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RESEARCH ARTICLE

Smart and Sustainable Supplier Balanced Scorecard: A Novel Hybrid Best-Worst-Based Method

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ABSTRACT
This study's novel smart and sustainable supplier scorecard is based on the best-worst method-enhanced balanced scorecard approach for supplier assessment and monitoring. The proposed smart and sustainable supplier scorecard evaluates suppliers in six dimensions: performance, quality management, risk analysis, environmental management, smartness, and legitimacy. Quantitative indicators and metrics calculate each dimension. The smart and sustainable supplier scorecard is designed for businesses to assess and monitor their suppliers' performance regarding digitization and sustainability and evaluate strategies and initiatives that meet their objectives and targets. Furthermore, we present a case study showing the applicability of the smart and sustainable supplier scorecard. The proposed approach will give organizations a holistic view of their suppliers, allowing them to achieve digitization and sustainability goals. Finally, we discuss the potential benefits and managerial implications of the smart and sustainable supplier scorecard.

Keywords: Supplier assessment, Supplier monitoring, Risk management, Smart and sustainable supply chain management, Balanced scorecard, Best-worst method

1. Introduction

The use of the balanced scorecard (BSC) can provide a comprehensive view of supplier performance, making it critical to any successful supply chain management (SCM) strategy (Hudnurkar *et al*., 2018; Knotts *et al*., 2006). A BCS combines financial and non-financial performance measures in a single scorecard, which guides strategy formulation, implementation, and communication, tracks performance, and provides quick feedback for control and evaluation (Pandey, 2005). BSC can be used as a supplier scorecard, identifying the most critical supplier performance metrics (Kumar *et al*., 2014). The supplier scorecard is a comprehensive supplier evaluation tool that enables organizations to assess the performance of their suppliers concerning key performance indicators (KPIs) (Doolen *et al*., 2006; Hudnurkar *et al*., 2018). Using BSC in supplier assessment has several benefits (Ferreira *et al*., 2016). It enables businesses to monitor the performance of their suppliers (Galankashi *et al*., 2016), identify improvement areas and develop strategies to address any issues (Doolen *et al*., 2006), and build a more collaborative relationship with their suppliers, improving performance and outcomes for both parties (Hudnurkar *et al*., 2018).

This paper proposes a novel approach to smart and sustainable supplier scorecards based on the BSC approach to develop, monitor, and inspect suppliers' impact on a company's production and supply chain effectiveness. By applying the BSC-based approach to smart and sustainable supplier scorecards, companies can gain a more comprehensive view of their suppliers regarding digitization and sustainability.

This study proposes the smart and sustainable supplier scorecard, which evaluates suppliers' performance based on the best-worst method (BWM) enhanced BSC approach. This approach comprises 6 parts representing one of the 4S-score dimensions: performance, quality management, risk analysis, environmental management, smartness, and legitimacy. The score for each dimension is calculated by evaluating the suppliers' performance, quality management system (QMS) development status, risk degree, environmental management system (EMS) development, smartness score, and legitimacy score. The 4S-score is calculated by adding the average dimension scores, and the BWM is used to determine the weights of strategies. The BWM-enhanced BSC

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evaluation matrix is then constructed by integrating the BSC framework with the BWM method. This BWM-enhanced BSC evaluation matrix is then used to calculate the prominence scores of strategies and initiatives.

This paper is organized as follows. Section 2 discusses the conceptual background of supplier assessment and monitoring and summarizes the implementation of the BSC approach in SCM. Section 3 presents a proposed framework for a smart and sustainable supplier scorecard that integrates the BSC approach with the BWM method. This framework includes a set of criteria for assessing and monitoring suppliers and a set of metrics for measuring performance. Section 4 provides the details of the case study, and Section 5 concludes with a discussion of the potential benefits of this approach and the potential implementation challenges.

2. Literature review

A company purchases materials or services from suppliers whose inspection, development, and performance evaluation (crucial for organizational performance) can affect production and supply chain quality. This section examines the literature on supplier evaluation and monitoring, focusing on sustainable supplier evaluation and the implementation of the BSC approach to SCM.

2.1. Supplier assessment and monitoring

Supplier assessment is essential to SCM; it assesses and selects potential suppliers based on multiple criteria such as cost, quality, and reliability (Chen and Wu, 2013). Due to environmental, social, and economic sustainability, supplier evaluation has become increasingly complex in recent years. This shift has resulted in various supplier evaluation methods to ensure the supplier management process is effectively performed (Sundtoft Hald and Ellegaard, 2011). The literature on supplier evaluation criteria and approaches is vast, with many studies published in the past two decades. For example, Govindan *et al*. (2015) analyzed research in international scientific journals and conference proceedings on green supplier selection, finding that EMSs were the most common criterion for green supplier selection. Ho *et al*. (2010) conducted a literature review of multi-criteria decision-making approaches for supplier evaluation and selection, finding that the most prevalently applied techniques were fuzzy-based single-model approaches. Zhang *et al*. (2020) conducted a comprehensive review of studies that aim to develop models and methods to help enterprises assess and select suitable green suppliers, finding that the most commonly used evaluation criteria were environmental, financial, and operational. Simić *et al*. (2017) reviewed the studies that aim to develop models and strategies to help enterprises assess and select suitable green suppliers. They also conducted a bibliometric analysis according to the frequency of supplier selection methods, citation number, publication year, journal, country, and application area. Vörösmarty and Dobos (2020) summarized findings about papers involving supplier selection and evaluation using data envelopment analysis, determining that most papers still focus on supplier selection, with few papers considering sustainability. Finally, Saidy *et al*. (2018) investigated current practices of supplier delivery assessment and the valuation of management decisions regarding underperforming suppliers. They proposed an analytic hierarchy process (AHP)-based method that enables purchasing firms to assess their suppliers and take proactive measures against underachieving suppliers.

