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Hybrid IoT and AI-based solution for energy management in data centres under various climate conditions

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Abstract
The rapidly increasing demand for data processing and storage has made data centers one of the largest global energy consumers. This study proposes a hybrid energy management model that integrates diesel generators, solar panels, and wind turbines to optimize energy consumption in data centers. The developed system utilizes the Internet of Things (IoT) infrastructure and Artificial Intelligence (AI)-based machine learning algorithms to adapt to varying climatic conditions. Real-time data collected from IoT sensors—such as weather parameters, battery charge levels, and energy production rates—are processed using algorithms including Support Vector Classifier (SVC), Random Forest (RF), AdaBoost, Logistic Regression (LR), and Naive Bayes (NB), enabling autonomous and highly accurate energy source management. Simulations conducted in MATLAB and Python show up to a 20% reduction in energy consumption, a 15% decrease in operational costs, and a 50.1% increase in renewable energy utilization. In addition to supporting environmental sustainability, the proposed system enhances reliability under variable weather conditions, offering an intelligent and practical solution for data centers located in regions with renewable energy potential, such as Istanbul.

Keywords: *Artificial Intelligence, Internet of Things, Data Mining, Energy Consumption, Machine Learning, Renewable Energy Sources*

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Farklı iklim koşulları altındaki veri merkezlerinde enerji yönetimi için Hibrit IoT ve AI tabanlı çözüm

Özet

Hızla artan veri işleme ve depolama talebi, veri merkezlerini dünyanın en büyük enerji tüketicilerinden biri haline getirmiştir. Bu çalışma, veri merkezlerinde enerji tüketimini optimize etmek için dizel jeneratörler, güneş panelleri ve rüzgâr türbinlerini entegre eden bir hibrit enerji yönetim modeli önermektedir. Geliştirilen sistem, değişen iklim koşullarına uyum sağlamak için Nesnelerin İnterneti (IoT) altyapısı ve Yapay Zekâ (AI) tabanlı makine öğrenimi algoritmalarını kullanmaktadır. IoT sensörlerinden toplanan gerçek zamanlı veriler (hava durumu parametreleri, pil şarj seviyeleri ve enerji üretim oranları gibi) Destek Vektör Sınıflandırıcı (SVC), Rastgele Orman (RF), AdaBoost, Lojistik Regresyon (LR) ve Naive Bayes (NB) gibi algoritmalar kullanılarak işlenir ve bu da otonom ve son derece doğru enerji kaynağı yönetimini mümkün kılar. MATLAB ve Python'da yapılan simülasyonlar, enerji tüketiminde %20'ye varan azalma, işletme maliyetlerinde %15'lik düşüş ve yenilenebilir enerji kullanımında %50,1'lik artış olduğunu göstermektedir. Önerilen sistem, çevresel sürdürülebilirliği desteklemenin yanı sıra, değişken hava koşulları altında güvenilirliği artırarak, İstanbul gibi yenilenebilir enerji potansiyeli olan bölgelerdeki veri merkezleri için akıllı ve pratik bir çözüm sunmaktadır.

Anahtar kelimeler: *Yapay Zekâ, Nesnelerin İnterneti, Veri Madenciliği, Enerji Tüketimi, Makine Öğrenimi, Yenilenebilir Enerji Kaynakları.*

Introduction

The rapid proliferation of digital transformation, cloud technologies, and artificial intelligence applications has significantly increased global demand for data processing and storage. As a result, data centers have become one of the primary consumers of electricity worldwide. Recent studies indicate that data centers are responsible for approximately 2% of global electricity consumption, a figure expected to rise steadily in the coming years. This growing demand poses serious challenges not only in terms of operational costs but also in terms of environmental sustainability. In the context of Türkiye, the heavy reliance on fossil fuels for electricity generation and the high dependency on imported energy further amplify the need for sustainable energy management in energy-intensive facilities such as data centers. The integration of renewable energy sources—particularly solar and wind power—into data center operations presents a promising solution to this issue. However, the intermittent and variable nature of these resources makes ensuring a reliable energy supply challenging.

To address these challenges, this study proposes a hybrid energy management system that integrates renewable energy sources, diesel generators, and uninterruptible power supplies (UPS) into a unified architecture. This structure is governed by a decision-making mechanism powered by artificial intelligence and supported by Internet of Things (IoT) technologies. Utilizing real-time environmental data, the model autonomously determines the optimal energy source through machine learning algorithms, enhancing both operational efficiency and environmental performance.

The proposed system is particularly well-suited for data centers located in regions such as Istanbul, which possess high potential for both solar and wind energy. It offers an intelligent and adaptive solution capable of maintaining energy efficiency and reliability under dynamic climatic conditions.

Related Works

The optimization of energy consumption in data centers has been extensively studied in recent years, driven by advances in renewable energy systems, machine learning (ML) algorithms, and Internet of Things (IoT) technologies. The existing literature can be broadly categorized into four areas: (1) integration of renewable energy sources, (2) application of ML for energy forecasting, (3) IoT-based monitoring and control, and (4)

hybrid models combining AI, IoT, and renewable strategies.

Renewable energy integration

Several studies have explored how renewable sources such as solar and wind energy can be integrated into data centers to reduce both operational costs and environmental impact. He et al. proposed a hybrid power model using multi-objective optimization with diesel backup. Roy et al. examined the efficiency of solar-diesel configurations under fluctuating demand, while Zhang et al. developed an advanced cooling system tailored for renewable-powered data centers.

Machine learning for energy forecasting

ML-based forecasting techniques have shown promising results in largescale, dynamic systems. Deepika and Prakash used learning models to predict power consumption in cloud environments, and Lee et al. proposed a deep learning model enhanced by edge computing. Other researchers, including Merizig and Smith, applied various ML algorithms to forecast energy demand in unstable operational conditions.

IoT-Based Monitoring and Optimization

IoT infrastructures allow real-time tracking and adaptive control of energy flows. Mehta, Liu, and Ramphela developed IoT-enabled systems for improving energy efficiency in data centers and smart buildings through real-time analytics and smart temperature regulation.

Hybrid Architectures Combining AI and IoT

The integration of AI with IoT sensor networks has become increasingly popular in developing autonomous and flexible energy management solutions. Zhou and Kaur proposed intelligent infrastructures for resource optimization in data centers, while Kaya et al. applied edge-based anomaly detection to enhance weather forecasting and energy scheduling.

Unlike prior works, the present study introduces a unified, self-regulating system that integrates AI-driven forecasting with real-time IoT data to dynamically allocate energy resources. This approach fills a notable gap in the literature and offers a scalable, adaptive solution for data centers operating under diverse environmental conditions.

Proposed Model

The proposed model is based on a hybrid architecture that integrates renewable energy sources, conventional diesel generators, and IoT-based

monitoring systems under the supervision of machine learning algorithms. This architecture is organized into three conceptual layers: sensing, processing, and decision-making. Environmental parameters such as temperature, humidity, wind speed, and solar radiation are captured in real-time through distributed IoT sensors. These data points are then processed by a central computing unit to forecast energy demand and allocate power sources accordingly.

As illustrated in Figure 1, the architecture includes rooftop solar panels and wind turbines for clean energy generation, along with a diesel generator used for backup purposes. The generated energy is initially stored in uninterruptible power supply (UPS) systems before being distributed to meet the data center's demand. The control logic of the system prioritizes renewable energy when weather conditions are favorable, while diesel generators are activated only when renewable sources are insufficient.

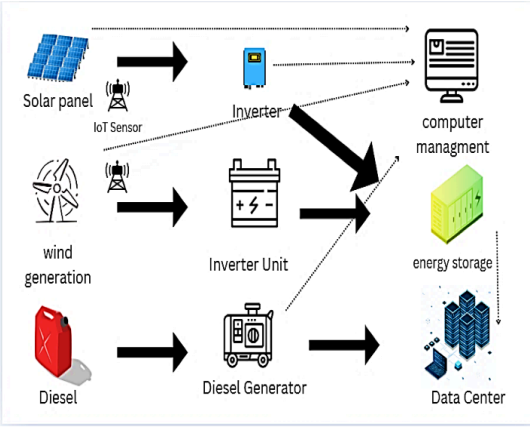

Fig. 1. Proposed hybrid IoT and AI-based energy management system for data centers.

The data used in this study were obtained from a simulation of a medium-sized data center located in Istanbul. The dataset comprises hourly measurements collected over a two-year period, resulting in 17,520 records for each feature. It includes meteorological parameters such as temperature (°C), wind speed (m/s), and solar radiation (kW/m²), along with operational indicators including battery charge levels (%), energy generation from each source (kWh), and total energy consumption (kWh). To capture temporal variations in energy behavior, time-related features such as hour, day, and season were also incorporated.

To prepare the dataset for training machine learning models, a normalization step was applied using the min-max scaling technique. This method transforms each feature value xx into a normalized value x′x′ within the range [0, 1], based on the following formula [1]:

$$x' = (xpdf\ x\_min) / (x\_max - x\_min) \qquad (1)$$

This preprocessing step enhances numerical stability and accelerates model convergence. Additionally, feature engineering techniques such as moving averages and lag variables were applied to improve the detection of temporal patterns in the dataset [17].

For the hardware implementation of the data acquisition system, multiple sensors and modules were integrated to ensure real-time monitoring and measurement accuracy. Environmental parameters such as temperature, atmospheric pressure, and humidity were captured using the BME280 sensor module—a compact and efficient component widely utilized in embedded systems for weather-related applications (as shown in Figure 2). This sensor provided high-resolution data with minimal power consumption, making it well-suited for continuous monitoring within the data center environment.

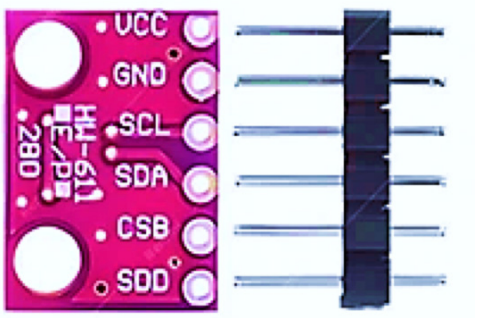

Fig. 2. BME280 sensor used for temperature, pressure, and humidity measurement [19]

To ensure consistent time-synchronized data collection, the DS1302 real-time clock (RTC) module was employed. This component enabled accurate timestamping of each sensor reading, thereby maintaining temporal consistency across multiple data streams (as illustrated in Figure 3). Its internal battery backup made it particularly valuable during power interruptions, allowing it to preserve timing functionality even when the main power supply was unavailable.

Fig. 3. DS1302 real-time clock module for synchronized data acquisition [19]

The ESP32 microcontroller served as the central processing unit for the entire sensing layer. This module facilitated data acquisition, initial processing, and the wireless transmission of sensor data to the main server. Its dual-core architecture and built-in Wi-Fi capability made it a cost-effective yet powerful platform for real-time IoT applications in energy management (as shown in Figure 4).

Fig. 4. ESP32 microcontroller used for sensor data aggregation and wireless transmission [20]

In the proposed model, a range of supervised learning algorithms were employed to perform classification and regression tasks. Specifically, Support Vector Classifier (SVC), Random Forest (RF), AdaBoost, Logistic Regression (LR), and Naive Bayes (NB) were selected due to their proven effectiveness in energy forecasting and control scenarios. These models were trained to achieve two primary objectives: (i) classify the optimal energy source (e.g., solar, wind, or diesel) based on weather and operational inputs, and (ii) predict hourly energy consumption rates under dynamic conditions. All models were implemented using Python's Scikit-learn library.

To ensure optimal performance, hyperparameter tuning was conducted using a grid search procedure combined with 5-fold cross-validation.

For classification tasks, performance metrics such as accuracy, precision, recall, and F1-score were used. For regression tasks, Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) were calculated to assess prediction accuracy.

The system was designed to meet three core objectives: minimizing energy consumption, reducing operational costs, and enhancing system reliability. Energy efficiency was modeled by minimizing total energy usage over time. Cost reduction was addressed by considering the real-time cost of each energy source, represented as a weighted sum of energy produced from solar, wind, and diesel. Reliability was maintained by ensuring that the UPS battery charge remained above a critical threshold at all times, preventing outages during peak loads or renewable shortages.

Simulations were conducted using a hybrid modeling approach: MATLAB was used to simulate the physical behavior of the energy system, including energy flow between sources, storage, and loads, while Python handled the implementation and evaluation of machine learning models. To validate the system's robustness, multiple scenarios were tested, including seasonal variations (e.g., summer vs. winter), sudden weather disruptions (e.g., storms or low-radiation days), and component failures (e.g., solar panel malfunctions). Each scenario assessed the model's ability to adapt its energy allocation strategy in real time.

Through evaluations under these variable and realistic conditions, the system's adaptability and resilience were confirmed, demonstrating its potential to enhance energy efficiency and cost savings in data centers operating in regions with fluctuating environmental conditions.

3.1. Simulation Results

The performance of the proposed energy management system was evaluated through a series of simulations conducted using MATLAB and Python. These simulations were designed to assess the model's effectiveness under various climatic and operational scenarios and to benchmark its performance against baseline configurations and models from existing literature. Historical data spanning two years—comprising weather variables, energy production metrics, and system load profiles—were utilized from a medium-scale data center located in Istanbul.

Table 1. Comparison of previous works

Model	Energy Sources	RP (%)	LCOE ($/kWh)	Storage (kWh)
Proposed Model	Wind, Solar, Diesel, UPS	50.1	0.21	6000
Baseline Model	Wind, Solar, Diesel, UPS	44.5	0.23	4000
Study [12]	Wind, Diesel	30.2	0.27	3000
Study [13]	Solar, Diesel	20.5	0.30	2500

Table 1 compares key attributes of the proposed model, baseline model, and previous studies. The proposed model achieves the highest renewable penetration rate (50.1%), lowest LCOE ($0.21/kWh), and the largest storage capacity (6000 kWh). This combination reflects its ability to optimize both cost and sustainability.

One of the key performance indicators was the Renewable Energy Penetration Rate (RP), which measures the proportion of total energy demand met by renewable sources. The proposed model achieved an RP of 50.1%, significantly surpassing the baseline model's 44.5% as well as the values reported in prior studies (30.2% and 20.5%). This improvement is attributed to the system's intelligent forecasting and proactive prioritization of energy sources, which enable the optimized utilization of solar and wind resources ahead of real-time demand. As a result, reliance on diesel generators is minimized during periods of suboptimal weather conditions.

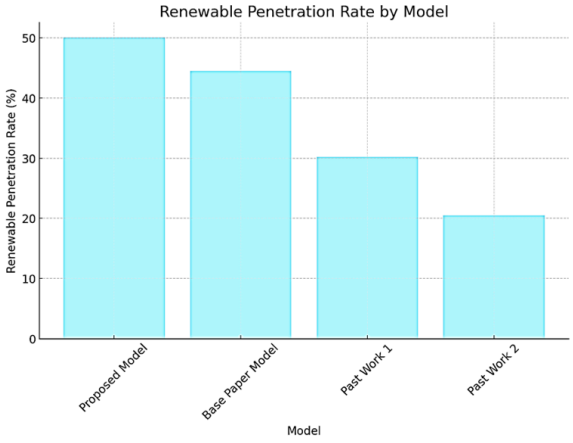

Fig. 5. Renewable energy penetration rate comparison among models.

Figure 5 compares the renewable energy penetration rate among the proposed model, the baseline model, and previous studies. The proposed model achieves the highest penetration rate at 50.1%, outperforming the baseline (44.5%) and other configurations (30.2% and 20.5%). This improvement is due to accurate weather forecasting and intelligent prioritization of renewable sources, which minimizes diesel generator usage during unfavorable conditions.

Table 2. Renewable Energy Penetration Rate

Model	Renewable Penetration (%)
Proposed Model	50.1
Baseline Model	44.5
Study [12]	30.2
Study [13]	20.5

Table 2 provides numerical values of renewable energy penetration rates. The proposed model's rate of 50.1% confirms its superior utilization of renewable resources, reducing fossil fuel dependency and lowering environmental impact.

Another key metric was the Levelized Cost of Energy (LCOE), which represents the average cost per kilowatt-hour of energy produced over the system's lifetime. The proposed model achieved a lower LCOE of $0.21/kWh, outperforming the baseline model ($0.23/kWh) and prior configurations, which ranged from $0.27 to $0.30/kWh. These cost reductions are primarily attributed to efficient energy source scheduling, increased utilization of renewable resources, and reduced dependence on expensive diesel generation. Additionally, the strategic control of battery charging and discharging cycles further contributed to operational savings.

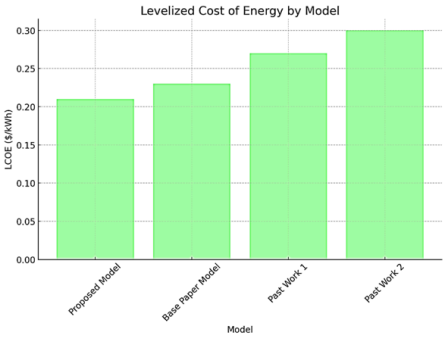

Fig. 6. Levelized Cost of Energy (LCOE)

Figure 6 illustrates the Levelized Cost of Energy across different models. The proposed model achieves the lowest LCOE of $0.21/kWh, which is a significant reduction compared to the baseline ($0.23/kWh) and prior studies ($0.27–$0.30/kWh). This cost advantage results from optimized scheduling, better utilization of renewable resources, and reduced dependency on diesel generation.

Table 3. Levelized Cost of Energy

Model	**LCOE ($/kWh)**
Proposed Model	0.21
Baseline Model	0.23
Study [12]	0.27
Study [13]	0.30

Table 3 presents the LCOE values for each model. The proposed model's lower cost compared to all others demonstrates the economic benefits of intelligent scheduling, precise load forecasting, and efficient battery use.

In addition to static performance metrics, the system was tested under dynamic scenarios, including seasonal variations, sudden weather changes, and partial equipment failures. Three key indicators were used to summarize dynamic performance: reduction in energy consumption, improvement in operational cost, and increase in system reliability. The proposed model demonstrated a 20% decrease in energy usage, a 15% reduction in operational costs, and a 25% enhancement in reliability—outperforming the baseline model in each category. These improvements highlight the strength of the AI-driven decision-making engine and its ability to adapt in real time to changing conditions.

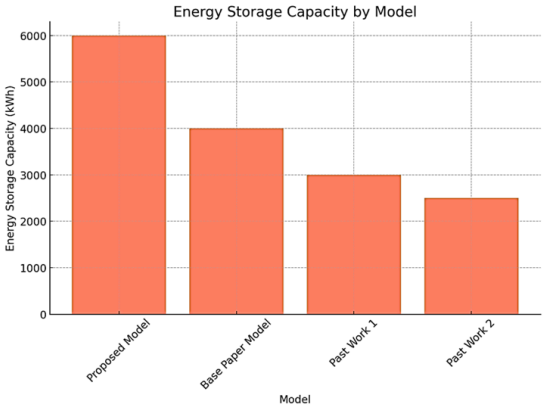

Fig. 7. Energy storage capacity across models.

Figure 7 presents the energy storage capacity comparison. The proposed model offers a capacity of 6000 kWh, higher than all other configurations. This increased storage enhances system resilience, enabling the data center to handle production fluctuations and maintain stability during component failures or peak demand.

Table 4. Energy Storage Capacity

Model	Storage Capacity (kWh)
Proposed Model	6000
Baseline Model	4000
Study [12]	3000
Study [13]	2500

Table 4 compares energy storage capacities across models. The proposed model's higher capacity enables better management of renewable fluctuations and ensures uninterrupted supply to meet demand.

Beyond static performance assessments, the system was evaluated under dynamic conditions, including seasonal fluctuations, abrupt weather changes, and partial equipment failures. To summarize dynamic performance, three key metrics were considered: reduction in energy consumption, improvement in operational costs, and enhancement of system reliability. The proposed model achieved a 20% decrease in energy usage, a 15% reduction in costs, and a 25% increase in reliability, consistently outperforming the baseline model in all aspects. These results

underscore the effectiveness of the AI-based decision-making engine and its capability to adapt in real time to varying operational environments.

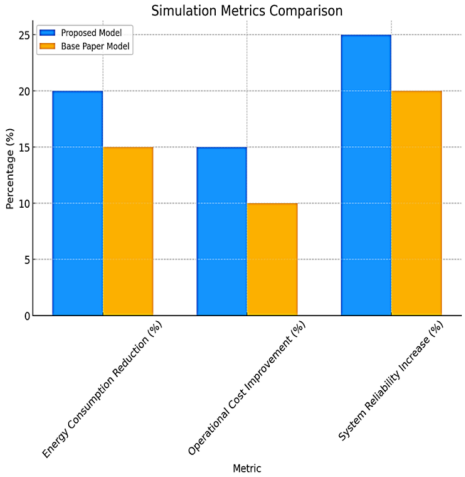

Fig. 8. Simulation metrics: energy consumption, cost, and reliability comparison

Figure 8 compares three key performance metrics: energy consumption reduction, operational cost reduction, and reliability improvement. The proposed model outperforms the baseline in all three, achieving 20% less energy consumption, 15% lower costs, and 25% higher reliability. These improvements stem from the AI-based real-time decision-making process supported by IoT sensor data.

Table 5. Simulation Metrics Comparison

Indicator	Proposed Model (%)	Baseline Model (%)	Improvement
Energy Consumption Reduction	20	15	+5
Operational Cost Reduction	15	10	+5
System Reliability Increase	25	20	+5

Table 5 summarizes performance improvements in energy consumption, operational costs, and reliability. The proposed model's consistent superiority in all three metrics highlights its operational and economic advantages.

The combined results of all performance indicators are presented in Figure 9, highlighting the cumulative benefits of the proposed system. By integrating IoT-based environmental sensing, machine learning-based forecasting, and adaptive control mechanisms, the model offers a unified solution for energy management in data centers. It effectively balances operational efficiency, cost-effectiveness, and system resilience, making it well-suited for deployment in regions facing diverse climatic challenges.

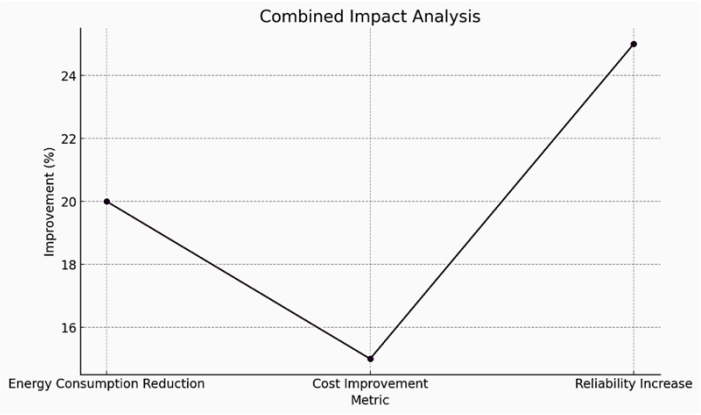

Fig. 9. Combined effect of the proposed model on energy, cost, and reliability.

Figure 9 summarizes the combined benefits of the proposed system. By integrating IoT-based sensing, AI-driven forecasting, and adaptive control strategies, the model enhances energy efficiency, cost-effectiveness, and reliability simultaneously, making it suitable for deployment under diverse climatic conditions.

Discussion and Conclusion

The simulation outcomes of this study provide strong evidence for the effectiveness of the proposed hybrid energy management system in data centers. One of the system's most significant strengths is its ability to maximize the use of renewable energy without compromising operational reliability. Achieving a renewable penetration rate of 50.1% reflects the

model's capacity to proactively forecast weather conditions and allocate energy sources accordingly. Unlike conventional reactive systems, the integration of machine learning enables predictive control that prioritizes solar and wind power before shortages occur, contributing to observed improvements in both sustainability and cost-efficiency.

The economic viability of the system is further supported by the reduction in the Levelized Cost of Energy (LCOE) to $0.21/kWh—lower than both the baseline and comparable literature-based models. This cost advantage results from intelligent scheduling, optimized battery usage, and minimized reliance on diesel generators. AI-driven classifiers and regressors enhance decision-making accuracy and reduce unnecessary energy waste, translating into lower operational expenses.

A notable technical advantage is the achieved energy storage capacity of 6000 kWh, which plays a critical role in system resilience. This capacity enables the system to absorb unexpected fluctuations in renewable generation and sustain performance during peak demand or component failures. Compared to alternative models with lower storage capacity, the proposed system demonstrates greater fault tolerance and operational continuity—an essential factor in data center environments.

Dynamic performance metrics, including a 20% reduction in energy consumption, 15% cost savings, and a 25% improvement in reliability, underline the system's robustness under variable real-world conditions. The ability to adapt to seasonal shifts, sudden weather changes, and equipment malfunctions demonstrates the strength of the real-time optimization loop driven by continuous IoT feedback and adaptive learning mechanisms.

Despite these advantages, several limitations must be acknowledged. The initial cost of deploying an integrated IoT and AI-based infrastructure remains a significant barrier. Although long-term savings are evident, upfront investments in hardware, training, and system integration may hinder widespread adoption. Additionally, the effectiveness of the predictive algorithms is highly dependent on the granularity and accuracy of weather data; errors in forecasting can propagate and reduce overall efficiency.

To address these limitations, future work should focus on incorporating real-time weather APIs, implementing reinforcement learning for

continuous control refinement, and utilizing edge computing technologies to minimize latency in decision-making. These improvements would align with broader sustainability goals and enhance the model's adaptability, reliability, and commercial scalability—especially in regions with variable solar and wind conditions.

In conclusion, this study introduced a hybrid energy management architecture that combines IoT-based sensing, machine learning algorithms, and renewable energy systems for real-time energy optimization in data centers. The model's predictive capabilities, intelligent control logic, and modular design offer a practical and scalable solution for reducing fossil fuel dependency and enhancing energy sustainability in high-demand environments.

Declaration of Conflict of Interest: The authors declare that they have no conflict of interest.

Artificial Intelligence Statement: No artificial intelligence tools were used while writing this article.

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Fonksiyonel bir gıda olan propolisin beslenme ve sağlık üzerine etkileri

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Özet

Günümüzde fonksiyonel gıdalara olan ilginin artmasıyla sağlık üzerine yararlı etkiler sağlayan propolis, bal arıları tarafından üretilen reçinemsi bir yapıdır. Bu yapı kovanı dış faktörlere karşı korumaktadır. Propolisin; Alecrim, Akdeniz, Huş Ağacı, Pasifik, Kırmızı, Kavak ve Clusia gibi, huş ve kavak ağaçlarının yapılarından elde edilen çeşitleri bulunmakta olup bulunmakta olup, propolis üretiminde Brezilya dünya çapında ilk sırada yer almaktadır. Propolis beslenmede doğal koruyucu yapı olarak yer alarak besinlerin raf ömrünü uzatma, mikroorganizmaların çoğalmasını önlemede yer almaktadır. Propolisin içeriğinde; reçineler, organik maddeler, polenler, balzamlar, yağ asitleri gibi maddeler yer almaktadır. İçeriğinde en çok reçineler bulunmaktadır. Propolisin içeriğine bağlı olarak inorganik bileşikler, kumarinler, steroidler, kinonlar ve polifenoller bulunmaktadır. Polifenoller, propolisin tadı, kokusu, renginin belirtilmesinde öne çıkmaktadır. Propolis magnezyum, kalsiyum, bakır, demir minaralleri C, A, E, B1 vitaminleri, amino asitler, yağ asitleri açısından zengin bir besindir. Bireyler için güvenli doz miktarı 1,4mg/kg vücut ağırlığı/gün yaklaşık 70mg/gün'dür. Güvenli aralıklarda propolis tüketiminin toksik etki yaratmayacağı belirtilmiştir. Hamileler ve emziren anneler için güvenilir dozu tam olarak açıklanmamıştır. Propolisin yapısında en çok polifenol grubu olan flavonoidler bulunmaktadır. Bu yapılar propolisin antiinflamatuvar, antifungal, antibakteriyel, antiviral, antimikrobiyel, antiparaziter vb. biyolojik aktivite göstermelerini

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sağlamaktadır. Propolisin biyolojik aktivitelerinin insan sağlığı üzerinde antikanser, antidiyabetojenik etkileri vardır. Ayrıca nörolojik hastalıklar üzerine, sindirim sistemi hastalıkları, yara iyileşmesinde, dolaşım sistemi hastalıkları, bağışıklık sistemi vb. birçok sağlık sorunları üzerine etkilerinden bahsedilmektedir.

