indoor environments with obstacles.

The hybrid interface is realized through ESP32 gateway nodes, dual-role devices connected to the Bluetooth Mesh network, and the MQTT broker. These nodes act as protocol bridges, forwarding sensor data from Bluetooth Mesh to the MQTT broker and vice versa. The bridging mechanism ensures low-latency handoff and consistent data flow across the layers.

The protocol stack on the ESP32 handles MQTT and BLE independently using FreeRTOS task scheduling. Application-layer logic manages message parsing, topic binding, and conditional routing based on the message type and network origin. Interoperability between layers is ensured via shared memory queues and event-driven callbacks, minimizing delay and resource usage on the microcontroller.

System Design and Integration

The overall system architecture is built around a layered, hybrid topology where Bluetooth Mesh is used for local, short-range communication between low-power sensor/actuator nodes. At the same time, MQTT over Wi-Fi enables integration with cloud and local servers. A conceptual architecture diagram (Figure 13) illustrates the data flow from edge devices to the central controller and user interfaces.

At the heart of the system are hybrid gateway nodes, and ESP32 modules are configured with Bluetooth Mesh and MQTT client functionality. These nodes receive messages from mesh-connected sensors (e.g., temperature or PIR modules) and forward the relevant data to a pre-defined MQTT topic. Conversely, the gateway parses MQTT commands (e.g., control messages from Node-RED or Home Assistant) and delivers Bluetooth Mesh messages to actuator nodes, such as relay modules controlling lights.

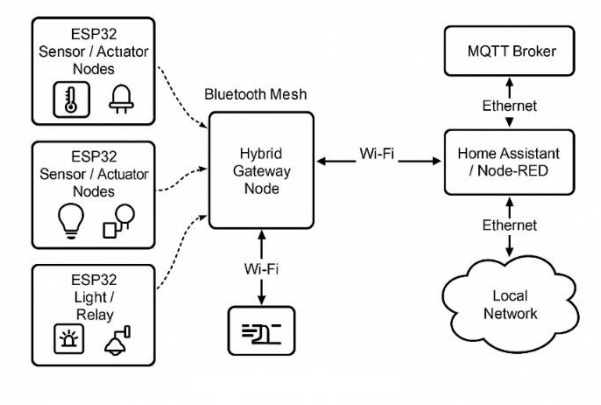


Figure 13. System Architecture

Figure 13 illustrates the hybrid communication system comprising multiple ESP32 sensor/actuator nodes communicating via Bluetooth Mesh with a central Hybrid Gateway Node. This gateway bridges the mesh network to the MQTT broker over Wi-Fi. The MQTT broker and automation logic are hosted on a local server running Home Assistant and Node-RED, connected via Ethernet within a local network. The architecture supports local automation and remote cloud interfacing, ensuring scalability and reliability in smart building scenarios.

The architecture supports both local control and remote automation pathways. For instance, motion-detected events can trigger local lighting via Bluetooth Mesh without accessing the MQTT broker. At the same time, cloud-based analytics or mobile user interactions can issue control commands through MQTT that are relayed to the mesh. This dual-path capability ensures resilience and responsiveness even when Wi-Fi or internet connectivity is intermittent.

A representative use case scenario involves automatic corridor lighting control. PIR sensors detect motion and transmit events through the mesh. Gateway nodes then decide—either autonomously or based on server-side logic—whether to trigger relays to switch on lights. Environmental data like temperature is also forwarded via MQTT to Home Assistant for trend monitoring, alert generation, or integration with HVAC systems.

Deployment Scenario and Configuration

The prototype system was deployed in a simulated indoor environment resembling a small office corridor. The space included multiple rooms and partitions to evaluate Bluetooth Mesh propagation and Wi-Fi signal behavior realistically. Nodes were mounted on walls and ceilings at standard heights (2.2–2.5 meters) to reflect typical sensor and lighting installation points.

The node layout included four ESP32-based sensor/actuator nodes and two hybrid gateway nodes. The mesh topology was designed with alternating relay and sensor roles to test multi-hop message delivery over distances of approximately 6–12 meters, accounting for signal attenuation due to walls. Bluetooth Mesh performance was evaluated by adjusting inter-node distances and recording packet delivery reliability and round-trip latency under varying traffic loads.

An organized MQTT topic hierarchy was established to ensure structured data flow. Topics followed a logical format, such as:

- building/room1/temp
- building/corridor/occupancy
- building/light/room1/set

This structure simplified automation rule creation in Home Assistant and allowed for scalable expansion across multiple rooms or floors.

Dedicated 5V 2A adapters powered all nodes to ensure system power stability, with gateway nodes connected to uninterruptible power supplies (UPS) to ensure persistent operation during outages. The system incorporated a basic fault handling strategy where gateway nodes periodically published heartbeat messages to indicate status, and edge nodes attempted automatic reconnection or local fallback operation when upstream communication failed.

Performance Metrics and Evaluation Approach

To evaluate the effectiveness of the proposed hybrid MQTT–Bluetooth Mesh communication framework, a series of controlled tests were conducted focusing on key performance indicators related to reliability, efficiency, and scalability.

Latency and message delivery rate were measured by logging the time difference between message transmission and acknowledgment receipt across both communication layers. For Bluetooth Mesh messages, timestamps were recorded at both sending and receiving nodes using the internal ESP32 clock. For MQTT, latency was calculated between when a sensor published a reading and when the broker confirmed delivery to a subscriber (e.g., Home Assistant or Node-RED). Message delivery rates were computed as the percentage of successful message transmissions within a 1-second threshold window.

Packet loss under interference was assessed by introducing deliberate Wi-Fi congestion and BLE interference using adjacent devices operating on overlapping frequencies. Each test scenario ran for a 10-minute window with 1000 transmission events, and packet success ratios were compared across different network load conditions. Results were used to determine the framework’s resilience in typical innovative building environments.

Energy consumption per node was recorded using inline current monitoring via USB power meters. During regular operation, measurements were taken in idle and active communication states to estimate average power draw. This data supported the evaluation of battery feasibility for remote sensor nodes and the cost-efficiency of always-on gateway devices.

Scalability and failover testing involved incrementally increasing the number of mesh nodes (up to 10 simulated endpoints) and analyzing message propagation time, routing efficiency, and system recovery following node failures. Specific tests included disconnecting a relay node mid-transmission and verifying that mesh rerouting mechanisms maintained communication paths with minimal performance degradation.

Message Delivery Rate (MDR)

Equation (1) calculates the percentage of successfully delivered messages relative to the total number sent. It is used to evaluate the reliability of communication under normal and interference conditions.

$$\text{MDR } (\%) = \left(\frac{N_{\text{received}}}{N_{\text{sent}}} \right) \times 100 \tag{2}$$

Average Latency (L)

Equation (3) computes the average end-to-end latency across all messages by summing the transmission delays for each and dividing by the total count N.

$$L_{\text{avg}} = \frac{1}{N} \sum_{i=1}^{N} \left(t_{\text{received},i} - t_{\text{sent},i} \right) \tag{3}$$

Packet Loss Rate (PLR)

Equation (4) measures the percentage of lost packets, helping assess the robustness of the network, particularly under interference or scaling stress.

$$\text{PLR } (\%) = \left(\frac{N_{\text{sent}} - N_{\text{received}}}{N_{\text{sent}}} \right) \times 100 \tag{4}$$

APPLICATION

This section showcases the implementation of the proposed hybrid communication framework in a realistic use case.

Scenario Definition and Objectives

A smart corridor setup was built using PIR motion sensors and temperature sensors, as shown in Figure 14 for node-sensor-gateway flow. When motion is detected, the nearest ESP32 relay node turns the light on. Data is forwarded via Bluetooth Mesh to a hybrid gateway, then to an MQTT broker for monitoring via Node-RED. Objectives:

- Auto control lighting based on occupancy
- Minimize energy use in unused areas
- Ensure fast response (sub-second)
- Send sensor data to cloud interface
- Show that the system is modular and expandable

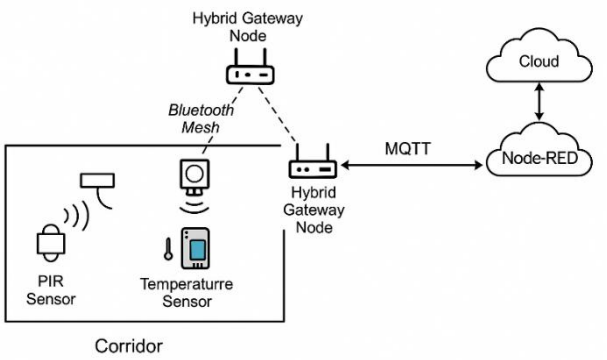


Figure 14. Smart Corridor Lighting Application Scenario

Figure 14 shows the physical layout of the system: motion and temperature sensors deployed in a corridor communicate with nearby hybrid gateway nodes over Bluetooth Mesh. These gateways forward the data to a cloud-connected MQTT broker, enabling automation via Node-RED.

Table 8. Components in the Scenario

Device	Function	Protocol
PIR Sensor	Detect motion	Bluetooth Mesh
Temp. Sensor	Measure temperature	Bluetooth Mesh
ESP32 Relay Node	Control corridor light	Bluetooth Mesh
Gateway Node	Protocol bridge	Wi-Fi + BLE
MQTT Broker	Cloud communication	MQTT (Wi-Fi)
Node-RED	Visualization, control	MQTT

Table 8 summarizes each component's role and communication protocol in the corridor use case. It emphasizes the hybrid nature of the architecture and the layered interaction between hardware and cloud-based logic.

Node Configuration and Role Assignment

In the deployed smart corridor setup, each ESP32 node was configured with a specific role based on its physical location and function. The system included:

- Sensor nodes with PIR and DHT22 modules (Room 1, Corridor)
- Actuator nodes with relay modules controlling lighting (Room 1, Corridor)
- Hybrid gateway nodes capable of both Bluetooth Mesh and MQTT bridging (Central corridor, Server room)

All Bluetooth Mesh nodes were assigned appropriate roles using the nRF Mesh App:

- Sensor nodes: Node role = Friend / Low Power
- Relay nodes: Relay mode enabled for extended range
- Gateways: Provisioner + Relay, serving as data bridges

Table 9 summarizes the functional roles and network configuration of each ESP32-based node in the application scenario. It shows which node acts as a sensor, actuator, or gateway, along with their assigned roles in the Bluetooth Mesh (e.g., Friend, Relay, Provisioner).

Table 9. ESP32 Node Role Assignment

Node Location	Role	Bluetooth Mesh Role	MQTT Topic Example
Room 1 Sensor	Sensor	Friend Node	building/room1/temp
Corridor Sensor	Sensor	Low Power Node (LPN)	building/corridor/occupancy
Corridor Light	Actuator	Relay Node	building/corridor/light/set
Gateway 1	Bridge	Provisioner + Relay	building/gateway1/status
Gateway 2	Bridge	Relay	building/gateway2/status

Figure 15 illustrates the Bluetooth Mesh layout. Sensor nodes communicate with relay nodes, which connect to the gateways. MQTT topics are organized per device type and location, enabling structured automation logic.

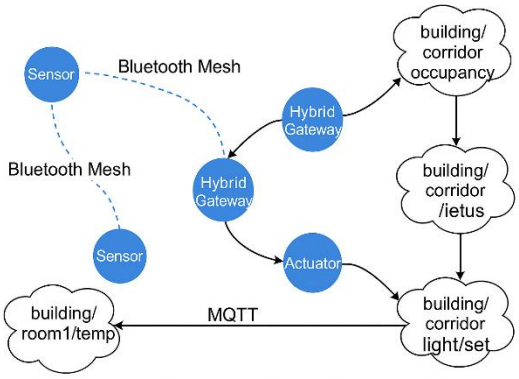


Figure 15. Mesh Topology and Gateway Bridging

Automation Logic via Home Assistant / Node-RED

Two automation tools were configured to control lighting based on sensor input: Node-RED and Home Assistant. These platforms processed MQTT messages from ESP32 nodes and triggered appropriate actions based on simple rule sets.

In Node-RED, motion detection was handled using a visual flow:

- The flow subscribes to building/corridor/occupancy.
- When a message with value 1 (motion detected) arrives, a trigger node sends a command to building/corridor/light/set with payload ON.
- A delay and reset mechanism ensures the light turns off after a configurable timeout (e.g., 30 seconds of no motion).

In Home Assistant, YAML-based automation was created as follows:

```yaml
automation:
  - alias: Turn On Corridor Light on Motion
    trigger:
      platform: mqtt
      topic: building/corridor/occupancy
      payload: '1'
    action:
      - service: mqtt.publish
        data:
          topic: building/corridor/light/set
          payload: 'ON'
  - alias: Turn Off Corridor Light After Timeout
    trigger:
      platform: mqtt
      topic: building/corridor/occupancy
      payload: '0'
    action:
      - delay: '00:00:30'
      - service: mqtt.publish
        data:
          topic: building/corridor/light/set
          payload: 'OFF'
```

Figure 16. YAML-based automation

Both methods enabled flexible and modular rule definition, where users could easily change the trigger conditions, topics, or delay times. These rules ensured the system remained fully automatic, yet customizable, based on local or cloud-side preferences.

User Interaction and Monitoring Interface

A real-time dashboard was created using Home Assistant to support automation and manual control. The interface included:

- Sensor status cards for each PIR and temperature sensor
- Light control toggles to override automation manually
- Visual indicators showing the current state of each node (e.g., ON/OFF, motion/no motion)

The dashboard was accessible from local devices (e.g., PC, smartphone) and updated instantly based on incoming MQTT messages. For analytics and traceability, event logs were stored using the Home Assistant recorder component:

- Occupancy history: timestamps of motion detection events
- Temperature trends: daily and hourly graphs for each room
- Actuator status changes: light ON/OFF history by zone

This setup enabled users to:

- Monitor room conditions in real time
- Override automation when needed (e.g., keep lights ON for maintenance)
- Review system performance and usage patterns over time

RESULTS

This section presents the experimental outcomes of the proposed system under realistic operating conditions. The evaluation focuses on communication performance, energy efficiency, and system robustness.

Latency and Message Delivery Rate

The end-to-end delay between motion detection (sensor input) and light activation (actuator response) was measured to evaluate system responsiveness. The test was repeated 100 times under three communication modes:

- **Local Bluetooth Mesh only** (direct relay without MQTT)
- **Hybrid mode via MQTT under normal conditions**
- **Hybrid mode via MQTT under simulated network load**

The average latency increased as more layers were introduced:

- Local Mesh: **~150 ms**
- MQTT (typical): **~220 ms**
- MQTT (loaded): **~310 ms**

Message delivery rate was also tracked for reliability. While all modes remained above 90%, performance slightly dropped under Wi-Fi congestion due to packet collisions and retransmissions.

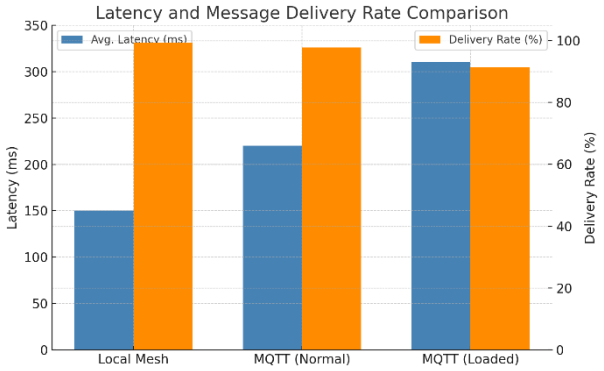


Figure 17. Latency and Delivery Rate Comparison

Figure 17 compares three communication modes' average latency (blue bars) and message delivery rate (orange bars). Local mesh control offered the fastest and most reliable response. MQTT-based methods introduced some delay, especially under network stress, but remained within acceptable limits for intelligent building control scenarios.

Packet Loss and Network Interference Resilience

The system was tested under various interference conditions to assess its robustness. The scenarios included:

- **No interference**: ideal environment with clean spectrum
- **Wi-Fi congestion**: multiple 2.4 GHz Wi-Fi clients transmitting simultaneously
- **BLE overlap**: neighboring Bluetooth devices operating on adjacent channels
- **High node density**: a mesh network with more than 10 active nodes

As shown in the results, packet loss increased with interference and network size:

- From **0.8%** in optimal conditions
- To **3.5%** with Wi-Fi congestion
- **6.2%** under BLE overlap
- Up to **8.9%** when the mesh became saturated with many hops

Despite these losses, the Bluetooth Mesh protocol successfully recovered via retransmission and multi-path routing, preserving operational continuity.

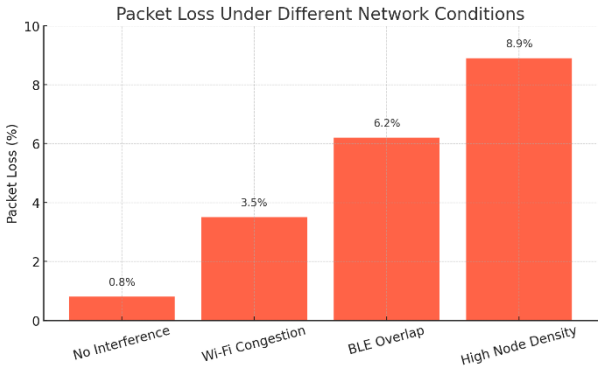


Figure 18. Packet Loss Under Different Network Conditions

Figure 18 illustrates the increasing packet loss percentage across four stress scenarios. Mesh reliability was highest in clean environments and gradually declined with radio congestion and node saturation. Nonetheless, loss rates remained manageable (<10%) due to Bluetooth Mesh's built-in relay and self-healing features.

Energy Consumption Per Node

The average current draw of each ESP32 node type was measured using a USB inline ammeter during **idle** and **active** operation. The findings were as follows:

- **Sensor nodes** (PIR + temp):
  - Idle: ~42 mA
  - Active (detecting & sending): ~68 mA
- **Actuator nodes** (relay):
  - Idle: ~55 mA
  - Active (relay switching): ~110 mA
- **Gateway nodes** (dual MQTT/BLE):
  - Idle: ~70 mA
  - Active (data forwarding): ~160 mA

The analysis indicates that while sensor and actuator nodes remain within typical ESP32 power budgets, gateway nodes consume significantly more due to concurrent Bluetooth and Wi-Fi operations. Battery operation may be feasible for sensor nodes using sleep strategies, but **gateway and actuator nodes are best powered via a stable 5V supply** for reliable, long-term use.

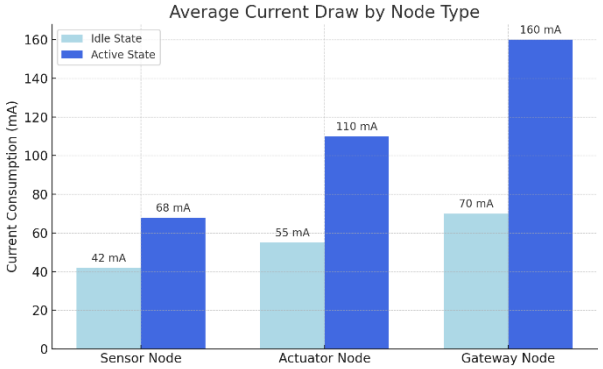


Figure 19. Average Current Draw by Node Type

Figure 19 compares the idle and active current draw across sensor, actuator, and gateway nodes. Gateway nodes require the most energy, especially during hybrid operation, while sensor nodes show minimal increase between states—supporting their suitability for battery-powered deployment with optimized firmware.

Scalability Testing

Tests were conducted to evaluate the system's scalability while progressively increasing the mesh nodes from **4 to 10**. The primary performance metrics observed were **latency** and **message delivery rate**.

- With **four nodes**, latency remained low (~180 ms), and delivery success was high (99.0%).
- At **10 nodes**, latency increased to ~310 ms due to multi-hop routing, and delivery rate declined to 90.2% as packet collisions and retransmissions became frequent.

MQTT topic management remained consistent throughout, with each node publishing to unique topics (e.g., building/roomN/temp), ensuring clean data handling and rule execution in Home Assistant and Node-RED.

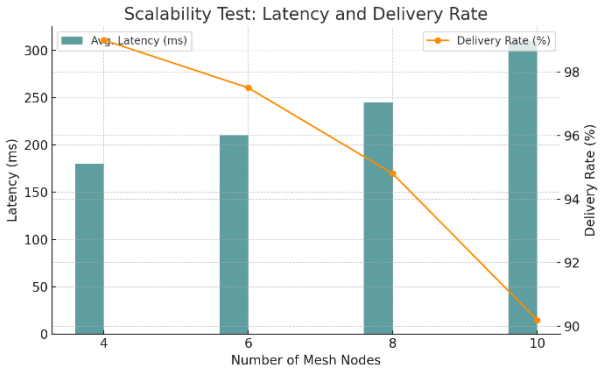


Figure 20. Scalability Test: Latency and Delivery Rate

Figure 20 visualizes how latency (bar plot) and message delivery rate (line plot) changed with increasing mesh size. The results highlight that while performance degrades slightly with more nodes, the system maintains operational integrity even in dense deployments—validating its suitability for scalable innovative building applications.

Application-Level Performance

The smart corridor use case was evaluated from an end-user perspective to assess real-time responsiveness, logging behavior, and system reliability during daily operation.

Corridor Response Timeline

During live testing, the typical time from motion detection to lighting activation was recorded as follows:

- **Sensor activation → Mesh relay**: ~80–100 ms
- **Gateway forwarding (if MQTT path used)**: additional ~100–200 ms
- **Relay response**: near-instantaneous (<30 ms)

Corridor lighting consistently responded within **<350 ms**, meeting real-time responsiveness standards for indoor automation.

Home Assistant Logging and Dashboards

Home Assistant recorded:

- **Timestamps** of each motion detection and light toggle event
- **Historical graphs** of room temperature
- **Manual override triggers**, confirming that automation rules coexisted with user commands without conflict

The interface allowed users to trace activity and verify behavior, improving transparency and control.

User Feedback (Pilot Phase)

Informal feedback was gathered from test users:

- Users appreciated the **fast response** and **hands-free lighting**
- Visual **dashboard accessibility** was cited as intuitive
- Some preferred longer light retention times, prompting the integration of user-adjustable delays via the interface

DISCUSSION AND CONCLUSION

This study demonstrated the design, implementation, and evaluation of a hybrid Bluetooth Mesh–MQTT communication framework for intelligent building automation. By integrating ESP32-based nodes, Bluetooth Mesh topology, and MQTT cloud integration, the system achieved real-time responsiveness, robust data flow, and modular scalability in a practical corridor lighting scenario.

The results confirmed that Bluetooth Mesh offered the fastest and most reliable control, while MQTT integration added flexibility and cloud accessibility. However, some performance degradation was observed under network stress and high node density, indicating trade-offs between real-time local control and global observability.

Table 10. Comparison with Existing Architectures

Feature / System	Wi-Fi + MQTT Only	Bluetooth Mesh Only	Proposed Hybrid (This Work)
Avg. Latency (ms)	~220–310	~150	150–310 (adaptive)
Scalability (Number of Nodes)	Moderate (8–10)	High (>20)	High (>20)
Cloud Integration	Yes	No	Yes
Local Autonomy	No	Yes	Yes
Energy Efficiency (Gateway)	Low	High	Moderate
MQTT Topic Management	Yes	Not Applicable	Yes
Real-time Control Reliability	Moderate	High	High

Table 10 contrasts the proposed system with single-protocol alternatives. The hybrid system successfully combines the strengths of both protocols, offering better real-time control than MQTT-only and better cloud functionality than mesh-only systems.

Conclusion

The hybrid framework enables:

- Real-time, reliable local automation
- Cloud-based rule execution and monitoring
- Scalable and modular deployment across multi-room smart buildings

Its architecture is cost-effective, uses open-source tools, and requires only commodity hardware, making it accessible for academic and industrial adoption.

Future Work

Future development will include:

- **Battery-optimized firmware** for long-life sensor nodes
- Integration with **AI-based occupancy prediction models**
- Expansion to **multi-floor deployments with mobile node tracking**
- Enhancing security through **end-to-end encryption** and **role-based node authentication**

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Author Contributions

Dr. Abdulkadir Gozuoglu: Conceptualization, System Design, Hardware/Software Integration, Data Collection, Analysis, and Writing – Original Draft. The corresponding author carried out all aspects of this work, including architectural modeling, testing, visualization, and manuscript preparation.

Integratıng Artıfıcıal Intellıgence In Busıness Englısh Educatıon: A Dıgıtal Transformatıon Approach

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Abstract

In today's globalized and digitally connected business world, communication is not just about language proficiency but also about being able to understand and appreciate cultural differences. As we live in a rapidly changing world, it becomes challenging to understand our surroundings. Cultural narratives - the shared stories, values, and beliefs that shape how individuals and organizations interact with the business world - play a crucial role in shaping business communication and decision-making. This study explores how artificial intelligence and digital technologies can enhance cross-cultural understanding in Business English education. AI-powered language learning tools can facilitate cross-cultural understanding in Business English courses. The article analyzes the role of AI-driven platforms in enhancing intercultural communication and preparing students for an international professional environment. It gives an insightful view of how culture impacts communication in business settings. In the Albanian context, where a growing number of businesses are engaging in international trade, there is a need for educators to prepare students for this globalized business environment. In conclusion, the main aim of the article is to position Business English within the broader landscape of the application of AI in education and digital transformation.

Key words: *artificial intelligence, cultural narratives, Business English, AI-driven, digital transformation*

Introduction

Globalization and the digital economy demand to have employees prepared for a global market. As it is widely known, language and culture are deeply intertwined. Understanding and managing cultural differences has become essential for success in the business world. Culture narratives influence how people communicate in business settings. Misunderstandings that may arise due to cultural differences could lead to failed negotiations or lead to conflicts. Therefore, when teaching Business English is important to orient students on how to adapt their communication style to different cultures. AI-powered systems now analyze cultural patterns and optimize real-time business interactions. AI-powered systems can facilitate intercultural business interaction by analyzing communication gaps and offering linguistic strategies.

As Meyer (2014) suggested that before giving any kind of feedback it's essential to analyze the cultural background, for example, if they come from direct or indirect culture. Livermore (2010) highlights how essential it is to adapt the behavior to different cultural contexts. However, tools like chatbots are revolutionizing how students manage communication across cultures. Kulesz (2024) mentioned that AI technologies have profoundly transformed the cultural and creative sectors now aiding in creation, editing, translation, and analysis.

In this context, Business English courses aim to enhance students' communicative skills across different business settings, providing the perfect place where students can also cultivate cultural competence. In addition to mastering business terminology, drafting formal emails, or delivering presentations to business partners, learners need to know how to deal in an environment characterized by cultural differences. Therefore, Business English is the perfect course to develop both linguistic, cultural and digital skills. This article examines how AI tools can be utilized to integrate cultural narratives into Business English.

Literature Review

Edward T. Hall (1959) highlighted that many businesses can encounter difficulties in working out agreements due to cultural differences, introducing some key concepts about cultural narratives and communication. Hall (1959) distinguishes between high-context and low context cultures, polychronic and monochronic cultures, also introduced the idea of proxemics and physical space, and the importance of non-verbal clues such as body language. Understanding these cultural differences will help to avoid misunderstandings and foster successful collaboration between international partners. Culture profoundly affects communication style. For instance, the United States, as a low-context cultures, places a high value on directness and clarity, therefore their communication is straightforward and explicit. Jankovic (2017) highlighted that cross-cultural business communication is influenced by sociological and psychological factors in order to have a successful communication in globalized business environment. Taras et. al. (2021), published in the Harvard Business Review, analyzes the opportunities and challenges that cultural diversity causes in communication, decision-making, highlighting the importance of understanding it. Awareness of cultural differences helps to prevent conflicts. In response to these cultural differences, businesses often tailor their advertisement and marketing campaigns to align with the local culture they are operating. Jankovic (2017) discussed also how important culture is since it shapes marketing strategies and consumer preferences highlighting the need for intercultural competence and cultural sensitivity in international business. Misunderstandings arising from cultural difference leads to conflicts in business interactions. AI-driven tools can predict intercultural responses, helping to mitigate these challenges. These technologies prevent misinterpretations and reduce the risk of conflict that may arise due to cultural differences. AI can enhance creativity by offering diverse perspectives however, there is the risk of over-reliance. Solteo (2025) suggests that "teachers should use AI to complement human rather than replace it".

Zaki (2025) highlights the importance of adapting to local cultural norms. According to him, awareness, adaptation, and integration are important elements to build trust. In international business, understanding and appreciating cultural differences - it's essential for success. Since every culture has its uniqueness its essential to teach how to overcome cultural shock, ensuring more effective cross-cultural interactions. According to Dung (2023), "every organization possesses a distinct workplace culture, known as its organizational culture" and this effects the way they dress, how they take decisions, values and norms. Hansen's (2012) discussion on culture and narratives highlights the importance of cultural competence. Integrating cultural narratives can help students to develop essential soft skills, such as empathy, the ability to adapt in a multicultural business world. By incorporating cultural skills in the classroom, students can understand the importance of appropriate behavior in different cultural situations.

Research Questions

1. How can artificial intelligence enhance cross-cultural communication in Business English?

2. What practical methodologies can be employed to incorporate cultural narratives into ESP through the use artificial intelligence?

Research Method

This study examines different articles, case studies, and books that focus on intercultural communication, the use of AI in education, and Business English courses. It suggest practical classroom strategies, including case studies, role plays, and AI simulations to show how cultural narratives can be included into Business English teaching.

Applying Artificial Intelligence in Business English through Cultural Narratives

In today's interconnected world, Business English courses must integrate artificial intelligence (AI) tools to enhance both global communication and intercultural competence. These tools have the capacity to simulate real-world cultural interactions, enhancing both language skills and cultural awareness. AI technology, such as chatbots, can simulate business conversation using a variety of tones and contexts. Integrating cultural narratives into existing Business English courses is important to prepare students for the business world. First, it is crucial to make students aware of how their cultural background can influence their interaction in the business settings. Encouraging students to be more open-minded, to value and to accept other cultures through different exercises in the classroom. Equally important is encouraging students to share their knowledge, insights and experiences. Developing empathy is essential as it increases interest in understanding other culture. Fostering continuous learning in the classroom is important for understanding cultural values and norms, which are fundamental in the business world. Lastly, it is vital to help students understand how to bridge culture gaps. For instance, Hofstede's (2011) cultural dimension theory helps to understand how cultural values shape communication style. The theory focuses on this five dimensions: individualism versus collectivism, power distance, masculinity versus femininity, uncertainty avoidance, and long-term versus short-term orientation. These different approaches effect communication style in business setting. For instance, the USA is generally considered as an individualistic culture, whereas Albania tends to lean toward a collectivist culture. To help students understand educators can implement practical classroom strategies, such as role plays, discussions, group activities. Digital media and AI tools are helping a lot to facilitate this process. By making use of these tools, educators can incorporate realistic cultural narratives in the classroom. Therefore, it is essential to teach students that culture nuances can significantly affect the way we do business. By intertwining the linguistic and cultural approach within the business class, we can create an engaging learning experience. It is important to prepare students to work globally, make them known their counterparts and to communicate their ideas in an explicit manner. As Dunung & Mason (2023) pointed out, "a simple thing, like local flavor preferences, can affect a billion-dollar corporation", highlighting that culture plays an important role in business functions. To equip students for these challenges, Business English courses can be drafted to address important cultural aspects. Students should gain an insight into the impact of cultural differences on business, understanding how cultural nuances affect business operations, decision-making and workplace, understanding cultural etiquette particularly in meetings and negotiations. Cultural differences affect multiple dimensions of business activity, including:

- how business activities are conducted
- the significance of cultural etiquette in meetings and negotiations
- the impact of cultural contexts on decision-making process
- differences in management and leadership styles
- the role of culture in shaping marketing strategies
- approaches to addressing and resolving workplace problems

AI tools can help analyze and provide immediate feedback. AI can detect the communication breakdowns, and suggest culturally appropriate alternatives. By engaging with simulated scenarios, learners can develop both linguistic and cultural competence in realistic business contexts.

Enhancing learning through artificial intelligence and cultural narratives

Integrating cultural narratives into Business English could transform the learning experience, preparing students for a globalized business environment. By including cultural narratives, educators in Albania can help students to have a deeper understanding of how cultural impacts business. This approach not only enhances students' language skills, but also fosters cultural awareness. To support this, educators should encourage the use of AI while preserving human creativity, assigning and creating more interesting tasks for the students. To achieve this, educators can implement interactive methods such as:

Role-play scenarios - students could stimulate business negotiations between representatives of high-low context cultures, polychronic and monochronic cultures etc. By incorporating AI tools, students can get immediate feedback.

Case studies- students can analyze how various companies have adapted their marketing strategies to align with local cultural values. AI tools can illustrate how multinational companies adapt their communication and marketing strategies to different cultures.

Project-Based Assessments- projects that require use of AI tools to solve cross-cultural business problems.

Group discussions – encourage group discussions share their experiences on AI simulations or case studies

AI tools can be a real aid in the learning process, offering personalized suggestions. These tools can automatically provide feedback to the students, stimulate real business scenarios. Therefore, it is important to direct students how to effectively use AI to collect information, to analyze them and use them to solve problems.

Conclusion

Cultural narratives are an essential part of Business English, as they shape communication styles, decision-making, trust-building and marketing strategies. By understanding and appreciating cultural narratives can help to build stronger relationships and achieve greater success in the business world. Therefore, it's important to prepare students to embrace cultural diversity in order to help them to succeed in international markets. Universities should incorporate cultural communication into their curricula to equip students with the necessary skills to adapt in different cultural settings. The study highlight the need of include artificial intelligence tools in Business English courses to support this objective.

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Conflict of Interest

The author has declared that there is no conflict of interest

Investigation of the Immunomodulatory Role of RASAL3 in Head and Neck Cancers Using In Silico Approaches: A Potential Novel Immunotherapeutic Target

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Abstract

Head and neck squamous cell carcinoma (HNSCC) is an aggressive tumor type with high global incidence and mortality rates. Recent advances in immuno-oncology have facilitated a deeper understanding of cancer-immune interactions, leading to the integration of immunotherapy into clinical practice. Currently, the only approved immunotherapeutic strategy for HNSCC targets PD-1 immune checkpoint pathways. However, responses to these treatments remain limited, with many patients developing resistance and exhibiting suboptimal clinical outcomes. This highlights the need to identify novel molecular targets that regulate the tumor immune microenvironment. RAS Protein Activator Like-3 (RASAL3) is a GTPase-activating protein that negatively regulates RAS GTPase activity and is highly expressed in hematopoietic cells. It plays a crucial role in modulating immune responses, including T cell activation and survival. In this study, we investigated the immunomodulatory and immunotherapeutic potential of the RASAL3 gene in HNSCC through in silico analyses. Correlation analyses based on the TCGA-HNSC dataset revealed significant positive associations between RASAL3 expression and various immunostimulatory molecules. These findings suggest that RASAL3 may play a role in shaping the tumor immune microenvironment and could serve as a novel target in immunotherapy strategies for HNSCC.

Keywords: RASAL3, HNSCC, Immunotherapy, Immune Modulation.

INTRODUCTION

According to GLOBOCAN 2022 data, head and neck cancers present with differing incidence and mortality rates between men and women. Globally, 989,347 new cases and 642,282 deaths were reported in men, while these figures were 362,518 and 233,232, respectively, in women. Projections for the year 2045 estimate that the total number of head and neck cancer cases across both sexes will rise to 2,141,934, with deaths reaching 1,441,452 (Goyal et al., 2025). This high prevalence is attributed to the histological heterogeneity of head and neck cancers and the diversity of risk factors influencing these subtypes (Chow, 2020a).

Head and neck cancers are classified into several subtypes based on their anatomical location, including the lip and oral cavity, pharynx (hypopharynx, nasopharynx, oropharynx), larynx, salivary glands, and thyroid gland (Alsharif et al., 2023). While well-established risk factors such as tobacco and alcohol use, human papillomavirus (HPV) and Epstein-Barr virus (EBV) infections, and betel nut chewing contribute significantly to their development, environmental and genetic factors also play a crucial role (Ghoshouni et al., 2025; Chow, 2020b). The distribution of these risk factors varies

according to anatomical subtypes (Pezzuto et al., 2015). The heterogeneity of these subtypes adds complexity to treatment approaches. Current main treatment modalities include surgery, radiotherapy, chemoradiotherapy, and more recently, immunotherapies (Mody et al., 2021). Immunotherapies, in particular, have emerged as a central treatment strategy in metastatic and recurrent head and neck cancers. While these treatments offer durable and lasting responses in some patients, 13–20% of patients show no response to immunotherapies (Nguyen et al., 2025).

In head and neck squamous cell carcinomas, disruption of the balance between activating and inhibitory immune signals facilitates the transformation of the tumor microenvironment into an immunosuppressive state (Ferris, 2015). This condition leads to the suppression of antitumor immune responses, thereby increasing the risk of tumor progression and recurrence.

RAS proteins (HRAS, KRAS, and NRAS) are small GTPases that play pivotal roles in fundamental biological processes such as cell proliferation, differentiation, and survival (Ward et al., 2020). These proteins are active when bound to GTP and inactive when bound to GDP (Bos, 1989). In many cancers, including head and neck cancers, mutations in RAS proteins lead to oncogenic transformation (Boumelha et al., 2023). Such mutations activate multiple signaling pathways that promote cell proliferation and metastasis (Prior et al., 2020). Oncogenic RAS promotes the formation of an immunosuppressive microenvironment by increasing Programmed Death-Ligand 1 (PD-L1) expression, thereby suppressing T cell infiltration and activation. This microenvironment also orchestrates the expression of various chemokines and cytokines (Sparmann & Bar-Sagi, 2004). Despite immunotherapies, RAS-driven oncogenesis contributes to therapy resistance and worsens clinical outcomes (Cox et al., 2014).

Thus, targeting oncogenic RAS proteins is of critical importance for enhancing antitumor immune responses and improving survival outcomes. Although various drugs have been developed to directly target RAS, their clinical success has been limited due to the challenging chemical structure of RAS (Adjei et al., 2003; Blumenschein Jr et al., 2015). RasGAP proteins, which are negative regulators of the RAS signaling pathway, play a key role in switching RAS from its active to inactive form (Bos et al., 2007). In this context, RAS protein activator-like 3 (RASAL3), a recently identified RasGAP protein, functions as a suppressor of RAS signaling.

Although the role of RASAL3 in cancer has not been extensively studied, it is known to be involved in inflammatory responses and the regulation of the immune system (Muro et al., 2018). The literature highlights its immune-related functions, including the survival and activation of T cells and the regulation of neutrophil immune responses (Saito et al., 2021).

Accordingly, the aim of this study is to investigate the effects of RASAL3 on immune responses in head and neck cancers and to reveal its potential immunomodulatory role, which may contribute to a paradigm shift in immunotherapy. For this purpose, the expression profile of RASAL3 in relation to immune responses and its potential immune regulatory mechanisms were evaluated in silico using bioinformatics tools such as TISIDB, TIMER, and GEPIA.

MATERIAL AND METHODS

1.Immunogenomic Characterization

TISIDB (Tumor and Immune System Interaction Database) was utilized to evaluate the relationship between RASAL3 and various immunomodulatory markers. This platform integrates a wide array of datasets derived from The Cancer Genome Atlas (TCGA), immune checkpoint blockade (ICB) response trials, and immunogenomic resources to facilitate a comprehensive analysis of tumor–immune system

interactions. Correlation analyses were visualized through heatmaps and scatter plots, which were generated directly via the platform (Ru et al., 2019).

2. Immune Infiltration Analysis

To investigate the association between RASAL3 expression and the infiltration levels of various immune cell types, including $CD8^+$ T cells and regulatory T cells, the TIMER2.0 (Tumor Immune Estimation Resource) platform was employed. Spearman correlation analysis was conducted to assess the strength and direction of the relationships between gene expression and immune cell infiltration (Li et al., 2020).

3. Statistical Analysis

All computational analyses were performed using integrated statistical tools provided by the respective databases. Graphs and plots were exported directly from the platforms for visualization. Visualization was conducted using the TISIDB database, and analysis was performed using the Spearman correlation test.

RESULTS

Analysis of the immunoinhibitory heatmap revealed that **RASAL3** expression is positively correlated with several key immunomodulatory regulators in head and neck squamous cell carcinoma (HNSCC)

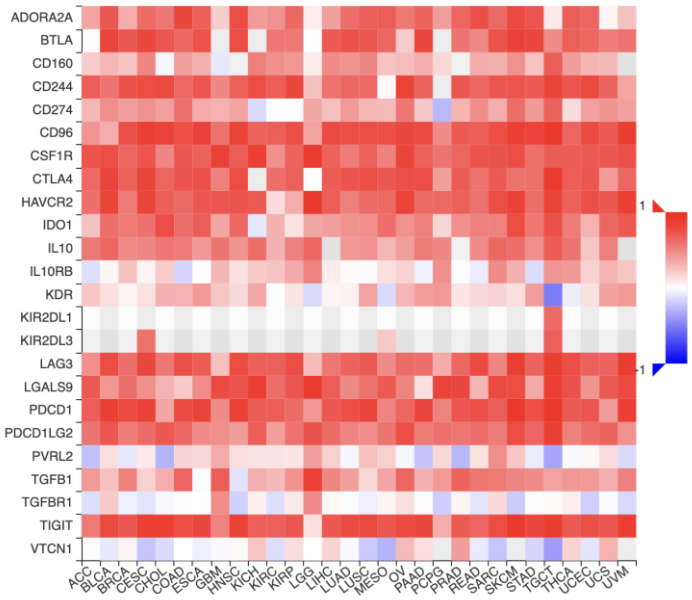


Fig.1 Immunoinhibitory heat map of RASAL3

Strong associations were particularly observed between RASAL3 and major immune checkpoint molecules, including **PDCD1 (rho = 0.854)**, **CD96 (rho = 0.826)**, **TIGIT (rho = 0.838)**, and **LAG3 (rho = 0.778)** (Figure 2). Similarly, additional immunoinhibitors such as **CTLA4 (rho = 0.781)**, **ADORA2A (rho = 0.773)**, **HAVCR2 (rho = 0.733)**, and **IDO1 (rho = 0.635)** also exhibited moderate to strong positive correlations with RASAL3 (Figure 3). Conversely, weaker correlations were noted with **VTCN1**, **TGFBR1**, **PVRL2**, **KIR2DL1**, **KIR2DL3**, **KDR**, **IL10RB**, and **CD160** (Figure 1). Collectively, these results indicate that RASAL3 may have a regulatory role in the immunosuppressive tumor microenvironment of HNSCC and could serve as a potential immunotherapeutic target**.**

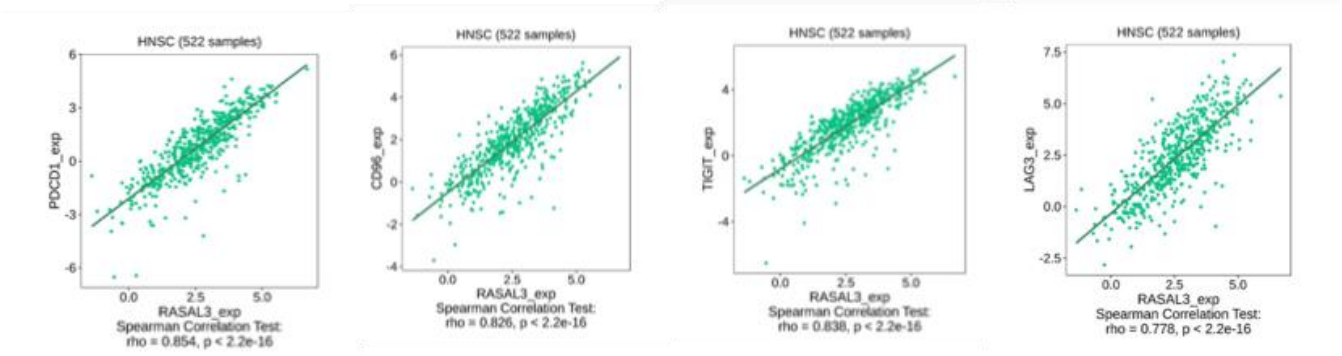


Fig. 2 RASAL3 shows a strong positive correlation with key immune checkpoint molecules

HNSCC.

Visualization was conducted using the TISIDB database, and analysis was performed using the Spearman correlation test. A total of 522 samples from head and neck cancers were included in the study. The correlations were statistically significant with $p < 2.2e\text{-}16$.

RASAL3 expression is positively correlated with additional immune regulators CTLA4, ADORA2A, HAVCR2, and IDO1 in HNSCC.

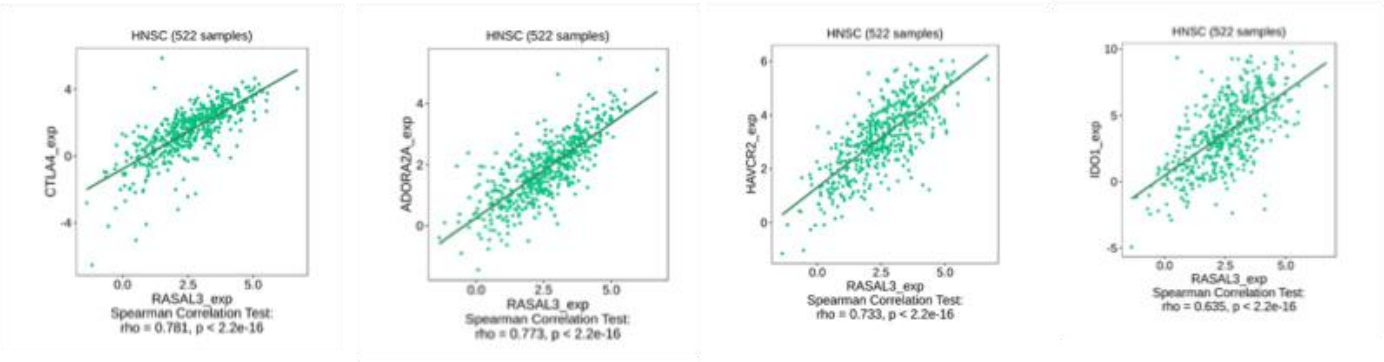


Fig 3. Correlation of RASAL3 Expression with Additional Immune Checkpoint Regulators

Visualization was performed using the TISIDB database. Correlations of RASAL3 with CTLA4, ADORA2A, HAVCR2, and IDO1 in head and neck cancers were analyzed based on 522 samples. The correlations were statistically significant with $p < 2.2e\text{-}16$.

In the tumor-infiltrating lymphocyte heatmap of RASAL3 across various cancer types, the gene exhibited strong correlations with certain immune cell populations, while showing weaker associations with others (Figure 4). Specifically, in head and neck cancers—the focus of our study—RASAL3 expression demonstrated strong positive correlations with several immune markers, including Myeloid-Derived Suppressor Cells (MDSCs; $\rho = 0.794$), Immature B cells (Imm B; $\rho = 0.812$), Activated B cells (Act B; $\rho = 0.782$), Activated CD8+ T cells (Act CD8; $\rho = 0.751$), and Effector Memory CD8+ T cells (Tem CD8; $\rho = 0.795$) (Figure 5). In contrast, weaker correlations were observed with Neutrophils, Immature Dendritic Cells (iDCs), and Plasmacytoid Dendritic Cells (pDCs), indicating potential

differences in how RASAL3 influences specific components of the immune landscape in head and neck cancers (Figure 4).

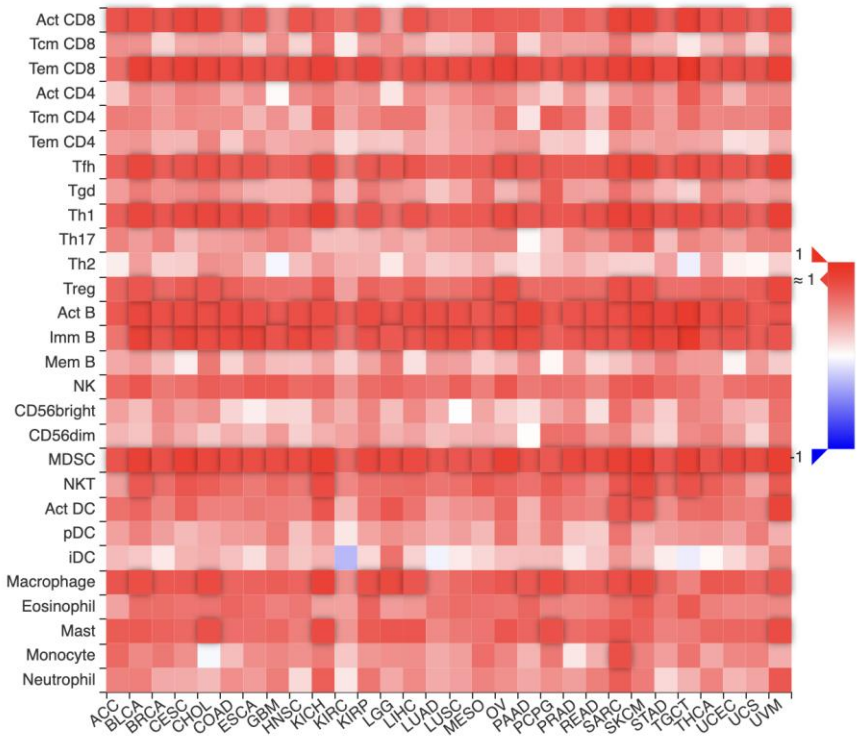


Fig. 4 Heat diagram of tumor-infiltrating lymphocytes.

Heatmap visualization of the Spearman correlations between RASAL3 expression and immunoinhibitory markers across various human cancers. Generated using the TISIDB database. Red tones indicate strong positive correlations, while blue tones represent negative or weak correlations, highlighting the differential immunomodulatory associations of RASAL3 in distinct tumor types.

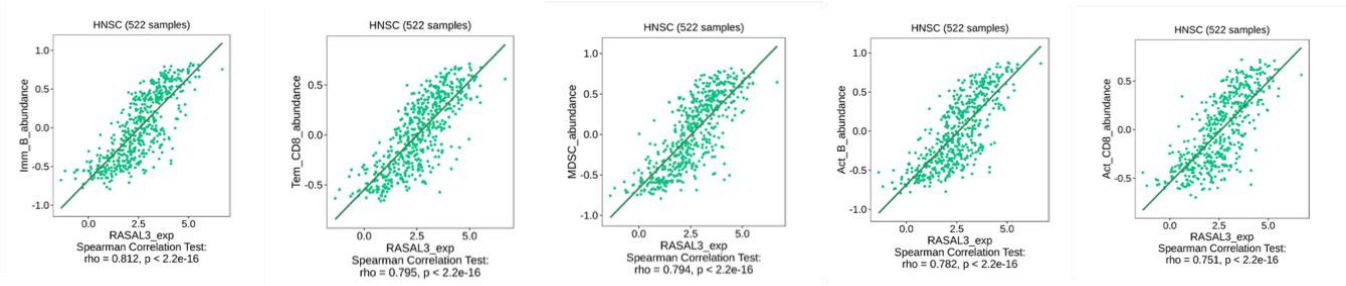


Fig 5. Spearman correlation analysis between RASAL3 expression and immunoinhibitory molecules across various human cancer types.

The heatmap was generated using the TISIDB database, illustrating the degree of correlation between RASAL3 and key immunoinhibitory markers. A total of 522 samples from head and neck cancers were included in the study. The correlations were statistically significant with $p < 2.2e\text{-}16$.

Warmer colors indicate stronger positive correlations, suggesting a potential role for RASAL3 in modulating immune suppression within the tumor microenvironment.

The results obtained from the TIMER 2.0 database supported the immunological associations observed in the TISIDB platform, reinforcing the potential immunomodulatory role of RASAL3 in head and neck cancers. A strong positive correlation was identified between RASAL3 expression and the infiltration levels of CD8+ T cells (rho = 0.811) and B cells (rho = 0.665), suggesting that RASAL3 may contribute to the recruitment or activation of adaptive immune components within the tumor microenvironment. These findings imply a possible role for RASAL3 in enhancing anti-tumor immune responses, particularly through CD8+ cytotoxic T lymphocytes and B cell-mediated pathways. In contrast, RASAL3 expression exhibited a significant negative correlation with myeloid-derived suppressor cells (MDSCs) (rho = –0.548), a population known for its immunosuppressive functions in cancer. This inverse relationship may indicate that RASAL3 expression is associated with a reduction in immunosuppressive cell populations, further supporting its potential involvement in shaping a more immunoreactive tumor milieu. Collectively, these findings highlight the dual regulatory capacity of RASAL3 in modulating both pro- and anti-tumor immune elements and provide a rationale for further investigation of its mechanistic role and therapeutic relevance in head and neck squamous cell carcinoma.

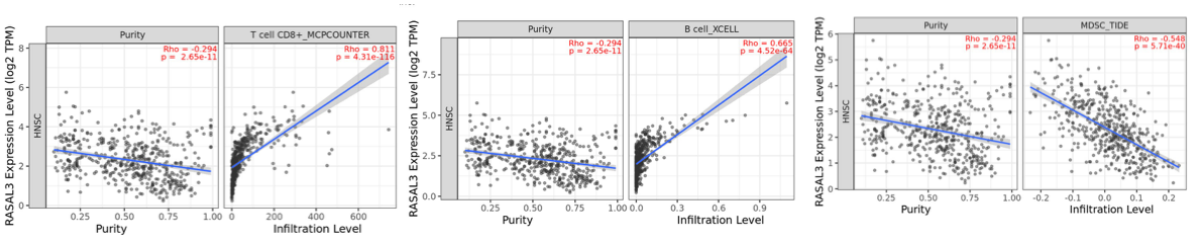


Fig. 6. Association between immune infiltrates and gene expression

DISCUSSION AND CONCLUSION

In recent years, increasing attention has been directed toward the immunoregulatory mechanisms underlying tumor progression in head and neck squamous cell carcinoma (HNSCC). In this study, we investigated the immunological role of **RASAL3**, a Ras GTPase-activating protein, using bioinformatics platforms including TISIDB and TIMER 2.0. Our findings demonstrate that RASAL3 expression is positively correlated with multiple key immune checkpoint inhibitors, particularly **PDCD1 (PD-1)**, **CTLA4**, **TIGIT**, **LAG3**, and **HAVCR2 (TIM-3)**, in HNSCC

These strong correlations suggest that RASAL3 may be involved in immune escape mechanisms by shaping an immunosuppressive tumor microenvironment.

Furthermore, heatmap analyses revealed a significant positive correlation between RASAL3 and adaptive immune cell markers such as activated B cells, memory CD8+ T cells, and effector CD8+ T cells, suggesting a role in promoting anti-tumor immune activity. Interestingly, RASAL3 was also negatively correlated with MDSCs (myeloid-derived suppressor cells), which are known to suppress T cell responses and facilitate tumor progression. This inverse relationship may reflect a dual function of RASAL3 in modulating both immune activation and suppression pathways within the tumor microenvironment.

The TIMER 2.0 database further supported these associations, showing high expression of RASAL3 in correlation with CD8+ T cells (rho = 0.811) and B cells (rho = 0.665) in HNSCC. Conversely, its negative correlation with MDSCs (rho = –0.548) strengthens the hypothesis that RASAL3 may contribute to reducing immunosuppression in certain immune contexts.

Taken together, these findings highlight the complex and context-dependent immunomodulatory role of RASAL3 in HNSCC. The observed correlations between RASAL3 and both stimulatory and inhibitory immune markers suggest that RASAL3 may serve as a key modulator of immune balance within the tumor microenvironment. Understanding its dual functions could open new avenues for therapeutic targeting, especially in combination with immune checkpoint inhibitors. Further experimental validation is needed to elucidate the mechanistic pathways through which RASAL3 influences immune cell dynamics and contributes to immune evasion or activation in head and neck cancers.

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Author Contributions

Contributions of the authors to the study can be explained.

Expression and Immunoregulatory Roles of NINJ1 and NINJ2 in Head and Neck Squamous Cell Carcinoma: A Bioinformatic Evaluation with Clinicopathological Insights

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Abstract

Head and neck cancers (HNCs), particularly head and neck squamous cell carcinoma (HNSCC), have emerged as a significant global health issue due to their high invasiveness and increasing incidence rates. These cancers, which can develop in various anatomical regions such as the lips, oral cavity, pharynx, and larynx, represent a major cause of morbidity and mortality worldwide. Despite advancements in treatment strategies, including surgery, radiotherapy, and chemotherapy, the prognosis for patients with recurrent or metastatic HNSCC remains poor, underscoring the need for novel therapeutic approaches. Immunotherapy has shown promise as a potential treatment option, yet its clinical success has been limited by a lack of understanding of the immune-suppressive mechanisms within the tumor microenvironment of HNCs. Recent studies have identified the Ninjurin protein family, particularly NINJ1 and NINJ2, as key regulators of immune responses in these cancers. NINJ1, a transmembrane protein, plays a crucial role in immune modulation by mediating plasma membrane rupture and the release of damage-associated molecular patterns (DAMPs), which amplify inflammatory responses. On the other hand, NINJ2 facilitates immune cell migration to inflammatory sites but does not contribute to membrane rupture. While the function of NINJ1 in immune regulation and tumor progression is well-established, the biological role of NINJ2 remains less understood. This review highlights the expression and immune-related functions of NINJ1 and NINJ2 in HNSCC, utilizing bioinformatics tools like UALCAN, TİMER, cBioPortal, and GEPIA to explore their potential as therapeutic targets. A deeper understanding of these molecules in HNCs could lead to the development of more effective immunotherapies, ultimately improving clinical outcomes for patients affected by these aggressive malignancies.

Key Words: *Head and neck cancer malignancies**,** cancer therapy, immune response, bioinformatics tools.*

Introductıon

Head and neck cancers have become a significant public health problem globally due to their high invasive potential and increasing incidence rates (Gao et al., 2024) (Sun et al., 2024). Characterized by approximately 700,000 new cases and 350,000 deaths annually, these cancers rank as the sixth most common cancer worldwide, with mortality rates continually rising (Bray et al., 2018). More than 95% of these tumors consist of head and neck squamous cell carcinoma (HNSCC), which can develop in anatomically distinct regions such as the lips, oral cavity, pharynx, and larynx (Nguyen et al., 2025).

The risk factors involved in the etiology of HNSCC vary according to the anatomical region, with common contributing factors including tobacco and alcohol use, genetic predisposition, viral infections (especially HPV and EBV), and betel nut chewing (Gao et al., 2024). Significant differences in tumor biology and treatment responses have been observed between HPV-positive and HPV-negative HNSCC patients. There-shaping of immune responses by the viral oncoproteins of HPV is considered one of the main reasons for these differences. Currently, combinations of surgery, radiotherapy, and chemotherapy are the primary treatment approaches, but these methods often prove insufficient in recurrent or metastatic cases (Sun et al., 2024).

In this context, immunotherapies have emerged as a promising alternative, but clinical success rates remain limited. This limitation stems from the insufficient understanding of the immunosuppressive mechanisms in the tumor microenvironment (Nguyen et al., 2025). The identification of new molecules involved in immune responses is critical for understanding resistance mechanisms to therapy and developing more effective immunotherapeutic strategies.

The identification of novel molecules involved in regulating immune responses could facilitate the understanding of resistance mechanisms to therapy and the development of more effective immunotherapeutic strategies. In this context, the Ninjurin protein family stands out as a significant research area (Shen et al., 2024a). The NINJ1 protein in this family is a transmembrane protein of approximately 16 kDa with an amphipathic N-terminal region and two hydrophobic transmembrane helices (Kayagaki et al., 2021).

First identified in 1996, NINJ1 was shown to play a role in regenerative processes following nerve injury, regulating cell-cell interactions between neurons and Schwann cells (Araki & Milbrandt, 1996; Sahoo et al., 2025a). Subsequent studies revealed that NINJ1 is not only involved in nerve regeneration but is also associated with cell migration, invasion, and various forms of programmed cell death (apoptosis, necroptosis, pyroptosis, ferroptosis).

Its role in mediating plasma membrane rupture and the release of cellular contents places it in a key regulatory position in shaping immune responses (Chen et al., 2025; Kim et al., 2020). Damage-associated molecular patterns (DAMPs) released during the process of plasma membrane rupture mediated by NINJ1 exacerbate inflammatory responses and can lead to tissue and organ damage due to prolonged inflammation. Therefore, blocking NINJ1 is considered a potential therapeutic strategy to reduce DAMP release, control inflammation, and limit tissue damage.

Another member of the Ninjurin family, NINJ2, was also initially identified as playing a role in nerve regeneration, like NINJ1 (Sahoo et al., 2025b). NINJ1 and NINJ2 proteins share 52% sequence identity and 67% similarity (Kayagaki et al., 2021). Structurally, NINJ2 filaments resemble NINJ1, but they have a more curved morphology. This curved structure prevents NINJ2 from performing the membrane rupture function exhibited by NINJ1, instead facilitating the migration of immune cells to sites of inflammation via molecules secreted from the plasma membrane (Ahn et al., 2009). In terms of tissue distribution, NINJ1 is widely expressed in epithelial tissues such as the liver, breast, and spleen, while NINJ2 is highly expressed in hematopoietic and lymphatic tissues (Araki et al., 1997; Araki & Milbrandt, 2000).

Although NINJ1 is known to have multifaceted roles in angiogenesis, inflammation, immune regulation, cell death, bone and muscle homeostasis, and tumor formation, the biological function of NINJ2 remains less understood compared to NINJ1 (Liu et al., 2024).

Particularly in immune-related tumors such as head and neck cancer, gaining a more comprehensive mechanistic understanding of NINJ1's functions could enable the development of more effective immunotherapeutic approaches and improve patient prognosis (Berkel & Cacan, 2023). While therapeutic approaches targeting the Ninjurin family have not yet been widely applied at the clinical level, these molecules are emerging as promising targets in future cancer therapies (Shen et al., 2024b).

This article emphasizes the role of NINJ1 and its close paralogue NINJ2 in activating immune responses and their expression in head and neck malignancies, using bioinformatics tools such as UALCAN, TİMER, cBioPortal, and GEPIA.

MATERIAL AND METHODS

Gene Expression Analyses

The expression levels of NINJ1 and NINJ2 genes across various cancer types, as well as their intergenic correlations, were analyzed using the Pan-Cancer Atlas and TIMER 2.0 databases. In addition, UALCAN was utilized to investigate gene expression profiles in relation to clinicopathological features. Genomic data from patients with head and neck cancer were retrieved from the cBioPortal database.

Statistical Analysis

Genetic and transcriptomic data utilized in this study were obtained from **UALCAN**, **TCGA Pan-Cancer Atlas**, **TIMER. UALCAN** was used to compare gene expression levels between normal and tumor tissues, and statistical significance across clinical subgroups was assessed. Student's *t*-test and one-way ANOVA were performed, with $p<0.05$ considered statistically significant. Data from the **TCGA Pan-Cancer Atlas** were used to analyze the relationship between gene expression and clinical parameters. Additionally, immune cell infiltration levels and their correlation with gene expression were assessed using the **TIMER** resource. Spearman's correlation coefficient was used for correlation analysis, with $p<0.05$ considered significant.

RESULTS

NINJ1 and NINJ2 Expression Profiles Across Human Cancers

Based on transcriptomic data retrieved from the GEPIA and TIMER 2.0 databases, differential expression patterns of NINJ1 were observed across multiple cancer types. NINJ1 expression was significantly upregulated in tumor tissues compared to normal counterparts in several cancer types, including esophageal carcinoma (ESCA), glioblastoma multiforme (GBM), kidney renal clear cell carcinoma (KIRC), kidney renal papillary cell carcinoma (KIRP), lung adenocarcinoma (LUAD), lung squamous cell carcinoma (LUSC), and head and neck squamous cell carcinoma (HNSCC) (Figure 1, top panel). Conversely, in cancers such as cervical squamous cell carcinoma and endocervical adenocarcinoma (CESC), kidney chromophobe (KICH), KIRP, pancreatic adenocarcinoma (PAAD), pheochromocytoma and paraganglioma (PCPG), prostate adenocarcinoma (PRAD), and uterine corpus endometrial carcinoma (UCEC), NINJ1 expression was relatively higher in normal tissues compared to tumor tissues (Figure 1, top panel).

Focusing on head and neck squamous cell carcinoma (HNSCC), which is the primary cancer type of interest in our study, NINJ1 was significantly overexpressed in tumor tissues relative to adjacent normal tissues. This upregulation was found to be statistically significant ($p < 0.0001$), suggesting a potential role for NINJ1 in HNSCC tumorigenesis.

Similarly, NINJ2, the homolog of NINJ1, displayed expression patterns that partially mirrored those of NINJ1. According to online analyses, NINJ2 was also found to be upregulated in tumor tissues in

various cancer types including bladder urothelial carcinoma (BLCA), colon adenocarcinoma (COAD), GBM, KICH, KIRC, KIRP, stomach adenocarcinoma (STAD), UCEC, ESCA, and HNSCC (Figure 1, bottom panel). In contrast, for LUAD and LUSC, higher expression of NINJ2 was observed in normal tissues relative to tumors (Figure 1, bottom panel).

These findings highlight the tumor type-specific expression patterns of both NINJ1 and NINJ2 and underscore their potential involvement in cancer progression, particularly in head and neck squamous cell carcinoma.