Sustainable supplier evaluation is a vital component of the supply chain process, and it has become increasingly important in the modern manufacturing industry (Reuter *et al*., 2010). Identifying, assessing, and treating supplier sustainability risks have become a priority for purchasing and supply management functions (Förstl *et al*., 2010). As the Industry 4.0 environment has grown, managing suppliers more efficiently and effectively has become vital (Esmaeilian *et al*., 2020; Núñez-Merino *et al*., 2020). There is a need to evaluate and monitor suppliers systematically to consider green supply chain performance (De Giovanni and Cariola, 2021). Recent research has proposed several frameworks and methods for assessing and managing suppliers in various industries. For example, Zheng *et al*. (2022) proposed a three-phase model that utilizes the AHP and entropy weight method to determine the weights of evaluation indices. Coşkun *et al*. (2022) suggested an integrated sustainable supplier evaluation and development framework to support chemical manufacturers in managing supplier relationships according to sustainability's economic, environmental, and social dimensions. Chang *et al*. (2021) proposed four dimensions for sustainable supplier evaluation and selection: economic, social, environmental, and institutional sustainability. Lo *et al*. (2021) presented a two-stage multi-criteria decision-making approach for sustainable supplier evaluation and transportation planning in multi-level supply chain networks. Chen and Hu (2022) suggested a method for analyzing enterprise supplier characteristics using data mining and mathematical programming models. Cinnirella *et al*. (2022) proposed an AHP-TOPSIS (technique for order of preference by similarity to ideal solution) method applied to suppliers for a company operating in the waste management sector. Şişman *et al*. (2022) identified criteria for sustainable supplier performance in monitoring and evaluation; they used the interval-valued intuitionistic fuzzy AHP method to calculate the criteria weights. Tolooie *et al*. (2022) suggested an integrated fuzzy decision model for sustainable supplier evaluation and selection. Govindan *et al*. (2023) proposed a theoretical framework to analyze KPIs for developing sustainable collaboration.

2.2. Balanced scorecard (BSC) and its supply chain management (SCM) implementations

BSC is a performance measurement framework widely used in various industries and supply chains (Schiffling and Piecyk, 2014). The BSC framework is based on four perspectives: financial, customer, internal process, and learning and growth (Bigliardi and Bottani, 2010). It provides a comprehensive view of performance, allowing organizations to measure the tangible and intangible aspects of their operations (Barber, 2008). BSC can measure total supply chain performance and incorporate the intangible value-adding aspects of the total value chain, such as customer satisfaction, on-time delivery, and cost reduction (Rahimnia *et al*., 2014). Thus, BSC allows organizations to assess the success of their supply chain operations more comprehensively. The BSC framework is used to evaluate the impact of the alignment between supply chain strategy and environmental uncertainty on supply chain performance (Chang, 2009). BSC is also used for performance measurement that aligns the employees' incentives to motivate collaborative supply chain behavior (Brewer, 2002). Finally, BSC can be used to measure and monitor the supply chain's performance from the perspective of senior supply chain executives (Chia *et al*., 2009). The BSC for sustainable SCM is discussed in the following subsection.

2.2.1. The use of the BSC for sustainable SCM

The use of BSC for sustainable SCM has become increasingly important in recent years (Kim and Rhee, 2012; Reefke and Trocchi, 2013). The growing awareness of environmental issues has led companies to increasingly look for ways to reduce their environmental impact and improve their sustainability performance (Rahimnia *et al*., 2014). BSC is a performance measurement tool that can be used to assess a supply chain's sustainability (Aliakbari Nouri *et al*., 2019); it is a comprehensive framework that considers four key sustainability perspectives: financial, customer, internal business, and the learning and growth perspectives (Jalali Naini *et al*., 2011). The financial perspective focuses on the financial performance of the supply chain, such as profitability, cost savings, and return on investment (Lin *et al*., 2014). The customer perspective examines customer satisfaction, loyalty, and retention (Khan *et al*., 2016). The internal business process perspective concerns the efficiency and effectiveness of the supply chain, such as inventory management, order fulfillment, and delivery performance (Thanki and Thakkar, 2018). Finally, the learning and growth perspective includes the ability of the supply chain to innovate and adapt to changing market conditions (Khaleeli *et al*., 2021). BSC can be used to assess a supply chain's sustainability in several ways (Ferreira *et al*., 2016). For example, a sustainable supply chain scorecard considers economic, social, and environmental indicators (Sislian and Jaegler, 2018). First, it can identify areas of improvement and strength, which can help companies determine issues and make changes to improve their sustainability performance. Second, BSC can be used to measure the performance of the supply chain over time, which can help companies track their progress and identify areas where they must concentrate their efforts. Finally, BSC can be used to compare the performance of different supply chains, allowing companies to identify best practices and areas to learn from other firms.

2.2.2. The use of the BSC for supplier selection and evaluation

The use of BSC for supplier selection and evaluation has become increasingly popular in recent years (AlMaian *et al*., 2016; Galankashi *et al*., 2016; Hudnurkar *et al*., 2018). It provides a comprehensive framework for assessing supplier performance and can be tailored to the buyer company's needs (Doolen *et al*., 2006). BSC can be used to develop a supplier collaborative performance index (Hudnurkar *et al*., 2018) and a supplier scorecard (Doolen *et al*., 2006), which can be used to assess suppliers' performance and determine the extent of collaboration between the buyer company and its suppliers (Brege *et al*., 2008). BSC can evaluate suppliers in four dimensions (Basu *et al*., 2009). First, it can be used to assess the financial performance of suppliers, such as their ability to meet deadlines and provide quality products at competitive prices (Hudnurkar *et al*., 2018). It can assess the customer service provided by suppliers, such as their responsiveness to customer inquiries and their ability to provide timely delivery of products (Galankashi *et al*., 2016). Second, BSC can be used to evaluate the internal business processes of suppliers, such as their ability to manage inventory and meet production deadlines (Doolen *et al*., 2006). Third, BSC can be used to assess suppliers' innovation and learning capabilities, such as their ability to develop new products and services and stay up-to-date with industry trends (Basu *et al*., 2009). Finally, BSC can also be used to develop a supplier collaborative performance index (Hudnurkar *et al*., 2018). This index can quantify the extent of collaboration between the buyer company and its suppliers. The supplier collaborative performance index is based on factors and their indicators that affect collaboration with the supplier, such as the supplier's financial performance, customer service, internal business processes, and innovation and learning capabilities (Galankashi *et al*., 2016). The higher the value of the supplier's collaborative performance index, the better the chance to move to the next level of maturity in the relationship. Furthermore, BSC can be used to develop a supplier scorecard (Doolen *et al*., 2006), which can assess suppliers' performance regarding their ability to meet deadlines, provide quality products at competitive prices, and respond to customer inquiries. The scorecard can assess the internal business processes of suppliers, such as their ability to manage inventory and meet production deadlines (Basu *et al*., 2009).

2.3. Literature gap

The previous sections reviewed the extensive literature on supplier assessment, monitoring, and using the BSC approach in SCM. While the BSC approach has been successfully applied to various SCM contexts, more research is needed on its application to smart and sustainable supplier assessment and monitoring. This paper aims to fill this gap by proposing a novel approach to supplier scorecards based on the BSC approach, emphasizing smartness and sustainability.