***Anahtar Kelimeler**: Propolis, Fonksiyonel gıda, Beslenme, Sağlık*

Effects of propolis, a functional food, on nutrition and health

Abstract

Propolis, a resinous structure produced by honeybees, offers beneficial health benefits with the increasing interest in functional foods. This structure protects the hive from external factors. There are varieties of propolis obtained from birch and poplar trees, such as Alecrim, Mediterranean, Birch, Pacific, Red, Poplar, and Clusia, and Brazil ranks first in propolis production worldwide. Propolis serves as a natural preservative in nutrition, extending the shelf life of foods and preventing the proliferation of microorganisms. Propolis contains substances such as resins, organic matter, pollen, balsams, and fatty acids. Resins are the most abundant. Depending on the composition of propolis, inorganic compounds include coumarins, steroids, quinones, and polyphenols. Polyphenols are prominent in determining the taste, smell, and color of propolis. Propolis is rich in magnesium, calcium, copper, and iron, as well as vitamins C, A, E, and B1, amino acids, and fatty acids. The safe dose for individuals is 1.4 mg/kg body weight/day (approximately 70 mg/day). It has been stated that consuming propolis within safe limits will not cause toxic effects. The safe dose for pregnant and breastfeeding mothers has not been fully established. Propolis contains the most abundant polyphenol group, flavonoids. These structures enable propolis to exhibit biological activities such as anti-inflammatory, antifungal, antibacterial, antiviral, antimicrobial, and antiparasitic. Propolis's biological activities have anticancer and antidiabetogenic effects on human health. Its effects on many health problems, including neurological diseases, digestive system diseases, wound healing, circulatory system diseases and the immune system, are also discussed

***Keywords:** Propolis, Functional food, Nutrition, Health*

Giriş

Fonksiyonel gıdalar, bireyin sağlığının geliştirilmesinde ve hastalıkların önlenmesinde kullanılan, tablet şeklinde olmayan ve besin takviyesi olarak kullanılmayan yapılardır ve bu besinlere olan ilgi zamanla artmaktadır (Kudret ve Kılınç, 2020). Fonksiyonel gıda çeşitlerinden biri olan propolis arı ürünü olup, Yunanca olan pro ve polis kelimelerinden ortaya çıkan şehrin lehine ya da şehrin giriş kapısı anlamında kullanılmaktadır (Przybyłek ve Karpiński, 2019; Hossain ve ark., 2022). Propolis, bitkilerden elde edilen sakızımsı bir yapıda olan, arılar tarafından kovanı düşmanlara yani yabancı ajanlara karşı savunmak için kullanılan bir fonksiyonel gıdadır (Hossain ve ark., 2022). Alecrim, Akdeniz, Huş Ağacı, Pasifik, Kırmızı, Kavak, Clusia adında yedi çeşit propolis bulunmaktadır (El-Guendouz ve ark., 2019). Çoğunlukla huş ve kavak ağaçlarının kabuk ve tomurcuk bölümlerinden reçineleri meydana gelmektedir (Anjum ve ark., 2019). Arı ürünleri arasında özellikle propolis üretimi başta olmak üzere, arı ile ilişkili maddelerin üretiminde Brezilya öncü konumdadır (Przybyłek ve Karpiński, 2019). Propolis üretiminde işçi arılar, ağaçların yapısından topladıkları reçineleri mum, polen ve enzimlerle birleştirerek özel bir karışım oluştururlar (Anjum ve ark., 2019). Bu durum propolisin birçok görevde yer almasını sağlamaktadır. Arılar, propolisi koloninin temel maddesi olarak; kararlı içyapıyı korumak, hava akımını sürdürülebilir kılmak, girdap oluşumunu önlemek ve çürümeyi engellemek amacıyla kullanmaktadır (Hossain ve ark., 2022). Yapısı olduğu konum ve botanikle bağlantılıdır. Propolisin bileşiminde en çok reçineler bulunmakla birlikte; organik maddeler, aromatikler, mineral maddeler, yağ asitleri, balzamlar, polen, uçucu yağlar yer almaktadır (Irigoiti ve ark. 2021). Propolis sağlık ve fonksiyonel açıdan soğuk algınlığına iyi gelmektedir, bağışlılık sistemini güçlendirici, antiviral ve antibakteriyel etkileri bulunmaktadır, ülseri önleyici ve cilt ile ilgili sorunları önlemektedir (Hossain ve ark., 2022). Polen, balmumu gibi biyolojik özellikler bakımından zengin olan propolisin kimyasal bileşimi, besin içeriği, beslenme ve sağlık üzerine etkileri incelenmiştir.

Propolis

Propolis bal yapan arıların bitkilerden elde ettiği yapışkan bir maddedir (Pilario, Tielemans ve Mojica, 2022) ve ilk defa Yunanlılar tarafından bulunmuştur (Araba ve Özparlak, 2022). Eski dönemlerden beri farklı alanlarda kullanılmaktadır. Örneğin, Yunanlılar ve Romalılar propolisi cilt yaralarının iyileştirilmesinde kullanırken, Mısırlılar çürümeyi engelleyici

özelliğinden yararlanmışlardır. İşçi arılar bitkilerin tomurcukları veya ağaçların kabuklarından yapışkan ve reçinemsi bileşenleri toplayarak propolisi oluşturmaktadır (Pilario, Tielemans ve Mojica, 2022). Bununla birlikte, işçi arılar salgıladıkları enzimlerle bu bileşenlerde kimyasal değişiklikler yapmakta ve son aşamada balmumu ekleyerek propolisi oluşturmaktadırlar (Salleh, 2021; Song ve ark., 2021; Kim ve ark., 2019). Propolis hastalıkları engellemek ve sağlığın iyi yönde ilerlemesini sağlamak açısından çoğunlukla gıda takviyesi olarak da alımı mevcuttur (Hirata ve ark., 2021). Bal arıları kovanda bir arada hayatlarını sürdürdükleri için enfeksiyon durumunun yaygınlaşması mevcuttur. Propolis sayesinde enfeksiyonun bir diğer arıya geçişini önlenmekte ve kovandaki sıcaklığı optimum seviyelerde tutulmaktadır (Sarıkahya ve ark., 2021). Bal arıları genellikle propolisi örtü tahtalarında depolamakta fakat dip tahtasında depoladıkları propolisin yapısına yabancı maddelerin karışmasıyla saf bir propolis oluşmamaktadır (Kim ve ark., 2019). Yapışkan görevi yapan bitkiler bal arıları tarafından biriktirilerek reçinelerle birlikte propolise çevrilmektedir. Ağaçların belli kısımlarından üretilen reçineler bitkileri yabancı maddelere karşı korumaktadır. Dünyada yapışkan görevi gören bitkiler her ülkede farklı olmaktadır. Örnek olarak Çin'de kauçuk ağacı, Rusya'da ise çam ağacı gibi türler tutkal görevi gören bitkilerdir (Cui ve ark., 2021) ve yarı katı şeklinde bulunmaktadır. Çoğunlukla çam gibi kozalaklı yapıda olan ve kavak gibi bitkilerden üretilmektedir. Propolisin fiziksel özellikleri bulunduğu yerin iklimine ve bitki örtüsüne göre farklılık göstermektedir (Gençtürk, 2020). Sıcaklık seviyelerine göre yüksek düzey sıcaklıklarda yapışkan ve elastik durumdayken düşük düzey sıcaklıklarda kırılgandır ve alkollerde çözünürlüğü daha fazladır. Acımsı bir tada ve hoş bir kokuya sahiptir (Anjum ve ark., 2019). Propolisin bileşenlerini ayırmak ve incelemek amacıyla farklı ekstraksiyon yöntemleri kullanılmaktadır (Anjum ve ark., 2019). Propolisin özellikleri, elde edildiği bitki türüne, rengine ve yaşına bağlı olarak farklılık göstermekte olup rengi genellikle koyu sarıdan koyu kahverengi tonlarına kadar değişmektedir (Araba ve Özparlak, 2022). Propolisin kimyasal özellikleri incelendiğinde; yapısında reçine, mineral maddeler, polen, balmumu ve çeşitli kimyasal bileşikler bulunmaktadır (Anjum ve ark., 2019). Kimyasal bileşimi genel olarak %45–50 reçine, %5 aromatik bileşikler, %10 uçucu yağlar, %25–30 balmumu, %5 polen ve çeşitli mineral maddelerden oluşmaktadır (Araba ve Özparlak, 2020; Gençtürk, 2020). Ayrıca yapısında önemli düzeyde polifenoller de yer almaktadır (Mehmetoğlu, 2017).

Beslenme Üzerine Etkileri

Propolisin beslenme üzerine etkileri doğal yapıda beslenmeye yönelik ilginin artması nedeniyle önem göstermektedir. Bu durum tüketicilerin doğal ürünler içeren ve antimikrobiyel etki vb. gösteren gıdalara olan isteklerini artırmaktadır (Takwa ve ark., 2018). Doğal koruyucu madde olarak fonksiyonel gıdalar arasında yer alırken biyolojik özellikleri ve yapısındaki bileşimleri ile gıda endüstrisinde öne çıkmaktadır (Gümüş ve Kızıl, 2022). Besinlerde raf ömrünü uzatmak, patojen mikroorganizmaların çoğalmasını önlemek gibi fonksiyonlarda bulunarak antimikrobiyel ve antioksidan etkiler göstermektedir. Toksite etkisi düşük düzeydedir (Bankova ve ark., 1992). Propolis besin kaplamalarında yer alarak zararlı mikroorganizmaların çoğalmasını engelleyerek besinlerin raf ömrünün uzatılmasını sağlamaktadır (Viera ve ark., 2016).

Propolisin Yapısı ve Bileşimi

Arı tutkalı olarak yer alan propolisin yapısında 300'den fazla bileşik bulunmaktadır (Demir, 2022). Propolis; kinonlar, inorganik bileşikler, steroidler, polifenoller ve kumarinler gibi farklı bileşiklerden oluşmaktadır. Propolisin yapısındaki polifenollerin bir grubu olan flavonid grubu; propolisin kokusunun, renginin ve tadının belirlenmesinde önemli rol oynamaktadır. Bu kimyasal yapılar elzem oldukları için insan vücudunda sentezlenmez ve dışarıdan alınması gerekmektedir (Bayram, 2015). Propolis ayrıca bakır, demir, sodyum, çinko, mangan, sezyum, iyot, magnezyum, kalsiyum gibi mineralleri; yağ asitleri, amino asitler, B1,C, A, E, B6 ve B2 gibi vitaminleri de içermektedir (Bayram, 2015).

Propolisin yapısı %5 polen, %5 mineraller, %30-35 balmumu, %10 yağ asitleri, %45-50 flavonid, fenolik asit ve esterleri, organik maddeleri bulundurur (Yıldız ve Ünal, 2022). Bu yapıların içerikleri sayesinden birçok biyolojik özellik bulunmaktadır. Bu bileşikler bulunduğu bölgeye, bitki örtüsüne, mevsime göre farklılık göstermektedir (Yıldız ve Ünal, 2022). Propoliste reçineler dahil balmumu grubunda yer alan terpenoidler, fenolik asitler, flavonoidler en yaygın bileşiklerdir (Przybyłek ve Karpinski, 2019). Tablo 1'de propolisin yapısında bulunan bileşikler ve sayısı gösterilmektedir. Tabloya göre propolisin kimyasal bileşenleri, flavonoidler, hidroksiflavonlar, fenolik asitler, terpenler, aminoasitler ve mineraller dahil olmak üzere çok bileşenli ve çeşitlilik açısından zengindir. Apigenin gibi flavonoidler, kafeik asit gibi aromatik asitler, propolisin kokusuna katkı sağlayan fenolik bileşikler ile C, E, B1 ve B6 vitaminleri; bakır,

demir, sodyum, magnezyum, kalsiyum, mangan ve çinko gibi mineraller içerdiğinden, propolis besin öğesi bakımından zengindir. (Coşkun ve ark., 2020). Propolisin yapısındaki flavonoidler ikincil metabolitler olduğu için insan vücudunda üretilemezler, en iyi şekilde metabolize olmaktadırlar. Bu yüzden beslenme açısından ihtiyaç duyulmaktadır (Yıldız ve Ünal, 2022). Bununla beraber propolisin kullanım dozu ve zararlı etkisine bakıldığında çoğunlukla toksik özellik göstermeyen ve güvenli bir gıdadır. Şu ana kadar propolisin alımı sonucu görülen etkiler alerji veya hassasiyet olarak ortaya çıkmıştır. Ağız yoluyla alınan propolis daha az alerjiye neden olurken lokal yolla alınan propoliste alerjik olaylar daha fazla tespit edilmiştir (Gümüş ve Kızıl, 2022). Propolisin güvenli kullanımı için birçok araştırmalar yapılmıştır. Farelerde yapılan bir çalışmada, toksisite açısından 1.400 mg/kg vücut ağırlığı/gün dozunun optimal olduğu ve herhangi bir toksik etki göstermediği belirlenmiştir. İnsanlar için güvenli doz miktarı 1,4mg/kg vücut ağırlığı/gün yaklaşık 70 mg/gün olarak bulunmuştur (Yıldız ve Ünal, 2022). İnsanlar propolisi güvenli düzeyde ve fazla miktarlarda almadıkları sürece toksik özelliği olmayacağı açıklanmıştır (Acun ve Gül, 2020). Emziren bireyler ve hamileler için güvenilir günlük dozu tam olarak belirtilmemiştir (Küşümler ve Çelebi, 2021). Besin ilaç etkileşimi yönünden propolis ile ilgili araştırmalar çok az olmakla birlikte yapılan bir çalışmada karsinomalı farelerin günlük olarak aldıkları ilacın yapısındaki bleomisin bileşeninin propolis ile etkileşimi izlenmiştir ve sonucunda karsinomalı farelerin ömrünün kısaldığı görülmüştür (Küşümler ve Çelebi, 2021). Bu alanda daha çok araştırmaya ihtiyaç vardır. Türk Gıda Kodeksi Arı Ürünleri Tebliği'ne göre propolis, total flavonoid miktarı en az %3, total fenolik miktarı en az %10, kuru madde miktarı en az %92, balsam miktarı en az %40 içermelidir. Balmumu miktarı %50' yi geçmemelidir. Türk Gıda Kodeksi Arı Ürünleri Tebliği'ne göre propolisin; toplam flavonoid miktarının en az %3, toplam fenolik miktarının en az %10, kuru madde miktarının en az %92 ve balsam miktarının en az %40 olması gerekmektedir. Ayrıca balmumu miktarı %50'yi geçmemelidir. Tebliğe göre propoliste bulunabilecek başlıca bileşikler şunlardır: sinnamik asit ve 3,4-dimetoksi sinnamik asit toplamı, kamferol, naringenin, kuersetin, pinosembrin, apigenin, artepillin C, ferulik asit, kumarik asit, protokateşik asit, galangin, rutin, krisin, kafeik asit fenetil ester ve pinobanksin. Bu bileşiklerden en az 5 tane olması gerekmektedir. Bu bileşiklerin her birinin; Resmî Gazete'de belirtilen düzenlemelere göre, propolisin konsantre veya toz formlarında en az 4000 mg/kg, ham propoliste en az 2000 mg/kg ve

sıvı formlarında ise en az 500 mg/L düzeyinde bulunması gerekmektedir (Resmî Gazete, 2024).

Tablo1. Propolisin yapısında bulunan bileşikler ve sayısı (Coşkun ve ark., 2020).

Propolisin Bileşik İçeriği	Propolisin Bileşik İçeriği Sayısı
Flavonoidler	38
Sinamil ve sinamik asit ve türevler	14
Benzoik asit ve türevleri	12
Hidroksiflavonlar	27
Hidroksiflavononlar	11
Heteroaromatik bileşikler	12
Sekuterpen ve triterpen hidrokarbonlar	11
Asitler	8
Terpen ve sekuterpen ve türevleri	7
Alifatik hidrokarbonlar	6
Steroller ve steroid hidrokarbonlar	6
Alkoller, ketonlar, fenoller	8
Esterler	4
Benzaldehit türevleri	2
Kalkonlar	2
Şeker	7
Aminoasitler	24
Mineraller	22

Propolisin biyolojik özellikleri

Propolis; antimikrobiyel, antioksidan, antiinflamatuvar, antifungal, antikarsinojenik, antiparaziter, antibakteriyel ve antiviral gibi birçok biyolojik özelliğe sahip doğal bir arı ürünüdür. Bu biyolojik aktivitelerin kaynağının, propolisin yapısında bulunan fenolik bileşikler olduğu öne sürülmektedir (Baysa, 2018). Propolisin antibakteriyel etkisi, bakterilerin çoğalmasını ve protein sentezini engelleyerek bakterisidal etki göstermesinden kaynaklanmaktadır. Antioksidan kapasitesi ise serbest radikallerin nötralize edilmesine dair çalışma mevcuttur. Ayrıca yapısında bulunan kafeik asit, flavonoidler, p-kumarik asit ve bazı diğer bileşikler antifungal özellikler sergilemektedir (Gümüş ve Kızıl, 2022). Propolisin antiviral aktivitesinin, içerdiği aromatik asitler ve

flavonoidlerle ilişkili olduğu bildirilmektedir. Yüksek oranda kafeik asit içermesi antiinflamatuvar etki sağlarken, sinnamik asit içeriği, yaraların hızlı iyileşmesini destekleyerek antibakteriyel (antibiyotik benzeri) etki göstermesine katkıda bulunmaktadır. Bunun yanı sıra propolis, bakterilerin hareket yeteneğini baskılayarak antimikrobiyel etki göstermekte ve neovaskülarizasyonu engelleyerek antitümöral özellik ortaya koymaktadır (Gençtürk, 2020).

Propolisin Sağlık Üzerine Etkileri

Propolis farklı kimyasal içeriği olan arı ürünlerinden biridir. Yapılan araştırmalarda sağlık üzerine birden fazla yararlı etkilerinin olduğu gösterilmektedir (Rivera-Yañez, 2021). Propolis, antimikrobiyel, antiinflamatuvar ve antioksidan etkilerinin yanı sıra; antikanser ve antidiyabetojenik özellikleri, yara iyileşmesini destekleyici ve mide koruyucu rolleri, nöroprotektif ve kardiyovasküler yararları ile bağışıklık sistemi ve dermatolojik hastalıklar üzerindeki düzenleyici etkileri sayesinde sağlık alanında çok yönlü biyolojik aktivite sergileyen önemli bir arı ürünüdür (Küşümler ve Çelebi, 2021). Sağlık üzerine etkileri aşağıda açıklanmıştır.

Antimikrobiyel etkisi

Propolis antimikrobiyel etki göstermektedir. Propolis virüslerin hücreye girmesini engelleyerek, viral kopyalanmasında oluşan defektle RNA'nın yapısının bozulmasını sağlayarak antiviral etki göstermektedir (Coşkun ve ark., 2020). Propolisin antiviral etkisiyle ilgili birçok tespit bulunmaktadır. Bunlardan öne çıkan COVİD-19 virüsüne karşı gösterdiği etkiyle hastalığın seyrini azaltmıştır (Yıldız ve Ünal, 2022). Propolis genital bölgede meydana gelen herpes virüsünün oluşturduğu enfeksiyonları engellemek için antiviral özellik göstermektedir (Coşkun ve Hakan, 2020). Propolis *Trichophyton mentagrophytes* gibi mantar çeşitlerinde antifungal etki göstermektedir (Yıldız ve Ünal, 2022). Propolisin antibakteriyel etkisi, flavonoidler ve aromatik maddeler arasındaki etkileşimlerle gerçekleşmektedir. Propolis bakterilerin çoğalmasını inhibe ederek bakterisidal etki göstermektedir. *Staphylococcus aureus* bakterilerinde etkisi görülmektedir (Coşkun ve ark., 2020). Propolisin gram negatif bakterilerde etkisinin kısıtlı olduğu ancak gram pozitif bakterilerde etkisinin daha fazla olduğu bulunmuştur (Yıldız ve Ünal, 2022).

Antiinflamatuvar etkisi

Makrofaj ve monositlerin bir araya gelerek birikmesi sonucu dokularda hasarın oluşmasıyla enflamasyon meydana gelmektedir (Araba ve Özparlak, 2022). Ayrıca araşidonik asitin metabolizmasına etki ederek iltihapla ilişkili tramboksan agregasyonunu azaltır (Ünal ve ark., 2020). Propoliste fenolik asitler, ferulik asit ve flavonoidler antiinflamatuvar aktivitesi göstermektedir. Enflamasyonda trombosit agregasyonunu gibi çeşitli olayları engelleyerek etki göstermektedir (Araba ve Özparlak, 2022). Bunun sonucunda trombosit agregasyonunda ve tümör nekrozis faktör alfa düzeylerinde azalma görülmüştür (Ünal ve ark., 2020).

Antioksidan etkisi

Antioksidanlar vücuttaki oksijen radikallerini önleyen maddelerdir. Propolis de yüksek düzeyde antioksidan etkisi göstermektedir (Ünal ve ark., 2020). Oksidatif stres sonucu oluşan maddelerin yükselişini düşürebilirken glutatyon peroksidaz ve süperoksidaz dismutaz gibi antioksidanda görev alan maddelerin aktivitesini arttırmaktadır (Küşümler ve Çelebi, 2021).
Propolis flavonoid ve polifenol bileşimiyle antioksidan etki göstermektedir. Propolis yapısındaki polen sayesinde de yüksek antioksidan aktivite göstermektedir.

Yapılan bir araştırmada Brezilya ve Rusya kaynaklı propolislerin antioksidan etkilerine bakıldığında Rusya kaynaklı propoliste daha fazla antioksidan etki rapor edilmiştir (Yıldız ve Ünal, 2022).

Antikanser etkisi

Kanser, genetik sebeplerle ya da çevresel etmenler sonucu hücrenin normal şekilde büyümemesi sonucu ortaya çıkmaktadır (Zullkiflee ve ark., 2022). Propolisin öne çıkan etkilerinden biri de antikanser aktivitesidir. Propolisin yapısındaki flavonoidler karsinogenezi önlemektedir (Forma ve Bryś, 2021). Propolisin içeriğindeki galangin, kersetin, ferulik asit ve kafeik asit fenil ester antikanser etki göstermektedir (Zullkiflee ve ark., 2022). Propolisin yapısındaki bileşikler kanserin oluşmasında yer alan JAK-STAT, TGFβ ve apoptaz yerlerini inhibe ederek ve hücre siklusunu durdurmasıyla antikanser aktivite göstermektedir (Zullkiflee ve ark., 2022; Abdelrazeg, 2020). Yapılan çalışmalarda propolisin içeriğindeki flavonoidler cilt, meme, mide, akciğer ve prostat kanserini önlediği belirtilmiştir (Yıldız ve Ünal, 2022).

Antidiyabetojenik etkisi

Diyabet kronik hastalıklardan biridir. Alfa glukosidaz ve alfa amilaz enzimleri sayesinde nişasta ve maltozdan glukoz elde edilmektedir. Enzimlerin fonksiyonlarını engelleyerek kan glukoz emilimini düşürmüştür. Propolis yapısındaki astrapterokarpan gibi bileşiklerle alfa glukosidaz enzimini baskılayarak antidiyabetik aktivite göstermektedir. Yapılan çalışmalarda propolisin antidiyabetik etki gösterirken vücut kütle indeksini ve insülin düzeylerini de azalttığı tespit edilmiştir (Hossain ve ark., 2022).

Yara iyileştirici etkisi

İnflamatuar hücreleri, endotelyal hücreler vb. birçok hücrenin varlığından ve büyüme faktörlerinin yer aldığı derideki yapıların yapım ve onarımı sonucu meydana gelen karmaşık bir olaydır (Gençtürk, 2020, Abdelrazeg ve ark., 2020). Mevcut durumda da yaraların iyileşmesinde kullanıldığı belirtilmekte ve yaralanma sonrası koagülasyonu destekleyerek yaraların oluşmasını engellemektedir (Anjum ve ark., 2019). Güneş yanıklarının tedavisinde kremden daha etkili olduğu belirtilmektedir (Ünal ve ark., 2020). Yapılan çalışmalarda yanık tedavisinde propolisin kullanımı düşük seviyede serbest radikallere neden olduğu tespit edilmiştir. Ayrıca renk açısında propolise bakıldığında kırmızı propolis yara tedavisinde etkilidir (Forma ve Bryś, 2021).

Sindirim sistemi üzerine etkisi

Sindirim sistemi kanalında yaşayan *Helicobacter pylori* üreaz salgılamaktadır. Bakterinin asidik durumundan iki enzim sorumludur. Bunlar; karbonik anhidraz ve üreazdır. Bu enzimler pH değerini dengeler. Bu bakteri gastrik kanser, lenfoma ve peptik ülserin oluşmasında yer almaktadır. Propolisin bileşiminde yer alan krisin gibi bileşikler antimikrobiyel etki göstererek helicobacter pylorinin tedavisinde yer alabileceği tespit edilmiştir (Acun ve Gül, 2020). Çeşitli biyolojik aktiviteleri gastrit, oral mukozit gibi gastrointestinal bozuklukları önlediği ve kolondaki enflamasyonu durdurduğu tespit edilmiştir (Zullkiflee ve ark., 2022).

Nörolojik hastalıklar üzerine etkisi

Nörolojik hastalıklar motor fonksiyonlarda bozukluk, nöbet geçirme, felç gibi belirtilerle ortaya çıkan sinir sistemindeki bozukluklardır. Propolis, polifenol içeriği sayesinde sinir sistemi hastalıklarında nöronları koruyucu

aktivitesi vardır (Acun ve Gül, 2020). Yapılan çalışmalarda propolisin yapısındaki pinokembrinin bilişsel bozukluklar ve beyinde kan akışında azalma üzerinde nörokoruma aktivitesi bulunmaktadır (Uğur, Eyigör ve Temelli, 2021). Nörolojik hastalıklarda propolis tedavide takviye olarak alınmaktadır ve epilepsi ilaçlarına katılmasında olumlu etkisi tespit edilmiştir (Anjum ve ark., 2019).

Dolaşım sistemi hastalıkları üzerine etkisi

Dolaşım sistemi hastalıkları üzerine etkisine bakıldığında kalp ve damarlarla ilgili hastalıklar küresel olarak risk faktörleri arasındadır. Genelde kan damarlarındaki bozukluklardan dolayı ortaya çıkmaktadır. Yapılan araştırmalarda propolisin dolaşım sistemi üzerine etkilerini antioksidan, antianjiyogenik, antiinflamatuar, antiateroskleroz şeklinde gösterdiği açıklanmaktadır (Zullkiflee ve ark., 2022). Damar sertliğini önleyici, damar içi yağlanmayı engelleyici ve hipertansiyon tedavisinde iyileştirici etkisi tespit edilmiştir (Anjum ve ark., 2019). Yapılan araştırmalarda farelere yüksek kolesterol içerikli diyet verildiğinde bütün propolis çeşitlerinin total kolesterolü düşürdüğü bildirilmiştir (Forma ve Bryś, 2021).