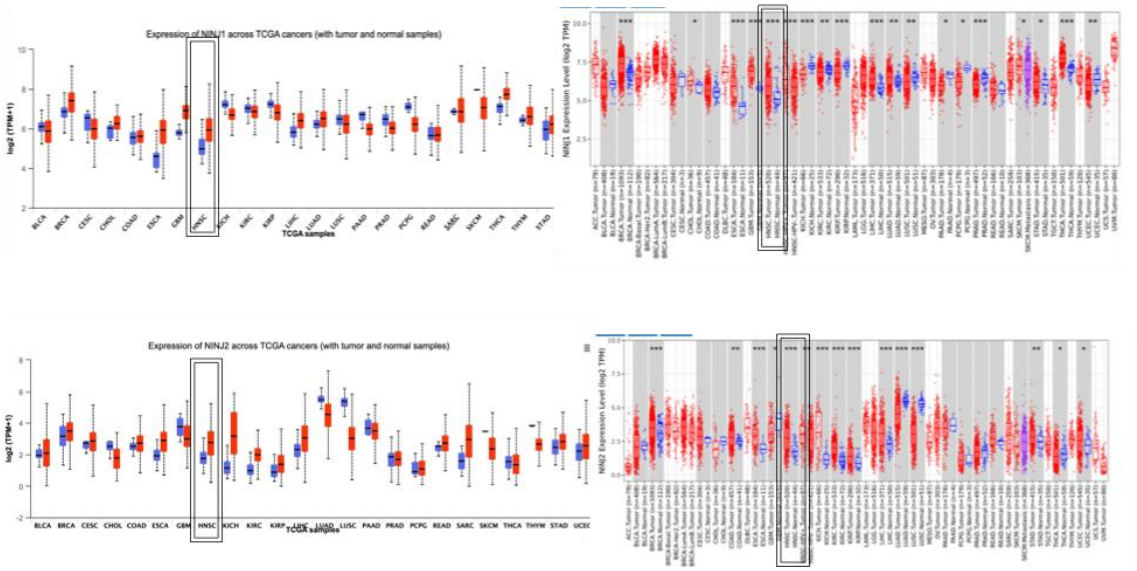


Fig. 1 Comparison of NINJ1 and NINJ2 gene expression levels across various cancer types using GEPIA and TIMER 2.0 databases**.**

Box plots illustrate gene expression in tumor (red) and normal (blue) tissues. The analysis focuses on head and neck squamous cell carcinoma (HNSCC), where both NINJ1 and NINJ2 show significantly higher expression in tumor tissues compared to normal tissues ($p < 0.0001$, denoted by ****). Expression comparisons were based on 520 tumor samples and 44 normal tissue samples. In addition to HNSCC, varying levels of statistical significance (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$) were observed in other cancer types, indicating tumor-type-specific expression differences.

NINJ1 and NINJ2 Clinico-Pathological Profiles in Head and Neck Squamous Cell Carcinoma (HNSCC)

Based on transcriptomic data obtained from the TCGA platform, both *NINJ1* and *NINJ2* show significantly elevated expression levels in primary tumor tissues compared to normal tissues in head and neck squamous cell carcinoma (HNSCC) (Figure 2A). When stratified by individual cancer stages, *NINJ1* expression exhibits a progressive increase from stage I through stage IV, with each stage showing significantly higher expression relative to normal tissue (Figure 2, bottom left). A similar trend is observed for *NINJ2*, where transcript levels are significantly elevated across all pathological stages compared to normal tissues (Figure 2, bottom right). The differences in expression between tumor and normal tissues across all stages were found to be statistically significant ($p < 0.0001$).

These findings suggest that *NINJ1* and *NINJ2* may be involved in tumor progression and could potentially serve as stage-associated biomarkers in HNSCC.

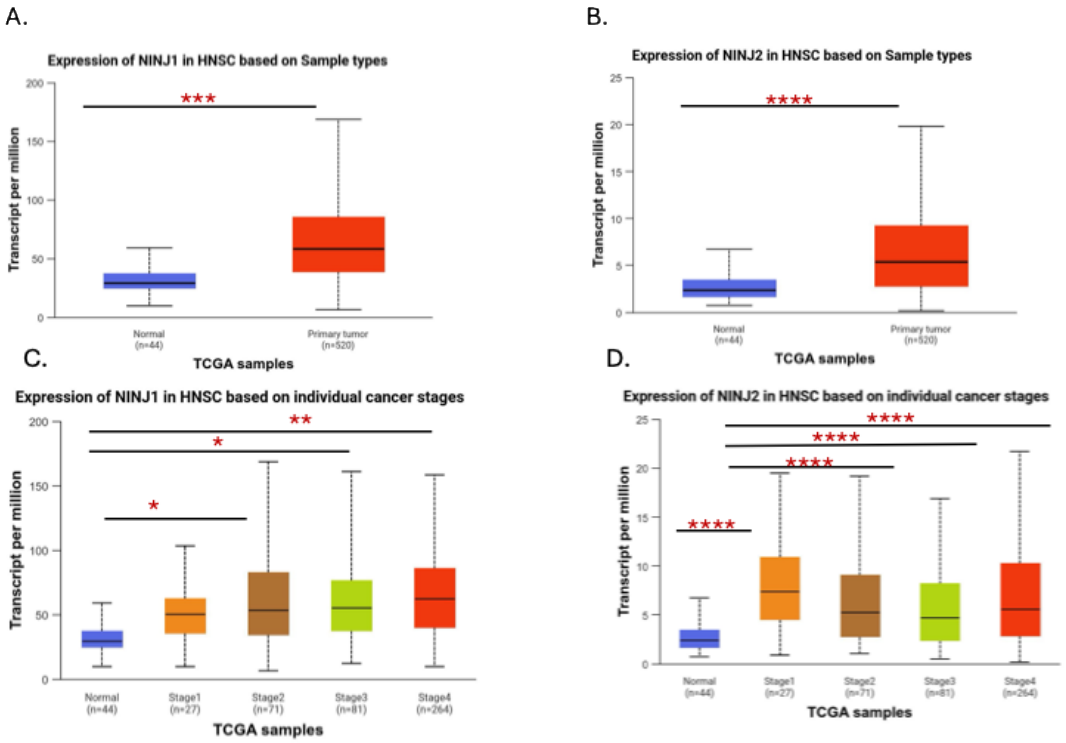


Fig.2 Comparison of *NINJ1* and *NINJ2* expression levels in HNSCC tissues and their distribution across pathological stages. NINJ1 and NINJ2 expression of Head and neck squamous carcinoma (HNSCC) based on tumor and normal tissues. (A-B). NINJ1 and NINJ2 expression of HNSC based on stage status. (C-D). Box plots were visualized using UALCAN.

Comparative analyses revealed that NINJ1 and NINJ2 genes exhibit similar expression profiles based on tumor grade (Figure 3, top panel). The expression levels of NINJ1 were found to be significantly elevated in tumor tissues at Grades 1, 2, 3, and 4 compared to normal head and neck tissues (Figure 3, top left). Similarly, when comparing the tumor grades of NINJ2 to normal tissues, a comparable expression pattern was observed, indicating similar clinicopathological characteristics with NINJ1 (Figure 3, top right).

In head and neck cancers, transcript levels of NINJ1 were significantly increased in N0 (no nodal metastasis) and N1 (limited nodal metastasis) stages compared to normal tissues (Figure 3, bottom left). Likewise, NINJ2 showed a significant increase in expression levels in N0, N1, and N2 (more advanced nodal metastasis) stages compared to normal tissues (Figure 3, bottom right). These findings suggest that NINJ1 and NINJ2 may exhibit similar clinicopathological behavior in head and neck cancers.

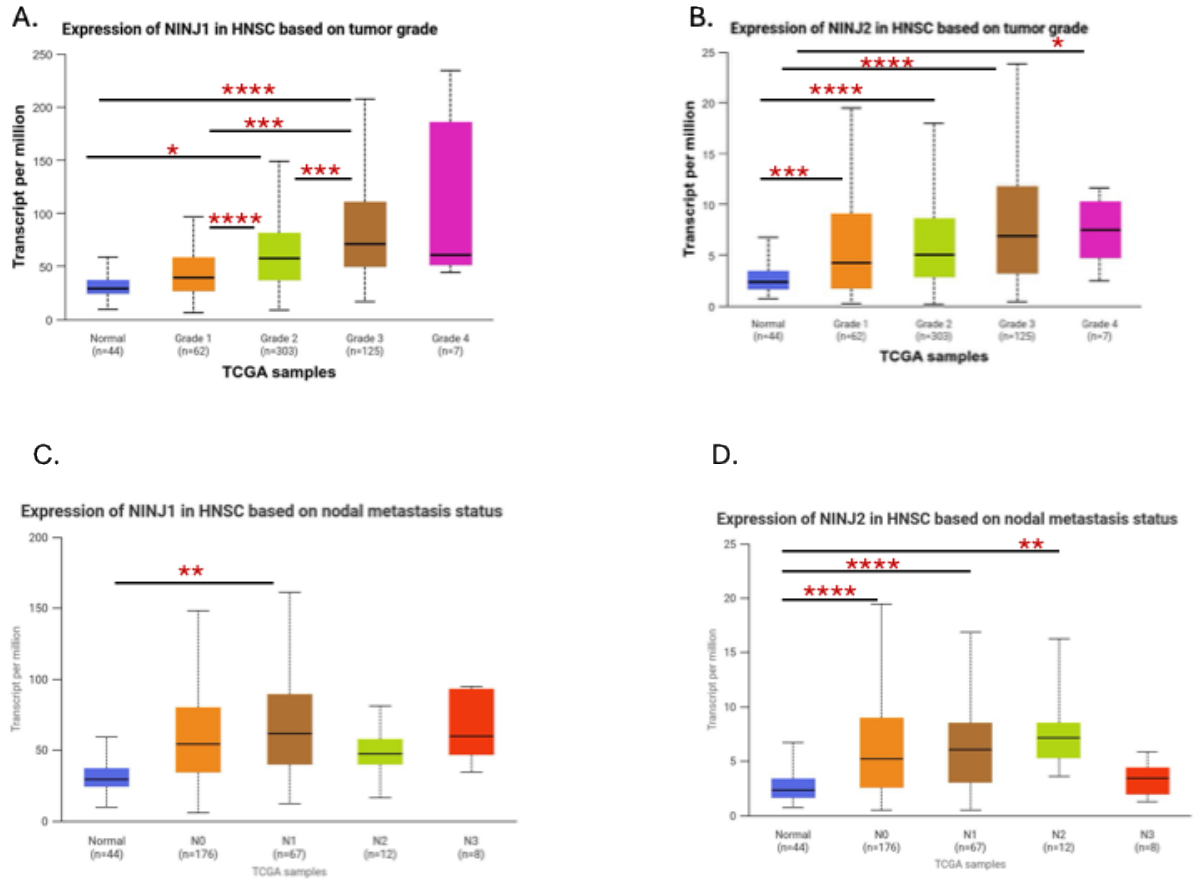


Fig.3 Transcript Levels of NINJ1 and NINJ2 Genes According to Tumor Grade and Nodal Metastatic Status.

(A-B) NINJ1 and NINJ2 expression of HNSCC based on grade status. (C-D) NINJ1 and NINJ2 expression of HNSCC based on nodal metastasis status. Box plots were visualized using UALCAN. ****: $p \leq 0.0001$, ***: $p \leq 0.001$, **: $p \leq 0.01$, *: $p \leq 0.05$.

Evaluation of NINJ1 and NINJ2 Gene Expression in Relation to Age and HPV Status

In head and neck cancers, the expression levels of *NINJ1* and *NINJ2* genes were found to be increased compared to normal tissues, depending on age groups and HPV status. Specifically, *NINJ1* expression was significantly elevated in tumor samples from patients aged 21–40 (n=20), 41–60 (n=236), and 61–80 (n=237), compared to normal tissues (n=44), with statistical significance (**$p \leq 0.01$; *$p \leq 0.001$) (Figure 1A). Similarly, *NINJ2* expression levels also showed an age-dependent increase, with statistically significant differences observed (*$p \leq 0.05$; ****p* ≤ 0.0001) (Figure 1B).

When stratified by HPV status, both *NINJ1* and *NINJ2* expression levels were significantly higher in HPV-positive patients (n=80) compared to normal tissues (n=44) and HPV-negative patients (n=434) (Figures 1C–D). These findings suggest that *NINJ1* and *NINJ2* expression may be modulated by both age and HPV positivity in head and neck cancers.

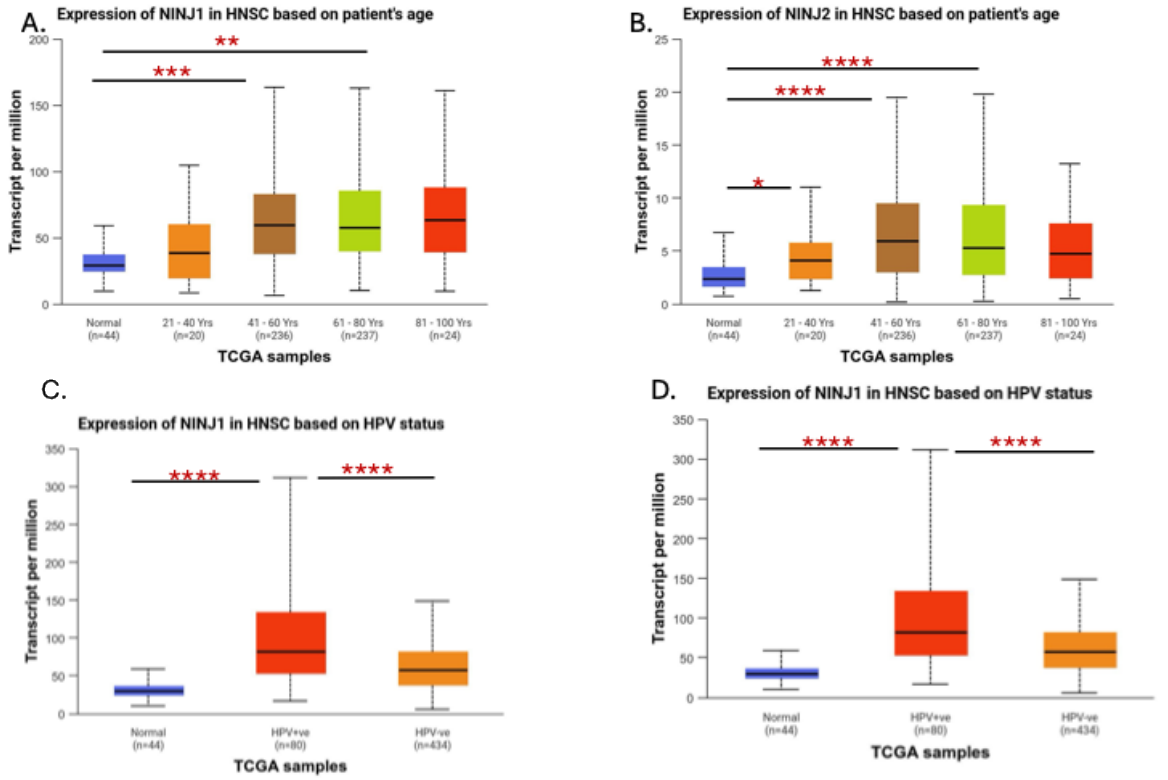


Fig. 4 NINJ1 and NINJ2 Expression in Head and Neck Cancer According to Patient Age and HPV Status

(A–B) Box plots illustrating *NINJ1* and *NINJ2* expression levels in head and neck squamous cell carcinoma (HNSCC) samples stratified by patient age: normal tissues (n=44), ages 21–40 (n=20), 41–60 (n=236), and 61–80 (n=237). (C–D) Expression levels of *NINJ1* and *NINJ2* in HNSCC samples based on HPV status: HPV-positive patients (n=80), normal tissues (n=44), and HPV-negative patients (n=434). Box plots were generated using the UALCAN database. Statistical significance is indicated as follows: ****p ≤ 0.0001, ***p ≤ 0.001, **p ≤ 0.01.

Correlation Between NINJ1 and NINJ2 Gene Expression and Immune Response

When examining the roles of the NINJ1 and NINJ2 genes in the immune response, a positive correlation was observed in CD8, CD4, and B cells. This suggests that increased expression of the NINJ1 and NINJ2 genes is associated with enhanced responses of key lymphocyte populations involved in the immune response(Figür 5).

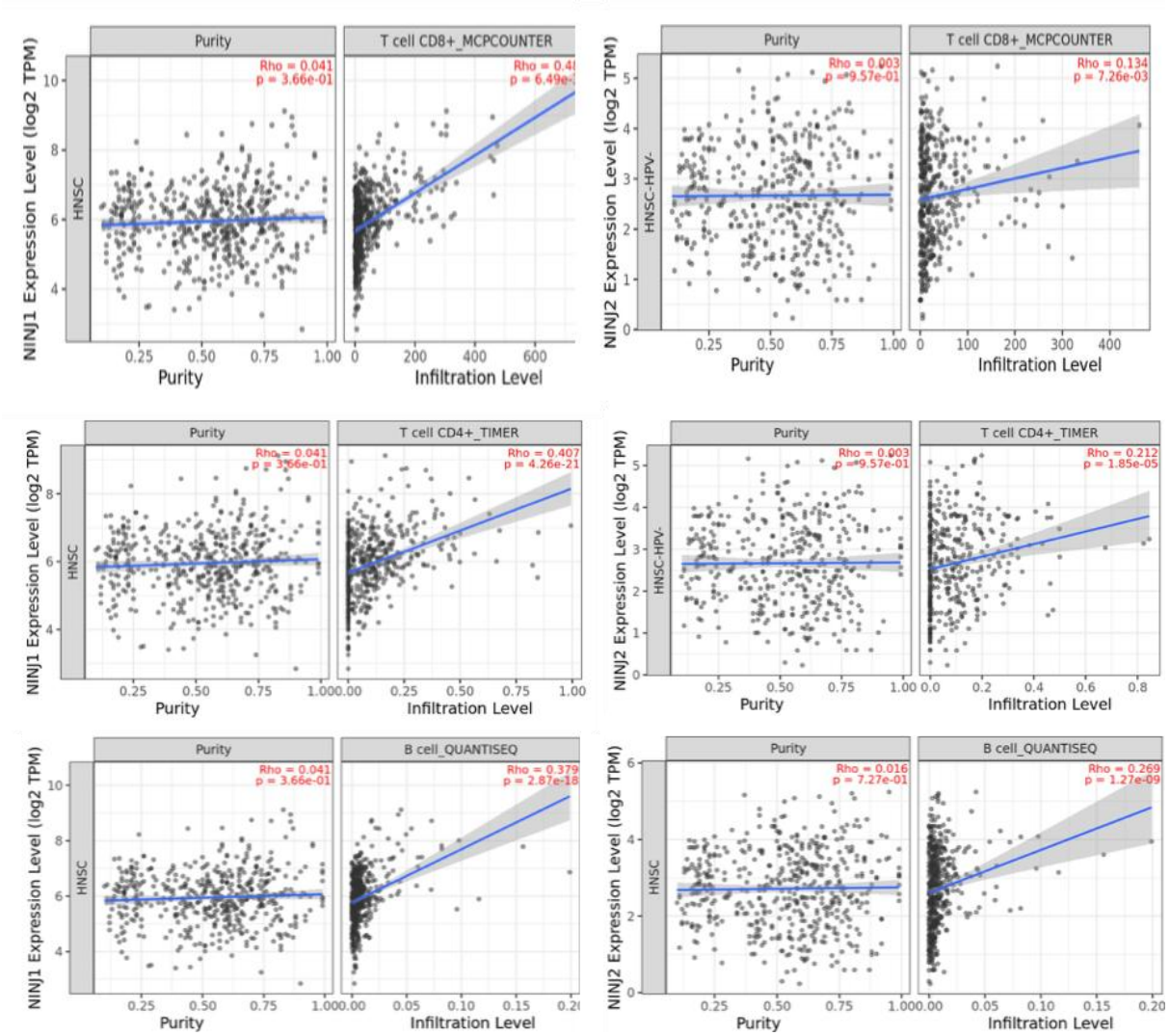


Fig. 5 Immunomodulatory Functions of NINJ1 and NINJ2 in the Regulation of Immune Responses

DISCUSSION AND CONCLUSION

Head and neck cancers (HNCs) affect a significant portion of the global population due to their heterogeneous anatomical origins and diverse risk factors. While these malignancies have traditionally been more prevalent among men, recent data indicate a rising incidence in women as well. Despite the application of standard treatment modalities—including surgery, radiotherapy, and chemotherapy—the presence of multiple subtypes contributes to variable therapeutic responses and often limits overall treatment success.

The introduction of immunotherapy as a treatment strategy has provided promising outcomes for a subset of head and neck cancer patients. However, its clinical efficacy remains limited to a small group of individuals. Therefore, the identification of new molecular targets that may enhance immunotherapeutic responses is of great importance. In this context, NINJ1 has emerged as a critical candidate due to its role as a terminal mediator of cell death mechanisms. Following tissue damage, NINJ1 facilitates inflammatory responses through its involvement in plasma membrane rupture and subsequent DAMP (damage-associated molecular pattern) release. Although NINJ2 shares significant

homology with NINJ1, it does not participate in membrane rupture or tissue damage, instead contributing to immune cell migration.

In this study, we initially examined the expression levels of **NINJ1** and **NINJ2** using bioinformatics databases such as **GEPIA** and **TIMER**. Our findings indicate that both genes are upregulated in tumor tissues compared to normal tissues. Subsequently, comprehensive analyses were performed using the **UALCAN** platform to compare expression profiles between primary tumor and normal tissues, as well as to assess differences based on tumor stage, grade, nodal metastasis status, patient age, and HPV status. The results consistently demonstrated a significant increase in the expression of **NINJ1** and **NINJ2** in head and neck squamous cell carcinoma (HNSCC) tissues across multiple clinical parameters.

Importantly, the parallel upregulation of both NINJ1 and NINJ2 suggests a potential coordinated role in the pathophysiology of HNSCC, although their functional mechanisms may differ. NINJ1's involvement in inflammation and regulated cell death points to its role in modulating the tumor microenvironment, whereas NINJ2's contribution may be more aligned with immune cell recruitment.

Our findings highlight the elevated expression of **NINJ1** and **NINJ2** in head and neck cancers compared to normal tissues, with significant associations across age groups, HPV status, and clinicopathological features. These results suggest that the Ninjurin family, particularly **NINJ1**, may serve as a novel target for enhancing immunotherapeutic approaches and modulating immune responses in head and neck cancer. Further functional and mechanistic studies are warranted to explore their roles in tumor progression, immune regulation, and potential as therapeutic biomarkers.

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Evaluating Blockchain for Supply Chains: SWOT Analysis and a Case Simulation Using the Sepolia Testnet Network

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Abstract

This paper begins with a detailed analysis of blockchain applications in supply chain. The analysis provides a structured evaluation of the key strengths, weaknesses, opportunities, and threats associated with the implementation of blockchain technology in global supply chains. It critically examines how blockchain addresses prevalent challenges such as fragmented data, limited visibility, and vulnerabilities to fraud, while also highlighting the potential barriers to its widespread adoption. In addition, this paper introduces a simulation platform designed to optimize the distribution of soft drinks in Albania. Powered by the Sepolia testnet, the platform, it features a smart control panel that allows producers to manage real-time inventory of soft drinks. Through this exploration, we demonstrate how blockchain technology can address key challenges in product traceability, inventory management, and supply chain visibility, while providing a practical application of these concepts through a real-world simulation.

Key words: *blockchain, smart-contract, supply-chain, SWOT*

INTRODUCTION

In today's complex global supply chains, ensuring the traceability of products — from origin to consumer — has become both a logistical necessity. Traditional supply chains often suffer from fragmented data, limited visibility, and vulnerabilities to fraud or error .Blockchain technology has emerged as a powerful tool to address these challenges by providing a transparent, tamper-proof, and decentralized method of tracking goods and information throughout the supply chain. Building on this foundation, we present a comprehensive SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis to critically assess blockchain's capabilities and limitations within real-world supply chain contexts. This structured approach allows us to identify where blockchain excels — such as in traceability, trust, and efficiency — while also acknowledging challenges like energy consumption, lack of standardization, and regulatory ambiguity. The SWOT framework helps illuminate the broader strategic implications of adopting blockchain, not just from a technical standpoint, but also from a business and policy perspective.

To complement this theoretical analysis, we introduce a blockchain-based simulation platform tailored for soft drink distribution in Albania. This system, implemented on the Sepolia Ethereum testnet, enables real-time inventory management, secure transaction logging, and decentralized control over distribution processes. Through this simulation, we we aim to demonstrate how blockchain's core properties can be applied to streamline supply chain operations.

A SWOT ANALYSIS OF THE POTENTIAL OF BLOCKCHAIN IN SUPPLY CHAIN MANAGEMENT

In order to gain a comprehensive understanding of blockchain's potential in supply chain management, we firstly conduct a SWOT analysis — examining its strengths, weaknesses, opportunities, and threats. This approach allows us to critically assess the technology's advantages while also acknowledging its limitations and risks in real-world applications.

-Strength

One of blockchain's core strengths is its ability to create immutable and verifiable records, which enhances transparency and builds trust across the supply chain. This feature guarantees that every transaction is permanently recorded, and any attempt to alter data is immediately detectable. This reliability is especially critical in industries like food safety, pharmaceuticals, and luxury goods, where counterfeit products and fraud are major concerns (Bai et al., 2020). Additionally, blockchain's auditable nature allows stakeholders to track a product's entire journey — from raw material sourcing to final sale — ensuring compliance with regulatory standards and quality assurance protocols (Saberi et al., 2019).

Blockchain also facilitates real-time monitoring, which proves particularly advantageous in situations such as product recalls or identifying fraudulent goods. In cases of quality issues, blockchain enables swift identification and isolation of affected products, thereby minimizing the impact of contamination or defects (Huang et al., 2021). This ability to respond quickly not only protects consumers but also safeguards the reputation of brands, making blockchain a critical tool for risk management in supply chains (Pereira et al., 2021).

Another significant strength of blockchain is its ability to improve traceability and accountability. By securely recording each transaction on a decentralized ledger, blockchain creates a clear, accurate record of a product's journey. This level of traceability is especially valuable in industries like agriculture and fashion, where ethical sourcing and sustainability are prioritized. Blockchain's proof of provenance helps build consumer confidence and supports businesses in meeting corporate social responsibility (CSR) objectives (Kshetri, 2018).

Furthermore, blockchain contributes to cost efficiency by removing the need for intermediaries in transactions. With a decentralized system, businesses can reduce costs associated with manual record-keeping, third-party verification, and disputes over data accuracy. This reduction in administrative overhead is particularly beneficial for small and medium-sized enterprises (SMEs), allowing them to streamline operations without compromising security or transparency (Choi & Lee, 2021).

Beyond cost efficiency, blockchain fosters collaboration among supply chain partners by providing a secure, shared platform for data exchange. This collaborative environment breaks down barriers, improving communication and information flow between stakeholders — from suppliers to manufacturers to retailers. Such cooperation is essential for optimizing supply chain processes, enhancing overall efficiency, and fostering stronger business relationships (Lee & Rungtusanatham, 2021).

Lastly, blockchain's scalability makes it adaptable to a wide range of industries and supply chain complexities. Whether dealing with small local suppliers or large global networks, blockchain can manage diverse transaction volumes and complexities without sacrificing security or performance (Kim & Kim, 2020).

- Weaknesses

While blockchain offers many advantages, there are also notable challenges that could hinder its widespread adoption in supply chains. One of the biggest concerns is high energy consumption. Blockchain, especially networks that use proof-of-work mechanisms, requires significant computational power to validate and secure transactions. This can result in high energy consumption, which poses a challenge for industries focused on sustainability. For companies striving to reduce their environmental impact, blockchain's energy demands might contradict their green goals (Sedlmeir et al., 2020).

Another limitation is the lack of standardization. Different blockchain platforms use varying protocols, and there is no universal standard for how they should be implemented across supply chains. This lack of standardization can lead to interoperability problems, making it difficult for companies to ensure seamless communication between different stakeholders and across diverse systems (Casino et al., 2019).

Regulatory uncertainty remains a significant concern. While blockchain can enhance transparency and compliance, the legal frameworks surrounding its use are still unclear. Many governments are yet to establish solid regulations, particularly when it comes to data privacy, liability, and international transactions. This uncertainty can make businesses wary of adopting blockchain, as they worry about future regulatory changes or the possibility of running into legal issues (Finck, 2019).

-Opportunities

Blockchain presents a range of promising opportunities for enhancing supply chain operations. One of the most notable is the potential for increased consumer trust through enhanced transparency. As consumers become more conscious of ethical sourcing and sustainability, blockchain can provide verifiable proof of a product’s origin, production conditions, and journey to the consumer. This can be especially valuable in sectors such as food, apparel, and electronics, where concerns about labor practices or environmental impact are common (Deloitte, 2017).

Another major opportunity lies in improving inventory and logistics efficiency. With blockchain-enabled smart contracts, businesses can automate processes such as payments, order confirmations, and inventory restocking based on predefined conditions. This reduces manual intervention and leads to faster, error-free transactions, ultimately optimizing overall supply chain performance (Logistics Viewpoints, 2025).

Blockchain also opens new pathways for collaborative innovation and ecosystem development. Companies across the value chain — including suppliers, logistics providers, and retailers — can build shared blockchain infrastructures that support secure and reliable data exchange. This shared visibility encourages partnerships, reduces duplication of efforts, and accelerates innovation in areas like circular economy logistics, and digital product passports (RINF Tech, 2024).

Blockchain can support data-driven decision-making. By offering accurate, real-time data across the supply chain, blockchain enables businesses to gain actionable insights, respond more effectively to market shifts, and anticipate disruptions before they occur (TVS Supply Chain Solutions, 2025). When combined with technologies like AI and IoT, blockchain’s data integrity forms a strong foundation for predictive analytics and advanced supply chain intelligence.

-Threats

Despite its many advantages, blockchain also faces several threats that could limit its successful adoption in supply chain management. One of the key concerns is vulnerability in smart contract design. While blockchain itself is considered secure, the smart contracts built on top of it are not immune to programming flaws. If not properly audited or tested, these contracts can be exploited by malicious actors, leading to security breaches or financial losses. Since smart contracts are typically immutable once deployed, even small errors can have significant consequences for operations (Atzei et al., 2017).

Another important issue is the high upfront cost and uncertain return on investment. Implementing blockchain technology requires considerable spending on infrastructure, software development, and employee training. For many businesses — especially small and medium-sized enterprises — these initial costs may be difficult to justify, particularly when the long-term benefits are not immediately visible. This financial risk can act as a deterrent, slowing down adoption in resource-constrained environments (Kouhizadeh et al., 2021). Lastly, there is the challenge of organizational resistance and stakeholder alignment. Supply chains involve many different actors, each with their own systems and priorities. Convincing all parties to adopt a shared, decentralized solution can be difficult, especially when some stakeholders are unfamiliar with the technology or fear losing control over their data. Without broad buy-in, the effectiveness of blockchain across the supply chain may be limited.

A SIMULATION PLATFORM FOR SOFT DRINK DISTRIBUTION IN ALBANIA, POWERED BY SEPOLIA TESTNET NETWORK

- *Interface*

The delivery has an interface that acts like a smart control panel for managing soft drink distribution. At the top, it shows the title "AL-Delivery" over a Coca-Cola-themed background, Just below that, there's a section dedicated to the producer, showing exactly how many bottles of Coca-Cola, Sprite, and Fanta (1.5L each) are currently in stock. This allows the producer to keep track of inventory in real time, which is essential for managing supply and meeting demand efficiently.

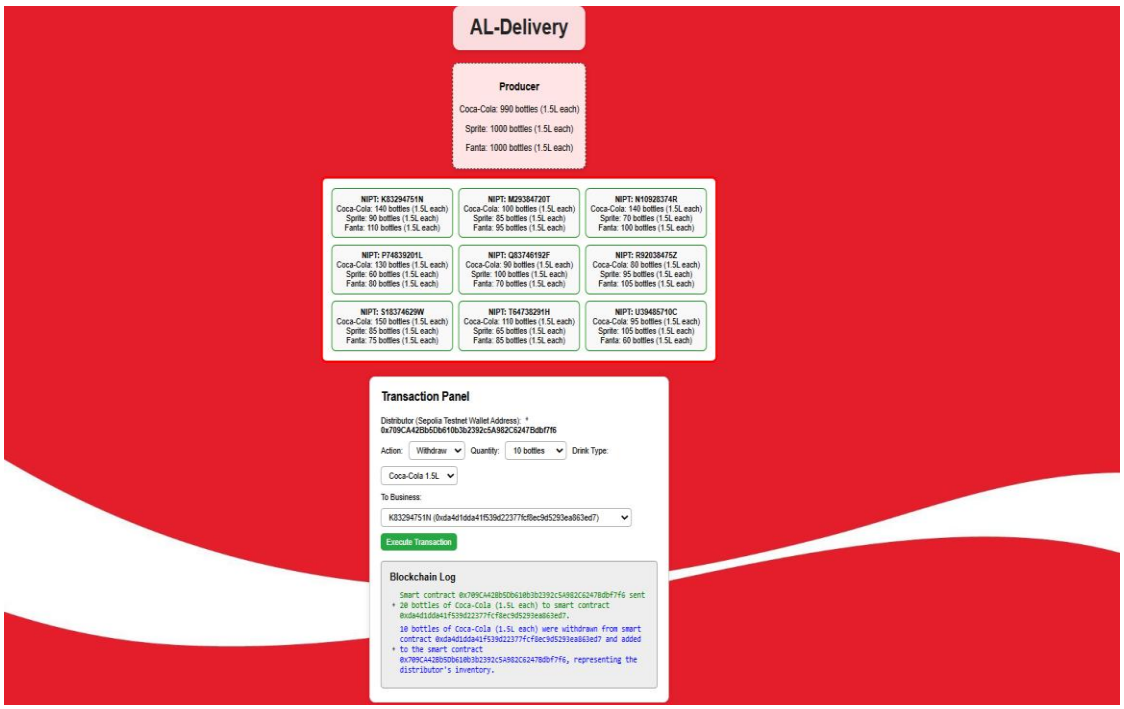


Figure 1. AL-Delivery Interface

Below the producer section, the interface displays a grid of tier-1 distributors—nine in total—each with its own identification number (NIPT – Albanian tax identification number) and individual stock levels for each drink. This matrix-style view lets the producer easily compare inventory levels across tier-1 distributors, identify which ones need restocking, and plan transactions accordingly.

To manage deliveries, the interface includes a transaction panel where the interface user can select an action—either sending drinks to a business or withdrawing them—along with the drink type, quantity, and destination. When a transaction is executed, it gets recorded in Sepolia testnet network and its corresponding log is mapped to the front-end of website. This log is designed to resemble the Ethereum transaction feed: each entry includes a blockchain icon, and a brief message describing the action (e.g., "Sent 10 Coca-Cola to NIPT A123..."). Transactions are color-coded—green for sends, blue for withdrawals (sending from small-businesses back to the inventory of Al-Delivery business.

- *The choice of Sepolia testnet network*

The Sepolia testnet has rapidly become a preferred environment for Ethereum developers due to its stability and efficiency in testing decentralized applications (dApps) and smart contracts. Initially launched in October 2021 as a proof-of-authority network, Sepolia transitioned to a proof-of-stake (PoS) consensus mechanism in July 2022, aligning with Ethereum's mainnet upgrade and enhancing its relevance for contemporary development workflows (Coindesk, 2022). A key feature of Sepolia is its permissioned validator set, which maintains a predictable network state and offers a more controlled and reliable testing environment compared to open-validator testnets (Validation Cloud, 2022). Its lightweight infrastructure reduces storage demands and synchronization time, contributing to its efficiency. Moreover, Sepolia's close alignment with the Ethereum mainnet increases the likelihood that applications tested on it will perform as expected in production environments (Alchemy, 2022).

Several empirical studies have also underscored Sepolia's utility in real-world applications. In the insurance sector, it has been employed to prototype a blockchain-based parametric insurance system ((arxiv.org, 2022a) — Collaborative and Parametric Insurance).Sepolia was selected over alternatives such as Goerli or Holesky due to its lower operational overhead, faster synchronization, and deterministic behavior—features that are critical for reproducibility and performance benchmarking in test environments (Web3 University, 2022). In telecommunications, it has supported the testing of a multi-contract blockchain framework for 6G inter-provider agreements, facilitating performance evaluations such as gas consumption for key operations and enabling optimization of smart contracts for large-scale decentralized applications ((arxiv.org, 2022b) — Performance Analysis of a 6G Inter-Provider DApp*)*. These practical advantages and proven use cases strongly motivated our choice of the Sepolia network over other available testnets.

- *Smart contract and its deployment.*

In Appendix 1, we attach the BottleTransfer smart contract. The BottleTransfer smart contract facilitates the controlled distribution of beverage bottles—Coca-Cola, Sprite, and Fanta—from a central producer to Tier-1 distributors. The producer's Sepolia testnet address is hardcoded to ensure that only this entity can perform sensitive actions such as transferring inventory or registering new businesses. Each business is uniquely identified by its NIPT (a business registration number), which is mapped to its wallet address. Upon deployment, the producer is initialized with a starting inventory, and additional businesses can be added through the setBusiness function. Inventory transfers are handled by the transferBottle function, which deducts bottles from the producer and credits them to the receiving business.

The deployment of the BottleTransfer smart contract is carried out using Remix IDE, a browser-based integrated development environment that is widely used for writing, compiling, and deploying Solidity smart contracts. Remix offers an intuitive interface, real-time compilation, and direct integration with MetaMask, making it especially suitable for development on Ethereum test networks such as Sepolia.

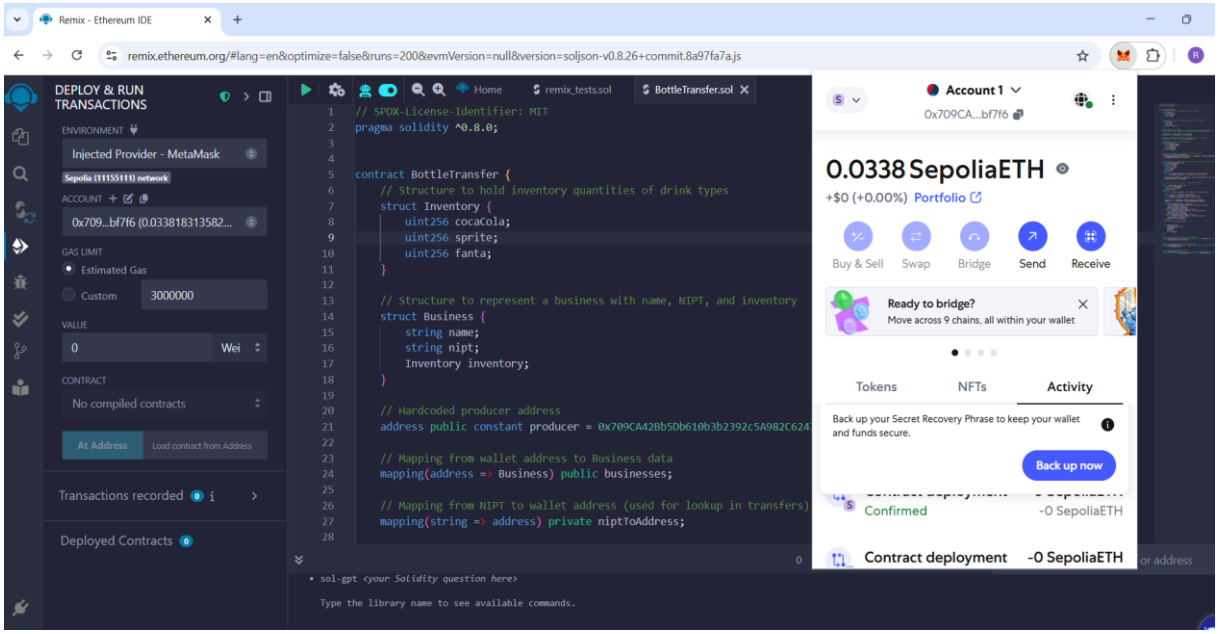


Figure 2. The deployment of smart-contract via REMIX IDE.

After compiling the contract using the Solidity compiler plugin within Remix, the deployment process continues under the “Deploy & Run Transactions” tab. The environment is set to Injected Provider - MetaMask, and the connected wallet should be funded with test ETH on the Sepolia Testnet. Once deployed, the contract automatically initializes the producer with a default inventory of Coca-Cola, Sprite, and Fanta (1,000 units each). The Producer can then register Tier-1 distributors using the setBusiness() function, providing each business’s wallet address, NIPT, and initial stock levels.

-Javascript interacion with smart-contract.

JavaScript interacts with the deployed BottleTransfer smart contract through the use of library Ethers.js, which allow browser-based applications to communicate with the Ethereum blockchain. This library enable JavaScript to connect to the user's wallet (typically via MetaMask) and interact with smart contract functions using the contract's ABI (Application Binary Interface) and deployed address.

In our implementation, when a user interacts with the interface—for example, selecting a drink, quantity, and destination business—JavaScript captures this input and invokes the smart contract’s transferBottle() function. MetaMask handles transaction confirmation, and once the blockchain confirms it, the interface updates to reflect the new inventory levels. This integration enables a seamless and secure bridge between the user-facing front-end and the underlying decentralized logic defined in the smart contract.

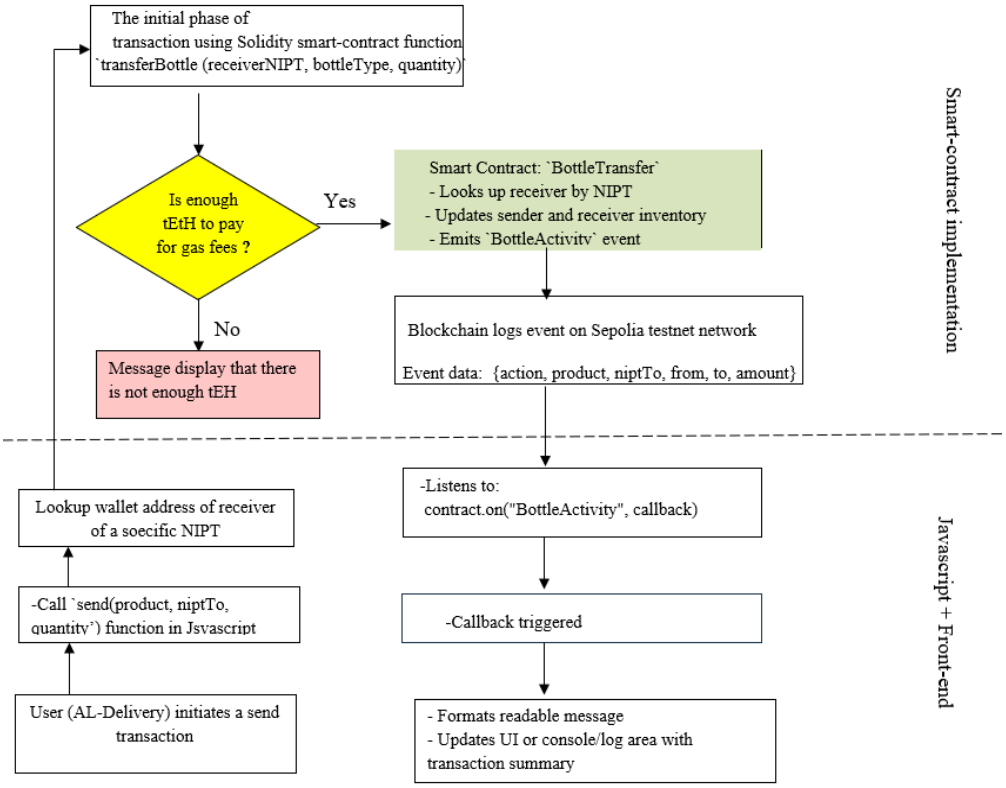


Figure 3. Smart contract transaction flow.

On the JavaScript side, the frontend listens for this BottleActivity event using contract.on(...) and captures the associated data, including the action, product, sender, receiver, and quantity. Once the event is received, a callback function formats the information and updates the user interface or transaction log. This seamless integration between the blockchain and UI ensures that users receive real-time feedback on their transactions, maintaining transparency and traceability of bottle movements across the distribution network.To verify the first transaction, we are attaching a screenshot from EtherScan, which is accessible via the following URL:

https://sepolia.etherscan.io/tx/0xb9b7a577ac9d140f9085de8eab0b4f013ebefa0601f33208b6274bdcff6f7cf9

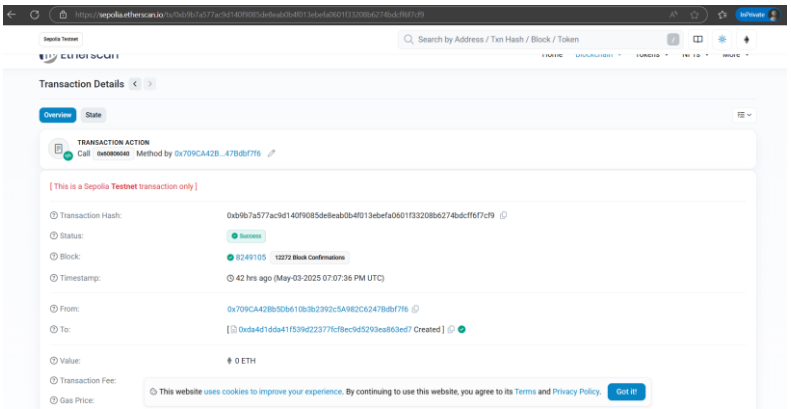


Figure 4 : The first system transaction record retrieved from the Sepolia Testnet network

- Scalability considerations

Scalability is a crucial factor when selecting a blockchain platform for real-world supply chain applications. As the number of participating businesses and transactions grows, the underlying blockchain must be capable of handling increased volume without compromising performance, latency, or reliability.

Among the various blockchain frameworks available, we, as the authors, would like to emphasize that Hyperledger Fabric stands out as the most suitable platform for scalability. Its modular architecture, support for private channels, and efficient consensus mechanisms (such as Raft or Kafka) make it particularly well-suited for enterprise-grade applications. Unlike public blockchains that may suffer from network congestion and variable transaction fees, Hyperledger Fabric provides predictable performance and the ability to isolate workloads, which is critical in large-scale, multi-stakeholder supply chain networks Although our prototype utilizes the Sepolia Ethereum testnet due to its convenience and public accessibility, future implementations aiming for high transaction throughput, privacy, and scalability could greatly benefit from migrating to a permissioned blockchain like Hyperledger Fabric.

Conclusions

This study explores the practical application of blockchain technology in supply chain management, with a focus on the distribution of soft drinks in Albania. Through a comprehensive SWOT analysis, we demonstrate that blockchain offers powerful capabilities for enhancing transparency, traceability, and operational efficiency. By leveraging the Sepolia testnet and a custom smart contract, our simulation platform showcases how decentralized technologies can manage inventory in real time and facilitate secure, auditable transactions among supply chain actors.

The interactive front-end, integrated with the Ethereum testnet, enables businesses to track and manage product flows with minimal reliance on intermediaries. Our implementation provides clear evidence of blockchain's ability to streamline supply chains, reduce administrative overhead, and improve stakeholder trust. Additionally, the event-driven feedback system ensures a responsive user experience aligned with the immutable records on the blockchain.

While Sepolia served as a reliable testing environment, scalability considerations suggest that enterprise-level deployments would benefit more from permissioned frameworks. As authors, we advocate for Hyperledger Fabric as a future direction due to its superior scalability, modular architecture, and suitability for complex, multi-organization networks.

Overall, this work underscores blockchain's transformative potential in supply chain logistics and lays the groundwork for future real-world applications and scalability-focused research.

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Conflict of Interest

The authors have declared that there is no conflict of interest

Toxicological Emergencies and Poisoning

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Abstract

Throughout history, humanity has recognized that exposure to various harmful substances in nature can impair health. These substances, referred to as poisons, cause damage to the human body, and this harmful interaction is known as poisoning. Emergency departments are the primary point of evaluation and treatment for patients with drug-related poisonings. Therefore, all healthcare professionals working in these settings must be well-informed about poisoning management. Treatment strategies include supportive care, decontamination, antidotal therapy, and elimination techniques. Developing effective treatment algorithms, monitoring protocols, and implementing strategic interventions are essential, as the correct application of these approaches can be life-saving. Due to the growing number and variety of toxic substances, the overlap of symptoms caused by many agents, and the variability of symptoms between individuals, clinical presentation alone is often insufficient to determine the exact toxic agent. At the beginning of emergency treatment, the specific substance causing the poisoning is frequently unknown. Thus, identifying the primary toxic agent is critical and generally requires laboratory confirmation. This review aims to examine toxicological emergencies and poisonings through the lens of current scientific literature.

Keywords: *Poisoning, Poisoning in the emergency room, Toxicology*

INTRODUCTION

Poisoning refers to the condition in which a living organism is adversely affected by exposure to a toxic agent. The concept of poisoning dates back to the 13th century and has persisted as a significant health concern throughout history (Pekdemir, 2002). Harmful substances found in the environment can enter the body through various routes including oral, parenteral, inhalation, dermal, and mucosal pathways—and lead to adverse effects (Hack, 2013). With technological advancements, the number and diversity of chemical substances have increased, resulting in more frequent exposure and a rise in poisoning cases (Aydın, 2006). Acute drug ingestion is a common cause of poisonings, making these cases a substantial portion of emergency department admissions. The increasing number of poison-related emergencies highlights the importance of emergency services in recognizing and managing such cases (Akkose, 2003). In Turkey, poisoning cases account for 0.46% to 1.57% of all emergency room visits (Yavuz, 2003).

Poisonings; Depending on the factors and the duration of admission to the hospital, it can lead to important results, and some of these patients may need intensive care units for advanced care after receiving correct and effective treatment in the Emergency Services (Şenol, 2002). In the study conducted by Kavalcı et al., the average time for patients to apply to the hospital varies between 155

and 180 minutes. In the study conducted by Yeşil et al., patients who were poisoned applied to the emergency room in an average of 456 minutes. Burilli-Putze et al. concluded that 34.2% of the cases applied to the emergency room within 2 hours after the poison was taken into the body. In the study conducted by Karcıoğlu et al., 50% of the patients applied to the emergency room within the first two hours **Poisoning cases** may present with various clinical manifestations depending on the affected organ systems.The scope of the symptoms may vary from gastrointestinal system complaints to central nervous system findings. At the beginning of emergency treatment, it is not known which type of drug caused the poisoning in many cases. Due to the abundance of substances that can cause poisoning, it is important to find the primary cause or causes of the event (Greene, 2021).

Gender and Age

Poisoning cases represent a significant portion of emergency admissions and predominantly affect younger individuals. These patients often respond well to treatment. Studies in Turkey have consistently shown a higher incidence of poisoning among women, ranging from 53% to 77% (Deniz, 2009; Gündüz, 2004). Studies have found that poisoning cases are seen at a young age (25 years and under). Studies have shown that poisonings for suicidal purposes are more common (Yeşil, 2008). The oral route is usually used in suicide attempts to attract attention (Kekeç, 2005).

Application Time

When the hospital admission times of poisoning cases are examined, it is seen that the most frequent admission time is between 16:00-24:00. Studies have shown that the reason for the accumulation in this time range is that a significant portion of drug intake for suicide is an attempt to obtain secondary income (Deniz, 2009).

Application Period

In the study conducted by Kavalcı et al., the average time for patients to apply to the hospital was between 155 and 180 minutes (2006). In the study conducted by Yeşil et al., it took an average of 456 minutes to apply to the emergency room (2008). Burillo-Putze et al. concluded that 34.2% of patients applied to the emergency room within 2 hours after ingestion of the poison (2003). In the study conducted by Karcıoğlu et al., 50% of patients applied to the emergency room within the first two hours (2000).

Laboratory and Imaging in Drug Poisoning

Laboratory tests such as hemograms, biochemistry, and drug-specific tests are examined as blood tests in poisoning patients (Prosser, 2009). **General laboratory tests** should include a comprehensive biochemical analysis comprising complete blood count, serum electrolytes, renal and liver function tests, glucose levels, coagulation parameters, cardiac markers, blood gas analysis, complete urinalysis, B-HCG level for every pregnant woman, and, if possible, drug levels (Linden, 1998).General laboratory tests can help to know the patient's initial blood values, recognize metabolic disorders caused by poisoning, and guide treatment. Although radiological imaging is sometimes useful in diagnosis, it can play an important role in the clinical management and follow-up of some poisonings (Camkurt, 2008). In poisoning cases, the main goal is to plan the patient's supportive treatment first, to reduce the toxin concentration in the target organ or tissue, and then to combat its pharmacological and toxicological effects. (Avcı, 2009). **The management of poisoning** consists of several stages: preventing the absorption of the toxic substance, eliminating it from the body, and neutralizing its toxic effects through symptomatic and supportive treatment and the use of antidotes (Kavalcı, 2006).

Gastric Lavage

Gastric lavage is a washing procedure performed to empty or cleanse the stomach, using a special catheter inserted into the stomach through the mouth (orogastric) or nose (nasogastric). In gastric lavage, an orogastric/nasogastric tube of appropriate size is sent to the stomach. After confirming the tube placement, gastric lavage is continued in adults until the effluent is cleared using an appropriate volume of fluid (Hack, 2013).

Application of Activated Charcoal

Activated charcoal binds irreversibly to drugs in the intestine, reducing drug absorption and enterohepatic circulation. It is thought to decrease the drug's blood concentration through two mechanisms: by creating a negative diffusion gradient between the intestinal lumen and the blood, and by facilitating the movement of the drug from the blood to the intestinal lumen, a process referred to as "gastrointestinal dialysis." It is believed that the earlier activated charcoal is administered, the more effective it is (Sarı, 2008).

Total Intestinal Irrigation

Whole bowel irrigation is a rapid and practical method that enables the evacuation of the intestines within 4 to 6 hours. In this way, the absorption of the toxic substance can be prevented by enteral administration of a high-volume electrolyte solution and by enhancing the rectal elimination of the ingested chemical (Prosser, 2009).

Hemodialysis

Hemodialysis is based on the principle of transferring toxic substances in the blood to the dialysis fluid in the dialysis machine.The benefits of hemodialysis are the removal of poison absorbed from the intestinal lumen, the removal of substances not bound to activated charcoal, and the elimination of active toxic metabolites together with the parent compound (Avcı, 2009). It can be applied in methanol, ethylene glycol, high-dose salicylate, theophylline, and also paracetamol, arsenic, bromide, chloral hydrate, ethanol, and lithium poisoning (Tunçok, 2000).

Observation

In the study conducted by Karcıoğlu and his colleagues, it was concluded that most of the cases were discharged from the emergency department within the first 24 hours. It can be said that most of the poisoned patients in our country are kept in the emergency departments for observation purposes more than necessary. In this regard, the problem can be solved if poison counseling centers direct emergency department workers with clearer information. (Karcıoğlu, 2000)

CONCLUSION

Emergency departments play a critical role in the initial evaluation and management of poisoning cases. Comprehensive knowledge of treatment strategies, including supportive care, decontamination, antidotal therapy, and elimination methods, is essential for healthcare providers. Proper implementation of monitoring protocols and clinical algorithms is vital, as these can significantly impact patient outcomes and save lives.

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Sağlık Bilişimi Destekli Hasta Eğitim Uygulamalarının Kan Basıncı ve Hastalık Kontrolüne Katkısı (243)

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Absract

According to the World Health Organization, approximately 1.28 billion adults aged 30-79 years are diagnosed with hypertension (HT). Still, many individuals (4 in 5) cannot control their blood pressure effectively. Planning cost-effective interventions is recommended to prevent premature deaths from HT. Traditionally, a wide range of non-pharmacological interventions have been implemented to improve blood pressure control, such as self-monitoring, educational interventions focused on patients, and managed care by health professionals. In addition, integrating technology into healthcare services, "health informatics" based solutions significantly contribute to hypertension control by increasing patient self-management. This review includes information on the contribution of health informatics-supported patient education applications to the blood pressure and disease control of hypertensive individuals.

Studies have reported the use of applications such as m-health, telehealth, tele-monitoring, home BP telemonitoring, personal digital assistant, smartphone tracking, mobile applications, and short message service to increase blood pressure (BP) control in hypertensive individuals. In hypertensive individuals, health informatics-supported education applications have been reported to increase BP control, decrease systolic and diastolic BP, increased medication adherence, increased knowledge, healthy eating and physical activity.

The findings show that health informatics-supported patient education practices significantly contribute to hypertension control. These applications increase individuals' knowledge levels, improve self-management skills, and improve clinical outcomes. However, it is emphasized that individuals should have good skills in using technology (digital literacy) for these applications to be practical. Furthermore, increasing the access of low socioeconomic individuals to health informatics tools is critical to reducing inequalities.

Keywords: *Hypertension, health informatics, blood pressure control, disease control, patient education*

GİRİŞ

Hipertansiyon, dünya genelinde ölümle sonuçlanan kardiyovasküler hastalıkların başlıca risk faktörlerinden biridir. Dünya Sağlık Örgütü'ne (WHO, 2023) göre 30-79 yaş aralığındaki yaklaşık 1,28 milyar yetişkin hipertansiyon tanısı almakta, ancak bu bireylerin önemli bir kısmı (5'te 4'ü) kan basıncını etkili bir şekilde kontrol edememektedir. 2019 Küresel Hastalık Yükü Çalışması, ülkelerin kan basıncı kontrolünü iyileştirmek ve hipertansiyondan ve buna bağlı kardiyovasküler hastalıklardan kaynaklanan erken ölümleri önlemek için maliyet-etkin müdahalelerin planlanmasını ve ülkelerin bu programlara yatırım yapmasını önermektedir (Roth ve ark., 2020). Küresel olarak, kan basıncının kendi kendine izlenmesi, hastalara odaklanan eğitim müdahaleleri ve sağlık profesyonelleri tarafından yönetilen bakım (hemşire, eczacı, toplum sağlık çalışanları) gibi kan basıncı kontrolünü iyileştirmek için çok çeşitli farmakolojik olmayan müdahaleler uygulanmaktadır (Lu ve ark., 2015). Geleneksel hasta eğitimi yöntemlerinin yanında, teknolojinin sağlık hizmetlerine entegrasyonu ile "sağlık bilişimi" tabanlı çözümler, hasta öz yönetimini artırarak hipertansiyon kontrolüne önemli katkılar sağlamaktadır (Almasi et al., 2020; Kes ve Polat, 2022).

Bu bağlamda, mobil uygulamalar, elektronik sağlık kayıtları, uzaktan izleme sistemleri, yapay zekâ destekli rehberlik uygulamaları ve hasta portalları gibi sağlık bilişimi araçları, bireylerin kendi sağlık durumlarını yönetmelerine destek olmaktadır. Bu çalışmada, sağlık bilişimi destekli hasta eğitim uygulamalarının hipertansiyon yönetimindeki rolü, literatür verileri ışığında detaylı bir şekilde incelenmektedir.

Sağlık Bilişimi Uygulamaları: Tanım ve Kapsam

Sağlık bilişimi, sağlık bilimlerinin uygulama alanlarında (sağlık hizmeti sunumu, yönetimi ve eğitimi için) bilgi iletişim teknolojilerinin kullanımını kapsayan bir alandır (Sood ve McNeil, 2017). Son dönemde bilim ve sağlık teknolojisindeki gelişmeler, tele sağlık, tele hemşirelik gibi sağlık bilişim sistemlerinin hastalık yönetiminde kullanıma girmesine neden olmuştur. Tele sağlık uygulamaları, sağlık hizmetine ulaşamayan veya evden takibi yapılması gereken bireylere uzaktan sağlık değerlendirmesi, tıbbi duruma göre gerekli müdahale ve yönlendirmenin yapılması, sağlık eğitimi ve danışmanlığı verilmesi gibi hizmetlerin ulaştırılmasını sağlamaktadır. Sağlık bilişimi uygulamaları, özellikle kronik hastalığı olan bireylerde öz-yönetim becerilerinin geliştirilmesi, bağımsızlık düzeyinin arttırılması, hastaneye bağlılığın azaltılması, zaman yönetimi ve yaşam kalitesinin arttırılmasına katkı sağladığı için tercih edilmektedir (Deveci ve Aydın, 2022). Hipertansif bireylerde de ideal kan basıncı düzeyini sürdürmek hastalık yönetiminde anahtar role sahiptir. Hipertansiyon yönetiminde kullanılan başlıca sağlık bilişimi araçları şunlardır:

- **Mobil Sağlık (mHealth/** m-Sağlık**) Uygulamaları**: m-Sağlık kronik hastalıkların sağlığın yönetilmesi, izlenmesi ve önlenmesinde sağlık hedeflerine ulaşılmasını desteklemek için mobil ve kablosuz teknolojilerin kullanılması ve uygulaması olarak tanımlanmaktadır (Değerli, 2021). M-sağlık uygulamalarına örnek olarak akıllı telefonlar üzerinden kan basıncı ölçümü kaydı, hatırlatıcılar, eğitim materyalleri sunan uygulamalar verilebilir (e.g., MyBP Lab, Omron apps).
- **Tele-sağlık Sistemleri**: Uzaktan hemşire izlemeleri, hasta-doktor sanal görüşmeleri ve evden ölçüm sistemlerini içerir. Hipertansiyon için sıklıkla tercih edilen tele sağlık uygulaması, evde dijital kan basıncı monitörüdür. Bu monitörler kan basıncı değerlerini ve hastalık ilişkili çeşitli klinik bilgileri hastaların yaşam alanlarından sağlık profesyonellerine iletilmesini sağlarlar. Bu uygulama ile iletilmesi gereken veriler hastanın bulunduğu yerden hastaneye uzaktan veri aktarımı yöntemiyle iletilir. Uygulamada ölçüm değerleri cihazın hafızasına kaydedilmekte ve ardından senkron veya asenkron olarak uzak bir ana bilgisayara gönderilmektedir. Veri iletimi

genellikle sabit hat veya mobil ağlar aracılığıyla, veri bütünlüğü ve güvenliğini sağlayan şifreleme iletim protokolleri kullanılarak web üzerinden gerçekleştirilmektedir (Omboni, Caserini ve Coronetti, 2016; Omboni, 2019b).

- **Elektronik Sağlık Kayıtları (EHR)**: Hastaların verilerinin kayıt altına alındığı, sağlık ekiplerinin erişebildiği sistemlerdir (e-nabız) (Yılmaz, Özkoç ve Ulaş, 2019).
- **Hasta Portalları**: Hastaların kendi laboratuvar sonuçlarına ulaşabildiği, mesajlaşma ve eğitim alabileceği online platformlar (Griffin ve ark., 2016).
- **Giyilebilir Teknolojiler**: Akıllı saatler ve bileklikler aracılığıyla tansiyon, kalp atım hızı gibi verilerin sürekli izlenmesini sağlar (Fitbit, Apple Watch vb.).
- **Yapay Zekâ Destekli Koçluk Sistemleri**: Kişisel sağlık verilerini analiz ederek bireye özel öneriler sunar (örnek: Lark Hypertension Management).

Bu uygulamalar, hastaların bilgiye erişimini kolaylaştırarak ve öz-yönetim yeteneklerini geliştirerek, hipertansiyonun daha etkili kontrolüne katkıda bulunmaktadır.

YÖNTEM

Bu çalışma, 2014–2024 yılları arasında PubMed, CINAHL, Scopus ve Web of Science veri tabanlarında yayımlanmış randomize kontrollü çalışmalar, sistematik derlemeler ve meta-analizler taranarak hazırlanmıştır. Anahtar kelimeler: "hypertension", "health informatics", "digital health intervention", "patient education", "self-management".

AMAÇ

Bu bildirinin amacı, sağlık bilişimi destekli hasta eğitim uygulamalarının hipertansiyon kontrolüne olan etkisini değerlendirmek, kullanılan farklı sağlık bilişimi teknolojilerini tanımlamak ve bu uygulamaların klinik sonuçlara yansımalarını ortaya koymaktır.