The proposed smart and sustainable supplier scorecard is designed to provide a broader view of supplier performance while considering smartness and sustainability. This approach can provide organizations with a comprehensive understanding of supplier performance, enabling them to identify areas of improvement and ensure that suppliers help the organization meet its smartness and sustainability goals. Table 1 summarizes BSC utilizing studies that focus on SCM and addresses the gap in the literature.

Table 1 shows that extensive research used the BSC approach in SCM and supplier assessment and monitoring areas; however, no study utilizes the BSC framework for supplier assessment considering smartness and sustainability. Most studies using the BSC approach for SCM issues have adopted surveys, case studies, or conceptual methodologies; few have used multi-criteria decision-making methods, e.g., AHP, analytic network process (ANP), or decision-making trial and evaluation laboratory (DEMATEL). To the authors' best knowledge, this study is the first attempt to integrate the BSC framework with the BWM.

Table 1. Summary of BSC utilizing studies focusing on SCM

Study	Supply chain focus	Method	Purpose
Doolen *et al.* (2006)	Supplier performance	Case study	To design a supplier scorecard for supplier performance improvement
Knotts *et al.* (2006)	Supplier performance	Survey	To examine the usefulness of BSC in measuring merchandising supplier performance
Sharma and Bhagwat (2007)	Supply chain performance	AHP	To develop an integrated BSC-AHP approach for SCM evaluation
Varma *et al.* (2008)	Supply chain performance	AHP	To suggest a method to evaluate the performance of the petroleum industry supply chain
Chang (2009)	Supply chain performance	Case study	To evaluate the SCM performance of Taiwan industries by using BSC
Chia *et al.* (2009)	Supply chain performance	Survey	To examine how senior supply chain executives measure performance from a BSC perspective
Bigliardi and Bottani (2010)	Supply chain performance	Case study	To develop a BSC model for performance measurement in the food supply chain
Jochem *et al.* (2010)	Process quality and performance	Conceptual	To investigate the alignment of the KPIs with the company's processes having bottlenecks alongside the value chain
Jalali Naini *et al.* (2011)	Supply chain performance	Case study	To propose a performance measurement system using a combination of evolutionary game theory and BSC in environmental SCM
Dhiaf *et al.* (2012)	Supply chain flexibility	Survey	To present a conceptual framework to uncover the effects of different dimensions of supply chain flexibility on global performance
Franceschini and Turina (2012)	Business performance	Case study	To propose a performance dashboard for monitoring the water and sewage service companies
Kim and Rhee (2012)	Green supply chain management performance	Survey	To examine the impact of green SCM critical success factors on BSC-based performance
More and Babu (2012)	Supply chain flexibility	Conceptual	To develop a flexibility scorecard focusing on the flexibility metric in a balanced way
Schloetzer (2012)	Supply chain information sharing	Survey	To examine the influence of hold-ups in supply chains on the extent of process integration and information sharing between partners
Chang *et al.* (2013)	Supply chain integration	Case study	To discuss the integration of the supply chain and performance based on BSC measures
Reefke and Trocchi (2013)	Supply chain sustainability	Conceptual	To facilitate a balanced approach to performance measurement for sustainable supply chains
Lin *et al.* (2014)	Green supply chain management performance	ANP	To propose a hybrid approach to evaluate the performance of a firm's green SCM
Rahimnia *et al.* (2014)	Supply chain performance	Survey	To propose an extended framework to consider the impact of supply chain strategy and environmental uncertainty on supply chain performance
Schiffling and Piecyk (2014)	Organizational performance	Conceptual	To develop a performance measurement framework that considers the key stakeholders of the logistics departments or personnel in humanitarian organizations
Cunha Callado and Jack (2015)	Supply chain performance	Survey	To identify how many metrics are used in BSCs related to specific supply chain roles
Liang (2015)	Supply chain performance	AHP	To measure inter-organizational information systems' performance in the supply chain
AlMaian *et al.* (2016)	Supplier quality	SMART	To describe applying the SMART technique to analyze supplier quality management practices
Aqlan *et al.* (2016)	Supply chain performance	Simulation	To propose a framework to assess supply chain readiness for transformation
Ferreira *et al.* (2016)	Environmental performance of supply chain	Case study	To suggest a model for the assessment of the environmental performance of a supply chain

Table 1. Continued

Study	Supply chain focus	Method	Purpose
Galankashi *et al.* (2016)	Supplier selection	AHP	To propose an integrated BSC-Fuzzy AHP model to select suppliers in the automotive industry
Golrizgashti (2016)	Supply chain value	Case study	To explore the effects of knowledge management applications on value creation in a supply chain
Cunha Callado and Jack (2017)	Supply chain performance	Survey	To explore the actual use of performance metrics in non-integrated supply chains
Chorfi *et al.* (2018)	Supply chain performance	AHP	To introduce a framework based on BSC and the SCOR model integrating the performance measurement systems for public healthcare supply chains

Table 1. Continued

Study	Supply chain focus	Method	Purpose
Hudnurkar *et al.* (2018)	Supplier collaboration performance	AHP	To develop a BSC-based index for quantifying the suitability of suppliers
Susanty *et al.* (2018)	Supply chain performance	Interviews & survey	To evaluate the performance of the relationships between farmers, dairy cooperatives, and industrial milk processors
Thanki and Thakkar (2018)	Lean and green performance of supply chain	ANP & DEMATEL	To propose a BSC and strategy map-based framework for assessing a supply chain's lean and green performance
Aliakbari Nouri *et al.* (2019)	Supply chain sustainability	Delphi method	To provide a framework to assess the sustainability of service supply chains
Anjomshoae *et al.* (2019)	Supply chain performance	AHP	To propose an integrated performance measurement scheme that consolidates KPIs into the performance indicators of humanitarian supply chains
Chandra and Kumar (2019)	Supply chain performance	AHP	To identify the KPIs of a vaccine supply chain
Al Naimi *et al.* (2020)	Supply chain reconfiguration	ANP	To prioritize supply chain reconfiguration variables by using BSC and ANP
Taifa *et al.* (2020)	Supplier performance	Conceptual	To identify and rank the critical success decision criteria for multiple suppliers working as an extended enterprise
Frederico *et al.* (2021)	Supply chain digitization performance	Conceptual	To present a BSC-based theoretical approach regarding performance measurement in supply chains for Industry 4.0
Khaleeli *et al.* (2021)	Business performance	Survey	To explore the potential of using BSC to measure the effect of green marketing, green supply chain, and green human resources on the performance of the firms
Shinkevich *et al.* (2021)	Supply chain digitization performance	Survey	To build a BSC framework for controlling procedures of petrochemical and fuel and energy enterprises in the context of the transition to Industry 4.0
Fernandes *et al.* (2022)	Business performance	Survey	To understand the impact of supply chain quality management dimensions on the organization's performance based on BSC perspectives
Nazari–Ghanbarloo (2022)	Supply chain performance	Simulation	To propose a model combining dynamic BSC with system dynamics to explore an efficient supply chain performance measurement tool
Saroha *et al.* (2022)	Circular supply chain performance	Conceptual	To identify the circular supply chain performance indicators using the modified BSC technique
Saleheen and Habib (2023)	Supply chain performance	Conceptual	To formulate an integrated supply chain performance measurement model
This study	**Supplier assessment and monitoring**	**BWM**	**To propose a method to assess and monitor suppliers considering smartness and sustainability**

3. Methodology

This study's novel smart and sustainable supplier scorecard is based on the BWM-enhanced BSC approach that evaluates suppliers. This section explains the methodological steps of the proposed scorecard, formulating each dimension based on its indicators and metrics.