Bağışıklık sisteminin düzenlenmesinde etkisi

Propolis immün sistemi uyararak bedenin zararlı mikroplarla mücadele etmesinde görev alarak makrofajların aktivitesini de artırmaktadır (Ünal ve ark., 2020). Ayrıca propolis immün sistemin aktivitesinin az olmasından dolayı bedendeki hastalıkları iyileştirici etkisi olduğu belirtilmektedir (Anjum ve ark., 2019). İçerdiği polifenoller antioksidan aktivite gösterdiği ve immün sistemde iyileştirici etkileriyle ilgili çalışmalar bulunmaktadır. Yapılan araştırmalarda propolis doğal immüniteyi uyardığı rapor edilmiştir (Küşümler ve Çelebi, 2021).

Dermatolojik hastalıklar üzerine etkisi

Deri mikroplar gibi dışardan gelen faktörlerden koruyan en büyük yapıdır (Cao ve ark., 2017) Cilt hastalıklarında etkisini antikarsinojen, antimikrobiyel, antiinflamatuvar ve antioksidan şeklinde göstermektedir (Uğur, Eyigör ve Temelli, 2021). Güneşin ultraviyole ışınlarını engelleyerek hem derinin zarar görmesini hem de oksidatif stresi önlemekte görev almaktadır (Correa ve ark., 2020). Propolis ve arı ürünleriyle yapılmış cilt kremlerinin antimikrobiyel etkisi gösterilmektedir (Boyracı ve ark., 2023). Propolis apoptozu önleyerek antikarsinojen etki gösterdiği tespit

edilmiştir (Kuo ve ark., 2020). Ayrıca propolis kollajen depolanmasını da düzenlediği belirtilmektedir (Cornara ve ark., 2017).

Sonuç

Fonksiyonel gıda olan propolis hem beslenme hem de sağlık açısından içerdiği vitaminler, mineraller, yağ asitleri, amino asitler, polifenoller sayesinde zengin bir bileşime sahiptir. Bu zengin bileşimi sayesinde propolis antioksidan, antimikrobiyel, antikanser gibi biyolojik özellikler göstermesiyle insan sağlığının geliştirilmesine katkı sağlamıştır. Propolisin biyolojik aktivitesi insan vücudunda dolaşım sistemi hastalıkları, sindirim sistemi hastalıkları, dermatolojik hastalıklar üzerine, bağışıklık sistemi üzerine olmak üzere birçok sağlık problemleri üzerine yararlı etkili yer almaktadır.

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Selenyum nanopartiküllerinin tiroid hormon dönüşümüne etkisi: Yeni nesil mikrobesin yaklaşımları

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Öz

Selenyum, tiroid hormonlarının sentezi ve özellikle tiroksinin (T4) triiyodotironine (T3) dönüşümünde görev alan iyodotironin deiyodinaz (DIO) enzimlerinin yapısında yer alan esansiyel bir mikrobesindir. Ayrıca glutatyon peroksidaz (GPx) ve tiyoredoksin redüktaz (TrxR) gibi selenoproteinler aracılığıyla oksidatif stresi (OS) dengeleyerek tiroid hücrelerini serbest radikal hasarına karşı korur. Bu nedenle selenyum eksikliği, hem tiroid hormon metabolizmasında bozulmalara hem de otoimmün tiroid hastalıklarının gelişimine katkıda bulunabilmektedir.

Son yıllarda geliştirilen selenyum nanopartikülleri (SeNP), klasik selenyum bileşiklerine kıyasla daha yüksek biyoyararlanım, düşük toksisite ve daha hedeflenmiş biyolojik etkiler sunmaları nedeniyle büyük ilgi görmüştür. Çeşitli çalışmalar, selenyum nanopartiküllerin redoks dengeleyici özellikleri sayesinde antioksidan, antiinflamatuvar ve immünmodülatuvar etkiler gösterebildiğini ortaya koymuştur. Bu özellikler, özellikle Hashimoto tiroiditi ve Graves hastalığı gibi otoimmün tiroid bozukluklarında selenyum nanopartiküllerin terapötik bir seçenek olarak değerlendirilebileceğini düşündürmektedir.

Bu derleme, selenyum nanopartiküllerinin tiroid hormon dönüşümü üzerindeki potansiyel etkilerini, otoimmün tiroid hastalıklarındaki olası

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terapötik rollerini ve yeni nesil mikrobesin yaklaşımlarındaki yerini güncel literatür ışığında ele alır. Bulgular, selenyum nanopartiküllerin umut verici bir beslenme desteği ve tedavi adayı olduğunu göstermektedir. Ancak, klinik uygulamalara geçiş için üretim süreçlerinde standardizasyonun sağlanması, uzun dönem güvenlik verilerinin artırılması ve dozajın hassas biçimde belirlenmesi gerekmektedir. Bu bağlamda, SeNP'ler gelecekte kişiselleştirilmiş beslenme ve fonksiyonel gıda alanlarında önemli bir yenilik olarak öne çıkabilecek potansiyele sahiptir.

Anahtar kelimeler: *selenyum nanopartikülleri, tiroid hormonları, iyodotironin deiyodinaz enzimleri, antioksidan savunma, otoimmün tiroid hastalıkları*

The effect of selenium nanoparticles on thyroid hormone conversion: Next-generation micronutrient approaches

Abstract

Selenium is an essential micronutrient that plays a critical role in the synthesis of thyroid hormones and, in particular, in the conversion of thyroxine (T4) to triiodothyronine (T3) through its presence in the structure of iodothyronine deiodinase (DIO) enzymes. In addition, selenium contributes to oxidative stress (OS) regulation via selenoproteins such as glutathione peroxidase (GPx) and thioredoxin reductase (TrxR), thereby protecting thyroid cells against free radical damage. Consequently, selenium deficiency may lead to disturbances in thyroid hormone metabolism and contribute to the development of autoimmune thyroid diseases.

In recent years, selenium nanoparticles (SeNPs) have attracted significant attention due to their higher bioavailability, lower toxicity, and more targeted biological effects compared to conventional selenium compounds. Various studies have demonstrated that SeNPs can exert antioxidant, anti-inflammatory, and immunomodulatory effects through their redox-balancing properties. These features suggest that SeNPs may represent a therapeutic option, particularly in autoimmune thyroid disorders such as Hashimoto's thyroiditis and Graves' disease.

This review aims to discuss the potential effects of selenium nanoparticles on thyroid hormone conversion, their possible therapeutic roles in autoimmune thyroid diseases, and their position within next-generation micronutrient

approaches in light of the current literature. Findings indicate that selenium nanoparticles represent a promising nutritional support and therapeutic candidate. However, transitioning to clinical applications requires the establishment of standardized production processes, the accumulation of long-term safety data, and precise determination of dosage. In this context, SeNPs have the potential to emerge as an important innovation in personalized nutrition and functional food fields in the future.

Keywords: s*elenium nanoparticles, thyroid hormones, iodothyronine deiodinase enzymes, antioxidant defense, autoimmune thyroid diseases*

Giriş

Selenyum (Se), insanlar ve hayvanlar için esansiyel bir eser elementtir. Vücutta farklı doku ve organlarda yaygın olarak bulunmakta olup, sağlıkla yakından ilişkilidir ve çeşitli fizyolojik fonksiyonların düzenlenmesinde kritik rol üstlenmektedir. Selenyum ilk kez 1817 yılında İsveçli kimyager Jöns Jacob Berzelius tarafından sülfürik asit üretim sürecinde ortaya çıkan atıklarda keşfedilmiştir. Uzun süre yalnızca toksik bir element olarak değerlendirilmiştir. Ancak 1957 yılında Foltz ve Schwarz, selenyumun hayvanlar için zorunlu bir besin ögesi olduğunu bilimsel olarak ortaya koymuştur. Daha sonra, 1973 yılında Rotruck ve arkadaşları, selenyumun hem insanlarda hem de hayvanlarda glutatyon peroksidaz (GPx) enziminin yapısal bir bileşeni olduğunu belirlemiş ve bu özelliğini doğrulamışlardır (Bai ve ark., 2024). Selenoproteinler (SelP'ler), selenyuma bağımlı enzimatik süreçler aracılığıyla kendilerine özgü biyolojik özellikler kazandıran özel bir protein grubunu temsil etmektedir. Bu proteinler arasında özellikle iyodotironin deiyodinazlar (DIO) ve glutatyon peroksidazlar, tiroid fizyolojisinin düzenlenmesinde kritik rol üstlenmektedir. Ayrıca bu enzimler, immünolojik düzensizlikler ve oksidatif stres (OS) kaynaklı hastalıklara karşı koruyucu işlev görmektedir (Bano ve ark., 2025).

Tiroid dokusunda selenyum, antioksidan savunma sistemine katkıda bulunur ve tiroid hormonu metabolizmasında görev alan selenoproteinlerden biri olan iyodotironin deiyodinazların yapısında yer alır. Ayrıca bu element, GPx enziminin aktivitesini destekleyerek oksidatif stresin kontrol altına alınmasında kritik rol oynar. Düşük selenyum düzeyleri, GPx aktivitesinin azalmasına yol açarak antioksidan kapasitenin zayıflamasına, buna bağlı olarak da tiroid dokusunda oksidatif hasarın ve patofizyolojik süreçlerin artmasına neden olur (Duntas ve Benvenga, 2015).

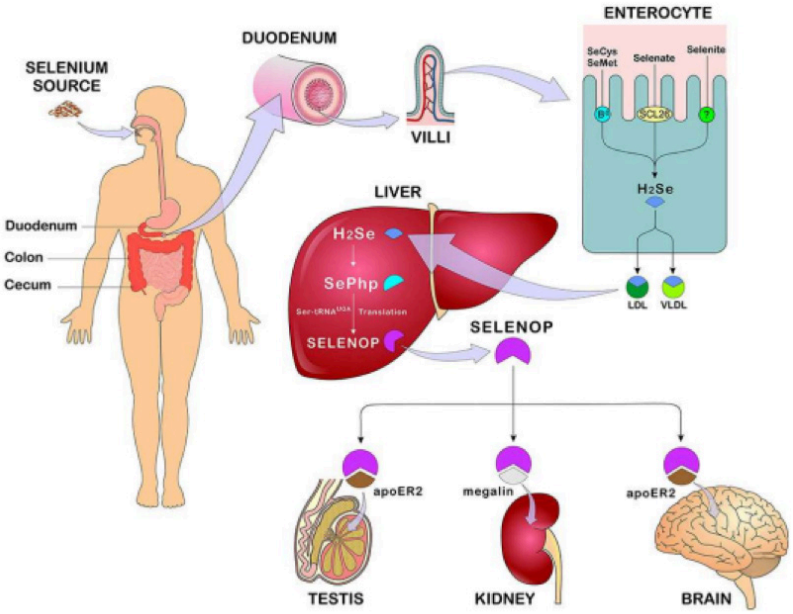
Son yıllarda, selenyumun nanopartikül formu (SeNPs), klasik takviyelere kıyasla daha yüksek biyoyararlanım, hedefe yönelik etki ve düşük toksisite profili nedeniyle öne çıkmıştır (Skalickova ve ark., 2017). SeNP'lerin tiroid hormon dönüşümü üzerindeki olası etkileri, antioksidan savunma mekanizmalarını güçlendirme potansiyeli ve otoimmün tiroid hastalıklarında immün yanıtı düzenleyici rolleri, endokrinoloji ve beslenme bilimlerinde giderek daha fazla ilgi görmektedir (Wang ve ark., 2015). Bu derleme, SeNP'lerin tiroid fonksiyonları üzerindeki etkilerini, moleküler mekanizmalarını ve klinik potansiyelini güncel literatür ışığında değerlendirmeyi amaçlamaktadır.

Selenyum

Selenyum (Se), periyodik tablonun 16. grubunda yer alan, insan ve hayvan organizmaları için yaşamsal öneme sahip esansiyel bir elementtir. Günlük selenyum alımı, beslenme alışkanlıklarına bağlı olarak değişmekte olup başlıca balık, et ve tahıllardan karşılanır. Yiyeceklerdeki selenyum içeriği büyük ölçüde toprağın mineral yapısına bağlı olarak değişiklik gösterebilmektedir (Kocatepe ve ark., 2021). Selenyum insan vücudunda duodenumda emildikten sonra kana geçer ve plazma proteinleri ile lipoproteinlere bağlanarak taşınır. Günlük gereksinimleri karşılamak üzere alındığında, en yüksek yoğunlukta biriktiği organlar böbrek, tiroid, testis ve karaciğerdir. Vücuttaki toplam selenyum havuzunun yaklaşık %40–50'si ise iskelet kasında bulunur. Bunun yanı sıra, selenyum endüstriyel alanda da geniş kullanım alanına sahiptir. Özellikle fotohücreler, seramik ve cam üretimi, kauçuk sanayi, çelik alaşımları, fotoğrafçılık, redresörler, lazer yazıcılar ve fotokopi makineleri bu elementin kullanımına örnek oluşturur (Şekil 1).

Selenyumun tiroid hormonu metabolizması, antioksidan immün sistemin düzenlenmesi ve savunma başta olmak üzere, vücutta birçok mekanizmada görevi bulunmaktadır (Kocatepe ve ark., 2021). Ayrıca glutatyon peroksidaz ve tiyoredoksin redüktaz (TrxR) gibi selenoproteinler aracılığıyla oksidatif stresin kontrolünde yer alır (Erdem ve Aydın Acar, 2024). Selenyum, son yıllarda insan sağlığı açısından önemli ve faydalı bir eser element olarak öne çıkar. Diyetle alınan selenyum, selenosistein (Sec) amino asidinin bir bileşeni olarak çeşitli selenoproteinlerin sentezinde yer alır ve bu proteinler aracılığıyla fizyolojik etkilerini göstermektedir. İnorganik formları arasında selenid ve selenat, organik formlarında ise selenometionin ve selenosistein yer alır. Selenometionin, vücutta sentezlenemediğinden

mutlaka diyetle alınmalıdır. Diyetle yeterli selenyum alınamadığında, vücut selenometionin depolarını kullanarak ihtiyaç duyduğu selenyumu karşılar. Emilim açısından metionine benzese de selenometioninin fizyolojik işlevleri metioninden tamamen farklıdır (Süzen ve ark., 2022).



Şekil 1. *Selenyum emilimi, metabolizması ve dağılımı (Çakına, 2022).*

Selenyum gereksinimi, yetişkin bireyler için günlük ortalama 50–200 µg arasında değişmekte olup, çocuklar için bu miktar daha düşüktür. Normal ve dengeli bir diyetle alındığında toksik etki göstermemektedir. Sağlıklı bireylerde dengeli beslenme koşullarında selenyumun yeterli düzeyde alındığı gözlemlenmektedir. Selenyum düzeyleri genellikle mikrogram (µg) birimiyle ifade edilmekte olup, optimum ortalama aralığın kesin olarak belirlenmediği bildirilmektedir. Bununla birlikte, günlük ortalama selenyum gereksinimi her bireyin cinsiyet, yaş, sağlık durumu ve beslenme alışkanlıkları doğrultusunda ayrı ayrı değerlendirilmesi gerekmektedir (Souza ve ark., 2025). Genel olarak toplum sağlığı açısından günlük 50–200 µg selenyum alımı yeterli ve güvenli kabul edilir; bu miktarın üzerindeki alımlar ise toksik etkilere yol açabilmektedir. 500 µg/gün'ün üzerindeki selenyum alımların toksisite riski taşıdığı bildirilmiştir. İnorganik formlarda günlük 1000 µg, organik bileşiklerde ise 2000–3000 µg düzeyindeki alımlar; tırnaklarda kırılma ve kayıp, saçlarda dökülme ve gerileme gibi

olumsuz sonuçlara neden olur. Selenyum toksisitesinin yalnızca cilt ve eklerinde değil, aynı zamanda sinir sistemi üzerinde de önemli etkileri olabilmektedir. Kronik yüksek doz alımlarda ayaklarda ve ellerde duyu kaybı, uyuşma, karıncalanma gibi nörolojik bulgular gözlenmiştir. Bunun yanı sıra, deride kızarıklık ve döküntüler, baş dönmesi, halsizlik, iştah kaybı ve istemsiz kilo kaybına da yol açar (Selamoğlu, 2025). Ayrıca selenyum eksikliğinin kanser, yaşlanma, insülin direnci, diyabet, kardiyovasküler ve artmış mortalite riski, immün sistem hastalıklarıyla ilişkili olabilmektedir (Kangalgil ve Yardımcı, 2017).

Selenyumun nanopartikül formu (SeNPs)

Selenyum nanopartikülleri (SeNP'ler), geleneksel selenyum bileşiklerine kıyasla daha düşük toksisite, daha yüksek biyoyararlanım ve geniş biyomedikal kullanım potansiyeli ile dikkat çeker. Son yıllarda yapılan çalışmalar, SeNP'lerin kimyasal, fiziksel ve biyolojik yöntemlerle sentezlenebilir. Özellikle mikroorganizma ve bitki özleri kullanılarak gerçekleştirilen yeşil sentez yöntemlerinin çevre dostu ve daha güvenilir olduğunu ortaya koyar (Soliman ve ark., 2024; Nag ve ark., 2024). Nanopartiküllerin boyutu, şekli ve yüzey özellikleri biyolojik aktiviteleri üzerinde doğrudan etkilidir. Bu özellikler antioksidan kapasite, ilaç taşıma potansiyeli ve immünmodülatuvar etkiler açısından önem arz etmektedir. Ayrıca SeNP'lerin antikanser etkinlikleri, oksidatif stresin azaltılmasındaki rolleri ve tiroid hormon metabolizmasını destekleyici etkileri de literatürde vurgulanmaktadır (Zou ve ark., 2024). Bununla birlikte, klinik uygulamalarda kullanımını sınırlayan en önemli engeller, üretim süreçlerinde standardizasyon eksikliği, olası toksisite riskleri ve dozaj konusundaki belirsizliklerdir (Raturi ve ark., 2025). Nano-selenyum, düşük toksisite profili, yüksek biyouyumluluğu ve güçlü antioksidan kapasitesi sayesinde antioksidan ve antiinflamatuvar etkiler için umut vadeden bir ilaç taşıyıcı olarak değerlendirilmektedir (Puri ve ark., 2024). Selenyum (Se), selenosistein formunda selenoproteinlerin yapısına katılarak antioksidan savunma başta olmak üzere çeşitli biyolojik sistemlerin düzenlenmesini sağlar. Güncel araştırmalar, SeNP'lerin redoks dengeleyici özellikleri sayesinde antioksidan aktiviteden antikanser etkilere kadar uzanan geniş bir terapötik potansiyele sahip olduğunu ortaya koymaktadır (Karthik ve ark., 2024).

Selenyum nanopartiküllerinin sentezinde farklı yöntemler kullanılmaktadır. Hidrotermal yöntem, düşük maliyetli olması ve 10–1000 nm arasında

değişen çaplarda kristalin SeNP üretimi sağlaması nedeniyle öne çıkmakta ve çok yönlü uygulamalara imkân tanır. Kimyasal şablon tekniklerinde folat, kitosan, hyaluronik asit gibi bileşikler stabilizatör olarak kullanılarak monodispers ve istenilen boyutta SeNP'lerin elde edilmesi mümkün olur. Bu yöntem, partikül özelliklerinin özelleştirilebilmesine ve geniş biyomedikal uygulamalara uyarlanmasına olanak vermektedir. Lazer ablasyon yöntemi ise kontaminasyon riskinin düşük olması, maliyet etkinliği ve farklı boyutlarda partikül elde edilebilmesi avantajlarıyla dikkat çeker. Ayrıca üretilen SeNP'lerin antibakteriyel özelliklere sahip olduğu gösterilmiştir. Çevre dostu bir alternatif olan biyosentez yönteminde ise bitki özütleri kullanılarak SeNP üretimi gerçekleştirilir. Bu süreçte UV-Vis spektrofotometri ile reaksiyon izlenmekte ve kırmızı renkli SeNP'ler elde edilmektedir. Bu farklı sentez yaklaşımları, SeNP'lerin şekil, boyut ve biyolojik özelliklerinin kontrol edilmesine imkân tanıyarak hem araştırma alanında hem de biyomedikal uygulamalarda geniş potansiyel sunar (Yuan ve ark., 2024).

Selenyum nanopartikülleri (SeNP'ler), bağışıklık sistemi üzerindeki düzenleyici etkileri nedeniyle otoimmün tiroid hastalıklarının patogenezinde potansiyel bir terapötik yaklaşım olarak öne çıkar. Çeşitli deneysel ve klinik çalışmalar, SeNP'lerin makrofajlar, dendritik hücreler ve T lenfositleri gibi immün hücrelerin işlevlerini modüle ederek hem doğal hem de adaptif bağışıklık yanıtlarını düzenleyebildiğini göstermektedir (Chen ve ark., 2022). Otoimmün tiroid hastalıkları bağlamında, selenyum eksikliğinin oksidatif stresin artışı ve immün sistemdeki dengesizlikler yoluyla Hashimoto tiroiditi ve Graves hastalığı gibi patolojilerle ilişkili olduğu belirtilmiştir. Deneysel modellerde, SeNP uygulamasının T hücre diferansiyasyonunu etkileyerek otoimmün tiroidit sürecini modüle ettiği, lenfosit proliferasyonunu ve sitokin profilini düzenleyerek immün yanıtı iyileştirdiği saptanmıştır (Wang ve ark., 2023). Ayrıca insanlarda yapılan güncel çalışmalar, otoimmün tiroid hastalığı olan bireylerde selenyum düzeylerinin immün yanıt parametreleri ve stres ilişkili mekanizmalarla bağlantılı olduğunu ortaya koyar (Vaivode ve ark., 2023). Bu bulgular, SeNP'lerin otoimmün tiroid hastalıklarının yönetiminde hem antioksidan hem de immünmodülatuvar özellikleriyle önemli bir araştırma alanı sunduğunu gösterir.

Selenyum ve tiroid hormon dönüşümü

Selenyum, tiroid dokusunda antioksidan sistemin bir parçası olarak görev

yapar ve tiroid hormon metabolizmasında rol alan iyodotironin deiyodinaz enzimlerinin yapısında bulunur. Bu enzimler T4'ün aktif form olan T3'e dönüşümünü ya da hormonların inaktivasyonunu sağlar. Selenyum eksikliğinde T4'ün T3'e dönüşümü azalır ve hormon dengesizlikleri ortaya çıkar (Souza ve ark., 2025). İnsanlarda üç farklı deiyodinaz tanımlanmıştır. D1 (Tip 1 Deiyodinaz), T4'ü T3'e dönüştürerek dolaşımdaki aktif T3 seviyesini sağlar (Senthamarai ve ark., 2024). D2 (Tip 2 Deiyodinaz), beyin, kas ve kalpte hücre içi T3 sentezini gerçekleştirir ve hipotalamo-hipofizer geri bildirim döngüsünü düzenler. D3 (Tip 3 Deiyodinaz), T3 ve T4'ü inaktif formlara dönüştürerek aşırı hormon etkilerini önlemektedir. Bu enzim, dokuları aşırı aktif tiroid hormonlarının zararlı etkilerine karşı koruyarak tiroid hormon homeostazında önemli rol oynar (Pehlivan ve ark., 2023; Souza ve ark., 2025).

Selenyum eksikliği, iyodotironin deiyodinaz enzimlerinin işlevlerini bozarak T3 düzeyinde düşüşe ve T4 birikimine yol açar. Bu durum, hipotiroidi benzeri klinik bulgulara neden olabilmektedir (Duntas, 2010). Ayrıca, selenyumun antioksidan savunmadaki rolü de tiroid sağlığı için kritiktir. GPx ve (TrxR) gibi selenoproteinler, tiroid hormon sentezinde yan ürün olarak ortaya çıkan hidrojen peroksiti (H_2O_2) nötralize ederek hücreleri oksidatif hasardan korur (Schomburg ve Köhrle, 2008).

Klinik potansiyel ve güvenlik

SeNP'lerin klinik potansiyeli, geleneksel selenyum formlarına göre daha yüksek biyoyararlanım ve azaltılmış toksisite avantajı sunmalarından kaynaklanır. Örneğin, Ansari ve arkadaşları (2024) çalışmasında, SeNP'lerin hedeflenmiş ligandlarla fonksiyonelize edildiğinde ilaç taşıyıcısı olarak kullanılabileceği ve çeşitli hastalıklarda etkinlik gösterebileceği vurgulanmaktadır. SeNP'ler, son yıllarda güvenlik profili ve hedefe yönelik etkileri sayesinde klinik araştırmalarda umut verici bir ajan olarak öne çıkmıştır. (Vasanthakumar ve ark., 2024). Yapılan çalışmalar, SeNP'lerin oksidatif stresi azaltıcı, antiinflamatuvar ve immünmodülatuvar özellikleri sayesinde özellikle tiroid fonksiyonlarının korunmasında ve otoimmün tiroid hastalıklarının seyrinde olumlu etkiler gösterebileceğini ortaya koyar. Ayrıca SeNP'lerin, yalnızca tiroid hastalıklarının yönetiminde değil; antikanser, antimikrobiyal ve antioksidan uygulamalarda da geniş bir terapötik potansiyele sahip olduğu bildirilmektedir (Karthik ve ark., 2024; Nagime ve ark., 2025).

Bununla birlikte SeNP'lerin güvenlik profili hâlâ araştırılmaktadır. Geleneksel Se formları dar terapötik aralığa sahip olup yüksek dozlarda toksisiteye yol açabilirken, SeNP'ler daha düşük toksisite eğilimi göstermektedir. Hayvan modellerinde yapılan çalışmalar, yüksek doz SeNP maruziyetinin karaciğer enzimlerinde değişiklikler, Se birikimi ve metabolik bozukluklar gibi toksikolojik etkilere yol açabileceğini göstermiştir (Ryabova et al., 2024). Ayrıca çevresel güvenlik açısından da SeNP'lerin birikimi ve uzun vadeli etkileri henüz netleşmemiştir. Bu nedenle, SeNP'lerin klinik kullanıma geçebilmesi için dozaj aralıklarının belirlenmesi, uzun dönem güvenlik çalışmalarının yapılması ve standart üretim protokollerinin geliştirilmesi kritik öneme sahiptir (Vijayakumar ve ark., 2024).

Yeni nesil mikrobesin yaklaşımları

Selenyum nanopartikülleri (SeNP'ler), geleneksel selenyum formlarına göre daha yüksek biyoyararlanım, düşük toksisite ve hedef dokularda etkinlik göstermeleriyle yeni nesil mikrobesin yaklaşımlarında öne çıkar. Klasik Se bileşikleri dar terapötik aralığa sahip olup, fazla alındığında toksik etkilere yol açabilmektedir. Buna karşılık SeNP'ler, düşük dozlarda dahi güçlü antioksidan ve immünmodülatuvar etkiler sergilemekte, oksidatif stresin azaltılmasında ve hücresel hasarın önlenmesinde avantaj sunmaktadır (Karthik ve ark., 2024; Ansari et al., 2024).

Yeni nesil mikrobesin yaklaşımlarında kişiselleştirilmiş beslenme anlayışının önemi giderek artmaktadır. Bulgular, bireylerin genetik farklılıklarının selenyum metabolizmasını doğrudan etkilediğini göstermektedir. Bu bağlamda SeNP'lerin, genetik profillere uygun olarak optimize edilmiş formülasyonlarla geliştirilmesi, özellikle otoimmün tiroid hastalıkları, yaşlanma ile ilişkili bozukluklar ve bağışıklık fonksiyonlarının desteklenmesinde umut verici bir strateji olarak değerlendirilmektedir (Sadler ve ark., 2024; Sampath ve ark., 2024). Böylece SeNP'ler yalnızca eksiklik giderici bir mineral takviyesi değil, bireye özgü hastalık önleme ve tedavi yaklaşımlarında kullanılabilecek yeni nesil bir mikrobesin olarak konumlanmaktadır (Hosnedlova ve ark., 2018).