BULGULAR

Çeşitli klinik çalışmalar, sağlık bilişimi destekli eğitim uygulamalarının hipertansiyon kontrolünde etkili olduğunu göstermektedir. Elde edilen önemli çalışma sonuçları aşağıda sunulmuştur:

Tablo 1. Sağlık Bilişimi Destekli Uygulamaların Hipertansiyon Üzerindeki Etkileri

Yazar (Yıl)	Uygulama Türü	Örneklem	Müdahale	Müdahale Süresi	Ana Bulgular
Logan ve ark., (2012)	Mobil Telemonitoring	110 hasta	Hipertansif diyabetik hastaların her ölçümden hemen sonra akıllı telefonlarına kendi kendine bakım mesajları sağlayan bir ev kan basıncı telemonitoring sisteminin kan basıncı kontrolünü iyileştirme üzerine etkisi. Mesajlar, iletilen ölçümlerin ortalamalarıyla tanımlanan bakım uygulamalarına dayanmaktadır.	6 ay	Müdahale grubunda sistolik KB'de 9,1 ± 15,6 mmHg düşüş
Margolis ve ark., (2013)	Evde KB telemonitorizasyonu	450 hasta	Hastalara modem aracılığıyla verileri depolayan ve güvenli bir web sitesine (AMC Health) ileten bir ev BP monitörü verilmiştir. Her bir katılımcıyla eczacı HT'ye ilişkin bir saatlik eğitim uygulamış. Hastalara haftada en az 6 KB ölçümü (3 sabah ve 3 akşam) iletmeleri talimatı verilmiş. Müdahalenin ilk 6 ayında, hastalar ve eczacılar KB kontrolü 6 hafta boyunca sağlanana kadar her 2 haftada bir telefonla görüştüler ve daha sonra sıklık aylık olarak düşürüldü. Müdahalenin 7 ila 12. aylarında, telefon ziyaretleri her 2 ayda bir gerçekleşti. 12 aydan sonra hastalar telemonitör kullanımını bıraktılar, birincil hekimlerinin bakımına geri döndüler ve artık bir çalışma eczacısından destek almadılar.	12 ay müdahale ve müdahale sonrası 6 ay takip	Telemonitoring müdahale grubundaki hastalarda sistolik kan basıncı 6. ayda 10,7 mm Hg, 12. ayda 9,7 mm Hg ve 18. Ayda 6,6 mm Hg düşüş
Moore ve ark., , (2014)	Kişisel dijital asistan	42 hasta (20/22)	Tablet ve mobil telefonlara kurulabilen CollaboRhythm yazılımı kullanıldı. Bu yazılımın özellikleri arasında şunlar yer aldı: İlaç alımı ve kan basıncı ölçümü için günlük alarmlar	3 ay	Müdahale edilen deneklerde 12. haftada sistolik KB'de kontrol deneklerine göre daha büyük bir düşüş elde edildi

			gönderme ve hasta verilerinin sağlık hizmeti sağlayıcılarına eş zamanlı olarak aktarılması ve verilerin daha iyi anlaşılması için veri görüntüleme araçlarının kullanılması.		(26,3 mm Hg - 16,0 mm Hg, P = 0,009)
Rubinstein ve ark., , (2016)	Akıllı telefon	533 hasta (266/267)	Deney grubuna diyet ve fiziksel aktiviteler hakkında günlük bir kısa mesaj gönderilmesi	12 ay	Müdahale, sistolik kan basıncındaki (ortalama net değişim -0,37 mm Hg) veya diyastolik kan basıncındaki (0,01 mm Hg) değişikliği, olağan bakıma kıyasla etkilemedi
Varleta ve ark., , (2017)	SMS	314 hasta (163/151)	Müdahale, her 12-14 günde bir kısa mesaj göndermeyi içeriyordu. Kısa mesajların içeriği, sağlıklı diyetler, tuz tüketimi, hipertansiyon ilaçlarının tüketiminin planlanması, ilaç tüketiminin önemi ve tedaviye uyum konusunda eğitim bilgilerini içeriyordu.	6 ay	Başlangıç ortalama BP, SMS ve SMS olmayan gruplarda sırasıyla 142,7/81,1 mm Hg ve 140/78,4 mm Hg idi. Son ortalama BP, SMS grubunda 134,6/77,5 mm Hg ve SMS olmayan grupta 136,8/78,3 mm Hg idi.
Omboni ve ark., (2020)	Telemedicine		Birkaç randomize kontrollü çalışma, TM aracılığıyla hipertansif hastalarda gelişmiş hipertansiyon yönetimi ve iyileştirilmiş KB kontrolünü belgelemiştir. TM'nin potansiyel ek etkileri, tedaviye uyumun iyileştirilmesi, ilaç kullanımının yoğunlaştırılması ve optimize edilmesi, yaşam kalitesinin iyileştirilmesi, kardiyovasküler komplikasyonlar geliştirme riskinin azaltılması ve maliyet tasarrufu ile temsil	Derleme	Ortalama sistolik KB düşüş ve KB kontrolünde artış

			edilmektedir.		
Meurer et al (2019	Akıllı telefon	55 hasta (28/27)	Metin mesajı deney grubu için haftada bir kez kullanıldı. Metin mesajı yaşam tarzı, fiziksel aktiviteler, beslenme ve alınacak ilaç türü hakkında rehberlik	4 ay	9,1 mmHg düşüş
Márquez Contreras et al (2019	Akıllı telefon	154 hasta (77/77)	Müdahale, uygulamayı hastaların cep telefonlarına yüklemeyi ve doktorların uygulamayı nasıl kullanacaklarını öğretmesini içeriyordu. Bu uygulama, kişisel bilgileri kaydetme, doktorların ilaçlarla ilgili notlarını kaydetme, alarmlar ayarlama, randevular ayarlama, kan basıncı ölçüm sonuçlarını kaydetme, yüksek kan basıncı durumunda hastalara alarmlar gönderme ve eğitim modülleri içeriyordu.	12 ay	Başlangıçtaki ortalama BP (DG: 134,7±14 mmHg, KG: 134,47±8 mmHg) ve son DG: 132,2±12, KG: 134,4±11 mmHg)
Chandler ve ark., , (2019)	Akıllı telefon	64 hasta (26/28)	Müdahale, hastalara her üç günde bir sabah ve akşam kan basıncını ölçmek için bir kısa mesaj gönderilmesini içeriyordu. Mesajlar yaşam şekli değişimini destekleyen ve klavuzlara göre hazırlanmış kısa video klipler içeren metin mesajları şeklindeydi.	9 ay	SKB ortalamaları DG ve KG gruplarında anlamlı derecede düşüktü (sırasıyla 1. ay: 125,3'e karşı 140,6; 3. ay: 120,4'e karşı 137,5, 6. ay: 121,2'ye karşı 145,7 mmHg; 9. ay: 121,8'e karşı 145,7)
Kes ve Polat (2022)	Nurse-led telephone support	77 hasta	Hastalara kan basıncı ölçümünü hatırlatan kısa mesajlar gönderimi	3 ay	İlaç uyumunda artış, kan basıncı değerlerinde düşüş
Liu ve ark (2023)	m-Sağlık	297 hasta	Müdahale grubu katılımcılarına eğitim verildi ve 6 ay boyunca Blood Pressure Assistant adlı bir mHealth uygulamasını kullanmaları istendi.	6 ay	Müdahale grubunda ortalama sistolik ve diyastolik BP sırasıyla 25,83 ve 14,28 mm

			Uygulamayı kullanarak hayati belirtileri kaydedip yükleyebildiler, eğitim materyallerine erişebildiler ve yüklenen verilerin analizine göre sağlık hizmeti sağlayıcılarından öz yönetim hatırlatıcıları ve geri bildirim alabildiler.		Hg düşüş. Bilgi düzeyi, ilaç uyumu, sağlıklı beslenme, düşük tuz tüketimi ve fiziksel aktivitede artış.

KB: Kan basıncı

Bu sonuçlar, sağlık bilişimi destekli eğitim programlarının hem fizyolojik parametrelerde hem de davranış değişikliklerinde anlamlı olumlu etkiler yarattığını göstermektedir.

Sağlık Bilişimi Uygulamalarının Hasta Uyumu Üzerindeki Etkisi

Birçok çalışma, dijital araçlarla yapılan müdahalelerin hastaların tedaviye uyum oranlarını artırdığını ve KB değerlerinde düşüş oluşturduğunu göstermektedir. Hastalar hatırlatıcı bildirimler, eğitim videoları ve bireyselleştirilmiş öneriler sayesinde günlük rutinlerine daha kolay adapte olabilmekte, dolayısıyla öz-yönetimleri de paralelinde artmaktadır (Kitsiou ve ark., , 2017; Chandler ve ark., 2019; Kes ve Polat, 2022).

Davranış Değişikliği Üzerindeki Etkiler

Mobil uygulamalar ve hasta portalları, bireylerin diyet, egzersiz, stres yönetimi ve KB kontrolü gibi alanlarda olumlu davranış değişiklikleri gerçekleştirmelerine yardımcı olmaktadır. Bu, hipertansiyon yönetiminde sürdürülebilir sonuçlar doğurmaktadır (Free ve ark., 2013; Liu ve ark., 2023). Margolis ve arkadaşlarının uzun süreli çalışması mobil uygulamaların davranış değişimindeki etkisini net şekilde ortaya koymaktadır. Çalışmada ilk 6 ay KB kontrolü sağlanıncaya kadar haftada bir gibi sıklıkla gerçekleştirilen görüşmeler 6 aydan sonra sıklığı azaltılarak devam ediliyor ve 12. Aydan sonra görüşmeler kesilerek bireyler üzerindeki etkisinin devam edip etmediği test ediliyor. Sonuçtan ilk 6 ayda 10,7 mm Hg, 12. ayda 9,7 mm Hg ve 18. ayda 6,6 mm Hg düşüş oluştuğu raporlanıyor. Görüşmeler kesildikten sonraki 6 aylık uzunca bir sürede hastalardaki başlangıç değerine nazaran 6,6 mmHg'lik düşüş, davranış değişiminin olumlu yönde olduğunu göstermesi bakımından kıymetlidir (Margolis ve ark., 2013).

Hasta Güvenliği ve Sağlık Sonuçları Üzerindeki Etkiler

Dijital sağlık uygulamaları ile erken komplikasyon tespiti, anormal kan basıncı değerlerine hızlı müdahale sağlanabilmektedir. Bu, özellikle yüksek riskli hipertansiyon hastalarında hastane başvurularını ve mortaliteyi azaltabilmektedir (Márquez Contreras ve ark., 2019).

TARTIŞMA

Elde edilen bulgular, sağlık bilişimi destekli hasta eğitim uygulamalarının hipertansiyon ve KB kontrolünde önemli katkılar sağladığını göstermektedir. Bu uygulamalar bireylerin bilgi düzeylerini artırmakta, öz yönetim becerilerini geliştirmekte ve klinik sonuçları iyileştirmektedir (Liu ve ark., 2023). Ancak, bu uygulamaların etkili olabilmesi için bireylerin teknolojiyi kullanma becerilerinin (dijital okuryazarlık) iyi olması gerektiği vurgulanmaktadır (Choi ve DiNitto, 2013). Ayrıca, düşük sosyoekonomik düzeydeki bireylerin sağlık bilişimi araçlarına erişiminin artırılması, eşitsizlikleri azaltmak açısından kritik önem taşımaktadır. Bunun yanında davranış değişimi oluşturulabilmesi ve yönetim becerisinin kalıcı hale getirilmesi için eğitim ve izlemin sürekli ve uzun vadeli olması gerekmektedir. Yapılan çalışma sonuçlarında 3 aylık eğitim veya 6 aylık eğitim sonrası KB düzeylerinde düşme olduğu aşikardır ancak bu kontrolün olumlu etkilerinin sürekli olması gerekmektedir. Hipertansiyon ömür boyu devam eden kronik bir hastalıktır ancak doğru yaşam stili değişikliği ile kontrol altına alınabilen bir hastalıktır. Bunun yanında kontrol istenen düzeyde sağlanmazsa maalesef çok yıkıcı (inme, kalp krizi) sonuçları olan ve ölümle sonuçlanan bir hastalıktır. Bu nedenle bu hastalıkla yaşamayı öğrenmek için öz-yönetim becerilerinin arttırılması elzemdir. Evde kendi kendine kontrol sağlanması için de bilişim teknolojilerinin kullanımı büyük avantaj oluşturmaktadır. Kontrolün arttırılması, komplikasyonların azaltılmasındaki olumlu etkiler yadsınamaz düzeydedir. Ancak sağlıkta ve ekonomik şartlardaki eşitsizlikler ve sağlık bilişim okuryazarlığının düşüklüğü bazı kesimler tarafından bu uygulamaların kullanımını sınırlandırmaktadır. Ülkelerin eylem planları yaparken söz konusu eşitsizlikleri de dikkate alarak hazırlık yapması ve gerekirse mali destekle herkes için eşit sağlık sunumuyla eğitim uygulamalarına erişimin arttırılmasını sağlaması gerekmektedir.

7. SONUÇ ve ÖNERİLER

Sağlık bilişimi destekli hasta eğitim uygulamaları, hipertansiyonun yönetiminde etkili ve yenilikçi bir yaklaşımdır. Özellikle dahiliye hemşirelerinin, bu teknolojileri hasta eğitimi ve izlemlerinde aktif olarak kullanması önerilmektedir.

Öneriler:

- Hemşireler için sağlık bilişimi okuryazarlığı eğitim programları düzenlenmelidir.
- M-Sağlık uygulamaları, hastaların bireysel ihtiyaçlarına göre özelleştirilmelidir.
- Erişilebilir ve kullanıcı dostu platformlar geliştirilmeli, sosyoekonomik farklılıklar göz önünde bulundurulmalıdır.
- Uzun dönemli etkileri ölçmek amacıyla daha kapsamlı randomize çalışmalar yapılmalıdır.

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Application Areas and Some Operational Characteristics of Precision Machine Parts made of Composite Materials

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Abstract

The article describes the preparation of precision parts of machines produced in various fields of modern mechanical engineering from composite materials and the replacement of metal parts by these precision machine parts made of composite materials, their application areas, the quality requirements imposed on them, as well as some operational characteristics depending on the working and operating conditions.
Keywords*: Composite Materials, Operational Characteristics, Precision Machine Parts, Application Areas, Solid Polyvinylchloride*

INTRODUCTION

Making precision-sized parts of machines and devices produced in various fields of modern mechanical engineering from composite materials allows for reducing the volume of heavy parts. Depending on the composition and production structure of composite materials, high economic efficiency is achieved due to the increased wear resistance and increased corrosion resistance of machine parts produced, as a result of which the weight of machines made of these materials is reduced, and the volume of special materials, alloyed steels, etc. used in their production is reduced. In this regard, one of the main and most important reasons for the high durability and longevity of precision machine parts made of composite materials, which are a key component of modern mechanical engineering, is the precise investigation and characterization of the operational properties of these materials. Thus, the above characteristics should be studied for each precision machine part, mainly in accordance with the operating conditions. The rapid development of innovative scientific and technological progress and the emergence of the 4th industrial revolution have led to the replacement of some precision machine parts with precision machine parts made of composite materials, depending on the operating and maintenance conditions.(Aliyev I.Z., et al,2016).The operation of these machine parts is also of characteristic importance mainly due to their application areas. These separate operation application areas mainly cover the automobile manufacturing industry, the aviation manufacturing industry, the weapons manufacturing industry, the

oil machinery industry, the space rocket manufacturing, shipbuilding and other important fields.(Huseynov A.G.,et al. 2024).

MATERIAL AND METHODS

In the automotive industry, the body and accessories of every car manufacturer are made almost entirely of composites, and the gaskets that prevent oil leaks in car engines are made of composite materials. (Fig. 1)



Figure 1. Solid PVC composite material gasket

With the advent of composite materials, aircraft construction, although not a revolution, gave impetus to the development of a strong scientific civilization. As a result, the lightweight and low-cost nature of their construction has led to serious technological changes in the direction of innovative development in aircraft production and composites. Here, the engine covers and pylons of the aircraft, the lower parts of the fuselage, the tail section panel, the tail section arches, and the wings of the aircraft must be resistant to the friction caused by high speed.

The application of parts made of composite materials is also widely used in the oil industry. Here, a long process, starting from the stages of production and transportation of petroleum products to the storage of oil, its processing and sale of finished products, is associated with products made of composite materials. At the same time, the demand for composite materials in the geophysical research and exploration of oil and gas, drilling, and the production of modern oil and gas equipment covers a wide range.(Huseynov A.G. et al,2024). Carbon-containing polyvinyl chloride (solid PVC) composites are widely used in the oil industry. PVC has high heat resistance, high mechanical strength and corrosion resistance, as well as excellent chemical resistance. At the same time, PVC parts have hermetic and impermeable properties. (Fig. 1) There are several main advantages of using composite materials in the oil industry: Mechanical operational strength and durability, heat resistance to the most extreme temperatures and atmospheric conditions, high strength under the main types of loads, ease and speed of processing in any production conditions, light weight of products, which is important when transporting over long distances or by air, durability of storage of composite elements, environmental properties, high fire safety, etc. they have properties.

The rocket and space industry is one of the main locomotives of the development of a new generation of polymer composite materials, and composites, in turn, largely determine the direction of development of rocket technology. This knowledge-intensive industry requires more and more new types of composite materials that can withstand extreme loads. The operational characteristics of polymer composite materials in the rocket and space industry are mainly: high temperature during launch into orbit; resistance to pressure during overload; as well as vibration loads during the launch of a spacecraft into space; low temperature and deep vacuum of space; exposure to strong radiation and the impact of microparticles, etc. must provide resistance to such phenomena. Parts made of these

materials, depending on the design, allow reducing the weight of a rocket or spacecraft by up to 50% and, as a result, significantly reducing rocket fuel consumption. Machine parts made of composite materials are used in rocket engineering, space-breathing cylinders, rocket and auxiliary fuel tanks, engine housings, balloons, pressure accumulators and many more parts made of composite polymers. At the same time, rocket nose cones, engine nozzles, and other parts of spacecraft that are exposed to extreme aerodynamic loads are made from this material. The scope of application of composite materials in rocket engineering is not only wide, but also comprehensive, covering everything from engines to astronauts' space suits and space communication antennas.

Parts made of composite materials are widely used in the construction of frameless hull structures of ships from sandwiches with strong steel layers and a layer of low-density polymers in the middle. These technologies provide the shipbuilding industry with a platform for the production of high-speed, modern ships. Polymer coatings for multifunctional heat and sound insulating composites are of particular importance, mainly due to the requirements for standardization of ship fire safety and environmental friendliness. The main areas of application of parts made of composite materials in shipbuilding include: the production of heavy-duty hulls (hull elements) for ships, the production of reliable ship control elements and systems, the use of composites in the production of ship engines and engine propellers, etc.

Material

As a result of the conducted research, the following operational properties of precision machine parts made of composite materials have been determined:

wear resistance

In order to increase the wear resistance of these machine parts in the production process, their physical and mechanical properties are adjusted to the required indicators using metal-containing stabilizers.

resistance to oxidation and corrosion

Methods

In the production of these machine parts, some stabilizers are added to the composition of the composites during production to increase their resistance to oxidation and corrosion. These stabilizers mainly consist of salicylic additives and copper oxyquinolides. At the same time, there are constructive requirements imposed on these materials, which are lightness of construction, low cost, and easy transportation. (Fig.1)

DISCUSSION AND CONCLUSION

Depending on the application areas, operation and working conditions of precision machine parts made of composite materials, it is necessary to accurately investigate some operational characteristics in order to ensure high durability and longevity during operation. In this article, the characteristic features of these indicators were analyzed.

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Conflict of Interest

"The authors have declared that there is no conflict of interest".

Over Kanserinde Güncel Tedavi Yöntemleri

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Özet

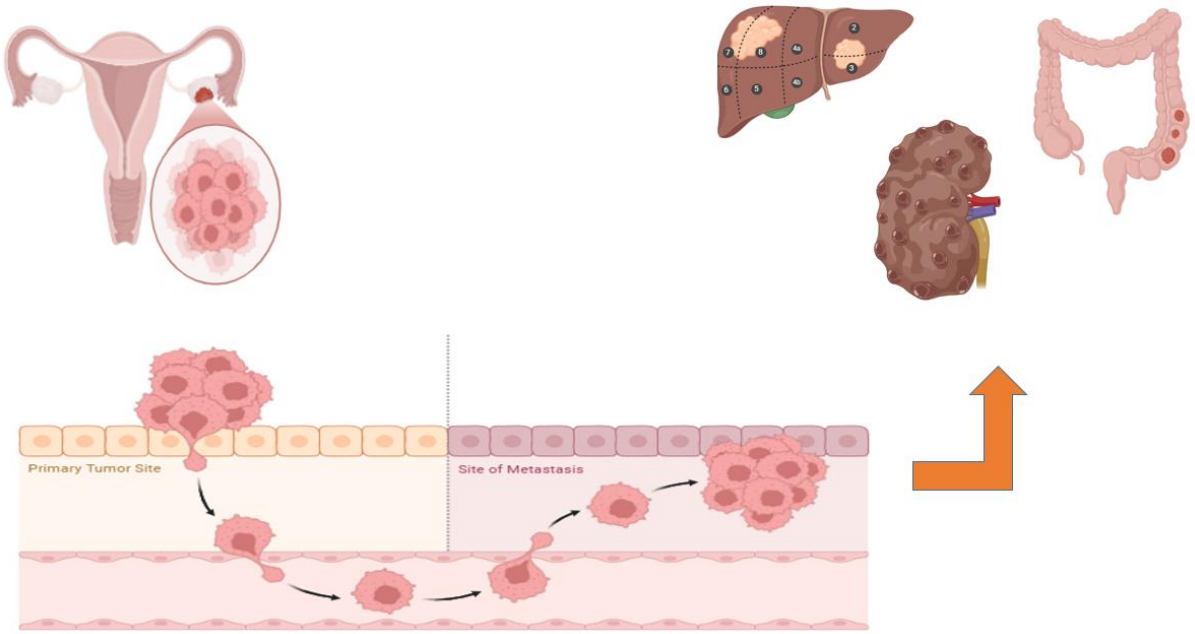
Over kanseri jinekolojik maligniteler içerisinde en ölümcül olanıdır. Yumurtalık kanseri tek bir hastalık olmamakla beraber en az beş farklı histolojik alt tipe bölünebilmekte ve tanımlanabilmektedir. Bu tipler farklı risk faktörleri, orijin hücreleri, moleküler bileşimleri, klinik özellikleri ve tedavileri olarak sıralanmaktadır. Yumurtalık kanserinin etiyolojisi net olmasa da, bu hastalığın etiyolojisinde yumurtlama, gonadotropik ve steroid hormonları, germ hücresi tükenmesi, onkogenler ve tümör baskılayıcı genler, büyüme faktörleri, sitokinler ve çevresel etkenler gibi belirli faktörler rol oynamaktadır. Yumurtalık kanseri tipik olarak geç bir aşamada teşhis edilmekte ve etkili bir tarama stratejisinin olmaması nedeniyle erken teşhis genellikle zor olmaktadır. Over kanserinde güncel tedavi yöntemlerinde cerrahi yaklaşımlar, antianjiyojenikler ve poli ADP-riboz polimeraz inhibitörleri gibi hedefli tedaviler ve geliştirilmekte olan yeni terapötik ajanlar ve kombinasyonları hakkındaki gelişen verilerle, ileri epitel over kanserinin sonunda evrensel olarak ölümcül bir hastalıktan giderek daha fazla tedavi edilebilen bir hastalığa dönüşeceği öngörülmektedir. Bu derlemede over kanserinde güncel tedavi yöntemleri, güncel literatür ışığında ele alınmıştır.

Anahtar kelimeler: *over kanseri, güncel tedavi, yöntem*

Giriş

Over kanseri jinekolojik maligniteler içinde en ölümcül olanıdır. Küresel olarak 2022 verilerine göre, 2050 yılına kadar dünya çapında yumurtalık kanseri teşhisi konulan kadın sayısı %55'ten fazla artarak 503,448'e ulaşacak. Her yıl yumurtalık kanserinden ölen kadın sayısının 2022'ye göre yaklaşık %70 artarak 350.956'ya çıkması öngörülüyor (World Ovarian Cancer Coalition, 2022). Güncel tedavi yöntemlerinin olmasına rağmen evre III veya IV hastalık teşhisi konan kadınlar için 5 yıllık sağ kalım oranı <%25'tir. Bu hastaların > %80'i başlangıçta tedaviye yanıt vermektedir (Afşin & Kamalak, 2022). ABD Gözetim Epidemiyoloji ve son sonuçlar neticesinde yumurtalık kanseri olan tüm hastalar için genel sağ kalımın oranı %45,6 olduğunu bildirmektedir. Ancak bu ilk tanıdaki evreye göre büyük ölçüde değişmektedir. Evre I kanseri olan hastalarda 5 yıllık genel sağ kalım %92,1 iken, evre III ve evre IV kanseri olan hastalarda %25'tir (Afşin & Kamalak, 2022).

Yumurtalık kanseri tek bir hastalık olmamakla beraber en az beş farklı histolojik alt tipe bölünebilmekte ve tanımlanabilmektedir. Bu tipler farklı risk faktörleri, orijin hücreleri, moleküler bileşimleri, klinik özellikleri ve tedavileri olarak sıralanmaktadır. Yumurtalık kanseri tipik olarak geç bir aşamada teşhis edilmekte ve etkili bir tarama stratejisinin olmaması nedeniyle erken teşhis genellikle zor olmaktadır.



Şekil 2: Yumurtalık karsinogenezinde metastaz.

Yaş, üreme geçmişi, değiştirilebilir yaşam tarzı faktörleri, aile geçmişi ve genetik mutasyonlar dahil olmak üzere çeşitli yumurtalık kanseri risk faktörleri tanımlanmıştır (Collaborative Group on Epidemiological Studies of Ovarian Cancer, 2008 ; Barry ve ark ., 2014 ; Collaborative Group on Epidemiological Studies of Ovarian Cancer, 2012 ; Pennington & Swisher, 2012). Yumurtalık kanseri hücreleri büyüme ve göç için enerji kaynağı olarak yağ hücrelerini kullanmaktadır (Nieman ve ark., 2011). Ancak obezite, tip II DM ve metabolik sendrom gibi değiştirilebilir yaşam tarzı faktörlerinin etkisiyle metabolik bozuklukların yaygınlığı dünyanın birçok yerinde önemli ölçüde artmıştır. Son raporlar, bu durumların her biri ile yumurtalık kanseri arasında bir ilişki olduğunu göstermektedir (Siegel ve ark ., 2018 ; Protani ve ark ., 2012 ; Shah ve ark ., 2014 ; Lauby-Secretan ve ark ., 2016).

Obezite dünya çapında salgın haline gelmiş ve kadınlarda görülme sıklığı son yıllarda giderek artmaktadır (NCD-RisC, 2016). Son araştırmalar BKİ artışı ile over kanseri riskinin artması arasında bir ilişki olduğunu bildirmişlerdir (Collaborative Group on Epidemiological Studies of Ovarian Cancer, 2008 ; Olsen ve ark ., 2013) ve obezitenin over kanseri olan kadınların sağ kalımı üzerindeki olumsuz etkilerini bildirmiştir (Protani ve ark ., 2012 ; Bae ve ark ., 2014 ; Yang ve ark., 2011). Önceki çalışmalar DM ile yumurtalık kanseri olan kadınlarda daha kötü kanser sonuçları ve daha kısa sağ kalım arasındaki ilişkiyi göstermiştir (Shah ve ark ., 2014 ; Bakhru ve ark ., 2011). Ayrıca, 2022'de yapılan bir meta-analizin sonuçları aşırı kilolu kadınlarda yumurtalık kanseri riskinin normal kilolu kadınlara kıyasla daha fazla olduğu görülmüştür (Huang et al. 2022).

Literatür incelediğinde, Poole ve ark . (2016) tarafından yapılan çalışmada, değiştirilebilir yaşam tarzı faktörlerinden biri olan tanı öncesi BKİ'nin yumurtalık kanseri hastalarının sağ kalımını etkileyebileceği ve tanı öncesi düşük BKİ'nin daha iyi bir prognoz ile ilişkili olabileceği öne sürülmüştür. Yine, Bae ve ark. (2014) tarafından yürütülen kapsamlı bir meta-analizde, tanı anında obezite ile yumurtalık kanseri hastalarının sağ kalımı arasındaki bağlantının belirsizliğine rağmen, yumurtalık kanseri tanısından beş yıl önce obezite ve genç yaşta obezitenin kötü prognozla ilişkili olduğu bildirilmiştir.

Over Kanserinde Risk faktörleri

Yumurtalık kanseri, kadınlarda en sık görülen beşinci kanser türüdür ve Kuzey Amerika'da jinekolojik kanser ölümlerinin önde gelen nedenidir (Momenimovahed ve ark, 2019). Yumurtalık kanserinin etiyolojisi net olmasa da, bu hastalığın etiyolojisinde yumurtlama, gonadotropik ve steroid hormonları, germ hücresi tükenmesi, onkogenler ve tümör baskılayıcı genler, büyüme faktörleri, sitokinler ve çevresel etkenler gibi belirli faktörler rol oynamaktadır. Meme veya yumurtalık kanseri aile öyküsü, yumurtalık kanseri için belirgin bir risk faktörüdür ve yumurtalık kanserlerinin %5-10'u kalıtsal riske bağlıdır (Yoshida., 2021). Menopoz yaşı ve infertilite gibi üreme faktörleri yumurtalık kanseri riskini artırırken, gebelik, tüp ligasyonu ve histerektomi riski azaltmaktadır (Ali et al., 2023). Epidemiyolojik çalışmalar hormon replasman tedavisinin (HRT) yumurtalık kanseri için daha büyük bir risk faktörü olduğunu bulmuştur (Xiang ve ark., 2024). Hormonların ve üreme faktörlerinin yumurtalık kanseri üzerindeki belirgin etkisi, endokrin bozucuların riski etkileyebileceğini düşündürmektedir (Amir et al., 2021). Sigara içme, obezite ve diyet gibi yaşam tarzı faktörleri yumurtalık kanseri riskini etkileyebilir. Talk, pestisitler ve herbisitler gibi belirli çevresel etkenlere maruz kalma yumurtalık kanseri riskini artırabilmektedir (Shankar ve ark., 2020).

Germline BRCA1 ve BRCA2 mutasyonları yumurtalık kanseri için bilinen en önemli genetik risk faktörleri olup her iki mutasyon da hastaların %21,15'ine varan oranda bulunduğu bildirilmiştir (Ashour et al., 2019). Bunun yanı sıra BRCA1 mutantlı yüksek dereceli seröz over karsinomu hücrelerinde DYNLL1'in silinmesinin kemoterapi direncinde artışa neden olduğu bildirilmiştir (Berkel & Cacan, 2020). Epitelyal yumurtalık kanserinin çoğu alt tipi germ hattı BRCA mutasyonları ile ilişkili olduğu görülmektedir. Ancak HGSC'ler en yaygın olarak kabul edilmekte olup müsinözün alt tipleri ile nadiren ilişkilidir. Yumurtalık kanseri olan ancak BRCA1 ve BRCA2 için en şiddetli tip olan kadınlara kıyasla germ hattı BRCA mutasyonları taşıyan yumurtalık kanserli kadınlar için tedaviye yanıt verdiği saptanmıştır (Liu et al., 2020). Germline BRCA2 mutasyonlar, germline BRCA1 mutasyonlarına kıyasla sağ kalım oranının daha yüksek olduğu bildirilmiştir. BRCA2 gelişmiş platin duyarlılığına ve dolayısıyla kanser hücrelerinin BRCA1'den daha fazla öldürülmesine neden olmasından kaynaklandığı bulunmuştur (Mylavarapu et al., 2018). Hem BRCA mutasyonunun gen içindeki konumu hem de mutasyonun tipi de yumurtalık kanseri gelişme riskini etkileyebilmektedir. Meme kanseri veya yumurtalık kanserinin oluşma riski teşhis anında yaşı ve germ hattı BRCA1 veya BRCA2 mutasyonları olan hastalarda mutasyon tipine göre değişiklik gösteren nükleotid pozisyonu ve mutasyonun fonksiyonel sonucuna göre değişmektedir (Pourmasoumi et al., 2024).

Oral kontraseptif kullanımının germline BRCA1 mutasyonu olan bireylerde olduğu kadar genetik yatkınlığı olmayanlarda da yumurtalık kanseri gelişme riskini azalttığı gösterilmiştir (Schrijver et al., 2021). Bir meta-analiz ortalama 5 yıl boyunca oral kontraseptif kullanımıyla yumurtalık kanseri için yaşam boyu %0,54'lük bir azalma olduğunu göstermektedir (Van Bommel et al., 2023). Oral kontraseptiflerdeki göreli östrojen ve progestin dozları yumurtalık kanseri insidansını etkilememektedir. Ancak daha uzun süreli oral kontraseptif kullanımı düşük risk ile ilişkili olduğunu söylenebilmektedir (Barsky et al., 2021). Hormon replasman tedavisinin menopoz sonrası kadınlarda yumurtalık kanseri gelişme riskini arttırdığı gösterilmiştir. Sadece östrojen tedavisi riski %22 artırdı ve kombine östrojen ve progesteron tedavisi riski %10 artırdığı ortaya koyulmuştur (Graham, et al., 2022). Bir meta-analiz hormon replasman tedavisi kullanan menopozdaki kadınlarda tedavinin yalnızca östrojen veya östrojen ve progesteron kombinasyonu içermesine bakılmaksızın yumurtalık kanseri özellikle seröz ve endometrioid karsinomlar geliştirme riskinde benzer bir artış göstermiştir (Tempfer et al., 2020).

Doğum yapmış kadınların yumurtalık kanserinin tüm alt tiplerine yakalanma riskleri doğum yapmamış kadınlara kıyasla daha düşüktür. Tek taraflı ooferektomi histolojik alt tipe özgü olmayan

yumurtalık kanseri riskinde %30'luk bir azalma ile ilişkili olduğu bildirilmiştir (Afşin & Kamalak, 2022). Tüp ligasyonu ve histerektomi ayrıca yumurtalık kanseri gelişme riskinde bir azalma ile ilişkilidir. Bir çalışmada, tüp ligasyonu, ≥2 oranında endometriozis ve daha genç yaş gibi üreme risk faktörleri ile baskın yumurtalık tümörlerinin gelişimi daha güçlü bir şekilde ilişkili olduğu saptanmıştır (Huang, et al., 2020). Germ hattı BRCA mutasyonları olan kadınlarda tüp ligasyonu ve emzirme benzer şekilde yumurtalık kanseri riskinin azalmasıyla ilişkili risk faktörleri olarak tanımlanmıştır (Afşin & Kamalak, 2022).

Over Kanserinde Tedavi Yöntemleri

Over Kanserinde Cerrahi Tedavi Yaklaşımları

Over kanseri, kadınlarda jinekolojik kanserler arasında en ölümcül olanlardan biridir. Cerrahi tedavi, bu kanserin yönetiminde temel taşıdır ve hastalığın evresine, tümör yayılımına, hastanın genel sağlık durumuna ve fertilite isteğine göre değişen yöntemler içerir (Taveres et al., 2021).

Erken Evre Over Kanseri

Erken evre hastalarda temel hedef, doğru evreleme ve tümörün tam olarak çıkarılmasıdır. Standart prosedür, total abdominal histerektomi, bilateral salpingo-ooforektomi ve omentektomiyi içerir. Bunun yanında, pelvik ve paraaortik lenf nodu diseksiyonu yapılması önerilir. Fertilite koruma talebi olan genç hastalarda, tek taraflı salpingo-ooforektomi ve evreleme cerrahisi düşünülebilir, ancak bu durum dikkatlice değerlendirilmelidir (Brydges et al., 2020).

İleri Evre Over Kanseri

İleri evrelerde, sitoredüktif cerrahi ("debulking") temel tedavidir. Amaç, makroskopik tümör dokusunu tamamen ortadan kaldırarak kemoterapinin etkinliğini artırmaktır. Sitoredüktif cerrahinin başarısı, deneyimli cerrahi ekiplerin olduğu merkezlerde daha yüksek olmaktadır. Gerekirse diyafragmatik stripping, bağırsak rezeksiyonları ve peritonektomi gibi agresif cerrahiler uygulanabilir (Hishida et al., 2021).

Cerrahi Tekniklerde Yenilikler ve Yaklaşımlar

Laparoskopik Cerrahi*:* Özellikle erken evrede yeterli tecrübeye sahip merkezlerde minimal invaziv cerrahi önerilmektedir. Bu yöntem daha hızlı iyileşme ve daha az komplikasyon sunar (Madhok et al., 2022).

Frozen Section Analizi*:* Operasyon sırasında malignite şüphesini doğrulamak için kullanılan bu yöntem, cerrahi prosedürün yönlendirilmesine olanak tanır (Garcia et al., 2021).

Fertilite Koruyucu Cerrahi: Fertilite isteği olan hastalarda, düşük dereceli tümörlerde ve erken evrelerde fertilite koruyucu cerrahi bir seçenektir. Ancak bu yaklaşım, hastanın uzun dönem sağkalımına yönelik riskleri de beraberinde getirebilir ve kararlar multidisipliner bir ekip tarafından dikkatlice verilmelidir (Nitecki et al., 2020).

Cerrahinin Rolü: Neoadjuvan Kemoterapi ve Interval Cerrahi

İleri evre vakalarda, önce neoadjuvan kemoterapi uygulanarak tümör boyutunun küçültülmesi sağlanabilir ve ardından interval sitoredüktif cerrahi yapılabilir. Bu yaklaşım, komplikasyonları azaltabilir ve cerrahinin etkinliğini artırabilir (Lyons et al., 2020).

Komplikasyonlar ve Yönetimi

Cerrahi müdahaleler sonrası en sık karşılaşılan komplikasyonlar arasında enfeksiyon, kanama, bağırsak hasarı ve lenfödem yer alır. Özellikle agresif cerrahi girişimler, deneyimli merkezlerde yapılmalıdır (Escandón et al., 2022).

Kemoterapinin Rolü ve Kullanımı

Kemoterapi, over kanserinde çoğunlukla platin bazlı ajanlarla uygulanır. İlk basamak tedavide cerrahi sonrası (adjuvan kemoterapi) veya cerrahi öncesi (neoadjuvan kemoterapi) olarak kullanılabilir. İleri evre hastalıkta, sitoredüktif cerrahiden sonra standart kemoterapi rejimi şunları içerir (González-Martín et al., 2023).

Tablo 1: Kemoterapi ilaçları guruplandırılması ve etki mekanizması

İlaç Grubu	İlaçlar	Etki Mekanizması
Platin Türevleri	*Sisplatin, Karboplatin*	DNA zincirinde çapraz bağlar oluşur.
Takzanlar	*Paklitaksel, Dosetaksel*	Mikrotübülizasyon stabilizasyonunu bozarak hücre bozukluklarını engeller.
Antimetabolitler	*Gemsitabin*	DNA sentezini sağlar.
Topoizomeraz İnhibitörleri	*Topotekan, Etoposid*	DNA topoizomeraz enzimini inhibe eder.
Alkilleyici Ajanlar	*Siklofosfamid, İfosfamid*	DNA'ya alkillerin birleştirilmesiyle hücre ölümüne neden olur.
PARP İnhibitörleri	*Olaparib, Niraparib, Rucaparib*	DNA tamir oranlarını engeller.
Antrasiklinler	*Doksorubisin, Lipozomal Doksorubisin (Doxil)*	DNA ve RNA sentezini inhibe eder.
Vasküler Hedefli Ajanlar	*Bevasizumab*	VEGF'yi inhibe ederek tümör anjiyogenezini durdurur.

Tedavi Protokolleri

Standart İlk Basamak Kemoterapi*:*

Karboplatin ve paklitaksel kombinasyonu 3 haftada bir uygulanır. Tedavi genellikle 6 kür üzerinden planlanır (Yu, et al., 2020).

Nüks ve Dirençli Hastalıkta Kemoterapi*:*

Platin-duyarlı hastalarda platin bazlı tedaviye devam edilir. Platin-refrakter veya dirençli hastalarda liposomal doksorubisin, topotekan veya gemcitabin gibi ajanlar tercih edilir (LaCasce, 2019).

Hedefe Yönelik Tedaviler ve Kemoterapi

Son yıllarda, kemoterapiye ek olarak hedefe yönelik tedaviler de over kanseri tedavisinde kullanılmaktadır. Örneğin:

PARP inhibitörleri*:* Özellikle BRCA1/2 mutasyonu taşıyan hastalarda platin bazlı kemoterapi ile birlikte veya sonrasında kullanılır. *Somatik veya germ hattı BRCA* mutasyonu veya HRD'si olan over kanseri hastalarında birinci basamak platin bazlı tedaviye yanıttan sonra PARP inhibitörünün idamesi artık standart bakım olarak kabul edilmektedir. PARP inhibitörleri, miyelodisplastik sendrom

(MDS) ve akut miyeloid lösemi (AML) dahil olmak üzere terapiyle ilişkili miyeloid neoplazi riskinin artmasıyla ilişkilidir. Hastalar, uzun süreli PARP inhibitörü tedavisi (2 yıldan fazla), önceden yoğun platin maruziyeti öyküsü ve *BRCA* mutasyon taşıyıcılarıysa hematopoietik maligniteler geliştirme açısından artmış risk altındadır. PARP inhibitörleriyle tedavi edilen hastalar, ilacın kesilmesinden sonra bile terapiyle ilişkili miyeloid neoplazi açısından sürekli izleme gerektirir. Bu nadir ancak ölümcül yan etki göz önüne alındığında, PARP inhibitörlerinden fayda görme olasılığı en yüksek hastaları daha iyi belirlemek ve AML/MDS geliştirme riski en yüksek olanları belirlemek için odaklanmış çabalar olmuştur (Moufarrij et al., 2023).

Anti-anjiyojenik tedaviler: Bevacizumab gibi ajanlar tümörün kan damarlarını hedef alır (Secord et al., 2021). Over kanserinde kemoterapi, özellikle platin bazlı ajanlar ve taxanların kombinasyonu, tedavinin temel taşıdır. Günümüzde hedefe yönelik tedavilerin kemoterapiye entegrasyonu, hastaların yaşam süresini ve kalitesini artırmıştır. Erken tanı yöntemlerinin geliştirilmesi ve yeni tedavi yaklaşımlarının araştırılması, over kanseri tedavisindeki başarı oranını daha da yükseltebilir (Tavares et al., 2024).

Over Kanserinde Radyoterapinin Rolü

Radyoterapi, over kanserinde 20. yüzyılın ortalarında sıkça kullanılmıştır. Ancak, ileri evre hastalıklarda etkisinin sınırlı olduğu anlaşılmış ve genellikle kemoterapinin gelişimi ile birincil tedavi modalitesi olarak geri planda kalmıştır. Modern radyoterapi teknikleri, bu yöntemi tekrar gündeme getirmiştir (Akhtaruzzaman, 2019).

Adjuvan Tedavi:
Radyoterapi, nadiren adjuvan tedavi olarak kullanılır. Özellikle erken evre, düşük dereceli tümörlerde cerrahi sonrası rezidüel hastalık riski yüksek olan durumlarda tercih edilebilir (Kris et al., 2017).

Lokal Rekürrens:
Radyoterapi, pelvis içindeki lokal nükslerde kontrol sağlamak için kullanılabilir. Cerrahi uygulanamayan veya kemoterapiye dirençli hastalarda bir seçenektir (Baumann et al., 2021).

Palyatif Amaçlı Kullanım:
Semptomları hafifletmek amacıyla, özellikle ağrı, kanama veya bağırsak tıkanıklığı gibi komplikasyonlarda radyoterapi uygulanabilir (Flores et al., 2020).

Modern radyoterapi yöntemleri, çevre dokuların korunmasını sağlayarak tedavinin etkinliğini artırmıştır. Bu yöntemler arasında şunlar yer alır:

Yoğunluk Ayarlı Radyoterapi (IMRT): Tümör üzerine yüksek doz verirken çevre sağlıklı dokulara daha düşük dozların verilmesini sağlar.

Stereotaktik Vücut Radyoterapisi (SBRT): Özellikle küçük ve sınırlı metastazların tedavisinde etkili bir seçenektir.

Brachytherapy (İç Radyoterapi): Tümör yatağına lokal yüksek doz radyasyon uygulayarak yan etkileri minimize eder (Griffin et al, 2020).

Radyoterapinin lokal kontrol oranları seçilen hastalarda tatmin edici düzeyde olabilir. Ancak, pelvis içinde çevre dokuların radyasyondan etkilenmesi gastrointestinal ve üriner sistem yan etkilerine neden olabilmekte olup modern tekniklerle bu yan etkiler azaltılmıştır (Hendrickx et al., 2020).

Radyoterapi, over kanseri tedavisinde sınırlı ancak stratejik bir role sahiptir. Özellikle nüks ve palyatif tedavide etkili bir seçenek olarak kullanılabilir. Teknolojik gelişmeler, bu yöntemin güvenliğini ve etkinliğini artırmaktadır. Gelecekte, radyoterapinin biyolojik belirteçlere dayalı olarak daha kişiselleştirilmiş bir şekilde kullanılması beklenmektedir (Dercle et al., 2021).

Over Kanseri İmmünoterapisinin Güncel Durumu

Çoğu yumurtalık kanseri immünoterapi tedavi yöntemi şu anda klinik çalışmalarda test edilmektedir. Yumurtalık kanserinde adaptif bağışıklık, ağırlıklı olarak aşılama yoluyla, yumurtalık kanserinin dendritik hücre (DC) aracılı sunumunu artırmak için hızla genişlemektedir (Caro et al., 2022). Sitotoksik T lenfositler (CTL'ler), tümörle ilişkili antijenleri (TAA'lar) ve özellikle neoantijenleri tanıdıktan sonra aktive olurlar (Andersen, 2023). Yumurtalık kanseri tümör hücreleri genellikle tümördeki inhibe edici sinyaller yoluyla CTL'ler tarafından yok edilmekten kaçınır. Mucin 16, α-folat reseptörü ve mezotelin, yumurtalık kanseri için kimerik antijen reseptörü T (CAR-T) hücre terapilerinin genetik modifikasyonunun spesifik hedefleri olarak araştırılmaktadır. Genetik mühendisliğinden yararlanan onkolitik viral tedavi, tümör hücrelerini seçici olarak enfekte eden ve tümör hücresi lizisine yol açan virüsler oluşturmak için de kullanılmaktadır (Tian et al., 2022).

Epitelyal over kanserinde immünoterapötik stratejiler, son yirmi yıldır büyük ölçüde tümör antijenleri ve antikor yanıtları hakkındaki bilgideki önemli ilerlemeler ve kanser aşıları, lenfosit transferi ve immünomodülatör tedavi alanlarındaki ilerlemeler nedeniyle artan bir ilgi alanı olmuştur. Artık over kanserlerinin immünojenik tümörler olduğuna yaygın olarak inanılmaktadır. Over karsinomlarında anti-tümör bağışıklık yanıtlarının ilerlemesinde büyük bir basamak, tümör infiltre eden lenfositlerin (TIL'ler) karakterizasyonu olmuştur. İleri evre over karsinomu olan hastalarda TIL'lerin varlığı ile uzun süreli progresyonsuz (PFS) ve genel (OS) sağkalım arasındaki korelasyon gösterilmiştir (Hudry et al., 2022). TIL'lerin prognostik değerinin hastalığın evresi veya derecesinden bağımsız olarak tüm popülasyonlarda devam ettiği gösterilmiştir (Oble et al., 2009). Özellikle CD8+ TIL'lerin varlığının sağ kalımın artmasıyla ilişkili olduğu gösterilmiştir (Li et al., 2021). CD8+ TIL'ler prognoz için üstün bir belirteçtir, çünkü bunların varlığı over karsinomunun tüm evreleri ve histolojileri ile ilişkilidir, CD3+ T hücreleri ise yalnızca seröz over karsinomlarında prognostik önem göstermektedir (Vihervuori et al., 2019). Daha fazla CD8+ T hücresine sahip hastaların tümör küçültme işleminden bağımsız olarak daha uzun bir sağ kalım gösterdiğini, düşük CD8+ T hücresine sahip hastaların ise optimum şekilde küçültme işlemi yapıldığında, optimum olmayan küçültme işlemi uygulanan hastalara kıyasla önemli ölçüde daha iyi bir prognoza sahip olduğunu bildirmiştir (Bansal et al., 2021). Bu çalışmalar, gelecekte bireyin bağışıklık proliferasyonuna dayalı kişiselleştirilmiş tedavinin sonuçları değiştirebileceği yönünde ortaya çıkan bir fikir birliğinin oluşmasına neden olmuştur.

Buna karşılık, CD4+/CD25+/FoxP3+ T hücreleri olarak sınıflandırılan immünosüpresif düzenleyici T hücrelerinin (Treg'ler) varlığı, over karsinomunda sağ kalımın azalmasıyla ilişkilendirilmiştir (Hariyanto et al., 2022). İleri evre over kanseri olan hastalarda immünosüpresif TGF-β salgılayan CD4+CD25+ tümör ilişkili Treg hücrelerinin oranlarının arttığını gösteren ilk kişiler arasındaydı (Cassar et al., 2022). Treg'lerin in vitro nonspesifik T hücre aktivasyonunu inhibe ettiği ve endojen tümör ilişkili antijen (TAA) spesifik T hücre bağışıklığını baskıladığı bulunmuştur (Dong, et al., 2024). Yumurtalık kanserlerinde Treg'lerin varlığı ile hasta sağkalımı arasında ters bir korelasyon olduğunu göstermiştir (Li et al,.2023). Düşük CD8+/Treg oranlarına sahip hastalarda sağ kalımın azaldığını, yüksek CD8+/Treg oranlarının ise sağ kalımın artmasıyla ilişkili olduğunu daha da göstermiştir (Niederlova et al., 2021).

Ayrıca, over kanserleri tümör antijenlerini eksprese eder ve hastalar bu antijenlere özgü kendiliğinden anti-tümör yanıtları gösterirler (Yang et al., 2020). Yumurtalık kanserinde çeşitli aşılama stratejileri için potansiyeli olan bir dizi potansiyel tümör antijeni tanımlanmıştır (Tanyi et al., 2018). Bu antijenler, tümör ilişkili antijenler (TAA'lar) ve evrensel tümör antijenleri olarak ayrı ayrı sınıflandırılır. TAA'lar sitoredüktif cerrahi sırasında toplanan asitlerden veya tüm tümörden izole edilebilir. TAA'lar bir hastaya ve tümöre özgü olabilse de, genellikle normal hücreler tarafından da ifade edilir ve bu da kullanımları için sınırlamalar yaratır. Şu anda yumurtalık kanseriyle ilişkili birkaç TAA tanımlanmıştır ve bunlar arasında HER2/neu, p53, CA125, STn, FR-α, mezotelin, NY-ESO-1 ve cdr-2 bulunur. hTERT ve survivin dahil olmak üzere evrensel tümör antijenleri, çeşitli tümörlerde ifade edilenlerdir ve çoğu normal insan hücresinde bulunmazlar. Tümör antijenine özgü anti-tümör yanıtlarını güçlendiren immünoterapötik rejimler, hem tekrarlayan hem de mikroskobik rezidüel hastalığı olan kadınların tedavisinde büyük potansiyele sahiptir (Terlikowska et al., 2021).

Over kanseri tümörleri için altın standart yaklaşım hala karboplatin ve paklitaksel ile sitoredüktif cerrahinin bir kombinasyonudur. Ancak, yumurtalık kanserinin immünojenitesi gelecekteki tedaviler için büyük bir umut vaat etmektedir.

İnhibitör ve Modülatör

İmmün kontrol noktası inhibitörlerine karşı tümör yanıtlarını tahmin etmeye yardımcı olan önemli faktörler, efektör immün hücre kullanılabilirliği, ulaşılabilirlik ve tümörün immün kontrol noktası yollarına bağımlılığıdır (Park et al., 2018). TIL'ler ve PD-L1, inhibitörlere karşı immün yanıtı tahmin etmek için belirteçler olarak tanımlanmıştır. Bu belirteçler kullanılarak, gelişmiş SOC'lerin %50'sinden fazlasının adaptif immün direnç yoluyla immün kontrol noktası inhibitörlerine yanıt olarak hareket ettiği tahmin edilmektedir. Düşük dereceli SOC'lerde neredeyse yoktur, diğer patolojik tip kanserlerde daha düşüktür (Azzalini et al., 2023). Şu anda, birkaç immün kontrol noktası inhibitörü hayvan çalışmalarında test edilmektedir (Chen et al., 2021).

Mevcut tüm inhibitörlerin kullanıldığı klinik çalışmalardan elde edilen ön veriler, %15 objektif yanıt oranı (ORR) ile OC'de sınırlı etkinlik ortaya koymaktadır. Bu nedenle, bağışıklık kontrol noktası inhibitörleri için daha fazla biyobelirteç belirlemek için gelecekteki çalışmalara ihtiyaç duyulmaktadır. Olaparib (Poli ADP riboz polimeraz [PARP] inhibitörü) ve durvalumab (anti-PD-L1) için bir faz I çalışması için %83 hastalık kontrol oranı ile %17 ORR bildirilmiştir (Borella et al., 2020).

Evlat Edinici Hücre Terapisi-Evlat Edinici T Hücre Transferi

Periferik kan lenfositleri (PBL'ler) hastaların kanından ayrılır ve tümöre özgü lenfositlerin izolasyonu için kullanılır. Tümöre özgü PBL'ler hastaya geri beslemek için büyütülür. PBL'lerin kanser karşıtı etkisi genetik modifikasyonla da artırılabilir (Fang et al., 2022). OK için ACT'nin klinik denemeleri devam etmektedir. ACT, metastatik melanomda üç yıldan uzun süren yaklaşık %72 reaksiyon oranı göstermiştir. Bu, OK terapisinde Adoptif hücresel terapi (ACT) için koşulların optimize edilmesiyle OK terapisine çevrilebilecek çok ümit verici bir sonuçtur (Sarivalasis et al., 2021).

CAR-T-Kimerik Antijen Reseptörü T

ACT denemelerinin başlangıç aşamalarındaki en büyük sınırlama, işlevsel kansere yanıt veren T hücrelerinin izolasyonu ve kültürlenmesine duyulan ihtiyaçtı. Tasarlanmış T hücrelerinin ortaya çıkışı, kanser bağışıklık tedavisini geliştirmek için umut verici bir araç haline geldi (Alvi et al., 2019). T hücresi ve CAR'ların hasta reseptörleri kullanılarak tümöre özgü hedefleme elde edilebilir. Majör histokompatibilite kompleksinde (MHC) tümör tanınması CAR-T hücreleri tarafından sağlanabilir. T hücresi uyarımı ve antijen özelliklerinin seçiciliği tek bir kombinasyon molekülünde birleştirilmiştir

(Akatsuka, 2020). CAR-T terapötik etkinliğinin OC'de hala iyileştirilmesi gerekiyor. Bu sorunların üstesinden gelmek için kombinasyon tedavi modaliteleri yeni bir yaklaşım olabilir. Bağışıklık kontrol noktası inhibitörlerini CAR-T hücreleriyle birleştirmek, OC için daha iyi bir terapötik seçenektir (Al-Haideri et al., 2022).

Over Kanseri Tedavisinde Kullanılan 11 Aşı

Kanser tedavisinde kullanılan aşılar, kanserli hücrelerin ortadan kaldırılması için bağışıklık hücrelerini aktive edecektir. Spesifik tümör ilişkili antijenler (TAA'lar) çeşitli yöntemler kullanılarak uygulanır. Kanser aşısı olarak test edilen yaygın aşıların bazıları çeşitli yöntemler, epigenetik ve genetik kullanılarak geliştirilir. Aşılar, sitokinler veya diğer hızlandırıcı faktörlerle birlikte uygulanır (Aly, 2012).

CA125, p53 proteini, folat reseptörü-alfa (FRα), insan epidermal büyüme faktörü reseptörü-2 (HER2) ve melanomla ilişkili antijen A4 (MAGE-A4) ve New York-özofageal skuamöz hücreli karsinom11 (NY-ESO-1) gibi kanser testis antijenleri, OK'de bulunan potansiyel TAA moleküllerididir (Chandra et al., 2019). Kanser Aşısı terapötik araştırması OK araştırmalarında aktif olarak büyüyen bir alandır. Şu anda, OK'de terapötik aşıların kullanımıyla ilgili çoğunlukla pilot ve faz I veya II çalışmalar bulunmaktadır (Chow, 2020).

OC'deki aşırı ekspresyonu nedeniyle hedefli aşı için potansiyel bir molekül olan NY-ESO-1, T hücrelerine özgü uyarılmış bağışıklık tepkisi gösterdi. Tekrarlayan hastalığı olan hastalarda terapötik etkinliğin artırılması için NY-ESO-1'in DNA metilasyon inhibitörleri ve kemoterapi ile kombinasyon tedavisi uygulandı (Alsalloum et al., 2024). Bu, OC hastalarında klinik yanıta yol açan NY-ESO-1 antikor bulunabilirliğini ve T hücresi yanıtlarını artırır.

Tümör hücre aşıları, spesifik TAA'ya kıyasla daha geniş bir antijen yelpazesi için immünolojik reaksiyona neden olmaktadır. T hücreleriyle daha geniş reaksiyon, tüm aşı kullanılarak da tetiklenebilmektedir. Aşı tedavisinde bir diğer önemli yol, insan lökosit antijeni ve IgG ifadelerine bağlı olarak bireysel tümörden geliştirilen kişiselleştirilmiş peptit aşılarıdır (Hu et al., 2018). Klinik araştırmalar, Pt'ye duyarlı kanserli hastaların 39,3 ay genel sağ kalım oranına sahip olduğunu göstermiştir.

Başka bir yeni tedavi yöntemi, kanser hücrelerini tümöre virüsleri iletmek için hastadan kullanmanın araştırılmasıdır. Tümör mikroçevresi, kanser hücrelerini virüs taşıyıcıları olarak kullanarak manipüle edilebilir. "Soğuk" bir kanseri "sıcak" bir kansere dönüştürmek, kanser karşıtı reaksiyonu güçlendirir. Bu, suboptimal immün infiltrasyon nedeniyle mevcut tedavilerden fayda görmeyen OC hastaları için umut vadeden bir stratejidir (Fucikova et al., 2021).

Sonuç

Over kanseri, jinekolojik maligniteler arasında hem insidansı hem de mortalitesi yüksek bir hastalıktır. Son yıllarda, moleküler biyoloji ve genetik alanındaki gelişmeler sayesinde over kanseri tedavisinde önemli ilerlemeler kaydedilmiştir. Özellikle hedefe yönelik tedaviler ve immünoterapiler, standart cerrahi ve kemoterapilere ek olarak umut verici seçenekler sunmaktadır. PARP inhibitörleri, BRCA mutasyonu taşıyan hastalarda progresyonsuz sağkalımı artırmada önemli bir rol oynamıştır. Anti-anjiyogenik ajanlar, tümör büyümesini baskılayarak tedavi başarısını artırmaktadır. PD-1/PD-L1 inhibitörleri ve kanser aşıları gibi immünoterapiler, over kanseri tedavisinde immün yanıtı güçlendirerek yeni bir çığır açmaktadır. Bununla birlikte, bu tedavilerin etkinliği ve optimal kullanım stratejileri hâlen araştırma aşamasındadır. Cerrahi ve kemoterapi ile hedefe yönelik ajanların veya immünoterapilerin kombinasyonu, tedavi etkinliğini artırma potansiyeli taşımaktadır. Bu yaklaşımların kişiselleştirilmiş

tedavi stratejileri ile birleştirilmesi, hastaların yaşam sürelerini ve yaşam kalitesini iyileştirme fırsatı sunmaktadır. Gelecekte, genomik ve proteomik teknolojilerle bireysel tümör profillemesinin yaygınlaşması, over kanserinde tedavinin daha da kişiselleştirilmesine olanak tanıyacaktır. Bununla birlikte, bu yeniliklerin geniş kitlelere erişebilmesi için ekonomik ve lojistik zorlukların da çözülmesi gerekmektedir. Sonuç olarak, over kanseri tedavisindeki gelişmeler umut verici olmakla birlikte, multidisipliner bir yaklaşım ve hasta merkezli uygulamalarla bu ilerlemelerin daha geniş bir hasta kitlesine fayda sağlaması hedeflenmelidir.

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Developing human-machine collaboration in future aviation systems and Technologies

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Abstract

This paper focuses on showcasing the emerging technologies related to AI human-machine collaboration in both civilian and military aviation applications. This is necessary due to the congestion of our airspaces, so we will discuss many aspects of human-machine collaboration including air traffic management. First, the problem of congested airspaces due to drones and urban air mobility and the approaches to how it could be solved in the future. As well as the use of Artificial copilots in civil aviation and military applications alike with the necessary support infrastructure. Furthermore, we will delve deeper into the workings of AI and automation, including the questions trustworthiness and responsibility. Finally, the necessary steps to take and consider in order to make this future a reality.

Key words: *Human-machine collaboration, Automation, Urban air mobility, Airspace design, Artificial intelligence*

INTRODUCTION

Nowadays our airspaces are getting more and more crowded due to the development of drones and urban air mobility as well as the continued growth of commercial air traffic. Therefore, we require a solution to solve this issue. This is where the new technology of Artificial Intelligence comes into play. More specifically Human Machine Collaboration.

What is Human Machine Collaboration? It is the seamless interaction between human operators and advanced technological systems. This can be achieved with the help of AI that understands language models and shares the same model of operation with the human pilot. This way the thought processes can be followed and interrupted if needed. The goal is to enhance safety, efficiency and decision making, while maintaining the same level of safety as with redundant multi crew operations. [1]

For a bit of history: The first ever autopilot was built in 1912 and the only task it could do was navigate a magnetic course in straight level flight with the help of gyroscopes and hydraulics. Jumping to the 1970s, we have the first alert systems built in for safety such as the Ground Proximity Warning System (GPWS). In the 1980s it was followed by the introduction of the early Traffic Collision Avoidance System, TCAS for short. In the following decades the technology for fly-by-wire systems matured and by the 1990s they were available in most aircrafts. Since then, many new and enhanced safety systems were introduced integrating the previous versions. The common factor being that the level of automation is steadily increasing with the passing of time. [2]

With the rise of drone technology and Urban Air Mobility (UAM) just around the corner, we need to upgrade our systems to be able to handle the influx of new traffic. For any new technology related to

aviation, we need to first address the regulations so that we can safely introduce the new technology to our existing ecosystem. First things first, where can you fit all this traffic when our airspaces are already cramped? We need to redesign the existing airspaces, allocating the lower levels near populated areas to delivery drones and urban air mobility. However, there are a lot of challenges when designating the no fly zones for low level traffic. First you need to avoid collision, then we need to account for the winds, noise and privacy criteria. Once we layer all these factors, we get a resulting no-fly zone. Now we need to build our airspace from the ground up to avoid this no-fly zone and still have space for all the other traffic. [3]

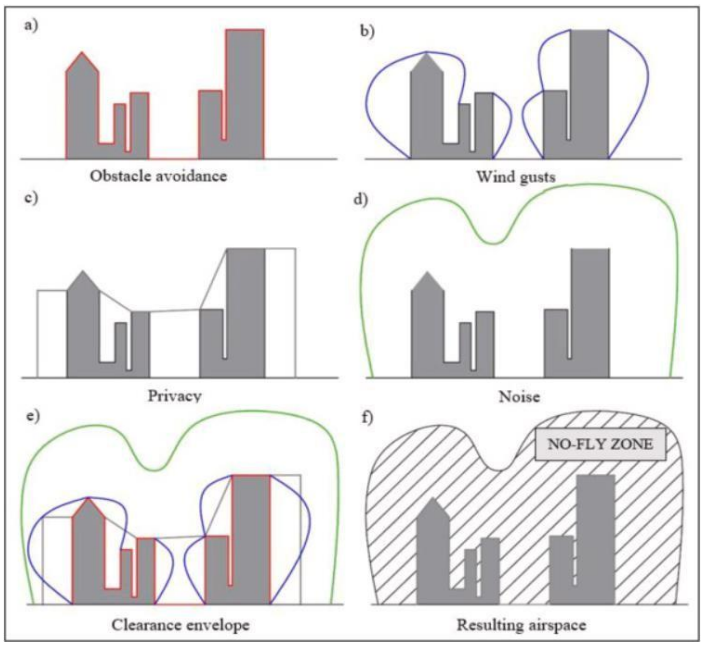


Figure 1:Urban airspace obstacles [3]

There are many models being researched now. For example, here is a very basic view of drones in the bottom, urban mobility a little higher and the rest of the flying traffic goes above, like it is now. VFR (Visual Flight Rules) traffic right above the UAM and IFR (Instrument Flight Rules) traffic at the top.