We propose a novel supplier evaluation score, "4S-score" (Smart and Sustainable Supplier Surveillance), demonstrated in the hexagon shape in Fig. 1.

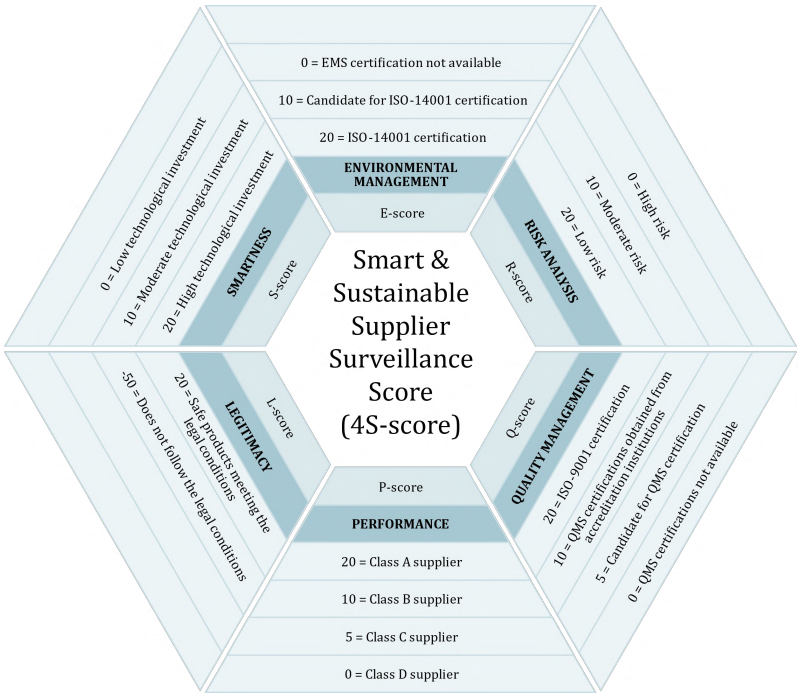

Figure 1. Dimensions of the smart and sustainable supplier surveillance score (4S-score)

The hexagon comprises six parts (wings), each representing one of the 4S-score dimensions: performance, quality management, risk analysis, environmental management, smartness, and legitimacy. The indicator for each dimension is demonstrated within each wing. For example, the performance dimension comprises four parts: class A supplier, class B supplier, class C supplier, and class D supplier.

Scores for each dimension are indicated using initials inside the hexagon: P-score, Q-score, R-score, E-score, S-score, and L-score. These dimensions and 4S-score are calculated by applying the following steps. Fig. 2. illustrates the methodological steps involved in the BWM-enhanced smart and sustainable supplier scorecard approach.

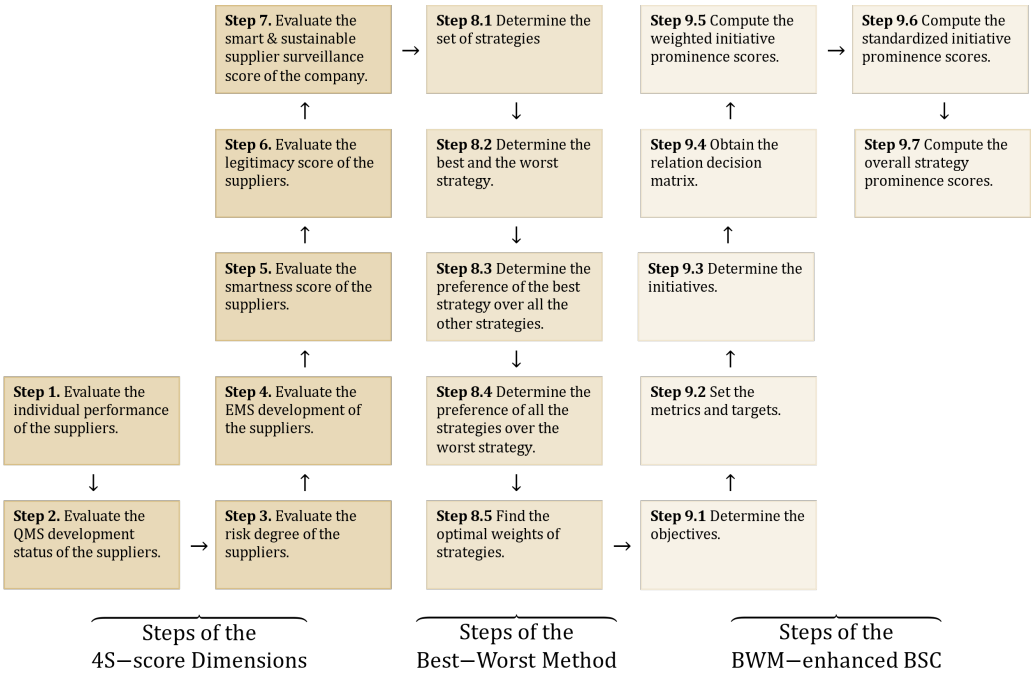

Figure 2. Methodological steps of the BWM-enhanced smart and sustainable supplier scorecard

Step 1: Evaluate the suppliers' individual performance.

Equation 1 computes supplier e's performance score (P_e), which is a function of the supplier performance evaluation score (p_e):

$$P_e = \begin{cases} 20, 85 \leq p_e \leq 100 \\ 15, 70 \leq p_e < 85 \\ 10, 50 \leq p_e < 70 \\ 0, p_e < 50 \end{cases} \quad (1)$$

Suppliers are classified according to their performance scores; evaluation scores (p_e) are 85–100 for class A suppliers, 70–85 for class B suppliers, 50–70 for class C suppliers, and 0–50 for class D suppliers.