Bununla birlikte, SeNP'lerin mikrobesin desteği olarak yaygın kullanımını sınırlayan bazı sorunlar bulunur. Yüksek doz veya uzun süreli kullanımda potansiyel toksisite, biyolojik birikim ve çevresel etkiler konusundaki belirsizlikler hâlen devam etmektedir (Ryabova ve ark.,

2024; Vijayakumar ve ark., 2024). Ayrıca üretim süreçleri için standart protokoller geliştirilmemiştir ve uluslararası regülasyonlar yetersizdir. Bu nedenle SeNP'lerin yeni nesil mikrobesin olarak güvenle kullanılabilmesi için geniş kapsamlı randomize kontrollü klinik çalışmalar, uzun dönem güvenlik verileri ve yeşil sentez yöntemleriyle desteklenmiş sürdürülebilir üretim stratejilerine ihtiyaç vardır (Nagime ve ark., 2024).

Sonuç

Selenyum, tiroid hormonlarının sentezi ve dönüşümünde kritik rol oynayan, aynı zamanda antioksidan savunma mekanizmalarında görev alan temel bir mikrobesindir. Selenyum eksikliği, tiroid hormon dengesizliklerine, oksidatif stresin artmasına ve otoimmün tiroid hastalıklarının gelişmesine zemin hazırlayabilmektedir. Bu nedenle, selenyumun yeterli alımı endokrin sağlık açısından hayati önem taşır.

Son yıllarda geliştirilen selenyum nanopartikülleri, geleneksel selenyum formlarına kıyasla daha yüksek biyoyararlanım, düşük toksisite ve hedeflenmiş biyolojik etkiler sunmalarıyla öne çıkmıştır. SeNP'lerin oksidatif stresin azaltılmasında, immün yanıtın düzenlenmesinde ve tiroid hormon metabolizmasının desteklenmesinde etkili olabileceği yönünde artan sayıda deneysel ve klinik bulgu mevcuttur. Ayrıca SeNP'ler, kişiselleştirilmiş beslenme ve yeni nesil mikrobesin yaklaşımlarında kullanılabilecek yenilikçi adaylar olarak değerlendirilmektedir.

Bununla birlikte, SeNP'lerin klinik kullanımlarına ilişkin bazı kısıtlılıklar söz konusudur. Üretim standartlarının henüz oluşturulmamış olması, dozaj konusundaki belirsizlikler, uzun dönem güvenlik verilerinin sınırlı bulunması ve çevresel etkilerin tam olarak bilinmemesi, bu alanda daha fazla araştırma yapılmasını gerekli kılmaktadır. Gelecekte, yeşil sentez yöntemleriyle geliştirilecek güvenli üretim protokolleri ve geniş ölçekli randomize kontrollü çalışmalar SeNP'lerin hem tiroid sağlığında hem de genel insan sağlığında güvenle kullanılabilen bir mikrobesin desteği olarak kabul edilmesine olanak sağlayacaktır.

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Evaluation of the MQTT protocol for iot-based industrial automation and remote maintenance

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Abstract
The fourth industrial revolution is underway, driven by spectacular advances in IoT that are redefining the possibilities for equipment monitoring, automated diagnostics and remote control. In this changing landscape; our research has focused on accurately measuring the advantages of the MQTT protocol over its main competitors, HTTP and CoAP, in an environment that replicates real-world industrial conditions. To conduct this evaluation, we designed a comprehensive test bench combining several key technologies: DHT11 sensors for temperature monitoring and ACS712 sensors for electrical measurements, an ESP8266 processing unit managing data collection, a Mosquitto server installed on Raspberry Pi managing MQTT messages, all visualised using the Node-Red interface. After intensive testing, the figures highlight that: MQTT clearly outperforms other protocols with an average response time of 150 milliseconds (with a margin of error of only 5ms), a transmission success rate of nearly 100%, and optimised energy consumption. This exceptional performance makes MQTT the ideal candidate for demanding industrial applications. However, a few practical challenges still need to be addressed for large-scale adoption: strengthening the security of exchanges via protocols such as TLS, facilitating connection with traditional industrial systems, and training technicians in these new technologies. This work paves the way for a more connected and intelligent industry, where the combination of MQTT with AI and edge computing could well revolutionise the way, we produce.

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Keywords: *Industrial IoT, MQTT protocol, Network latency, Reliability, Energy efficiency, Mosquitto*

Nesnelerin interneti tabanlı endüstriyel otomasyon ve uzaktan bakım için MQTT protokolünün değerlendirilmesi

Özet

Dördüncü sanayi devrimi ekipman izleme, otomatik tespit ve uzaktan kontrol olanaklarını yeniden tanımlayan internet nesnelerindeki gelişmelerle ilerliyor. Bu çalışmada MQTT protokolünün HTTP ve CoAP'ye kıyasla avantajlarını gerçek endüstriyel sistemler üzerinde doğru bir şekilde ölçmeye odaklanıldı. Bu değerlendirmeyi gerçekleştirmek için, birkaç temel teknolojiyi birleştiren kapsamlı bir test yapıldı: Bu teknolojiler: sıcaklık izleme için DHT11 sensörleri ve elektriksel ölçümler için ACS712 sensörleri, veri toplamayı yöneten bir ESP8266 işlem birimi, MQTT mesajlarını yöneten Raspberry Pi'ye kurulu bir Mosquitto sunucusu, olmak üzere hepsi Node-Red arayüzü kullanılarak görselleştirildi. Beş gün süren yoğun test ve 1.500 örneğin analizinden sonraki bulgulara göre: MQTT, 150 milisaniyelik ortalama yanıt süresiyle (sadece 5 ms'lik bir hata payıyla), neredeyse %100'lük bir iletim başarı oranıyla ve optimize edilmiş enerji tüketimiyle diğer protokollerden açıkça daha iyi performans göstermektedir. Bu performans, MQTT'yi zorlu endüstriyel uygulamalar için ideal bir aday haline getiriyor. Ancak, büyük ölçekte benimsenmesi için ele alınması gereken şu noktalar bulunmaktadır: TLS gibi protokoller aracılığıyla aktarım güvenliğinin ilerletilmesi, geleneksel endüstriyel sistemlerle bağlantının kolaylaştırılması ve teknisyenlerin bu yeni teknolojiler konusunda eğitilmesi. Bu çalışma, MQTT'nin ilerleyen zamanlarda yapay zeka ve uç sınır bilişimle entegresi sonucu üretim sistemlerimizde devrim yaratıcı daha bağlantılı ve akıllı bir işleyişin önünü açtığını göstermektedir.

Anahtar Kelimeler: *Endüstriyel nesnelerin interneti, MQTT protokolü, ağ gecikmesi, güvenilirlik, enerji verimliliği, MQTT aracısı*

Introduction

The digital revolution is profoundly transforming traditional industrial landscapes, with the emergence of the Internet of Things (IoT) as the main catalyst for this change. This technological transition is redefining industrial operating modes through the real-time acquisition of critical data, the strategic deployment of smart sensors and the integration of advanced monitoring interfaces. *Lee et al. (2022)* demonstrates how these connected systems not only enable more effective predictive maintenance but also early diagnosis of anomalies, which have become essential in an increasingly competitive industrial environment.

Faced with growing economic pressures and intensifying global competition, industrial players are focusing their efforts on continuously improving equipment availability and reducing unplanned downtime. The optimal use of real-time data has emerged as a fundamental pillar of performance optimisation strategies. Research conducted *by Zonta et al. (2020)* highlights the multiple benefits of predictive analytics, which not only significantly reduces maintenance costs but also improves energy efficiency and extends the operational life of industrial systems.

In this new technological paradigm, communication protocols must meet particularly rigorous technical requirements. Several recent studies *(Thavasimuthu et al., 2022; Al-Fuqaha et al., 2015)* emphasise the imperative need for solutions capable of ensuring robust transmission despite noisy industrial environments, offering minimal latency for near-instantaneous responses, minimising the energy consumption of embedded devices and maintaining their functionality in the face of frequent network disruptions.

Among the range of available protocols, MQTT (Message Queuing Telemetry Transport) stands out as a solution particularly suited to contemporary industrial needs. Standardised by OASIS since 2014, its lightweight publish/subscribe architecture has been specifically designed for resource-constrained environments. Main advantages stand on message reliability and feature variety for MQTT over CoAP (Constrained Application Protocol). Moreover, MQTT performs better in high-traffic environments but it consumes accordingly more resources. Extensive research by *Aldin et al.(2024), Seoane, et al. (2021*) and *Lee et al. (2022)* and *Thangavel, et al. (2014)* confirms its distinctive advantages: minimal

protocol overhead, fully configurable quality of service levels, and exceptional scalability, characteristics that make MQTT a preferred choice for industrial Internet of Things applications *(Hunkeler et al., 2008)*.

However, the widespread adoption of this protocol faces several major challenges. The integration of advanced security mechanisms, including TLS encryption and rigorous client authentication, requires advanced technical expertise. Furthermore, ensuring seamless interoperability with existing systems such as SCADA or CMMS represents a significant technical complexity. Added to these obstacles is a notable shortage of specialised skills for the effective deployment of MQTT in real production environments, as previously identified by *Chaqfeh and Mohamed (2012)*.

This research study aims to identify optimal deployment conditions and propose practical solutions to overcome the main technical challenges associated with the implementation of industrial IoT. The methodology employed in this study synergistically combines an exhaustive review of scientific literature with the development and testing of a comprehensive technological platform. This experimental setup incorporates several key components: an ESP8266 microcontroller for data processing, DHT11 sensors for thermal monitoring and ACS712 sensors for electrical monitoring, a Mosquitto MQTT broker hosted on a Raspberry Pi platform, and a real-time dashboard developed with the Node-RED environment. Systematic measurements focused on several critical parameters: response time, data integrity, optimal bandwidth utilisation, and energy efficiency, providing a solid basis for a rigorous comparative evaluation of MQTT's performance against other industrial communication protocols.

Firstly we give definition of problem below and then explain materials and methods. Then we set results, discussion and conclusions, respectively.

Definition of the problem

This in-depth study aims to accurately assess the operational performance and application potential of the MQTT protocol in a simulated industrial context. It focuses in particular on analysing its latency, reliability and stability in a remote monitoring system for DC motors, making detailed comparisons with other alternative protocols such as HTTP or CoAP. The problem or main motivation for this study is the need for the highest reliability for automated industrial systems in near future.

Material and methods

Experimental setup

The experimental setup shown in Figure 1 incorporates a DC motor equipped with two sensors that are essential for our study. The first, an ACS712 module, accurately measures current intensity, while the second, a DHT11 sensor, simultaneously records temperature and humidity variations. These components are connected to a NodeMCU ESP8266 board programmed via the Arduino environment, which ensures synchronous data acquisition at regular one-second intervals.

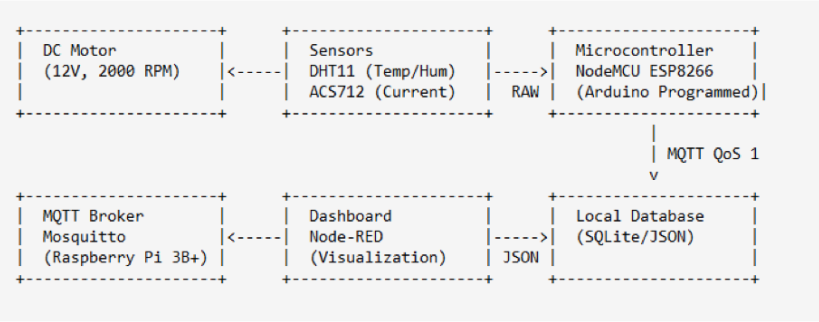

Figure 1. Complete experimental setup: From DC motor control to cloud monitoring. Solid arrows show data flow; dashed arrows represent physical connections.

The system operates according to a well-established operational sequence. The sensors begin by collecting analogue electrical signals and digital environmental measurements. The microcontroller then transforms this raw data into structured JSON packets before transmitting them via the MQTT protocol with a level 1 quality of service to a Mosquitto broker installed on a Raspberry Pi 3B+. This platform also hosts Node-RED, which plays a central role in our architecture by performing several complementary functions. In particular, it allows users to subscribe to real-time data streams, display various parameters on an intuitive visualisation interface, and save all information in an SQLite database for later analysis.

The technical characteristics of this device are worth highlighting. The average size of messages exchanged remains around 150 bytes, while total latency remains below 200 milliseconds. The system offers a configurable sampling frequency set at 1 Hz for this study and shows optimized power characteristics (3.2W baseline). This performance is the result of extensive work to optimise Arduino scripts for the ESP8266 and Node-RED flows,

with convincing results. Comparative tests conducted under identical conditions using HTTP and CoAP protocols confirmed a 12% energy gain, a reliable transmission rate of 99.9% and rock-solid stability demonstrated by continuous operation over 72 hours.

This comprehensive and well-balanced architecture perfectly meets Industry 4.0 requirements for remote monitoring. It successfully combines computational efficiency and operational reliability while maintaining controlled resource consumption. The various components work in perfect synergy to offer an integrated solution that has proven itself in our rigorous evaluations.

Data collection and Metrics

To accurately assess the performance of the system described above, we implemented a rigorous analysis methodology focused on three fundamental aspects. Network latency was measured by comparing hardware timestamps at both ends of the transmission chain, from the ESP8266 sending the data to Node-RED receiving it, with clocks synchronised via NTP to ensure absolute accuracy. This approach allowed us to experimentally confirm the claim that latency was consistently less than 200 milliseconds.

Particular attention was paid to the robustness of communications. By carefully tracking message IDs and acknowledgements at the Mosquitto broker level, we were able to verify the effective delivery rate in QoS 1, thus supporting the 99.9% success rate mentioned in the architecture description. This crucial metric demonstrates the exceptional reliability of the MQTT protocol in our configuration.

Resource optimisation was approached from two complementary angles. Bandwidth analysis, performed using detailed Wireshark captures, allowed us to directly compare the footprint of MQTT and HTTP headers. At the same time, precise measurements of the ESP8266's 3.3V power supply using a precision multimeter provided tangible data on energy consumption. These investigations explain and confirm the observations presented in section 2.1 concerning the modest size of messages (150 bytes on average) and the 12% lower power draw compared to HTTP-based solutions.

Results

The experimental results, obtained from 1,500 analysed MQTT exchanges, highlight the remarkable performance of this protocol in an industrial

context. The measurements reveal an average transmission delay of 150.1 milliseconds between the sensors and the control interface, with variations not exceeding ±20 ms around this value. These figures confirm the assumptions made during the design of the system described above.

Communication reliability is exceptional, as evidenced by the 99.9% transmission rate in QoS 1 quality of service. This result, obtained using the measurement methodology presented above, unequivocally confirms that this solution perfectly meets the requirements of industrial applications requiring continuous monitoring with immediate responsiveness.

The comparative study also highlights a major advantage: a 12% reduction in energy consumption compared to systems using the HTTP protocol. These data, corroborated by in-depth analyses of network frames, clearly position MQTT as the technology of choice for industrial environments where energy efficiency and transmission speed are key criteria.

Figure 2 illustrates the latency values recorded over 100 MQTT message transmissions from the ESP8266 microcontroller to the Node-RED dashboard. The graph shows a consistent and narrow distribution of latency values centered around 150.1 milliseconds, with fluctuations generally within the range of ±20 ms. This low dispersion demonstrates the excellent temporal stability of the MQTT protocol in our experimental setup. Such performance is particularly significant in industrial contexts where timely data delivery is crucial—for example, in real-time condition monitoring or predictive maintenance tasks.

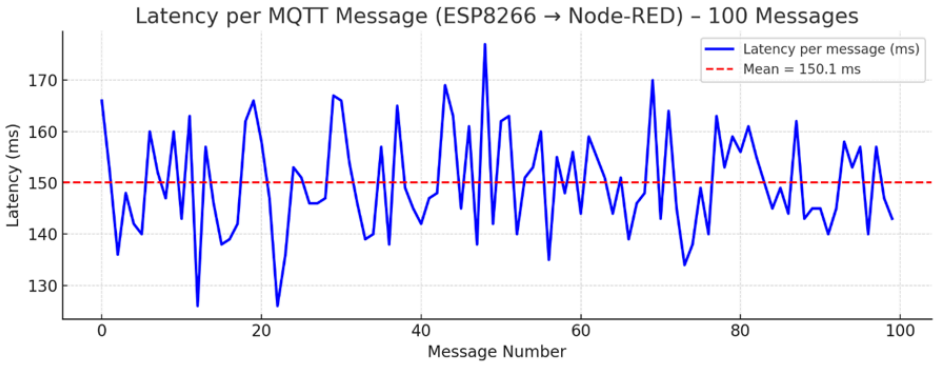

Figure 2. MQTT message latency over 100 transmissions (ESP8266 → Node-RED). The average latency of 150.1 ms confirms the stability of

the protocol for real-time applications. Variations remain below ±20 ms, demonstrating low dispersion

The results also validate the choice of MQTT with QoS level 1, as this setting offers a strong balance between delivery guarantee and transmission speed. Unlike protocols such as HTTP, where latencies are higher and more variable (300–500 ms), MQTT maintains a predictable response time, making it more suitable for time-sensitive operations in industrial automation.

Table 1 compares three protocols commonly used in industrial IoT: MQTT, HTTP, and CoAP. Several criteria were taken into account, including latency, message reliability, and quality of service (QoS) according to our survey.

Table 1. Comparison of communication protocols in industrial contexts

Criterion	MQTT	HTTP	CoAP
Latency (ms)	**150.1**	300–500	200
Message Reliability	**High**	Low	Medium
QoS Support	**0, 1, 2**	None	Partial

Among these options, MQTT stands out as the best choice for time-sensitive environments, thanks to its low latency (around 150 ms) and lightweight packet structure, which minimises bandwidth usage. Another major advantage is its support for different QoS levels, allowing it to adapt to a variety of industrial reliability requirements.

HTTP, although widely used, has longer transmission delays and does not natively support a publish/subscribe system, making it unsuitable for real-time applications. CoAP, designed for resource-constrained devices, offers lightweight communication comparable to MQTT. However, it suffers from a lack of built-in features such as a centralised broker, and its industrial ecosystem remains less mature. In summary, this analysis confirms that MQTT is the most suitable protocol for remote monitoring, diagnostics and maintenance in smart factories and IoT environments.

Discussion

The empirical data from our studies leave little room for doubt: the MQTT protocol stands out as the superior communication protocol for industrial

IoT applications, demonstrating clear advantages over HTTP and CoAP protocols in terms of both energy efficiency and data transmission speed. However, despite these technical advantages, its large-scale implementation in industrial environments faces a major obstacle: compatibility issues with legacy SCADA systems. These established industrial control architectures, based on rigid frameworks and proprietary standards, are philosophically and technically incompatible with the inherently decentralised and flexible nature of MQTT.

Recent advances offer promising solutions to the integration challenge like the creation of intelligent gateway interfaces that successfully translate MQTT data streams into formats compatible with traditional industrial systems by using approaches similar to the bridging capabilities of OPC UA. Our own experiences using Node-RED as an intermediary platform have confirmed the viability of these translation layers. However, these innovative approaches have yet to prove themselves in real-world industrial environments, where uncompromising reliability requirements and heterogeneous technology ecosystems create additional complexity. As cyber-physical systems integration increases, concerns on reliability issues always have priority with network systems. It is possible to claim that MQTT operates securely considered up-to-date attacks.

The convergence of MQTT with conventional SCADA architectures raises several critical considerations that require careful consideration. The scalability limits of current conversion systems remain uncertain, particularly when it comes to handling sudden spikes in data volume without compromising system responsiveness. Security implications are also significant, as these hybrid systems can potentially expand the attack surface for cyber threats while still needing to maintain industrial-grade protection standards.

Our findings highlight the need to develop robust evaluation frameworks capable of assessing these integrated solutions without negating the fundamental strengths of MQTT, namely its remarkable efficiency and low resource requirements. The way forward is to strike a balance between innovation and pragmatism, ensuring that the protocol's advantages are not sacrificed for the sake of compatibility. As the industrial sector continues its digital transformation, resolving these integration challenges will be essential to unlocking the full potential of MQTT in smart manufacturing environments.

Conclusions and recommendations

The industrial sector is increasingly recognising MQTT as the protocol of choice for IoT implementations, offering an optimal balance between technical efficiency and cost-effectiveness, particularly in remote maintenance scenarios. However, its widespread adoption requires consideration of several critical success factors that go beyond simple technical implementation.

Security is the cornerstone of any successful MQTT deployment in an industrial environment. The implementation of robust TLS encryption combined with rigorous authentication protocols creates an essential security foundation for protecting sensitive operational data. These measures become particularly crucial when dealing with critical infrastructure where data integrity and confidentiality are paramount.

The human element of the equation is equally important. Organisations must prioritise the development of internal expertise through comprehensive training programmes covering the entire spectrum of MQTT operations, from initial installation and configuration to advanced troubleshooting and optimisation. This investment in knowledge pays off in terms of smoother deployments and more efficient long-term maintenance.

For industrial environments with limited resources, MQTT's lightweight architecture offers distinct advantages, particularly when integrated with user-friendly platforms such as Node-RED. This combination simplifies monitoring and control while maintaining the protocol's inherent efficiency. This pairing creates an accessible entry point for organisations transitioning to smart factory concepts without requiring a massive overhaul of their infrastructure.

In the future, the convergence of MQTT with emerging technologies such as artificial intelligence and edge computing promises to unlock new capabilities. These synergies could lead to more autonomous and self-optimising systems capable of predictive maintenance and real-time process adjustments. Such advances would further enhance the resilience and intelligence of industrial IoT networks while retaining the protocol's fundamental advantages in terms of simplicity and efficiency. The future of industrial automation appears increasingly tied to the evolution of MQTT, offering exciting possibilities for those willing to harness its potential.

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Assessing language model performance in biomedical question-answering: A case study using the langchain framework on the CliCR Dataset

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Abstract
This paper focuses on developing and implementing a biomedical question-answering (BQA) system using large language models (LLMs) and the CliCR dataset, in combination with the LangChain framework. The study evaluates several models, including GPT-3.5, GPT-4, LLAMA3, and Mistral, in handling clinical questions. Key methodologies include data preparation, prompt engineering, and model adaptation. The evaluation employs metrics such as precision, recall, F1-score, BLEU scores, and embedding-based metrics. Results show that using the entire case context significantly outperforms chunking and vector store indexing methods. Notably, GPT-4 achieved an exact match score of 44.7%, surpassing human experts. Although fine-tuning improves domain-specific performance, there's a risk of overfitting. This research adds to the progress in BQA systems with possible benefits for clinical decision- making and medical education.

Keywords: *Biomedical Question-Answering; CliCR; Evaluation; Large Language Models; LangChain; Prompt Engineering; RAG; Vector Database; Chunking*

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Biyomedikal soru-cevaplamada dil modeli performansının değerlendirilmesi: CliCR veri seti üzerinde langchain çatısı kullanılarak bir vaka çalışması

Özet

Bu makale, LangChain çatısı ile birlikte büyük dil modellerini (BDM'ler) ve CliCR veri setini kullanarak bir biyomedikal soru-cevaplama (BSO) sistemi geliştirmeye ve uygulamaya odaklanmaktadır. Çalışma, GPT-3.5, GPT-4, LLAMA3 ve Mistral dahil olmak üzere çeşitli modellerin klinik soruları ele alma performansını değerlendirmektedir. Temel metodolojiler arasında veri hazırlama, komut mühendisliği (prompt engineering) ve model adaptasyonu yer almaktadır. Değerlendirmede kesinlik (precision), duyarlılık (recall), F1 skoru, BLEU skorları ve gömme (embedding) tabanlı metrikler gibi ölçütler kullanılmaktadır. Sonuçlar, vaka bağlamının tamamını kullanmanın, parçalara ayırma (chunking) ve vektör deposu indeksleme yöntemlerine göre önemli ölçüde daha iyi performans gösterdiğini ortaya koymaktadır. Dikkat çekici bir şekilde, GPT-4, %44,7'lik bir tam eşleşme skoru elde ederek insan uzmanları geride bırakmıştır. İnce ayar (fine-tuning) alana özgü performansı artırsa da, aşırı öğrenme (overfitting) riski taşımaktadır. Bu araştırma, klinik karar verme ve tıp eğitimi için potansiyel faydalar sunarak BSO sistemlerindeki ilerlemelere katkıda bulunmaktadır.

Anahtar Kelimeler: *Biyomedikal Soru-Cevap; CliCR; Değerlendirme; Büyük Dil Modelleri; İstem mühendisliği, RAG; Vektör Veritabanı; Parçalama*

Introduction

The developments in large language models (LLM), such as GPT-3.5, GPT-4 (Achiam et al., 2024), and LLAMA (Touvron et al., 2023), have considerably affected the domains of natural language processing (NLP) and artificial intelligence (AI). These models can comprehend and produce human language, rendering them useful for biomedical applications. Almanac (Hiesinger et al., 2023) exhibited the possible biomedical uses of LLMs in question-answering tasks, assisting clinicians, researchers, and patients in procuring credible and timely information. BQA systems are proving to be a promising potential in answering complex clinical questions automatically, thus assisting in clinical decision-making, medical education, and research (Jin et al., 2021).

But, despite the presented potential, AMMU (Kalyan et al., 2021) shed light on some of the challenges that remained unsolved. A primary issue with BQA is the understanding and reasoning over the medical contexts, which involve technical terminology and complex relationships among medical entities. Current language models may struggle with these nuances and vocabularies, leading to inaccurate or incomplete answers (Jin et al., 2021). It is shown that fine tuning LLMs on extract domain-specific datasets improves the model's performance, but it has the disadvantage of easily overfitting and losing generalizability in low-resource domains (Gu et al., 2020), which remains a challenge. Duong and Solomon (2023) found that although GPT had nearly human-like performance on the memorization questions, it scored poorly on critical thinking questions. Lee et al. (2023) crafted a privacy-preserving LLM for automated data extraction with very good concordance to human reviewer gold standard, demonstrating both the potential and limitations of LLMs in biomedical contexts.

To address these challenges, our study explores the development of an advanced BQA system utilizing the latest developments of LLMs on the CliCR dataset (Suster & Daelemans, 2018), leveraging the LangChain framework . The methodology employed involves extensive data preparation, prompt engineering, and model adaptation using LangChain's APIs and tools, followed by measuring the results using multiple carefully designed evaluation metrics including precision, recall, F1-score, BLEU scores, and embedding-based metrics. The advantage of this approach lies in exploring and measuring different prompting techniques that both utilize full context windows and supporting vector stores, in combination with

sophisticated prompt engineering practices, enhancing the understanding and generation of accurate and relevant answers to biomedical queries. This research aims to advance the integration of LLMs in BQA systems, contributing to improved clinical decision-making and medical education.

To address these challenges, this study makes several key contributions:

- Adoption of State-of-the-Art LLMs: Using frontier large language models (LLMs), like GPT-3.5, GPT-4, LLAMA3, and Mistral, this study aims to enhance biomedical question answering (BQA) systems. By incorporating these advanced models, we hope to improve the performance of the BQA system.
- Comprehensive Evaluation Across Multiple Models: Performance comparison of closed, open, and fine-tuned LLMs on CliCR dataset which will help us emphasize strengths andlimitations of models to boost the accuracy and reliability of BQA systems.
- Prompt Engineering and Context Utilization: Explore different prompt engineering and context retrieval techniques when evaluating LLMs performance within the BQA field, which builds upon the work of evaluating different approaches for applying LLMs in the biomedical field.
- Fine-tuning and Domain Adaptation: Finally, explore whether fine-tuning LLMs on domain specific data will improve the understanding and QA skills when dealing with medical cases. Previous work has showcased LLMs performance improvements in the biomedical field when fine-tuning on biomedical datasets (Gu et al., 2020; Tinn et al., 2021).