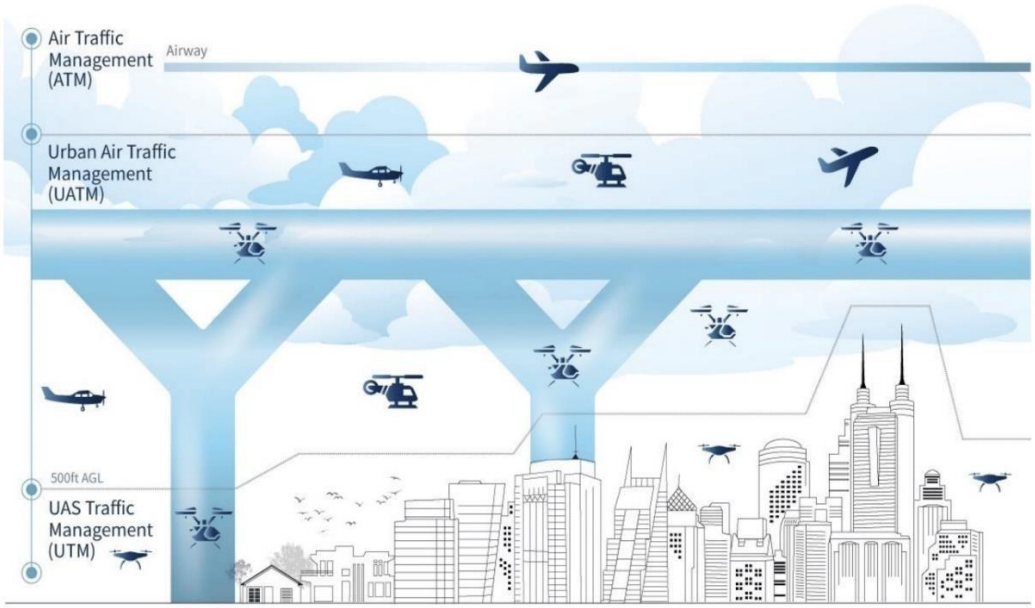


Figure 2: Possible airspace design incorporating UAM [4]

A quick comparison of safety, complexity and capacity can roughly outline the differences between the models. Basically, the more free you want the movement to be, the less structured it will get but the risk of collision rises. The more restricted the movement gets, the efficiency and the capacity drop. [3]

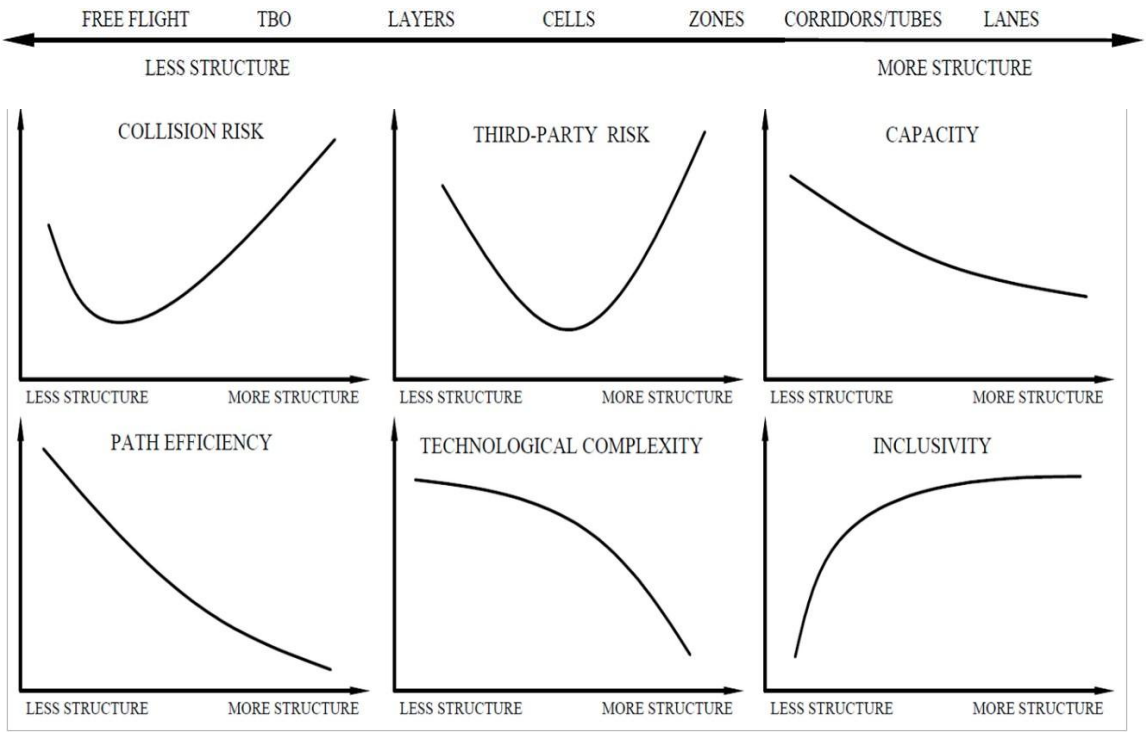


Figure 3: Performance vs Airspace structure [3]

Another use for AI in aviation will be Single Pilot and Remote Operations. Due to the shortage of commercial pilots and as a method to battle rising operating costs Single Pilot and Remote Operations are being researched. With the rise of AI technology, there now exists a possible replacement for a second pilot on board. The purpose of the AI is to act as a copilot, reducing the necessary workload in all conditions, while keeping the pilot in command in complete control. There are a few applications that already exist, particularly in the military field: such as the ARTUμ. It is an AI copilot developed by the US Air Force deployed on a U2 "Dragon Lady" spy plane. Its purpose is to use the onboard sensors to track enemy targets and provide tactical navigation, so the pilot only needs to focus on flying. Another recent development is SAAB`s Gripen E which uses AI systems to integrate all available information in a simple and user-friendly manner to the pilot's HUD. The technology fuses information from submarines, ships and land vehicles alike, and they work best with multiple fighter aircraft. The system uses the data from all the sources and gives each pilot the necessary information for their specific task. In civilian applications, AIRBUS's extended Minimum Crew Operation, (previously CONNECT project) aims to automate flight, so the pilot is only a supervisor in the loop. In the meantime, NASA and Boeing are researching the ground copilot program. In case an emergency occurs during Single Pilot

Operation or in case of incapacitation of the pilot in command, a second pilot on the ground can become the copilot from the ground. [5], [6], [7]

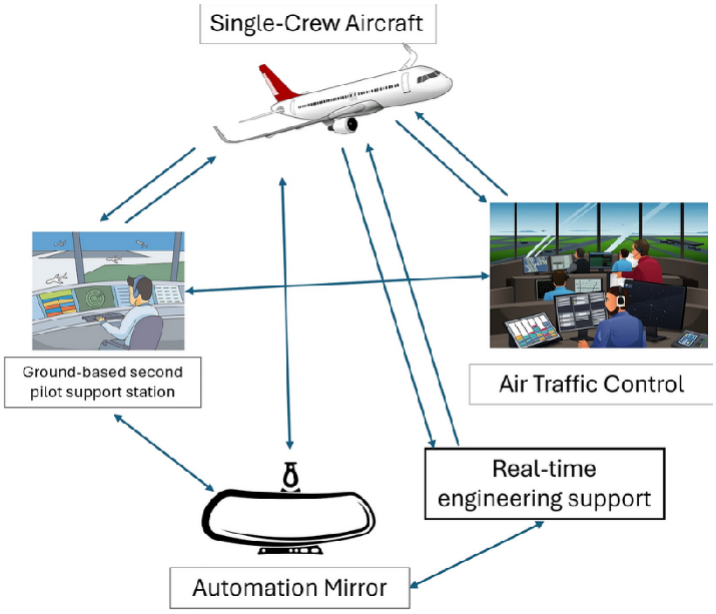


Figure 4: Single Pilot operation [7]

Lastly, the DARWIN project by the joint undertaking SESAR (Single European Sky ATM Research) aims to develop a digital copilot on board to support Single Pilot Operation and reduce workload. It incorporates sensors including eye tracking and health data from the pilot and monitors task load to assess where help is needed. [8], [9]

The future seems to be mapped out quite nicely, however there are still a few challenges to these upcoming technologies. Primarily, the problem of trust comes into play. For artificial intelligence to take over the role of a pilot, people need to trust it with their lives, quite literally. With the state of AI technology today, most operate based on neural networks, which function a lot like a human brain. There is a lot of information, and it tries to make sense of the data as it goes along. And through many iterations, it learns to do a task to achieve a specific outcome, however no one programmed this function manually, so in reality no one knows what the internal logic is based on. Essentially the AI is a black box which we can't see inside of. We input a lot of information and sensor data, and we get something out on the other end, however we have no idea what goes on inside the system. Without this transparency how can you trust the logic of the AI? [10], [11]

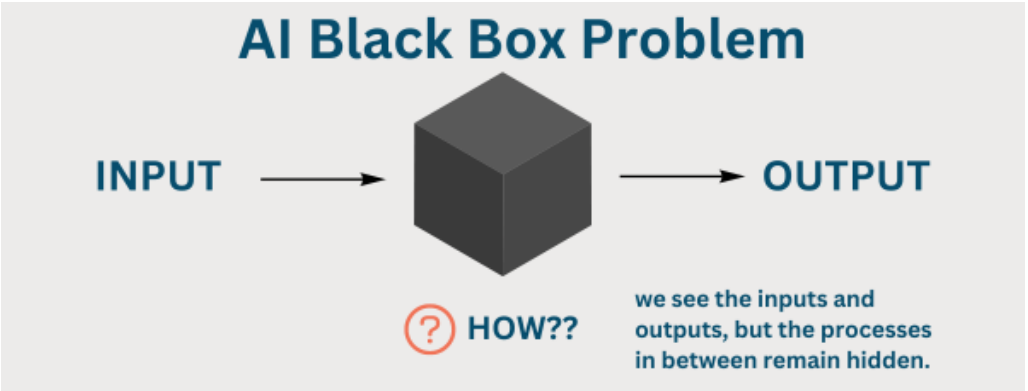


Figure 5: AI inexplicability "Black box" effect [11]

Subsequently, in aviation almost everything is regulated, so are new technologies. As such, AI and Single Pilot Operations would need strict regulations which take a lot of time and testing to approve. This may slow down progress for the foreseeable future, unless we try to keep up with the development process. On a more serious note, we need to consider the risk from malicious humans, in other words cybersecurity. While there are many measures taken to ensure safety in aviation, introducing a copilot which can be "reprogrammed" might be a significant risk. By accessing the AI system, a skilled individual could take control of an aircraft with 200 people on board, while being safe on the ground. Or maybe even worse if the equipment can be controlled remotely maybe the manufacturing countries would take control of the fighters they sold to other countries, to cripple their infrastructure in times of war. Lastly, a very simple causality, if we overly rely on automation, we are bound to forget and lose the hard-earned expertise of the past decades. Simply put, human skill will degrade over time. As we introduce new modes of transport, we need to be able to control this influx of traffic. To get ahead of this rise in traffic, we need to develop a system that helps air traffic controllers to manage their airspace. Since most new traffic is predicted to be unmanned, it would be beneficial to have AI or digital systems help control them. For drone traffic the FAA has a project called UTM (Unmanned aircraft system Traffic Management) which specializes in drone traffic management. Its end goal would be to get the system to level 5 "Swarm automation". However, we are still far off: The system only functions as an advisor between operators at the moment, similar to a central database. [1], [10], [11]

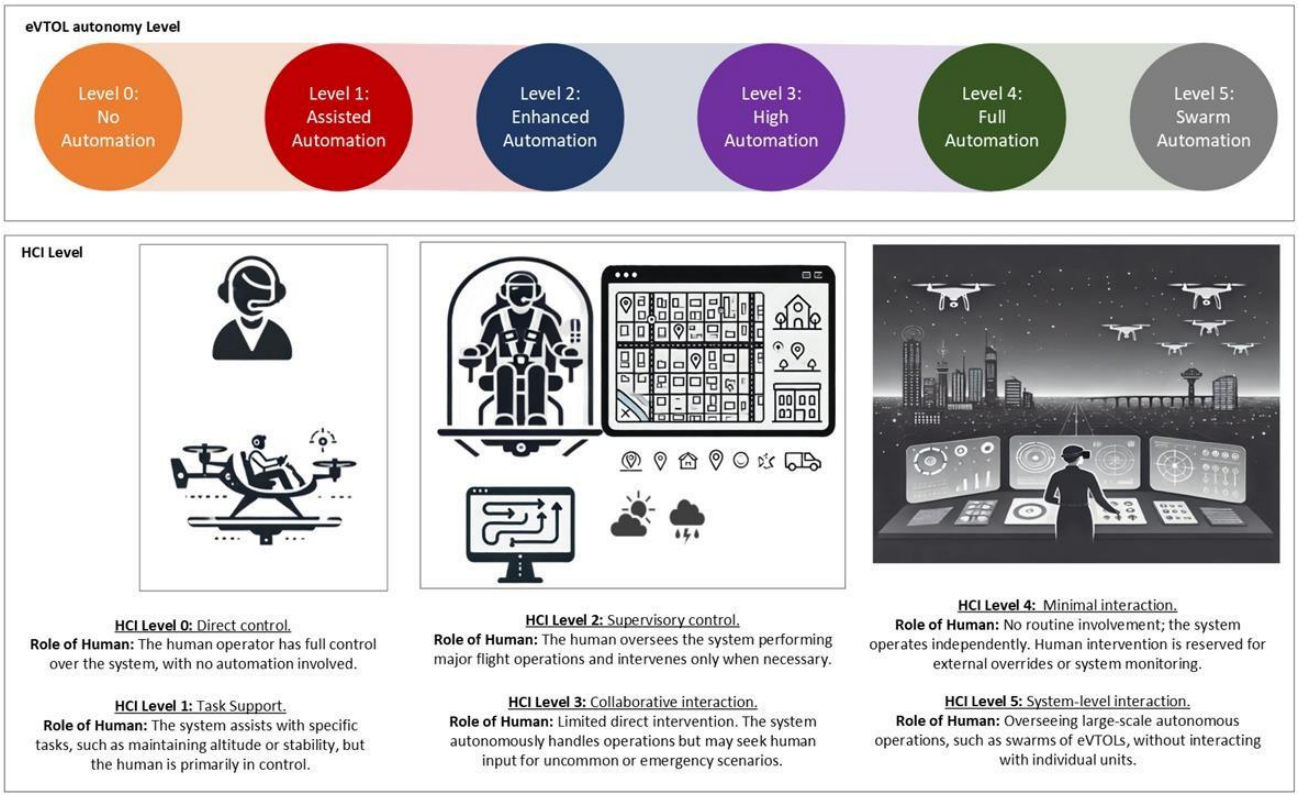


Figure 6: Levels of automation [1]

For commercial aircraft, SESAR is developing the AWARE program, which is an AI that understands the situation and the intention of the pilots according to the flight plan and weather information. It will help reduce the workload of the controllers and help in flow management of airspaces. Flow management is particularly important so that other neighbouring sectors don't get flooded with too much traffic at a single time. Regarding airport ground traffic NASA is developing its ATD-2 system which helps manage taxiing traffic. This project started way back in the 1990s, leading to the key discovery that traffic congestion on the airport surface can't be solved in isolation, it is necessary to know what will come next. It predicts traffic from all the data available: schedules, inbound aircraft, outbound aircraft, maintenance vehicles and all ground traffic movement. With all this it can successfully optimize departure order and cut waiting times and fuel consumption. [12], [13]

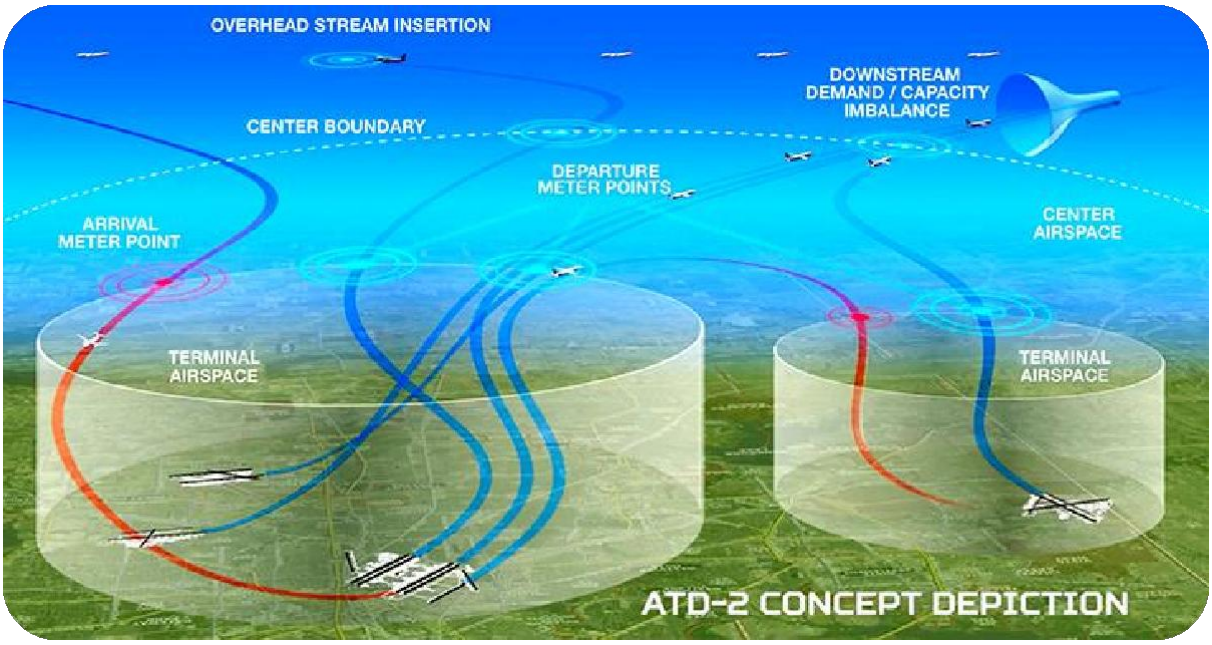


Figure 7: ATD-2 FAA-NASA joint project [13]

The last example is mentioned because air navigation service providers (ANSPs) must decide on their capacity provision for a particular day of operation several weeks or even months in advance, whereas airspace users need flexibility in flight planning and prefer to make their route choice decisions at shorter notice. This is where COCTA (Coordinated Capacity Ordering and Trajectory pricing in ATM) comes in. The system helps to plan airspace usage by operating in a demand driven approach, the airspace users can choose between different price plans. Either get a plan fixed to their desired target route within a certain range for a premium price or get a more flexible route for easier airspace management for cheaper prices. [14]

This trend of automation doesn't stop while on the ground either. Many organizations have their own version of predictive maintenance based on AI and Machine Learning. The goal is to predict failure before it happens. For example, AIRBUS' Skywise uses real time sensor data from the whole fleet to spot anomalous data and flag it for maintenance. Boeing on the other hand uses machine learning algorithms to predict failure based on historical data. Rolls-Royce has a more hands-on approach by reading sensor data that monitors engine vibration and performance to see if they are within expected margins. In my opinion GE Aviation's FlightPulse is the most advanced. It uses AI to analyse fuel efficiency, engine wear and stress levels in the airframe as well as how much time the engine spent at full power and what landing configurations were used to predict failure points. [15], [16]



Figure 8: GE FlightPulse Data preview [16]

There are many Benefits to Predictive Maintenance, such as reduced aircraft downtime due to scheduled and planned stops. The supply chain is also optimized, so that parts arrive at the maintenance location in time for the repairs. This lowers maintenance cost because only the predicted systems need changing and enhances fuel efficiency due to the airplane functioning at optimum state. Finally, it increases safety because all the necessary repairs have been addressed in time. [17]

So far, we have discussed several areas where AI can be utilized. Let's now discuss why it is advantageous to utilize Human-Machine Collaboration. It can increase safety and efficiency even with increased traffic, while lowering the workload for pilots and controllers so they can focus more on the important situations. Planned and predicted maintenance and organized airspace capacity can help cut costs and maintain ecological standards. All in all, the systems will help to better allocate resources where they are needed. When considering the military aspects, SAAB's next generation Gripen E was built around the concept of smarter, not harder, using superior information to defeat a possibly stronger enemy. Utilizing shared information from all the available assets, filtered by AI and fed into the user's HUD, all assets can focus on their own task and maintain situational awareness of a much greater standard than their adversaries. [18]

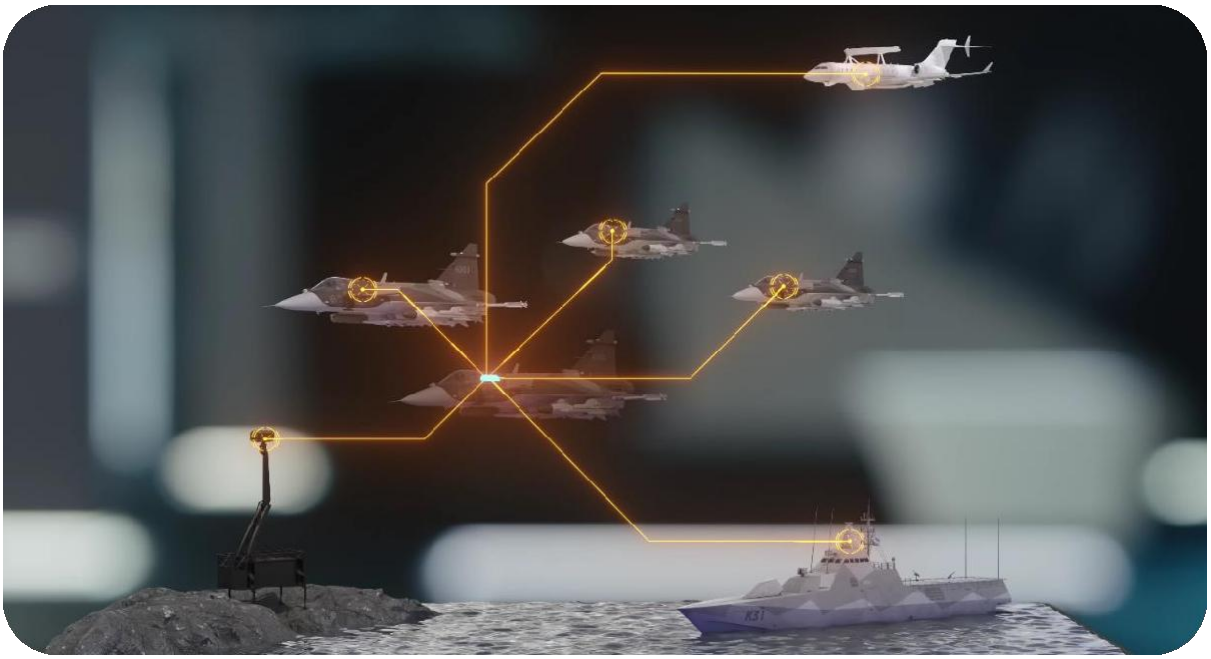


Figure 9: Gripen E Information network [6]

The challenges and limitations of AI systems boil down to a few key points, such as trust, cybersecurity and regulation limitations. Human trust in AI automation is lacking, we just don't trust the machine with our lives yet. However, for that to change we need to make a few key changes. First of all, Bi-directional communication is required, so that the pilot and the AI can converse through natural language. The human can ask about reasoning: Why this? Why not that? How sure are you about …? They can add new information by telling it directly. Most importantly the possibility to bounce ideas off each other like teammates. Secondly, we need transparency, the ability to know what the system is doing, why it is doing it, and what can be expected next. [10]

Now the important question: How much, is too much transparency? If you overwhelm the user with information, it will have a negative effect on their performance. If you take away too much information you lose trust and possibly functionality. The goal is to reach a state which is just right. We also need the AI to have a shared model of system operations and the environment, so we don't have any misunderstandings while interacting with it reliably. It is also important to have an interface that is directed at the pilot so that communication is easy and effortless. [10]

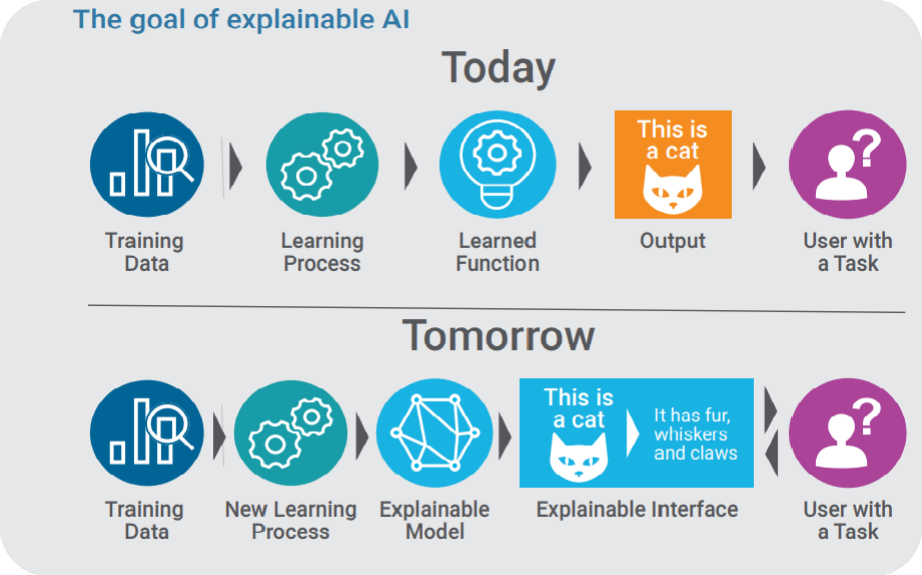


Figure 10: Explainability in AI [19]

Finally, we need meaningful human control, the ability to make alterations while the AI is working. It is very important that the human has input and not just launches Skynet with the push of a button. Human input is also necessary to add critical information to the decision- making loop when it's not already present in the system. This way the human decision-making skill remains in use even in ethically challenging situations. [10]

Cybersecurity is also a limiting factor at the moment, because no matter how secure a system you design, in 10 years' time the stronger, faster computers might be able to crack it. Introducing a new avenue of failure and attack. Regulations can also limit the adaptation period because they take a long time to test and then finally pass a new regulation. And similarly to the captain from WALL-E if we overuse automation, the actual hard-earned knowledge of the humans is going to degrade over time. [11]

The future roadmap for human-machine collaboration includes a few key phases outlined in the EASA future roadmap 2.0. Phase I is the first usable guidance for level 1 AI/Machine Learning, only for assistance, originally predicted for 2021, it is already available. Predicted for 2023, level 2 automation with Human-AI teaming was developed. For phase II, level 3 automation and the consolidation of level 2 AI and Machine learning is the goal, predicted for 2026. From 2028 onwards, level 3 integration and further developments are planned. [19]

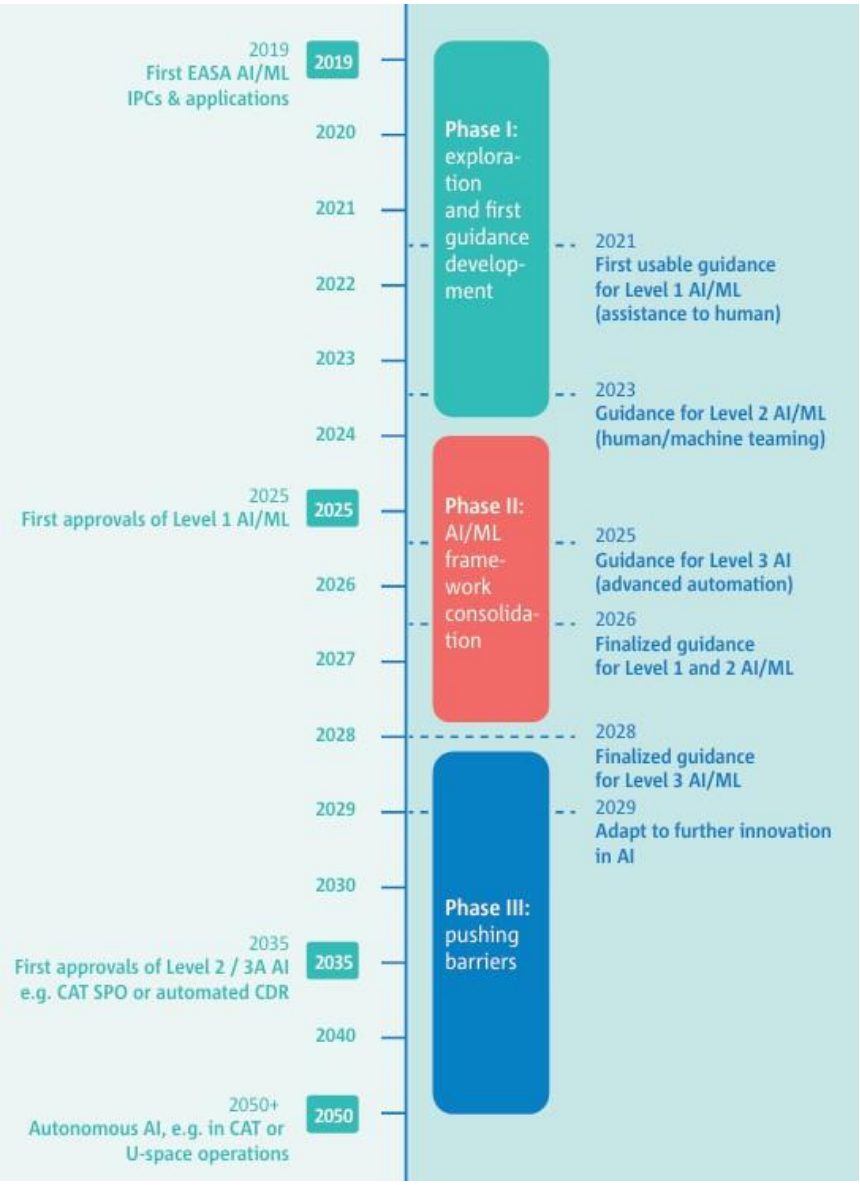


Figure 11: AI roadmap according to EASA [19]

The Future is ever changing, so we cannot be entirely sure that these predictions will come to fruition on time. However, we are ready to push the boundaries of what's possible and there are many countries, companies and entrepreneurs ready to make the next step a reality.

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Features of Movement of Composite Alloys in the Technological Process of Their Production on İnjection Casting Machines

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Abstract

The effect of the correct selection of technological equipment and their working bodies applied in the production process, which is one of the main factors in extending the service life of machine parts made of composite materials and obtaining a quality product, on the processing modes, and at the same time taking into account the physical and mechanical properties of solid polyvinyl chloride as a material, the kinematic and geometric parameters of the working bodies, the screw and its nozzles with their heads were calculated, and the expression of the resistance coefficient arising during the flow according to the law was given.
Key words: *Composite material, Screws, Nozzles, Movement speed, Resistance coefficient.*

INTRODUCTION

One of the most important tasks of modern mechanical engineering is to improve the quality of manufacturing machine parts operating in difficult operating conditions, which is achieved through the use of existing innovative technologies. In this regard, the demand for machine parts operating in difficult and severe operating conditions has increased, primarily in the aviation industry, space industry, shipbuilding and other strategically important industries. At the same time, the production of these machine parts using modern innovative technologies has become one of the most pressing issues of our time, a key problem. Along with all this, replacing these machine parts with non-metallic, more durable, light and inexpensive materials has become a priority task. Therefore, achieving increased product production quality through optimization of processing modes of technological equipment increases the longevity and operability of these machine parts. One of the main factors in extending the service life of machine parts made of composite materials and obtaining a quality product is the correct choice of process equipment and its working parts used in the production process, as well as compliance with processing modes. (1.Aliyev I.Z. and others 2016). The basis of this process equipment is injection molding machines -injection molding machines, extruders and other devices for injection molding.(Fig. 1)



Figure 1. Thermoplastavtomat TP-125

The replacement of machine parts with non-metallic, stronger, lighter and cheaper materials is more typical for rigid polyvinyl chloride (PVC), which is mainly used in positions with difficult operating conditions and in more strategic areas. This rigid PVC-based composite material is used as a sealant for machine parts to prevent leaks in internal combustion engines, aircraft engines, high-pressure fountain fittings in the aerospace industry and other high-pressure operating conditions (Figure 2).



Figure 2. Solid PVC composite material gasket

The composition and physical properties of the sealing material, the composition of the sealant shown in Figure 2, is a solid polyvinyl chloride, which is resistant to high temperatures and includes the following other physical properties:

- specific gravity 1.34-1.4 g / cm^3;
- tensile strength 500-700 kg / cm^2;
- combustion temperature 1100 ° C;
- freezing temperature -80 ° C;
- flexural and compressive strength 800-1200 kg / cm^2;
- thermal conductivity, ° C 3.8×10^{-4} ... 4×10^{-4}

MATERIAL AND METHODS

The correct selection and operation of the working parts of injection molding machines and injection molding machines have become a key issue for ensuring the required quality indicators of machine parts made of composite materials.(7.Huseynov A. G. and others, 2024). The working parts of these machines

are screws, and the main technological tool at their ends are nozzles designed to shape the composite alloy during the spraying process. (Fig. 3)

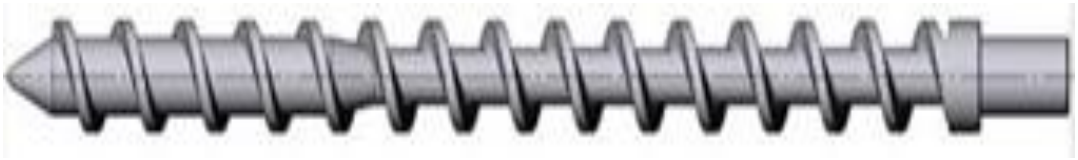


Fig. 3. Worm auger

The correct application of the configuration and design of these tools ensures the systematic movement of the composite liquid alloy along the screw, starting from the loading zone, through the pressing and dosing zones, and spraying into the mold, resulting in the structural formation of the finished machine part emerging from the mold. (Fig. 4)

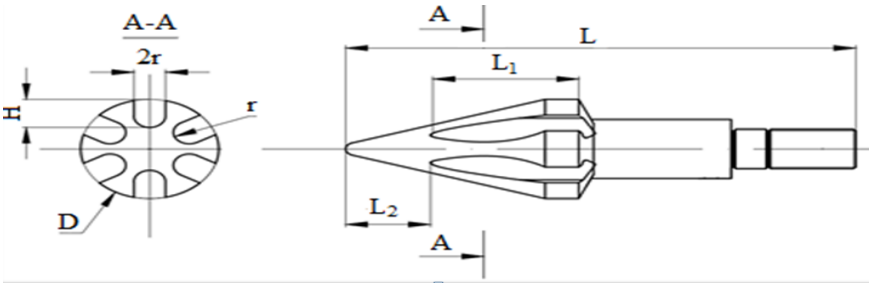


Fig. 4. Nozzle for worm screw head

Research has shown that this process, where liquid composite alloy circulates through a screw and is sprayed into a mold, has a number of disadvantages:

- the mold is filled with air bubbles;

- incomplete dissolution of the mixture leads to crystallization in the screw head and nozzle;

- depending on the angle of the screw, the alloy slows down in the direction of flow;

- stagnant (inactive) zones are formed in the screw channel of the final screw of the screw;

- the rotation speed of the suction screw of the screw does not coincide with the speed of the liquid flow;

- when the liquid composite alloy moves, the pressure of the alloy is not proportional to the flow rate of the channel, etc.

SOLUTION TO THE PROBLEM

The most productive part of the motion of the composite alloy in the zones along the axis of the screw is the dosing zone, the efficiency of which largely depends on the geometric parameters of the screw. The efficiency here depends significantly on the geometric dimensions of the screw, the number of revolutions and the design of the nozzle. (1.Aliyev I.Z. and others,2016). Research has shown that the hydrodynamics of the composite alloy in contact with the working bodies in the dosing zone is based on three main flow patterns:

The flow of the alloy moves along the axis of the screw from the loading zone to the dosing zone; that is, the flow created when the screw rotates;

The flow resulting from the pressure drop (ΔP) in the opposite direction along the axis of the screw;

Fluid flow resulting from flow losses moving between the outer surface of the worm screw and the inner surface of the cylinder.

As a result of the conducted studies, if we consider the movement of the section of the screw channel of the endless screw in the technological process of welding hard PVC and other parts and take its speed relative to the screw as Vs (Fig. 5), the speed relative to the cylinder as Va, and the circumferential speed as Vc, then the consumption of hard PVC-composite alloy along the screw will be:

$$V_{\text{ox boyu}} = \frac{Vs \sin a \sin Vc}{\sin(\alpha + Vc)},$$

where Vc is the value of the peripheral speed determined by the friction of the hard PVC composite alloy against the surface of the screw and cylinder.

The formation of the friction angle as a result of the research is shown in the diagram in Figure 5.

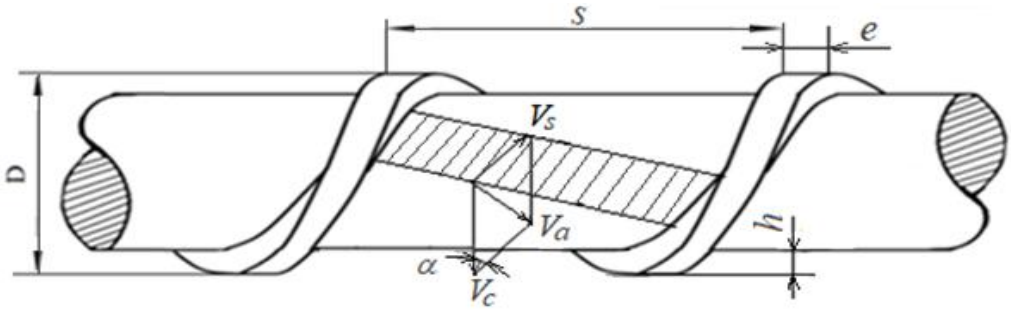


Fig. 5. Scheme of the formation of the friction angle

In this case, the friction angle is calculated using the following formula:

$$tgV_c = \frac{\frac{q}{n}}{\pi\,(D-h2)Dh2\left(1-\frac{ie}{s}\right)-\frac{q}{n}ctg\alpha}$$

where, q/n is the amount of solid PVC alloy discharged per one screw cycle, cm3/cycle; D is the screw diameter, mm; h2 is the depth of the endless screw channel in the loading zone, cm; S is the screw pitch, cm; e is the width of the screw cross-section, cm; α is the angle of inclination of the screw, degrees; i is the number of endless screw strokes. Thus, the friction angle tanVc depends on the peripheral speed Vc and the compression ratio. Research shows that the value of tgVc remains constant at 2–3° after a certain speed.

A liquid composite alloy made of solid PVC is poured into the mold, moving at a constant speed towards the nozzle through a screw. In this process, after a fairly stable speed of movement of the composite alloy, a sediment is formed at the end of the flow channel of the nozzle, which subsequently breaks down and causes crystallization. This crystallization, in turn, creates resistance to the flow in straight-through nozzles. The geometric characteristics of straight-through nozzles are determined by the total resistance coefficient:

$$K_{mus} = \frac{1}{\frac{1}{k1}+\frac{1}{k2}+\frac{1}{k3}+\cdots.+\frac{1}{kn}},$$

Here, K mus is the nozzle resistance, k1, k2, k3, and kn are the resistance coefficients of the individual areas of the nozzle along the flow channel.

Thus, the flow of solid PVC composite alloy from the screw dosing zone towards the nozzle should be directed as much as possible. This will prevent stagnation in individual zones and will ultimately ensure that all pores in the mold are filled with the alloy. As a result of the research, it was found that the speed and direction of movement of the solid PVC composite alloy along the flow should coincide with the speed and direction of rotation of the screw and nozzle.

DISCUSSION AND CONCLUSION

The main indicator of obtaining a fully formed, flawless product by filling a solid PVC composite material into a mold is the nozzles at the tip of the screw, the current design of which does not solve the problems indicated in the article. From this point of view, it is necessary to consider the issue of the invention of updating the existing designs of nozzles in order to obtain a new high-quality, durable and long-lasting product.

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Conflict of Interest

"The authors have declared that there is no conflict of interest".

The Effect of Personal Grooming and Appearance on Social Communication: A Quantitative Analysis

Bu bildiri yazarlar tarafından geri çekilmiştir. / This conference paper has been withdrawn by the authors.

Content Analysis of Vaccine Promotion Videos Published on the YouTube Channel of the Turkish Ministry of Health

Bu bildiri yazarlar tarafından geri çekilmiştir. / This conference paper has been withdrawn by the authors.

T.C. Sağlık Bakanlığı'nın YouTube Kanalında Yayınlanan Aşı Teşvik Videolarının İçerik Analizi

Bu bildiri yazarlar tarafından geri çekilmiştir. / This conference paper has been withdrawn by the authors.

Gazeteciliğin Dijitalleşme Süreci: Gelenekselden Dijitale Gazeteciliğin Dönüşümü

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Özet

İnsanoğlu için haber ve bilgi ihtiyacı her zaman en önemli unsurlardan olmuştur. Tarihsel süreç içerisinde çeşitli kitle iletişim araçları ortaya çıkmış ve insanların haber ve bilgi ihtiyacını karşılamıştır. Geleneksel kitle iletişim araçları olarak ifade edilen gazete, radyo, televizyon gibi kitle iletişim araçları insanların haber ve bilgi ihtiyacını karşılayan başlıca iletişim araçlarıdır. Günümüzde ise internet teknolojisi geleneksel iletişim araçlarını bir değişim ve dönüşüm sürecine dâhil etmiştir. 1990'lı yıllarda internet teknolojisindeki ilerlemeler ve yaygınlaşmayla birlikte çeşitli medya kuruluşları dijitalde de yerini almış, buna ek olarak sadece internet üzerinden yayın yapan haber siteleri de ortaya çıkmıştır. 2000'li yılların başında web 2.0 teknolojisinin ortaya çıkışıyla insanlar, alımlayıcı olmalarına ek olarak potansiyel birer yayıncı haline de dönüşmüşlerdir. Bu süreçte ortaya çıkan sosyal medya platformları kullanıcılara hem alımlayıcı hem de yayıncı olma özelliği katmıştır. Aynı zamanda bu teknoloji kullanıcıların haber üretim sürecine dahil olmasına imkanı sağlamıştır. Günümüzde değişim ve dönüşümü devam eden gazetecilikte yapay zeka uygulamaları da kullanılmaktadır. Haber üretim sürecinde etkin bir rol oynayan bu teknoloji bazı etik ve güvenilirlik tartışmalarını da beraberinde getirmiştir. Bu bildiri geçmişten günümüze gazeteciliğin geçirmiş olduğu tarihsel süreci ele almakta ve dijitalleşme sürecini ortaya koymaktadır. Ayrıca bildiride günümüzde gazetecilikte kullanılan yapay zekanın gelecekte gazeteciliğe ne gibi bir etkisinin olacağı da tartışılmaktadır.

Key words: *Gazetecilik, Dijital dönüşüm, Online gazetecilik.*

GİRİŞ

İlk insandan günümüze insanoğlunun en önemli ihtiyaçlarından biri haberleşme olmuştur. Çünkü insan sosyal bir varlık olarak çevresinde olan bitenleri bilme isteği içerisinde olur. Tarihsel süreçte insanoğlunun haber ve bilgi ihtiyacı çeşitli araçlarla giderilmiştir. Matbaanın icadı ve sonrasında gazetelerin kitleselleşmesi ve yaygınlaşmasıyla birlikte insanların en önemli haber kaynaklarından biri gazeteler olmuştur. Sonrasında radyonun icat edilmesi kitle iletişiminde önemli bir devri başlatmıştır. Televizyonların icadı ise görüntülü yayını olanaklı hale getirmiştir. Her bir kitle iletişim aracı bir devrim niteliğinde olmuş ve toplumsal hayatı önemli derecede etkilemiş, değiştirmiş ve dönüştürmüştür.

Kitle iletişim araçlarının gelişim sürecinde internetin icat edilmesi kritik bir noktayı oluşturmaktadır. İlk zamanlar halkın kullanımına açık olmayan internet, süreç içerisinde halkın kullanımına da açılmıştır. Bu süreçte bir dizi teknik ilerleme ve gelişme yaşanmıştır. Örneğin bilgisayarların ortak bir protokol üzerinden iletişim kurmaya başlaması ve world wide web (www) teknolojisinin geliştirilmesi bu sürecin hızlanmasını sağlayan etkenlerden olmuştur. Kitle iletişim araçları da bu süreçte hızla konumlanmış ve yayınlarını internet üzerinden de oluşturmaya başlamıştır. Yani geleneksel kitle iletişim araçları kendilerine internetten yayın yapma olanağı da bulmuştur.

İnternet teknolojisi toplumsal hayatta birçok değişim ve dönüşüme neden olurken kitle iletişim araçlarının dönüşümünü de sağlamıştır. Geleneksel kitle iletişim araçları kendi yayınlarına ek olarak

internet üzerinden çeşitli içerikleri takipçileriyle paylaşmaya başlamıştır. 1990'lı yıllar itibariyle gazetecilik faaliyetleri internet üzerinden de yapılır hale gelmiştir. Geleneksel kitle iletişim araçlarının yanı sıra tamamıyla internet üzerinden yayın yapan gazetelerin ortaya çıkışı da bu tarihlerde gerçekleşmiştir.

2000'li yıllardan itibaren internet teknolojisi gelişimini devam ettirmiştir. Bu süreçte web 2.0 teknolojisinin ortaya çıkışı yepyeni bir dönemi de açmıştır. Artık sosyal medya devri başlamıştır. Bu devir kullanıcıların içerik üretmesine imkan veren bir teknoloji olarak ifade edilebilir. Yine bu süreçte mobil cihaz teknolojilerinde de önemli ilerlemeler kaydedilmiştir. İlkin sadece sesli iletişimin olanaklı olduğu mobil iletişim, yani cep telefonlarında giderek bilgisayar özellikleri görülmeye başlamıştır. Buna ek olarak cep telefonlarında internet teknolojisi kullanılır hale gelmiştir.

Mobil cihazlarda yaşanan teknolojik ilerlemeler kullanıcılarına birçok imkan tanımaktadır. Bu cihazlara indirilen uygulamalar yolu ile her bir mobil cihaz kullanıcısı istediği birçok hizmete daha rahat ulaşır hale gelmiştir. Örneğin bankacılık hizmeti giderek cep telefonu üzerinden giderilir hale gelmiştir. Buna ek olarak toplumsal hayata giren çeşitli sosyal medya platformları mobil cihazlar üzerinden giderek daha çok kullanılmaya başlamıştır. Bu süreçte habercilik faaliyetleri de yeni platformlar üzerinden kendine yer bulmaya başlamıştır.

Günümüzde gazetecilik faaliyetleri çeşitli araçlar üzerinden yapılmaktadır. Geleneksel kitle iletişim araçlarının yanı sıra internet üzerinden faaliyet gösteren haber siteleri, gazeteciler ve çeşitli platformlar bulunmaktadır. Bu araçlara ek olarak sosyal medya üzerinden de gazetecilik faaliyetleri yürütülmektedir. Dolayısıyla gazetecilik kendine yeni mecralar bulmuş ve bu süreç gazeteciliğin dönüşümünü de beraberinde getirmiştir.

Gelinen son dönemde yapay zeka uygulamaları gazetecilerin haber üretim sürecinde önemli roller üstlenmektedir. Yani haberin yazımını gerçekleştiren uygulamalar görülmeye ve bu uygulamalar giderek yaygınlaşmaya başlamıştır. Bu süreçte birçok etik tartışmalar da ortaya çıkmıştır. Bu bildiri, tarihsel süreçte gazeteciliğin değişim ve dönüşümünü incelemektedir. Aynı zamanda yapay zekanın haber üretimi sürecini tartışmaya açmaktadır.

GELENEKSELDEN DİJİTALE KİTLE İLETİŞİM ARAÇLARI

"İnsanların gerek yakın gerekse uzak çevrelerinde olup bitenler hakkında bilgi almalarını, günümüzde özellikle bu amaçla geliştirilmiş ve uzmanlaşmış bazı araçlar sağlamaktadır. Bu araçlara genel bir terim kullanarak kitle iletişim araçları adını veriyoruz" (Tokgöz, 2022, s. 125). Kitle iletişim araçlarına zamanla yenileri de eklenmiştir. Özellikle internetin geliştirilmesi sonrasında kitle iletişim araçlarının bazıları geleneksel olarak ifade edilmeye başlamıştır. Günümüzde geleneksel kitle iletişim araçları olarak ifade edilen araçlar gazete, radyo ve televizyon olarak bilinmektedir. Bu araçların günümüzde dijital versiyonları da bulunmaktadır. Bu araçların her biri toplumsal hayatın vazgeçilmezlerinden olan haber ve bilgi ihtiyacını karşılayan önemli kitle iletişim araçlarıdır. Günümüz internet çağında geleneksel kitle iletişim araçlarına yenileri de eklenmiştir. Artık bu araçlara ek olarak geleneksel olarak bir yayını olmayan ancak internet üzerinden yayın yapan birçok kuruluş da haber ve bilgi ihtiyacını karşılamaya başlamıştır. Dolayısıyla kitle iletişim araçları tarihsel süreçte gelişmiş ve yeni kitle iletişim araçları toplumsal hayata dahil olmuştur.

En eski kitle iletişim araçlarından biri gazetelerdir. Gazetelerin ortaya çıkışı ve toplumsal yapıda yaygınlaşması bir sürecin sonunda gerçekleşmiştir. Bu süreçte bir dizi teknik ilerlemelerin yanı sıra toplumsal ve siyasal gelişmeler de etkili olmuştur. Teknik ilerleme konusunda en kritik adım matbaanın bulunuşudur. Matbaanın bulunuşuna kadar toplumlarda yazılı iletişim el yazması kitaplarla mümkünken matbaanın bulunuşu ile birlikte baskı süreci başlamıştır (Aziz, 2016, s. 131). Gazetelerin giderek

kitleselleşmesinde ve yaygınlaşmasında matbaaya ek olarak başka faktörler de öne çıkmıştır. Yazının ve kağıdın bulunuşu, matbaanın icadı, basım, haberleşme ve dağıtım konusundaki bir dizi gelişme günümüz çağdaş basınını oluşturmuştur (İnuğur, 2005, s. 27). Dolayısıyla gazetenin gelişim sürecinde birçok teknik buluş etkili olmuş, süreç içerisinde gazeteler giderek yaygınlaşmış, insanların dünyada olup bitenleri öğrendiği önemli bir kitle iletişim aracı olmuştur.

Kitle iletişim araçları içerisinde sesin bir yerden bir yere ulaşmasını sağlayan radyo da önemli buluşlar içerisinde kendini konumlandırmaktadır. Gazete, telgraf ve telefon gibi önemli icatlardan sonra ortaya çıkan bu kitle iletişim aracı bir dizi teknik ilerlemelerle mümkün hale gelmiştir. Yapılan ilk çalışmalar 19. yüzyılın ikinci yarısında Avrupa ülkelerinde başlamıştır (Aziz, 2016, s. 141). Bu alanda yapılan çalışmalar sonucunda ilk radyo yayınları 20'nci yüzyılda başlamıştır. Bu bağlamda, ilk radyo yayınları 1920 yılında ABD'de ve Hollanda'da yapılan yayınlar olarak ifade edilmektedir (Baldini, 2000, s. 90). Rayonun bulunuşu ve sonrasında giderek yaygınlaşması kitle iletişim araçlarına bir yenisini eklemiştir. İnsanların haber ve bilgi ihtiyacı süreç içerisinde gazetenin yanı sıra radyodan da karşılanır hale gelmiştir.

Sesin naklinin yanı sıra görüntünün naklinin de olanaklı hale geldiği bir diğer buluş televizyondur. Bu buluş kitle iletişim araçlarına bir yenisini daha eklemiş ve kitle iletişim araçları çeşitlenmiştir. Diğer buluşlarda olduğu gibi televizyonun icat edilmesi de birçok başkaca teknik ilerlemelerin de eklemlendiği bir dizi teknik ilerlemeyi kapsamaktadır. Bu alanda da yapılan çalışmalar sonucu Londra'da ilk televizyon yayını 1936'da yapılmıştır (Baldini, 2000, s. 91). 1920'lerde geliştirilmeye başlanan televizyon 20. yüzyılın ikinci yarısından itibaren hızlı bir şekilde yaygınlaşma süreci yaşamıştır (Erdoğan, 2011, s. 357). Süreç içerisinde televizyonlar yaygınlaşmış, insanların haber ve bilgi ihtiyacını karşılayan ve neredeyse her evde bulunan bir kitle iletişim aracı olmuştur.

Teknik ilerlemelerin yanı sıra toplumsal talep kitle iletişim araçlarının giderek yaygınlaşmasını sağlamıştır. İcadı yapılan her bir araç kitle iletişim araçlarını çeşitlendirmiştir. Yani toplumsal alanda haber ve bilgi ihtiyacı hem gazeteden hem radyodan hem de televizyondan karşılanır hale gelmiştir. Süreç içerisinde kitle iletişim araçları için de yeni bir süreci başlatan bilgisayar ve internet teknolojisi hem toplum hem de kitle iletişim araçları için kritik bir noktada yer almaktadır. Koloğlu (2020, s. 183) yazılıdan sözlü ve görüntülü medyaya geçen oradan da elektronik uygulamaya ulaşan medyanın bu yeni süreçte yepyeni bir aşamaya vardığını ifade etmektedir. Dolayısıyla bilgisayar ve internet teknolojisi kitle iletişim araçları için de kritik ve önemli bir icat olarak öne çıkmaktadır. Bu icat birçok alanın değişimini ve dönüşümünü sağlamıştır.

Tarihsel süreçte bilgisayarların gelişimi birçok alanın dönüşümünü sağlamıştır. Baldini (2000, s. 105) bilgisayarların iletişim galaksisindeki farklı mecraları birleştirerek, geleneksel kitle iletişim araçları izler kitlesinin ilk anda anlayamayacağı biçimde iletişim dünyasını temelden değiştirdiğini belirtmektedir. Bu bakımdan bilgisayarlar iletişim araçları için oldukça önemli bir noktada yer almaktadır. Ayrıca, bilgisayarların gelişimi izler kitle açısından da yeni bir sürecin başlangıcı olmuştur.

Diğer birçok icat gibi bilgisayarlar da birçok teknik gelişimin birleştiği bir teknolojidir. İlk olarak hesap makinesi mantığıyla başlayan süreçte bilgisayarlar giderek günümüzdeki şeklini almıştır. İlkin sanayi ve ticaret alanlarında kullanılan bilgisayarlar 1977 sonrasında bireysel kullanıma da açılmıştır (Geray, 1994, s. 29). Günümüze kadar bilgisayar teknolojisi büyük ilerlemeler kaydetmiştir. Medya alanında ise bilgisayarlar giderek daha fazla kullanılır hale gelmiş, günümüzde ise neredeyse her iş bilgisayarlar aracılığıyla yapılmaya başlamıştır. Örneğin geleneksel bir gazetenin mizanpaj tasarımı ya da bir televiyon programının video kurgusu bilgisayar üzerinden çeşitli programlarla yapılmaktadır. Dolayısıyla günümüzde bilgisayarlar medya araçları için olmazsa olmaz bir nitelik taşımaktadırlar.

Tarihsel süreçte bilgisayarlar arası iletişim de olanaklı hale gelmiştir. Bu süreç günümüzde yaygın bir şekilde kullanılan internetin icat edilmesini sağlamıştır. ARPANET olarak ifade edilen ilk bilgisayar şebekesi Amerikan Savunma Bakanlığı tarafından geliştirilmiştir (Erdoğan, 2011, s. 358). Dolayısıyla internetin keşfinde ilk olarak askeri nedenler etkili olmuştur (Castells, 2008). İlk kullanıcılarının üniversiteler olduğu internet teknolojisinde ilk eposta 1972'de uygulamaya konulmuş, 1989'da ise world wide web (www) teknolojisi geliştirilmiştir (Basım, 2002, ss. 14-15). Dolayısıyla, tarihsel olarak 1969 yılında icadı gerçekleşen internetin ilk hali giderek yaygınlığı artan ve günümüzün vazgeçilmezleri arasına giren bir teknoloji olarak toplumdaki yerini almıştır. Bu alanda yapılan teknik ilerlemeler internetin giderek yaygınlaşmasını sağlamıştır.

Geleneksel kitle iletişim araçları süreç içerisinde çoğalmış ve çeşitlenmiştir. Günümüzde gazete, radyo ve televizyonun yanı sıra internet mecrası da toplumsal hayatta haber ve bilgi ihtiyacını gidermeye başlamıştır. İlk olarak yalnızca haber alabilmek için gazete okuyanlar süreç içerisinde radyo dinleyerek, televizyon izleyerek, yeni iletişim teknolojileri aracılığıyla haber almaya başlamıştır (Tokgöz, 2022, s. 132). Dolayısıyla tarihsel süreçte yaşanan teknolojik gelişmelerle birlikte günümüzde kitle iletişim araçları çoğalmış, insanların haber ve bilgi alabilecekleri mecralar çeşitlenmiştir.

Geleneksel kitle iletişim araçları bilgisayar ve internet teknolojisinin gelişimi ile radikal bir değişim ve dönüşüm sürecine dahil olmuştur. Kitle iletişim araçları içerisinde yer alan gazeteler de bu süreçten etkilenmişlerdir.

TÜRKİYE'DE İLK DİJİTAL GAZETELER

Günümüzde sıklıkla kullanılan kavramlardan biri dijital kavramıdır. "Dijital kavramı çoğu elektronik araçları veya süreçleri nitelemek için kullanılmaktadır. Yaygın anlayışın aksine dijital, elektronik cihazlar değil, verinin elektronik olarak işlenip gösterilmesidir" (Bozkurt, vd., 2021, s. 36). Dolayısıyla dijitalleşme sürecinde verilerin elektronik ortamda oluşu öne çıkmaktadır. TDK (t.y.)'ye göre ise dijital kelimesi sayısal, sanal anlamına gelmektedir. Bu bağlamda dijital kavramı bilgisayar ile de oldukça ilintili bir kavramdır. Çünkü bilgisayar teknolojisi de sayısal tekniğe dayanmaktadır (Geray, 1994, s.22). Bu bağlamda, dijital kavramını verilerin sayısal oluşu ya da bilgisayar ortamında oluşu olarak ifade etmek mümkündür.

Dijitalleşme süreci günümüzde birçok alanı değiştirmiş ve dönüştürmüştür. Bu süreçten gazeteler de etkilenmişlerdir. Özellikle bilgisayar teknolojisinin ilerlemesi ve süreç içerisinde internet teknolojisinin de yaygınlık kazanması gazeteleri değişim ve dönüşüm sürecine sokmuştur. Örneğin, gazetelerin hazırlık sürecinde bilgisayarlar birçok kolaylığı beraberinde getirmiştir. Özellikle gazetenin sayfa tasarımın yapılması ve sonrasındaki süreçlerin bilgisayarlar aracılığıyla yapılır hale gelmesiyle önemli bir iş yükü ortadan kalkmıştır. Diğer yandan, internetin kullanılması gazetecilik için yeni bir mecra sağlamıştır. Bu süreci hızlandıran başlıca etkenlerden biri www teknolojisinin icadıdır. Bu teknoloji 1989 yılında geliştirilmiştir (Basım, 2002, ss. 14-15).

İlk sanal gazetelerin başlama süreci de 1990'lı yıllara denk gelmektedir. 1995 yılında ilk olarak aralarında Washington Post'un da olduğu bazı gazeteler ABD'de sanal gazeteleri başlatmıştır (Koloğlu, 2020, s.180). Bu süreç Türkiye'de fazla bir gecikme yaşanmaksızın uygulamaya konulmuştur. Bu bağlamda yine aynı tarihte Türkiye'de de internet üzerinden gazete yayınlanmaya başlamıştır (Gezgin, 2002, s. 34). Koloğlu, (2020, s. 181) Türkiye'nin elektronik gazetecilik bağlamında dünyadaki gelişmeleri yakından takip ettiğini ifade etmektedir. Bu anlamda, gazetelerden Zaman gazetesi 1995'te sanal ortamda yayınlanmaya başlarken Milliyet 1996'da, Hürriyet ve Sabah 1997'de internetteki yerini almıştır (Gürcan, 1999, s. 48). Bu doğrultuda, sanal gazeteler konusunda Türkiye'de, tarihsel olarak dünyadaki gelişmelerle yakın tarihlerde atılımların yapıldığı görülmektedir. İnternet mecrasından

yayınlanan gazeteleri süreç içerisinde diğer kitle iletişim araçları takip etmiştir. Örneğin televizyon kanallarından Kanal D, ATV, Show TV, Star TV ve NTV kanalları 1997 yılında internetteki yerlerini alan televizyon kanalları olmuştur (Gürcan, 1999, s. 50). Bu süreç ilerleyen dönemlerde tüm kitle iletişim araçlarını kapsamaya başlamıştır.

Yukarıda bahsi geçen gazeteler basılı gazeteleri olan ve sanal ortamda da gazetelerini yayınlayan gazetelerdir. Buna ek olarak süreç içerisinde sadece internet üzerinden yayınlanan gazeteler de oluşmaya başlamıştır. Türkiye'de tamamıyla internette yayınlanan ilk gazete 1996 yılında oluşturulmuştur (Gezgin, 2002, s. 34). Bu gazete Xn olarak isimlendirilmiştir. Xn'de günlük gazeteler taranmakta ve seçme haberler ile köşe yazıları internete aktarılmaktadır (Basım, 2002, s. 15). Xn gazetesi haberleri devamlı yenileyerek farklı bir gazetecilik anlayışı geliştirmiştir (Özgen, 2012, s. 60).

Basılı gazetelerin yanı sıra basılı gazetesi olmaksızın internette yer alan gazeteler süreç içerisinde çoğalmıştır. Xn gazetesi ilk sanal gazete olarak görülmektedir. 1998 yılında yayınlanmaya başlayan Net Gazete ise yeni bir anlayış ortaya koymuştur. Gazete kendi haberlerini yapıp yayınlayan ilk haber sitesi olarak ifade edilmektedir (Çevikel, 2004, s. 153). Dolayısıyla internet mecrası üzerinden yayınlanan bu gazete derleme haberler yerine kendi haberlerini üreten bir gazete niteliği taşımaktadır.

Günümüzde geleneksel olarak yayınlanan tüm gazetelerin aynı zamanda internet mecraları da bulunmaktadır. Buna ek olarak sadece internet üzerinden yayınlanan gazeteler de yayın yapmaktadırlar. Dolayısıyla tarihsel süreçte yaşanan teknolojik yenilikler gazeteleri değiştirmiş, dönüştürmüş ve internetle birlikte yeni bir mecra toplumsal hayata girmiştir.

WEB 2.0 TEKNOLOJİSİ VE GAZETECİLİĞE ETKİLERİ

İnternetin gelişim tarihinde önemli kırılma noktaları bulunur. İlk çıktığında kullanımı özel uzmanlık gerektiren bir teknoloji iken zaman içerisinde bu teknoloji hemen herkesin cebinde taşıdığı cihazlarla da kullanılır hale gelmiştir. Bir dizi teknolojik ilerleme bu sürecin oluşumunu mümkün kılmıştır. World wide web teknolojisinin icadı internetin toplum içinde yaygınlaşmasında kritik bir rol üstlenmiştir. Süreç içerisinde önemli bir yenilik olarak ortaya çıkan web 2.0 teknolojisi de toplumsal hayatta önemli bir süreci başlatmıştır. Günümüzde yapay zeka teknolojisinin de gündelik hayatta her geçen gün daha fazla kullanıldığı görülmektedir. Bu yeniliklerin her biri internetin toplumsal hayatta daha fazla yer edinmesini sağlayan başlıca etkenlerden olduğu ifade edilebilir.

World wide web (www) teknolojisinin icadı internetin yaygınlaşmasını etkilemiştir. Bu teknoloji içerisinde, kullanıcılar daha çok internet üzerinden belirli bir sayfaya erişmekte ve bu sayfayı alımlamaktadır. Bir başka ifadeyle web 1.0 teknolojisinde kullanıcılar bilgiyi yalnızca alımlayıcı konumundadır (Latorre, 2021, s. 345). Dolayısıyla kullanıcılar birer izleyicidir. Yani webin bu ilk neslinde, varolan içeriğe herhangi bir müdahalesi olmayan kullanıcılar bulunmaktadır. Web 2.0 teknolojisi ise bu süreci bir ileri noktaya taşımıştır.

Web teknolojisi içerisinde en önemli ve kritik dönemlerden biri web 2.0 teknolojisinin başladığı dönem olarak ifade edilebilir. Genel olarak web 2.0 nesli forum, blog, yorum ve sosyal ağları içermekte ve bilgi paylaşımına izin vermektedir (Latorre, 2021, s. 344). Dolayısıyla bu dönemde kullanıcıların yayıncıya dönüşebildiği bir süreç yaşanmaktadır. Bu dönemde facebook ve sonrasında ortaya çıkan sosyal medya platformları kullanıcıların kendi gönderilerini oluşturup paylaşabildiği mecralar olmuştur. Yani, facebook, youtube, instagram, X gibi sosyal medya platformlarından kullanıcılar kendi gönderilerini yayınlama olanağı yakalamışlardır. Günümüzde ise bu süreç daha da etkili bir hale gelmiştir.

Tüm bu süreçler internetin kullanımını daha fazla artırmakta ve kullanıcılara birçok alanda çeşitli kolaylıklar sağlamaktadır. We are Social 2025 raporunda dünyada 5,56 milyar kişinin internet kullandığı, 5,78 milyar kişinin cep telefonu kullandığı ve sosyal medya kullanıcı kimliklerinin ise 5,24 milyar olduğu belirtilmektedir (Wearesocial, 2025). Bu bilgilerden hareketle dünyada hem internet hem de sosyal medyanın yaygın olarak kullanıldığı ve yaygınlığın ise günden güne artış gösterdiği ifade edilebilir.

İnternetin gelişim evreleri ve giderek yaygınlaşması birçok iş kolu ve sektörü de etkilemiştir. Bu etki gazetecilik mesleğinde de yaşanmıştır. Geleneksel kitle iletişim araçları, yani gazete, televizyon ya da radyodan gazetecilik faaliyeti yürüten gazeteciler yeni dönemde gazetecilik faaliyetlerini internet mecrası üzerinden de yapmaya başlamışlardır. Gazeteciler için internet ve sosyal medya birçok kolaylığı beraberinde getirmiştir. Yeni oluşan mecra üzerinden de yayın yapma olanağı bulan yayın kuruluşları bu süreçte bir değişim ve dönüşüm süreci içerisine de girmişlerdir.

İnternet teknolojisiyle birlikte geleneksel kitle iletişim araçları aynı zamanda internet üzerinden de yayın yapmaya başlamışlardır. Buna ek olarak sadece internet üzerinden yayınlanan gazeteler ortaya çıkmıştır. Tüm bu süreçler web 2.0 teknolojisinin getirmiş olduğu yeni platformlarla yeniden bir dönüşüm sürecine girmiştir. Artık toplumsal hayatta giderek daha fazla yer alan sosyal medya platformları gazeteciler için de kullanışlı bir alan yaratmıştır. Yeni dönemde sadece sosyal medya üzerinden yayın yapan gazeteciler ortaya çıkarken sosyal medya giderek insanların daha fazla bilgi ve haber talep ettiği mecralar olmuştur.

Web 2.0 teknolojisinin bir etkisi de sıradan insanlara gazetecilik yapma olanağı vermesidir. Bu süreç, gazetecilikle ilgisi olmayan vatandaşların gazetecilerin yaptığı işe benzer işler yapmasına imkân vermiştir. Bu süreçte, haber ve bilgi paylaşımında dikkat edilmesi gereken temel bilgilerden yoksun içerik üreticileri çeşitli yayınlarla bu alanda var olmaya başlamışlardır. Bu da haber ve bilgi yayılımı için çeşitli etik ihlalleri ve riskleri beraberinde getirmiştir. Bilgi kirliği, yanlış bilginin dolaşıma daha fazla girmesi ve mahremiyet ihlalleri gibi etik ihlaller bunların başlıcaları olarak ifade edilebilir.

GÜNÜMÜZDE HABER ÜRETİMİ VE YAPAY ZEKÂ

Günümüzün popüler kavramlarından biri yapay zekâ kavramıdır. Gündelik yaşamda kullanılırlığı ve etkisi giderek artan yapay zekâ birçok alanda kullanılmaya başlamış ve birçok iş kolunu etkisi altına almıştır. Yakın gelecekte yapay zekânın birçok alanda başlıca başvurulan teknoloji olacağı görülmektedir.