The supplier performance evaluation score (p_e) is calculated by weighting the supplier capability score (p_{1e}), supplier shipment score (p_{2e}), and supplier price advantage score (p_{3e}):

$$p_e = 0.50p_{1e} + 0.35p_{2e} + p_{3e}. \quad (2)$$

1.1: Supplier capability score

The supplier capability score (p_{1e}) is calculated using Equation 3, which divides the amount accepted according to the quality acceptance standards during the period (p_{11e}) by the amount received (p_{12e}):

$$p_{1e} = 100 \times \frac{p_{11e}}{p_{12e}}. \quad (3)$$

1.2: Supplier shipment score

The supplier shipment score (p_{2e}) is calculated using Equation 4, which divides the quantity received on time (p_{21e}) by the order quantity (p_{22e}):

$$p_{2e} = 100 \times \frac{p_{21e}}{p_{22e}}. \tag{4}$$

1.3: Supplier price advantage score

Supplier price advantage score (p_{3e}) is calculated using Equation 5, which is a function of the purchasing price of goods (p_{31e}) to the average market price of purchased goods (p_{32e}):

$$p_{3e} = \begin{cases} 15, p_{31e} > p_{32e} \\ 0, p_{31e} \leq p_{32e} \end{cases} \tag{5}$$

Step 2. Evaluate the suppliers' QMS development status.

Equation 6 is used to calculate supplier e's quality management score (Q_e):

$$Q_e = \begin{cases} 20, & \text{Supplier } e \text{ holds ISO-9001 certification.} \\ 10, & \text{Supplier } e \text{ holds a QMS certification from accreditation institutions.} \\ 5, & \text{Supplier } e \text{ is a candidate for QMS certifications.} \\ 0, & \text{QMS certification is not available.} \end{cases} \tag{6}$$

Step 3. Evaluate the suppliers' risk degree.

Equation 6 is used to calculate supplier e's risk degree (R_e):

$$R_e = \begin{cases} 20, & \text{Supplier } e \text{ poses a low risk.} \\ 10, & \text{Supplier } e \text{ poses a moderate risk.} \\ 0, & \text{Supplier } e \text{ poses a high risk.} \end{cases} \tag{7}$$

The suppliers' risk degrees are determined based on the risk matrix in Appendix A; the first column represents the technological level of the supplier's production performance. Moving below the column means the supplier has a proven, reliable, up-to-date technological infrastructure. The second column shows the supplier's delivery performance. Moving below the column indicates that the supplier meets the requirements, reducing the risk. The rows of the risk matrix represent the production complexity of the parts supplied and their criticality for the system in terms of technical characteristics. Moving to the right of the row means the importance and complexity of the supply part increase. The decision-maker determines the supplier's risk according to the degrees of the columns and rows in the risk matrix. The supplier risk is classified into three levels: H for high risk, M for medium risk, and L for low risk.

Step 4. Evaluate the suppliers' EMS development.

Equation 8 calculates supplier e's environmental management score (E_e):

$$E_e = \begin{cases} 20, & \text{Supplier } e \text{ holds ISO-14001 certification.} \\ 10, & \text{Supplier } e \text{ is a candidate for ISO-14001 certification.} \\ 0, & \text{EMS certification is not available.} \end{cases} \tag{8}$$

Step 5. Evaluate the suppliers' smartness score.

Equation 9 calculates supplier e's smartness score (S_e):

$$S_e = \begin{cases} 20, & \text{Supplier } e \text{ has high technological investments.} \\ 10, & \text{Supplier } e \text{ has moderate technological investments.} \\ 0, & \text{Supplier } e \text{ has low technological investments.} \end{cases} \tag{9}$$

Step 6. Evaluate the legitimacy score of the suppliers.

Equation 10 calculates supplier e's smartness score (L_e):

$$L_e = \begin{cases} 20, & \text{Supplier } e \text{ offers safe products and meets legal conditions.} \\ -50, & \text{Supplier } e \text{ does not meet legal conditions.} \end{cases} \quad (10)$$

Step 7. Evaluate the smart and sustainable supplier surveillance score of the company.

The company's smart and sustainable supplier surveillance score (4S-score) is calculated by Equations 11–12. T_e represents the supplier e's score for the dimensions of the supplier scorecard, i.e., performance (P_e), quality management (Q_e), risk analysis (R_e), environmental management (E_e), smartness (S_e), and legitimacy (L_e). The 4S-score is calculated by adding up the average dimension scores ($\overline{P}, \overline{Q}, \overline{R}, \overline{E}, \overline{S}$, and $\overline{L}$), where these scores are the arithmetic mean of supplier E's scorecard dimension scores. The 4S-score represents the metric values of the smart and sustainable supplier scorecard.

$$4S = \overline{P} + \overline{Q} + \overline{R} + \overline{E} + \overline{S} + \overline{L} \quad (11)$$

$$\overline{T}\Sigma_{e=1}^{E} \frac{T_e}{E}, T_e = \{P_e, Q_e, R_e, E_e, S_e, L_e\} \quad (12)$$

Step 8. Determine the weights of strategies by using the BWM.

BWM is a multi-criteria decision-making method that compares the best criteria (alternatives) to the other criteria (alternatives) and all the other criteria (alternatives) to the worst criteria (alternatives). This study utilizes the BWM for weighting the strategies; thus, the method's criteria are substituted with alternative strategies. This process makes a comparison system composed of two comparison vectors, aiming to determine the optimal weights and consistency ratio through a simple optimization model constructed using the comparison system. The BWM comprises five steps (Rezaei, 2015).

Step 8.1: Determine the set of strategies.

In the first step, the decision-makers determine alternative strategies to improve the suppliers according to the scorecard dimension target values. Suppose that A_i (i=1,2,. . . ,m) represents the set strategies.

Step 8.2: Determine the best (e.g., most desirable or most important) and the worst (e.g., least desirable or least important) strategy.

Step 8.3: Determine the preference of the best strategy over all the other strategies by setting a ranking number between 1 and 9.

The resulting best-to-others vector is shown in Equation 13:

$$X_Y = (x_{Y1}, x_{Y2}, \ldots, x_{Ym}) \quad (13)$$

where x_{Ym} indicates the preference for the best strategy, A_Y, over strategy A_i; x_{YY}=1.

Step 8.4: Determine the preference of all the strategies over the worst strategy by setting a ranking number between 1 and 9.

The resulting others-to-worst vector is shown in Equation 14:

$$X_Z = (x_{1Z}, x_{2Z}, \ldots, x_{mZ}) \quad (14)$$

where x_{iZ} indicates the preference for strategy A_i over the worst strategy A_Z. It is clear that x_{ZZ}=1.