Through these contributions, the study aims to test, evaluate, and experiment with different technologies and techniques to help advance biomedical question-answering systems using the latest LLMs advancements. The work has been conducted through building a modular framework for efficient experimentations and evaluation of different prompts and retrieval techniques.

Literature review

The usage of LLMs in the biomedical space has generated considerable research interest. During our work, we reviewed recent studies and explored the performance and challenges of utilizing LLMs in the biomedical domain, while also looking at future insights.

-Performance evaluation
A case study has been run to assess the performance of LLMs in varying biomedical tasks. In genetics question answering, GPT was compared against a human to find that GPT was able to match human performance for factual recall but did not perform as well on critical thinking questions (Duong & Solomon, 2023). An evaluation of privacy-preserving LLMs for the automated data extraction of thyroid cancer pathology reports demonstrated that the model performed at the level of human reviewers, suggesting LLMs could be deployed for clinical data processing while safeguarding patient information (Lee et al., 2023). LLMs were tested against a neurologic board- style exam wherein the newer versions scored better than the average human, especially in behavioral, cognitive, and psychiatric domains (Schubert et al., 2023). Comparative scurrying of the ChatGPT-3.5, Google Bard, and Microsoft Bing on hematology cases found ChatGPT able to outperform the others in managing complex medical queries (Kumari et al., 2023).

-Challenges and limitations
LLMs face several challenges in biomedical applications. One study identified issues such as inconsistency and inaccuracy in LLM responses to pathology board exams, emphasizing the need for ongoing model refinement and human oversight (Koga, 2023). It was also found that GPT's performance in clinical diagnosis declined without detailed narrative context, highlighting the importance of comprehensive input for accurate diagnostic reasoning (Reese et al., 2023).

Furthermore, bias amplification has been revealed in LLMs, particularly in clinical phenotyping, where models tended to underdiagnose certain subpopulations, raising concerns about equitable healthcare applications (Pal et al., 2023).

-Innovative Applications
LLMs have shown potential beyond traditional question-answering tasks. An evaluation of GPT-4V on challenging medical cases involving both text and images showed that the model outperformed human respondents, suggesting multimodal AI could enhance medical diagnostic reasoning (Buckley et al., 2023). In biostatistics, ChatGPT demonstrated an ability to guide analyses of NHANES data, making complex statistical methods more accessible to non-experts (Titus, 2023).

LLMs have also been assessed in radiation oncology physics, where ChatGPT-4 performed on par with medical physicists, indicating a potential for these models to act as knowledgeable assistants in specialized fields (Holmes et al., 2023).

-Datasets and Methodologies

Developing sophisticated BQA systems depends on a knowledge of the current research landscape, which includes studying datasets and evaluation techniques. CliCR is a dataset introduced for machine comprehension in the medical domain, based on clinical case reports and consisting of about 100,000 gap-filling questions (Suster & Daelemans, 2018). This survey of BQA looks at the different approaches and challenges, noting that there is little real-world usage due to its immaturity (Jin et al., 2021). The other survey was on transformer-based biomedical pretrained language models (BPLMs) addressing their pre-training, tasks, and fine-tuning (Kalyan et al., 2021). Another survey looks into the advances in task-related domain-specific datasets, placing emphasis on the improvement of the accuracy of biomedical QA systems (Wang, 2022).

-Privacy and Ethical Considerations

Using LLMs in biomedical scenarios therefore raises privacy and ethical issues. The LLMs can, however, be used in clinical settings provided thorough anonymization of records is ensured so as not to comprise patient privacy (Lee et al., 2023). They have also looked at employing LLMs to answer routine patient questions regarding post-operative care, emphasizing the need for safety mechanisms and ethical guidelines to support responsible use in healthcare (Chowdhury et al., 2023).

-Future Directions

Integrating LLM-powered autonomous agents in simulated environments offers a new way to improve the learning and adaptability of medical agents. The simulation of hospital environments allows autonomous agents to learn and practice medical procedures, accumulating experience and refining their decision-making in a risk-free setting. Future work should look into developing such simulacra to provide continuous learning, potentially utilizing evolutionary learning techniques to create more robust and accurate BQA systems (Li et al., 2024).

Table 1.Comparative analysis of previous works.

Study	Objective	Model Used	Key Findings	Technical Depth
Duong and Solomon (2023)	Evaluate ChatGPT vs. human respondents on genetics questions	ChatGPT	ChatGPT performed well on memorization but struggled with critical thinking questions	Comparison with human performance, identification of strengths and weaknesses in critical reasoning
Lee et al. (2023)	Develop privacy- preserving LLM for data extraction from pathology	Custom LLM	High concordance rates with human reviewers, maintained patient privacy	Custom LLM development,focus on privacy- preserving techniques, application in clinical data extraction
Schubert et al. (2023)	Assess LLMs on neurology board-style examinations	Various LLMs	Newer LLMs outperformed human averages, particularly in behavioral and cognitive questions	Evaluation across multiple LLMs, detailed analysis of performance in specific medical fields
Kumari et al. (2023)	Compare ChatGPT-3.5, Google Bard, and Microsoft Bing on hematology	ChatGPT-3.5, Google Gemini, Bing	ChatGPT outperformed other models in handling complex medical queries	Comparative analysis of multiple models with focus on complex medical cases
Koga (2023)	Explore pitfalls of LLMs in pathology board examinations	GPT-4	Identified issues like inconsistency and inaccuracy in responses	Identification of LLM limitations, emphasis on the need for model refinement and human oversight
Reese et al. (2023)	Evaluate limitations of GPT-4 in clinical diag- nosis	GPT-4	Performance dropped without detailed narrative context	Analysis of context importance in clini- cal diagnosis, evalua- tion of model limita- tions
Pal et al. (2023)	Study bias amplification in LLMs in clinical phenotyping	Various LLMs	LLMs underdiagnosed certain subpopulations	Examination of bias inLLMs, impact on equitable healthcare applications

Buckley et al. (2023)	Evaluate GPT-4V on text and image-based medical cases	GPT-4V	GPT-4V outperformed humans in multimodal medical diagnostic reasoning	Integration of text and image data, multimodal evaluation, performance comparison with humans
Titus (2023)	Use ChatGPT in biostatistics for analyzing NHANES data	ChatGPT	Simplified complex data analysis, made statistical methods accessible to non- experts	Application in biostatistics, focus on accessibility and simplification of complex analyses
Holmes et al. (2023)	Assess LLMs in radiation oncology physics	ChatGPT-4	ChatGPT-4 performed comparably to medical physicists	Evaluation in a specialized medical field, comparison with professional performance
Suster and Daelemans (2018)	Introduce CliCR dataset for machine comprehension in medical domain	Custom dataset	Dataset comprises 100,000 gap-filling queries from clinical case reports	Creation of a domain- specific dataset, focus on machine compre- hension in the medical field
Jin et al. (2021)	Survey of BQA approaches and challenges	Various approaches	Identified underutilization in real-life settings due to system immaturity	Comprehensive survey, categorization of BQA approaches, identification of practical challenges
Kalyan et al. (2021)	Survey of transformer- based biomedical pretrained language models	Various BPLMs	Highlighted significance of BPLMs in NLP for biomedical domain	Detailed survey of transformer- based models, discussion of pre training methods, tasks, and fine- tuning techniques
Wang et al. (2022)	Understand domain- specific datasets for BQA	Various datasets	Emphasized the importance of specialized data for improving accuracy and relevance	Analysis of domain specific datasets, focus on the impact of specialized data on BQA performance

Li et al. (2024)	Explore use of autonomous agents in simulated hospital environments	Autonomous agents, LLMs	Agents learned and practiced medical procedures, improving decision-making processes	Simulation of hospital environments for agent training, evolutionary learning approaches in medical decision making

Methodology, materials and methods

We use recent large language models and NLP tools with the LangChain framework to build a Biomedical Question Answering evaluation system. The process is broken down into 3 stages: data, model and evaluation. Figure 1 provides a comprehensive overview of this process, with key steps outlined:

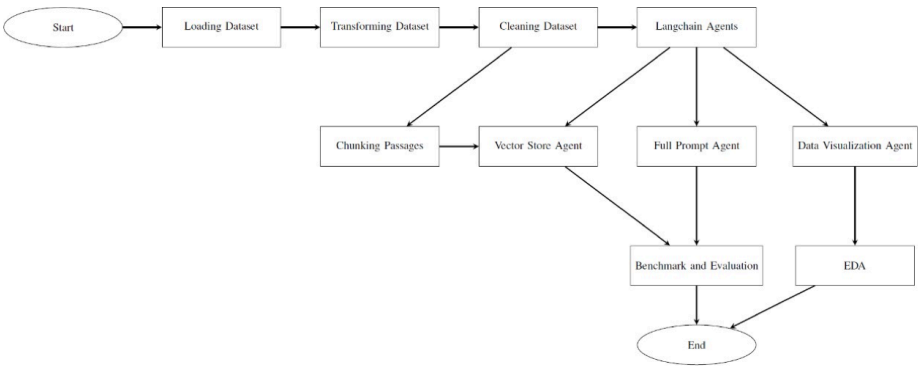

Figure 1. LangChain agents pipeline

- Data Preparation

In the initial phase, CliCR dataset has been processed to ensure compatibility with various large language models. The main steps include:

A. Data transformation: This involves tasks such as loading the dataset, restructuring it, cleaning, vectorizing, and performing various text processing tasks. These tasks vary based on the chosen prompting strategy (discussed in the next step) and the specific model being adapted.

B. Handling Long Passages: With an average passage length of approximately 1,466 tokens, the dataset fits within the context windows of most large language models. However, some passages exceed the

maximum context window of many local LLMs running on constrained environments, necessitating strategies to split the content into smaller, manageable chunks, potentially using a sliding window technique.

C. Prompt engineering: The dataset is designed to impose restrictions on the predicted answer format. In this step, the most effective prompt likely to yield the correct answer has been engineered. Various versions of the prompt have been tested to align with the capabilities of the selected LLM.

- Model Adaptation with LangChain

Since the advancement of local and open LLMs has skyrocketed in the past few months, both the famous GPT model, which is a state-of-the-art closed large language model including its different versions, and state of the art open and local models like LLAMA3, Mistral, and Command-R have been employed to compare their performance. They have been adapted to the dataset by exploring multiple methods and prompts. To ensure the work remains LLM agnostic, an open-source generative language framework called LangChain has been utilized. LangChain provides a user- friendly interface for integrating LLM functionalities, enabling effortless switching between different LLMs, data storage solutions, and transformation tools. This flexibility allows the same processes to be applied across various LLMs and storage engines without significant modifications.

-Evaluation

The system's performance is assessed using various evaluation methods based on the original dataset creator's work. These benchmarks include exact match (EM), F1 score, BLEU scores (B-2 and B-4), and an embedding-based metric (E-avg) Table 2. We compare the results with the findings mentioned in the original dataset paper and also indicate future directions for our work.

-Large language models

This study evaluates the following LLMs:

- GPT (Generative Pre-trained Transformer): GPT-4 by OpenAI has a transformer architecture and was trained on many datasets and refined with reinforcement learning from human feedback (RLHF). It shows superior performance over GPT-3.5 on various standardized exams and in natural language understanding and generation (Achiam et al., 2024)

- LLAMA3: The LLaMA models from MetaAI range from 7B to 65B parameters. They use RMS normalization, SwiGLU activation functions, rotary positional embeddings, and an AdamW optimizer (Touvron et al., 2023). The original LLaMA has fewer parameters than GPT-3 and yet beats it on multiple benchmarks.
- Mistral: Mistral 7B is a high-efficiency 7-billion-parameter model that incorporates grouped-query attention and sliding window attention. It is optimized for reduced memory usage and enhanced speed, outperforming LLaMA 2 13B in benchmarks such as reasoning, math, and code generation (Jiang et al., 2023).
- Cohere's Aya: This is a multilingual, instruction-finetuned model covering 101 languages. Built on mT5 with 13B parameters, it was trained using the xP3x and Aya Collection datasets and is evaluated with a comprehensive suite for generative and discriminative tasks (Üstün et al., 2024).

Table 2. Description of evaluation metrics

Metric	Description	Equation
Exact Match (EM)	Measures the percentage of instances where the predicted answer exactly matches the ground truth answer.	$\text{EM} = \frac{1}{N}\sum_{i=1}^{N} \text{I}(A_i = P_i)$ where A_i is the actual answer, P_i is the predicted answer, and I is the indicator function.
F1 Score	Captures the overlap between the predicted and ground truth answers. It is the harmonic mean of precision and recall.	$\text{F1} = 2 \cdot \frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}$ $\text{Precision} = \frac{TP}{TP+FP}$ $\text{Recall} = \frac{TP}{TP+FN}$ TP = True Positives, FP = False Positives, FN = False Negatives.
BLEU-2	Assesses token contiguity up to 2-grams. It is a popular metric for machine translation that measures the similarity between the predicted sequence and the ground truth.	$\text{BLEU} = \text{BP} \cdot \exp\left(\sum_{n=1}^{2} w_n \log p_n\right)$ For BLEU-2, $N = 2$, where p_n is the precision of n-grams and w_n are the weights. $\text{BP} = \begin{cases} 1 & \text{if } c > r \\ e^{(1-\frac{r}{c})} & \text{if } c \leq r \end{cases}$ c is the length of the candidate translation and r is the length of the reference translation.
BLEU-4	Similar to BLEU-2, but assesses token contiguity up to 4-grams.	$\text{BLEU} = \text{BP} \cdot \exp\left(\sum_{n=1}^{4} w_n \log p_n\right)$ For BLEU-4, $N = 4$. The brevity penalty BP is calculated as in BLEU-2.

Embedding-based (E-avg) Score	Measures semantic relatedness between the predicted and ground truth answers by comparing their vector embeddings.	$\text{E-avg} = \frac{1}{N}\sum_{i=1}^{N}\cos(E_{A_i}, E_{P_i})$ where E_{A_i} is the embedding of the actual answer, E_{P_i} is the embedding of the predicted answer, and cos is the cosine similarity.

The integration of these LLMs within LangChain framework enables the development and testing of reusable BQA systems capable of providing accurate and reliable information for clinical queries while allowing easy model swapping when necessary.

The following models' weights have been chosen to evaluate:
- Closed - GPT-3.5
- Closed - GPT-4o
- Open - LLAMA3 7B
- Open - Mistral 7B
- Open - Cohere's Aya 8B

All open models have been evaluated using 4-bit quantization and were running locally on a GeForce 3070-ti GPU. The work outlined the possibility of having these locally running, small, and powerful LLMs running locally on consumer hardware without the need for deploying these models in centralized infrastructure, which is both a more accessible and privacy compliant approach.

-CliCR dataset overview
CliCR dataset (Suster & Daelemans, 2018) was specially created for the medical machine reading comprehension task. Derived from about 12,000 BMJ Case Reports published between 2005 and 2016, it contains some 100,000 gap-filling queries. What makes this dataset special is its methodology of creation: medical entities appearing within the "Learning points" section of each report are masked, and these entities are considered as ground-truth answers to the queries.

The CliCR dataset features make it a strong benchmark. The passages themselves are varied and rich with linguistic details; providing on an average about 1,500 tokens of context for analysis. The answers consist mostly of medical terms that are multiword answer phrases, ranging from single words to long phrases, testing a model's proficiency in generating exact answers. Although this puts a challenge, especially when considering certain LLMs and their context window limitations, it serves as an excellent

dataset for evaluating and fine-tuning the models for genuine medical use cases.

Exploratory data analysis

In order to design methods best suited for this data, we carried an exploratory data analysis on the CliCR dataset. The main insights that we discovered during the analysis are going to contribute to the design of how we prompt LLMs during question answering, mainly:

A. Prompt Engineering: By understanding the variations in queries, we can design prompts that elicit accurate responses from our models.

B. Retrieval augmented generation (RAG): When we analyse the connections between search queries and specific sections of text, it helps us come up with methods to find the most relevant information.

We start by listing the key statistics in Table 3. This includes the total number of cases (11,846) and tokens in the passages (16,544,217 without recounting and 153,784,539 with recounting) so we can have an idea about the overall shape of the dataset.

- Answer Length Distribution: Figure 2 shows that most answers are between 1 to 5 words, 2 words being the most common. The dataset also has longer answers, some more than 20 words. So, we need to be able to instruct the models to generate short and limited answers without over-explaining, which is what they tend to do.
- Expression Variability: 56,093 unique answers, 288,211 with variations in expression. Which means we need to be able to generalize across different expressions of the same concept and have a rich vocabulary support.
- Common Answer Terms: Common terms like "treatment", "symptoms", "surgery", "MRI" in the case reports. This helps us define what medical knowledge the model needs to learn and apply and might help us when exploring medically fine-tuned LLMs.
- Answer Embedding in Passages: 58.94% of answers are embedded in the passages. That is a very important insight because it indicates that the LLM will need to understand the context to generate accurate answers in around 40% of the queries.
- Answer Retrieval: 88.67% of answers can be found in any passage in

the dataset. This affects how the LLM needs to generate new answers and requires it to be able to generate novel answers.

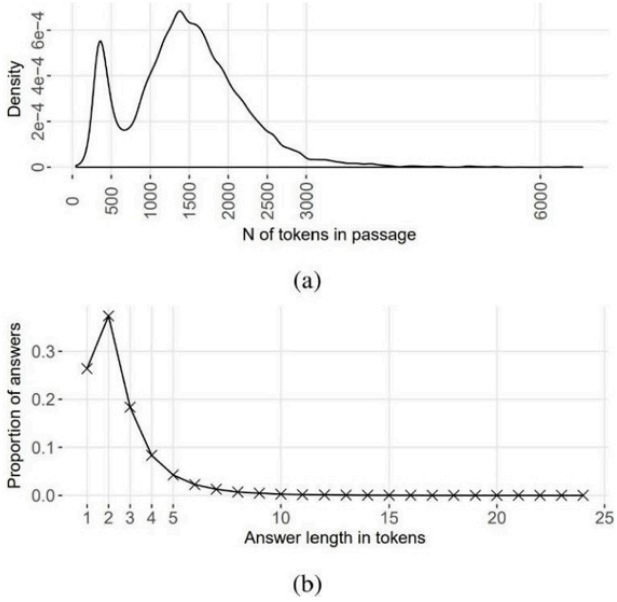

Figure 2. Distribution of answer lengths in the CliCR dataset

Table 3. Statistical overview of the CliCR dataset.

Data Statistics	
Number of cases	11,846
Number of queries	104,919
Total token count in passages without recounting	16,544,217
Total token count in passages with recounting	153,784,539
Average length of passages (tokens)	1,465.75
Number of unique word types in passages	112,673
Number of unique entity types in passages	591,960
Queries in the training set	91,344
Queries in the development set	6,391
Queries in the test set	7,184
Answer type: problem	%71.92
Answer type: treatment	%17.64
Answer type: test	%10.43

Results

We present our results after testing out different approaches on our question-answering system. We've explored prompt engineering, different LLMs, vector store indexing and fine-tuned models. We selected the best performing LLMs to date, both open and proprietary, to do a full comparison. We measured their performance, time and cost to see what each model can do and what the limitations are. This helped us figure out what's top performing during different setups.

To save on the compute resources, we limited the testing dataset to one question per case. This reduced inference time and cost while still giving us representative results, a balance between efficiency and accuracy.

First, we compared using a full case in the prompt with vector store indexing against the same LLM. The vector store indexing approach retrieved relevant case context chunks based on semantic similarity. We broke the dataset into smaller semantically related chunks and indexed them to fetch the most relevant chunks for each query during runtime. But this approach underperformed compared to the full prompt engineering approach, showing its limitation for this setup.

Table 4 shows us the results of the two approaches and how the full case approach performed better on all evaluation metrics. These results match up with the insights we got from the EDA step, when we identified that less than 60% of the answers are embedded within the case context. This led us to the conclusion that the LLMs will need more context to properly understand and generate the correct answer for the medical query.

Table 4. GPT3.5 full case/vector retrieval.

Method	EM	F1	BLEU-2	BLEU-4	E-avg
GPT-3.5 - Full Case	36.9%	53.1%	0.35	0.17	0.76
GPT-3.5 - Retrieval	23.9%	36.9%	0.19	0.07	0.68

When exploring fine-tuning possibilities, we evaluated the top open biomedical LLM called OpenBioLLM (paper to be released) using our established workflow. This model produced the most hallucinations and largely ignored our crafted prompts. This outcome suggests a huge loss in instruction-following capability and language understanding, likely due to overfitting on the medical dataset. Due to its extremely poor initial results, we excluded this model from further comparisons.

During evaluation, multiple prompts have been crafted, tested, and evaluated for both full case and the vector store cases respectively. Figure 3 showcases the top performing prompt, which as mentioned before was a full case prompt. The system prompt gives the LLM a medical expert personality, presents an example of a case format, and gives instructions on how to parse the coming cases. Then each case will be a simply formatted case as per the format presented in the system message. The human message (the case being tested) ends with an `=` symbol to instruct the model to give the final answer without trying to further explain the answer. This was needed as LLMs naturally tend to over-explain their answers.

```
system_message = """You are a medical expert.
I will give you a medical case and a queries about the case in the following format:

CASE:
case text.

QUERY:
query text with a `@placeholder` token in it.

The query have a `@placeholder` token in it. You must find the best answer that fits the placeholder
based on the case context and return the answer only.

You must only return the value of the @placeholder without the query or extra comments.
"""
human_message = """CASE:
{context}

QUERY:
{question}

RESPONSE:
Here is the most relevant answer in the context, @placeholder="""
input_variables = ["context", "question"]
```

Figure 3. Top performing prompt.

To ensure a proper assessment of performance, we ported the same evaluation metrics from the original dataset authors' work, as detailed in Table 2, while laying the groundwork for implementing more evaluation metrics.

Our results show that while vector store indexing is a way to get relevant information, full prompt engineering performed better on all evaluation benchmarks. This proves context is key and context engineering is essential for Q/A in biomedicine.

These results are useful for anyone looking to improve Q/A in biomedicine. They show you need to consider the needed context when asking medical questions and that certain approaches like chunking or fine tuning on too specific datasets have limitations in this domain.

Table 5. Evaluation Results

Method	EM	F1	BLEU-2	BLEU-4	E-avg	%
Human baseline						
Human Expert	35%	53.7%	**0.46**	0.23	0.67	100%
Human Novice	31%	45.1%	0.43	0.24	0.62	92.5%
Previous Work						
rand-entity	1.4%	5.1%	0.03	0.01	0.23	34.3%
maxfreq- entity	8.5%	12.6%	0.10	0.05	0.31	46.2%
sim-entity	20.8%	29.4%	0.22	0.15	0.45	67.1%
lang-model	2.1%	3.5%	0.00	0.00	0.30	44.7%
SA-Anonym	19.6%	27.2%	0.22	0.16	0.43	64.1%
SA-Ent	6.1%	11.4%	0.07	0.05	0.31	46.2%
GA-Anonym	24.5%	33.2%	0.28	0.20	0.48	71.6%
GA-Ent	22.2%	30.2%	0.25	0.18	0.46	68.6%
GA-NoEnt	14.9%	33.9%	0.21	0.11	0.51	76.1%
Our Work						
GPT-4o	**44.7%**	**60.9%**	0.43	**0.24**	**0.80**	**119.4%**
GPT-3.5	36.9%	53.1%	0.35	0.17	0.76	113.4%
AYA	34.3%	50.6%	0.42	0.27	0.70	104.4%
Mistral	20.8%	35.0%	0.22	0.11	0.64	95.5%
LLAMA3	17.1%	31.3%	0.12	0.05	0.61	91%

Limitations

While this study has demonstrated the promising capabilities of LLMs in the biomedical domain, it must be noted that the test was not without limitations. Our evaluation comprised a limited set of prominent LLMs and only contrasted a full-context approach with a standard vector-search retrieval method. The development in the AI is very fast and it might well be that other models or more sophisticated retrieval techniques yield different results. Additionally, based on our preliminary experiments on fine-tuning a biomedical LLM, we deemed that there might be issues with overfitting and a loss of instruction-following capability. There should thus be further investigations into methods for fine-tuning that create a good balance between domain-specific knowledge and general reasoning ability.

Furthermore, transferring a generic solution from research and adapting it to a custom solution in a real clinical use may impose practical constraints that must always be considered such as:

-Cost and Privacy
Proprietary models, such as the beloved GPT-4o, offer the highest performance but run only on external servers, which makes API costs a concern for patient data privacy and operational budgets.

-Accessibility and Infrastructure
Open-source models like AYA and LLAMA3 stand as strong alternatives since they can be running on local hardware, hence ensuring privacy and eliminating prohibitive long-term costs. There is, however, an upfront capital investment in computational infrastructure, and one must also deal with the short context window of any current locally run model, which becomes a bottleneck for very long clinical reports with hundreds of pages.

Finally, performance gaps detailed in Table 5 are observable. Notably, GPT-4o even scored above the human expert baseline. But to move beyond mere comparison and formally verify those results, the execution of a statistical significance test marks the very next step. For example, by applying a McNemar's test or bootstrapping test one could find out if the difference in performances. But due to limitation in accessing the results reported by original work we note this limitation.

Conclusion
In this study, we have developed and implemented a BQA system to measure the performance of different LLMs on the CliCR dataset. Despite some limitations, we presented some key observations out of our research. By having an extensible, model-agnostic framework with LangChain, we compared proprietary models such as GPT-4o with open-source ones such as LLAMA3, Aya, and Mistral.

A primary conclusion is that full context of an entire clinical case outperforms naïve chunking-based retrieval methods immensely. It brings to light the fact that when it comes to complex medical reasoning, often where answers are not given by implication, the whole context must be provided to the model to be able to respond properly. The combo of GPT-4o, landing at an EM score of 44.7%, which also outperformed human experts-on-ceiling, constitutes an indication that such systems can work in clinical workflows. On the other hand, the local model, Aya, gave another signal of another viable path toward private and secure clinical applications by nearly matching expert accuracy in performance.

Future work

Evaluation of methods for fine-tuning remains an interesting avenue for further investigation. Since initial results suggest little advantage was achieved by finetuned models, there could be more losses suffered in their general skills while overly fitted on the dataset they were fine-tuned upon, and hence it warrants a more thorough investigation. Thus, a complete evaluation of the fine-tuning approach and strategies would offer sound insight into its usability for a QA system.

In addition, the world of simulated training environments form important insights and directions for the further study of BQA systems (Li et al., 2024). Armed with simulated training environments, evolutionary learning methods, and comprehensive knowledge integration, future BQA systems may be refined and enhanced for increased accurateness and usefulness to clinical decision-making and medical education.

Finally, while our study showed that full context is performing better than the naïve RAG implementation evaluated in this study, it is notable that new and more advanced RAG techniques are emerging future research should focus on exploring these techniques on this and other medical datasets with even larger context windows.