Artificial Intelligence (AI) olarak ifade edilen kavram günden güne toplumsal hayata daha fazla girmektedir. "AI'ın amaçları, makineler, normalde elektronik makineler, aracılığıyla insanın ussal etkinliğini olabildiğince taklit etmek ve belki sonuçta insanın ussal etkinlik yeteneğini geliştirmektir" (Penrose, 2004, s. 11). Dolayısıyla temel olarak yapay zeka, insan zekası ile bilgisayar becerilerini bir araya getiren bir kavram olarak öne çıkmaktadır. Yani, yapay zeka, bilgisayarların insan gibi düşünüp karar verebilecek bir iş yükü ile ilintilendirilebilir. Bu bağlamda, yapay zeka kavramı tarihsel süreçte üzerinde durulan bir araştırma konusu olarak ortaya çıkmaktadır. Tarihsel olarak bakıldığında yapay zeka kavramının 1956'da yapılan bir konferansta doğduğu ve bu konferansta J. McCharty, M. Minsky, C. Shannon, A. Newell ve H. Simon tarafından zeka ile donatılmış bilgisayar programlarının geliştirilmesi ihtimalinin araştırılması önerilmiştir (Haton & Haton, 1991, s. 8).

Süreç içerisinde yapay zeka teknolojisi giderek daha çok gelişim göstermiştir. Günümüzde adı daha fazla duyulan bu alan birçok sektörde kullanılmaya başlamıştır. Araçlarda, mobil cihazlarda, güvenlik

teknolojilerinde, eğitimde, sağlıkta ve birçok alanda yapay zekanın kullanıldığı bilinmektedir. Sektörler dışında gündelik yaşamda da yapay zeka teknolojileri giderek daha bilinir hale gelmekte ve kullanılmaktadır. Dijital Tüketici Trendleri 2024 raporunda Türkiye'de üretken yapay zeka farkındalığı ve kullanımı konusunda katılımcıların %69'unun yapay zekadan haberdar oldukları, %52'sinin yapay zekayı kullandıkları ifade edilmektedir (Deloitte, 2024). Dolayısıyla Türkiye'de ankete katılan her iki kişiden birinin yapay zekayı kullandıkları sonucu ortaya çıkmaktadır.

Yapay zeka teknolojisi özellikle çok fazla verinin işlenmesi konusunda kullanıcılara büyük avantajlar sağlamaktadır. Bu teknolojiyi kullanan bir işkolu da kuşkusuz gazeteciliktir. Gündelik haber akışı içerisinde hızın oldukça önem taşıdığı gazetecilikte yapay zeka gazetecilere önemli bir katkı sağlamaktadır. Örneğin, LA Times, 18 Mart 2014'te Los Angeles'ta meydana gelen depremi robot gazetecilik kullanarak 3 dakika içinde haberleştirerek insan gücüne ihtiyaç duymadan son dakika haberi olarak yayınlamıştır (Kalsın, 2016, s.87). Dolayısıyla, hızın önemli olduğu gazetecilikte bu teknolojinin kullanılması gazetecilere büyük avantaj sağlamaktadır.

Haber için gerekli bilgilerin toplanması ve bir veri olarak çeşitli yapay zeka uygulamalarına girilmesi ile bir haberin üretimi mümkün hale gelmiştir. Ayrıca haberin geliştirilmesi için çeşitli öneriler almak, başlıkları düzenlemek, anlam kargaşasını önlemek ve yazım denetimi yaptırmak gibi işlevsel görevler de yapay zeka aracılığı ile gazetecilerin işini kolaylaştırmaktadır. Yapılan bir çalışmada görüşülen kişilerin yapay zekanın zaman tasarrufu, verimliliğin artması gibi faydalarla gazeteciliğe olumlu yönde etki edeceği konusunda görüş birliği içerisinde oldukları belirtilmektedir (Noain-Sánchez, 2022). Gül (2024) yapmış olduğu araştırmada yapay zekanın gazetecilikte olumlu ve olumsuz etkilerinin olduğunu ifade ederek bilgi toplama, çeviri, haber öneri sistemleri geliştirme gibi olumlu özelliklerinin yanı sıra yapay zekanın bazı etik sorunları daha da artırdığını belirtmektedir. Yapılan bir çalışmada görüşülen medya profesyonellerinin yapay zekanın gazeteciliğe doğru şekilde eklemlediğinde faydalı olacağını ancak, etik, gazetecilik mesleğinin niteliği ve istihdam konularında medya profesyonellerinin endişeli oldukları belirtilmektedir (Kırık, vd., 2024).

Yukarıda da vurgulandığı gibi yapay zeka birçok alanı etkisi altına almıştır. Bu alanların biri de kuşkusuz gazeteciliktir. Günümüzde yapay zeka uygulamaları oldukça gelişmiştir. Gelişim süreci de artarak devam etmektedir. Bu teknolojinin önemi ise giderek artacaktır. Yapay zeka uygulamalarının gazetecilikte ilerleyen dönemlerde daha fazla kullanılacağı açıktır.

SONUÇ VE TARTIŞMA

Bu çalışma gazeteciliğin dijitalleşme sürecini ele almakta ve gelenekselden dijitale gazeteciliğin dönüşümüne odaklanmaktadır. Tarihsel süreçte bilgisayar teknolojisi ve internetin çeşitli ilerlemeler kaydederek günümüzdeki halini alışı birçok alanı etkilemiştir. Doğal olarak gazetecilik de bilgisayar ve internet teknolojisinden etkilenmiştir. İnternetin ortaya çıkışı ve yaygınlaşmaya başladığı süreçte kitle iletişim araçları gelenekselden yayın yapmanın yanı sıra internet ortamından da yayın yapmaya başlamışlarıdır. Bu bağlamda geleneksel kitle iletişim araçları için internet ortamı yeni bir mecra yaratmıştır. Süreç içerisinde tüm kitle iletişim araçları internette yer almış sadece internet üzerinden yayın yapan internet medyası da oluşmuştur.

Dijitalleşme ve internetin gelişim sürecinden gazetecilik mesleği de etkilenmiştir. Bu kapsamda gazetecilik pratikleri dönüşmeye başlamıştır. Geleneksel gazetelerin yanı sıra internet gazetelerinin de ortaya çıkışı habercilik pratiklerini değiştirmeye başlamıştır. Haberin üretimi, bilgi toplanması, kaynak ile iletişim, haberin kitle iletişim aracının merkezine iletilmesi, düzenlenmesi ve dağıtımı giderek daha fazla bilgisayarlar ve internet üzerinden yapılmaya başlanmıştır. Günümüzde ise bu süreçlerde tamamıyla bilgisayar ve internet teknolojisi kullanılmaktadır.

Süreç içerisinde web 2.0 teknolojisi gelişmiş, sosyal medya platformları ortaya çıkmıştır. Sosyal medya platformları giderek daha fazla insanın ilgisini çekmiş ve bu platformlar da oldukça yaygınlaşmıştır. Sosyal medya devrinin başlaması da gazeteciliği değişim ve dönüşüm sürecine sokmuştur. Haber toplama sürecinden haber yazımına kadar hatta haberin dağıtımına kadar gazeteciliğin tüm iş yapış süreçleri internet teknolojisinden etkilenmiştir. İnternetten daha fazla bilgiye erişebilen gazeteciler aynı zamanda kaynak bulmada daha fazla olanak elde etmişlerdir. Bu olanaklar kuşkusuz gazeteciler için oldukça kolaylıklar sağlamaktadır. Ancak, internette çok fazla bilgi kirliliği de bulunmaktadır. Özellikle sosyal medya mecralarında birçok amatör içerik üreticisinin olduğu günümüzde yanlış bilginin hacminin de arttığı görülmektedir. Dolayısıyla bu süreçte gazetecilerin bilgi ve kaynak bulması kolaylaşırken yanlış bilgi ile karşılaşması da kolaylaşmıştır. Bu bağlamda, gazetecilerin oldukça dikkatli bir şekilde araştırmasını yapması zorunlu hale gelmiştir.

Haberin anında okuyuculara iletilmesi, gazetecinin kaynak ile internet üzerinden röportaj, mülakat, görüşme yapabilmesi, haberin hızlıca üretilmesi ve dağıtılması internet sürecinde gazeteciler için oldukça faydalı olmuştur. Ancak, bu durum gazetecilerin çok yönlü olmalarını da gerekli hale getirmiş ve iş yüklerini daha da artırmıştır. Geleneksel kitle iletişim araçlarına kıyasla internet teknolojisi gazetecilik için hız baskısını da artırmıştır. Dolayısıyla gazetecilikte dijital dönüşüm ve internet teknolojisinin getirmiş olduğu olanaklar aynı zamanda bazı dezavantajları da beraberinde getirmiştir.

Günümüzde ismi sıklıkla duyulan yapay zeka teknolojisi gazetecilik için artık daha fazla kullanılır hale gelmiştir. Kuşkusuz yapay zeka teknolojisini kullanan bir insandır. Ancak birçok insanın yaptığı, yapmaya çalıştığı ve uzun sürelerde yapabildiği işi yapay zeka teknolojisi saniyeler içerisinde yapabilmektedir. Bu durum da gazeteciler için istihdam sorunlarını ortaya çıkaracaktır. Yani bir yandan yapay zeka teknolojisi gazeteciler için oldukça işlevsel iken bir yandan da gazetecilerin işini elinden alabilecek potansiyeli bulunmaktadır.

İnternet teknolojisinin giderek gelişim gösterdiği günümüzde tüm kitle iletişim araçları internette yer almaktadır. Gazeteler de internetteki yerlerini almışlardır. İnternet ve dijitalleşme süreci diğer birçok alanı değiştirdiği ve dönüştürdüğü gibi gazeteleri ve gazetecilik mesleğini de değişim ve dönüşüm süreci içerisine sokmuştur. Sonuç olarak kitle iletişim araçları ve gazeteler internetin icadından ve gelişiminden oldukça etkilenmişlerdir. İnternetin ve dijitalleşmenin etkisi ise aratarak devam edecektir.

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Modern Topraksız Sera Koşullarında Aşılı ve Aşısız Fide Kullanılarak Yapılan Patlıcan Üretiminin Karlılığı

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ÖZET

Patlıcan, önemli bir sebze türü olup, gerek taze tüketim gerekse sanayiye yönelik kullanım açısından stratejik bir yere sahiptir. Türkiye'de sofralık tüketiminin yanı sıra közlenmiş, kurutulmuş, konserve ve turşu gibi işlenmiş formlarda da yaygın şekilde değerlendirilen önemli bir sebze türüdür. Aynı zamanda ülke genelinde geniş üretim alanlarına sahip olup hem iç piyasa hem de ihracat açısından ekonomik değeri yüksek ürünler arasında yer almaktadır. Üretim sürecinde hastalıklara duyarlılığı, uzun yetişme süresi ve iklimsel koşullara bağlı verim değişkenliği gibi faktörler nedeniyle modern üretim tekniklerinin kullanımı önem arz etmektedir. Bu bağlamda özellikle topraksız tarım uygulamaları, kaynak kullanım etkinliğini artırarak sürdürülebilir ve kontrollü üretime katkı sağlamaktadır.

Bu çalışma, 1 da modern topraksız serada aşılı ve aşısız fide kullanılarak yapılan patlıcan yetiştiriciliğinin maliyet analizine odaklanmaktadır. Araştırmada fide maliyeti, saksı, cocopeat, tarımsal ilaçlar, gübre, askı ipi ve klipsi, işçilik giderleri, döner sermaye ve diğer değişken masraflar detaylı biçimde ele alınmış ve her iki üretim yöntemine ait maliyet kalemleri karşılaştırılmıştır. Aşılı fidelerin daha yüksek birim maliyetlerine rağmen, üretim sürecindeki dayanıklılık ve potansiyel verim artışı göz önünde bulundurularak ekonomik açıdan sağladığı avantajlar analiz edilmiştir. Çalışmanın sonuçları, topraksız tarımda maliyet optimizasyonu yapmak isteyen üreticiler için önemli bir referans kaynağı sunmakta ve özellikle modern seracılık yatırımları öncesinde karar destek mekanizması olarak kullanılabilecek öneriler ortaya koymaktadır.

Key words: *Patlican, Maliyet analizi, Topraksız Tarım, Modern Sera*

GİRİŞ

Küresel iklim değişikliği, nüfus artışı ve tarım arazilerinin daralması, geleneksel üretim sistemlerinin sürdürülebilirliğini sorgulatmakta; kaynak verimliliğini önceleyen modern tarım tekniklerine olan ilgiyi artırmaktadır. Bu bağlamda topraksız tarım sistemleri, su ve besin kullanımında yüksek etkinlik sağlamaları ve yıl boyu üretime olanak tanımaları sayesinde günümüzde stratejik bir üretim modeli olarak öne çıkmaktadır (Gruda, 2009; Van Os et al., 2020; Savvas & Ntatsi, 2011).

Özellikle patlıcan (Solanum melongena L.), Türkiye'de önemli bir sebze türü olup hem iç tüketimde hem de işleme sanayinde stratejik bir yer tutmaktadır. Patlıcan üretiminde topraksız tarım uygulamaları, çevresel kontrol ve besin yönetiminin optimizasyonuyla kaliteli ve sürekli ürün elde edilmesini sağlamaktadır (Tüzel ve ark., 2009). TÜİK 2024 yılı verilerine göre patlıcan üretim miktarı, Tokat için 11084 ton iken, Türkiye geneli için bu rakamın 827004 ton olduğu görülmüştür. Tokat ili ve Türkiye için ekim alanı ise sırasıyla 4456 ve 193067 da olarak kaydedilmiştir. Türkiye geneli için örtüaltı

sebzeciliği verilerine göre 2024 yılında toplam 29163 dekar ekilen alan bulunmaktadır. Bununla beraber 368186 ton üretim gerçekleştirilmiştir (TÜİK, 2024).

Ancak üretim sisteminin başarısı yalnızca altyapıyla sınırlı olmayıp kullanılan fide türü de önemli bir rol oynamaktadır. Bu noktada; aşılı fide kullanımı, bitki gelişimi, stres toleransı, hastalıklara dayanıklılık ve verim üzerine olan olumlu etkileriyle ön plana çıkmaktadır (Yetisir ve Sari, 2003; Oda ve ark., 2005). Aşılı fideler, özellikle kök hastalıklarına karşı direnç sağlamakta ve üretim süresince daha az kayıpla daha yüksek verim alınmasını mümkün kılmaktadır (Tüzel ve Gül, 2008). Ancak aşılı fidelerin üretim ve temin maliyetleri, aşısız fidelerle kıyaslandığında daha yüksek olabilmektedir (Baytorun ve ark., 2002). Bu durum, üreticilerin karar verme sürecinde ekonomik analizleri dikkate almasını zorunlu kılmaktadır.

Literatürde aşılı ve aşısız fide kullanılarak yapılan üretimlerin teknik avantajlarına dair çok sayıda çalışma bulunmasına rağmen, özellikle modern topraksız seralarda yapılan uygulamaların maliyet kalemleri bazında kapsamlı şekilde incelendiği çalışmalara daha fazla ihtiyaç duyulmaktadır. Bu bağlamda, bu çalışma; 1 hektarlık modern bir serada aşılı ve aşısız patlıcan fideleri kullanılarak yapılan üretimin, girdi kalemleri temelinde ekonomik karşılaştırmasını yapmayı amaçlamaktadır. Elde edilen bulgular hem üreticilere hem de yatırımcılara karar verme süreçlerinde önemli katkılar sunacaktır.

MATERYAL METOT

Bu çalışma, 1 hektarlık modern bir serada, aşılı ve aşısız patlıcan fideleri kullanılarak yapılan üretimin ekonomik analizini gerçekleştirmeyi amaçlamaktadır. Çalışmada, her iki üretim yöntemi için kullanılan girdiler ayrıntılı şekilde incelenmiş, üretim süreci boyunca oluşan maliyet içerisinde masraf unsurları oransal olarak karşılaştırılmıştır.

Analizlerde kullanılan veriler, 2024 yılı üretim sezonuna ait olup, uygulama sahasındaki gerçek üretim kayıtlarına dayanmaktadır. Üretim sürecinde kullanılan girdiler; fide maliyeti, saksı, cocopeat, ilaç, gübre, işçilik, askı ipi, askı klipsi, döner sermaye değişken masraflar olarak, elektrik, su, sera amortismanı, yönetim giderleri ve sulama sistemleri ise sabit masraflar olarak sınıflandırılmıştır. Aşılı ve aşısız fidelerin seradaki performansları birbirinden bağımsız parsellerde aynı çevresel koşullar altında değerlendirilmiş ve üretim girdileri ayrı ayrı takip edilmiştir.

Girdi maliyetleri hesaplanırken T.C. Ziraat Bankası'nın bitkisel üretim faaliyetlerine yönelik 2024 yılı faiz oranı olan %9,45 esas alınmış, yıl içine yayılan değişken giderler için bu oranın yarısı (%4,725) dikkate alınmıştır (Kıral ve ark., 1999). Genel idari giderler, toplam değişken giderlerin %3'ü olarak kabul edilmiştir.

Uluslararası karşılaştırmalarda kullanılmak üzere, Türkiye Cumhuriyet Merkez Bankası'nın 2024 yılı üretim dönemi olan haziran-aralık ayı ortalama döviz kuru olan 1 ABD Doları = ₺33,71 esas alınarak toplam maliyetler döviz cinsine çevrilmiştir. Böylece, farklı ülkelerde yapılan benzer çalışmalarla sağlıklı bir kıyaslama yapılması hedeflenmiştir.

Elde edilen veriler doğrultusunda, aşılı ve aşısız patlıcan üretiminde birim alan başına düşen toplam üretim maliyetleri hesaplanmış; kârlılık düzeyleri ekonomik analiz yöntemleriyle karşılaştırılmıştır.

BULGULAR VE TARTIŞMA

Bu çalışma, modern seracılıkta yaygın olarak kullanılan aşılı ve aşısız patlıcan fideleriyle yapılan üretimin ekonomik açıdan karşılaştırılmasını amaçlamaktadır. Özellikle bir hektarlık modern bir serada yürütülen üretim sürecinde, her iki fide türünün üretim maliyetlerine olan etkisi, girdi kalemleri bazında

ayrıntılı olarak analiz edilmiştir. Böylece üreticilerin ve yatırımcıların, hangi üretim yönteminin daha ekonomik ve sürdürülebilir olduğunu değerlendirebilmeleri için karar süreçlerine katkı sunacak somut veriler ortaya konmuştur. Aşağıda yer alan tabloda, her iki üretim yöntemine ait değişken masraflar ortaya konmuştur.

Tablo 1. Değişken Masraflar

	Aşılı	%	Aşısız	%
Fide maliyeti	11539,47	24,01	4615,79	11,27
Saksı	5192,76	10,81	5192,76	12,68
Cocopeat	13165,49	27,40	13165,49	32,14
İlaç (İnsektisit)	1468,66	3,06	1468,66	3,59
İlaç (Fungusit)	655,65	1,36	655,65	1,60
Gübre	2360,35	4,91	2360,35	5,76
İşçilik	12297,4	25,59	12297,4	30,02
Askı ipi	131,13	0,27	131,13	0,32
Askı klipsi	118,02	0,25	118,02	0,29
Döner sermaye	1126,29	2,34	960,26	2,34
Değişken masraf	**48055,22**	**100,00**	**40965,51**	**100,00**

Tablo 1, patlıcan yetiştiriciliğinde aşılı ve aşısız fide kullanımına göre değişken masraf kalemlerinin dağılımını göstermektedir. Aşılı fide ile yapılan üretimde toplam değişken masraf 48.055,22 dolar iken, aşısız üretimde bu tutar 40.965,51 dolar olarak gerçekleşmiştir. Masraf farkının temel nedeni, aşılı fidelerin 11.539,47 dolar ile %24,01 oranında yüksek bir maliyet oluşturmasıdır; bu kalem, aşısız üretimde yalnızca 4.615,79 dolar ile %11,27'lik bir paya sahiptir. Her iki sistemde de cocopeat ve işçilik en yüksek paya sahip gider kalemleri olup, cocopeat %27,40 (aşılı) ve %32,14 (aşısız), işçilik ise %25,59 (aşılı) ve %30,02 (aşısız) oranlarında toplam masraflar içinde yer almaktadır. Saksı, ilaç, gübre ve askı ekipmanları gibi diğer kalemlerde ise tutarlar aynı kalmakta, ancak yüzdesel oranlar toplam masraflardaki farklılık nedeniyle değişiklik göstermektedir. Bu durum, aşılı sistemin başlangıçta daha yüksek maliyetli olduğunu ancak potansiyel olarak daha dayanıklı ve verimli bir üretim süreci sunduğunu göstermektedir.

Patlıcan yetiştiriciliğinde üretim sürecinin toplam maliyet yapısını daha bütüncül bir şekilde değerlendirebilmek amacıyla sabit masraflar da dikkate alınmalıdır. Sabit masraflar, üretim dönemi boyunca doğrudan değişmeyen ancak toplam maliyet üzerinde önemli etkisi olan kalemleri kapsamaktadır. Bu bağlamda, aşağıda sabit masraf kalemlerine ilişkin detaylar Tablo 2 de sunulmuştur.

Tablo 2. Sabit Masraflar

	Aşılı	%	Aşısız	%
Yönetim gideri	1441,66	7,74	1228,97	6,68
Elektrik	4851,82	26,06	4851,82	26,36
Su	1311,3	7,04	1311,3	7,12
Sera amortismanı	8392,34	45,07	8392,34	45,59
Sulama sistemi	2622,61	14,09	2622,61	14,25
Sabit masraf	**18619,73**	**100,00**	**18407,04**	**100,00**

Tablo 2, patlıcan üretiminde aşılı ve aşısız fide kullanımına göre sabit masraf kalemlerinin dağılımını göstermektedir. Her iki üretim sisteminde de sabit masraflar birbirine oldukça yakın olup, aşılı üretimde toplam sabit masraf 18.619,73 dolar, aşısız üretimde ise 18.407,04 dolar olarak gerçekleşmiştir. En yüksek payı her iki sistemde de sera amortismanı oluşturmakta ve yaklaşık %45 oranında toplam sabit masraflar içinde yer almaktadır. Elektrik gideri %26 civarında, sulama sistemi ise %14 oranında paya sahiptir. Su giderleri aynı kalırken, yönetim gideri aşılı üretimde biraz daha yüksek olup %7,74 ile aşısız üretimin %6,68'lik oranının üzerinde yer almaktadır. Genel olarak, sabit masraflar üretim şekline göre büyük farklılık göstermemekte; bu masraflar daha çok altyapı yatırımları ve üretim tesislerinin sabit giderlerini yansıtmaktadır.

Değişken masraflar ve sabit masraflar bir araya geldiğinde toplam üretim masraflarını oluşturmaktadır. Bu masrafların kendi içerisindeki paylarının yüzdesel olarak gösterimi aşşağıda verilen Tablo 3 de yer almaktadır.

Tablo 3. Toplam Üretim Masrafları

	Aşılı	%	Aşısız	%
Değişken Masraf	48055,22	72,07	40965,51	69,01
Sabit Masraf	18619,73	27,93	18407,04	30,99
Toplam Masraf	66674,94	100	59372,55	100
Maliyet	0,19		0,19	

Tablo 3, patlıcan üretiminde aşılı ve aşısız fide kullanımına göre toplam masraflar gösterilmektedir.. Her iki üretim sisteminde de de toplam masraflar birbirne yakın çıkmıştır. Aşılı üretimde değişken masraflar toplam masrafların %72,07 sini oluştururken,sabit masraflar %27,93 ünü oluşturmaktadır. Aşısısz üretimde ise sabit masraflar toplam masrafların %69,01 ini oluştururken sabit masraflar 30,99 unu oluşturmaktadır.

Genel olarak, aşılı fide ile üretim yapmak daha pahalı olsa da, bu fark büyük oranda fide maliyetinden kaynaklanmaktadır. Diğer tüm kalemler her iki üretim türü için aynıdır.

1 hektar serada yapılan patlıcan yetiştiriciliğinde, aşılı ve aşısız fidelerle elde edilen üretim miktarı ve gelirler aylara göre değişmektedir. Haziran ayından Aralık ayına kadar süren hasat döneminde toplamda 7 ay boyunca ürün alınmaktadır. Aşılı üretimde toplam 352.550 kg, aşısız üretimde ise 314.090

kg patlıcan elde edilmiştir. Bu verim farklılığı, doğal olarak gelirleri de etkilemektedir. Haziran ayında aşılı üretimde 42.306 kg, aşısızda ise 38.460 kg ürün elde edilmiştir. Bu ayda kilogram fiyatı 0,39 dolar olup, gelirler sırasıyla 16.642,80 dolar ve 15.129,82 dolardır. Temmuz ayında ise fiyat 0,34 dolara düşerken, aşılı üretim 53.844 kg, aşısız üretim 47.434 kg olarak gerçekleşmiş ve gelirler sırasıyla 18.357,51 ve 16.172,10 dolardır. Ağustos ve Eylül aylarında fiyat 0,29 dolara gerilemiş; bu durum, yüksek üretim miktarına rağmen gelirleri biraz düşürmüştür. Ağustos'ta aşılı üretim 56.408 kg ile zirveye çıkarken, gelir 16.272,96 dolar olmuştur. Eylül ayında yine 53.844 kg ürün alınmış ve gelir 15.533,28 dolar olarak hesaplanmıştır. Aşısız üretim için de bu aylar sırasıyla 49.998 kg ve 14.423,76 dolar gelir ile 49.998 kg ve yine 14.423,76 dolar gelir getirmiştir. Ekim ayında kilogram fiyatı yeniden 0,34 dolara yükselmiş ve üretim aşılıda 51.280 kg, aşısızda 46.152 kg olarak gerçekleşmiştir. Bu dönemde aşılı üretimden 17.483,34 dolar, aşısızdan ise 15.735,01 dolar gelir elde edilmiştir. Kasım ve Aralık aylarında fiyatlar tekrar artış göstererek sırasıyla 0,37 ve 0,39 dolar olmuştur. Kasım ayında aşılı üretim 48.716 kg ve gelir 17.886,81 dolar olurken, Aralık ayında 46.152 kg üretim ile 18.155,78 dolar gelir elde edilmiştir. Aşısız üretim aynı aylarda sırasıyla 43.588 kg ve 16.003,99 dolar; 38.460 kg ve 15.129,82 dolar gelir sağlamıştır. Tüm bu veriler sonucunda, hasat dönemi boyunca aşılı patlıcan üretiminden toplam 120.332,49 dolar, aşısız üretimden ise 107.018,30 dolar gelir elde edilmiştir.

Ancak yapılan hesaplamalar aylar itibarı ile değil toplam üzerinden ortalama fiyat ve üretim miktarları kullanılarak yapılmış, ilişkili tablo 4 te verilmiştir.

Tablo 4. Patlıcan üretimi karlılık durumu

	Aşılı	**Aşısız**
Üretim miktarı (kg). A	**352550**	**314090**
Satış fiyatı (dollar/piece). B.	0.35	0.35
Üretim maliyeti (dollar/piece) C	66674,94	59373,55
Üretim değeri (dollar/piece) A*B=G	123392,5	109931,5
Birim maliyet (dollar/piece) D=C/A	0,19	0,19
Net kar (dollar/ piece) B -D	0.16	0.16
Nisbi kar G/C	1.85	1.85
Mutlak kar G-C	56717,56	50557,95

Tablo 4'te aşılı ve aşısız patlıcan üretiminin ekonomik açıdan karşılaştırılması yapılmıştır. Verilere göre, aşılı üretimde 352.550 kg, aşısız üretimde ise 314.090 kg ürün elde edilmiştir. Karlılık oranı her iki yöntemde de 1,85 olarak hesaplanmış, bu da bir birim maliyet karşılığında 1,85 dolar gelir elde edildiğini göstermektedir. Mutlak kara bakıldığında ise aşılı üretimde 56717,56 dolarken, aşısız üretimde bu rakam 50557,95 dolardır.

SONUÇ

Bu çalışma, Tokat ilinde 1 hektarlık modern bir topraksız tarım serasında, aşılı ve aşısız patlıcan fideleri kullanılarak gerçekleştirilen üretimin ekonomik analizini sunmaktadır. Patlıcan, Türkiye'de hem taze hem de işlenmiş formda yüksek talep gören stratejik bir sebze olup, topraksız tarım sistemleri sayesinde yıl boyu sürdürülebilir üretim imkânı sunmaktadır. Araştırmada, üretim sürecindeki değişken ve sabit

maliyet kalemleri ayrıntılı biçimde değerlendirilmiş; fide maliyeti, cocopeat, işçilik, gübre gibi unsurlar karşılaştırılmıştır.

Değişken masraflar açısından, aşılı üretimde toplam 48.055,22 dolar, aşısız üretimde ise 40.965,51 dolar gider gerçekleşmiştir. Bu farkın en temel nedeni, aşılı fidelerin %24,01'lik yüksek maliyet oranıdır (11.539,47 dolar). Cocopeat ve işçilik her iki yöntemde de en yüksek maliyet kalemleri arasında yer almakta; aşılı üretimde cocopeat %27,40, işçilik %25,59 oranına sahiptir.

Sabit masraflar açısından, her iki yöntem birbirine oldukça yakın olup, aşılı üretimde 18.619,73 dolar, aşısız üretimde ise 18.407,04 dolar olarak hesaplanmıştır. En büyük sabit masraf kalemi %45 oranıyla sera amortismanıdır.

Hasat döneminde (Haziran–Aralık) aşılı üretimde toplam 352.550 kg, aşısız üretimde ise 314.090 kg ürün elde edilmiştir. Ortalama kilogram satış fiyatı 0,35 dolar olarak kabul edildiğinde, aşılı üretimden 123.392,50 dolar, aşısız üretimden ise 109.931,50 dolar brüt gelir sağlanmıştır. Her iki yöntemde birim maliyet 0,19 dolar/kg, kârlılık disbi kar ise 1,84 olarak hesaplanmıştır.

Bu sonuçlar, özellikle yüksek verim hedefleyen modern seralarda, aşılı fide kullanımının ekonomik anlamda daha avantajlı olduğunu ortaya koymaktadır.

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Çıkar Çatışması

Yazarlar çıkar çatışması olmadığını beyan etmişlerdir.

Yazar Katkıları

Tüm yazarlar çalışmaya eşit katkı sağlamıştır.

Türkiye Domates Ticaretindeki Uzun Vadeli Eğilimler: İhracat ve İthalat Verilerinin Trend Analizi

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ÖZET

Domates, dünya genelinde en fazla üretilen ve tüketilen sebzelerden biri olup, hem beslenme hem de ekonomik açıdan stratejik bir üründür. Türkiye, sahip olduğu uygun iklim koşullar ve üretim kapasitesi sayesinde dünya domates üretiminde üst sıralarda yer almakta; domates, ülke tarımında gerek üretim miktarı gerekse dış ticaret katkısı açısından öncelikli bir konumda bulunmaktadır. Üretim, yalnızca açık alanda değil, ayni zamanda örtüaltı sistemlerde de yapılmakta ve bu sayede yıl boyu sürdürülebilmektedir. Örtüalti üretim, verimliliği artırarak Türkiye'nin domates üretiminde rekabetçi bir avantaj sağlamaktadır.

Çalışmanın ana amacı, yıllık ihracat ve ithalat verileri üzerinde trend analizi uygulayarak, Türkiye'nin domates ticaretindeki yönelimlerini incelemektir. Veriler, Türkiye İstatistik Kurumu (TÜİK), FAO VE USDA dan elde edilecektir. Çalışmada Türkiye'nin son 20 yıllık domates ihracat ve ithalat verilerini analiz ederek, domates ticaretindeki uzun vadeli eğilimleri belirlemeyi ve Türkiye'nin domates ticaretindeki stratejik pozisyonunu değerlendirmeyi amaçlamaktadır.

Bu çalışma, Türkiye'nin domates ihracat ve ithalatındaki yıllık değişimleri inceleyerek, dış ticaretin ülke ekonomisine etkisini ve potansiyel büyüme alanlarını ortaya koymayı amaçlamaktadır. Ayrıca, üretim kapasitesindeki artış ve dış pazar taleplerindeki değişiklikler gibi faktörlerin ticaret üzerindeki etkilerini değerlendirerek, Türkiye'nin domates üretimi ve dış ticaret politikalarının daha verimli hale getirilmesine yönelik stratejik öneriler sunacaktır. Bu bulgular, özellikle tarım sektöründeki üreticiler, ihracatçılar ve politika yapıcılar için önemli bir rehber olacak ve domates ticaretinin gelecekteki yönelimleri hakkında daha sağlam bir anlayış sağlayacaktır.

Key words: *Domates, Üretim, Trend Analizi, İthalat, İhracat*

GİRİŞ

Tarım, insanlık tarihinin en temel üretim faaliyetlerinden biri olarak, sadece gıda ihtiyacının karşılanmasında değil, aynı zamanda ekonomik büyümenin sağlanmasında, istihdamın artırılmasında ve kırsal kalkınmanın desteklenmesinde de kritik bir rol oynamaktadır (Direk, M. 2012). Gelişen teknolojiler, değişen iklim koşulları ve artan nüfus gibi faktörler, tarımsal üretimin yapısını dönüştürmekte; sürdürülebilirlik, verimlilik ve kalite gibi kavramları ön plana çıkarmaktadır (TARIM, İ. D. D. 2023).

Tarımsal üretim sistemlerinde yaşanan dönüşüm, bitkisel üretim faaliyetleri içerisinde önemli bir yer tutan sebzeciliği ön plana çıkarmaktadır. Kısa üretim süresi, yüksek ekonomik getirisi ve artan pazar talebi gibi faktörler, sebzeciliği üreticiler açısından cazip ve sürdürülebilir bir alt üretim kolu hâline getirmiştir (Demir ve ark. 2010). Özellikle kentleşme, iklim değişikliği ve teknolojik gelişmelerin

etkisiyle tarımın yapısal dönüşüm süreci hız kazanmış; bu süreçte sebzecilik, hem ekonomik değeri hem de üretim kapasitesiyle stratejik bir konuma ulaşmıştır (Arısoy, H., & Avcı, Y. 2020; Öztürk, H. İ., & Dursun, A. 2017).

Bu kapsamda, son yıllarda tarımsal üretim desenlerinde gözlemlenen değişim, sebzecilik faaliyetlerinin hem üretim hacmi hem de dış ticaret potansiyeli açısından daha fazla önem kazanmasına yol açmıştır. Artan nüfus, tüketici taleplerindeki çeşitlenme ve beslenme alışkanlıklarında yaşanan dönüşüm, sebze üretiminin genişlemesini destekleyen temel unsurlar arasında yer almaktadır. Sebzeler, vitamin, mineral ve lif açısından zengin içerikleriyle dengeli ve sağlıklı beslenmenin vazgeçilmez bir parçası olarak insan sağlığı açısından hayati bir öneme sahiptir. Ayrıca seracılık uygulamalarında görülen teknolojik ilerlemeler ve kamu politikalarıyla sağlanan destekler, sebze üretiminde dikkate değer bir artış eğilimini beraberinde getirmiştir. Türkiye geneline ait üretim verileri bu durumu açıkça ortaya koymakta olup, aşağıda sunulan Tablo 1 de sebzecilikteki bu yükseliş eğilimini yıllar itibarıyla somut biçimde yansıtmaktadır.

Tablo.1 Sebze Üretimi, İhracat ve İthalat ile Yeterlilik Göstergeleri Tablosu

Piyasa yılı Marketing year	**SEBZE Üretim (Ton)** Production (Tonnes)	**SEBZE İhracat (Ton)** Exports (Tonnes)	**SEBZE İthalat (Ton)** Exports (Tonnes)	**Yeterlilik derecesi (%)** Degree of self-sufficiency (%)
2023/'24	29 045 761	3 064 481	198 345	111,3
2022/'23	29 098 845	3 382 299	504 402	111,3
2021/'22	29 120 849	3 626 719	255 682	113,5
2020/'21	28 780 284	2 896 619	154 312	110,9
2019/'20	28 786 548	1 980 305	101 110	107,2
2018/'19	27 984 444	1 792 124	158 243	106,4
2017/'18	28 572 251	1 844 824	120 573	106,6
2016/'17	28 037 155	1 792 265	82 686	106,7
2015/'16	27 578 234	1 779 047	69 357	106,8
2014/'15	26 606 476	1 705 222	79 368	106,7
2013/'14	26 456 335	1 784 816	78 360	107,1

Tablo 1'de görüldüğü üzere, Türkiye'nin toplam sebze üretimi, 2013/2014 piyasa yılından 2023/2024 sezonuna kadar genel olarak artış eğilimi göstermiştir. 2013/2014 sezonunda 26,46 milyon ton olan üretim, 2023/2024 itibarıyla 29,04 milyon tona ulaşarak yaklaşık 2,6 milyon tonluk bir artış sağlamıştır. Bu büyüme, Türkiye'nin sebze üretim kapasitesindeki sürekliliği ve sektördeki istikrarı yansıtmaktadır.

Sebze ihracatında da dikkate değer bir artış yaşanmıştır. 2013/2014 sezonunda yaklaşık 1,78 milyon ton olan ihracat, 2021/2022 sezonunda 3,63 milyon tonla zirveye çıkmış, 2023/2024 sezonunda ise 3,06 milyon ton seviyesinde gerçekleşmiştir. Bu gelişmeler, Türkiye'nin sebze üretiminde sadece iç talebi karşılamakla kalmayıp, artı üretimini dış pazarlara da başarıyla yönlendirdiğini göstermektedir.

Yeterlilik derecesi, 2013/14–2023/24 döneminde her yıl %106 ile %113,5 arasında değişmiş ve her koşulda iç piyasada talebi karşılamaya fazlasıyla yetmiştir. Özellikle 2021/2022 sezonunda %113,5'lik oran, Türkiye'nin sebze üretiminde yüksek düzeyde kendi kendine yeterlilik sağladığını ve dış ticarete güçlü şekilde katkıda bulunduğunu ortaya koymaktadır.

Türkiye'nin sebzecilik alanında üretim hacmini istikrarlı bir şekilde artırması ve yüksek yeterlilik oranlarını sürdürebilmesi, büyük ölçüde belli başlı sebze türlerinde sağlanan güçlü üretim kapasitesine dayanmaktadır. Domates, biber, salatalık, patlıcan, kabak, soğan, havuç, lahana ve marul gibi ürünler; hem geniş üretim alanlarına sahip olmaları hem de yıl boyunca yüksek tüketim talebi görmeleri nedeniyle sebze üretiminin temelini oluşturmaktadır (Yavuz, F. 2005). Bu ürünlerin farklı iklim ve toprak koşullarına uyum sağlayabilmesi, Türkiye'nin sahip olduğu agro-ekolojik çeşitlilik ile birleşerek sebze üretiminin yurt genelinde dengeli bir şekilde yayılmasını mümkün kılmaktadır (Abak ve ark 2010).

Türkiye'nin ekolojik çeşitliliği sebebiyle farklı bölgelerde uygulanan örtü altı ve açıkta yetiştiricilik yöntemleri, domates üretiminde önemli bir avantaj sağlamaktadır (Güvenç İ. 2019). Domates, farklı iklim ve toprak koşullarına uyum sağlayabilmesi sayesinde hem açık alanlarda hem de seralarda (örtü altı) başarılı bir şekilde yetiştirilebilmektedir. Özellikle örtü altı yetiştiricilik, domatesin üretim sezonunun uzatılmasına ve daha kontrollü bir şekilde üretilmesine olanak tanımaktadır (Peet, M. M., & Welles, G. 2005). Bu yöntem, verimliliği artırırken, aynı zamanda iklimsel riskleri minimize ederek üreticilerin daha stabil gelir elde etmelerini ve bu sektördeki istihdam süresinin yıl boyuna yayılmasını sağlar (Peet, M. M., & Welles, G. 2005). Açıkta üretimde ise, özellikle sıcak iklimlerde ve geniş alanlarda daha verimli sonuçlar verebilmekte, ülke genelinde domatesin üretim alanlarını genişletmektedir. Bu çeşitlilik, Türkiye'nin tarımsal üretim kapasitesinin esnekliğini artırmakta ve yerel ekosistemlere uygun çözümler sunmaktadır.

Meyvesi yenen sebzelerden biri olan domates, hem iç pazarda hem de dış ticarette yüksek talep görmektedir (Arslan Ş ve ark, 2022). Yüksek üretim hacmi ve geniş üretim alanlarıyla domates, Türkiye'nin sebze ihracatında en önemli ürünlerden biri olup, ülkenin tarımsal dış ticaretinde stratejik bir rol oynamaktadır. Türkiye, domates üretiminde dünya genelinde 4. sırada yer alarak küresel ölçekte de önemli bir üretici konumundadır. (FAO, 2022). Ayrıca, domatesin farklı iklim koşullarına ve toprak çeşitliliğine uyum sağlayabilmesi, üretimin yıl boyunca sürdürülebilir olmasına olanak tanımakta; bu durum hem yerli tüketimin hem de ihracatın karşılanması açısından önemli bir avantaj yaratmaktadır (Özmaya, M. 2024). Hem taze tüketim hem de sanayiye yönelik kullanım potansiyeliyle öne çıkan domates, tek başına toplam sebze üretiminin üçte ikisine yakınını oluşturarak (yaklaşık %60) üretim hacmine en fazla katkı sağlayan ürün konumundadır (TÜİK, 2023). Tablo 2 de domatesteki yükseliş eğilimini yıllar itibarıyla somut biçimde yansıtmaktadır.

Tablo.2 Domates Üretimi, İhracat ve İthalat ile Yeterlilik Göstergeleri Tablosu

Piyasa yılı Marketing year	**DOMATES Üretim (Ton)** Production (Tonnes)	**DOMATES İhracat (Ton)** Exports (Tonnes)	**DOMATES İthalat (Ton)** Exports (Tonnes)	**Yeterlilik derecesi (%)** Degree of self-sufficiency (%)
2023/'24	13 300 000	1 999 047	125 120	117,1
2022/'23	13 000 000	2 286 366	414 381	117,5
2021/'22	13 095 258	2 574 375	156 960	123,7
2020/'21	13 204 015	1 927 500	75 390	117,0
2019/'20	12 841 990	1 219 985	17 249	110,7
2018/'19	12 150 000	1 155 102	34 806	110,6
2017/'18	12 750 000	1 205 511	11 243	110,7
2016/'17	12 600 000	1 246 147	10 405	111,3
2015/'16	12 615 000	1 195 050	10 950	110,8
2014/'15	11 850 000	1 127 216	9 725	110,8
2013/'14	11 820 000	1 259 287	11 302	112,3

Tablo 2'de de görüldüğü üzere, Türkiye'nin domates üretimi, 2013/2014 piyasa yılından itibaren genel olarak artış eğilimi göstermektedir. 2013/2014 sezonunda 11,82 milyon ton olan üretim, 2023/2024 sezonunda 13,3 milyon tona ulaşarak yaklaşık 1,5 milyon tonluk bir büyüme gerçekleştirmiştir. Bu artış, üretim kapasitesindeki gelişmenin yanı sıra, sektördeki sürdürülebilirliğin de bir göstergesi olarak değerlendirilebilir.

Bu dönemde domates ihracatında da dikkat çekici bir yükseliş yaşanmıştır. 2013/2014 sezonunda 1,26 milyon ton civarında gerçekleşen ihracat miktarı, 2023/2024 itibarıyla 2 milyon tonun üzerine çıkarak üretimin yaklaşık %15'ine karşılık gelmiştir. Bu gelişme, Türkiye'nin domates üretiminin sadece iç piyasaya değil, aynı zamanda dış pazarlara da güçlü şekilde entegre olduğunu göstermektedir.

Domatesin yeterlilik derecesi, incelenen on yıllık süreçte %110 ile %123,7 arasında değişmiş ve her yıl iç talebin rahatlıkla karşılandığını ortaya koymuştur. Özellikle 2021/2022 sezonunda bu oran %123,7 ile en yüksek düzeye ulaşmıştır. Bu veriler, Türkiye'nin domates üretiminde tam anlamıyla kendine yeterli bir ülke olduğunu, hatta üretim fazlasını dış ticaret yoluyla ekonomik değere dönüştürdüğünü göstermektedir.

Sonuç olarak, 2013/2014–2023/2024 dönemine ait veriler, Türkiye'nin domates üretiminde sürdürülebilir büyüme sağladığını, ihracat kapasitesini artırdığını ve bu ürünün ülkenin tarımsal dış ticaretinde stratejik bir yer edindiğini açıkça ortaya koymaktadır.

Bu sebeple, domates üretiminin gelecekteki seyri, özellikle ithalat ve ihracat değerleri açısından büyük bir öneme sahiptir. Üretim hacmindeki değişiklikler, ülkenin gıda güvenliğini doğrudan etkileyebilmekte ve dış ticaret dengelerini şekillendirebilmektedir. Bu bağlamda, domatesin ithalat ve ihracat değerlerinin geleceğe yönelik tahmin edilmesi, üreticilerin doğru stratejiler geliştirmelerine ve politika yapıcıların uygun ticaret politikalarını belirlemelerine olanak sağlayacaktır. Minitab paket

programı kullanılarak, domatesin ithalat ve ihracat verileri üzerinde trend analizi yapılacak ve beş yıllık tahminler gerçekleştirilecektir. Bu analiz, geçmiş veriler ışığında daha güvenilir sonuçlar sunarak, gelecekteki ticaret eğilimlerini belirlemeye yardımcı olacaktır. Literatürde, domatesin ithalat ve ihracatına dair geleceğe yönelik çalışmalara sıklıkla rastlanmaması, bu da yapılan çalışmanın alana önemli bir katkı sağlayacağını ve domatesin ticaretine yönelik daha verimli politika ve stratejiler geliştirilmesine imkân tanıyacağını göstermektedir.

MATERYAL METOT

Bu çalışmanın materyalini, Türkiye'nin 2000-2023 yılları arasındaki yıllık domates ithalat ve ihracat verileri oluşturmuştur. Söz konusu veriler, Türkiye İstatistik Kurumu (TÜİK) veri tabanından temin edilmiş olup, ithalat ve ihracat miktarları ton cinsinden kaydedilmiştir. Veriler analize alınmadan önce doğruluk ve tutarlılık açısından kontrol edilmiş; eksik veya uç değer içermediği tespit edilmiştir.

Verilerin analizinde, zaman serisi içerisindeki eğilimlerin belirlenmesi ve geleceğe yönelik öngörülerin yapılabilmesi amacıyla trend analizi uygulanmıştır. Bu amaç doğrultusunda, Minitab paket programı kullanılarak trend modelleri oluşturulmuş ve elde edilen seriler doğrultusunda 2024-2028 yıllarını kapsayan beş yıllık projeksiyonlar yapılmıştır.

Analiz sürecinde; lineer, kuadratik ve üstel (growth curve) olmak üzere üç farklı trend modeli değerlendirmeye alınmıştır. Model seçiminde yalnızca doğruluk ölçütleri olan Ortalama Mutlak Yüzde Hata (MAPE), Ortalama Mutlak Sapma (MAD) ve Ortalama Kareli Sapma (MSD) gibi nicel kriterler değil, aynı zamanda modelin zaman serisi boyunca veriye grafiksel uyumu da dikkate alınmıştır. Grafikler üzerinden yapılan görsel değerlendirmeler, zaman serisi analizlerinde model performansının desteklenmesinde tamamlayıcı bir unsur olarak kullanılmıştır.

Bu bağlamda, ihracat verileri için yapılan analizlerde, üstel (growth curve) model, hem doğruluk ölçütleri açısından en düşük hata değerlerini sunmuş hem de verinin hızla artan eğilimini grafiksel olarak en doğru biçimde yansıtmıştır. Bu nedenle, domates ihracatı için en uygun modelin üstel trend modeli olduğuna karar verilmiştir. Buna karşılık, domates ithalat verilerinde gözlenen dalgalı yapı ve zaman içerisindeki yön değişimleri nedeniyle kuadratik modelin daha iyi bir uyum sağladığı belirlenmiştir. Kuadratik model, doğrusal olmayan eğilimleri ve potansiyel dönüm noktalarını daha iyi temsil edebilme kapasitesi sayesinde, domates ithalat verilerinde tercih edilmiştir.

Elde edilen tahmin sonuçları, Türkiye'nin domates dış ticaretindeki potansiyel gelişmeleri ortaya koymuş; ithalat ve ihracatta beklenen artış veya azalış yönündeki eğilimlerin belirlenmesine olanak tanımıştır. Bu doğrultuda çalışma, tarımsal dış ticaret politikalarının şekillendirilmesine katkı sağlayabilecek öngörüler sunarken, aynı zamanda domates ürününe yönelik literatürdeki tahmin odaklı modelleme eksikliğini gidermeyi hedeflemiştir.

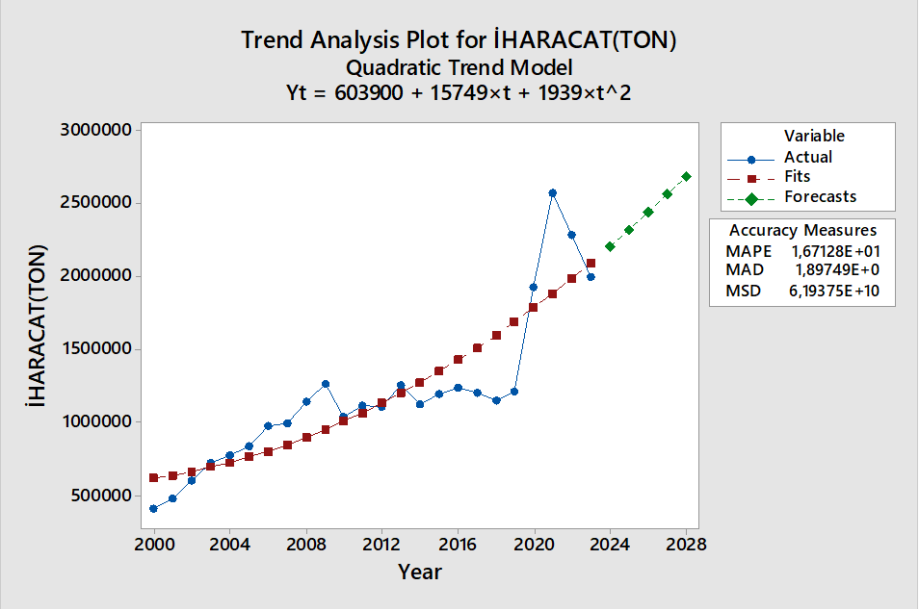
ARAŞTIRMA BULGULARI

Analizlerde, domates ihracatı ve ithalatı için doğrusal olmayan fakat sistematik bir değişim gösteren kuadratik (quadratic) trend modeli en iyi uyumu sağlayan model olarak seçilmiştir. Seçim sürecinde, farklı trend analiz türleri gözlemlenmiş, grafik eğrileri karşılaştırılmış ve en düzgün artış eğilimini yansıtan model görsel olarak belirlenmiştir.

Domates ihracatına ait kuadratik trend modeli ,TREND modeli (1) numaralı denklemde gösterilmiştir.

$$Yt = 603900 + 15749 \times t + 1939 \times t^2$$

Bu denkleme göre, Türkiye'nin yıllar içerisindeki domates ihracat miktarlarında belirgin ve hızlanarak artan bir yükseliş eğilimi gözlemlenmektedir. Kuadratik modelin tercih edilmesinin temel nedeni, verilerde doğrusal olmayan, fakat düzenli bir artış eğilimi gözlenmiş olmasıdır. Modelin performansını değerlendirmek amacıyla hesaplanan hata ölçütlerinden MAPE (Mean Absolute Percentage Error) 16,71, MAD (Mean Absolute Deviation) 189.749 ve MSD (Mean Squared Deviation) ise $6{,}19\times10^{10}$ olarak bulunmuştur.



Şekil 1: Trend Analiz Quadratic Model Çıktısı

MAPE (16,71) değeri, modelin tahmin ettiği değerler ile gerçek değerler arasındaki yüzde farkın ortalama olarak %16,71 olduğunu göstermektedir. Literatürde MAPE değeri %20'nin altında olan modeller genellikle iyi uyum sağlayan modeller olarak kabul edilir. Bu bağlamda, elde edilen MAPE değeri, ihracat modelinin kabul edilebilir düzeyde başarılı tahminler sunduğunu göstermektedir.

MAD (189.749), modelin yaptığı tahminlerin ortalama olarak yaklaşık 189 bin tonluk bir sapma gösterdiğini ifade etmektedir. Bu değer, mutlak bazda sapmanın düzeyini yansıttığı için, sektör büyüklüğü ile birlikte değerlendirilmelidir. Türkiye'nin yıllık domates ihracat hacmi düşünüldüğünde, bu sapma nispeten makul bir düzeyde kabul edilebilir.

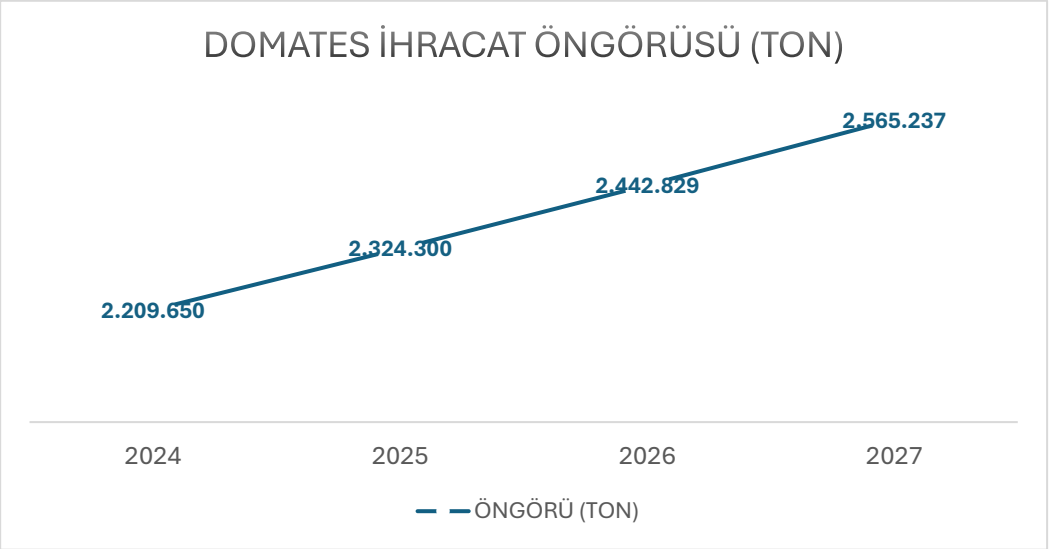
MSD ($6{,}19 \times 10^{10}$) ise modelin tahmin hatalarının karelerinin ortalamasını verir. Yüksek değerler hataların büyüklüğünü gösterebilir ancak bu ölçüt özellikle uç değerlerin etkisine karşı daha hassastır. Bu nedenle MSD değeri tek başına değil, diğer hata ölçütleriyle birlikte değerlendirilmelidir. Bu çalışmada MSD değeri ile MAPE ve MAD uyumlu sonuçlar vermiştir.

Bu değerler, modelin verilerle iyi bir uyum içinde olduğunu ve öngörü kabiliyetinin yüksek olduğunu göstermektedir. Model aracılığıyla yapılan beş yıllık öngörüler Tablo 3 de verilmiştir.

Tablo 3. Domates İhracatı Öngörüsü

YIL	ÖNGÖRÜ (TON)
2024	**2.209.650**
2025	**2.324.300**
2026	**2.442.829**
2027	**2.565.237**
2028	**2.691.522**

Tablo 3 e göre ihracat değerlerinde artış öngörülmektedir. Bu artış, Türkiye'nin domates ihracatında istikrarlı bir büyüme yakaladığını ve bu durumun gelecek yıllarda da süreceğini göstermektedir.



Şekil 2: Domates İhracat Öngörü Grafiği

Projeksiyon grafiği incelendiğinde, artış eğiliminin hızlandığı net bir şekilde gözlemlenmektedir. Bu durum, Türkiye'nin domates üretimi ve dış ticaret politikalarının olumlu yönde geliştiğini göstermesi bakımından dikkat çekicidir.

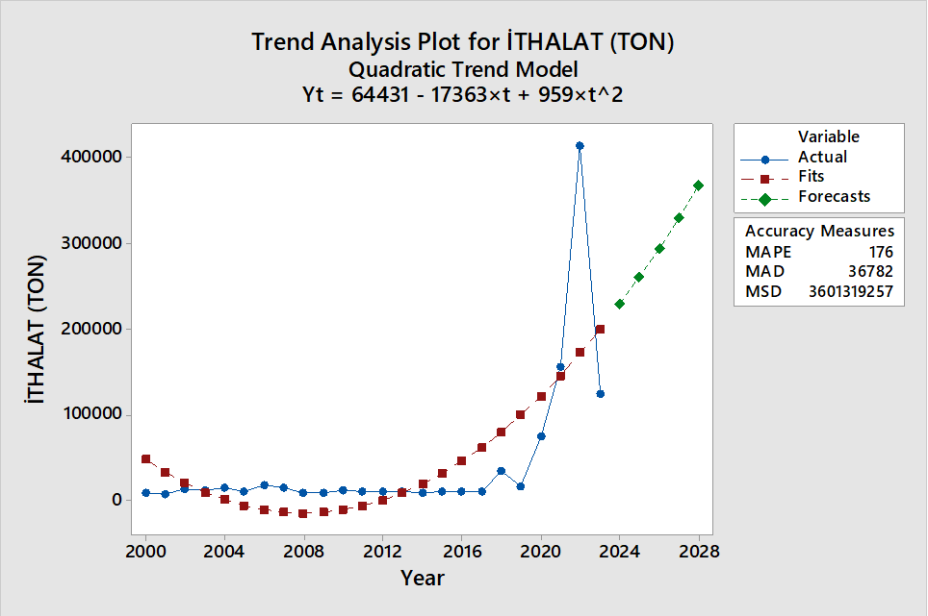
Domates ithracatına ait kuadratik trend modeli, TREND modeli (2) numaralı denklemde gösterilmiştir.

$$Yt = 64431 - 17363 \times t + 959 \times t^2$$

Bu model, domates ithalatında zamanla değişen doğrusal olmayan bir yapı olduğunu göstermektedir. Modeldeki negatif eğilimli doğrusal terim ile pozitif eğilimli ikinci dereceden terim birlikte değerlendirildiğinde, ithalatın belirli bir dönem boyunca azalma eğiliminde olduğu, ancak son yıllarda tekrar artmaya başladığı sonucuna varılmaktadır. Bu durum, ithalat verilerinin dalgalı yapısını yansıtmaktadır.

Modelin hata ölçütleri incelendiğinde, MAPE 176 gibi oldukça yüksek bir değere sahiptir. Bu, modelin tahmin doğruluğunun sınırlı olduğunu ve ithalat verilerinin dalgalı yapısının model uyumunu zorlaştırdığını göstermektedir. Diğer hata ölçütleri MAD: 36.782 ve MSD: $3{,}60 \times 10^9$ olarak

hesaplanmıştır. Her ne kadar MAPE değeri yüksek olsa da, model genel eğilimi yansıtabilme açısından belirli bir yeterliliğe sahiptir.



Şekil 3: Trend Analiz Quadratic Model Çıktısı

MAPE (176) değeri, modelin tahmin gücünün ihracat modeline kıyasla oldukça düşük olduğunu göstermektedir. %100'ün çok üzerinde olan bu değer, modelin tahminlerinde yüksek oranda hata içerdiğini ve verinin oldukça değişken bir yapıya sahip olduğunu ifade etmektedir. Bu nedenle, ithalat verileri için tahmin yapılırken daha temkinli yorumlar yapılması gerekmektedir.

MAD (36.782) değeri, ithalat modelinin ortalama olarak yaklaşık 36 bin tonluk mutlak sapma ile tahmin yaptığını göstermektedir. Bu değer sektörel büyüklük dikkate alındığında belirli bir kabul edilebilirlik sunsa da, yine de modelin güvenilirliği açısından sınırlı bir gösterge olarak kalmaktadır.

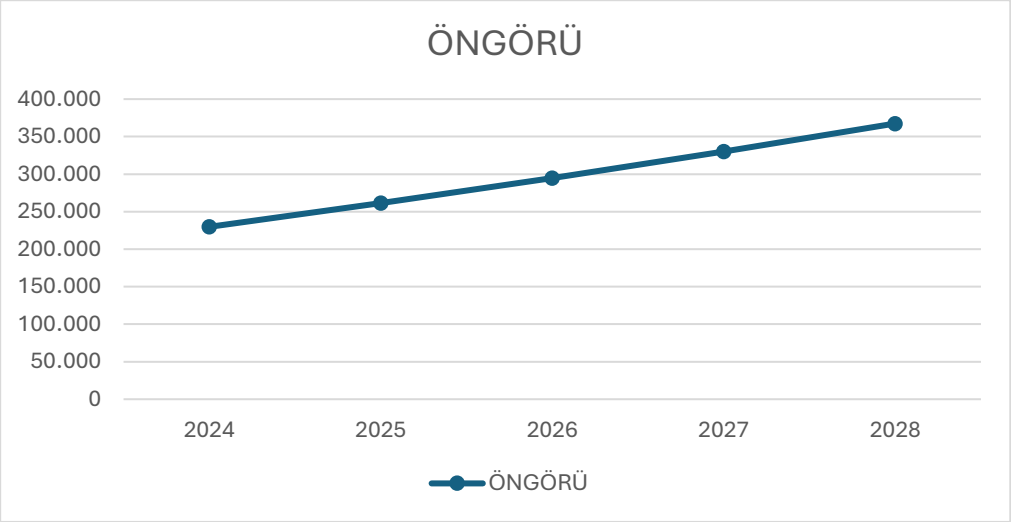
MSD ($3{,}60 \times 10^9$) değeri, tahmin hatalarının karelerinin ortalaması olarak hesaplanmıştır. Bu değerin yüksek çıkması, modelin bazı dönemlerde oldukça uzak tahminlerde bulunmuş olabileceğine işaret etmektedir. Bu durum, özellikle ithalat verilerinin yıllar içinde tutarlı bir trend izlememesi ile ilişkilidir.

Özellikle MAPE değerinin yüksek olması, ithalat verilerinin düzensizliğini ve tahmin doğruluğunun ihracata kıyasla daha düşük olduğunu göstermektedir. Model aracılığıyla yapılan beş yıllık öngörüler Tablo 4 de verilmiştir.

Tablo 4. Domates İthalat Öngörüsü

YIL	ÖNGÖRÜ (TON)
2024	**229.756**
2025	**261.304**
2026	**294.770**
2027	**330.153**
2028	**367.455**

Tablo 4 e göre veriler, Türkiye'nin ithalatında gelecek yıllarda kademeli bir artış yaşanabileceğine işaret etmektedir. Ama kademeli olarak gözlenen artıştaki veriler domateste kendimize yeterlilik oranımız paralelinde ihracat verilerine nazaran daha düşük seviyelerde seyretmektedir.



Şekil 4: Domates İthalat Öngörü Grafiği

Projeksiyon grafiği incelendiğinde, ithalat miktarlarında sabit bir artış eğilimi gözlemlenmektedir. Bu artış bazı durumlarda, özellikle dışa bağımlılığın artabileceği endişesini beraberinde getirmektedir. Fakat domates üretimde ülkemizin kendine yetme düzeyi bu düşüncenin önünü kesmektedir. Bu nedenle, ithalat eğiliminin nedenleri detaylı olarak araştırılmalı ve üretim planlaması stratejileri ile destekleyici politikalar geliştirilmelidir.

SONUÇ

Bu çalışma, Türkiye'nin 2000-2023 yılları arasındaki domates ithalat ve ihracat verilerini esas alarak, bu alandaki dış ticaret hareketlerinin yönünü ve olası gelecek eğilimlerini ortaya koymak amacıyla gerçekleştirilmiştir. Minitab yazılımı kullanılarak uygulanan trend analizi kapsamında, farklı model türleri (lineer, kuadratik ve üstel) değerlendirilmiş; veri setine en uygun eğilim çizgisi grafiksel ve istatistiksel ölçütler doğrultusunda belirlenmiştir. Bu bağlamda, domates ihracatında en uygun model kuadratik (quadratic) model olarak belirlenmiş ve 2024-2028 dönemi için geleceğe yönelik projeksiyon tahminleri yapılmıştır. Aynı yöntem ithalat verilerine de uygulanmış ve yine en uygun model kuadratik olarak seçilmiştir.

Elde edilen sonuçlar, Türkiye'nin domates ihracatında yıllar içinde düzenli bir artış eğilimi gösterdiğini ve bu eğilimin önümüzdeki yıllarda da devam edeceğini ortaya koymuştur. İhracat modelinde elde edilen hata ölçütleri (MAPE %16,7) modelin tahmin başarısının yüksek olduğunu göstermektedir. Bu durum, ihracatın yapısal olarak daha istikrarlı ve öngörülebilir olduğunu ortaya koymaktadır. Öte yandan, domates ithalat verilerinde elde edilen tahmin modeli, görece daha düşük doğrulukta sonuçlar üretmiştir (MAPE %176). Bu durum, ithalat verilerinin düzensiz yapısından ve yıllar içindeki dalgalanmalardan kaynaklanmaktadır.

Araştırma sonucunda, Türkiye'nin domates dış ticaretinde ihracat odaklı bir eğilim gösterdiği; ithalatın ise sınırlı düzeyde gerçekleştiği anlaşılmıştır. Geleceğe dönük tahminler, ihracatta artan bir seyir beklenirken, ithalatın da belirli bir ölçüde artabileceğine işaret etmektedir. Bu bulgular, tarım ve ticaret politikalarının oluşturulmasında karar alıcılara veri temelli stratejik katkılar sunabilir. Özellikle

ihracat kapasitesinin sürdürülebilirliği ve pazar çeşitlendirilmesi, önümüzdeki dönemlerde politika yapıcılar için önemli odak alanları olmalıdır.

Sonuç olarak, bu çalışma, Türkiye'nin domates ithalat ve ihracatındaki yapısal eğilimlerin anlaşılmasına ve geleceğe yönelik planlamaların bilimsel temele oturtulmasına katkı sağlamayı amaçlamıştır. Çalışmanın bulguları, literatürdeki benzer araştırmaları destekleyici nitelikte olmakla birlikte, farklı ürün grupları ve daha geniş zaman dilimlerine uygulanabilecek analizler için de yol gösterici olabilir.