Step 8.5: Find the optimal weights of strategies.
$(w_1^*, w_2^*, \ldots, w_m^*)$

The optimal weight for the strategies is the one where for each pair of w_Y/w_i and w_i/w_Z , we have $w_Y/(w_i = x_{Yi})$ and $w_i/(w_Z = x_{iZ})$. To satisfy these conditions for all i, we find a solution that minimizes the maximum absolute differences, $\left|\frac{w_Y}{w_i} - x_{Yi}\right|$ and $\left|\frac{w_i}{w_Z} - x_{iZ}\right|$, for all i. Considering the non-negativity and sum condition for the weights, the following problem results as shown in Equation 15:

$$min \max_i \left\{ \left|\frac{w_Y}{w_i} - x_{Yi}\right|, \left|\frac{w_i}{w_Z} - x_{iZ}\right| \sum_i w_i = 1 \right. \quad s.t. \tag{15}$$

$w_i \geq 0$, for all$i$.

Equation 15 can be transferred to the following problem, as shown in Equation 16:

$$min\, \xi$$

s.t.

$$\begin{aligned} &\left|\frac{w_Y}{w_i} - x_{Yi}\right| \leq \xi \text{for all } i \\ &\left|\frac{w_i}{w_z} - x_{iW}\right| \leq \xi \text{for all } i \\ &\sum_i w_i = 1 \end{aligned} \tag{16}$$

$w_i \geq 0$, for all i.

By solving Equation 16, the optimal weights $(w_1^*, w_2^*, \ldots, w_m^*)$ for each strategy A_i and the consistency ratio (ξ^*) are obtained.

Step 9: Integrate the BSC framework with BWM.

Suppose that x_{ijk} represents the initiative relation score for the initiative B_{ij} (i=1,2,. . . ,m;j=1,2,. . . ,n) of strategy A_i (i=1,2,. . . ,m). It also considers BSC dimensions (D_k) (k=1,2,. . . ,K), i.e., performance, quality management, risk analysis, environmental management, smartness, and legitimacy. Fig. 3 illustrates the BWM-enhanced smart and sustainable supplier scorecard, which comprises the output of calculations that integrate the BSC framework with BWM.

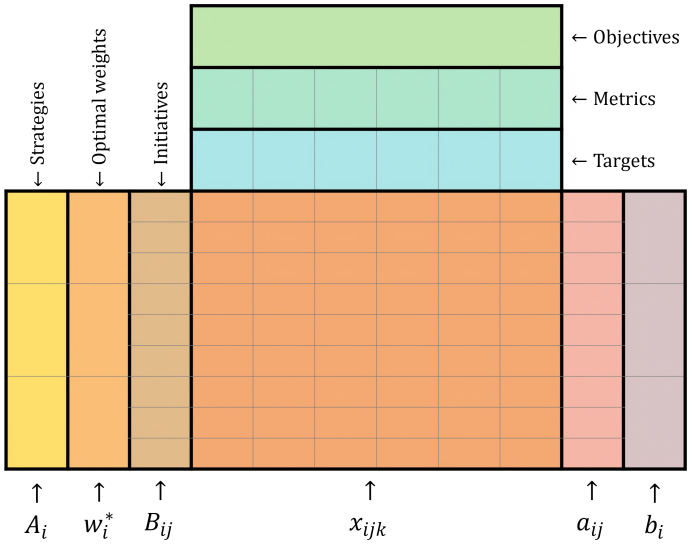

Figure 3. BWM-enhanced smart and sustainable supplier scorecard

Step 9.1: The decision-makers determine the objectives, translating strategic goals to performance targets.

Step 9.2: The metrics and targets are set as the dimensions of the supplier scorecard hexagon. The 4S-score represents the metric values of the smart and sustainable supplier scorecard. The targets are set as the theoretical maximum value of each dimension equals 20.

Step 9.3: The decision-makers determine the initiatives, confirming that each initiative yields a specific strategy.

Step 9.4: Obtain the relation decision matrix.

The initiative relation scores (x_{ijk}) are obtained from decision-makers' evaluations. Decision-makers are asked to evaluate the relation level between the initiatives and BSC dimension with a five-point Likert-type scale (1 = not at all related, 2 = slightly related, 3 = moderately related, 4 = highly related, and 5 = extremely related).

Step 9.5: Compute the weighted initiative prominence scores.

The weighted initiative prominence score (a^*_{ij}) for each initiative is calculated using Equation 15. Optimal weights (w^*_i) are determined via the BWM method in Step 8.5.

$$a^*_{ij} = \Sigma^K_{k=1} w^*_i x_{ijk} \tag{17}$$

Step 9.6: Compute the standardized initiative prominence scores.

Equation 16 is used to calculate the standardized initiative prominence score (a_{ij}) for each initiative. The standardization process includes dividing the weighted initiative prominence score (a^*_{ij}) by 5K, where 5 represents the maximum value of the Likert-type scale.

$$a_{ij} = \frac{a^*_{ij}}{5K} \tag{18}$$

The standardized initiative prominence score (a_{ij}) represents the relative effectiveness of an initiative to achieve scorecard dimension targets.

Step 9.7: Compute the overall strategy prominence scores.

Equation 17 is used to calculate the overall strategy prominence score).

$$b_i = \Sigma^n_{j=1} \frac{a_{ij}}{n} \tag{19}$$

The overall strategy prominence score (b_i) represents the relative effectiveness of a strategy to achieve scorecard dimension targets. Next, we test the applicability of the proposed approach via a case study.

4. Case study: Calculating the 4S-score of an HVAC company

We implemented the proposed smart and sustainable supplier scorecard method within a company that operates in the air heating, ventilation, and air conditioning (HVAC) industry. HVAC products are used in buildings to regulate temperature and humidity and maintain air quality (Design Buildings, 2023). The global HVAC market reached a value of over 158 billion United States dollars (USD) in 2022 and is expected to reach a value of about 227 billion USD by 2028, with a compound annual growth rate of 6.2% over 2023–2028 (Expert Market Research, 2023). Turkey has recently become a significant player in the global HVAC industry. Turkey is the fifteenth largest exporter of HVAC products globally, with exports totaling over 859 million USD in 2022, a significant increase from 676 million USD in 2021 (Trade Map, 2023). The Turkish HVAC industry is highly competitive, with many products and services available. The government supports the industry with incentives and subsidies for innovation and growth. The Turkish HVAC industry is well-positioned to benefit from the increasing demand for energy efficiency and green technologies. ISKID (2023), The Turkish Air Conditioning Industry Association, reported a 20% increase in split air conditioning production, a 2% increase in domestic sales, and a 20% increase in exports compared to 2022. The domestic market also increased by 15%, and VRF/VRV/VRS product exports increased by 150%. Rooftop air conditioner units increased by 30% in production and 50% in the market compared to the 2022. Heat pumps also increased by 140% in imports from 2017–2022, along with a 40% increase in exports.