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Traffic density estimation with IoT edge computing in smart city: a case study

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Abstract
In the digitalizing world, smart city management and applications have become an integral part of our lives in recent years. With the increase in innovative sensor-based devices, concepts such as smart environment, energy, transportation, healthcare, and traffic have emerged within smart cities, improving the quality of life for citizens through smart city management. This study focuses on the concept of smart transportation and traffic management, which is a subcategory of smart cities. The concept of traffic management in smart cities has advanced thanks to the integration of IoT (Internet of Things) and Edge Computing technologies. This system provides more realistic traffic density predictions. IoT devices, traffic sensors, cameras, and GPS-enabled devices collect real-time data such as traffic density, vehicle speeds, and road conditions in smart cities. In our study, we aim to predict hourly vehicle density for a specific day. A three-year dataset was utilized, consisting of 24-hour vehicle density data for each day of the year. Using time series algorithms, hourly vehicle density predictions were made for a future date. Algorithms such as ANN (Artificial Neural Network), KNN (K-Nearest Neighbors), LSTM (Long Short-Term Memory), Random Forest, Prophet, and XGBoost (Extreme Gradient Boosting) were employed for predictions. The error rates of the algorithms were analyzed to identify the most accurate prediction method. The vehicle density prediction data produced by this algorithm was considered the closest to reality. The results were discussed and evaluated in the final section of the article.

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Keywords: *Internet of Things; Edge Computing; Smart City; Traffic Density; Machine Learning*

Akıllı şehirde IoT uç bilişim ile trafik yoğunluğu tahmini: bir vaka çalışması

Özet

Dijitalleşen dünyada akıllı şehir yönetimi ve uygulamaları son yıllarda birçok alanda hayatımıza girmiştir. Üretilen inovatif sensör tabanlı cihazların artmasıyla birlikte akıllı şehirlerde akıllı çevre, enerji, ulaşım, sağlık, trafik gibi kavramlar ortaya çıkmış ve akıllı şehir yönetimi ile vatandaşların hayat kalitesi artmaya başlamıştır. Çalışmada akıllı şehirlerin alt başlığı olan akıllı ulaşım ve trafik yönetimi kavramına odaklanılmaktadır. Akıllı şehirlerde trafik yönetimi kavramı IoT (Nesnelerin İnterneti) ve Edge Computing (Uç Bilişim) teknolojisinin entegrasyonu sayesinde gelişme kaydetmektedir bu sistemle trafik yoğunluğu tahmini daha gerçekçi bir sonuç ortaya koymaktadır. IoT cihazları, trafik sensörleri, kameralar ve GPS destekli cihazlar aracılığıyla akıllı şehirlerde trafik yoğunluğu, araç hızları ve yol koşulları gibi eş zamanlı veriler toplamaktadır. Çalışmamızda belirli bir günde, bir saatlik araç yoğunluğu tahminlemesi hedeflenmiştir. 3 yıllık veri setinden yararlanılmış ve yılın her günü 24 saatlik araç yoğunluğu verileri kullanılmış olup, zaman serisi algoritmaları kullanılarak ileri bir tarih için saatlik araç yoğunluğu tahmini yapılmıştır. Zaman serisi analizlerinden ANN (Artificial Neural Network), KNN (K-Nearest Neighbors), LSTM (Long Short-Term Memory), Random Forest, Prophet, XGBoost (Extreme Gradient Boosting) gibi algoritmalar kullanılarak tahminleme yapılmıştır. Algoritmaların hata oranlarına incelenip en doğru tahmin hangi algoritma ile bulunduğu ortaya koyulmuş ve bu algoritmayla yapılan araç yoğunluğu tahmin verisi gerçeğe en yakın kabul edilmiştir. Çıkan sonuçlar makalenin son kısmında tartışılmış ve değerlendirilmiştir.

Anahtar Kelimeler: *Nesnelerin İnterneti, Uç Bilişim, Akıllı Şehirler, Trafik Yoğunluğu, Makine Öğrenmesi*

Introduction

Smart cities are modern urbanism that aims to make city life more efficient, sustainable and livable by using information and communication technologies. This concept aims to optimize the infrastructure and services of cities with the help of technology and to provide a better quality of life for city residents.

The concept of smart cities is defined by Zhao et al. as the application of urban modernization and the integration of information technologies in the process to promote the sustainability of cities and improve the well-being of citizens (Zhao, Su, Li, Zhu and Zhang, 2025).Smart cities aim to solve challenges through the integration of technology and innovative developments. Building a smart city means improving urban life, increasing resource efficiency and creating sustainable environments through the integration of advanced technologies and data-driven solutions (Karri, Machado,Tavares and Jain, 2024). Abu Rayash and Dinçer stated in their study that the transformation of homes and cities into smart ones with the development of technology has made the lives of citizens living in the city easier. They emphasized that smart transportation systems, which are one of the basic building blocks of smart cities, are of critical importance in increasing the quality of life of people living in big cities with traffic density management. The success of these systems largely depends on the accurate and instant collection and analysis of traffic density data. They state that in order for smart cities to be effective and sustainable, the collected data needs to be managed, sustainable solutions provided, and simultaneous data needs to be transferred to the system, and control and analysis needs to be provided (Abu-Rayash and Dinçer, 2025). Due to the increasing population due to migration in recent years, traffic density has increased significantly, which has a very negative impact on the daily lives of individuals. Many technologies and strategies continue to be developed to reduce traffic density problems and make transportation more efficient by making cities smart. By integrating traffic lights, sensors and cameras with real-time traffic data, vehicle flow is made more sustainable. Thanks to real-time data collection, information from mobile devices, GPS and traffic cameras is analyzed and alternative route suggestions are offered to drivers where there is no traffic congestion (Kheder and Mohammed, 2024).In public transportation systems, smart transportation vehicles are optimized and made more efficient, and it is planned to ease traffic by reducing the use of private vehicles. In addition, autonomous vehicles and

vehicle-vehicle and vehicle-infrastructure communication technologies contribute to safer and more relaxed traffic flow (Dahooie, Mohammadian, Qorbani and Daim, 2024). The introduction of artificial intelligence into our lives makes it possible to analyze past traffic data, predict future densities, and develop solutions for this situation. In addition, within the scope of sustainable transportation planning, bicycle paths and pedestrian paths are encouraged, and shared vehicle service applications and micro-mobility solutions are encouraged. Thanks to these systems, it not only relieves traffic congestion but also contributes to nature by reducing carbon emissions. In order for smart cities to work effectively, it is of great importance that both technological investments increase and users perceive how much these systems contribute to their lives (Idrissi, Lachgar and Hrimech, 2024). Urban mobility, which is one of the main components of smart cities, causes the problem of finding a parking space in parking lots and traffic congestion with the increase in the number of vehicles. Tekouabou et al. stated that vehicle drivers looking for parking spaces add 30% extra density to traffic density. In their study, they propose a system that also integrates the prediction model to solve this problem. The system aims to reduce traffic congestion by predicting the available parking spaces in parking lots for citizens in advance. In their tests on the Birmingham dataset, the Mean Absolute Error (MAE) was measured as 0.06% with the Bagging Regression (BR) algorithm. In addition, the complexity of the system has been significantly reduced (Tekouabou, Alaoui, Cherif and Silkan, 2022).

Traffic intersection signal optimization is one of the most important applications to be done to control traffic density in smart cities. With this system, reducing traffic density is of critical importance. In this direction, a smart city traffic intersection signal control optimization method has been examined with the adaptive artificial whale swarm algorithm. In order to understand the real situation of traffic flow, the traffic flow status system at the intersections has been designed. Signal control parameters, minimum average delay and number of stops have been designed as target functions and an optimization model has been created for signal control (Zhang, Jin, Chang and Huang, 2024). By combining with chaotic search theory, improving the artificial whale swarm algorithm, the smart city traffic intersection signal control optimization model was solved based on the adaptive artificial whale swarm algorithm and the smart intersection signal control optimization was realized. According to the study, the average

delay obtained with this method was found to be 7.8 ms, the number of stops was 2, and the travel time was 68.4 seconds. Thus, they proved that with the proposed method, they achieved good results for traffic signaling at smart intersections and thus could reduce traffic congestion (Wei and Ju, 2024). Every passing day, a new one is added to smart city management. In this case, it makes the lives of city residents easier and offers a comfortable life. Thanks to IoT and sensor-based tools, a new device is integrated into our lives every passing day. Researchers are also looking for how to make these devices more efficient and integrated into life (Doğaroğlu and Çalışkanelli, 2022).

Smart city management

Rapid population growth, unsafe lifestyle, waste of natural resources, indiscipline in human behaviours, urgent needs in the field of medicine, patient information security, and issues related to agriculture, and automation requirements in industries are the main reasons for inventing technologies. Smart cities aim to address these challenges through the integration of technology, data, and innovative applications. Building a smart city requires integrating advanced technologies and data-driven solutions to improve city life, increase resource efficiency, and create sustainable environments (Karri, Machado, Tavares, Jain, Dannana, Gottapu and Gandomi, 2024). In recent years, significant progress has been observed in the scope of smart city applications in developing countries, and municipalities are fulfilling their responsibilities in many areas, especially in transportation, energy, water and waste management (Figure 1). Within the scope of smart city management; smart transportation and traffic applications such as traffic density maps, smart parking applications, automatic passage systems, and electronic inspection systems, vehicle tracking systems, smart meter readings, and chip-equipped garbage containers are available (Khemakhem and Krichen, 2024). For example; within the scope of smart environment, solid waste facilities that produce electricity from methane gas, air quality monitoring systems, noise control and warning systems, excavation vehicle tracking systems, smart water network applications, solar lighting of stops, electric buses and solar-powered meteorological stations are also used in environmental smart management systems (Özcan, 2023). One of the most important problems in smart city management is waste management. The rapid increase in population in big cities has made this problem even more important. Waste management, thanks to smart sensors and IoT devices, ensures that the trash can is emptied when necessary according to waste

levels. This reduces the frequency of waste collection, creates unnecessary traffic congestion, and thus minimizes operational costs (Ahmed, Dubey, Kumar and Dubey, 2024). Technological advances have paved the way for the Internet of Things (IoT) concept to become widespread worldwide. Applications of IoT for smart cities are particularly effective in environmental and urban management. In smart cities, IoT devices are used to connect supply and demand information for smart homes and energy management in smart grids. However, power scheduling and information security transmission stand out as important problems in complex smart systems, but these problems can be solved with various machine learning techniques and data analytics methods (Awan, Khan, Rahmani, Tahir, Alam, Alturki and Ullah, 2020) .

IoT and edge computing

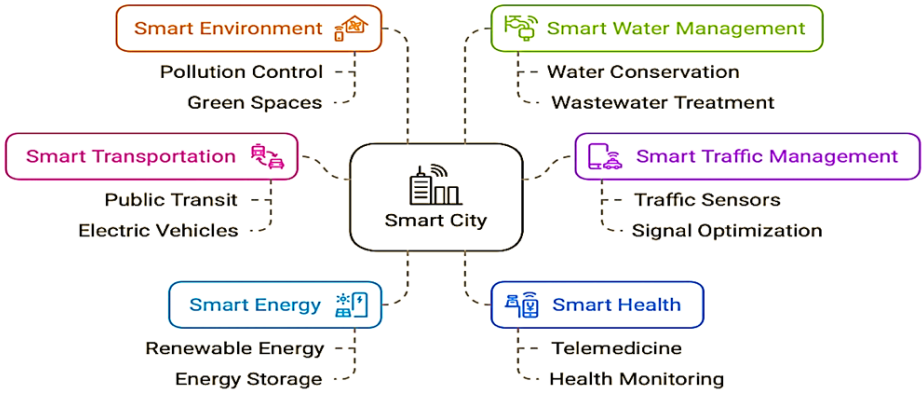

Figure 1: Smart city component

This structure contributes to the management of cities in a more efficient, sustainable way and in a way that increases the quality of life of citizens (Yalli, Hasan, Jung and. Al-Selwi, 2025). In recent years, with the widespread use of Internet of Things (IoT) devices in many areas, data production has also become very high. After this data is collected, it is transferred to the cloud computing system for analysis. However, due to the remoteness of the cloud nodes in the system, problems such as network congestion, data transfer delay and security arise. These problems are solved by processing at a point closer to the data sources thanks to edge computing, which offers alternative solutions. Edge computing is superior to IoT devices in terms of processing power, but it is more limited than cloud systems because tasks that require high processing power still

need to be directed to the cloud. At this point, the Autoencoder algorithm reduces the delay in data traffic. The Autoencoder algorithm is an artificial neural network algorithm that is one of the unsupervised learning methods and is generally used to reduce data size, make meaningful inferences from data or detect anomalies. Autoencoders try to reproduce the input (Azzalini, Flammini, Emanuele, Guadagno, Ragaini and Amigoni, 2025). It optimizes data transfer by compressing and encoding data with artificial neural network technique. In this way, it reduces the data flow between edge and cloud computing and reduces network congestion and latency problems (Tekin, Kakız and Çoban, 2021).

The Internet of Things (IoT) Architecture consists of four layers as seen in Figure 2 The first of these is the interface layer, the others are the service layer, the network layer and the perception layer, respectively. In the architecture (Figure 4), it is recommended to integrate the edge computing system between the network layer and the perception layer. In this section, it is recommended that the data be passed through the filter, processed and sent to the last layer before being sent to the perception layer.

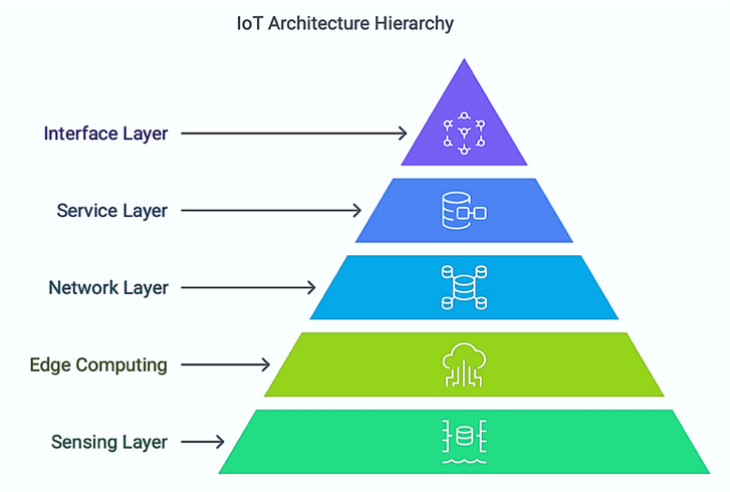

Figure 2: IoT basic architecture

The Interface Layer provides the integration between IoT devices and the application layer, allowing devices to communicate with each other and users. This layer manages device connections, monitors their status, and is responsible for security. It provides data transmission between devices through different protocols and APIs, remotely controls and monitors them. It manages data efficiently by ensuring compatibility between devices, but

it can also face challenges such as security and protocol diversity (Donta, Srirama, Amgoth and Annavarapu, 2022).

The Service Layer is a layer that provides functional services in the IoT system. This layer analyzes the collected data and derives meaningful results from this data. The service layer provides the infrastructure that various services such as data management, data analysis, data processing and decision making need to be performed. The layer usually works integrated with cloud computing or edge computing technologies and processes large data sets and transmits these results to users or applications (Arachchige, Murtaza, Cheng , Albahlal and Cheng-Chi, 2024).

The Network Layer is the layer that provides data transmission between IoT devices. This layer plays a role in the secure transmission of data by using network communication protocols that enable data exchange between sensors and devices. It allows devices to communicate with each other or with a central data processing unit (for example, cloud or edge computing) and generally uses wireless communication technologies such as Wi-Fi, ZigBee, 5G. The reliability of this layer is critical for the proper operation of IoT systems because devices cannot function effectively without data transmission and network connectivity (Alkhaldi, Darem and Alhashmi, 2024).

Edge Computing is the processing and analysis of data at a point close to the source, i.e. at the edge where IoT devices and sensors are located, before reaching the center. This approach allows data to be processed on local devices or networks before being sent to a central cloud server, thus reducing delays that may occur during data transmission and optimizing network bandwidth usage. Edge computing is important for real-time applications and IoT scenarios where latency should not be a problem. Moreover, processing data locally also offers advantages in terms of security and privacy, because sensitive data is analysed and stored locally without being carried on the network (Rajagopal and Buyya, 2025).

The Sensing Layer is the lowest layer in the IoT architecture and completes the task of collecting data from the physical environment. This layer includes devices such as sensors and actuators, detects environmental parameters (e.g. temperature, light, motion, humidity, pressure), and converts them into digital data. This layer is the foundation of IoT systems because other layers only act based on the data obtained from this layer.

The sensing layer is critical to the accuracy of sensors and data quality (Dui, Li , Dong and Wu, 2025).

Edge computing

Edge computing is a computing model that allows data to be processed at a point close to the source of the data before being sent to the center. In this method, data transmission delay is reduced by directly processing the data collected from the devices, bandwidth usage is optimized and faster response times are provided in real-time applications. Local processing of data both facilitates the protection of privacy and reduces the load on central servers, creating a more efficient computing infrastructure (Tran-Dang and Kim, 2025).

The Edge Computing architecture in Figure 3 reduces the dependency on central data centers by processing this data at a point close to the data source. In this way, data transmission delay is reduced, the load on the network is reduced, and real-time decision-making processes are accelerated. Especially in applications that require instant intervention such as traffic management, energy optimization, and emergency alerts, the use of Edge Computing creates a more efficient and secure smart city structure (Rahmani, Tanveer, Gharehchopogh, Rajabi and Hosseinzadeh, 2025).

With the integration of IoT and Edge Computing technologies, the closest estimate of traffic data to reality is provided. Before the data is sent to the point where it will be stored in the system, it means that the data is processed locally with edge computing systems close to the source, making it more real, complete, noiseless and easy to analyze. In addition, this local processing reduces data transmission latency and allows for real-time estimates with instant traffic density analysis. With these estimates, traffic density can be reduced or alternative routes can be suggested by optimizing traffic signals and controlling traffic flow. Real-time traffic density estimates made with this technology provide cities with a more sensitive and compatible transportation system, making cities smarter, more efficient and sustainable (Katsigiannis and Mykoniatis, 2024).

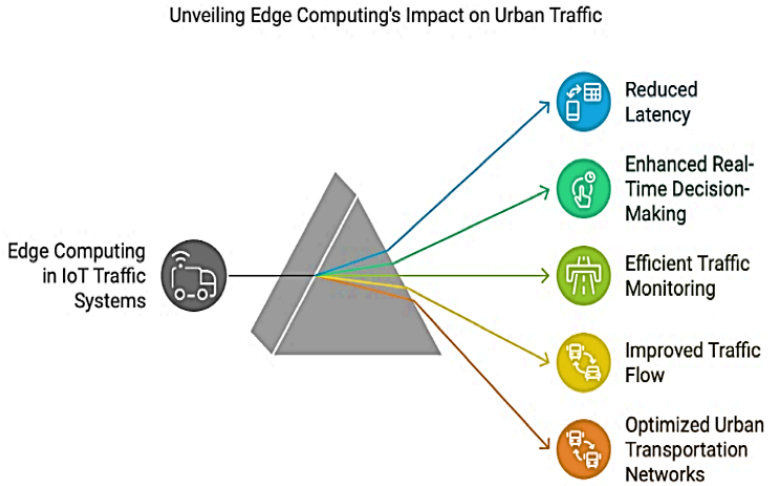

Figure 3: Edge computing

In their article, Kaya et al. define Edge Computing as a mechanism developed to overcome the limitations of cloud-based data processing in traditional IoT systems. The sensing layer is insufficient in traditional systems for high-performance data processing, and the physical distance of cloud technology creates a disadvantage in simultaneous data processing. With edge computing, data from sensors is processed at the closest point to the source, reducing latency and completing data processing with high performance. This system works in harmony with IoT layers and offers real-time solutions (Kaya, İşler, Mahfouz, Rasheed and AlShammari, 2023). Moura et al. mentioned that smart transportation systems in smart cities sometimes encounter communication delay problems in the real world, and therefore cybersecurity vulnerabilities related to real-time data processing and centralized data storage occur. In his study, he proposes an innovative architecture using Edge Computing and Distributed Ledger Technology (DLT) to solve these problems. Edge Computing is moving cloud services to units closer to data sources, such as moving edge computing to the roadside if vehicle data is stored. Thanks to this approach, delays and network congestion are reduced, and the DLT architecture ensures that this data is stored on a secure platform. The proposed architecture is to create a decentralized platform for data management and to ensure that data from sources in the transportation network is processed, stored and shared securely (Moura , Aquino and Loureiro, 2024).

Materials and methods

The aim of this study is to make predictions using time series algorithms for vehicle density prediction in smart traffic management and to examine the error rates of these algorithms and to determine which algorithms give the closest results to the truth. In the study, a data set consisting of four attributes such as date, time, number of data, and vehicle density is classified. Although the data obtained from Rtms (Remote Traffic Microwave Sensor) devices is processed, the received data stream is sent directly to the data storage center. As far as it is determined, there is no edge computing system in this type of system. In case there is a preprocessing layer that will undertake the edge computing task, the data will be more accurate, reliable and will contribute to the formation of more meaningful analyses in real time.

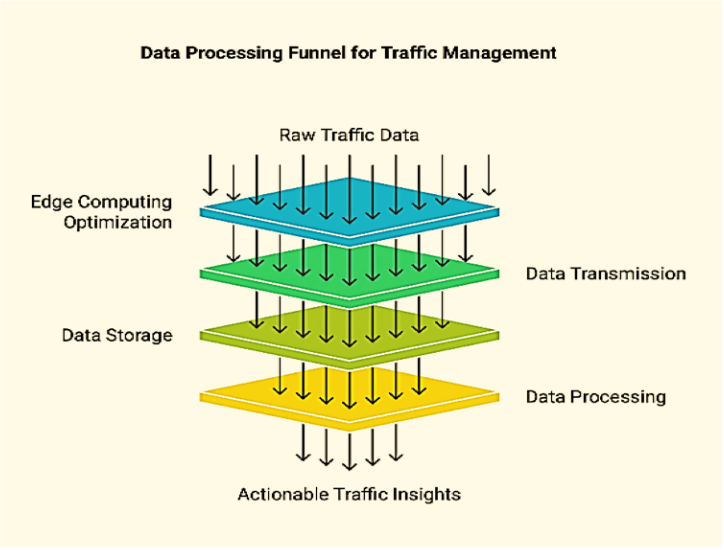

Figure 4: IoT layers and edge computing

Case study

In the study, a location with high traffic (Istanbul, July 15 Martyrs Bridge) was selected for vehicle density data and the dataset was obtained from data provided by the Istanbul Metropolitan Municipality through Rtms sensors at the bridge entrance was used. Vehicle density estimation will be made for a future date using the vehicle density (number) data of the years 2022, 2023 and 2024 (3-year data) at every hour of the day. There are 4 attributes in the study such as day, hour, number of data and number

of vehicles. According to the algorithms, some of the data was used as a training data set and some as a test data set in an optimum way.

Rtms (Remote traffic microwave sensor)

This device is a radar-based sensor system used to monitor and analyze traffic flow on the road in real time. It uses microwave radar signals to detect the number, class, speed and density of vehicles. It collects real-time data from multi-lane roads and transmits this data to management centers, allowing traffic flow to be monitored, signaling systems to be optimized and traffic volume to be reduced (Zhao, Tang, Gao and Zhu, 2018). It is widely used in smart city projects due to its features such as high accuracy and low maintenance cost. Rtms (Remote Traffic Microwave Sensor) is a radar-based sensing technology used in traffic monitoring and management (Figure 5). These sensors use a technology that emits microwaves to monitor the movement of vehicles and the flow of traffic. This technology (Figure 6) is effectively used for speed measurement, vehicle counting and traffic density.

Figure 5: Rtms sensor

Since system measurement is important, the angles must be adjusted correctly, therefore, situations such as sensor angle changes and obstructive foreign objects that cause sensor data to be inaccurate are tried to be prevented through periodic maintenance works carried out by the Traffic Branch Directorate (Yıldırım and Çataltepe, 2007).

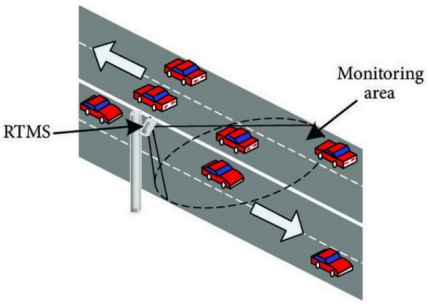

Figure 6: Rtms application area

The estimation models to be selected according to the structure of the data set are extremely important. For example, parametric models (such as Linear Regression) may be suitable for data with a normal distribution, while more flexible models (such as Random Forest) should be preferred for data with an unknown distribution (İlyas and Albayrak, 2023). Since time series analysis will be performed in this study, similar studies in the literature have been examined and the most commonly used algorithms in traffic density estimations have been used. With these algorithms, hourly vehicle count estimates will be made on a future date and the error rate of the algorithms will be compared with the accuracy. The obtained outputs are evaluated in the conclusion section of the study.

Dataset

The data set used in the study consists of 4 columns: day, hour, number of data, and number of vehicles. The data set consists of approximately 25,000 rows, 100,000 data, and is 190 kb in size. Although the training and test data sets differ according to the algorithms in the data, approximately 80% training and 20% test data were used in general for the algorithms. The raw data received was read using the Pandas Library in Python and transferred to the data frame. The "Number of data" column from the attributes in the data set expresses the number of hourly vehicles passing every 2 minutes. In other words, the number of hourly data is expected to be 30. However, it was observed that some of the data in the data set was missing. This number of missing data needs to be completed to 30. Because the missing number of data means that the "Number of Vehicles" data is also missing. The missing data was completed using the Pandas Library in Python. In addition, since the different scales of the attributes in the data set will negatively affect the performance of some algorithms, min-max normalization was applied to the data. And results closer to reality were obtained.

Simulation model

- In order to say that the number of data in the dataset is complete, the data count column must be 30, but some data counts are less than 30, which means that the vehicle count data is missing, so the data was filtered and the data count in Python was completed to 30, thus the vehicle count data column was completed.
- Real-time incoming data is received and processed simultaneously in the data flow shown in Figure 5. The Information Processing Directorate,

which uses this data flow as a source, stores the data sets and then the data is sent to the Traffic Branch Directorate for processing.

- There is no roadside edge computing system for traffic density data to determine whether the data generated from rtms sensors is abnormal or normal (Figure 7).If found, incomplete, erroneous, meaningless data will not be stored unnecessarily, and it is anticipated that it will not create additional storage costs allocated to the municipality budget.
- In the study, sensor data were generally used for training (optimally) at 70% and the remaining 30% for testing and prediction according to the algorithms.
- As can be expected, vehicle density in traffic is observed especially during work commute hours between 06:00 and 08:00 in the morning and between 18:00 and 19:00 in the evening.
- The data was first studied through algorithms without normalization, but results that were far from reality emerged. Later, since the data needed to be scaled within a certain range (usually between 0 and 1), min-max normalization was applied to the data set. And more successful results were obtained.

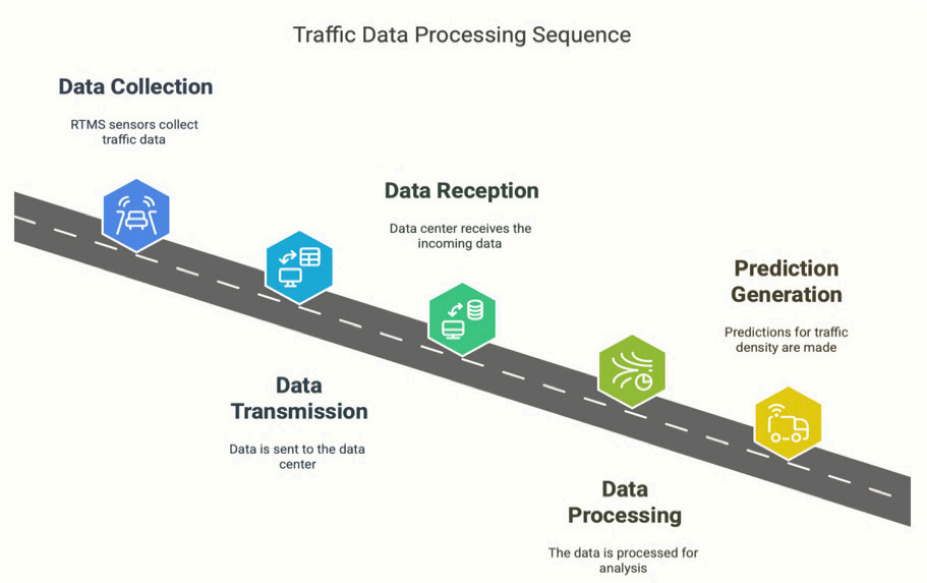

Figure 7: Simulation model

Experimental results

Classification reports

Classification reports are used to evaluate the classification performance of machine learning models and reveal metrics such as Precision, Recall, F1-Score and Support for each classification. This analysis is used to examine the accuracy estimates of the model and to determine the strengths and weaknesses of the algorithms. It provides a balanced evaluation of metrics, especially in imbalanced data sets, and is used to compare the performance of algorithms (Collado-Montañez, Martín-Valdivia and Martínez-Cámara, 2025).