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Çıkar Çatışması

Yazarlar çıkar çatışması olmadığını beyan etmişlerdir.

Yazar Katkıları

Tüm yazarlar çalışmaya eşit katkı sağlamıştır.

Optimizing Multiuser MIMO Uplink Performance at Stationary Base Stations in Dynamic Traffic Scenarios Using Non-linear Detection (case study)

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Abstract

This research focuses on analyzing the uplink performance of multiuser Multiple-Input Multiple-Output (MIMO) systems at stationary base stations operating in dynamic traffic environments, leveraging advanced non-linear detection techniques. Given the increasing demands for efficient wireless communications characterized by dynamic user mobility and varying traffic loads, conventional linear detection methods at the infrastructure level often fall short in achieving optimal Quality of Service (QoS). Consequently, this study evaluates advanced non-linear detection algorithms, specifically Successive Interference Cancellation (SIC), Sphere Decoding (SD), and Maximum Likelihood (ML) detection techniques, to quantify their impact on system performance metrics such as throughput, Bit Error Rate (BER), latency, and interference mitigation at the base station level. The objectives of this study are to quantify the uplink performance improvements achievable through non-linear detection algorithms deployed at stationary base stations in realistic dynamic traffic scenarios, to integrate Internet of Things (IoT) sensors communication protocols for real-time traffic and environmental data acquisition to support adaptive detection and to validate the proposed methodologies through comprehensive MATLAB-based simulations and practical experiments. The methodological framework includes deploying IoT sensors in urban environments to gather real-time data on traffic density, user distribution, and channel state information (CSI). These data inputs are integrated into MATLAB-based simulations, employing custom-designed scenarios that realistically emulate dynamic mobile user behavior and varying network conditions. Performance metrics will be assessed systematically for each detection algorithm, comparing their efficiency and adaptability under different traffic and channel load conditions from the perspective of stationary base stations. Expected results of the study include demonstrating enhanced uplink system capacity, improved QoS at the network edge, reduced uplink interference, and increased robustness of base station signal detection strategies when employing advanced non-linear detection techniques. The analysis will provide valuable insights into the optimal selection and real-world deployment of detection methods tailored for intelligent and traffic-aware wireless communication infrastructure.

Key words: *CSI, ML, QoS (Quality of Service), Non-Linear techniques*

INTRODUCTION

Smart “antenna” MIMO have become a key technique in any modern cellular system that refers to the use of multiple antennas for better optimization at both the transmiter and receiver ends. Wireless networks with multiple input – multiple output have drastically improved data transmission rate, proportionally with antenna numbers, thus keeping constant values for transmission range and power efficiency. The primary scientific research challenge in contemporary wireless communication lies in creating robust broadband wireless systems capable of effectively delivering multimedia services across diverse and electromagnetically challenging environments. A critical limitation in this context is the scarcity of available radio frequency spectrum. One of the most promising approaches to overcome this barrier involves employing multiple antenna techniques combined with advanced multicarrier modulation schemes, such as Orthogonal Frequency Division Multiplexing (OFDM) and Multi-Carrier Code Division Multiple Access (MC-CDMA).

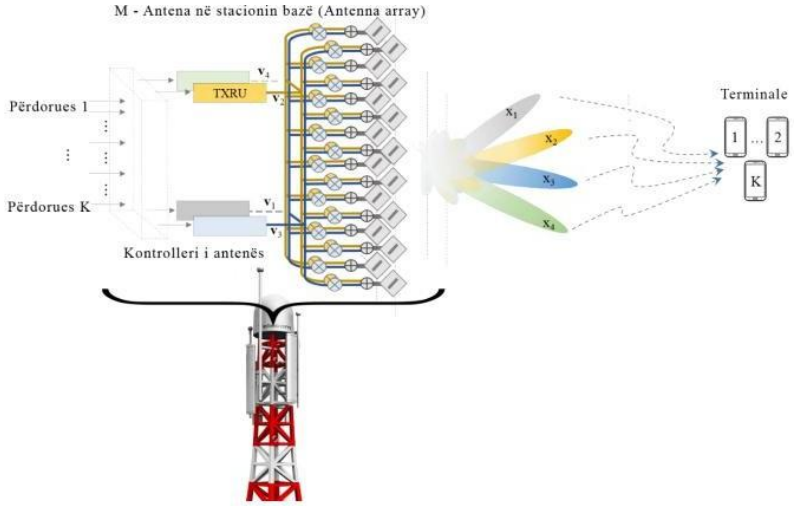


Figure 1. Relationship between K-users in array MIMO antennas for providing better spectral efficiency

Compared to traditional single-antenna configurations, multiple-antenna systems that use NT transmit antennas and NR receive antennas can significantly enhance channel capacity by a factor of min(NT, NR). Importantly, this increase in capacity occurs without requiring additional bandwidth or increased transmission power. Driven by the growing demand for faster data rates in modern and next-generation telecommunication systems, extensive research efforts have explored multiple-antenna technologies, leading to their successful integration into emerging broadband wireless standards, such as Mobile WiMAX.

However, having high channel capacity alone does not ensure efficient high-speed or highly reliable data transmissions thus, specialized techniques are necessary. Multiple-antenna methods typically fall into two main categories: diversity techniques and spatial multiplexing techniques. Diversity approaches aim to improve reliability by transmitting or receiving identical signals through multiple antennas, thus mitigating issues related to signal degradation. Fundamentally, diversity techniques transform inherently unstable, Rayleigh fading channels into more stable, AWGN-like channels, substantially reducing the probability of severe signal fades and enhancing overall communication reliability.

Detection in OFDMA

In Orthogonal Frequency-Division Multiple Access (OFDMA) systems, data transmission typically occurs using multiple subcarriers organized into subsets known as subbands. Each subband consists of

contiguous subcarriers, and a data burst may be transmitted across different subbands in successive time slots. Employing distinct subbands over multiple time slots helps mitigate burst errors and exploit

frequency diversity, particularly beneficial in frequency-selective fading channels. This strategy, known as frequency hopping (FH), systematically shifts subbands in frequency according to a predefined hopping pattern, thus enhancing system robustness and reliability (Goldsmith, 2005).

Frequency hopping is especially advantageous in cellular OFDMA systems as it effectively averages out inter-cell interference. By assigning distinct hopping patterns to adjacent cells, the collisions of subbands among neighboring cells become randomized, significantly reducing interference effects. This specific application of frequency hopping within OFDMA systems is known as frequency-hopping OFDMA (FH-OFDMA). However, implementing FH-OFDMA presents practical challenges, notably requiring substantial memory capacity. This is because receivers must buffer the entire data burst over the duration of the hopping pattern for effective decoding (Cho, 2010).

Besides managing frequency diversity and inter-cell interference, OFDMA systems often utilize multiple antennas to increase the achievable channel capacity. In comparison to conventional single antenna systems, employing multiple antennas denoted as having NT transmit antennas and NR receive antennas enhances channel capacity by a factor of min(NT,NR) without necessitating additional transmission power or spectral bandwidth. Such advancements are increasingly essential given the escalating demand for higher data transmission speeds in contemporary and emerging broadband wireless technologies, including Mobile WiMAX systems (Gesbert, 2003).

Even with channels capable of supporting high capacities, achieving reliable high-speed data transmission requires robust transmission techniques. Multiple antenna methodologies are typically categorized into two primary types: diversity techniques and spatial-multiplexing techniques. Diversity techniques focus on transmitting or receiving identical data across multiple antennas to bolster transmission reliability, thereby transforming Rayleigh fading channels into more predictable and stable additive white Gaussian noise (AWGN)-like environments. Such techniques significantly reduce the likelihood of catastrophic signal fading, enhancing overall communication reliability and stability (Proakis, 2008).

Spoofing attack detection

A number of recent advancements have been made to address the pilot contamination attack (PCA) in wireless systems, a critical vulnerability particularly in multi-user and multi-cell scenarios. One notable strategy involves superimposing a random sequence onto the training sequence at the legitimate receiver. This modification, evaluated using the Minimum Description Length (MDL) criterion (Wang, 2016), has shown promise in detecting pilot spoofing attacks. Another effective approach introduces an auxiliary trusted node, enabling a three-phase uplink training framework. This method enhances the system's ability to identify malicious transmitters by cross-validating pilot transmissions across nodes (Chen, 2017).

More recent techniques focus on signal characteristics altered by a pilot spoofing attack. For instance, the attack often results in a noticeable power leakage at the receiver. Leveraging this, a detection scheme was proposed based on monitoring the received power-to-noise ratio (Zhao, 2018). In a related work, legitimate users initially transmit pilot signals to the base station (BS), which then returns the conjugate of the received signal. The users analyze this response to make the final decision regarding PSA detection (Lee, 2019).

Additionally, a detection mechanism has been developed based on inconsistencies in the estimated channel response, as PSA distorts the original channel characteristics. These anomalies serve as reliable indicators for attack presence (Zhang Q. L., 2020).

A recurring assumption in much of the literature is that large-scale fading coefficients are known in advance. However, in practical settings—particularly in complex multi-cell and multi-user environments this assumption is often impractical due to the excessive overhead required to acquire these coefficients (Huang, 2021). Even if long-term observation is used to estimate these parameters, the process is susceptible to PSA interference. Longer observation windows increase the likelihood of attack-induced distortion, undermining the reliability of detection mechanisms.

In response to these limitations, we propose a novel detection approach using dedicated signals sent from the base station to verified users. This method minimizes reliance on vulnerable long-term estimates and enhances detection reliability by leveraging secured downlink communication.

Objectives of the study

Massive MIMO (Multiple-Input Multiple-Output) has emerged as a foundational technology in the evolution of next-generation wireless communication systems. It leverages a high number of antennas at the base station to exploit spatial degrees of freedom (DoFs), enabling advanced techniques such as spatial multiplexing and beamforming. These enhancements translate directly into improved spectral efficiency, increased throughput, and greater user connectivity. Massive MIMO has particularly benefited enhanced Mobile Broadband (eMBB) services by allowing simultaneous transmission to multiple users with minimal interference. In parallel, the technology is also critical for ultra-reliable low-latency communication (URLLC), where it supports features like channel hardening and favorable propagation, which are essential for achieving deterministic, low-latency links in applications like autonomous vehicles and industrial automation (Larsson, 2014).

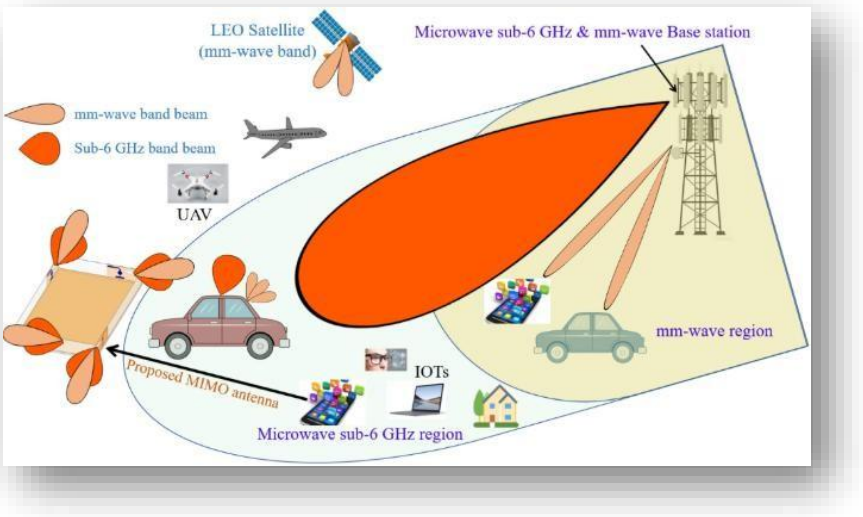


Figure 2. Hybrid Multi-Band MIMO Communication Architecture for Integrated Sub-6 GHz and mmWave Networks

The increasing use of mobile devices and IoT sensors has created significant uplink demand at the base stations. While the availability of multiple antennas allows for signal multiplexing, not all configurations are power-efficient, as redundant MIMO channels can lead to unnecessary energy

consumption without increasing coverage range. Thus, system design must be tailored to specific use cases such as smart cities, UAV communications, vehicular networks, and satellite-assisted hybrid networks operating across sub-6 GHz and mmWave frequencies. To fully exploit spectral and energy efficiency, advanced detection methods like Successive Interference Cancellation (SIC), Maximum Likelihood (ML), and Sphere Decoding (SD) are vital. These techniques provide enhanced interference suppression and robust signal recovery in high-density user environments. This study aims to investigate scalable, low- complexity detection algorithms suitable for future heterogeneous MIMO systems that span terrestrial, aerial, and satellite platforms. Special focus will be given to identifying trade-offs between performance and complexity in dynamic multi-band environments.

SIC ALGORITHM

In a MIMO communication system, the received signal is modeled as $\mathbf{y} = \mathbf{Hx} + \mathbf{n}$, where $\mathbf{H} \in \mathbb{C}^{Nr \times Nt}$ represents the complex channel matrix, $\mathbf{x} \in \mathcal{S}Nt$ is the transmitted symbol vector drawn from a modulation constellation $\mathcal{S}$, and $\mathbf{n}$ is additive white Gaussian noise with zero mean and covariance $\sigma^2\mathbf{I}$ (Verdu, 1998). The Successive Interference Cancellation (SIC) algorithm seeks to detect $\mathbf{x}$ by iteratively estimating and removing the contribution of one symbol at a time. At each step k, the detector constructs an MMSE filter based on the remaining columns of the channel matrix.

The filter is computed as $w_k = \left(H_k H_k^H + \frac{\sigma^2}{E_s} I\right)^{-1}$

$\mathbf{H}_k$, where $\mathbf{H}_k$ is the effective channel after cancelling the previous $k-1$ streams (Viswanath, 2005). The output vector $\hat{\mathbf{z}_k} = \mathbf{W}_k{}^{H}\mathbf{y}_k$ provides soft estimates of the remaining symbols, and the stream corresponding to the most favorable metric (often highest post-detection SINR) is selected for decision and cancellation.

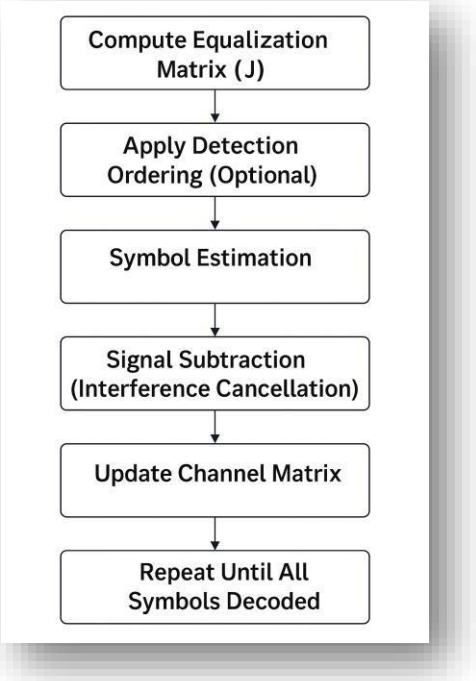


Figure 3. Flowchart scheme for Successive Interference Cancellation algorithm

Once a symbol $\hat{x}ik$ is decided, it is removed from the received signal: $\mathbf{y}k+1 = \mathbf{y}k - \mathbf{h}ik\hat{x}ik$, and the corresponding column $\mathbf{h}ik$ is removed from the channel matrix for the next iteration. This process is repeated until all symbols are detected. One major limitation of SIC is the risk of error propagation. If a symbol is incorrectly estimated at any stage, the error propagates through all subsequent cancellation steps, degrading overall detection accuracy. This problem can be mitigated by optimal ordering strategies that prioritize the most reliable symbols or by introducing reliability checks and feedback mechanisms.

From a computational standpoint, MMSE-SIC is more efficient than full maximum likelihood detection but still incurs significant cost. Each filtering step involves matrix inversion, typically requiring $\mathcal{O}(N_r^3)$ operations. Since the algorithm proceeds sequentially for all Nt transmit streams, the total complexity scales with $\mathcal{O}(N_t N_r^3)$. For balanced systems where $N_t \approx N_r = N$, the complexity becomes $\mathcal{O}(N^4)$, although optimized implementations using matrix downdates and reuse of computations can reduce this to $\mathcal{O}(N^3)$ per full detection. Despite these challenges, MMSE-SIC remains a popular trade-off between performance and complexity in practical MIMO systems, especially when combined with smart ordering and hybrid iterative refinements (Y. Zhang and S. Shin, May 2012.).

SYSTEM MODEL

In the context of massive MU-MIMO systems, the trade-off between energy consumption and spectral efficiency is a critical design consideration, particularly when deploying a base station (BS) equipped with significantly more antennas than the number of single-antenna users (i.e., $N \gg K$). The system under investigation employs Zero-Forcing (ZF) precoding to manage interference between users, where the transmit signal is expressed as $y = G_s W_s P_s s + n$. Here, s denotes the transmit symbol vector, $Ps = \mathrm{diag}(\sqrt{p_1}, \sqrt{p_2}, \ldots, \sqrt{p_K})$ is the power scaling matrix, and Ws is the precoding matrix derived using ZF criteria as $W_s = G_s H(G_s G^H{}_s)^{-1}$, ensuring that inter-user interference is minimized.

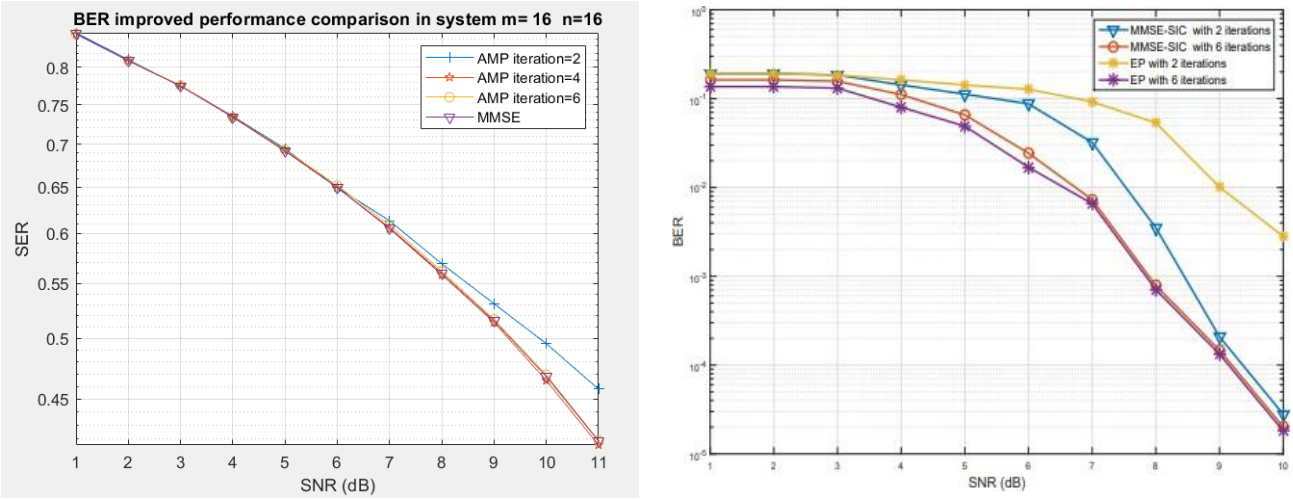


Figure 4. Comparison in BER performance using 16 x 16 versus 64 x 64 transmitters and receivers (from left-to right)

To quantify power efficiency, the total system power consumption is modeled as $P_{Tot} = \frac{B \cdot P_t}{n} + N_t \cdot P_{Bc} + P_{etc}$, where Pt = tr($W_s P_s^2 W_s^H$) is the total transmit power, n represents the power amplifier efficiency, P_{BC} is the power consumed per RF chain, and P_{etc} accounts for fixed circuit overhead. This model reflects how increasing the number of antennas N_t enhances beamforming gain and spatial multiplexing, but also results in higher hardware-related energy costs (Ngo, 2013).

Incorporating detection techniques such as MMSE-SIC into this framework offers a pathway to improve spectral efficiency without proportionally increasing power consumption. By iteratively detecting and cancelling interference, SIC allows each user's data stream to be recovered more reliably, even in the presence of dense interference or imperfect channel conditions. When combined with optimal ZF precoding, SIC can significantly reduce the bit error rate (BER) and symbol error rate (SER), effectively improving the system's energy efficiency by minimizing retransmissions and error correction overhead (Zhang, 2012). This is especially important in high-dimensional systems where maximizing throughput per unit energy is essential. Moreover, by integrating SIC in the receive architecture and ZF in the downlink precoding, the system can leverage both spatial diversity and interference suppression, leading to enhanced spectral utilization (Tse).

RESULTS

The observed behavior—where the 4×4 MIMO system produced two bit errors while the 8×8 and 16×16 systems yielded zero—can be attributed to the enhanced spatial diversity and channel hardening effects inherent in larger antenna arrays. As the number of antennas increases, the system benefits from more independent propagation paths, reducing the likelihood of simultaneous deep fades and thus improving the reliability of each transmitted stream. Moreover, larger MIMO configurations tend to produce more well-conditioned channel matrices, which improves the effectiveness of MMSE-SIC detection by stabilizing the inversion step and limiting noise amplification. This results in fewer symbol misdetections, especially under moderate SNR conditions. However, it is important to note that these results stem from a single random channel realization; multiple trials would typically show some errors even at higher dimensions due to statistical variation. These principles are rooted in well-known MIMO behaviors, particularly channel hardening and diversity gain, as generally described in literature such as (Rusek, 2013), although this explanation is based on general theory rather than direct citation of those sources.

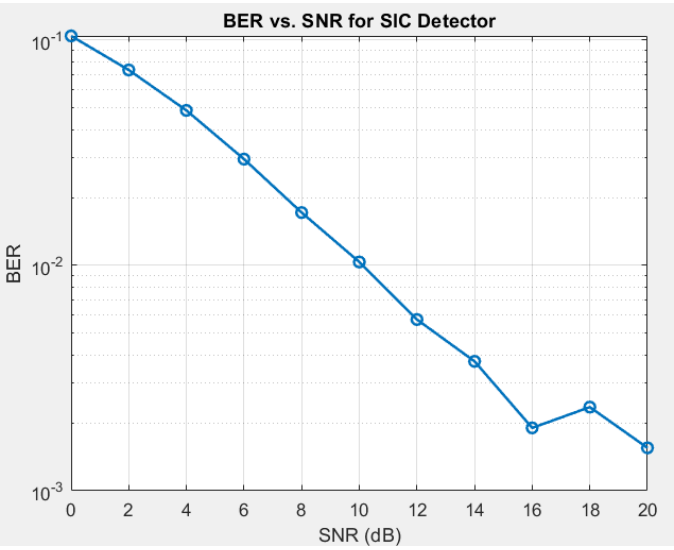


Figure 5. BER Performance of SIC Detector over Varying SNR in MIMO System

From the results we observe that when using a 4×4 MIMO system produced two bit errors while the 8×8 and 16×16 systems yielded zero. This phenomenon can be attributed to the enhanced spatial diversity and channel hardening effects inherent in larger antenna arrays. As the number of antennas increases, the system benefits from more independent propagation paths, reducing the likelihood of simultaneous deep fades and thus improving the reliability of each transmitted stream. Moreover, larger MIMO configurations tend to produce more well-conditioned channel matrices, which improves the effectiveness of MMSE-SIC detection by stabilizing the inversion step and limiting noise amplification. This results in fewer symbol misdetections, especially under moderate SNR conditions. However, it is important to note that these results stem from a single random channel realization; multiple trials would typically show some errors even at higher dimensions due to statistical variation. These principles are rooted in well-known MIMO behaviors, particularly channel hardening and diversity gain, as generally described in literature such as (F. Rusek et al., Jan. 2013.) and (T. L. Marzetta, 2010), although this explanation is based on general theory rather than direct citation of those sources.

DISCUSSION AND CONCLUSION

In large-scale MIMO systems, the effectiveness of detection methods such as MMSE, MMSE-SIC, and Expectation Propagation (EP) varies considerably depending on system complexity and dimensionality. The conventional MMSE detector, while computationally efficient and straightforward to implement, tends to perform poorly as the number of antennas increases, primarily due to its limited ability to handle inter-stream interference. As system size grows, MMSE detection suffers from error floors, making it unsuitable for high-reliability applications in massive MIMO environments. MMSE-SIC improves performance by sequentially cancelling interference from previously detected streams, offering better BER results. However, this approach remains sensitive to detection errors that can propagate across layers and is computationally intensive due to its cubic complexity in the number of antennas.

On the other hand, Expectation Propagation provides a more scalable and robust solution by iteratively refining symbol estimates through approximate Bayesian inference. It achieves stronger BER performance than MMSE-SIC, particularly as the number of iterations increases. EP's ability to parallelize symbol updates and its more favorable computational scaling typically linear in the number of antennas per iteration makes it well-suited for large-scale systems. While EP does require careful parameter tuning and additional memory to store intermediate estimates, its advantages in accuracy and scalability make it a preferred option in dense MIMO scenarios. Overall, MMSE-SIC remains practical for medium-sized systems, but EP stands out as a high-performance alternative in large antenna array environments.

FUTURE WORK

Building on the current findings, a compelling direction for future research lies in refining the detection ordering strategy of MMSE-SIC, which plays a pivotal role in minimizing error propagation. The algorithm's performance can be significantly influenced by the sequence in which symbols are estimated and canceled. Therefore, integrating adaptive or machine learning-based ordering techniques could offer a substantial improvement in both accuracy and computational efficiency. Furthermore, the implementation of multi-objective heuristic optimization algorithms such as genetic algorithms or particle swarm optimization has shown promise in balancing competing trade-offs like error rate reduction and processing latency, particularly in high-dimensional MIMO systems.

Expanding MMSE-SIC's capabilities to support higher-order modulation schemes such as 16-QAM, or adapting it to operate under non-ideal conditions like spatial correlation, mobility-induced fading, and imperfect channel state information (CSI), would also enhance its robustness and applicability. A

novel approach could involve using machine learning models not only for ordering but also for learning optimal detection strategies based on channel statistics. This data-driven adaptation could make SIC-based detectors more resilient and spectrum-efficient in future wireless communication networks, including 6G and beyond.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Leveraging Transformer-Based Generative Adversarial Networks to Improve Intrusion Detection in Networks

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Abstract

Cyber threats in modern digital ecosystems keep changing but Network Intrusion Detection Systems (NIDS) play a great part in protecting these threats. NIDS rely on machine learning based models but their effectiveness, due to the scarcity of diverse and up to date data, is hindered especially when they encounter a rare or new attack pattern. To address this limitation this study aims to generate synthetic network traffic with the help of Transformer-based Generative Adversarial Networks (GANs), that closely resemble the real one. We have focused on enhancing the performance of NIDS for the minority Botnet attack class, by utilizing the CIC-IDS2017 dataset. To generate synthetic samples with high quality, three transformer-based GAN variants, Vanilla GAN, Wasserstein GAN, and Conditional Tabular GAN are implemented. To ensure the similarity and the authenticity of the synthetic data, statistical similarity measures including Frechet Inception Distance (FID) and Cosine Similarity are used to evaluate these models. Then the synthetic data is combined with real data, and the augmented dataset is used to train the model of NIDS. This significantly improved the performance of the systems to detect the minority Botnet attack class. Our results show the potential of transformer based GANs, offering a scalable solution for cybersecurity applications to handle the data imbalance challenge along with accuracy and the robustness of the NIDS by data augmentation.

Key words: *Network Intrusion Detection System, Generative Adversarial Networks, Transformer Based Architecture, Deep Learning*

INTRODUCTION

Nowadays unprecedented connectivity due to the advancement in Internet of Things (IoT) and the expansion of the devices generated a huge amount of data. This data is generated from increasing connectivity of the devices including smart industrial machines, laptops and smartphone. The systems are exposed to the malicious network intrusions due to this interconnection which also increases the surface attacks, though it brings remarkable convenience and innovation (Hussain et al., 2020). These flaws in conventional and the IoT devices and the surface attacks let the attackers take advantage (Gupta, et al., 2022) (Kampouraki, et al., 2023). The attackers use different attacks including zero-day exploits, malware infections, man-in-the middle and the botnet traffic (Mustapha, et al., 2023; Beaman, et al., 2021; Zhao, et al., 2018; Conti, et al., 2016).. NIDS plays an important role against evolving threats and securing the networks against them. To analyze network traffic and monitor the packets being sent and receive NIDs are designed which are special tools that will identify authorized and unauthorized activities. The integration of machine learning models into NIDS has made these systems more robust and strong (Ahmad et al., 2021). These models enabled the NIDs (Vishwakarma and Kesswani, 2022)

with their strong defense mechanism to make real time detection (Chindove and Brown, 2021), effective and more adaptive (Injadat et al., 2020), by defending the valuable data and the devices within the interconnected environment.

Interconnected environment. There are still a lot of challenges faced by the NIDs including traffic encryption (Wang and V.L, 2023), advanced techniques for evasion (Afianian, 2019), concerns on the scalability of the NIDs (Raja et al., 2020) and the navigation of complex patterns of network traffic (Yang et al., 2021) but one of the major issues during the training of NIDS is class imbalance or the sample scarcity (Binbusayyis and Vaiyapuri, 2021). As compared to normal network traffic flow there are very few instances of anomalous attacks in the real network traffic which makes it difficult to represent that attack class in the dataset. The imbalance between the majority and minority classes reduces the sensitivity of attack detection and the learning model favours the majority class most of the time. These challenges are addressed by augmenting the data (Liu et al., 2022), resampling (Lee and Park, 2022) and feature engineering along with ensemble learning (Tama and Lim, 2021) (Thakkar and Lohiya, 2022). Using CIC-IDS2017 dataset our work generate samples for the minority attacks by using Generative Adversarial Networks (GANs) integrated with Transformer-based architectures, by building on the above foundation to enhance the performance of NIDS (Sharafaldin et al., 2018).

MATERIAL AND METHODS

Material

NIDS are divided into three types, first one is signature based where incoming traffic evaluated with the help of a preestablished dataset of know attacks (Hubballi and Suryanarayanan, 2014) (Khraisat et al., 2019). Second type is establishing a baseline for normal behaviour of traffic and then comparing the incoming traffic with it, know as anomaly-based NIDS (Jabez and Muthukumar, 2015). It is mainly used in NIDS for classification (Ravipati and Abualkibash, 2019). Third type of NIDS is hybrid detection which uses the features of both signature and anomaly based detection and increases the accuracy for unknow and unknown attacks (Dalai and Jena, 2017). Data generation is revolutionized in the unsupervised learning tasks with the help of GANs (Goodfellow et al., 2014). GANs have played a significant role with different application in computer vison (Özkanoğlu and Ozer, 2022), natural language processing (Liang et al., 2021), generative tasks (Civit et al., 2022) and the detection of anomalies (Schlegl et al., 2019). The synthetic data can be used to augment the training data in NIDS (Shahriar et al., 2020) which can improve the process of extracting features (Zhu et al., 2022) and the signature based and anomaly-based detections (Patil et al., 2022). For anomaly detection (Patil et al., 2022) has used bidirectional GAN to augment the data with KDDCUP-99 dataset (Tavallaee et al., 2009) and to enhance detection accuracy (Truong-Huu et al., 2020) has used GANS with UNSW-NB15 (Moustafa and Slay, 2015) and CIC IDS2017.

Additionally, GANs are also used to generate realistic yet malicious traffic designed to avoid detection. Chauhan et al. introduced a GAN model for generating DDoS synthetic traffic with dynamic attack features (Chauhan and Heydari, 2020), while Lin et al. (Lin et al., 2022) developed a GAN-based framework to change malicious traffic into benign-looking patterns. Mustapha et al. (Mustapha et al., 2023) used GANs to change attack features, reducing IDS effectiveness. On the other hand, GANs are also used to generate synthetic data to improve performance of the systems. Lee et al. (Lee and Park, 2021) addressed class imbalance by generating attack samples using GANs, outperforming conventional methods like SMOTE (Zhang and Liu, 2022). Shahriar et al. (Shahriar et al., 2020) demonstrated that GAN augmented IDS models outperformed standalone systems, and Bourou et al. (Bourou et al., 2021)

utilized CTGAN (Xu et al., 2019) and TableGAN (Park et al., 2018) to generate synthetic attacks for training machine learning models.

Building on the strengths of GANs, our work introduces several advancements:

Transformer-Based GANs: Unlike traditional GAN architectures, we integrate Transformer-based mechanisms to enhance data generation capabilities. Transformers offer superior learning of complex data distributions, enabling more realistic attack sample generation.
Comprehensive Evaluation: Multiple statistical metrics are used to assess the similarity between the real Botnet samples and fake generated samples by GAN. This lets the NIDS to rely on the synthetic data by ensuring robustness and reliability of the synthetic data.
Impact of Synthetic Data: We evaluate the scalability and performance improvements of NIDS across different scenarios by generating varying quantities of attack samples and integrating them into the CIC-IDS2017 dataset. Compared to existing methods our approach demonstrates superior precision, recall, and F1-score.

This work leverages the transformer-based GAN models to generate diverse attack samples by employing CIC-IDS2017 dataset's realistic traffic. Thereby enhancing NIDS effectiveness against sophisticated intrusion attempts, the proposed approach aims to address class imbalance and sample scarcity. We aim to contribute to a more adaptive and resilient intrusion detection framework by incorporating Transformer-based GANs.

Methods

The Collection of the Data

We started with the CIC-IDS2017 dataset, doing its preprocessing and categorization the attack present in the dataset into broader classes. This cleaned and pre-processed dataset is then used to train an Intrusion Detection System (IDS) that serves as a baseline. Next, we explore Generative Adversarial Networks (GANs), our focus is on generating additional Botnet samples, as this class is underrepresented in the dataset followed by describing the three variants, we implemented for enhancing IDS performance: Vanilla GAN, Wasserstein GAN (WGAN), and Conditional GAN (CGAN). Next, we generated synthetic samples, checked their similarity to real data instances, and integrated them into the dataset to improve IDS performance.

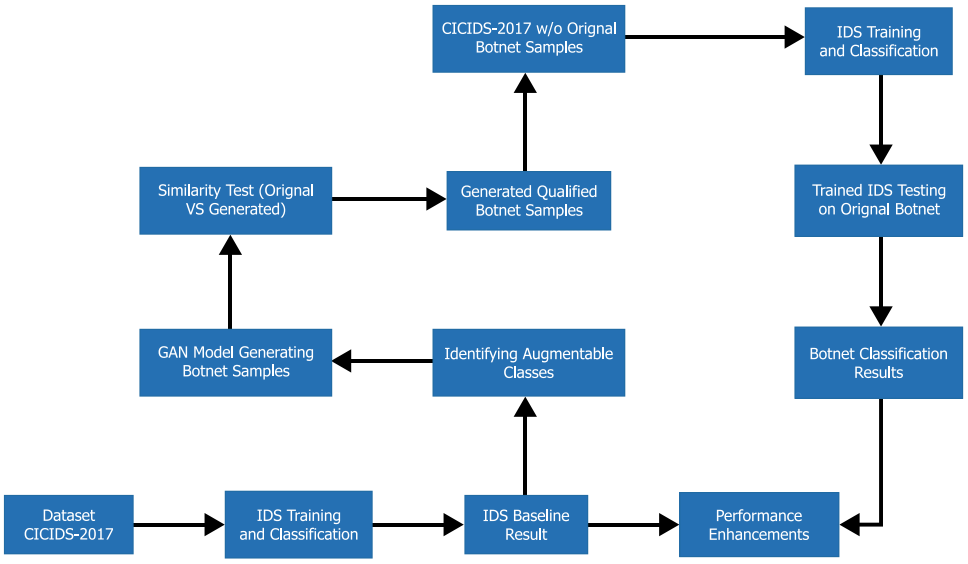


Figure 1. Flow of data generation and IDS enhancement

The Dataset

The CIC-IDS2017 dataset is designed for evaluating network security solutions and IDS and it is publicly available dataset. It is suitable for enhancing multi-class IDS performance by doing data augmentation as it includes different types of attacks and normal traffic. The dataset has remained stable over time which ensures consistency of our selection for benchmarking. The dataset is pre-processed by removing rows with infinite or null values and then the related attack types sharing common features are regrouped into broader classes. Table 1 shows processed CICIDS-2017 dataset while Table 2 shows the grouping of original classes into more general classes. These regrouping enables better classification and addresses class imbalance.

Table 1. Processed Dataset

Classes	Instances
Benign	2271320
DoS Hulk	230124
PortScan	158804
DDoS	128025
DoS GoldenEye	10293
FTP-Patator	7935
SSH-Patator	5897
DoS slowloris	5796
DoS Slowhttptest	5499
Bot	1956
Web Attack: Brute Force	1507
Web Attack: XSS	652
Infiltration	36
Web Attack: Sql Injection	21
Heartbleed	11

Table 2. Class after regrouping

New Classes	Orignal Classes
Benign	Benign
Botnet	Bot
Brute Force	FTP-Patator, SSH-Patator
DDoS	DDoS
DoS	DoS GoldenEye, DoS Hulk, DoS Slowhttptest, DoS slowloris, Heartbleed
Probe	PortScan
Web Attack	Web Attack: Brute Force, Web Attack: Sql Injection
Infiltration	Infiltration

After regrouping, the dataset contains the following major classes: Benign, Botnet, DoS, DDoS, Brute Force, Web Attack, Probe, and Infiltration. We focus on the Botnet class, which has 1,966 instances, making it a good candidate for synthetic sample generation. Table 3 presents the updated class distribution after regrouping.

Table 3. Attacks with instances

New Classes	Number of Instances
Benign	2273097
Botnet	252672
Brute Force	158930
DDoS	128027
DoS	13835
Probe	2180
Web Attack	1966
Infiltration	36

The IDS Baseline and Motivation

We use a Random Forest (RF) classifier to establish the baseline performance for the IDS, trained on the regrouped classes using the top 32 features **s**hown in **Figure 2** are selected via Random Forest feature importance test.

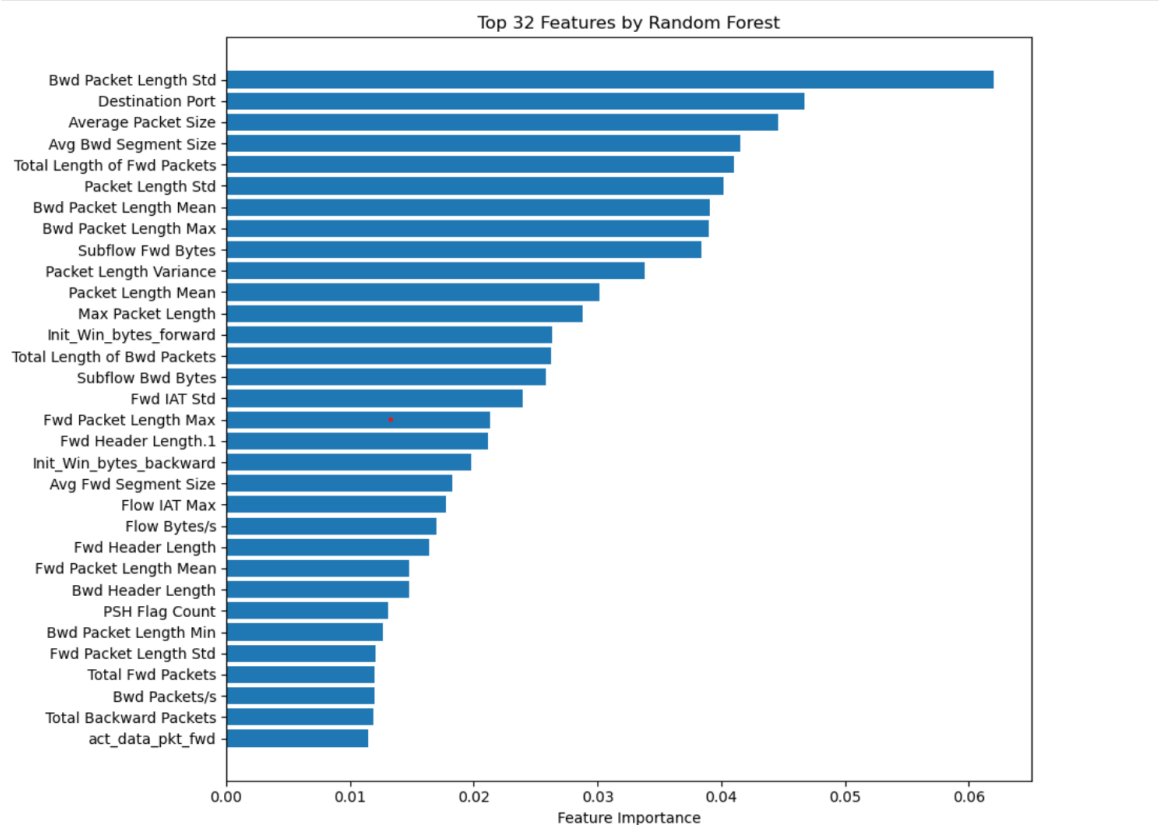


Figure 2. Selected Features using RF

The baseline model achieves high accuracy across most classes, as shown in Table 4. However, the Botnet and Infiltration classes exhibit lower precision and recall due to the scarcity of data. This motivates our use of GANs to generate additional Botnet samples, improving classification performance for this class. We have selected Botnet class because the Infiltration class contains only 36 instances, which will limit the performance of the GAN to generate the synthetic data because GANS need few hundred samples for training to generate realistic samples. Table 4 shows the results of baseline model.

Table 4. Results of baseline model

Classes	Precision	Recall	F1-Score
Benign	1.00	1.00	1.00
Botnet	**0.90**	**0.76**	**0.83**
Brute Force	1.00	1.00	1.00
DDoS	1.00	1.00	1.00
DoS	1.00	1.00	1.00
Infiltration	1.00	1.00	1.00
Probe	0.99	1.00	1.00
Web Attack	0.99	0.97	0.98

The Basic GANs

Generative Adversarial Networks (GANs) consist of a generator and a discriminator. The duty of the generator is to create new data samples, while the discriminator is responsible to distinguishes between real and generated samples. This adversarial training process results in a production of increasingly realistic data by the generator. All the GANs have used the custom dataset of Botnet class only to train the generator better.

Vanilla GAN with Transformer-Based Architecture: Vanilla GAN (VGAN) acts as base for the generative model's framework and uses binary cross-entropy as loss function. In our setup the discriminator producing an output D(x), which represents the probability that the input is real and distinguishes between real and generated data. Below is the loss function of discriminator where first term encourages the discriminator to assign a high probability to real data as close to 1, whereas the second term in the function makes the discriminator to give a low probability to the data indicating the data being fake.

$$L_D = -E_{x\sim p_{data}(x)}[log\ D\ (x)] - E_{x\sim p_{gen}(x)}\big[log\big(1 - D(x)\big)\big]$$

The generator aims to aims to minimize the probability of the discriminator correctly classifying generated data as real or fake or we can say the expected value of the discriminator's output for generated data, shown by the loss function below.

$$L_G = -E_{x\sim p_{gen}(x)}[log\ D\ (x)]$$

Here x is the data sample, $p_{data}(x)$ is the distribution of real data, $p_{gen}(x)$is of generated data distribution $D(x)$ is the output of discriminator

Implementation and Settings for Transformer-Based VGAN: To enhance VGAN architecture and its generative capabilities we have added the transformer components in both the generator and discriminator. The generator has a fully connected layer which transforms the noise vector into feature space with ReLU as activation function. To add positional information to the feature vectors positional encoding is used for sequential context. To perform self attention and feedforward processing transformer blocks are added which includes multi-head attention for dependencies, layer normalization for stable training and feedforward layers for better feature representation. Finally, a linear layer maps the transformed features to feature dimension.

$$L_G = -E_{x\sim p_{gen}(x)}[log\ D\ (x)]$$

Discriminator has positional encoding for enhancing the sequential structure of input data and two transformer blocks like generator. The output is passed to fully connected layers with Leaky ReLU activation function followed by sigmoid in final layer to output the probability of data being real or not. In the training we have used BCE loss function and the Adam optimizer with learning rate 0.0005 for both generator and discriminator.

WGAN with Transformer-Based Generator and Critic: Simple GAN often encounter the issues like stability and the model collapse, the Wasserstein Generative Adversarial Network (WGAN) uses a penalty for the gradient called Gradient Penalty (GP) which provide the stable GAN training. Transformer-based architecture is used both in generator and critic of WGAN like VGAN. It replaces the traditional BCE loss with Earth-Mover's Distance or EMD and it defined as:

$$\text{EMD}(P, Q) = \min \sum \sum d(i,j) \cdot f(i,j)$$

Where EMD (P , Q) = Earth-Mover's Distance between P and Q, $d(i, j)$ = distance between data points (i, j) from P and Q and $f(i, j)$ = amount of mass to be moved from i to j (i in P and j in Q).

Implementation and Settings for Transformer-Based WGAN: To add positional information to the input data Positional Encoding added which enables the transformer to capture sequential relationships and is crucial for the processing of time series data. Each transformer block performs self-attention and feedforward processing which includes multi-head attention for dependencies, layer normalization for stable training and feedforward layers for better feature representation. Model learns the complex relationships within the data with the help of these blocks. Generator uses the random noise to generate the synthetic data with the help of transformer blocks. The discriminator or critic assures the quality of the data by using Wasserstein distance to measure of the difference between real and synthetic data distributions. WGAN uses gradient penalty which ensures that discriminator to satisfy the Lipschitz constraint. The implemented WGAN model shared similar settings as the Vanilla GAN in this study, except that it utilizes the Wasserstein distance as its loss function.

Conditional GAN (CGAN) Using Transformer-Based Architectures: In Conditional Generative Adversarial Network (CGAN) the standard GANs are extended by conditioning the generation process on auxiliary information such as class labels. The synthetic data is more controlled by the adaption of this approach. In our implementation both the generator and the discriminator of CGAN has integrated Transformer-based architectures to generate the Botnet samples. During the training we have used BCELoss for both the discriminator and the generator.

$$L_D = -E_{x\sim p_{data}(x)}[log\ D\ (x)] - E_{x\sim p_{gen}(x)}\big[log\big(1 - D(x)\big)\big]$$

Where x is the data sample, $p$data(x) is the distribution of real data, $p$gen(x) is of generated data distribution $D(x)$ is the output of discriminator.

Implementation and Settings for Transformer-Based CGAN: Like the other models, the generator and discriminator in the CGAN use transformer blocks, but the generator is conditioned on the Botnet class labels. The discriminator evaluates both the real and synthetic data in a conditional manner, accounting for both the feature dimensions and the class labels.

Transformer-Based GAN Architecture for Sequential Feature Modeling

We improve the attention to sequence in network traffic by using transformers in both the generator and the discriminator of our all GANs architecture. For each transformer block, the design is a multi-head self-attention mechanism, a position-wise feed-forward network, alongside residual connections

and layer normalization. The mechanism of self-attention calculates attention scores using the scaled dot-product.

$$\text{Attention}(Q, K, V) = \text{softmax}((Q \times K^T) / \sqrt{d_k}) \times V$$

The query, key and value matrices Q,K,V are built from input embeddings and i means the dimension of the keys. To remember where each token is positioned, we insert sinusoidal positional encoding into the input embeddings. A generator map takes Gaussian noise and generates realistic feature sequences using two transformer blocks and the discriminator checks sequence authenticity using a similar architectural setup. As a result, this design strengthens the way network traffic patterns are simulated in intrusion detection scenarios.

Synthetic Data Generation

After completing the training of each GAN model (Vanilla GAN, WGAN, and WGAN) we have generated the synthetic Botnet data. For generator we used a noise vector and the number of samples to be generated, and all the instances given the label 1 as after labelling the class 1 is used as the label of Botnet class. The generated is then reshaped to match the dimension of real data. The generated data is saved in a CSV file to be used later. This process makes the generated data consistent and enables direct comparison and evaluation of generated data across different models.

RESULTS

The Evaluation for Closeness

To evaluate the similarities between real and synthetic data we calculated the Fréchet Inception Distance (FID), and Mean Cosine Similarity (MCS). These statistical metrics tell us that how different GAN architecture generate the synthetic data that will closely resemble the real Botnet data of CIC-IDS2017. FID calculates the difference between the real feature distribution and the generated or synthetic distribution. Higher values of FID mean there is less similarity whereas lower values indicate the better generated values. MCS measures the average cosine similarity between the real and synthetic data. Its value ranges from 0 to 1 and the value near to 1 means greater similarity.

Table 5. Evaluation metrices

GAN Model	FID Score	Real Data Shape	Synthetic Data Shape	Mean Cosine Similarity
Vanilla GAN	57.564	(1966, 32)	(24329, 8, 32)	0.1072
WGAN	39.4566	(1966, 32)	(24329, 8, 32)	0.5690
CGAN	55.9234	(1966, 32)	(24329, 8, 32)	0.0611

Table 5 shows that WGAN has achieved the highset alignment with the distribution features as is has the lowest FID value **39.4566** showing that the generated data is closely related to real dataset. The Mean Cosine Similarity **0.5690** however, was relatively low. Though CGAN has achieved a relative high score **55.9234** but still its good as the value of FID ranges from 0 to 100 so a value near to 50 is considered good. It achieved the Mean Cosine Similarity **0.0611** indicating poor alignment of data points individually as compared to a bit poor distribution match. Lastly VGAN has the highest FID score **57.564** with a moderate value of Mean Cosine Similarity **0.1072** indicating less effectiveness of VGAN as compared to WGAN.

Evaluation with Random Forest (RF) Classifier

After data generation and evaluating its similarity with real data we combined the synthetic Botnet samples with the training set and applied the random forest model was trained again to evaluate the

performance of IDS with the generated data. We used an 8:2 training to test ration of augmented dataset and then evaluated the performance of the model using same metrics precision, recall and the F1-score which are also used before the data augmentation on the real dataset in the start after the preprocessing and the feature selection.

Vanilla GAN (VGAN): With the data generated by VGAN the RF model has achieved a perfect score for precision, recall and the F1-score with accuracy 1. Botnet class represented by Class 1 show a high recall 1.00 but a bit than other classes indication the room for improvement is there. Infiltration class which is Class 5 here showed the lowest recall 0.75 which means that GAN is still struggling with the minority class.

Table 6. Classification report of VGAN

	Precision	**Recall**	**F1-Score**	**Spport**
0	1.00	1.00	1.00	454127
1	1.00	1.00	1.00	19574
2	1.00	1.00	1.00	2802
3	1.00	1.00	1.00	25454
4	1.00	1.00	1.00	50627
5	1.00	0.75	0.86	9
6	0.99	1.00	1.00	31773
7	0.99	0.98	0.98	410

Wasserstein GAN (WGAN): WGAN showed the performance like VGAN almost across all classes as compared to other classed with precision is 1. WGAN showed a better margin of handling rare class attack with better performance for the Class 7 (recall = 0.97).

Table 7. Classification report of WGAN

	Precision	**Recall**	**F1-Score**	**Spport**
0	1.00	1.00	1.00	454127
1	1.00	1.00	1.00	19574
2	1.00	1.00	1.00	2802
3	1.00	1.00	1.00	25454
4	1.00	1.00	1.00	50627
5	1.00	0.75	0.86	9
6	0.99	1.00	1.00	31773
7	0.99	0.97	0.98	410

Conditional GAN (CGAN): The performance metrics of CGAN were like WGAN for all classes. For Class 5 it also showed similar results to WGAN, with a recall of 0.75, indicating that CGAN also manages rare classes better than VGAN.

Table 8. Classification report of CGAN

	Precision	**Recall**	**F1-Score**	**Spport**
0	1.00	1.00	1.00	454127
1	1.00	1.00	1.00	19574
2	1.00	1.00	1.00	2802

3	1.00	1.00	1.00	25454
4	1.00	1.00	1.00	50627
5	1.00	0.75	0.86	9
6	0.99	1.00	1.00	31773
7	0.99	0.98	0.98	410

Based on the IDS assessment of the original and augmented Botnet samples collected in this study, it evident that Transformer-based GANs generated samples have a positive influence. In particular, the augmentation led to increased precise and recall on Botnet detection and the accuracy of detection was enhanced. This shows that incorporating GAN synthesized Botnet samples into the dataset improves IDS performance for use in network security applications.

DISCUSSION AND CONCLUSION

This study has outlined several directions for further research to improve the application of GAN-based solutions for intrusion detection. Out of these future research directions, the first is the understanding of the interactions within the GAN architecture and the adoption of new forms of GANs like transformer-based GANs or diffusion models to enhance the quality of generative data. Moreover, using multi-modal GANs may make it possible to capture some relationships of higher-order within the structure of the high-dimensional network traffic datasets. Using real time network traffic data and different types of networks will be very essential for the evaluation of these methods realistic usability and the ability to generalize the results. Another crucial factor for the future work is checking the quality of the generated synthetic data with more precise metrics such as Maximum Mean Discrepancy (MMD). It could also mean that generated data would mimic real attack patterns thereby making machine learning models effective. Potential future work includes using more combinations of augmentation techniques such as using GANs in conjunction with oversampling methods including SMOTE to solve the problem of class imbalance, especially for the attack type level. Perhaps, the fine-tuning of both GANs and classifiers, possible with tackling of the applicability of deep learning classifier for this purpose could also produce enhanced performance and resilience. Finally, using the methods of explainability for interpreting the effects of synthetic data on model choices will improve the reliability and intelligibility of such systems, which will lead to the use of such systems in real-life intrusion detection.

This study showed that GAN-based synthetic data enhancement for IDS utilising CICIDS2017 was beneficial for this project's objectives. The experiments showed that by adding extra new samples synthetically created by the Vanilla GAN (VGAN), Wasserstein GAN (WGAN), and the Conditional GAN (CGAN), high accuracy is obtained with novel Random Forest classifiers, including enhancement of the differentiability of classes that are rare occurrences. In the results, it is revealed that GANs can overcome the problems of data imbalance and enhance the performance of IDS for less samples including attacks such as Botnet traffic. Out of the variants of GAN, WGAN and CGAN came out to be more effective for generating synthetic data with particularly high quality for the rare classes. The consistency in achieving the accuracy could be ascribed to the effectiveness of GAN-based augmentation techniques in improving the detection on challenging data sets.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Author Contributions

I and Syed Hassan Ali jointly implemented the research work. I prepared the initial draft of the manuscript, and Syed Hassan Ali contributed significantly by refining and shaping the final version. The study was a collaborative effort with shared responsibility throughout.

Adana İli Seyhan İlçesinde Zirai İlaç Bayilerinin Çevre Duyarlılıkları

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Özet

Tarımsal üretimde verimliliği artırmak ve zararlılarla mücadelede etkin bir araç olan zirai ilaçların bilinçsiz ve aşırı kullanımı, ekosistem üzerinde olumsuz etkiler yaratmaktadır. Bu kapsamda, zirai ilaç bayilerinin üreticilere yönelik danışmanlık kapasiteleri ve çevresel farkındalık düzeyleri kritik bir öneme sahiptir. Bu çalışma, Adana ili Seyhan ilçesinde faaliyet gösteren zirai ilaç bayilerinin çevre duyarlılık düzeylerini, bilgi birikimlerini ve tarımsal mücadele yöntemlerine yönelik yaklaşımlarını değerlendirmeyi amaçlamaktadır. Bu araştırma Adana ili Seyhan ilçesinde faaliyet gösteren 50 zirai ilaç bayisi ile yüz yüze anket uygulanmıştır. Veriler bilgisayar ortamında Excel programı kullanılarak çizelgelere dönüştürülerek yorumlanmıştır. Araştırma sonucunda Bayilerin tarımsal mücadele, entegre mücadele ve erken uyarı sistemleri konusundaki bilgi düzeyleri genel olarak yüksek bulunmuştur. Ancak, üreticilerin bu sistemleri uygulama düzeylerinin daha düşük olduğu gözlemlenmiştir. Zirai ilaç bayileri, üreticilerin tarımsal ilaç satın alma davranışlarında önemli bir rol oynamaktadır. Üreticilerin büyük bir kısmı sorunu söyleyip bayiye danışırken, bir kısmı da sorunun yerinde incelenmesini istemektedir. Bayilerin tamamı, yüksek zarar riski taşıyan ilaçların kullanımını engellemek amacıyla üreticilere uyarı ve önerilerde bulunmaktadır. Yapılan Ki-Kare analizi ile bayilerin yaş, mesleki deneyim, mezun olunan bölüm ve mesleki statü ile tarımsal mücadele uygulama yöntemleri gibi faktörler arasında ilişki olduğu belirlenmiştir. Yaş grubu değişkeni incelendiğinde, özellikle reçete sistemine yönelik görüşler ile kültürel ve yapışkan mücadele yöntemleri açısından istatistiksel olarak anlamlı ilişkiler tespit edilmiştir ($p<0.05$). Bulgular, genç yaş grubundaki bireylerin hem reçeteli satış uygulamasına daha sıcak baktıklarını hem de kültürel ve yapışkan mücadele gibi çevre dostu yöntemleri daha fazla tercih ettiklerini ortaya koymuştur. Sonuç olarak, zirai ilaç bayilerinin sürdürülebilir tarım uygulamalarına yönelik rehberlik kapasitelerinin artırılması, çevre dostu tarımsal girdilerin kullanımının teşvik edilmesi ve çevresel farkındalık düzeylerinin geliştirilmesi gerekmektedir.

Key words: *Çevresel duyarlılık, Zirai ilaç bayi, Pestisit*

GİRİŞ

Tarım sektörü, dünya nüfusunun beslenmesi ve sürdürülebilir gıda güvenliğinin sağlanması açısından büyük bir öneme sahiptir (FAO, 2021). Üreticiler verimi ve kaliteyi arttırmak amacıyla bazı girdilerin miktarlarını artırmaktadır. Bu girdilerden biride zirai ilaçlardır.

Zirai ilaçlar zararlılarla mücadelede etkin bir araç olsalar da bilinçsiz ve aşırı derecede kullanımı; toprak, su ve hava kalitesinin bozulmasına, biyolojik çeşitliliğin azalmasına ve insan sağlığı üzerinde ciddi risklere yol açmaktadır (FAO, 2021).

Tarımsal üretimde üreticilerin temel amacı minimum girdi masrafı ile maksimum kalite ve verim elde etmektir. Tarımsal verimi önemli ölçüde etkileyen hastalık ve zararlılara yönelik uygulanan birçok yöntem, uzun ve masraflı süreçler gerektirmektedir. Ancak, kimyasal mücadele kısa sürede etki

göstermesi ve kullanımının kolay olması nedeniyle, dünyada olduğu gibi Türkiye'de de en çok tercih edilen yöntemdir (Özercan ve Özdem 2015).

Tarım ürünlerinde zararlı organizmaların ve hastalıkların kontrol altına alınmaması durumunda, %45 ile %65 arasında değişen oranlarda ürün kayıpları meydana gelebilmektedir. Bu durum, hem tarımsal verimliliği hem de ekonomik kazancı ciddi düzeyde olumsuz etkileyebilmektedir. Tarımsal üretimde verim artışını sağlamak ve kayıpları minimize etmek için tarım ilaçlarının kullanımı kaçınılmaz bir girdi olarak değerlendirilmektedir. (İnan, 2001).

Tarım ilaçlarının etkisini kısa sürede göstermesi ve kullanımının kolaylığı, ulaşılabilir olması, tarım işçilerinin kullanılarak yabancı ot temizliği yapılmasıyla karşılaştırıldığında zamandan ve ekonomik açıdan daha avantajlı olması gibi nedenlerle kullanımını yaygınlaştırmaktadır. (Tiryaki ve ark., 2010).

Dünyada gelişmiş ülkeler başta olmak üzere, bütün ülkelerde 1980'li yılların başlarına kadar tarımsal üretimi; birim alan verimini yükselterek artırmak ve bu yolla üretim maliyetini azaltmak, başlıca tarım politikası hedefi olmuştur (Gül ve ark., 2014). Günümüz koşullarında tarım ürünlerinin korunması ve gıda güvencesinin sağlanması amacıyla bitkisel üretimde pestisit kullanımı kaçınılmaz bir yöntem haline gelmiştir. Bu durum, dünya genelinde tarımsal ilaç kullanımında belirgin bir artışa yol açmış ve tarımsal mücadele yöntemlerinin önemini daha da artırmıştır (Özel, 2004).

Birleşmiş Milletler Gıda ve Tarım Örgütü (FAO) verilerine göre; Dünya'da 2022 yılında hektar başına düşen pestisit kullanımı 2,37 kilogramdır. Dünya ortalaması ise 2,26 kilogramdır. Türkiye'de bu oran dünya ortalamasıyla aynı seviyededir (FAO, 2025).

TÜİK verilerine göre; Türkiye'de 2022 yılında toplam tarım ilacı kullanım miktarı, 2021 yılına göre % 4,5 artarak 55,374 ton' a yükselmiştir (TÜİK, 2025). Tarım ilacı kullanım miktarları Dünyada olduğu gibi Türkiye'de en büyük grubu fungusitler (mantar öldürücü) oluşturmuştur (TOB, 2023).

Bölgeler bazında incelendiğinde Türkiye'de 2022 yılında kullanılan 55,374 ton pestisitin %27.28'i Akdeniz, %20.16'sı Marmara, %19.68'i Ege, %17.84'ünün İç Anadolu, %9.35'inin Güneydoğu Anadolu, %5.12'sinin Karadeniz ve %0.57'sinin Doğu Anadolu Bölgesi'nde kullanılmıştır. Çalışmanın yürütüldüğü Adana ili pestisit kullanımının en yüksek olduğu Akdeniz Bölgesi'nde yer almaktadır (GKGM, 2025).

Bitki koruma ürünlerinin doğru ve etkin bir şekilde kullanımı, tarımsal üretimin sürdürülebilirliği açısından önemlidir. Bu ürünlerin doğru zamanda, doğru teşhis edilmiş zararlıya karşı kullanılması, doğru doz ve uygulama yönteminin benimsenmesi, hem çevrenin korunmasına hem de insan sağlığı üzerindeki olumsuz etkilerin en aza indirilmesine olanak sağlamaktadır. Bu faktörlerin doğru bir şekilde uygulanması, sadece üreticilerin bilgi ve becerilerine göre değil, aynı zamanda zirai ilaç bayilerinin rehberlik ve yönlendirme kapasitelerine de bağlıdır (Erdoğan, 2024). Hastalık ve zararlıların mücadelesinde kullanılan ilaçların çiftçiye ulaştırılması zirai ilaç bayileri aracılığıyla gerçekleştirilmektedir (Bayav ve Ak, 2024).

Zirai ilaç bayi üreticilerin bitki koruma ile ilgili sorunlarını çözmede ve üreticilere yeni teknik bilgilerin aktarılmasında önemli bir bağlantı noktasıdır (İnan ve Boyraz 2003). Bitki koruma alanında çiftçileri bilgilendiren zirai ilaç bayileri, tarımsal üretim süreçlerinde kritik bir rol üstlenerek çiftçilerin bilinçli kararlar almasına önemli katkılar sağlamaktadır (Altınköy ve ark., 2020).

Bu çalışmada Adana ili Seyhan İlçesinde faaliyet gösteren zirai ilaç bayilerinin yapısı, bilgi düzeyleri, çevre duyarlılık düzeyleri belirlenmeye çalışılmıştır. Çalışma kapsamında, bayilerin çevreye duyarlılık konusunda sahip oldukları bilgi düzeyi, çevre dostu ürünlerin teşvik, konularında değerlendirmelere yapılacaktır.

MATERYAL YÖNTEM

Bu çalışmanın ana materyalini Adana ili Seyhan ilçesi Zirai İlaç Bayilerinden alınan veriler oluşturmaktadır. Bu araştırma, Adana ili Seyhan ilçesinde faaliyet gösteren zirai ilaç bayilerinin çevre duyarlılık düzeylerini belirlemek amacıyla yürütülmüştür.

Çalışmada, zirai ilaç bayilerinin genel yapısı, bilgi düzeyleri, pestisit kullanımına yönelik yaklaşımları ve çevreye duyarlılık konusundaki tutumları incelenmiştir. Bu doğrultuda, araştırma bölgesi olarak Adana ili Seyhan ilçesi seçilmiş olup, bölgenin tarımsal üretimde önemli bir konumda yer alması, yoğun zirai ilaç kullanımına sahip olması ve tarımsal girdilerin kullanımına yönelik bayilerin rolünün belirgin olması dikkate alınarak çalışmanın yürütüleceği alan belirlenmiştir.

Adana ili Seyhan İlçe Tarım ve Orman Müdürlüğünden elde edilen toplam zirai ilaç bayi sayısı 57 olarak belirlenmiş, tam sayım yöntemi kullanılarak 57 bayiden sadece 50 bayi ile görüşme sağlanmıştır. Araştırmada tüm zirai ilaç firmaları ile görüşülmek istenmiş fakat pandemi dolayısıyla sadece 50 bayi ile görüşme sağlanabilmiştir. Görüşülen 50 bayi ile yüz yüze anket uygulanmıştır. Anket formlarının ilk bölümünde sosyo-demografik sorulara yer verilmiştir. Ankette ayrıca bayilerin tarımsal mücadele yöntemleri, tahmin ve erken uyarı sistemleri, entegre mücadele konusundaki bilgi düzeyleri ile çevre duyarlılığına ilişkin algıları ölçülmüştür. Araştırma kapsamında anketlerden elde edilen veriler oransal tablolara dönüştürülmüş olup Khi-Kare yöntemi ile analiz edilmiştir ve istatistiksel olarak değerlendirilmiştir.