ABC (founded in 1967) is one of Turkey's largest cooling/ventilation system manufacturers; due to the company's confidentiality policy, the company is renamed and referred to as ABC. The company produces various products, including cooling towers, industrial air conditioners, heating and cooling appliances, fan coil units, heat recovery exchangers, and air handling units (see Fig. 4). The company exports its products to over 30 countries, including India, the United States, Kazakhstan, Germany, France, Italy, Spain, and the United Kingdom. ABC company works with 140 domestic and 20 international suppliers. The company wants to assess its suppliers in terms of their smart and sustainable practices to comprehend their effects on production and supply chain quality. Fig. 5 illustrates ABC's supply chain network. ABC implements this study's BSC-based approach to a smart and sustainable supplier scorecard with approval from the company's top management. The quantitative data are collected using semi-structured interviews and observations. The 4S-score is calculated through Equation 11 by summing the averages of six-dimension scores. This section presents the result of the case study.

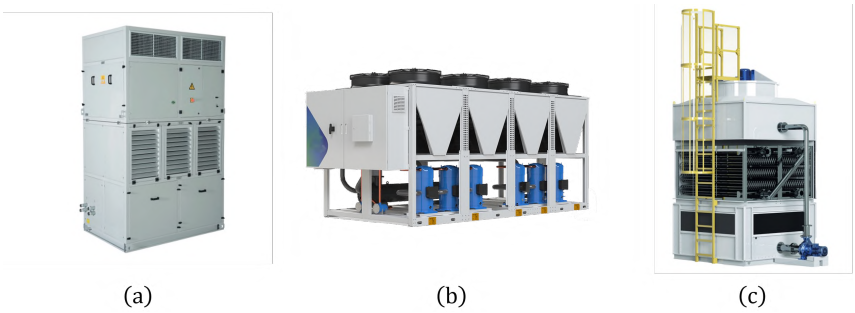

Figure 4. Sample of ABC's products (a: water-cooled industrial type air conditioner; b: air-cooled chiller; c: closed-circuit water cooling tower)

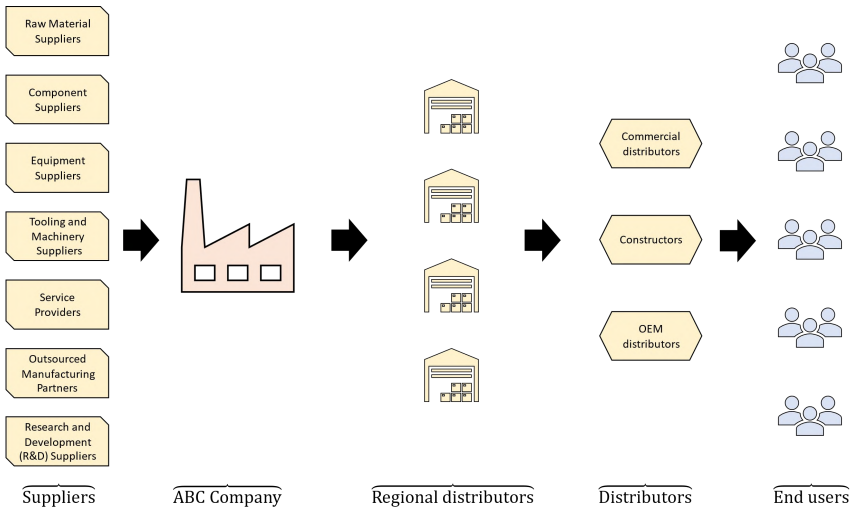

Figure 5. ABC's supply chain network

ABC's strategies and initiatives are determined by three representatives (general manager, operation manager, and finance manager). The case study's strategy and initiative determination process involves the representatives working together to identify the best strategies and initiatives to improve the company's smart and sustainable supplier assessment and monitoring process. The representatives review the SCM literature and research to identify the most effective strategies. They then discuss and evaluate the strategies that suit the company's smart and sustainable supplier assessment goals, considering its resources and capabilities to ensure the strategy is feasible and achievable. Once strategies and initiatives have been identified, the representatives develop a set of implementation initiatives, including setting goals, timelines, and budgets for each strategy. The representatives also consider the risks associated with each strategy and initiative and develop appropriate mitigation stratagems. Table 2 presents the strategies and initiatives adopted by the company representatives in this case study.

Table 2. Strategies and initiatives adopted in this study

Denotation	Strategy/Initiative	Source
$\boldsymbol{A_1}$	**Investment and collaboration strategy**	Klassen and Vachon (2009)
B_{11}	Information sharing with the suppliers	Liu *et al.* (2022)
B_{12}	Capacity sharing with suppliers	Hosseinnezhad *et al.* (2023)
B_{13}	Partner up with the suppliers by investing in shares	Fu *et al.* (2020)
$\boldsymbol{A_2}$	**Training and auditing strategy**	Sperber (1998)
B_{21}	Organize training programs for suppliers	Yu *et al.* (2022)
B_{22}	Set audit visits with firm inspectors to the suppliers' facilities	Asif *et al.* (2022)
B_{23}	Designate a third-party auditor to inspect the suppliers' facilities	Gonzalez–Padron (2016)
$\boldsymbol{A_3}$	**Competitive strategy**	Sillanpää *et al.* (2015)
B_{31}	Explore alternative or substitute parts, products, and technologies	Lu *et al.* (2011)
B_{32}	Sourcing backup suppliers	Yin and Wang (2018)
B_{33}	In-house production of supplied parts/products	Lin *et al.* (2021)
$\boldsymbol{A_4}$	**Risk-hedging strategy**	Gao (2015)
B_{41}	Buffer stock against disruption risk	Silva *et al.* (2022)
B_{42}	Create a supply chain coordination network to tackle the bullwhip effect	Kilubi (2016)
B_{43}	Create a geographically dispersed supply chain network	de Moura *et al.* (2021)
$\boldsymbol{A_5}$	**Sustainability strategy**	Matthess *et al.* (2022)
B_{51}	Require climate change mitigation strategic plan from the suppliers	Cadez and Czerny (2016)
B_{52}	Develop corporate social responsibility (CSR) projects with the suppliers	Bae *et al.* (2021)
B_{53}	Set a joint sustainability committee in collaboration with suppliers	Burke *et al.* (2019)

After determining pairwise comparison vectors, we obtain the criteria weights by solving Equation 16 in Step 8.5 using the GAMS program (see Table 3).