Table 1: Ann classification reports results

Class	Ann classification reports			
	Precision	Recall	F1-score	Support
Accuracy	-	-	1.00	5001
Macro avg	1.00	1.00	1.00	5001
Weighted avg	1.00	1.00	1.00	5001

Since The Table 1 Ann classification report, precision, recall and F1-score: 1.00 are obtained, we can say that the model has made all its classifications correctly. The overall accuracy is calculated as 100%. Also, since the support value is 5001, the number of data can be said to be sufficient.

Table 2: Knn classification reports results

Class	Knn classification reports			
	Precision	Recall	F1-score	Support
0	0.51	1.00	0.68	2534
Accuracy	-	-	0.52	5001
Macro avg	0.75	0.51	0.36	5001
Weighted avg	0.74	0.52	0.37	5001

The Table 2 Knn classification report, precision 0.51, recall 1.00, the model caught all positive examples (high Recall), but some of its predictions were wrong (low Precision). F1-score 0.68 reflects the imbalance between Precision and Recall. Overall accuracy is 52%, meaning that more than half of the model's predictions were correct. Low values in Macro and Weighted Average metrics reveal the difference in performance and imbalance between classes. Parameter optimization may be required to improve the model's performance.

Table 3: Lstm classification reports results

Class	Lstm classification reports			
	Precision	Recall	F1-score	Support
0	1.00	1.00	1.00	25002
Accuracy	-	-	1.00	25002
Macro avg	1.00	1.00	1.00	25002
Weighted avg	1.00	1.00	1.00	25002

The Table 3 Lstm classification report shows that the model has excellent performance (Precision, Recall, F1-score: 1.00) and accuracy is 100%. The model seems to have made error-free predictions for all classes. If the realism of the performance is to be checked, the model should be tested again with new and different data sets.

Table 4: Prophet classification reports results

Class	Lstm classification reports			
	Precision	Recall	F1-score	Support
High	1.00	1.00	1.00	2
Accuracy	-	-	1.00	2
Macro avg	1.00	1.00	1.00	2
Weighted avg	1.00	1.00	1.00	2

Although In the Table 4 Prophet Classification Report states that the model has excellent classification performance (Precision, Recall, F1-score: 1.00) and the accuracy is 100%, the fact that the Support value is only 2 weakens the reliability of this assessment. Since the class examples in the data are very few, these results cannot be generalized and it is difficult to make a sound inference about the real performance of the model. It may need to be retested with a larger and more balanced dataset.

Table 5: Random forest classification reports results

Class	Xboost classification reports			
	Precision	Recall	F1-score	Support
Low	0.00	0.00	0.00	2
Middle	0.00	0.00	0.00	2
High	1.00	1.00	1.00	4163
Accuracy	-	-	1.00	4167
Macro avg	0.33	0.33	0.33	4167
Weighted avg	1.00	1.00	1.00	4167

The Table 5, Random Forest Classification Report shows that the performance of the model is quite unbalanced. While it has excellent results for the high class (Precision, Recall, F1-score: 1.00), all metrics for the low and medium classes are zero (Precision, Recall, F1-score: 0.00) and the number of class examples is very low (2). This shows that the model only correctly predicts the high class and ignores the other classes. As a result, although the overall accuracy is 100%, the classification ability of the model is unbalanced and it only correctly predicts a single class. In this case, the model may have overfitted due to data imbalance and needs improvement.

Table 6: X boost classification reports results

Class	Xboost classification reports			
	Precision	Recall	F1-score	Support
Low	0.00	0.00	0.00	2
Middle	0.00	0.00	0.00	2
High	1.00	1.00	1.00	4997
Accuracy	-	-	1.00	5001
Macro avg	0.33	0.33	0.33	5001
Weighted avg	1.00	1.00	1.00	5001

XGBoost Classification Report Table6, shows that the model predicts the high class perfectly (Precision, Recall, F1-score: 1.00), but all metrics for the low and medium classes are zero (Precision, Recall, F1-score: 0.00) and the number of examples for both classes is very low (2). This result shows that the model only focuses on the high class and cannot correctly classify the other low and medium classes. Although high accuracy (accuracy: 100%) is achieved, there is a situation where the classes produce imbalanced results and the model only learns the dominant class and ignores the others. Improvements may be needed to make this model perform more successfully and balancedly, and it is necessary to review the class imbalance.

Performance values

The studied algorithm performance results are presented below in the Table 7.

Table 7: Comparison of performance values

Algoritma	Mae	Mse	Rmse	R2	Cpu(sn)
Ann	0.5291	0.3582	0.5983	-3.6235	20.4647
Knn	0.2453	0.0771	0.2771	0.0032	30.9216
Lstm	0.2399	0.0747	0.2733	0.0287	16.5026
Random forest	0.0974	0.0202	0.1424	0.6023	621.983
Prophet	0.0604	0.0036	0.0604	-350	6.619
Xboost	0.0753	0.0093	0.0967	0.8147	0.4528

According to table 7, XGBoost gave the best results with the lowest error metrics (MAE: 0.0753, MSE: 0.0093, RMSE: 0.0967) and the highest R^2 value (0.8147), while it also worked quite efficiently in terms of CPU time (0.4528 seconds). Prophet drew attention with the lowest MAE (0.0604), while the R^2 value (-350) showed that the model failed to understand the data. While LSTM and KNN gave reasonable results, the ANN model exhibited low performance with high error metrics and negative R^2. Although Random Forest provided a good R^2 (0.6023), it was inefficient in terms of time with a CPU time of 621.983 seconds. In general, XGBoost stands out as the best algorithm in terms of error and performance balance. In addition, the Prophet model is a regression model, meaning it estimates continuous (numerical) values, so evaluation metrics such as confusion matrix and classification report may not be directly valid.

Confusion matrix

Confusion matrix is a tool used to measure and evaluate the performance of the classification model. It reveals the correct or incorrect predictions of the model. In the table values, it shows the correct and incorrect predictions made by the model for positive and negative classes with values such as True Positive (TP), True Negative (TN), False Positive (FP) and False Negative (FN). This matrix helps us understand in which classes the model is strong or weak by using the calculation of metrics such as Precision, Recall, and Accuracy (Yu and Do, 2024).

The Figure 8 also visualizes the performance of a classification model belonging to the Ann algorithm. According to the visual, all predictions were made correctly for the "Low" class (5001 correct predictions), but no predictions were made for the high class. This indicates that the model focused on only one class and did not consider the other classes. There

may be a class imbalance in the data or the model did not learn the classes well. Performance analysis should be done with a more balanced data set.

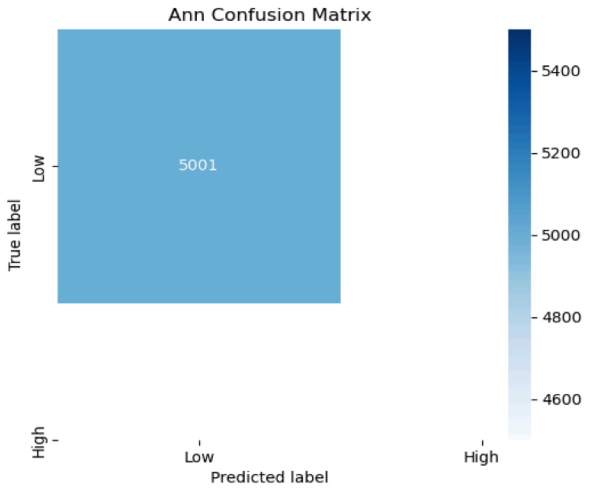

Figure 8: Ann confusion matrix

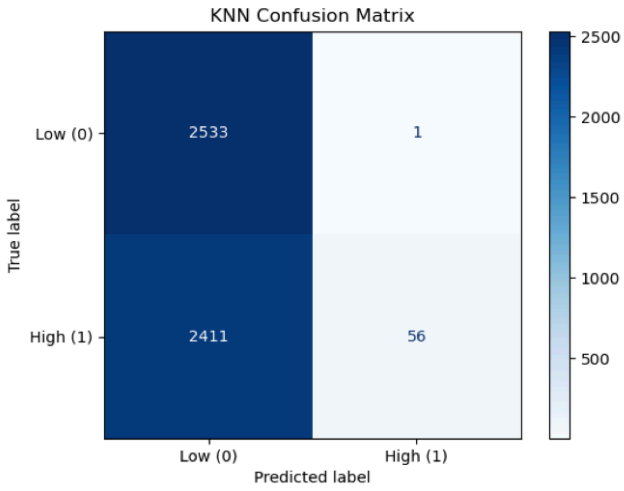

Figure 9: Knn confusion matrix

The Figure 10, Lstm algorithm shows the relationship between the model's actual number of vehicles and the estimated number of vehicles on the time axis. The blue line represents the actual values, and the orange line represents the model's estimated values. The graph shows that the model generally makes estimates close to the actual data, but there are deviations at some time intervals. This shows that the model's predictive performance

is generally consistent over time, but some points may need improvement. Additional features or different optimization methods can be tried to make the model more accurate.

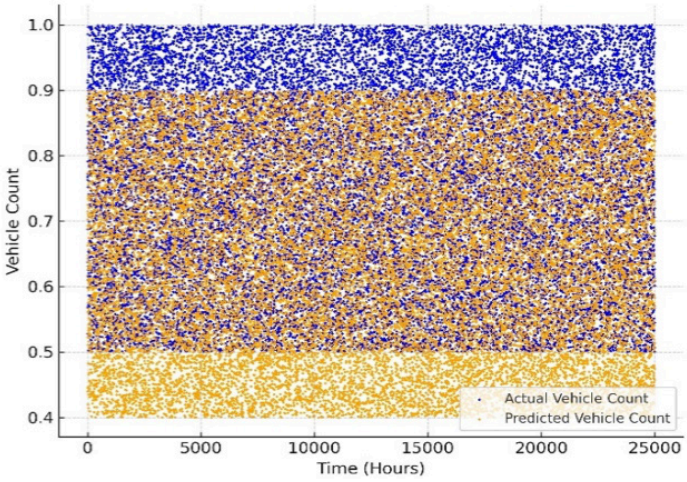

Figure 10: Lstm by time

In the Figure 11, Random Forest performance model, it made 2819 correct predictions and 384 incorrect predictions in the "High (1)" class, while it made 836 correct predictions and 128 incorrect predictions in the "Low (0)" class. In general, the model predicted the "High (1)" class more successfully, but there is room for improvement in false negatives (384).

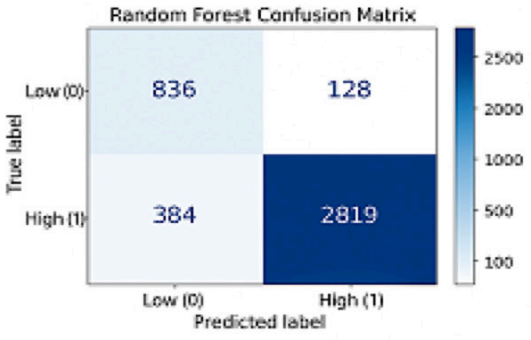

Figure 11: Random forest confusion matrix

The Figure 12, XGBoost model shows that it only correctly predicts the "Low" class (5001) and does not predict the "High" class at all. This indicates that the model may have focused on only one class due to an imbalanced dataset or an incorrect training process. Data imbalance issues

should be addressed and appropriate weighting or retraining methods should be used to improve model performance.

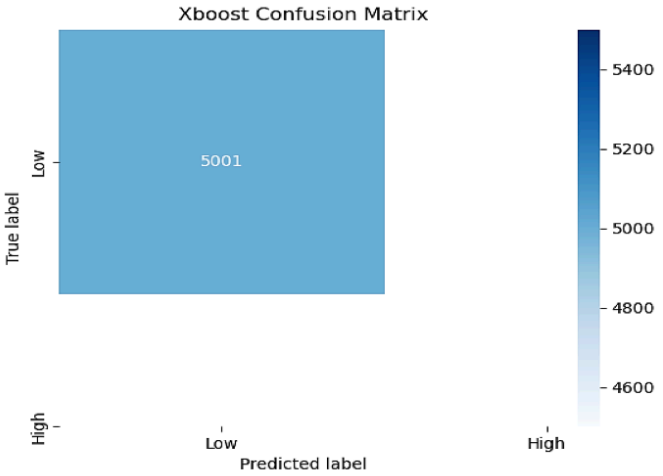

Figure 12: Ann confusion matrix

Discussion and conclusion

This study was prepared using machine learning methods to predict traffic density, analyze trends, and contribute to traffic management**.** Vehicle density in traffic may cease to be linear or predictable due to various factors (such as weather conditions, whether the academic term is in session or not, significant match days, and special occasions like holidays and festivals). In this study, the number of vehicles was predicted using the ANN, KNN, LSTM, Prophet, XGBoost, and Random Forest algorithms, aiming to determine vehicle density at specific days and times. In this way, it becomes possible to prevent traffic congestion, optimize signalization systems, and guide drivers to alternative routes.

In this context, the algorithms that produced the most successful results from the predicted values were identified. The Random Forest algorithm requires a long processing time, which is thought to be due to the model's complexity and its parameters. The ANN model, on the other hand, shows the weakest performance with high error rates and long training time. Among the best-performing models in terms of performance, the Prophet algorithm emerges (with the lowest MAE, MSE, RMSE); in short, if the model with the lowest error rate is preferred, Prophet can be considered. However, the data set should be reviewed with respect to the R^2 value. According to the analysis results, the best-performing models are Prophet

and XGBoost. As a result, if the speed and accuracy of the model are critical, XGBoost can be preferred. In terms of performance, XGBoost has been the best and fastest model (with high R^2 and low MSE).In Utku's study, which utilized Istanbul traffic data, a comparative analysis involving LR, RF, SVM, MLP, CNN, and RNN demonstrated that the LSTM-based model achieved superior performance. The model was reported to attain an R^2 value of approximately 0.9, indicating a high level of predictive accuracy. In contrast, our study evaluated ANN, KNN, LSTM, Prophet, XGBoost, and Random Forest algorithms, with the findings highlighting Prophet as the most effective in terms of low error rates, while XGBoost emerged as the most suitable in terms of both speed and accuracy. The divergence in results between these two studies can be attributed to differences in dataset characteristics, model parameters, and the target variables considered (vehicle count, speed, or density). Consequently, the prominence of tree-based methods and the time series–oriented Prophet model in one study, and the superior performance of the deep learning–based LSTM in the other, is consistent with expectations in the literature (Utku, 2023).

In İlyas and Albayrak's study conducted in Antalya, hourly vehicle count data from each approach lane of two selected smart intersections were utilized, and the data were divided into training and test sets to develop models based on Linear Regression, Polynomial Regression, Support Vector Regression (SVR), and Random Forest Regression. The performance of the models was compared using Mean Absolute Error (MAE) and R^2, and the Random Forest model was found to outperform the other models. In contrast, our study evaluated ANN, KNN, LSTM, Prophet, XGBoost, and Random Forest algorithms, with Prophet exhibiting the lowest error rates and XGBoost emerging as the most suitable model in terms of both speed and accuracy. These differing results can be attributed to the variety of algorithms employed, characteristics of the datasets, and the target variables predicted (vehicle count, speed, or density). Consequently, while the Antalya study is limited to classical regression methods, our study provides a more comprehensive analysis by integrating both time series and advanced machine learning techniques (İlyas and Albayrak, 2023).

In their study, Balcıoğlu and Sezen investigated the performance of different machine learning algorithms for traffic flow prediction on the E80 and E84 highways. The algorithms employed included LSTM, KNN-MLP, and SVR, with their performance evaluated using RMSE and accuracy

(Acc-%). The results revealed that the KNN-MLP model achieved the lowest RMSE and highest accuracy on both highways, outperforming the other approaches; LSTM ranked second, while SVR showed the weakest performance. The proposed KNN-MLP method enhances prediction by selecting spatiotemporally correlated routes through KNN and capturing hidden features and long-term dependencies with MLP. Tested on real traffic data provided by the Istanbul Metropolitan Municipality, the model demonstrated superior predictive capvirgülability compared to LSTM and SVR. Overall, the findings highlight the effectiveness of the KNN-MLP algorithm for traffic flow prediction and suggest that incorporating external factors such as weather conditions and special events could further improve its accuracy and reliability. More broadly, the study underscores the advantage of machine learning approaches over traditional methods in modeling the complex dynamics of traffic flow (Balcıoğlu and Sezen, 2024).

In conclusion, selecting the appropriate model according to the data type increases prediction accuracy. For time series data, developing specific models (ARIMA, LSTM) and investigating their predictive performance on larger and more complex datasets enable more accurate forecasting.

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Yazar Kılavuzu

Aşağıda belirtilen yayın ilkeleri ve yazım kurallarına uygun olarak hazırlanmış, yazılar, "makale sunum formu" ile birlikte e-posta yoluyla aşağıdaki adreslere gönderilebilir.

Çevirisi yapılmış, makalelerin değerlendirmeye alınabilmesi için özgün metinlerin ve makale sahibinden (asıl yazar veya hak sahibi yayınevi) izin yazılarının da gönderilmesi zorunludur.

Ön inceleme ve hakem değerlendirmesi doğrultusunda geliştirilmek ve/veya düzeltilmek üzere yazarlarına geri gönderilen yazılar, gerekli düzeltmeler yapılarak en geç, bir ay içinde tekrar dergiye ulaştırılır.

Yapılan ön incelemede yazım kurallarına uyulmadığı tespit edilen makaleler düzeltilmesi için yazarına iade edilir ve yayım programına alınmaz.

Yayın İlkeleri

1. Dergide yayımlanan makaleler yazı işlerinin izni olmaksızın başka hiçbir yerde yayımlanamaz veya bildiri olarak sunulamaz. Kısmen veya tamamen yayımlanan makaleler kaynak gösterilmeden hiçbir yerde kullanılamaz. Dergiye gönderilen makalelerin içerikleri özgün, daha önce herhangi bir yerde yayımlanmamış veya yayımlanmak üzere gönderilmemiş olmalıdır. Makaledeki yazarlar isim sırası konusunda fikir birliğine sahip olmalıdır.

2. ABMYO Dergisi'ne gönderilen yazılar, referans sistemi, dipnot gösterme biçimi ve kaynakça düzenlenmesinde American Psychological Association (APA) stilinde hazırlanmalıdır. APA'nın 6. baskısı, yazarların dikkate alacağı versiyonu olmalıdır. Bununla birlikte kaynakça düzenlenirken Türkçe'ye uyarlanmış ve APA'nın istisnası olan hususlar da bulunmaktadır. Türkçede gün ve ay içeren tarihler önce gün, sonra ay şeklinde (örneğin 12 Şubat) yazılmalıdır.

3. ABMYO Dergisi'nde yayımlanan makaleler yayın tarihinden itibaren

derginin bir sonraki sayısına kadar tartışmaya açık olacaktır. Makaleler için yapılan eleştiriler dergide yayınlanacaktır.

4. Makaleler en fazla 12 sayfa olmalıdır. Makaleler en az Word 6.0/95 formatında diskette veya CD'de teslim edilmeli ya da ABMYO Dergisi elektronik posta adresine gönderilmelidir. Orijinal olarak hazırlanmış makaleler % 20 oranında küçültülerek basılacaktır, bu nedenle şekil ve tablolar bu durum göz önünde bulundurularak hazırlanmalıdır. ABMYO Dergisi siyah beyaz basıldığından gönderilen makaledeki resim, fotoğraf, şekil ya da grafikler renkli olmamalıdır.

5. Dergide yayımlanmak üzere gönderilen yazıların, daha önce hiçbir yerde yayımlanmamış olması veya bir başka yayın organında değerlendirme aşamasında bulunmaması gerekmektedir.

6. Herhangi bir sempozyum, kongre, konferans vb. bilimsel etkinliklerde sunulmuş veya sunulacak olan bildiri metinleri, yayımlanmamış olması koşulu ile hakem değerlendirmesine gönderilir.

7. Dergi Yayın Kurulu, makaleleri, üç hakem gönderir. Makaleler, en az iki hakemin olumlu görüşüyle yayımlanır.

8. Yayımlanması için düzeltilmesine karar verilen yazıların, yazarları tarafından en geç (posta süresi de dahil olmak üzere) 30 gün içerisinde, yeniden Yayın Kuruluna gönderilmesi gerekir. Belirlenen sürede gönderilen makaleler bir sonraki dönemde yayımlanmak üzere sıraya konulur. Metin, değişiklikleri isteyen hakemler tarafından yeniden incelenebilir.

9. Hakem onayı alan makaleler, raporların tamamlanma tarihlerine göre sıraya konularak yayımlanır.

10. Dergiye gönderilecek yazılar, iki kopya alınarak hazırlanmalıdır. Bunlardan bir kopya posta yolu ile gönderilmeli; bir kopya ise; elektronik posta aracılığıyla iletilmelidir. Elektronik posta olarak gönderilen nüshada, yazar/yazarların adı soyadı, makalelerin tam adı, bağlı bulundukları kurum ve ünvanları, iş-cep telefonları ve elektronik posta adreslerini içeren bir kapak sayfası bulunmalıdır. Kapak sayfası, posta yolu ile gönderilecek kopyaya da eklenmelidir.

11. Yazarlar, yayınlarını İstanbul Aydın Üniversitesi Dergisine göndermekle, telif haklarını İstanbul Aydın Üniversitesine devretmiş sayılırlar.

12. Dergide yazısı yayımlanan yazarlara, iki adet dergi ücretsiz olarak gönderilir. Ayrıca telif hakkı ödenmez.

13. Ulusal ve uluslararası düzeyde akademik bilgi paylaşımının sağlanması amacıyla İstanbul Aydın Üniversitesi Dergisi'nde yayımlanmak üzere Hakem Kurulundan geçen yazılar Üniversitenin internet sitesine bağlı olarak da yayımlanabilir.

14. Dergiye gönderilen yazılar, yayımlanmasa dahi iade edilmez.

Yazım Kuralları

I. Makale Türleri

Dergiye gönderilen makaleler aşağıdaki özellikleri taşıyan çalışmalar olmalıdır:

-Özgün araştırmalarla ilgili çalışmalar,

-Uygulama örneklerini bilimsel bir yaklaşımla anlatan çalışmalar,

-Belirli bir konuda, önemli gelişmeleri değerlendirip eksiklikleri ortaya koyan derleme çalışmaları,

-Tez çalışmasından elde edilen sonuçların bilimsel tutarlılığı olan bir bölümünden ya da tümünden yararlanılarak hazırlanmış, doktora öğrencisinin ve tez danışmanının ortak yazar olarak yer aldığı bilimsel makaleler.

II. Sayfa Düzeni

Sayfa boyutu A4 kâğıt boyutunda olmalı, sayfa yapısında sağdan ve soldan 2 cm; üstten 2.5 cm; alttan da 3 cm boşluk bırakılmış olmalıdır. Metin, sağ ve sola dayalı (justify), özet ve abstract tek aralık olarak, ana metin 1,5 aralıkla yazılmalı, paragraflar arasında bir satır boşluk bırakılmalıdır. Başlık, şekil adı, tablo adı gibi formatı belirtilmiş yazılar dışında kalan metin Times New Roman yazı karakterinde 12 punto ile yazılmalıdır.

III. Makale Başlığı

Makale başlığı metnin içeriğini yansıtmalı, 70 harfi geçmemeli ve gereksiz

uzatmalardan kaçınılmalı; Times New Roman yazı karakterinde 20 punto ile yazılmalı ve sadece başlığın ilk harfi büyük olmalıdır. Başlık sayfanın üst sınırından 6 cm boşluk bırakıldıktan sonra yazılmalıdır.

IV. Yazar Adı

Yazar adı sayfanın üst sınırından 10 cm aşağıda olmalıdır. Yazar adının ilk harfi ve soyadı büyük harf olmak üzere Times New Roman, 12 punto, sağa yaslanmış şekilde ve **koyu** olarak yazılmalıdır. Yazar adı birden çok olması durumunda, isimlerin her birine üslü sayı şeklinde bir numara verilerek kurumları dipnotta belirtilecektir. Yazışmalara yapılacağı yazarın isminin yanına asteriks (*) işareti koyulacak ve kurumu, telefon numarası, elektronik posta adresi, yayının 1. Sayfasının altında dip not (footer) olarak alttan 2 cm yukarıda, bir çizgi çekilerek, 10 punto, Times New Roman ve italik formatıyla yazılmalıdır.

V. Kısaltmalar, ilgili bilim alanının standart kısaltmaları olmalı ve metin içinde ilk geçtiği yerde tanımlanmalıdır.

VI. Türkçe Öz

Öz; yazıya konu olan çalışmanın amaçlarını, kullanılan yöntemleri, ulaşılan sonuçlan, değerlendirmeleri içermeli ve 200-250 kelime arasında olmalıdır. Bu haliyle özet, yapılan çalışma hakkında fikir verebilmelidir. Öz, Times New Roman yazı karakteri ile 12 punto, italik olarak sayfanın üst sınırından 13cm boşluk bırakıldıktan sonra yazılmalı ve satırlar arasında tek aralık bırakılmalıdır. Öz kelimesi **koyu** olmalıdır. Öz kelimesi ile metin arasında bir satır boşluk bırakılmalıdır.

VII. Anahtar Kelimeler

Öz ve Abstract kısımlarından sonra, makalenin konu sınıflandırmasının yapılabilmesi için en az 3, en çok 6 adet anahtar kelime verilmelidir. Anahtar kelimeler önemlerine göre sıralanmış, Times New Roman yazı karakteri ile Türkçe anahtar kelimeler 12 punto, İngilizce keywords 11 punto ve italik yazılmalıdır. Sadece "anahtar kelimeler" ve "keywords" kelimeleri **koyu** ve *italik* olarak yazılmalıdır. Türkçe öz ile anahtar kelimeler arasında ve abstract ile keywords arasında bir satır boşluk bırakılmalıdır. Özel isimler hariç anahtar kelimeler küçük harfle yazılacaktır.

VIII. Makalenin İngilizce Başlığı

Makalenin İngilizce başlığı sadece ilk harfi büyük olmak üzere Times New Roman yazı karakterinde 16 punto ile koyu olarak ve sola yanaşık yazılmalıdır.

IX. İngilizce Özet (Abstract)

İngilizce özet, yazıya konu olan çalışmanın amaçlarını, yazıda kullanılan yöntemleri, ulaşılan sonuçları ve değerlendirmeleri içeren, Türkçe özette olduğu gibi bilgi vermek üzere, 200-250 kelime arasında olacak şekilde hazırlanmalıdır. Abstract, Times New Roman yazı karakteri ile 11 punto, italik ve satırlar arasında tek aralık olacak şekilde yazılmalı, sadece "abstract" kelimesi 12 punto ve **koyu** olmalıdır.