Zirai ilaç bayilerinin yaş grubu (0–35 yaş ve 35 yaş üzeri), deneyim, statü, mezun olunan bölüm ile tarımsal mücadele yöntemleri, zirai ilaç kullanımına ilişkin çeşitli tutum ve farkındalık düzeyleri arasındaki ilişkiler analiz edilmiştir. Araştırmada, kategorik değişkenler arasındaki ilişkiyi test etmek amacıyla Ki-Kare (χ^2) testi uygulanmıştır. Ki-kare testi, gözlenen ve beklenen frekanslar arasındaki farkların istatistiksel olarak anlamlı olup olmadığını test eden bir yöntemdir (Güngör ve Bulut, 2008). Bu yöntem, özellikle bağımsız iki değişken arasında ilişki olup olmadığını belirlemek ve gruplar arası farkları analiz etmek için yaygın olarak kullanılmaktadır.

ARAŞTIRMA BULGULARI

Çalışmaya konu olan 50 zirai ilaç bayi işletme sahipleri ile yüz yüze anket yöntemi ile görüşülmüştür. İlk olarak işletme sahiplerinin demografik özellikleri Tablo 1'de gösterilmiştir. İncelenen işletmelerin %96'sının erkek, %4'ünün kadın olduğu saptanmıştır. Benzer çalışmalara bakıldığında Okur ve Çiçek (2023)'in Tokat'ta yapmış oldukları çalışmada zirai ilaç bayilerinin %91,1'inin erkek, %8,9'unun kadın olduğu, Kan vd. (2023) Aksaray'da yapmış oldukları çalışmada ise %81,48 erkek %18,52'nin kadın, Bayav ve Ak (2024) Burdur İli ve ilçelerinde yapmış oldukları çalışmada %79.3'ünün erkek, %32.8'inin kadın olduğu saptanmıştır. Yapılan çalışmalardan da anlaşıldığı üzere zirai ilaç bayi açanların neredeyse çoğu erkek işletmeciden oluşmaktadır. Bunun sebebi ise anket esnasında birebir görüşmelerde işletme sahiplerinden sözlü aldığımız bilgiler doğrultusunda kadın mühendislerin daha çok kamu kurumlarında çalışma isteği olduğu ortaya çıkmıştır.

Tablo1. Zirai ilaç bayilerine ait genel bilgiler

		Frekans	Yüzde(%)
Bayi sahibinin yaş ortalaması (yıl)		34.68	
Bayi sahiplerinin cinsiyetleri	Kadın	2	4.0
	Erkek	48	96.0
Medeni Durum	Evli	21	42.0
	Bekar	29	58.0
Zirai İlaç Bayi Sahiplerinin Eğitim Durumu	Lise	1	2.0
	Üniversite	48	98.0
Zirai İlaç Bayilerinin Mezun Oldukları Bölümler	Bitki Koruma	20	40.0
	Tarla Bitkileri	6	12.0
	Bahçe Bitkileri	7	14.0
	Tohumculuk Programı	3	6.0
	Tarımsal Yapılar ve Sulama	2	4.0
	Toprak Bilimi ve Bitki Besleme	4	8.0
	Tarım Ekonomisi	1	2.0
	Bahçe Tarımı	1	2.0
	Ziraat Mühendisliği	5	10.0
	Reyhanlı Lisesi	1	2.0
Zirai İlaç Bayi Sahiplerinin Doğup Büyüdüğü Yer	Büyükşehir	13	26.0
	Küçükşehir	19	38.0
	Köy	18	36.0
	Genel Toplam	50	100.0

Zirai ilaç bayi sahiplerinin yaş ortalamasının ise 34,68 olarak belirlenmiştir. Bayi sahiplerinin %58'inin bekar, %42'sinin ise evli olduğu belirtilmiştir. Zirai ilaç bayi sahiplerinin %98'i üniversite mezunudur.

Araştırma sonuçlarına göre; bayi sahiplerinin %40'ı Bitki Koruma, %14'ü Bahçe Bitkileri,%12'sinin Tarla Bitkileri, %8'inin Toprak Bilimi ve Bitki Besleme, %10'unun Ziraat Mühendisliği,%2'inin Tarım Ekonomisi, %4'ünün Tarımsal Yapılar ve Sulama, %2'inin Bahçe Tarımı, %6'sı ise Tohumculuk Programı mezunudur (Tablo1). Yalçin (2020)'nin Diyarbakır ilinde yapılan çalışmada ise % 52.7'sinin Bitki Koruma mezunu, % 34.5'inin Tarla Bitkileri, % 7.4'ünün Bahçe Bitkileri, % 1.8'nin Tarım Ekonomisi, % 1.8'nin Toprak Bölümü ve % 1.8'nin ise Ziraat fakültesinin diğer bölümlerindeki mezunlardan oluştuğu saptanmıştır. Bayav ve Ak (2024)'ın yapmış oldukları çalışmada, ziraat fakültesinden mezun olanların %47.92'si Bitki Koruma Bölümü mezunu olduğu ifade edilmiştir. Bayi sahiplerinin %38'i Küçükşehir de %36'sı Köyde,%26'sı ise Büyükşehir de doğup büyüdüklerini belirtmiştir .

Zirai ilaç bayileri hakkındaki genel bilgiler Tablo 2'de incelenmiştir. Zirai ilaç ticareti ile ortalama uğraşma süresi 10,56 yıl olarak belirlenmiştir.

Tablo 2. Zirai ilaç bayilerinin genel bilgileri

		Frekans	Yüzde (%)
Zirai İlaç Ticareti ile Uğraşma Süresi Durumu (yıl)			10.56
Zirai İlaç Bayilerinde Görüşülen Kişilerin Statü Durumları	Firma Sahibi	16	32.0
	Mühendis	33	66.0
	Tekniker	1	2.0
Zirai İlaç Bayilerinin Hukuki Statü Durumu	Şahıs Şirketi	26	52.0
	Anonim Şirket	3	6.0
	Limited Şirket	18	36.0
	Kooperatif Şirket	2	4.0
	Diğer	1	2.0
	Genel Toplam	50	100.0

Araştırma sonuçlarına göre zirai ilaç bayilerinin %66'sı mühendis iken, %32'si firma sahibi, %2'si ise tekniker olduğu belirtilmiştir. İncelenen işletmelerde hukuki statüsüne bakıldığında; %52'si şahıs şirketi, %36'sı limited şirketi, %4'ünün kooperatif şirketi ve % 4'ü diğer şirket grubunda yer aldığı belirtilmiştir (Tablo 1). Bayav ve Ak (2024)'ın yapmış oldukları çalışmada, işletmelerin 20'si (%34.5) şahıs şirketi iken, 20'si (%34.5) kooperatif ve 18'i (%31) limited şirket statüsünde faaliyet gösterdiği ifade edilmiştir.

Tablo 3. Zirai ilaç bayilerinin entegre mücadele yöntemi ve erken uyarı hakkında bilgi düzeyleri

		Frekans	Yüzde (%)
İlaç Bayilerinin Entegre Mücadele konusundaki Bilgi Düzeyleri Durumu	Bilgisiz	0	0.0
	Az Bilgili	1	2.0
	Orta	6	12.0
	Bilgili	19	38.0
	Tam Bilgili	24	48.0
İlaç Bayilerinin Tahmin ve Erken Uyarı Hakkında Bilgi Düzeyleri Durumu	Bilgisiz	0	0.0
	Az Bilgili	1	2.0
	Orta	5	10.0
	Bilgili	23	46.0
	Tam Bilgili	21	42.0
İlaçlamalardaki Hedef Görüşler Durumu	Zararlı Popülasyonu ortadan kaldırmak	15	30.0
	Zararlı Popülasyonu EZE altında tutmak	35	70.0
Düzenli Aralıklarla İlaç Önerme Durumu	Evet	4	6.0
	Hayır	28	56.0
	Bazen	18	36.0
Zararlıyı veya Hastalığı Görür Görmez İlaç Uygulaması Önerisinde Bulunma Durumu	Evet	5	10.0
	Hayır	18	36.0
	Bazen	27	54.0
	Genel toplam	50	100.0

IPM (Integrated or Insect Pest Management), Türkçede "Entegre Mücadele Yöntemi" olarak bilinen bir teknoloji olup, zararlı popülasyonlarını kontrol altına almak için doğal parazitler ve avcıları kullanarak kimyasal ilaçların ekolojik ve sağlık açısından zararlarını azaltmayı amaçlayan bir yöntemdir

(Dasgupta, Meisner & Wheeler, 2007). Bu bilgiler doğrultusunda işletme sahiplerine entegre mücadele yönetimi-tahmin ve erken uyarı sistemi konusundaki görüşleri ve bilgi düzeylerini ölçmek amaçlı bazı sorular yöneltilmiştir (Tablo 3). Bu bağlamda görüşmeye katılan firma sahiplerinin, mühendislerin entegre mücadele konusundaki bilgi düzeylerine bakıldığında; %48'inin tam bilgili olduğu, %2'sinin ise az bilgili olduğu belirtilmiştir. Gül ve ark. (2014), yapmış oldukları çalışmada ise ilaç bayilerinin entegre mücadele konusundaki bilgi düzeyleri incelendiğinde %41.40'ının bilgili olduğu ifade edilmiştir. Tahmin ve erken uyarı konusunda bilgi düzeyleri incelendiğinde ise, %46'sı bilgili, %2'si ise az bilgili olarak bulunmuştur.

Bayi sahiplerine ilaçlama konusundaki hedef görüşleri sorulduğunda; %70'inin zararlı popülasyonu EZE altında tutmak olduğunu, %30'unun ise zararlı popülasyonu ortadan kaldırmak görüşüne katıldığı bulunmuştur (Tablo 3). Gül ve ark. (2014), yapmış oldukları çalışmada Görüşülen ilaç bayilerine zararlılara karşı yapılmasını önerdikleri ilaç hedefleri sorulduğunda %76.60'sında zararlı populasyonunu belirli bir seviyenin altında tutmak olduğu sonucuna ulaşılmıştır. İncelenen işletmelerde bitkileri kontrol etmeksizin düzenli aralıklarla ilaç önerme durumunda %56'sı hayır yanıtını verirken %36'sı ise bazen yanıtını vermiştir. Gül ve ark., (2010) tarafından yapılan çalışmada Isparta ilindeki ilaç bayilerinin %45.24'ü herhangi bir zararlı sorunu ile karşılaşmamak düşüncesiyle bitkileri kontrol etmeksizin düzenli aralıklarla ilaçlama önermediklerini belirtmişlerdir. Gül vd. (2014) yapmış oldukları çalışmada görüşme yapılan zirai ilaç bayilerine herhangi bir zararlı sorunu ile karşılaşmamak düşüncesiyle, bitkileri kontrol etmeksizin düzenli aralıklarla ilaçlama öneriyor musunuz sorusuna %51.7'si "Hayır" yanıtını verdikleri ifade edilmiştir. Zirai ilaç bayilerinde görüşülen kişilere bir zararlıyı veya hastalığı görür görmez ilaç uygulaması önerisinde bulunur musunuz? diye sorulduğunda; %54'ü bazen önerdiği yanıtını vermişlerdir.

Tablo 4. Tarım ilaçlarında etiket talimatlarına uyma durumu

		Frekans	Yüzde (%)
Ürün Etiket Talimatlarına Uyma Durumu	Evet	49	98.0
	Hayır	0	0
	Belki	1	2.0
	Genel toplam	50	100.0

İncelenen işletmeler doğrultusunda Görüşülen işletmelerde bulunan kişilerin ürün etiket talimatlarını okuyarak talimatlara uyma durumuna bakıldığında %98'i evet, %2'si ise hayır cevabını vermişlerdir (Tablo 4).

Tablo 5. Zirai ilaç bayilerinin üreticilere ilaç dozu önerme ve çevre duyarlılıklarına ilişkin gözlemleri

		Frekans	Yüzde (%)
Önerilen ilaçlama dozunun üreticilerin uyma durumu	Hiç	0	0
	Az	3	6.0
	Orta	17	34.0
	Fazla	23	46.0
	Çok fazla	7	14.0
Üreticilerin ilaçları alırken çevreye duyarlılıklarını belirtme durumu	Hiç	2	4.00
	Az	16	32.0
	Orta	17	34.0
	Fazla	8	16.0

Çok fazla	7	14.0
Genel Toplam	50	100.0

Tarımsal üretimde pestisit kullanımı, bitkisel üretimde verimliliği artırmak ve zararlılarla mücadele etmek açısından önemlidir. Yanlış veya aşırı pestisit kullanımı hem insan sağlığı hem de çevresel sürdürülebilirlik açısından riskler taşımaktadır. Bu bağlamda, üreticilerin önerilen ilaçlama dozlarına uyma düzeyleri ve çevresel duyarlılık eğilimlerine bakıldığında yapılan çalışmada üreticilerin %46'sı önerilen ilaçlama dozuna fazla düzeyde uyduğunu, çevresel duyarlılık açısından değerlendirildiğinde ise, üreticilerin %34'ü çevreye karşı orta düzeyde duyarlı olduklarını ifade edilmiştir (Tablo 5). Kan vd. (2023) Aksaray ilinde yapmış oldukları çalışmada üreticilerin %55.56'nın çoğu zaman önerilen dozda tarım ilacı kullandıkları ifade edilmiştir. Özyörük vd. (2019) Manisa ili Salihli ve Sarıgöl ilçelerindeki zirai ilaç bayileri ile yaptıkları çalışmada bayilerin %89,5'i üreticilerin önerilen dozu dikkate aldığını ifade ettiklerini bildirmiştir.

Tablo 6. Üreticilerin tarımsal ilaç satın alma davranışları ve zararlı ilaç kullanımına yönelik uyarıda bulunma durumu

		Frekans	Yüzde(%)
Üreticilerinin tarımsal ilaç satın alma konusundaki davranışları*	Belirli bir ilaç adı ile geliyorlar	14	28.0
	Sorunu söyleyip bize danışıyorlar	32	64.0
	Örnek getirip gereken ilacı istiyorlar	4	8.0
	Sorunu gidip görmemizi istiyorlar	22	44.0
Zarar düzeyi yüksek ilaçların kullanımını engellemek yönünde üreticilere uyarı ve öneride bulunma durumu	Evet	50	100.0
	Hayır	0	0
	Toplam	50	100.0

*Birden fazla seçenek işaretlenmiştir.

Görüşülen Zirai ilaç bayileri üreticilerin tarımsal ilaç satın alma konusundaki davranışları Tablo 6'da incelenmiştir. Üreticilerin ilaç satın alırken %64'ü sorunu söyleyip bayiye danıştıklarını, %44'ü sorunun yerinde incelenmesini ve %28'i ise, belirli bir ilaç ismiyle geldikleri saptanmıştır. İlaç bayileri üreticilerin tamamına (%100), yüksek zarar riski taşıyan ilaçların kullanımını engellemek amacıyla uyarı ve önerilerde bulundukları ifade etmişlerdir.

Tablo 7. Tarımsal ilaç girdilerini temin etme durumu

		Frekans	Yüzde(%)
Tarımsal ilaç girdilerini temin etme kanalları**	Toptancı bayi	29	58.0
	Bölge temsilcilikleri	16	32.0
	Üretici firma	36	72.0

**Birden fazla seçenek işaretlenmiştir.

Tarımsal ilaç girdilerinin temininde ise bayilerin %72'si doğrudan üretici firmalardan, %58'i toptancı bayilerden, %32'si ise bölge temsilcilerinden temin ettiklerini belirtmişlerdir. Tarımsal ilaç girdilerinin temininde en çok tercih edilen kanal üretici firmalar olsa da, toptancı bayiler de önemli bir yere sahiptir.

Tablo 8. Üreticiye Yönelik Ürün Tanıtımı ve Entegre Mücadele Yöntemleri Hakkında Bilgilendirme

		Frekans	Yüzde(%)
Üreticiye yönelik ürün tanıtımı ve zirai ilaç ilaçlama ile ilgili bilgilendirme yapıyor musunuz	Evet	38	76.0
	Hayır	11	22.0
	Bazen	1	2.0
	Toplam	50	100.0
Entegre mücadele yönteminin geliştirilebilmesi/yaygınlaştırılabilmesi için yapılması gerekenler *	Tarım ve Orman Bakanlığı il ve ilçe müdürlüğü personelinden bilgi eksikliği giderilmeli	20	40.0
	Demanstrasyon çalışmaları ile ilgili bilgi verilmeli	13	26.0
	Yayım ve çalışmalarına önem verilmeli	9	18.0
	Çiftçiler eğitilmeli, bilinçlendirilmeli	33	66.0
	Fikrim yok	1	2.0

*Birden fazla seçenek işaretlenmiştir.

Yapılan çalışmada üreticiye yönelik ürün tanıtımı ve entegre mücadele yöntemini geliştirilmesi için birtakım görüşler Tablo 8' de gösterilmiştir. İlaç bayilerinin %76'sı üreticilere ürün tanıtımı ve ilaçlama ile ilgili bilgilendirme yaptıklarını ifade etmişlerdir. İlaç bayileri özellikle sezon başında ve ekim öncesinde çiftçiyi bilgilendirdiklerini belirtmişlerdir. Bayilerin entegre mücadeleyi yaygınlaştırılması hakkındaki görüşleri sorulduğunda; %66'sı çiftçilerin eğitilmesi ve bilinçlendirilmesi gerektiğini, %40'ı Tarım teşkilatlarında görev yapan personelin bilgi eksikliğini gidermesi gerektiğini, %26'sı Demanstrasyon çalışmaları ile ilgili bilgilendirilmesi gerektiğini ,%2'si ise bu konuda herhangi bir görüş belirtmemiştir.

Tablo 9. Üreticilerin tarımsal ilaç dozunu belirlemelerine ilişkin bilgiler

		Frekans	Yüzde (%)
İlaç dozunu belirleme durumu	Etiket bilgisi	15	30.0
	Tecrübe	5	10.0
	İlaç atılacak alana göre	6	12.0
	İlacın etkisine göre	7	14.0
	İlacın ruhsatına göre	11	22.0
	Hastalık ve zararlının popülasyonuna göre	6	12.0
	Genel Toplam	50	100.0

Çiftçilerin ilaçlama dozunu belirleme durumu incelendiğinde ise; %30'u etiket bilgisine göre, %22'si ilacın ruhsatına göre, %14'ü ilacın etkisine ve %12'si ise hastalık ve zararlı popülasyonuna göre doz belirledikleri saptanmıştır (Tablo 9).

Tablo 10. Boş ürün ambalajlarını imha etme yöntemi

		Frekans	Yüzde(%)
Boş ürün ambalajlarını yok etme durumu	Yakılarak imha ediliyor	30	60.0
	Geri dönüşüme gönderiliyor	20	40.0
	Genel Toplam	50	100.0

Üreticilerin tarımsal ilaçlama da boş ürün ambalajının imha şekilleri önemli bir konu olup tablo10'da incelenmiştir. Araştırma kapsamında üreticilerin %60'ı ilaç kutularını yakarak imha ettiklerini, %40'ı ise geri dönüşüme gönderdiklerini belirtmişlerdir. Yüzbaşıoğlu ve Topkaya (2022), Tokat ilinde yapmış oldukları çalışmada, bitkisel üretim yapan üreticilerin %62'si kullandıkları ilaç kutularını yakarak imha ettiklerini, Erdil ve Tiryaki (2020), yapmış oldukları çalışmada %68.5'i boşalan ilaç kutularını yakarak imha ettiğini, Akar ve Tiryaki, (2018), üreticilerin %55'inin kullanılmış olan ilaç kutularını yakarak imha ettiklerini belirtmiştir.

Ki Kare Analiz Sonuçları

Araştırma sonucunda elde edilen bazı bulguların belirlenen değişkenler arasındaki ilişkileri istatiksel olarak anlamlı olup olmadığı Ki Kare analizi ile test edilmiştir. Araştırmada yaş grubu, mesleki deneyim, statü, mezun olunan bölüm gibi kriterler ve diğer değişkenler arasındaki ilişki incelenmiştir. Yapılan bu çalışmada öncelikle yaş kriteri dikkate alınmış olup, aşağıda yaş kriteri ve diğer kriterlerin birbirleriyle olan ilişkisine ait tablolar verilmiştir. Tablo 11'de Tarımsal mücadelede bilgi düzeyi ve yaş grubu arasındaki ilişki incelenmiştir.

Tablo 11. Tarımsal mücadelede bilgi düzeyi-tarım ilaçlarının reçete sistemiyle satışı ve yaş grubu arasındaki ilişki

Yaş faktörü	Görüş	0-35 yaş arası	%	35 yaş ve üstü+	%	Toplam	%
Tarımsal Bilgi düzeyi	Bilgili	26	52.00	6	12.00	34	64.00
	Bilgisiz	12	24.00	6	12.00	16	36.00
Chi-Square χ^2= 1.343					P değeri = 0.246		
Reçete Sistemi	Katılıyorum	25	50.00	9	18.00	34	68.00
	Katılmıyorum	7	14.00	9	18.00	16	32.00
	Genel Toplam					50	100.00
Chi-Square χ^2= 4.188					P değeri = 0.041		

Katılımcıların yaş grupları (0–35 yaş arası ve 35 yaş ve üzeri) tarımsal mücadele konusunda bilgi düzeyleri ile reçete sistemine yönelik görüşleri arasındaki ilişki ki-kare testi ile analiz edilmiş ve Tablo11'de verilmiştir. Yapılan Ki-kare testi sonucunda, yaş grupları ile reçeteli satışa yaklaşım arasında anlamlı bir ilişki bulunmuştur ($p < 0.05$). Analiz sonucuna göre gruplar arasında istatistiksel olarak önemli düzeyde farklılık bulunduğu belirlenmiştir. Ki-kare dağılımına göre daha genç bireylerin reçeteli satış sistemine daha fazla destek vermekte, ileri yaştakiler ise onaylamamaktadır.

İlaç bayilerinin tarımsal mücadele konusunda bilgi düzeyleri ile yaş grupları arasında yapılan analiz sonucunda ise, istatistiksel olarak bu yönlü bir ilişkinin bulunmadığı sonucuna varılmıştır ($p > 0.05$). Bu sonuç, tarımsal mücadele hakkında bilgi düzeyinin yaşa bağlı olarak değişmediğini, dolayısıyla yaşın bu bağlamda belirleyici bir etmen olmadığını ortaya koymaktadır.

Yaş değişkeni ve tarımsal mücadele yöntemlerini uygulama ile ilgili veriler Tablo 12'de verilmiştir.

Tablo12 . Yaş grubu - tarımsal mücadele yöntemleri uygulaması arasındaki ilişki

Yaş faktörü	Görüş	0-35 yaş arası	%	35 yaş ve üstü+	%	Toplam	%
Kültürel Mücadele	Uygulayan	27	54.00	5	10.00	32	64.00
	Uygulamayan	11	22.00	7	14.00	18	36.00
Chi-Square χ^2= 3.418					P değeri = 0.064		
Kimyasal Mücadele	Uygulayan	25	50.00	7	14.00	32	64.00
	Uygulamayan	12	24.00	6	12.00	18	36.00

	Chi-Square χ^2= 0.786				P değeri = 0.375		
Mekanik Mücadele	Uygulayan	14	28.00	18	36.00	32	64.00
	Uygulamayan	13	26.00	5	10.00	18	36.00
	Chi-Square χ^2= 3.760				P değeri = 0.053		
Yapışkan mücadele	Uygulayan	25	50.00	7	14.00	32	64.00
	Uygulamayan	6	12.00	12	24.00	18	36.00
	Chi-Square χ^2= 9.810				P değeri = 0.002		
Predatör Mücadele	Uygulayan	9	18.00	23	46.00	32	64.00
	Uygulamayan	6	12.00	12	24.00	18	36.00
	Chi-Square χ^2= 0.149				P değeri =0.700		
	Genel Toplam					50	100.00

Ki-Kare testine göre yaş grupları ile kültürel mücadele uygulayıp uygulamama konusunda bir ilişki olup olmadığı belirlenmeye çalışılmıştır. Yapılan analiz sonucunda, yaş grupları ile kültürel mücadele, kimyasal mücadele, predatör ile mücadele arasında anlamlı bir ilişki ($p < 0.05$) olmadığı belirlenmiştir.

Mekanik mücadele yönteminin yaş gruplarına göre kullanımına ilişkin ki-kare analizi sonucunda p değeri (p=0.053) bulunmuştur (Tablo 12). Bu değer, %5 anlamlılık düzeyine çok yakın olmakla birlikte, istatistiksel olarak anlamlı kabul edilmemektedir. Verilere göre, 35 yaş ve üzeri bireylerin bu yöntemi daha fazla kullandığı (%36), 0–35 yaş grubunda ise kullanım oranının daha düşük olduğu (%28) görülmektedir. Bu durum, yaşlı bireylerin mekanik mücadeleye daha yatkın olabileceğini, ancak bu farkın istatistiksel olarak anlamlı düzeyde olmadığını göstermektedir.

Yapışkanla mücadele yönteminin analiz sonuçlarına göre, yapışkanla mücadele yöntemi uygulayıp uygulamama ile bireylerin yaş grupları arasında güçlü bir ilişki bulunmaktadır (Tablo 12). Ki-kare testi, yaş grubu ile yapışkan mücadele yöntemlerini kullanma durumu arasında anlamlı bir ilişki olduğunu göstermektedir ($p < 0.05$). 0–35 yaş grubunun %50'si bu yöntemi uygularken, 35 yaş üstü grupta bu oran yalnızca %14'tür. Bu fark, genç bireylerin yapışkan tuzak gibi modern ve çevre dostu yöntemlere daha fazla ilgi duyduğunu göstermektedir. Yaş gruplarının bireylerin yapışkanla mücadele yöntemlerine yönelik tutumlarını etkileyen önemli bir faktör olduğunu desteklemektedir.

Ki kare dağılıma göre analiz sonuçları karşılaştırıldığında; kültürel mücadele yöntemi daha çok genç bireyler tarafından uygulanırken, mekanik mücadele daha çok 35 yaş+ bireyler tarafından tercih edilmektedir (Tablo 12). Kimyasal ve predatör mücadele yöntemlerinde yaş grupları arasında önemli bir fark bulunmamıştır. Özellikle Yapışkan Mücadele yöntemi konusunda yaş gruplarına göre istatistiksel olarak anlamlı düzeyde farklılık göstermekte ve güçlü bir ilişki bulunmaktadır ($p < 0.05$).

Tablo 13. Yaş grubu ile ürün üzerinde kalıntı olup olmama ve bekleme süresi hakkında uyarıda bulunma durumu

Yaş faktörü	Görüş	0-35 yaş arası	%	35 yaş ve üstü+	%	Toplam	%
Kalıntı	Evet	12	24.00	7	14.00	19	38.00
	Hayır	20	40.00	11	22.00	31	62.00
	Chi-Square χ^2=0.009				P değeri = 0.923		
Bekleme süresi	Evet	27	54.00	5	10.00	32	64.00
	Hayır	13	26.00	5	10.00	18	36.00
	Chi-Square χ^2= 1.063				P değeri = 0.302		
	Genel Toplam					50	100.00

Yapılan ki-kare analizi sonucunda, yaş grupları ile ürün üzerinde kalıntı olup olmaması ve bekleme süresi hakkında uyarıda bulunma durumu arasında anlamlı bir ilişki saptanmamıştır ($p > 0.05$). Bu bulgu, farklı yaş gruplarındaki bireylerin, ürün kalıntısına yönelik bilgilendirme veya uyarı yapma davranışlarının birbirine benzer düzeyde olduğunu göstermektedir (Tablo 13).

Tablo 14'de Yaş grubu ile korunma kurallarına ilişkin bilgi sahibi olma, boş zirai ürün ambalajlarını uygun şekilde yok etme, Korunma ve hijyen konusunda bilgilendirme yapma arasında istatistiksel olarak anlamlı bir ilişki saptanmamıştır ($p>0.05$)

Tablo 14. Yaş grubuna göre korunma, atık yönetimi ve hijyen bilgisi arasındaki ilişki

Yaş faktörü	Görüş	0-35 yaş arası	%	35 yaş ve üstü+	%	Toplam	%
Korunma bilgi	Evet	26	52.00	6	12.00	32	64.00
	Hayır	12	24.00	6	12.00	18	36.00
Chi-Square χ^2= 1.343					P değeri = 0.246		
Boş ambalaj	Evet	21	42.00	11	22.00	32	64.00
	Hayır	13	26.00	5	10.00	18	36.00
Chi-Square χ^2= 0.230					P değeri = 0.631		
Korunma Hijyen	Evet	24	48.00	8	16.00	32	64.00
	Hayır	12	24.00	6	12.00	18	36.00
Chi-Square χ^2= 0.397					P değeri = 0.529		
Genel Toplam						50	100.00

Genç bireylerin bu konuda daha bilgili oldukları gözlemlense de, fark anlamlı düzeyde değildir. Bu durum, yaş faktörünün korunma kurallarına dair bilgi düzeyine etkisinin sınırlı olduğunu göstermektedir.

Ki-kare analizleri sonucunda, mesleki deneyim süresi ile birçok değişken arasında analiz yapılmış olup, istatistiksel olarak anlamlı bir ilişki tespit edilmemiştir ($p > 0.05$). Ancak, sadece predatör ile mücadele yönteminde mesleki deneyim ile anlamlı bir ilişki bulunmuştur ($p < 0.05$) (Tablo 15).

Tablo 15. Pradatör ile mücadele yöntemi ve mesleki deneyim arasındaki ilişki

Deneyim (yıl)	Görüş	0-10 yıl arası	%	10 yıl ve üstü+	%	Toplam	%
Predatör ile mücadele	Uygulayan	8	16.00	25	50.00	32	66.00
	Uygulamayan	10	20.00	7	14.00	18	34.00
Genel Toplam						50	100.00
Chi-Square = 5.824					P değeri = 0.016		

Verilere göre, 10 yıl ve üzeri deneyime sahip üreticiler predatörle mücadele yöntemini daha yüksek oranda uygulamaktadırlar (%50). Deneyim süresi arttıkça üreticilerin geleneksel yöntemlerin ötesine geçerek daha çevreci ve biyolojik temelli mücadele yöntemlerine yöneldiğini göstermektedir. Uzun yıllardır tarımla uğraşan bireylerin, çevresel sürdürülebilirliğe duyarlılıklarının artması ve biyolojik mücadele konusunda daha bilinçli hale gelmeleri, bu sonuçla tutarlılık göstermektedir. Dolayısıyla, predatör kullanımındaki fark, sadece deneyimle değil, aynı zamanda deneyimle gelişen bilgi birikimi ve bilinç düzeyiyle de ilişkilendirilebilir.

Zirai ilaç bayilerinin mezun oldukları bölüm ile tarımsal mücadele yöntemlerine ilişkin bilgi düzeyleri, uygulama tercihleri ve tutumları arasında anlamlı bir ilişki bulunamamıştır ($p > 0.05$). Benzer

şekilde, bireylerin mesleki statüleri (firma sahibi ya da ziraat mühendisi olma durumları) ile kültürel, kimyasal vb. mücadele yöntemlerini uygulama eğilimleri, tutum ve farkındalık düzeyleri arasındaki ilişkiler istatistiksel olarak anlamlı farklılıklar tespit edilmemiştir.

Bu sonuçlar, eğitimsel arka planın ve mesleki konumun, bireylerin tarımsal mücadele pratiklerini tek başına belirleyici olmadığını göstermektedir. Söz konusu değişkenlerin anlamlı sonuçlar üretmemesi, tarımsal uygulamalarda yaş, deneyim ve bireysel alışkanlıklar gibi faktörlerin daha etkili olabileceğini düşündürmektedir. Ayrıca, sahada edinilen pratik bilgi ve deneyimin, teorik bilgi birikiminden daha baskın bir rol oynayabileceği de bu bulgularla desteklenmektedir.

SONUÇ

Tarımda çevresel duyarlılık, günümüzde sürdürülebilir tarım uygulamalarının temelini oluşturan, ekosistem sağlığını korumayı ve iyileştirmeyi hedefleyen bir yaklaşımdır. Bu yaklaşım, toprak, su, hava ve biyolojik çeşitlilik gibi doğal kaynakların korunması ve verimli kullanılması prensiplerine dayanır. Çevresel duyarlılık, tarımsal faaliyetlerin neden olduğu olumsuz çevresel etkileri en aza indirerek gelecek nesillerin ihtiyaçlarını karşılama yeteneğini korumayı amaçlamaktadır. Zirai ilaç bayileri, tarımsal üretimde pestisitlerin temini ve kullanımına yönelik üreticilere rehberlik eden önemli aktörlerdir. Bu bağlamda, çevre duyarlılığı, bayilerin yalnızca ürün satışıyla sınırlı kalmayıp sürdürülebilir tarımsal uygulamaları teşvik etme sorumluluğunu da içermektedir.

Bu çalışma, Adana ili Seyhan ilçesinde faaliyet gösteren zirai ilaç bayilerinin demografik yapısını, bilgi düzeylerini, tarımsal mücadele yöntemlerine yaklaşımlarını ve çevre duyarlılıklarını değerlendirmiştir. Adana ilinde gerçekleştirilen bu araştırmada Bayi sahiplerinin eğitim düzeyleri oldukça yüksek olup, %98'i üniversite mezunudur.

Çalışma kapsamında, bayilerin entegre mücadele ve erken uyarı sistemleri konusundaki bilgi düzeylerinin genellikle orta ve yüksek seviyede olduğu belirlenmiştir. Ancak, bu sistemlerin yaygınlaştırılması için çiftçilerin bilinçlendirilmesine yönelik eğitim ve yayım faaliyetlerinin artırılması gerekmektedir. Ayrıca, zirai ilaç kullanımında üreticilere yönelik danışmanlık hizmetlerinin daha etkin sunulması, sürdürülebilir tarımsal üretim açısından önemli bir gereklilik olarak ortaya çıkmaktadır.

Bayilerin %70'i ilaçlamalardaki hedefin zararlı popülasyonunu ekonomik zarar eşiği (EZE) altında tutmak olduğunu belirtmiştir. Üreticilerin ilaçları alırken çevreye duyarlılıklarını belirtme durumu ise değişkenlik göstermektedir; %34'ü orta düzeyde, %32'si az düzeyde ve %16'sı çok fazla düzeyde çevreye duyarlı olduklarını ifade etmiştir. Üreticilerin çevresel duyarlılık düzeylerinde belirgin bir farklılık olduğunu ve çevreye duyarlılığın bireysel farkındalık, eğitim seviyesi ve tarımsal uygulamalar konusundaki bilgi düzeyi gibi çeşitli faktörlere bağlı olarak değiştiğini göstermektedir. Orta düzeyde duyarlılık bildiren üreticilerin oranının en yüksek olması, çevre bilincinin gelişmekte olduğunu ancak henüz yeterli seviyeye ulaşmadığını düşündürmektedir.

Üreticilerin boş ürün ambalajlarını imha etme yöntemleri incelendiğinde, %60'ı yakarak imha ettiklerini, %40'ı ise geri dönüşüme gönderdiklerini belirtmişlerdir. Boş ürün ambalajlarının bertaraf edilmesi hususunda ise, çiftçilere yönelik bilgilendirmenin yetersiz olduğu ve uygun imha yöntemlerinin yaygınlaştırılması gerektiği belirlenmiştir.

Zirai ilaç bayileri, üreticilerin tarımsal ilaç satın alma davranışlarında önemli bir rol oynamaktadır. Üreticilerin %64'ü sorunu söyleyip bayiye danışırken, %44'ü sorunun yerinde incelenmesini istemektedir. Bayilerin tamamı (%100), yüksek zarar riski taşıyan ilaçların kullanımını engellemek amacıyla üreticilere uyarı ve önerilerde bulunduklarını belirtmiştir.

Yapılan çalışmada ,zirai ilaç bayilerinin yaş grubu (0–35 yaş ve 35 yaş üzeri), mesleki deneyim süresi, statü (firma sahibi/ziraat mühendisi) ve mezun oldukları bölüm gibi sosyo-demografik değişkenler ile tarımsal mücadele yöntemleri, zirai ilaç kullanımı konusundaki tutum ve farkındalık düzeyleri arasındaki ilişkiler Ki-Kare testi ile analiz edilmiştir.

Analiz sonuçlarına göre bayilerin yaş gruplarına göre çeşitli tarımsal mücadele yöntemlerini uygulama durumları arasında anlamlı bir ilişki olup olmadığı incelenmiştir. Elde edilen verilere göre, özellikle yapışkan mücadele yöntemi ile yaş grubu arasında istatistiksel olarak anlamlı ve güçlü bir ilişki mevcuttur ($p = 0.002$). Genç yaş grubunun (%50), bu yöntemi daha fazla tercih ettiği belirlenmiştir. Bu durum, yapışkan mücadele yönteminin özellikle genç kullanıcılar arasında daha yaygın olduğunu göstermektedir.

Mezun olunan bölüm ve mesleki statü değişkenleri ile tarımsal mücadele yöntemleri, bilgi düzeyi ve tutumlar arasında yapılan analizlerde istatistiksel olarak anlamlı bir ilişki bulunamamıştır ($p > 0.05$). Bu durum, teorik eğitimin veya mesleki pozisyonun tek başına uygulamalarda belirleyici olmadığını, pratik deneyim ve bireysel alışkanlıkların daha etkili olabileceğini ortaya koymaktadır.

Sonuç olarak, zirai ilaç bayilerinin çevreye duyarlılık düzeylerinin artırılması, tarımsal ilaç kullanımında sürdürülebilir yöntemlerin teşvik edilmesi ve entegre mücadele sistemlerinin yaygınlaştırılması için eğitim ve yayım çalışmalarına ağırlık verilmesi gerekmektedir. Tarımsal üretimde çevre dostu uygulamaların benimsenmesi, yalnızca bireysel farkındalıkla değil, aynı zamanda kamu politikaları ve denetim mekanizmalarının etkin uygulanması ile mümkün olacaktır. Bu doğrultuda, tarımsal girdilerin çevreye duyarlı şekilde yönetilmesi için zirai ilaç bayilerinin bilgi ve danışmanlık rollerinin güçlendirilmesi büyük önem taşımaktadır.

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Çıkar Çatışması

Yazarlar çıkar çatışması olmadığını beyan etmişlerdir.

Yazar Katkıları

Tüm yazarlar çalışmaya eşit katkı sağlamıştır.

A Class of Norm Inequalities for Operator Monotone Functions and Hyponormal Operators

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Abstract

In this paper, we establish several operator inequalities involving operator monotone functions, hyponormal operators, paranormal operators, and normal operators. Let A, B, X ∈ B(H) be such that A and B are strictly accretive. The inequalities we derive are proved under various assumptions, including cases where both A and B are normal, at least one of them is normal, or other related structural conditions.

Key words: Operator monotone function, Normal operators, Paranormal operators, Hyponormal operators

INTRODUCTION

Let $B(H)$ and $C_\infty(H)$ denote respectively spaces of all bounded and all compact linear operators acting on a separable, complex space H. Each "*symmetrically norming*" $(s.n.)$ function, whose domain consists of sequences of complex numbers, gives rise to a symmetric or a $u.i.$ norm.

If A is an operator, then $\big|\big|A\big|\big| = \Phi\left(\{s_n(A)\}_{n=1}^{\infty}\right)$, where $s_1(A) \geq s_2(A) \geq \cdot\ \cdot\ \cdot$ are the singular values of A, i.e., the eigenvalues of $|A| = (A^*A)^{1/2}$. Any such norm is defined on the naturally associated norm ideal $C_\Phi(H)$ of $C_\infty(H)$ and it satisfies the invariance property $\big|\big|UAV\big|\big|_\Phi = \big|\big|A\big|\big|_\Phi$ for all $A \in C_\Phi(H)$ and for all unitary operators $U, V \in B(H)$.

Best known $u.i.$ norms are Schatten p-norms defined by

$$\big|\big|A\big|\big|_p = \sum_{n=1}^{\infty}\left(s_n^p(A)\right)^{1/p}, \ for\ 1 \leq p < +\infty$$

while $\big|\big|A\big|\big|_\infty = s_1(A)$ coincides with the operator norm $||A||$. For $p = 1$ the corresponding $s.n.$ function is the trace $s.n.$ function (also denoted by l_1 or l^1), defined by $l((\lambda_n)_{n=1}^{\infty} = \sum_{n=1}^{\infty}|\lambda_n|$, while for $p = \infty$ the $s.n.$ function l^∞ is defined by $l((\lambda_n)_{n=1}^{\infty} = |\lambda_n|$.

Ideals of compact operators associated to these norms will be denoted by $C_p(H)$. Schatten $p-norms$ represent classical examples of (the degree) p modified norms. Namely, for any $p > 0$, a $u.i.$ norm

$||\cdot||$ can be p-modified by setting $\big||A|\big|_{\Phi^{(p)}} = \big||A|^p\big|_{\Phi}^{\frac{1}{p}}$, for all $A \in C_\infty(H)$ such that $|A|^p \in C_\Phi(H)$. We refer to a $s.n.$ function $\Phi^{(p)}$ as to a p-modified function.

Each norm $||\cdot||$ is lower semi-continuous, $i.e.$, $\big||w - A_n|\big|_\Phi \leq ||A_n||_\Phi$. This follows from the uniform boundedness principle and the well-known representation formula

$$\big||A|\big|_\Phi = \left\{ sup \frac{|tr(AB)|}{\big||B|\big|_{\Phi^*}} : B \; is \; a \; finite \; rank \; operator \right\}$$

where Φ^* stands for the $s.n.$ function dual to Φ.

Another useful property of all $u.i.$ norms is the monotonicity:

if $s_n(A) \leq s_n(B)$, for all $n \in N$, then $\big||A|\big|_\Phi \leq \big||B|\big|_\Phi$.

This may be combined with the monotonicity of singular numbers, which states that $s_n(A) \leq s_n(B)$, for all $n \in N$, whenever $0 \leq A \leq B$. Moreover, we have the following double monotonicity property for $u.i.$ norms, saying that $\big||AXB|\big|_\Phi \leq \big||CXD|\big|_\Phi$

We recall that an operator $A \in B(H)$ is called hyponormal if and only if $A^*A \geq AA^*$, and similarly, A is cohyponormal iff A^* is hyponormal, i.e., iff $AA^* \geq A^*A$. Also $A \in B(H)$ is called accretive iff $A_R = \frac{A+A^*}{2} \geq 0$ and strictly accretive iff $A_R \geq cI$ for some $c > 0$.

If (Ω, M, μ) is a space Ω with a measure μ on $\sigma-$algebra M, then we will refer to a function $A: \Omega \to B(H) : t \to A_t$ as to a weakly$*$-measurable if $t \to \langle A_t g, h\rangle$ is measurable for all $g, h \in H$. If, in addition, those functions are integrable, then there is a unique (known as Gel'fand or weak$*$-integral and denoted by $\int_\Omega A_t \, d\mu(t)$) operator in $B(H)$, satisfying

$$\langle \int_\Omega A_t \, d\mu(t)h, k\rangle = \int_\Omega \langle A_t h, \, k\rangle \, d\mu(t), \; \forall \, h, k \in H.$$

For every $h \in H$, the function $t \to ||A_t h||$ is also measurable, and, if additionally

$\int_\Omega \big||A_t h|\big|^2 \, d\mu(t) < +\infty$ for all $h \in H$, then there exists weak$*$-integral $\int_\Omega A_t^* A_t d\mu(t) \in B(H)$, satisfying $\langle \int_\Omega A_t^* A_t \, d\mu(t)h, \, h\rangle = \int_\Omega \big||A_t h|\big|^2 \, d\mu(t)$ for all $h \in H$.

Such families $\{A_t\}_{t\in\Omega}$will be simple called $[\mu]$ square integrable ($[\mu]$ $s.i.$).

For $J := [0, +\infty)$ we have the following integral representation theorem.

Theorem 1.1 A function $f : [0, +\infty) \to R$ is operator monotone if and only if there is $a \in R$, $b \geq 0$ and a positive Borel measure μ on $(0, +\infty)$ satisfying $\int_0^\infty \frac{\lambda}{1+\lambda} d\mu(\lambda) < +\infty$, such that

$$f(t) = a + bt + \int_0^\infty \frac{t\lambda}{t + \lambda} d\mu(\lambda)$$

According to (Hiai, F 2010) an operator increasingly monotone function ϕ on $(0, +\infty)$ admits its unique extension to the Pick class function, also denoted by (Bhatia R,1997) which is analitic in $C \setminus (-\infty, 0]$ and satisfies $\varphi(z) > 0$ for all $z > 0$. Moreover, $\varphi(z) = \varphi(0) + bz + \int_0^\infty \frac{zt}{z+t} \, d\mu(t)$, where $\int_0^\infty \frac{t}{1+t} d\mu(t) < +\infty$ for all z in the open right half plane $\Pi+= \left\{ z \in C : \frac{z+\bar{z}}{2} > 0 \right\}$. Thus

$\varphi(A) = bA + \int_0^\infty t\ A(t\ I + A)^{-1} d\mu(t)$ for an operator monotone function φ on $[0, +\infty)$ satisfying $\varphi(0) = 0$ and for all strictly accretive operator $A \in B(H)$.

Lemma 2.1 Let φ be an operator monotone function on $[0, +\infty)$, given with the integral representation (3), satisfying $\varphi(0) = 0$. Then $\varphi'(x) = b + \int_0^\infty \frac{t^2}{(x+t)^2} d\mu(t)$ for all $x \in (0, +\infty)$.

Proof: We start from the integral representation of an operator monotone function φ on $[0, +\infty)$ given by (3). Since $\varphi(0) = 0$, it follows that $a = 0$ and

$$\varphi(x) - \varphi(x_0) = a + bx + \int_0^\infty \frac{xt}{(x+t)}\ d\mu(t) - (a + bx_0 + \int_0^\infty \frac{x_0 t}{(x_0+t)}\ d\mu(t)) = b(x - x_0) + \int_0^\infty t\left(\frac{x}{(x+t)} - \frac{x_0}{x_0+t}\right) d\mu(t) = b(x - x_0) + \int_0^\infty \frac{t^2(x-x_0)}{(x+t)(x_0+t)}\ d\mu(t)$$

$$\Longrightarrow \frac{\varphi(x)-\varphi(x_0)}{x-x_0} = b + \int_0^\infty \frac{t^2}{(x+t)(x_0+t)}\ d\mu(t)$$

for any given $x_0 \in (0, +\infty)$. Therefore,

$$\left|\frac{\varphi(x) - \varphi(x_0)}{x - x_0} - (b + \int_0^\infty \frac{t^2}{(x_0 + t)^2}\ d\mu(t)\right| = \left| \int_0^\infty \frac{t^2(x_0 - x)}{(x + t)(x_0 + t)^2}\ d\mu(t)\right|$$

$$\leq |x - x_0| \int_0^\infty \frac{t^2}{|x_0 + t|^2 |x + t|}\ d\mu(t) \leq |z - z_0|$$

$$\int_0^\infty \left(1 + \left|1 - \frac{1}{x_0}\right|\right) \frac{2}{x_0} \cdot \frac{t}{1 + t}\ d\mu(t) \leq \varepsilon$$

$$\text{for } |x - x_0| < \frac{x_0}{2}$$

and

$$|x - x_0| < \frac{\varepsilon}{C \int_0^\infty \frac{t}{(1 + t)}\ d\mu(t)},$$

where $C = C_{x_0} = \left(1 + \left|1 - \frac{1}{x_0}\right|\right) \cdot \frac{2}{x_0}$ is a constant and $0 < \int_0^\infty \frac{t}{(1+t)}\ d\mu(t) < \infty$.

The first inequality in (4) follows because $|x - x_0| < \frac{x_0}{2}$ implies $\frac{x_0}{2} < x < \frac{3x_0}{2}$ and

$\frac{1}{x+t} < \frac{1}{1+\frac{x_0}{2}}$.

We obtain the second inequality in (4) by the following estimates

$$\frac{t + 1}{|x_0 + t|} = \left|1 + \frac{1 - x_0}{x_0 + t}\right| \leq 1 + \frac{|1 - x_0|}{x_0 + t} \leq 1 + \frac{|1 - x_0|}{x_0} = 1 + \left|1 - \frac{1}{x_0}\right|, \frac{1}{t + \frac{x_0}{2}} \leq \frac{2}{x_0}$$

and

$$\frac{t}{x_0 + t} \leq 1.$$

The case when

$$\int_0^{\infty} \frac{t}{(1+t)}\, d\mu(t) = 0$$

is trivial.

Lemma 2.2 If φ: $[0,+\infty) \to R$ is operator monotone function satisfying $\varphi(0) = 0$ and operators $A, B, X \in B(H)$ are such that A and B are accretive, then

$$AX\varphi(B) - \varphi(A)XB = \int_0^{\infty} t(t\,I + A)^{-1} A(AX - XB)B(t\,I + B)^{-1} d\mu(t). \quad (5)$$

Moreover, if A is also cohyponormal, then

$$(t\,I + A^*)^{-1}(t\,I + A)^{-1} \leq \left(t\,I + \frac{A + A^*}{2}\right)^{-2}.$$

Proof: The condition $\varphi(0) = 0$ is equivalent to the fact that $a = 0$ in the formula (3), so

$$\varphi(z) = bx + \int_0^{\infty} \frac{tx}{x+t}\, d\mu(t),$$

for all *x* satisfying $x \in [0,+\infty)$, where

$$\int_0^{\infty} \frac{t}{t+1} d\mu(t) < +\infty.$$

This implies

$$\begin{aligned} AX\varphi(B) - \varphi(A)XB &= AX\left(bB + \int_0^{\infty} t\,B(t\,I + B)^{-1} d\mu(t)\right) \\ &\quad - \left(bA + \int_0^{\infty} t\,A(t\,I + A)^{-1} d\mu(t)\right) XB \\ &= \int_0^{\infty} t\,(AXB(t\,I + B)^{-1} - A(t\,I + A)^{-1}XB)\, d\mu(t) \\ &= \int_0^{\infty} t(t\,I + A)^{-1}A(AX - XB)B(t\,I + B)^{-1}\, d\mu(t). \end{aligned}$$

The last equality in (7) follows from the following calculus

$$\begin{aligned} AX\,B(t\,I + B)^{-1} - A(t\,I + A)^{-1}XB &= (t\,I + A)^{-1}\big((t\,I + A)AX\,B - AX\,B(t\,I + B)\big)(t\,I + B)^{-1} \\ &= (t\,I + A)^{-1}(A^2XB - AX\,B^2)(t\,I + B)^{-1} \\ &= (t\,I + A)^{-1}A(AX - XB)B(t\,I + B)^{-1}. \end{aligned}$$

If A is additionally cohyponormal, then

$$(t\,I\,+\,A)(t\,I\,+\,A^*) = t^2\,I\,+\,t(A\,+\,A^*)+\,AA^*\,\geq\,t^2\,I\,+\frac{2t(\,A+A^*)}{2}+\frac{AA^*+A^*\,A}{2}$$
$$=\,t^2\,I\,+\,2t\frac{A+A^*}{2}+\left(\frac{A+A^*}{2}\right)^2+\left(\frac{A-A^*}{2i}\right)^2=\left(\,t\,I\,+\frac{A+A^*}{2}\right)^2+\left(\frac{A-A^*}{2i}\right)^2$$
$$\geq\left(t\,I\,+\frac{A+A^*}{2}\right)^2,$$

which proves the inequality (6) since the mapping $(0,\infty)\,\rightarrow\,(0,\infty):\,t\,\rightarrow\,t^{-1}$ is operator monotone decreasing.

Lemma 2.3 Let $A\in B(H)$ be a strictly accretive operator, satisfying $A\,\geq\,cI$ for some $c\,>\,0$ and let φ be an operator monotone function on $[0,+\infty)$, such that $\varphi(0)\,=\,0$.

Then $\varphi(c)\,-\,c\varphi'(c)\,>\,0$ and
$\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)\,\geq(\varphi(c)-\,c\varphi'(c))I$ (8)
$so\;\varphi\left(\frac{A+A^*}{2}\right)\;-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)$ is strictly positively definite and invertible.

Proof : Consider the function $g(x)\,=\varphi(x)\,-\,x\varphi'(x)$ on $[0,+\infty)$. Since $g''(x)\,\geq 0$ according to the properties of operator monotone functions (Hiai F, 2010), if follows that g is an increasing real function on $[0,+\infty)$. Therefore if $A_R\,\geq\,cI$ for some positive scalar $c\,>\,0$ it follows $g_R(A)\,\geq\,g(c)I\,>\,0$.

Indeed, from the spectral calculus we have $g(A_R-\,cI\,)=\int_{\sigma(A_R)}g((\lambda)\,-\,g(c))\,d_{E(\lambda)}$ and $\langle(g(A)\,-\,cg(I\,))h,\,h\rangle=\int_{\sigma(A_R)}\big(g(t)-\,g(c)\big)\,d\mu_h(t)\,>\,0$, where E is the spectral measure associated with A_R and μ_h is the associated (scalar) measure for an arbitrary $h\,\in\,H$, given by $d\mu_h(\delta)\,=\,\langle E(\delta)h,\,h\rangle$ for every Borel set $\delta\,\subset\,R$.

RESULTS

Theorem 3.1 *Let ψ,ϕ be s.n. functions, let $p\,\geq\,2$, and let φ be an operator monotone function on $[0,+\infty)$, such that $\varphi(0)\,=\,0$ and let $A,\,B,\,X\,\in\,B(H)$. If A and B are strictly accretive, such that $AX\,-\,XB\,\in\,C_\psi(H)$, then $AX\varphi(B)-\varphi(A)XB\,\in\,C_\psi(H)$ as well, satisfying*

$$\big|\big|AX\varphi(B)-\varphi(A)XB\big|\big|_\psi$$
$$\leq\left\|\sqrt{\varphi\left(\frac{A+A^*}{2}\right)\;-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)}\left(\frac{A+A^*}{2}\right)^{-1}A(AX\right.$$
$$\left.-XB)B\left(\frac{B+B^*}{2}\right)^{-1}\;\sqrt{\varphi\left(\frac{B+B^*}{2}\right)\;-\frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)}\right\|_\psi$$

(a1) If both A and B are normal,

(a2) If A is cohyponormal, B is hyponormal and at least one of them is normal, while: $\psi=\,\phi^{(p)^*}$,

(a3) If A is cohyponormal, B is hyponormal and $\psi=l^1$;

$$\left\| \frac{A+A^*}{2}\,(AX\varphi(B) - \varphi(A)XB)\frac{B+B^*}{2}\left(\varphi\left(\frac{B+B^*}{2}\right) - \frac{B+B^*}{2}\,\varphi'\left(\frac{B+B^*}{2}\right)\right)^{-\frac{1}{2}} \right\|_{\phi^p} \leq$$

$$\leq \left\| \sqrt{\varphi\left(\frac{B+B^*}{2}\right) - \frac{B+B^*}{2}\,\varphi'\left(\frac{B+B^*}{2}\right)}\, A(AX - XB)B \right\|_{\phi^p}$$

(b1) If A is normal, B is cohyponormal and $\psi = \phi^p$,

(b2) If A is hyponormal, B is cohyponormal and $\psi = l^2$, i.e. $||\cdot||_\psi$ is the Hilbert–Schmidt norm $||\cdot||_2$

$$\left\| \left(\varphi\left(\frac{A+A^*}{2}\right) - \frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)\right)^{-\frac{1}{2}} \frac{A+A^*}{2}\,(AX\varphi(B) - \varphi(A)XB)\frac{B+B^*}{2} \right\|_{\phi^{(p)}} \leq$$

$$\leq ||\, A(AX - XB)B \sqrt{\varphi\left(\frac{B+B^*}{2}\right) - \frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)}\, ||_{\phi^{(p)}}$$

(c1) If A is hyponormal, B is normal and $\psi = \phi^{(p)}$

(c2) If A is hyponormal, B is cohyponormal and $\psi = l^2$.

Proof: To prove (a1), let us first note that $\{A_t\}_{t\geq 0}$ given by

$$A_t = \sqrt{t(t\,I + A)^{-1}}^{\frac{(A+A^*)}{2}}$$

is the $[\mu]\ s.i.$ family, satisfying

$$\int_0^\infty A_t^* A_t\, d\mu(t) \leq \varphi\left(\tfrac{A+A^*}{2}\right) - \tfrac{A+A^*}{2}\varphi'\left(\tfrac{A+A^*}{2}\right).$$

Indeed, the estimate (12) is based on

$$0 \leq \int_0^\infty A_t^* A_t\, d\mu(t) = \int_0^\infty t\frac{A+A^*}{2}\left((tI+A)(tI+A^*)\right)^{-1}\frac{A+A^*}{2}\,d\mu(t)$$

$$\leq \int_0^\infty t\frac{A+A^*}{2}\left(tI + \frac{A+A^*}{2}\right)^{-2}\frac{A+A^*}{2}\,d\mu(t) = \varphi\left(\frac{A+A^*}{2}\right) - \frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)$$

The last equality follows from the following calculus

$$\int_0^\infty t\frac{A+A^*}{2}\left(tI+\frac{A+A^*}{2}\right)^{-2}\frac{A+A^*}{2}d\mu(t)$$
$$=\int_0^\infty t\frac{A+A^*}{2}\left(tI+\frac{A+A^*}{2}\right)^{-2}\left[tI+\frac{A+A^*}{2}-tI\right]d\mu(t) \;=\; b\frac{A+A^*}{2}\;-b\frac{A+A^*}{2}$$
$$+\;\int_0^\infty t\frac{A+A^*}{2}\left(tI+\frac{A+A^*}{2}\right)^{-1}d\mu(t)-\int_0^\infty t^2\frac{A+A^*}{2}\left(tI+\frac{A+A^*}{2}\right)^{-2}d\mu(t)$$
$$=\quad b\frac{A+A^*}{2}+\int_0^\infty t\frac{A+A^*}{2}\left(tI+\frac{A+A^*}{2}\right)^{-1}d\mu(t)$$
$$-\frac{A+A^*}{2}\left[bI+\int_0^\infty t^2\left(tI+\frac{A+A^*}{2}\right)^{-2}d\mu(t)\right]=$$
$$=\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right).$$

By analogy, by denoting $\{B_t\}_{t\geq 0}$ the family given by $B_t=\sqrt{t}\frac{B+B^*}{2}(tI+B)^{-1}$, we see that $\{B_t^*\}_{t\geq 0}$ is another $[\mu]\ s.i.$ family, which satisfies

$$0\leq\int_0^\infty B_tB_t^*\;d\mu(t)\leq\;\varphi\left(\tfrac{B+B^*}{2}\right)-\tfrac{B+B^*}{2}\varphi'\left(\tfrac{B+B^*}{2}\right)$$

Starting from the formula (5), an application of the *Cauchy–Schwarz* norm inequality to $[\mu]\ s.i.$ Families $\{A_t\}_{t\geq 0}$, $\{B_t^*\}_{t\geq 0}$ and $Y=\left(\frac{A+A^*}{2}\right)^{-1}A(AX-XB)B\left(\frac{B+B^*}{2}\right)^{-1}$ (instead of X) we get the next inequality in (15).

$$\left|\left|AX\varphi(B)-\varphi(A)XB\right|\right|_\psi=\left|\left|\int_0^\infty A_tY\,B_t\,d\mu(t)\right|\right|_\psi$$
$$\leq\left|\left|\left(\int_0^\infty A_t^*A_t\,d\mu(t)\right)^{1/2}Y\left(\int_0^\infty B_tB_t^*\,d\mu(t)\right)^{1/2}\right|\right|_\psi$$
$$\leq||\sqrt{\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)}\left(\frac{A+A^*}{2}\right)^{-1}A(AX-XB)B\left(\frac{B+B^*}{2}\right)^{-1}$$
$$\sqrt{\varphi\left(\frac{B+B^*}{2}\right)-\frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)}||_\psi$$

while the double monotonicity property (1), combined with (12) and (14), justifies the inequality in (16).

To prove the inequality (9) in the case (a2), we apply the *Cauchy–Schwarz* norm inequality in (Jocic, DR, Krtinic D, Lazarevc, 2020)

$$\|\int_\Omega^{\square}A_tYB_t\,d\mu(t)\|_{\Phi^{(p)*}}\leq\left|\left|\left(\int_\Omega^{\square}A_t^*A_t\,d\mu(t)\right)^{\frac{1}{2}}Y\left(\int_\Omega^{\square}B_tB_t^*\,d\mu(t)\right)^{\frac{1}{2}}\right|\right|_{\Phi^{(p)*}}$$

instead of (23) in Jocic, DR(2005)

$$\| \int_{\Omega}^{\square} A_t X B_t \, d\mu(t) \|_{\psi} \leq \left\| \left(\int_{\Omega}^{\square} A_t^* A_t \, d\mu(t) \right)^{\frac{1}{2}} X \left(\int_{\Omega}^{\square} B_t B_t^* \, d\mu(t) \right)^{\frac{1}{2}} \right\|_{\psi}$$

to the same families $\{A_t\}_{t\geq 0}$ and $\{B_t\}_{t\geq 0}$ and for the same Y appearing in the proof of (a1). The case (a3) of the formula (9) is proved by analogy to the proofs already given, but this time by applying *Cauchy–Schwarz* norm inequality (30) for trace ideal (in Jocic DR, Krtinic D, Lazarevc M, 2020).

If $A,\ B^* \in\ L_G^2(\Omega, \mu, B(H))$ and $X \in C_1(H)$, then

$$\| \int_{\Omega}^{\square} A_t X B_t \, d\mu(t) \|_{1} \leq \left\| \left(\int_{\Omega}^{\square} A_t^* A_t \, d\mu(t) \right)^{\frac{1}{2}} X \left(\int_{\Omega}^{\square} B_t B_t^* \, d\mu(t) \right)^{\frac{1}{2}} \right\|_{1}$$

instead of (Joci´c, D.R. 2005) to the same families $\{A_t\}_{t\geq 0}$ and $\{B_t\}_{t\geq 0}$ and Y as above.

$$A_t\ = \sqrt{t(t\,I\ +\ A)^{-1}}\,\frac{(A + A^*)}{2}, \quad B_t = \sqrt{t}\,\frac{B + B^*}{2}(tI + B)^{-1}$$

$$Y = \left(\frac{A + A^*}{2}\right)^{-1}\ A(AX - XB)B\ \left(\frac{B + B^*}{2}\right)^{-1}$$

b1) To prove the inequality (10) in the case b1), let us note that $\varphi\left(\frac{B+B^*}{2}\right) - \frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)$

is invertible according to *Lemma 2.3*. It follows that

$$\frac{A + A^*}{2}(AX\varphi(B) - \varphi(A)XB)\frac{B + B^*}{2}\left(\varphi\left(\frac{B + B^*}{2}\right) - \frac{B + B^*}{2}\varphi'\left(\frac{B + B^*}{2}\right)\right)^{-1/2}$$

$$= \frac{A + A^*}{2}\left(\int_0^{\infty} t(tI + A)^{-1}\ A(AX - XB)B(tI + B)^{-1}\, d\mu(t)\right)$$

$$\frac{B + B^*}{2}\left(\varphi\left(\frac{B + B^*}{2}\right) - \frac{B + B^*}{2}\varphi'\left(\frac{B + B^*}{2}\right)\right)^{-1/2} = \int_0^{\infty} C_t Y D_t \, d\mu(t)$$

where $C_t\ = \frac{\sqrt{t}(A+A^*)}{2}\ (t\,I\ +\ A)^{-1}$, $D_t = \sqrt{t}\ (t\,I\ + B)^{-1}\left(\varphi\left(\frac{B+B^*}{2}\right) - \frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)\right)^{-1/2}$ and $Y\ =\ A(AX\ -\ XB)B.$

By applying *Cauchy–Schwarz* inequality version for *Q*-norms in (Jocic DR, Miloševic S, Duric V, 2017) it follows that

$$\left\| \int_0^{\infty} C_t Y\, D_t \, d\mu(t) \right\|_{\phi^{(p)}} \leq \left\| \left(\int_0^{\infty} C_t C_t^* \, d\mu(t) \right)^{\frac{1}{2}} Y \right\|_{\phi^{(p)}} \left\| \int_0^{\infty} D_t^* D_t \, d\mu(t) \right\|^{\frac{1}{2}}$$

$$= \left\| \sqrt{\int_0^{\infty} \frac{A+A^*}{2} t\,(tI+A)^{-1}(tI+A^*)^{-1} \frac{A+A^*}{2} d\mu(t)}\ A(AX-XB)B \right\|_{\phi^{(p)}} \cdot$$

$$\| \left(\varphi\left(\frac{B+B^*}{2}\right) - \frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)\right)^{-1/2} \int_0^{\infty} t \frac{B+B^*}{2}(tI+B^*)^{-1}(tI+B)^{-1}$$

$$\frac{B+B^*}{2} d\mu(t) \left(\varphi\left(\frac{B+B^*}{2}\right) - \frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)\right)^{-1/2} \|^{1/2}$$

$$\leq \left\| \sqrt{\varphi\left(\frac{A+A^*}{2}\right) - \frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)} A(AX-XB)B \right\|_{\phi^{(p)}}$$

The inequality (17) is obtained analogously as in Theorem 3.1 a) according to the normality of the operator A and the cohyponormality of B, combined with the fact that $(0,+\infty) \to (0,+\infty) : t \to t^{-1}$ is operator monotone decreasing function, as well as the double monotonicity property (1) for $u.i.$ norms.

b2) For the proof of the inequality (10) in this case, we replace $||\cdot||_{(p)}$ by $||\cdot||_2$ and apply Cauchy–Schwarz norm inequality (28) in (Jocic DR, Krtinic D, Lazarevc M, 2020) on the same families C_t and D_t and the same *Y* instead of Cauchy–Schwarz inequality (33) in (Jocic DR, Miloševic S, Duric V, 2017) on those families and *Y.* In the case c1), the inequality in (11) is proved similarly to the inequality (10) by applying Lemma 2.3 and the Cauchy–Schwarz inequality (34) in (Jocic, D.R., Miloševic, S., Duric,V, 2017) for the families

$$\| \int_{\Omega}^{\square} C^*XD\, d\mu(t) \|_{(2)} \leq \| \left(\int_{\Omega}^{\square} C^*C\, d\mu(t) \right)^{\frac{1}{2}} \| \cdot \| X \left(\int_{\Omega}^{\square} D^*D\, d\mu(t) \right)^{\frac{1}{2}} \|_{(2)}$$

In the case c1), the inequality in (11) is proved in a similar way to the inequality (10) by applying Lemma 2.3 and the *Cauchy–Schwarz* inequality (34) in (Jocic DR, Miloševic S, Duric V, 2017) for the families $C_t = \sqrt{t}\left(\varphi\left(\frac{A+A^*}{2}\right) - \frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)\right)^{-\frac{1}{2}} \frac{A+A^*}{2}(tI+A)^{-1}$, where $D_t = \sqrt{t}(tI+B)^{-1}\frac{B+B^*}{2}$ consists of commuting normal operators, operator $Y = A(AX-XB)B$ and by using the hyponormality of the operator *A.* Similarly, in the case c2) the proof of the inequality (11) requires a to replace $||\cdot||_{(p)}$ by $||\cdot||_2$ and to apply the *Cauchy–Schwarz* norm inequality (29) in (Jocic DR, Krtinic D, Sal Moslehian, M. 2013) instead of the *Cauchy–Schwarz* norm inequality (34) in (Jocic, D.R., Miloševic, S., Duric, V 2017) to the same families C_t and D_t and the same *Y*.

Theorem 3.2 *Let be s.n. function, let φ be an operator monotone function on $[0,+\infty)$ such that $\varphi(0) = 0$ and let $A, B \in B(H)$. If A and B are strictly accretive normal operators, then for all $X \in C(H)$*

$$\left\|\left(\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)\right)^{-\frac{1}{2}}(AX\varphi(B)-\varphi(A)XB)(\varphi\left(\frac{B+B^*}{2}\right)\right.$$
$$\left.-\frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)\right\|_\psi \le \left\|\left(\frac{A+A^*}{2}\right)^{-1}A(AX-XB)B\left(\frac{B+B^*}{2}\right)^{-1}\right\|_\psi$$
$$\left\|\left|\frac{A+A^*}{2}(AX\varphi(B)-\varphi(A)XB)\frac{B+B^*}{2}\right|\right\|$$
$$\le \left\|\left|\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)A(AX-XB)B\sqrt{\varphi\left(\frac{B+B^*}{2}\right)-\frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)}\right|\right\|_\psi$$
$$\left\|\frac{A+A^*}{2}\left(\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)\right)^{-\frac{1}{2}}(AX\varphi(B)-\varphi(A)XB)(\varphi\left(\frac{B+B^*}{2}\right)\right.$$
$$\left.-\frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)\right\|_\psi \le \left\||A(AX-XB)B|\right\|_\psi$$

The proof goes by analogy to the proof of Theorem 3.1a). First notice that $\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)$ and $\varphi\left(\frac{B+B^*}{2}\right)-\frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)$ are strictly positively definite and invertible according to Lemma 2.3. To prove (19), we just apply (15) to

$$\left(\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)\right)^{-\frac{1}{2}}Y\left(\varphi\left(\frac{B+B^*}{2}\right)-\frac{B+B^*}{2}\varphi'\left(\frac{B+B^*}{2}\right)\right)^{-1/2}$$

instead of Y, where Y is the same as in Theorem 3.1. Similarly, (20) follows by direct application of (15) to $\frac{A+A^*}{2}Y\frac{B+B^*}{2}$ instead of Y, and to prove (21), we apply (15) to the operator

$$\frac{A+A^*}{2}\left(\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)\right)^{-\frac{1}{2}}Y\left(\varphi\left(\frac{A+A^*}{2}\right)-\frac{A+A^*}{2}\varphi'\left(\frac{A+A^*}{2}\right)\right)^{-1/2}\frac{B+B^*}{2}$$

instead of Y.

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Conflict of Interest

If there is no conflict of interest of the authors, it should be written as "The authors have declared that there is no conflict of interest".

Depresyonun Genetik Temellerine İlişkin Nörofizyolojik Bulgular

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ÖZET

Depresyon, insanların günlük yaşantılarını aksatan, yaşam konforunu, yaşam kalitesini hatta gün içinde yapılan rutin işlerin verimliliğini etkileyen, dünya çapında yaygın bir ruhsal sağlık sorunudur. Kadınlarda erkeklere göre daha sık görülür ve birçok türü vardır. Dünya Sağlık Örgütü'ne (WHO) göre dünya nüfusunun yaklaşık %3,8'i depresyon yaşamaktadır. Yine WHO verilerine göre ülkemizde nüfusun %4,4'ü, yani her 10 kişiden 1'i depresyon tanısı almaktadır. Bu çalışma depresyonun kalıtım yoluyla nesiller arası aktarımının nörofizyolojik yönlerini incelemeyi ve araştırmalar yoluyla bilimsel literatüre katkıda bulunmayı hedeflemektedir. Yakın bir zamana kadar depresyon, halk arasında ve bilim camiasında büyük ölçüde çevresel faktörlerin neden olduğu bir hastalık olarak görülmekteydi ancak İnsan Genomu Projesi'nin uygulamaya konulmasıyla birlikte genetik temelli araştırmalar hız kazanmış ve bu hastalığın temelinde birçok genin yattığı tespit edilmiştir. Güncel bilimsel araştırmalar depresyonun, nörofizyolojik ve genetik mekanizmaların etkileşimiyle ortaya çıktığını göstermektedir. Özellikle genetik yatkınlık, nörotransmitter sistemlerindeki anomaliler, beyin bölgelerinin fonksiyonel farklılıkları ve çevresel stres faktörlerinin birleşimi depresyonun oluşum sürecine katkıda bulunmaktadır. Bu çalışmalar güncel bilimsel gelişmelere önemli katkılarda bulunmuştur. Depresyonun nörofizyolojik ve genetik yönlerinin anlaşılması, hastalığın kökenine dair daha derin bir bakış açısı sağlamaktadır. Bu durum, gelecekte daha kapsamlı araştırmalara zemin hazırlayacaktır.

Anahtar kelimeler: *Depresyon, nörofizyoloji, genetik*

1. GİRİŞ

Depresif bozukluk (depresyon) (DP) yaygın bir ruhsal bozukluktur. Uzun süreler boyunca depresif bir ruh hali veya aktivitelerden zevk almama veya ilgi duymama durumunu içerir. Depresyon üzerine konuşulurken depresyondan kastımızın ne olduğunu büyük önem arz etmektedir. Belki halk arasında depresyonun çok sık kullanılmasından belki de her bunalım süreçlerine depresyon denilmesinden kaynaklı olarak, depresyon denilince akla genellikle çevresel sorunların doğurduğu bir bunalım hali olarak gelmektedir. Ancak depresyonun bu kadar sığ ve yüzeysel bir tanıma sığdırılması mümkün değildir. Depresyon, günlük yaşamla ilgili olağan ruh hali değişimlerinden ve hislerden farklıdır. Aile, arkadaşlar, toplum ilişkileri gibi yaşamın tüm yönlerini etkileyebilir. Ev, okul, işyeri gibi mekanlarda yaşanan sorunlardan tetiklenebilir. Depresyon herkesin başına gelebilir. İstismara, ciddi kayıplara, travmalara veya diğer sarsıcı olaylara maruz kalmış bireylerin depresyona girmesi muhtemeldir. Kadınların depresyona girme olasılığı erkeklerden daha yüksektir. Depresyonun birçok tedavi yöntemi vardır ancak burada dikkat edilmesi gereken nokta depresyonun tetiklenme etkenidir. Örneğin Mobbingden doğan bir depresyonun tedavi yöntemi ile genom bozukluğu sonucu tetiklenen depresyonun tedavi yöntemi genel hatları uyuşmayacaktır. 2020'lerin başında yapılan büyük ölçekli

çalışmalar, depresyonla ilişkili 200'den fazla gen bölgesi olduğunu göstermiştir. Yapılan deney ve araştırmalar artarak devam etmiş olup; zigot ikizler üzerine araştırmalar, aile öyküsü, genetik ve moleküler biyoloji, beyin görüntüleme, klinik gözlemler gibi yollar ile bu konudaki bilimsel dokümanlar artarak günümüzdeki literatürü oluşturmuştur. Bu yazıda bazı depresif bozuklukların genetik etmenler üzerine oturtulmasındaki nörofizyolojik kanıtları derleyip mekanizmaları incelenmeye çalışılacaktır.

2. TANIM VE GENEL YAKLAŞIM

2.1. DEPRESYONUN TANIM VE ANALİZİ

Duygudurum bozuklukları, belirti ve ara kümelerden oluşan, süresi haftalardan aylara kadar uzayabilen, kişinin her zamanki işlevselliğinin belirgin derecede değiştiği, dönemsel ya da döngüsel biçimde yinelemeye eğilimi olan sendromlardır. Duygudurum bozukluklarının klinik görünümünü belirleyen sendromlardan biri de depresyondur. Depresyon sözcüğü, çökme, kederli hissetme, işlevsel ve yaşamsal aktivitenin azalması gibi anlamlarda kullanılan dengesiz duygularını içeren duygusal bir yaşantıdır. Bu sendromun birçok alt dalı bulunur. Her türün kendine has ve benzer semptomları vardır (Christina Sobin ve ark., 1997).

Nörofizyolojik perspektife giriş yapmadan önce depresyonun alt dallarını tanımak konuya daha bütüncül yaklaşmamıza olanak sağlayacaktır. Unipolar majör, Distimi, bipolar bozukluk, mevsimsel, gebelikle ilişkili, psikotik, adet dönemi, atipik, melankolik depresyon olarak alt dallara ayrılabilmektedir.

Bunlar arasında insan genomunun etkisi en hissedilebilir olanlar unipolar, atipik, bipolar, melankolik türleridir.

2.1.1. UNİPOLAR DEPRESYON

Kalıtsaldır. Birinci derece yakınlarda majör depresyon tanısı varsa, kişide depresyon tanısı olma ihtimali artar. Kişinin normalde keyifle yaptığı etkinliklere ilgisinin azalması, uyku rutinine göre uykunun azalması veya iştahsızlık, radikal kilo kaybı veya artışı, dışa yansıyan ajitasyon veya bitkinlik yorgun düşme halsizlik dikkat dağınıklığı ve tekrarlayan intihar düşünceleri olması gibi belirtileri vardır.

2.1.2. DİSTİMİ DEPRESYON

Günün çoğunda kendini mutsuz ve melankolik hissetme, iştahta azalma veya artma, uyku rutinine göre uykunun azalması veya artması yorgunluk, konsantrasyonda veya karar vermede bozulma. Unipolar majör depresyondaki kadar keskin değildir.

2.1.3. BİPOLAR BOZUKLUKTAKİ DEPRESYON

Bipolar bozukluk, majör depresyona göre daha dominant bir genetik bileşene sahiptir. Birey 2 durum arasında gidip gelmektedir. Hastalığın mani döneminde uykusuzluk, aşırı neşe, aşırı hareketlilik gibi semptomları vardır. Depresyon döneminde ise mutsuzluk, çökkünlük, klasik depresyon belirtileri görülür. Depresif belirtilerle başvuran hastaların öyküsünde mani veya hipomani (maninin daha hafif formu) varsa teşhis bipolar depresyondur. Eğer öyküde mani veya hipomani yoksa tanı majör depresyondur.

2.1.4. MEVSİMSEL DEPRESYON

Son 2 yıldır majör depresif dönemlerin başlangıcının yılın belirli bir zaman dilimine girmesini ifade eder. Ek olarak hastalığın kontrol edilmesi yılın belirli bir zamanında gerçekleşir, örneğin, dönemler sonbaharda başlayabilir ve ilkbahar aylarında sona erebilir.

2.1.5. PSİKOTİK DEPRESYON

Psikotik özellikler, bir depresif dönem sırasında herhangi bir zamanda ortaya çıkabilen sanrılar (yanlış, sabit inançlar) ve halüsinasyonları (yanlış duyusal algılar) içerir.

2.1.6. MENSTRUAL DÖNEM DEPRESYON

Tekrarlayarak menstrual döngünün başlamasından birkaç gün sonra gerileyen duygusal ve davranışsal belirtilerle kendini gösterir. Kişinin yaşam kalitesini olumsuz etkiler.

2.1.7. ATİPİK DEPRESYON

Hoşuna gidecek olumlu olaylarda daha iyi hissetmek, iştah artışı veya kilo alımı, normal uyku rutinine göre aşırı uyumak. Sosyal veya mesleki deformasyona sebep olan, uzun süredir devam eden kişiler arası reddedilme duyarlılığı örüntüsü.

2.1.8. MELANKOLİK DEPRESYON

Kişinin normalde istekle yaptığı işleri çoğuna ilgisinin azalması veya keyif alamaması. Genellikle hoşuna gidecek olumlu olaylarda bile kendini daha iyi hissedememe, derin bir umutsuzluk veya karamsarlıkla kendini gösteren çökkün ve mutsuz hissetme, sabah erken uyanma, hareketsizlik veya ajitasyon (huzursuz hareketlilik) Anoreksiya.

2.2. KLİNİK DÜZLEMDE SEMPTOMLAR VE EPİDEMİYOLOJİSİ

Klinik anlamda melankoli, çökkünlük, psikomotor ajitasyon, bitkinlik, yorgunluk, halsizlik, hipersomnia, insomnia, iştahsızlık, aşırı iştah, anksiyete, anhedoni, derin düşünce nöbetleri, affektif anestezi, ağrı, fobik düşünceler, intihara meyilli olma durumu, radikal kilo kaybı ve artışı cinsel istekte azalma, psikomotor retardasyon, hafızada değişiklikler, algı değişikliği, konsantrasyonda bozulma, bilişsel bozukluklar gibi semptomlar birey üzerinde görülebilir (Johann Angst, 1992).

Epidemiyolojik perspektiften bakıldığında ise psikososyal, çevresel değişkenler; sosyoekonomik, sosyokültürel parametreler; geçmişte yaşanan travmalar, beyinin belli loblarında ortaya çıkan tümörler, gelecek kaygısı ve yüksek anksiyete, hormonâl bozukluklar, yetersiz beslenme, fiziksel ve psikolojik istismar, biyolojik, genetik, patolojik, nörofizyolojik etkenler depresyonu tetikleyebilecek sebepler içinde yer alır.

2.3. GENETİK VE NÖROFİZYOLOJİK YAKLAŞIMIN ÖNEMİ

Genetik ve nörofizyolojik yaklaşımlar modern bilimin insan gibi mozaik bir biyolojik temelleri olan organizmaları hem daha geniş yelpazede hem de incelikle incelenmesi ve anlaşılır bir zemine oturtulmasında büyük önem taşır. İnsan davranışlarının bazı bölümlerinin mikro ölçekli değişkenler tarafından domine edilmesi göz önünde bulundurulduğunda, bu yaklaşımların sahada kullanılması zorunlu hale gelir. Beyin ve davranış ilişkileri nöronal aktivite ile yakından ilişkilidir. Nörotransmitterlerle (dopamin, serotonin vb.) beyin yapıları arasındaki bağlantıyı en iyi nörofizyoloji açıklayacaktır diğer yandan kalıtım, zekâ, kişilik, insan davranışlarının evrimsel zemine oturtulması gibi konuların incelenmesi için genetik yaklaşıma başvurulmalıdır.

3. GENETİK TEMELLENDİRİLMEYE İLİŞKİN ARAŞTIRMALAR VE KANITLAR

3.1. DEPRESYON PATOFİZYOLOJİSİ VE BULGULAR

2023 yılında yayınlanan bir araştırma 371,184'ü duygudurum bozukluğu mevcut olan >1.3 milyon bireyin genom çapında bir ilişkilendirme çalışması ile meta-analizi gerçekleştirilmiş ve 243 risk (bu 243

lokusun içinde glutamat ve GABA reseptörlerini kodlayan genler de içinde olmak üzere 64 genetik lokus yeni keşfedilmiştir) bölgesi tespit edilmiştir (Thomas D. Als ve ark, 2023).

Fonksiyonel genomik verilerin birleşik analizi, belirli hastalıklarla ilişkili olası nedensel genleri önceliklendirmeyi sağlamış ve prenatal dönemdeki beyin gelişimine dair önemli bulgular ortaya koymuştur. Yapılan çalışmalar, GABAerjik nöronların, astrositlerin ve oligodendrosit soyların, kritik bir rol oynadığını göstermektedir. GABAerjik nöronların inhibisyon süreçlerinde, astrositlerin nöronal destek ve homeostazda, oligodendrositlerin ise miyelinasyon ve sinir iletiminde işlevlerinin prenatal dönemdeki genetik düzenlenmesinde, nörogelişimsel bozuklukların patogenezinde merkezi bir öneme sahip olabileceği anlaşılmaktadır (Thomas D. Als ve ark, 2023).

Tek nükleotid polimorfizmi kalıtsallığının %90'ını açıklayan ~ 11.700 varyant ile depresyonun oldukça poligenik olduğu ve diğer psikiyatrik bozukluklar için risk varyantlarının >%95'inin hem uyumlu hem de uyumsuz varyantlar göz önüne alındığında depresyon riskini etkilediğini ve neredeyse tüm depresyon risk varyantlarının eğitim kazanımını etkilediği ortaya konulmuştur daha basit düzlemde yorum yapmak gerekirse genetik olarak depresyona yatkınlık oluşturan varyantların çoğu, aynı zamanda bir bireyin eğitim başarısı veya eğitime devam etme olasılığı üzerinde de etkili olabilir (Thomas D. Als ve ark, 2023).

Tüm bunlara ek olarak depresyonun genetik riski, bozulmuş karmaşık biliş alanları ile bağdaştırılmış olup genetik ve klinik heterojenliği araştırılmıştır. Bunların neticesinde depresyonun alt grupları arasında farklı poligenik mimarileri ortaya çıkarılmıştır (Thomas D. Als ve ark, 2023).

Bu bulgular sadece duygudurum bozukluğunun değil özellikle şizofreni, otizm spektrum bozukluğu ve epilepsi gibi hastalıkların moleküler temellerinin aydınlatılmasına ve potansiyel tedavi hedeflerinin belirlenmesine önemli katkı sağlayacak niteliktedir.

3.1.1. KOHORT VERİ ANALİZİ VE META-ANALİZ ÇALIŞMALARI

Hem gen aktarımının düşük olması hem de klinik semptomların heterojenliği nedeniyle depresif fenotiplere ilişkin genetik risk genomlarının tespit edilmesi oldukça güç olmuştur.

2023 Yılında kohort verileri üzerinden yapılan bir araştırma, deney gruplarının genomik enflasyon faktörü (λGC) 1.89 çıktığını göstermektedir. Bu, test sonuçlarında normalden fazla pozitif ilişki olduğunu saptamaktadır. Ancak bu enflasyonun %95'inin, yani büyük kısmının, örneklemin yapısından (popülasyon farklılıkları, hata payları vs.) değil, genetik sinyallerin çok sayıda poligeniklikten kaynaklandığı bulunduğu belirtilmiştir. Ayrıca LDsc kesişim değeri 1.06 ve zayıflatma oranı 0.047 tespit edilmiştir. Bu da popülasyon yapısının etkisinin az olduğunu kanıtlamaktadır. Güçlü çift yönlü genetik korelasyonlar (rG) bulunması ve rG değerleri 0.77-0.95 arasında saptanması, İPSYCH kohortuna ait verilerdede genetik miras oranı (h^2SNP) %16.7 olarak hesaplanması, tüm oranların diğer gruplara göre daha yüksek çıktığı anlamına gelmektedir (fark: %5.7–%9.8 arası). Bu da iPSYCH örnekleminde depresyonun genetik etkisinin diğerlerinden daha belirgin olduğunu göstermektedir (Thomas D. Als ve ark, 2023; Adam Schork ve ark, 2018).

Yakın zamanda gerçekleştirilen başka bir araştırmaya göre üç farklı kohorttan >800.000 bireyi kapsayan bir genom çapında meta-analiz çalışması sonucunda, depresyonla ilişkili 102 anlamlı risk lokusu saptanmıştır (David M. Howard ve ark, 2018).

3.1.2. DP PATOFİZYOLOJİSİNİN NÖROTRANSMİTTER BOYUTU

Nörotransmitterlerin depresyon etiyolojisinde kritik bir rol oynadığı düşünülmektedir. 5-HT (serotonin), omurgalıların sinir sisteminde yaygın olarak bulunur ve eksikliği depresyon, fobiler, kaygı bozuklukları ve diğer ruh sağlığı sorunlarına yol açabilir. Son yıllarda, 5-HT hipotezi, depresyonun altında yatan nedenler üzerine araştırmaları yönlendirmiştir. Yapılan çalışmalar, depresyon hastalarının beyinlerinde düşük 5-HT seviyeleri ve değişmiş 5-HT reseptörleri (örneğin, artmış 5-HT2 reseptör aktivitesi ve azalmış 5-HT1A reseptör duyarlılığı) olabileceğini göstermektedir (Nicole Yohn ve ark, 2017).

Bu bulgular, serotonin sistemindeki bozuklukların depresyon patofizyolojisinde önemli bir faktör olduğunu desteklemektedir.

5-HT ve diğer nörotransmitterlerin sentezinde görev alan genlerin kalıtım yolu ile nesiller arasında aktarımla geçtiğini göz önüne alırsak mevcut genlerde oluşacak kalıtsal bir patolojinin diğer nesillere de geçebilme olasılığının olduğunu söyleyebiliriz.

3.2. DEPRESYON GENETİĞİ ÜZERİNE DENEYLER VE KALITIM

3.2.1. AİLESEL KALITIM ARAŞTIRMALARI

2016 Yılında yayınlanan bir araştırma ile MDD'nin (Major depresif bozukluk) genetik nedenleri incelenmiş özellikle bu bozukluğun kalıtsal olma derecesine ve anksiyete bozukluklarıyla olan genetik ilişkisine bakılmıştır. Bunun için yüksek risk taşıyan aile üyeleri üzerinde yapılan çok kuşaklı bir çalışmada değerlendirilmiş, 65 Aileden 545 katılımcı ile 30 yıl boyunca klinisyenler tarafından belli periyotlar depresyonun takibi denetlenmiştir. MDD'nin kalıtımının (h2) %67 olduğu tahmin edilmiştir. Yani genetik mirasın, depresyon riskini önemli ölçüde etkileyen bir parametre olduğu kanısı ortaya atılmıştır. Bu yüksek riskli örneklemdeki Anksiyete ve anksiyete bozuklukları için kalıtsallık oranı %49 ile %53 arasında bulunmuştur. Bu verilere bakarak kaygı bozukluklarında da kalıtımın kilit bir rolü vardır ancak depresyona göre bu oranlar düşüktür (Giuseppe Guffanti ve ark, 2016).

Depresyon ve anksiyete arasında güçlü bir genetik bağlantı (korelasyon) bulunmuştur (rhoG = 0.92). Bu, aynı genetik faktörlerin hem depresyon hem de anksiyeteye yol açabileceğini gözler önüne sermektedir. 0.92 gibi çok yüksek bir korelasyon değeri ile neredeyse bire bir benzer genetik etkilerden söz edilmektedir. İstatistiksel olarak ise (P ¼ 7.3 107) bu sonucun tesadüf olmadığını aksine çok anlamlı olduğunu göstermektedir (Giuseppe Guffanti ve ark, 2016).

MDD'si olan bireylerin birinci derece yakınlarının hastalığa yakalanma riski tüm popülasyona bakıldığında üç kat daha yüksek olduğu görülür. Özellikle hastalığın erken yaşta başlaması ve yineleyici epizotlarla seyretmesi durumunda, genetik katkının artacağı düşünülmektedir. Tek uçlu bozukluğun ortaya çıkışında, her biri küçük etkiye sahip birden fazla genin rol aldığı öne sürülmekte ve bu nedenle genetik bağlantı ve aday gen çalışmalarının sınırlı başarı sağladığı belirtilmektedir. Bu hastalıkla ilişkilendirilmiş başlıca genler arasında BDNF (Beyin nörotrofik faktör), MA0-A (monoamin oksidaz A), COMT (Katekol-O-Metiltransferaz), hTPH2 (Triptofan Hidroksilaz 2) ve HTTLPR (serotonin taşıyıcı geni) yer bulunmaktadır.

Yapılan çalışmalarda depresif bozukluğa sahip olan ebeveynlerin yavrularında bipolar bozukluğun görülme oranının nonpatojen çocuklara göre 7 kat yüksek bulmuştur

Bu veriler sadece bipolar bozukluk için değil depresyon ve anksiyete bozuklukları mevcut ebeveynlerin çocuklarında da bipolar bozukluğun görülme oranı nonpatojen çocuklara göre yüksektir.

Bipolar bozukluğu olan bireylerin birinci derece akrabalarında aynı bozukluğun görülme oranı yaklaşık %8.7 iken, majör depresif bozukluğu olan bireylerin birinci derece akrabalarında bu oranın %14.1'e kadar çıktığı bildirilmektedir. Bu bulgular hem bipolar hem de unipolar duygudurum bozukluklarında genetik geçişin rolünü vurgulamakta; ancak unipolar depresyonun ailesel kümelenme açısından daha belirgin olabileceğini göstermektedir. Bu araştırmaların dışında beş ailesel depresyon çalışmasının sonuçlarını karşılaştıran derleme tablosu:

Tablo 1. Beş Farklı Aile Deneyinin Karşılaştırılması

Çalışma (Yıl)	Ülke	Depresyonlu Ailelerde Görülme Riski (%)	Sağlıklı Ailelerde Görülme Risk (%)	Risk Katsayısı
Gershon (1982)	ABD	%16.6	%5.8	3.2x
MaiSer (1993)	Almanya	%21.6	%10.6	2.3x
Tsuang (1980)	ABD	%15.2	%7.5	2.2x
Weissman (1984)	ABD	%17.6	%5.9	3.4x
Weissman (1993)	ABD	%21.0	%5.5	4.6x

3.2.2. İKİZ (ZİGOT) DENEYLERİ

İkiz çalışmaları temelinde yapılan raporların meta analizi, MDD'nin kalıtım derecesinin 0,33 (güven aralığı, 0,26-0,39) olduğunu tahmin etmiştir (Richard Wurtman, 2005).

Unipolar depresyonda genetik faktörlerin rolü, şizofreniye kıyasla daha yüksektir. Monozigot ikizlerde unipolar depresyon konkordansı, nöbet sayısı ≥3 olan bireylerde %59, <3 olanlarda ise %33 olarak tespit edilmiştir (Herken ve Hasan, 2002).

Yine monozigot ikizlerde yapılan çalışmalarda bir kardeşte unipolar depresyon tanısının olması diğer kardeşte görülme olasığı %59-%92,5 oranlarında değişmektedir. Dizigot ikizlerde ise bu oran yaklaşık %20'dir, monozigot ikizlerde unipolar depresyon görülme olayı dizigot ikizlere göre 3,6 kat fazladır.

Monozigot ikizlerdeki oranın yüksekliğine bakarak depresyonu tetikleyen genlerin var olduğunu somut bir biçimde önümüze serer çünkü monozigot ikizlerden birinde bulunan gen yüksek ihtimal ile diğer kardeşte de bulunacak ve depresyon ondada tetiklenecektir.

Diğer (%41-%17,5) oranları incelersek bu verilerin kardeşlerde depresyonun görülmeme oranlarını görürüz bu da depresyonun bir bölümünün genlerden bağımsız olarak çevresel etmenler tarafından domine edildiğini gösterir.

Diğer yandan dizigot kardeşlere baktığımızda ise bu oranın monozigot kardeşlere göre açık ara düşük olduğunu ancak onlarda da görülmesinin yüksek olduğu kanısına varabiliriz.

Bu sonuçlar depresyonun açığa çıkmasında genetik yatkınlığın önemini ispat etmektedir.

Tablo 2. Dört Farklı Zigot Deneyinin Sonuçlarının Karşılaştırılması

Çalışma	Ülke	Cinsiyet	Genetik	Çevre	Monozigot	Dizigot
Bleru (1999)	Avustralya	Erkek	%24	%76	%34	%30
Bleru (1999)	Avustralya	Kadın	%44	%56	%50	%37
Kendler (1995)	İsveç	Erkek	%57	%43	%40	%33
Kendler (1995)	İsveç	Kadın	%78	%22	%67	%32
Lyons (1998)	ABD	Erkek	%36	%64	%23	%14
McGuffin (1996)	İngiltere	Kadın	%38	%62	%46	%22
ORTALAMA			**%37**	**%63**		

4. GENOM DÜZLEMİNDE DEPRESYON

5.1. DEPRESYONLA İLİŞKİLİ BAZI GEN BÖLGELERİ

Depresyonun genetik temelinde *NEGR1 LINCO1850* gibi genler rol oynar. GWAS çalışmaları, bu genlerdeki varyasyonların depresyon riskini artırabileceğini göstermiştir

Tablo 3. Depresyonu Tetikleyen Bazı Genler

Yer No	Kromozom	SNP Kimliği	Gen/Gen Bölgesi
8	1	rs753118	NEGR1
9	1	rs10890020	LINC01850
38	2	rs1320138	ARHGAP15
45	2	rs6715105	ANKRD44, SF3B1
53	3	rs56029819	SNRK, ANO10
80	5	rs4262121	TERT (yakını)
89	5	rs67379847	PRR16
93	5	rs2964003	GRIA1
94	5	rs4596421	GABRA6
98	6	rs35883476	HIST1, BTN3A2

99	6	rs10947690	MDC1
114	7	rs957360	SDK1
124	7	rs1966692	EXOC4
156	10	rs1909696	LHPP
158	10	rs1021363	SORCS3
191	13	rs9561331	GPC6
199	14	rs741014	-
210	15	rs4886915	LINC01105
225	17	rs60856912	BPTF, KMT2A
233	18	rs12967143	TCF4, MIR4529

(**Tablo 3. kaynakça:** Thomas D. Als ve ark, 2023; Detera ve ark, 1999; Henrik Ewald, 2000; Axel T. Brünger ve Paul D. Adams, 1998; Kelsoe ve J.R, 1999; Henning Knudsen ve ark, 1996; Nick Craddock ve ark, 1999; William H. Berettini, 1999; Richard E. Straub ve Thomas Lehner, 1994; Howard J. Edenberg ve Tatiana Foroud, 1997)

5.TARTIŞMA

Bu çalışmada, depresyonun genetik altyapısı ile nörofizyolojik mekanizmalar arasındaki ilişki çok yönlü olarak ele alınmıştır. Özellikle serotonin taşıyıcı gen polimorfizmi gibi genetik faktörlerin depresyon gelişiminde kritik roller üstlendiği görülmektedir. Bu genetik varyasyonların, bireylerin çevresel stres faktörlerine verdikleri nörofizyolojik tepkileri etkileyerek duygudurum düzenleme mekanizmalarını bozabileceği düşünülmektedir. Bulgular, depresyonun yalnızca psikososyal koşullarla açıklanamayacak kadar karmaşık bir bozukluk olduğunu, genetik yatkınlıkların beyin yapıları ve işlevleriyle olan etkileşimlerinin hastalığın ortaya çıkışında belirleyici olabileceğini göstermektedir. Elde edilen veriler, Genetik temelli depresyonun nörofizyoloji perspektifinden incelenmesinin önemini bir kez daha ortaya koymaktadır.

6.SONUÇ

Genetik faktörler, depresyonun gelişiminde önemli bir belirleyici olarak öne çıkmakta ve bireylerin stresli yaşam olaylarına verdikleri nörofizyolojik tepkileri şekillendirmektedir. Bu çalışma, depresyonun etiyolojisinin yalnızca çevresel ya da psikolojik faktörlere indirgenemeyeceğini; genetik yatkınlıkların beyindeki nörokimyasal ve yapısal değişikliklerle birleşerek hastalık riskini artırdığını ortaya koymuştur. Genom düzeyinde yapılan araştırmalarla, genlerdeki varyasyonların depresyon gelişimindeki rolleri desteklenmiştir. Gelecekte yapılacak daha kapsamlı çalışmaların, bireyin genetik profiline dayalı önleyici ve tedavi edici yaklaşımların geliştirilmesine ışık tutması beklenmektedir.

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Jeotermal Tesisler için Raspberry Pi Yönetimli Vana Kontrolü

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Özet

Fosil yakıtların günümüzde giderek tükenmesi yenilenebilir enerji sistemlerin kullanımın gün geçtikçe artırmasına neden olmaktadır. Ancak genel olarak, yenilenebilir enerji sistemlerin ilk kurulum maliyetlerinin çok yüksek olması, kendilerini amorti etme sürelerinin uzun olmasına sebep olmaktadır. Bu durum yatırımcıların bu tip tesislere yatırım yapma eğilimini azaltmaktadır. Bunun önüne geçmek için farklı ülkelerin yenilenebilir enerji yatırımcılarını teşvik etmek için farklı politikaları bulunmaktadır. Diğer bir yanda, amortisman sürelerinin kısa olabilmesi için yenilenebilir enerji sistemlerinden mümkün olabildiğince en yüksek verimi sağlayabilecek şekilde çalışması gerekmektedir. Bu çerçevede, jeotermal sistemlerde verimi artırmak için güneş enerjisinden yararlanılmaktadır. Ayrıca son yıllarda yapay zeka ve büyük veri modelleri gibi tekniklerden faydalanılmaktadır. Parabolik toplayıcılar sayesinde güneş enerjisinden çok yüksek ısılarda ısınmış akışkan elde edilmektedir. Parabolik oluk tipi toplayıcılardan elde edilen ısınmış akışkanın O anda sahip olduğu sıcaklığa bağlı jeotermal sistemde en uygun noktalara paylaştırılması ve dağıtılması için farklı noktalara yerleştirilmiş ısı vanaları kullanılmaktadır. Yapay zeka programların işledikleri anlık işletim verileri ile bu vanaların açılıp kapılma durumlarını yönetilmektedir. Bu şekilde güneş enerjisinden elde edilen ısı enerjisi jeotermal sistem üzerindeki farklı noktalara daha yüksek elektrik enerjisi eldesi için farklı ısı değiştiricilerine paylaştırılır maktadır. Bu çalışmada ısı vanalarının yapay zeka programlarından gelen değerlere bağlı, açılma yada kapanma durumlarını gerçekleştirmek için Raspberry Pi kontrollü PWM tekniği kullanan basit ve pratik bir sistem önerilmektedir. Simülasyonu gerçekleştirilen sistemde, ısı vanaların açılma-kapanma durumları set motorlar ile sağlanmaktadır, Isı transfer hesaplamaların yürütüldüğü, yapay zeka programından gelen tablo değerlerine bağlı, step motorun hareket yönü ve derecesi Raspberry Pi üzerinde çalışan Python kodları ile belirlenmektedir. Geliştirilen Python programı üzerinde çalışan PWM fonksiyonların ürettiği nabız genişlikleri, vanaların hareketini sağlayan step motorların hareketini sağlamaktadır. Bu şekilde ana borudan gelen ısınmış akışkan sahip olduğu anlık sıcaklık değerine bağlı en uygun ısı değiştiricilere yüksek verim için yönlendirilmektedir.

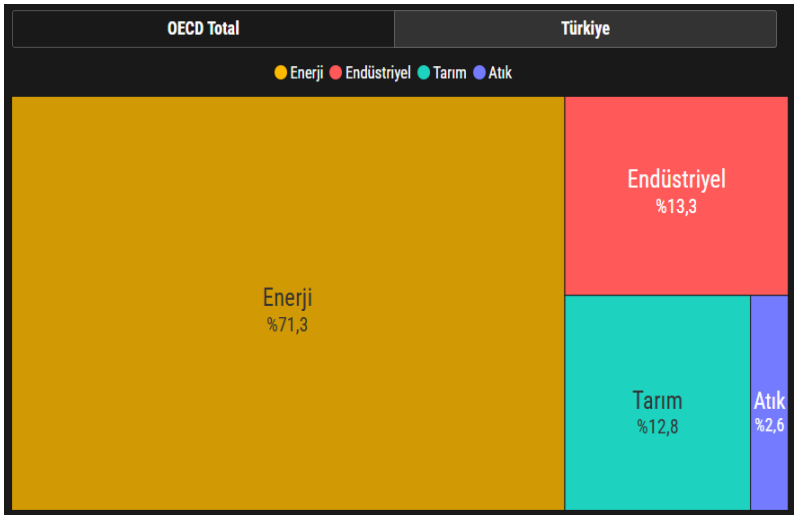
Anahtar Kelimeler: *Pyhton, Raspberry Pi, PWM, Endüstriyel Otomasyon, Jeotermal Enerji*

GİRİŞ

Yenilenebilir enerji sistemleri enerji ihtiyaçların karşılanmasında oldukça büyük bir öneme sahiptir. Bunun en önemli nedenlerinden biri küresel ısınmadır. Küresel ısınmanın etkisi her geçen mevsimlerde daha da his edilmeye başlanmıştır. Politik alanda yalnızca iklim değişikliğinin negatif sonuçlarının değil, azaltım politikalarının maliyetlerinin de toplumdaki farklı kesimler tarafından yüklenileceği ve paylaşılacağı aynı derecede açıktır. İklim değişikliği, iki önemli değer arasında kalan modern dünya için büyük bir zorluk teşkil etmektedir (S.Doğan,E.Doğan, M.Tüzeri, 2020). Sera gazlarının insan kaynaklı

emisyonları, küresel sıcaklıklarda 1,2 °C'lik öngörülebilir bir artışa yol açmıştır. Son 70 yılda bu artış jeolojik olarak eşi benzeri görülmemiş bir hızda ve ölçekte gerçekleşmiştir (D.G.Quirk, 2021). Atmosferde Sera Gazı Yoğunluğunun Artmasına neden olan başlıca insan faaliyetleri sıralanacak olursa (S. Kışkaya, P.Gençoğlu, 2017); doğal sera gazlarının salınımların da ki artış bunlardan biridir. Bu durum barınma, ulaşım, elektrik üretimi vb. sektörlerde fosil yakıt olarak adlandırılan kömür, petrol, doğal gaz gibi yakıtların tüketilmesi neticesinde milyonlarca yıldır yerin altında bulunan karbon moleküllerinin atmosferdeki oksijen (O2) gazı ile birleşerek doğal sera gazlarına dönüşmesi ve atmosfere karışmasıdır.

Endüstriyel sera gazlarının salınımlarında artış. Bu durum son yüzyılda geliştirilen yeni sanayi ürünlerinin üretimi yada tüketimi sırasında ortaya çıkan ve doğal sera gazlarından çok daha fazla ışınımsal zorlama yaratabilen sera gazlarının atmosfere salınmasıdır. Sera gazı yutaklarının yok edilmesi, orman alanlarının; tarım, konut, sanayi, enerji gibi amaçlarla yok edilerek, sera gazlarının atmosferden uzaklaşma hızlarının yavaşlatılması sayılabilir (S. Kışkaya, P.Gençoğlu, 2017). Son yıllarda sektörlere göre sera gazı salınımı dağılımı Şekil 1'de görülmektedir.



Şekil 1. Sektörlere göre sera gazı salınımı dağılımı (dogrulukpayı, 2025).

Ayrıca küresel ısınmanın dışında fosil rezervlerin zaman geçtik azalması, alternatif enerji kaynaklarına olan gereksinimi artırmaktadır. Bu yüzden yenilenebilir enerji kaynaklarına yatırım oldukça önemli bir konu haline gelmektedir. Fosil kaynakların tükenmesi ve dünya enerji ihtiyacının hızla artması, insanları yeni enerji kaynakları arayışı içerisine sokmuştur. Özellikle 1976 yılında yaşanan petrol krizi, tüm dünyaya fosil kaynaklı yakıtların arzının dengesiz olduğunu göstermiştir, bu nedenle sürekli arz edilebilen kaynak arayışına girilmesine neden olmuştur (M. Dok , M Acar , A.E. Çelik , G. Atagün, U. Akbaşı, 2019). Yenilenebilir enerji kaynakları arasında en önde gelenler; Yenilenebilir enerji kaynakları arasında en önde gelenler şunlardır: Güneş enerjisi. Dünya üzerindeki en büyük enerji kaynağıdır ve çoğunlukla elektrik ve ısı elde etmek için kullanılmaktadır. Rüzgar enerjisi. Yaygın olarak kullanılan ve pratikliği ile ön plana çıkan bu enerji türü, karbon salınımına neden olmaz ve çevreyi korunmaktadır. Hidroelektrik enerji suyun akış veya düşüş gücünden elde edilir ve engebeli, sulak bölgeler için daha avantaj sağlamaktadır. Bunların dışında ise biyokütle, jeotermal, dalga ve gel-git enerjileri de yenilenebilir enerji kaynakları arasında önemli bir yere sahiptirler. Jeotermal enerji doğrudan mekan ısıtma gibi uygulamalarda kullanılabileceği gibi, diğer yandan doğrudan olmayan

jeotermal enerji ile elektrik üretimi yoluyla gerçekleşmektedir (Ö.C. Külekçi, 2009). Yeni Zelanda 1958'de Wairakei'de Flash Yöntemi ile jeotermal enerjiden, geliştirilmiş bir sistemle elektrik üretilmiştir. Bu tarihten itibaren ve 1970'lerin ortalarındaki petrol kriziyle birlikte jeotermal enerji üretimi dünyada hızla gelişmiştir (H. Erkül, 2012). Jeotermal enerji birçok yenilene bilir enerji sistemleri gibi ilk yatırım maliyeti olarak yüksek yatırım giderlerine ihtiyaç duymaktadır. Bu yüzden kendilerini amorti edebilmeleri ve kısa zamanda kazanç sağlayabilmeleri için mühendislik açısından tasarımların enerji verimliklerini en üst seviyede tutacak şekilde yapılması gerekmektedir. Bu açıdan ekserji analizleri verimi en üst düzeyde tutabilmek için yapılamaktadır.

Ekserji analizleri, enerji sistemlerinin ve hal değişimlerinin gerçekçi ve anlamlı biçimde değerlendirilmesini ve karşılaştırılmasını sağlar. Bu analizler sayesinde: Termodinamik kayıpların yerleri, miktarları ve nedenleri bulunabilir (Guan, Y.; Grote, K,2023) Gerçek sistem performansı, maksimum performansla karşılaştırılabilir. Daha iyi tasarımlar yapılabilir ve sistem performansı iyileştirilebilir. Kaynakların kullanımında en fazla fayda elde edilmesi ve çevre kirliliğinin azaltılması sağlanabilir. Diğer taraftan yapay zeka sistemleri de önemli rol oynamaktadır. Yapay zekanın jeotermal enerji üretiminde verimliliği artırdığı ve maliyet düşüşüne yol açtığı, ayrıca çevresel endişelerin ele alınmasına yardımcı olmaktadır. Jeotermal sistemlerin kontrolünde ayrıca ısı değiştiricileri üzerinden verim düzeylerin derin öğrenme ve yapay zeka destekli yazılımlarla denetlemesi sağlanarak daha yüksek seviyede verimlerin elde edilmesi mümkün olabilmektedir (G.Uçkan, E.Çomak, O.Ekren, A.Yılancı, 2016). Bu çalışmada yapay zeka destekli jeotermal tesislerin, farklı sıcaklık değerleri için vana kontrol etkili bir şekilde gerçekleştirilmesini sağlayan, Raspberry Pi ile kontrol edilen bir vana kontrol sistemin prototipi geliştirilmiştir. Çalışma Pyhton kodları kullanılarak vana kontrol sistemin çalışması simülasyonu yazılımı üzerinden sağlanmıştır. Bu alanda daha önce yapılmış benzer çalışmalar araştırılıp aşağıda verilmiştir.

Literatür İncelemesi

Günümüzde yenilenebilir enerji kaynaklarının verimli kullanımı, sürdürülebilirlik politikalarının vazgeçilmez bir parçası hâline gelmiştir. Bu kapsamda jeotermal enerji sistemlerinin otomasyonu, hem enerji verimliliği hem de sistem güvenliği açısından önem arz etmektedir (Sun, Z.; Di, L.2021). Aşağıda, Raspberry Pi ve benzeri mikrodenetleyici tabanlı sistemlerle gerçekleştirilen çalışmalar şu şekildedir; Yılmaz ve arkadaşları (2021) – "Raspberry Pi ile Akıllı Sulama Otomasyonu". Bu çalışmada Raspberry Pi tabanlı bir sistem ile toprak nem sensörleri yardımıyla sulama vanalarının otomatik kontrolü sağlanmıştır. Kullanıcılar sisteme uzaktan erişim sağlayarak manuel ya da otomatik sulama modları arasında geçiş yapabilmiştir (Gamal, Y.; Soltan, A.; Said, LA; Madian, AH; Radwan.2023). Bu çalışma özellikle düşük maliyetli bileşenlerle akıllı kontrolün mümkün olabileceğini göstermiştir. Python programlama diliyle yapılan sistem, hem uzaktan erişim hem de çevresel faktörlere bağlı karar verebilme yeteneği kazandırmıştır. Ancak Sistem, özellikle endüstriyel kullanım için gerekli olan dayanıklılık testlerine tabi tutulmamıştır. Ayrıca vana motorlarının gerçek zamanlı durum takibi yapılmamış, sadece tetikleme odaklı bir kontrol yaklaşımı benimsenmiştir. Diğer bir çalışma ise Demir ve Şahin (2020) – "Jeotermal Enerji Santrallerinde Otomasyon Sistemleri: PLC vs Raspberry Pi Karşılaştırması". Çalışmada PLC tabanlı bir sistem ile Raspberry Pi tabanlı bir kontrol sisteminin jeotermal santrallerdeki olası kullanım senaryoları karşılaştırılmıştır. Vana kontrolü, sıcaklık sensörleri

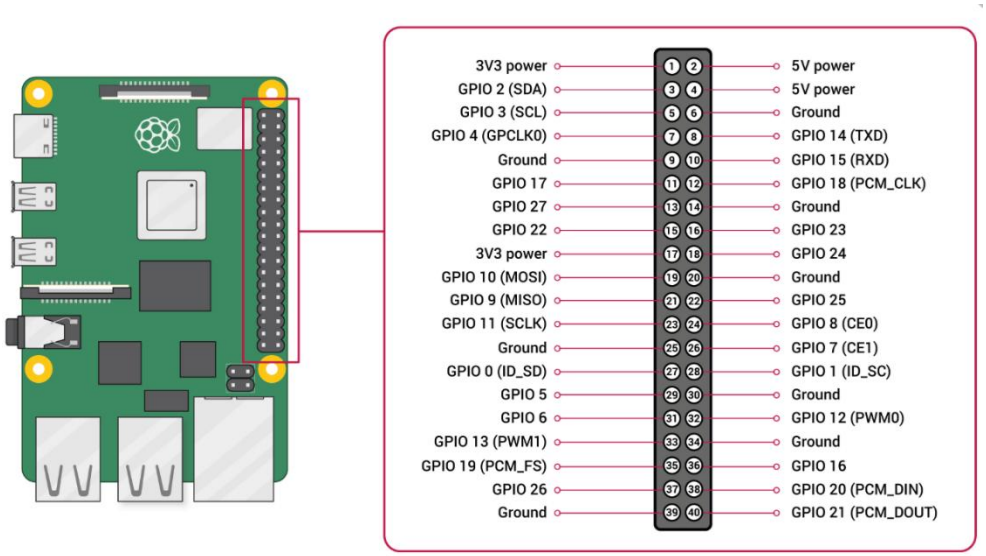
ve veri kaydı gibi işlevler test edilmiştir. Raspberry Pi, düşük maliyetli olması ve programlama esnekliği sayesinde avantajlı bulunmuştur (Touil, S.; Richa, A.; Fizir, M.; Argente Garcia, JE; Skarmeta Gomez, AF, 2022). Ayrıca verilerin bulut sistemine aktarılabilmesi ve açık kaynaklı yazılımlarla entegre çalışabilmesi gibi faydalar sağlanmıştır. Donanım açısından Raspberry Pi'nin zorlu çevre koşullarına dayanıklılığı sorgulanmıştır. Gerçek zamanlı çalışma ihtiyacı olan uygulamalarda gecikme yaşanabileceği belirtilmiş ve uzun vadeli kararlılık testleri yapılmamıştır. Başka bir çalışma ise Korkmaz (2019) – "Endüstriyel Otomasyonda Raspberry Pi Kullanımı: Bir Isı Kontrol Uygulaması Çalışmada, Raspberry Pi ve DS18B20 sıcaklık sensörü kullanılarak endüstriyel bir tank içerisindeki sıvının sıcaklığı kontrol edilmiştir (GS Campos, N.; Rocha, AR; Gondim, R.; Coelho da Silva, TL; Gomes, DG, 2019). Sisteme bağlı bir röle aracılığıyla ısıtıcı devresi açılıp kapatılmıştır. Proje, küçük ve orta ölçekli işletmeler için uygun maliyetli bir alternatif sunmuştur. Python ile esnek bir kontrol algoritması yazılmış ve veri kayıt/loglama özellikleri başarıyla uygulanmıştır. Ancak sistem sadece sıcaklık değerine bağlı çalışmakta, çok değişkenli sistem kontrolü yapılmamaktadır. Ayrıca, bir HMI (Human-Machine Interface) arayüzü bulunmamakta, kullanıcı etkileşimi ise sınırlı olmaktadır.

GEREÇ VE YÖNTEMLER

Çalışmanın gerçekleştirilebilmesi için gereç olarak Raspberry Pi, Python, ısı senörleri ve sürücüler kullanılmıştır. Vanaların hareket kontrollerini sağlamak için ise darbe genişliği modülasyonu PWM tekniği yazılımın geliştirilmesinde yöntem olarak kullanılmıştır. Sistemin çalışır hale gelemesi için aşağıdaki adımlar uygulanmalıdır. Gerekli malzemelerin hazırlanması. Raspberry Pi, breadboard, 5V güç kaynağı, mikro servo motor ve dişi-erkek jumper kablolar gereklidir. Devrenin kurulması. Servo motorun VCC pini Pico kartının VBUS pinine, sinyal pini GPIO0'a ve GND pini GND pinine bağlanır. Kodun yazılması. Python kodu, "servo.py" adıyla bir dosyaya kaydedilir. Kodun çalıştırılması. Python komutu olan "sudo python servo.py" ile sağlanmaktadır.

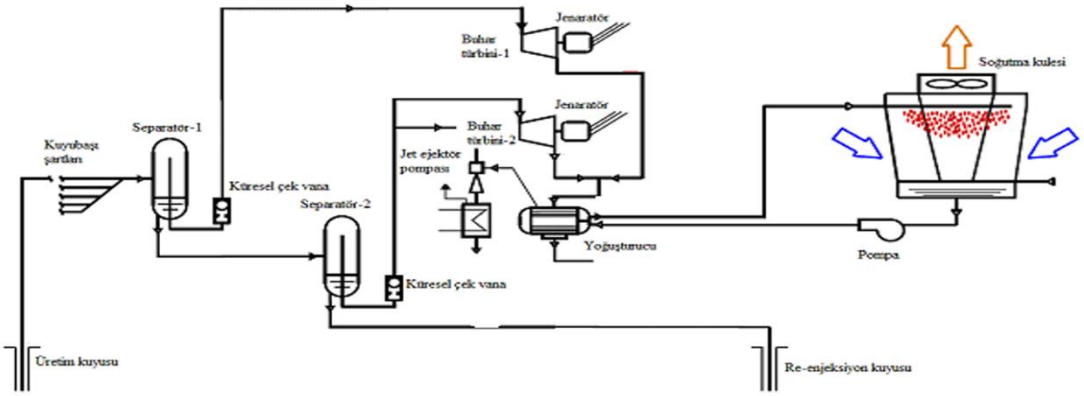
Gereç

Sistemde Raspberry Pi örnek modeli aşağıda Şekil 2'de görülmektedir.



Şekil 2. Sistemde kullanılan Raspberry Pi ve GPIO pin yerleşimleri (motorbit, 2025).

Yukarıda görülen şekilde belirlenen GPIO pinleri ile vana motorların hareketini sağlamak için yukarıda belirtildiği üzere PWM tekniği kullanılmıştır. Sistemde kullanılan servo motor tipi aşağıda şekilde verilmiştir. Sistemin yöneteceği jeotermal sistem örnek blok şeması Şekil 3'de görüldüğü gibidir.



Şekil 3. Jeotermal sistemin örnek blok şeması.

Yöntem

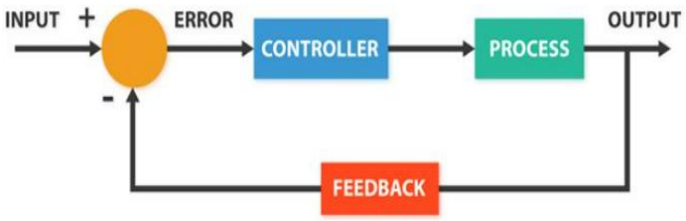
Vanaların hareket kontrollerini sağlamak için belirtildiği üzere darbe genişliği modülasyonu PWM tekniği yazılımın geliştirilmesinde uygulanması gerekmektedir.

PWM ile vanalara açısal hareketlerin verilmesi

Jeotermal tesis üzerinde bulunan ısı vanalarına açısal hareketlerin verilebilmesi için PWM tekniği ile Şekil 2'de görülen GPIO12 ile GPIO13 pinlerin kullanılması gerekir. Diğer pinlerin kullanımı PWM de sorun verecektir. Ayrıca Raspberry Pi üzerinde çalışacak Python kodlarına gerekli kütüphanelerin eklenmesi gerekmektedir. Bunlar için aşağıda verilen kodların geliştirilen programa eklenmesi gerekmektedir.

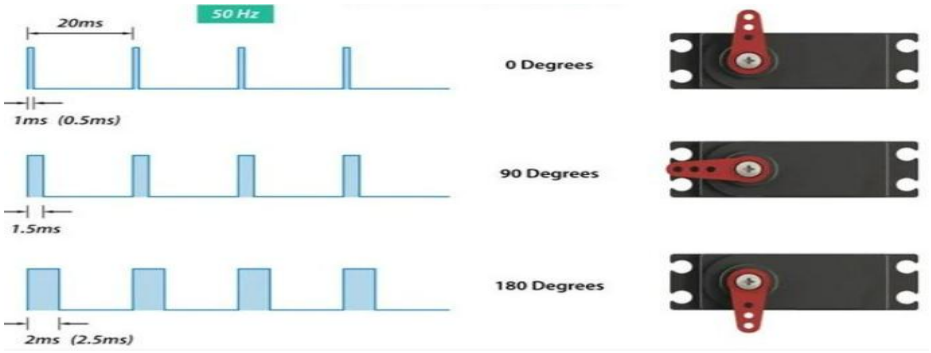
"pip install RPi.GPIO"
"import RPi.GPIO as GPIO"

Aşağıdaki şekilde ise servo motor hareketin kontrolü için kapalı tip kontrol blok şeması görülmektedir. Görüldüğü üzere kapalı çevirim olduğu için, vanaların sıcaklık sensörlerden gelebilecek sıcaklık değerlerini sürekli kontrol edip duruma göre tepki verebilmesi için vana kontrollerini yöneten Python program kodların döngü içerisinde yazılması gerekmektedir. Eğer bir sıcaklı değişim durumu olduğunda vana en yüksek verim için gerekli açısal hareketi vanaya kazandırabilmek için PWM tekniği üzerinden gerekli parametre değerini belirleyip Raspberry Pi üzerinden servo motora iletmektedir.



Şekil 4. Servo motor hareketin kontrolü için kapalı tip kontrol blok şeması (robotistan,2025).

Aşağıdaki Şekil 5'de PWM tekniğine bağılı darbe genişlik değerlerine göre servo motor dolayısı ile vanaların alacağı pozisyonlar görülmektedir.



Şekil 5. PWM tekniği ile kontrol edilebilen nabız genişliklerine göre vana dereceleri(robotistan,2025)

Yukarıda Şekil 5'de görülen resimde servo motorların çalışması durumnda vanaların alacağı açı değerleri aynı olacaktır. Vanaların alacağı açısal değerler doğrudan servo motorların alacağı açısal değerlere bağılıdır. Aşağıda Rapberry Pi üzerinde çalışacak kod örnekleri Şekil 6'da görülmektedir.

```
import RPi.GPIO as GPIO
import time

SERVO_PIN = 13

GPIO.setmode(GPIO.BCM)
GPIO.setup(SERVO_PIN, GPIO.OUT)

pwm_1 = GPIO.PWM(SERVO_PIN, 50)
pwm_1.start(0)

def set_angle(aci):
   duty_cycle = (aci/ 18) + 2.5
   pwm.ChangeDutyCycle(duty_cycle)
   time.sleep(0.5)

   GPIO.output(SERVO_PIN, False)
   pwm.ChangeDutyCycle(0)

while True:
   for pos in range(1000, 9000, 50):
      set_angle(pos)
   for pos in range(9000, 1000, -50):
      set_angle(pos)
```

Şekil 6. PWM tekniği ile Raspberry Pi üzerinden Python kodları ile vana yönetim kodları.

Yukarıda Şekil 6'da görüldüğü üzere "PWM(SERVO_PIN, 50)" fonksiyonu ile sistemde döndürülecek vanaya bağılı servo motorun açısal durumu yönetiliyor. Burada kodlardaki ChangeDutyCycle(duty_cycle) ile pwm'in ilişkilendirilmesi sonucu duty_cycle değişkeni ile belirlenen aci değişkeni ile Raspberry Pi'yın pinine bağılı servo motorun açısal dönüşü sağlanmaktadır.

Bu durum sensörden gelen değeri değerlendiren alt programın çalışması sonucu seçilecek vananın belirlenmesi sonucu yukarıdaki kodların devreye girmesiyle gerçekleşmektedir.

SONUÇLAR

Geliştirilen çalışmanın kodları Denizli-Kızıldere Jeotermal santrali üzerinde test edilmiştir. Test için kullanılan kuyu değerleri aşağıdaki şekilde görülmektedir. Denizli Kızıldere Jeotermal Santrali, üçlü flaş ve binary sistemlerinden oluşan bir jeotermal santral tipidir. Buna göre tablo değerlerine göre her bir kuyudan elde edilen yaklaşık ısı enerjisi ile vana kontrollü ve kontrolsüz grafiksel karşılaştırmaları aşağıdaki şekillerde görülmektedir. Literatürde yapılan çalışmalar ışığında ikincil jeotermal santrallerin örnek model için; eşanjörden çıkacak su ile, konut ve iş yerleri ısıtılması için çıkış suyunun 90°C olması tercih edilmektedir (A.R.Verel,2025).

Tablo 1. Kızıldere jeotermal santral kuyu değerleri (H. Erkül, 2012).

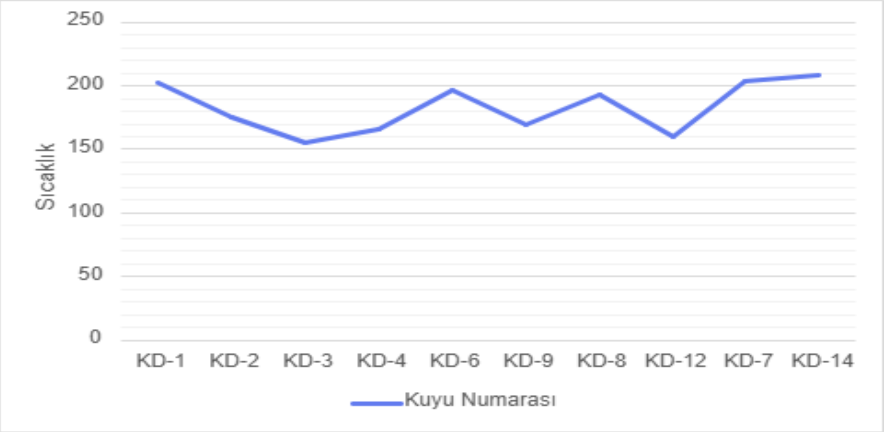
Kuyu No	Tarih	Derinlik (m)	Sıcaklık (^{0}C)
KD-1	1968	540	203
KD-1A	1968	451	198
KD-2	1968	705	175
KD-3	1969	370	155
KD-4	1969	368	166
KD-111	1969	505	164
KD-6	1970	851	196
KD-9	1970	1241	170
KD-8	1970	576	193
KD-12	1970	405	160
KD-7	1970	645	204
KD-14	1970	597	208
KD-13	1971	760	196
KD-15	1971	510	208
KD-16	1973	667	207
KD-17	1975	350	157
KD-22	1985	888	204
KD-21	1985	898	205
KD-20	1986	810	204
KD-R1	1998	2261	240
KD-R2	1999	1428	204

Çıkış suyu 72°C ise santral verimi yaklaşık %15, 90°C ise %12'dir (A.R.Verel,2025).

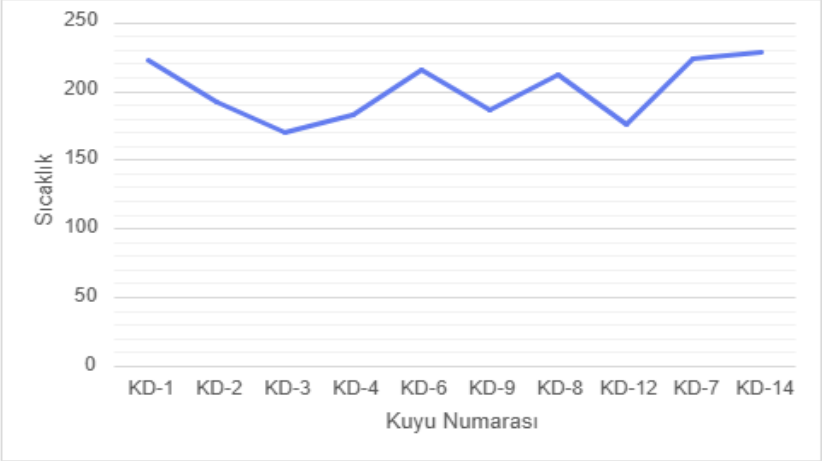
Tablo 2. Vana kontrollü ve kontrolsüz mekan ısırtma

Kuyu_No	Kuyu_Sic	Vana_ile	Mekan_Sic	Mekan_Vana
KD-1	203	223,3	37,21667	40,93833333
KD-2	175	192,5	32,08333	35,29166667
KD-3	155	170,5	28,41667	31,25833333
KD-4	166	182,6	30,43333	33,47666667
KD-6	196	215,6	35,93333	39,52666667
KD-9	170	187	31,16667	34,28333333
KD-8	193	212,3	35,38333	38,92166667
KD-12	160	176	29,33333	32,26666667
KD-7	204	224,4	37,4	41,14
KD-14	208	228,8	38,13333	41,94666667

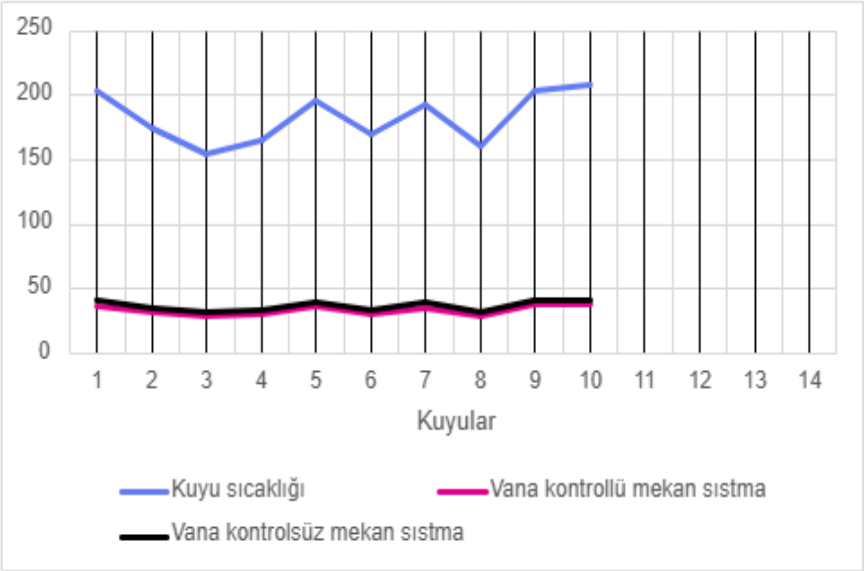
Buradan yola çıkarak orantısal olarak Tablo 1 yorumlandığında mekan ısıtama için elde edilecek mekan ısıtma için jeotermal tesisi verimi Tablo 2' de görülmektedir. Ayrıca bu çalışmada uygulanan doğru vana kontrollerin eklenmesi durumunda elde edilecek en yüksek verim Tablo 2'deki son sütunda görülmektedir.



Şekil 7. Kuyu numarası sıcaklık ilişkisi grafiği



Şekil 8. Kuyu numarası sıcaklık ilişkisi grafiği verimli vana kontrollü.



Şekil 9. Kuyu numarası sıcaklık ilişkisi grafiği verimli vana kullanımı ile.

TARTIŞMA VE ÖNERİLER

Yukarıdaki Şekil 9 dikkate alındığında, vana kontrollü sistemin yüzde 10 oranına kadar jeotermal mekan ısıtmada etki edebileceği görülmektedir. Bu çalışma ileride nesnelerin interneti kullanılarak geliştirilebilir. Bu şekilde farklı konumlarda bulunan jeotermal tesisler tek merkezli bulut üzerinde çalışan bir yazılım ile Rapberry Pi'ler üzerinden vana yönetimleri sağlanabilecektir. Bu şekilde sistem yazılım güncelemeler tek merkezden yapılması mümkün olacaktır. Ayrıca geliştirilen sistem jeotermal sistemlerin prototiplerin geliştirilmesinde dijital ikiz uygulamaları için bir alt yapı oluşturmaktadır.

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