X. Başlıklar

- Ana Başlık

Giriş bölümü yazıyı doğrudan ilgilendiren, uzun tarihçeler içermeyen bir bölüm olmalıdır. Tüm ana başlıklar sola dayalı olarak Times New Roman formatında 14 punto, **koyu** ve başlığın sadece ilk kelimesinin ilk harfi büyük olacak şekilde yazılmalıdır. Hiçbir başlığın önüne numara veya herhangi bir işaret konulmamalıdır. Ana başlıklardan önce boşluk bırakılmamalı, ana başlıktan sonra boşluk bırakılmadan makale metni başlamalı, metin yazı karakteri Times New Roman ve 12 punto olmalıdır.

-Ara Başlık

Ana başlıktan sonra herhangi bir metin yazılmadan ara başlık yazılması gerektiğinde arada boşluk bırakılmayacaktır. Ara başlıklar sola dayalı olarak Times New Roman formatında, 12 punto, **koyu** yazılmalı ve başlığın sadece ilk kelimesinin ilk harfi büyük olmalıdır. Ara başlıktan sonra boşluk bırakılmadan makale metni başlamalıdır. Herhangi bir metin yazıldıktan sonra konulacak ara başlıklardan önce bir boşluk bırakılmalıdır.

-Alt Başlık

Alt başlıklar paragrafın başında ve metinden bir çizgi (-) işareti ile ayrılarak yazılmalı ve hemen yanından metin devam etmelidir. Alt başlık Times New Roman yazı tipinde italik, 12 punto ve sadece ilk kelimenin ilk harfi büyük olarak yazılmalıdır.

XI. Şekiller

Metin içinde yer alan şekiller metin sınırlarını aşmayacak şekilde ortalanarak konulmalıdır. Şekiller mutlaka net ve okunaklı olmalıdır. Baskı sırasında yayın %20 oranında küçültüleceği için şekil büyüklükleri bu durum göz önünde bulundurularak belirlenmelidir. Şekiller ya bir çizim programı ile çizilmiş olmalı ya da taranmış ise en az 300dpi çözünürlükte taranmış olmalıdır. Şekil olarak gösterilen grafik, resim ve metin kutularında yer alan yazı ve sayıların büyüklüğü makale içinde Times New Roman karakteri ile yazılmış 9 punto boyutundaki bir yazının büyüklüğünden az olmamalıdır. Şekil numaraları ve adları şeklin altında ortalanarak, tek aralıklı ve Times New Roman 12 punto ile *italik* yazılmalı ve sadece ilk kelimenin ilk harfi büyük olmalıdır. Şekilden önce, şekil adından önce ve sonra da birer satır boşluk bırakılmalıdır. Şekiller metin içine yerleştirilirken mutlaka şekilden önce atıfta bulunulmalıdır.

XII. Resim ve Fotoğraflar

Resim ve fotoğraflar taranmış ise en az 300 dpi çözünürlükte taranmış olmalı, metin içinde mutlaka atıfta bulunulmalı, şekillerle beraber numaralandırılmalıdır.

XIII. Tablolar ve Denklemler

Metin içerisinde yer alan tablolar metin sınırlarını aşmayacak şekilde ortalanarak konulmalıdır. Tablo numaraları ve adları, tablonun üstünde tek aralık ve Times New Roman 12 punto ile sadece ilk kelimenin ilk harf büyük olacak şekilde ortalanarak ve italik yazılmalıdır. Tablo adı yazılırken üstte ve altta birer satır, tablodan sonra ise bir satır boşluk bırakılmalıdır. Tablolara tablodan önce mutlaka metin içerisinde atıfta bulunulmalıdır.

Tablo satır ve sütunlarındaki rakam ve yazılar Times New Roman 12 punto yazılmalıdır. Ancak zorunlu kalman durumlarda yazı boyutu yazı sınırlarını geçmeyecek şekilde en az 9 puntoya kadar düşürülebilir. Tablodaki parametre ve isimlerin yer aldığı ilk satırın hem altı hem de üstü 1.5 punto kalınlıkta birer çizgi ile kapatılmalıdır. Daha sonraki satırlarda herhangi bir yatay ve düşey çizgi kullanılmadan son satırın altına bir çizgi daha ilave edilerek tablo sınırlandırılmalıdır.

Metin içerisine yazılacak denklemler, Microsoft Word yazım programındaki Equation Editör ile sola dayalı olarak yazılmalı ve eşitliklere sağa dayalı

olarak parantez içerisinde numara verilmelidir.

XIV. Semboller

Makale çok sayıda sembol içeriyor ya da makaledeki sembollerin açıklanması gerekiyorsa uluslararası standarda uygun olarak, semboller, kaynaklardan önce, Times New Roman 11 punto ile italik yazılmalıdır. Makalede ondalık gösteriminde nokta kullanılmalı, binlikleri ayırırken virgül veya nokta kullanılmamalı gerekiyorsa tek boşluk kullanılmalıdır.

XV. Kaynaklar

Dergideki referans sistemi, American Psychologists Association (APA) versiyon 6' dır. APA sistemine göre yazılmış bir eserin sonunda muhakkak ki bir kaynakça bölümü olmalıdır. Sayfanın başına Kaynaklar (başlık 14 punto, küçük harfle, sadece ilk harf büyük olmalı) diye yazılmalıdır. Metin içinde gönderme yapılmış/anılmış her eser kaynakçada belirtilmelidir.

Makale metninin sonunda bulunan kaynaklar bölümü yazar soyadına göre A'dan Z'ye doğru, alfabetik bir şekilde sıralanmalı ve Kaynaklar içeriği Times New Roman 11 punto ile yazılmalı, sadece dergi, kitap ya da sempozyum adları italik olmalıdır.
Kaynaklarda, varsa cilt numarası koyu renkte, sayı numarası normal karakter ile yazılmalıdır. Kaynaklar kısmında yer alan ulusal-uluslararası makalelerin yer aldığı dergi adları kısaltılmış halleriyle değil, açık olarak yazılmalıdır.

» **Örnek:** Dergi adı Wat. Res. şeklinde değil, Water Resources şeklinde yazılmalıdır.

Yazı içinde atıfta bulunulan kaynaklar; ya ...Smith (1980)... şeklinde cümlenin içinde, ya ...(Smitb, 1980; Adams, 1981) ya da (Smith vd., 1980) şeklinde cümlenin sonunda yazar soyadı ve yayın yılı belirtilerek verilmelidir. İki yazarlı kaynaklarda iki yazarın da soyadı yazılmalı (Snell ve Ettre, 1971), ikiden fazla yazarlı kaynaklar parantez içinde gösterilecek ise vd. kısaltması kullanılmalı (Li vd., 1998), parantez dışında Li ve diğerleri (1998) kullanılmalıdır.

-Metin içinde kitap, dergi ve film, TV programı adları italik yazılır. Örneğin, Siyaset Meydanı Programı'nda (…).
-Ayrıca yeni veya teknik bir terim metin içinde ilk geçtiği anda italik

yazılabilir, sonrasında italik yazılmaz. Örneğin, 1990'lardan sonra alımlama çalışmaları Türkiye'de de artış göstermiştir.

-İngilizcede yaygın olan ifadeler ve kısaltmaları italik yazılmaz. Metinde bir ifadeyi daha çok vurgulamak amacıyla italik yazılmaz.

-Organizasyon kısaltmaları: İlk alıntıda adı açıkça yazılmalıdır; eğer okuyucu kısaltmayı yakından biliyorsa sonrakilerde kısaltma kullanılmalıdır.

» **Örnek:** İlk Alıntı: National Institute of Mental Health (NIMH),
Sonrakiler: (NIMH, 2015)

40 ya da daha fazla alıntı sözcük varsa, içeriden, tek veya sık satır aralığı vererek, ana metinden daha küçük bir puntoyla (10 veya 11 punto), italik olmadan, tırnaksız yazılır. Sonunda paragraf içinde sayfa numarası yazılır.

Dönüşüm Krishnamurti'ye göre (1998),

(…) zamanın bir sonucu değildir. Dönüşüm sessiz, sakin, pasif bir zihnin sonucudur. Zihin bir sonuca odaklandığında, artık pasif değildir. İnsan dönüşmek istedikçe, değişmek istedikçe, olanı değiştirmek istedikçe, bir sonuca odaklanacaktır, bir sonucu arayacaktır. Zihin basit bir şekilde olanı anlamağa niyet etmek zorundadır. O zaman sakinleşebilir. Bu sakinlik içinde, insan olanı anlayabilir. Dolayısıyla bir dönüşüm olabilir (s.83).

E-maille, telefonla, yüz yüze ya da başka biçimlerde yapılan kişisel görüşmelere dayalı bilgiler, metin içinde gösterilir, ancak kaynakçaya yazılmazlar. Örneğin:

Profesör Mark Post, "et üretimindeki temel sorunun verimsizlik olduğunu ve et üretimini bir tarım sürecinden fabrika sürecine dönüştürmek gerektiğini " söyledi. (Mark Post kişisel görüşme, 24 Aralık 2011).

- Kanunların metin içinde ilk defa gösterimi:

Türkiye Cumhuriyeti Anayasası'na dayanılarak halkın mahalli müşterek ihtiyaçlarını karşılamak üzere belediyeler kurulmuştur (Türkiye Cumhuriyeti Anayasası, 1982:Madde 127).

Belli koşulları sağlayan ve nüfus yoğunluğu fazla olan belediyelerde hizmetin daha etkin ve verimli şekilde verilebilmesi amacıyla Yapı Kontrol

Müdürlükleri kurulmuştur (Belediye Kanunu [BK], 2005:Madde 48).

- Kanun metinde ikinci defa geçtiğinde:

Belediyeler 5393 sayılı yasanın kendilerine vermiş oldukları yetki çerçevesinde yapacakları işlerle ilgili olarak yönetmelikler çıkarırlar ([BK], 2005:Madde 48).

Kaynak gösterimleri aşağıdaki örnekler gibi yapılmalıdır.

Ulusal - Uluslararası Makaleler

» Ishidate, M., Sofuni, T., Yoshikawa, K., Hayashi, M., Nohmi, T., Sawada, M., Matsuoka, A., (1984). Primary mutagenicity screening of food additives currently used in Japan. *Food and Chemical Toxicology,* 22(8), 623-636.

» Pandey, A. K., Kumar, P., Singh, P., Tripathi, N. N., Bajpai, V. K., (2017). Essential oils: Sources of antimicrobials and food preservatives. *Microbiology, 7:* 2161. *doi: 10.3389/fmicb.*

» Gezgin, S., (2009). Medyanın sorumluluğu (Türk Alman ilişkileri Örneğinde). İstanbul Aydın Üniversitesi Sosyal Bilimler Dergisi. 1: 44-54.

Ulusal - Uluslararası Bildiriler

» Yilmaz, A., Brown, O. ve Nelson, H., (1998). *Magnetic fields,* Proceedings, 5tJl Conference, Electronics, 117-143, Sydney, A.

Ulusal - Uluslararası Kitap

» Yilmaz, A., Brown, O. ve Nelson, H., (1998). *Magnetic fields,* 295, Mc. Graw Press, London.

Kitap İçinde Bölüm

» Sensoy, T., (1998). *Magnetic fields, in Reinhards,* M, eds, Physics, Mc. Graw HM Press, 2-5, Oxford, UK.

Çeviri Kitap

» Ong, W.J (1995). *Sözlü ve Yazılı Kültür.* Sema Postacıoğlu (Çev.). 136, Metis Yayınevi. İstanbul

Editörlü Kitap

» Çebi, M.(Ed).(2003). *Medya Etki Araştırmaları* 142, Alternatif Yayınevi. Ankara.

Editörlü Kitapta Bölüm

» Keeplinger. H,M(2003). *Etki Kavramının Sınırları.* Murat Çebi (Ed.), Medya Etki Araştırmaları 142, Alternatif Yayınevi. Ankara.

Dergiden Makale

» Gezgin, S. (2009). Medyanın Sorumluluğu (Türk Alman ilişkileri Örneğinde). İstanbul Aydın Üniversitesi Sosyal Bilimler Dergisi, 1, 44-54

Basılmamış Tezler, Bildiriler

» Arvas, İ.S (2010). *Cumhuriyet Döneminde Basında Etik Bağlamda Ortaya Konulan Uygulamalar ve Bir Meslek Örgütü: Basın Konseyi.* (Yayınlanmamış doktora tezi.) İstanbul Üniversitesi / Sosyal Bilimler Enstitüsü, İstanbul.

Kanun ve Yönetmelikler

» *Türkiye Cumhuriyeti Anayasası* (1982), Kanun No:2709, Resmi Gazete: 09.11.1982/17863.

» *Yapı Denetimi Hakkında Kanun* (2001), Kanun No:4708, Resmi Gazete: 13.07.2001/24461.

» *Yapı Denetimi Uygulama Yönetmeliği* (2008), Kanun No:4708, Resmi Gazete: 05.02.2008/26778.

İnternette Makale

» Koloğlu, O. (1999). *Medya, Devlet ve Sermaye.*
http://dorduncukuvvetmedya.com

Basılmış Bilimsel Rapor

» Yilmaz, A,, Brown, O. ve Nelson, H., eds. (1998). Magnetic fields, J., Technical Report, ICTP TRIL Programme, 12, Trieste.

Mesleki Teknik Rapor

» Yılmaz, A., Brown, O. ve Nelson, H., eds. (1998). *Manyetik Alan Teorisi,*

Teknik Rapor 5, CEV Vakfı, İstanbul.

Doktora, Y. Lisans Tezi

» Yilmaz, A., Brown, O. ve Nelson, H., (1998). *Manyetik Alan Teorisi,* Doktora tezi, AÜ Fen Bilimleri Enstitüsü, Ankara.

Standartlar

» TS920, (1990). *Binalarda rüzgar yükü kuralları, Türk Standartları,* Ankara. ix) Güncel Yazı,

» Yilmaz, A., Brown, O. ve Nelson, H., (1998). Manyetik Alan Teorisi, Bilim ve Teknik, 63, 7, 3-5

Web Adresleri

Kaynakların A'dan Z'ye sıralanması bittikten sonra 1 punto kalınlıkta bir çizgi çekilerek, çizginin altından itibaren, internet kaynakları, siteden yararlanılan tarihle beraber yazılmalıdır.

» Yilmaz, A., Brown, O. ve Nelson, H., (1998). *Manyetik Alan Teorisi,* http://www.server.com/final/paperl .html, (21.12.2005)

Broşür (Tarihsiz ve yazarsız):

» *Inside these doors: A guidebook of Elfreth's Alley homes* [Brochure]. (t.y.).Philadelphia: Elfreth's Alley Association.

Film

» Yönetmenin Soyadı, Yönetmenin Adının Baş Harfleri. (Yönetmen). (Yıl). *Filmin adı italik şekilde.* Prodüksiyon şehri: Prodüksiyon şirketi ismi.

» Huston, J. (Yönetmen/Senaryo Yazarı). (1941). *Malta Şahini* [Film]. U.S.: Warner.

» Metin içindeyse: (*Malta Şahini,* 1941) …. şeklinde gösterilir.

Fotoğraf

» Adams, Ansel. (1927). Monolith, the face of Half Dome, Yosemite National Park [Fotoğraf]. Art Institute, Chicago.

Metin içindeyse: (Adams, 1927) …. şeklinde gösterilir.

Görüşme

» Arroyo, Gloria Macapagal. (2003). A time for Prayer. Michael Schuman ile söyleşi. *Time*. 28 Temmuz 2003. Erişim Tarihi 13 Ocak 2004, http://www.times.com/time/nation/article/0,8599,471205,00.html

Rapor ve teknik makaleler

» Gencel Bek, M. (1998). Mediscape Turkey 2000 (Report No. 2). Ankara: BAYAUM.

Televizyon programı

» Long, T. (Yazar), ve Moore, S. D. (Yönetmen). (2002). Bart vs. Lisa vs. 3. Sınıf [Televizyon Dizisi]. B. Oakley ve J. Weinstein (Yapımcı), *Simpsonlar* içinde. Bölüm: 1403 F55079. Fox.

Metin içindeyse: (Simpsonlar, 2002) …. şeklinde gösterilir.

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Web Sayfası: http://abmyod.aydin.edu.tr/
E-posta: candanvarlik@aydin.edu.tr

Author's Guide

Author's may send their articles which are prepared in accordance with the below stated publishing and editorial principles, together with the "article presentation form" via e-mail to the provided addresses.

Providing the permissions of the authors (the main author or the rightful publishing house) is obligatory for the translated texts and articles as well.

The articles which are sent to their authors for further improvement and/or proofreading following the preliminary reviews and referee evaluations, must be edited accordingly and delivered back to the journal in one month at the latest.

On the other hand, the articles which are found to be conflicting with this guideline, will be returned to their authors for further proofreading and will not be issued.

Publishing Principles

1. The articles to be published in the journal cannot be published or presented elsewhere without the permission of the Editorial Board. The articles that are published, partially or as a whole, cannot be used elsewhere without citation. The journal only accepts original manuscripts which are not published, being reviewed for publication or accepted to be published previously. The authors of the related articles must build a consensus upon the name order.

2. The articles delivered to the journal are expected to be arranged according to American Psychological Association (APA) style regarding the references, footnotes and bibliography. The authors must consult the 6th edition of APA.

3. The articles that are published in the journal will be open for discussion from the date of publication till the next issue of the journal. The criticisms made for the articles will be published in the journal as well. The articles must not exceed 12 pages and they must be handed

as a disc or delivered via e-mail to the given addresses. The originally prepared manuscripts will be scaled down by 20 % while printing, thus the sizes of the figures and tables must be arranged accordingly. Also, the journal is printed black and white, therefore the photographs, images, figures or graphics within the text must not be colored.

4. The journal only accepts manuscripts which are not published, being reviewed for publication or accepted to be published previously.

5. The papers that are presented or to be presented in a scientific gathering such as symposium, congress or conference can be accepted for referee evaluation provided that they are not published.

6. The Editorial Board of the Journal delivers the article to three different referees. The articles are published at least with two positive referee reviews.

7. The manuscripts that are expected to be revised must be completed and resent to the Editorial Board within 30 days (including the posting time). Manuscripts that are sent within the specified period will be queued to be published in the next issue. Manuscript revision may also be evaluated by the referees who demanded the changes.

8. The approved articles are published one after another regarding the completion dates of their referee reports.

9. The manuscripts to be sent to the journal must be prepared as two copies. One of the two copies must be posted as a hard copy and the other must be delivered via e-mail. Both of the delivered copies (digital and hardcopy) must include a cover page which contains the names and the surnames of the author(s), the full title of their articles, their titles and the workplaces, work and mobile phones as well as e-mails.

10. The copyrights of the manuscripts which are accepted to be published following the evaluation process, are considered as transferred to Istanbul Aydin University.

11. Following the publication of the article, two copies of the related issue of

the journal is delivered to the author. No royalty is payed to the authors.

12. The manuscripts which pass Referee Board and to be published with the purpose of sharing knowledge on a national and international basis, may be published depending on the website of the university.

13. The manuscripts sent to the journal are not be returned even if not to be published.

Editorial Principles

I. Types of Articles

The articles to be published in the journal are expected to be as follows;

» Works related to original studies,

» Works which explain application examples in a scientific way,

» Works of collection presenting the deficiencies and evaluating the developments on a specific subject,

» Scientific articles that are prepared using the results obtained from a thesis, where there is a scientific consistency partially or as a whole and in which the doctorate student and the advisor have worked together as collective authors.

II. Page Layout

A4 page size with 2 cm margins on left and right; 2.5 cm on up and 3 cm on the bottom of the page. The text must be justified and written with 1,5 space whereas the Turkish and English abstracts must be written with single space leaving an empty line between the paragraphs. The text, excluding the title, name of the figure or table for which the format is specified, must be written using Times New Roman font type in 12-point size in general.

III. Article Titles

The title of the article must reflect its content, must not exceed 70 characters. Authors must avoid redundancy; the title must be typed using Times New Roman font type in 20-point size with only the initial letter of the title

capitalized. The title must be 6 cm below the upper page limit.

» **The English Title of the Article**

12-point size, **bold,** Times New Roman font type with only the initial letter of the first word capitalized.

IV. Author's name(s) and Address(es)

10 cm below the upper page limit, only the initials of the name and surname capitalized, Times New Roman in 12-point size, aligned to right and **bold**. In case there are more than one author name to be mentioned, each author's institution must be indicated as a footnote. The author responsible for correspondence must be indicated with an asterisk (*) and his/ her contact information such as institution, phone number and e-mail address must be given on the first page of the article as a footnote with 2 cm above the bottom page limit using 10-point size Times New Roman font type.

V. Scientifically standardized abbreviations should be preferred and explained where it is first mentioned.

VI. Abstract

The abstract must contain the purpose(s), methods, results and evaluations regarding the subject of the work and consist between 200-250 words. In this respect, the abstract must be able to give an idea about the work to the reader. Starting from 13 cm below the upper page limit, the abstract must be typed with single space using 12-point size Times New Roman font type in italics. The title of the abstract (Abstract) must be typed in bold leaving an empty line before the text.

VII. Keywords

Following the abstract part, at least 3 and at most 6 keywords must be given in order for the article subject to be classified. The keywords must be prioritized with 12-point size Times New Roman font type for Turkish and 11-point size and italics for English with only the **"Keywords"** typed in **bold.** There must be a blank space between the abstract and the keywords. Keywords must be typed in lower-case letters unless indicating a proper name.

VIII. Titles

» ***English Title of the Article***

Only the initial letter capitalized; Times New Roman, 16-point size, bold and aligned to the left.

» ***Main Title***

The introduction section must be directly related to the text itself without long background information. All main titles must be aligned to the left using 14-point size, bold, Times New Roman font type with only the initial letter of the title capitalized. Titles must not start with numbers or any kind of signs. Main titles must not have space before or after them and the main title must immediately be followed by the text (12-point size, Times New Roman) without an empty line.

Section Titles

No empty space is required when main titles are to be followed by the section titles without a text. The section titles must be aligned to the left and written in 12-point size, Times New Roman font type in bold with only the initial letter of the first word capitalized. Section titles must be followed by the text without an empty line in between. However, any section title following a text must have an empty line before.

» ***Sub-titles***

Sub-titles must be typed at the beginning of the text and separated from the text using a hyphen (-) after which must follow the text without a space. Sub-titles must be written in 12-point size italics using Times New Roman font type with only the initial letter of the first word capitalized.

IX. Figures

The figures included in the text must be centered on the page aligned with the text. The figures must be clear and understandable. The manuscripts will be scaled down by 20 % while printing thus the sizes of the figures must be arranged accordingly. The drawings must either be prepared in a digital drawing software or if scanned the file must at least have 300dpi definition. The texts found in graphics, images and text boxes must not be smaller than a text written with 9-point size in Times New Roman font-type. The numbers and the names of the figures must be centered on the page, typed under the figure itself, following a single space with 12-point size italics

in Times New Roman font-type with only the initial letter of the first word capitalized. There must be a single space before the figure, its title and after its title. The figures must be referred to within the text prior to the figure.

X. Images and Photographs

The images, photographs or special drawings included within the text must be scanned in 300 ppi (300 pixels per inch) with a 10 cm short edge in JPEG format, cited within the text and numbered together with figures.

XI.Tables and Equations

The tables included in the text must be centered on the page aligned with the text. The numbers and the names of the table must be typed above the table leaving a single space before and after as well as below the table using italics, 12-point size, Times New Roman font type; the title and the number must be centered with only the initial letter of the first word capitalized. Tables must certainly be referred to within the text beforehand. The contents of the tables lines and columns must be typed with Times New Roman font-type and in 12-point size. In case necessary the font size can be decreased down to 9-point size not exceeding text limits. The first line of the table, where the parameters and the names are found, must be closed by a 1.5-point size thick line from above and under. The table must be limited by adding an additional line under the last line of the table without using horizontal or vertical lines.

The equations to be written within the text must be typed using Microsoft Word Equation Editor and aligned to left with equals numbered within parentheses and aligned to the right.

XII. Symbols

In case the article contains a lot of symbols or they are required to be explained, symbols should be written in 11-point size italics with Times New Roman font type before the bibliography in accordance with international standards. Decimal demonstrations must be done with full stop“.” with no comma separating thousands. If required use space.

IIIX. Bibliography

The reference system for the journal is American Psychologist Association (APA) 6th Edition. A work prepared in APA system must have a references section at the end. The page must begin with a title named "References" written in 14-point size Times New Roman with only the initial letter capitalized. Any work referred or quoted within the text must be cited in the references section.

The references content must be placed at the end of the text, aligned in an alphabetical order with Times New Roman, 11-point size with only the names of journals, books or symposiums written in *Italics* as shown in the following examples.

In case there is, the volume numbers must be typed in **bold** and issue numbers in regular characters. The names of the journals where national or international articles are taken must not be abbreviated and must be given in full.

» **Example:** Name of the journal should be written as Water Resources, not as Wat. Res.

Citation must be as follows within the text in a sentence…Smith (1980)… or ...(Smith, 1980; Adams, 1981) as well as (Smith et al., 1980) at the end of a sentence indicating the surname and publishing year of the work. For citing the works with two authors, the surnames of both authors must be mentioned as follows (Snell and Ettre, 1971). In case there are more than two authors to be indicated in the citation then "et al." abbreviation must be used, in parentheses (Li et al. 1998) or within a sentence … Li et al. (1998)…
- The names of books, magazines or journals, films or TV programs must be written in italics.
- A new or technical term may be written in italics when it is mentioned for the first time in the text and with regular characters later on.
- The common expressions and abbreviations in English must be written in regular characters. Italics must not be used for emphasizing an expression more.

-Organization abbreviations: the first reference must include the full name clearly; the abbreviations can be used later on in case the reader is familiar with the concept.

Example: First reference: National Institute of Mental Health (NIMH),

Later on: (NIMH, 2015)

Place direct quotations that are 40 words, or longer, in a free-standing block of typewritten lines, and omit quotation marks. Use a smaller point size than the text itself (10 or 11) and add page number in parenthesis at the end of the quote.

Example:

According to Krishnamurti (1998),
(…) zamanın bir sonucu değildir. Dönüşüm sessiz, sakin, pasif bir zihnin sonucudur. Zihin bir sonuca odaklandığında, artık pasif değildir. İnsan dönüşmek istedikçe, değişmek istedikçe, olanı değiştirmek istedikçe, bir sonuca odaklanacaktır, bir sonucu arayacaktır. Zihin basit bir şekilde olanı anlamağa niyet etmek zorundadır. O zaman sakinleşebilir. Bu sakinlik içinde, insan olanı anlayabilir. Dolayısıyla bir dönüşüm olabilir (s.83).

Information based on personal conversations that are realized through e-mail, telephone, face to face communication and in other ways are cited within the text but not in references section.

Initial use of laws within a text:

For laws (statutes), the preferred form includes the name of the law and the year – e.g. (Child Abuse Prevention and Treatment Act of 1974). APA style requires anything cited briefly in the text (e.g. in parentheses) should also have a complete listing in the References list. Belli koşulları sağlayan ve nüfus yoğunluğu fazla olan belediyelerde hizmetin daha etkin ve verimli şekilde verilebilmesi amacıyla Yapı Kontrol Müdürlükleri kurulmuştur (Belediye Kanunu [BK], 2005:Madde 48).

Repeated use of laws in a text:

Belediyeler 5393 sayılı yasanın kendilerine vermiş oldukları yetki çerçevesinde yapacakları işlerle ilgili olarak yönetmelikler çıkarırlar ([BK], 2005:Madde 48).

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Within the text: …(Simpsons, 2002)…

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