Table 3. Best-to-others and others-to-worst pairwise comparison vectors and criteria weights according to the BWM method

Strategy	Best-to-others	Others-to-worst	Weight
Investment and collaboration strategy	1	7	0.459
Training and auditing strategy	2	5	0.254
Competitive strategy	5	2	0.102
Risk-hedging strategy	4	3	0.127
Sustainability strategy	7	1	0.059

The calculations produce a consistency ratio (ξ^*) of 0.049, suggesting the analysis yields reliable results (Rezaei, 2016).

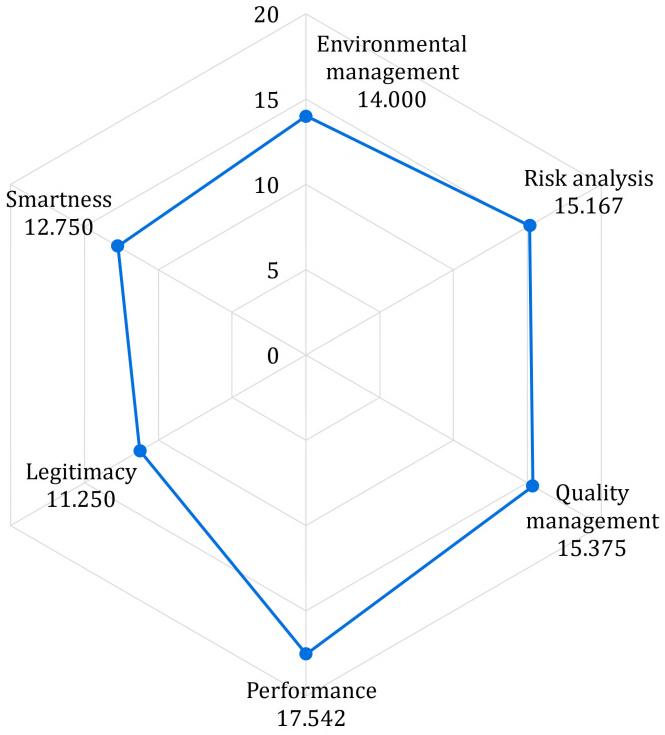

Figure 6. Radar chart of the 4S dimension scores

Fig. 6 demonstrates the dimension scores obtained from the 7 steps of the smart and sustainable supplier scorecard; each dimension's score was evaluated out of 20, and the 4S-score was evaluated out of 120. The highest scoring dimension is performance ($\overline{P}$=17.542), followed by quality management ($\overline{Q}$=15.375), risk analysis ($\overline{R}$=15.167), and environmental management ($\overline{E}$=14.000). The two dimensions with the lowest scores are smartness ($\overline{S}$ =12.750) and legitimacy ($\overline{L}$ =11.250). The sum of the scores for each dimension is calculated as 4S=86.084. The smart and sustainable supplier scorecard in Table 4 uses criteria weights obtained through BWM and dimension scores.

Table 4 presents the case study that applies the smart and sustainable supplier scorecard methodology to an HVAC company. The relation value matrix shows the relationship between the initiatives and metrics on a Likert-scale basis and is filled by the company representatives. The integration of BWM provides the optimal weight scores, representing each strategy's desirability. The optimal weight scores are multiplied with each relation value, and the standardized initiative prominence scores are computed for each initiative. We determine the overall strategy prominence score using the arithmetic mean of the three standardized initiative prominence scores. Investment and collaboration and training and auditing strategies are the most effective, with 0.296 and 0.186 overall prominence scores, respectively.

Table 4. Case study results for the smart and sustainable supplier scorecard

		Objectives	To improve supply chain efficiency and productivity							
		Metrics	**Performance**	**Quality management**	**Risk analysis**	**Environmental management**	**Smartness**	**Legitimacy**	**Standardized initiative prominence score** (a_{ij})	**Overall strategy prominence score** (b_i)
			$\bar{P} = 17.542$	$\bar{Q} = 15.375$	$\bar{R} = 15.167$	$\bar{E} = 14.000$	$\bar{S} = 12.750$	$\bar{L} = 11.250$		
		Targets	P→20	Q→20	R→20	E→20	S→20	L→20		
Strategy (A_i)	**Optimal weight** (w_i^*)	**Initiative** (B_{ij})	**Relation value** (x_{ijk})							
Investment and collaboration strategy	0.459	Information sharing with the suppliers	3	5	3	1	3	2	0.260	0.296
		Capacity sharing with suppliers	3	5	4	1	2	2	0.260	
		Partner up with the suppliers by investing in shares	4	5	5	2	3	5	0.367	
Training and auditing strategy	0.254	Organize training programs for suppliers	4	4	3	3	3	3	0.169	0.186
		Set audit visits with firm inspectors to the suppliers' facilities	4	4	4	3	3	4	0.186	
		Designate a third-party auditor to inspect the suppliers' facilities	4	4	4	4	3	5	0.203	
Competitive strategy	0.102	Explore alternative or substitute parts, products, and technologies	4	3	2	2	3	2	0.054	0.062
		Sourcing backup suppliers	4	3	1	2	1	2	0.044	
		In-house production of supplied parts/products	5	4	4	4	4	5	0.088	
Risk-hedging strategy	0.127	Buffer stock against disruption risk	4	3	4	1	2	2	0.068	0.079
		Create a supply chain coordination network to tackle the bullwhip effect	5	4	5	2	5	3	0.102	
		Create a geographically dispersed supply chain network	3	3	4	1	2	3	0.068	
Sustainability strategy	0.059	Require climate change mitigation strategic plan from the suppliers	1	2	2	5	3	4	0.033	0.032
		Develop CSR projects with the suppliers	1	2	2	5	2	2	0.028	
		Set a joint sustainability committee in collaboration with suppliers	1	2	3	5	3	5	0.038	

5. Discussion and implications

Our paper primarily contributes to the engineering management literature in the operations and SCM by introducing a six-dimension supplier assessment and monitoring tool. The proposed smart and sustainable supplier scorecard is designed based on the BWM-enhanced BSC approach, which helps company managers and decision-makers evaluate their suppliers' performance by incorporating digitization and sustainability. Several implications for managers can be extracted from the proposed assessment tool and case study. Managers should recognize that a supplier's performance is essential since it relates directly to the company's service level.

Table 4 evaluates and quantifies each strategy by weighting them using BWM. Each strategy comprises three initiatives, and the relation value matrix shows the relationship between each dimension and initiative. These scores are obtained by interviewing company representatives. Each initiative score is multiplied by the optimal weight scores for each strategy, and the sum of these scores is standardized, forming the standardized initiative prominence score for each initiative. The overall strategy prominence scores are determined by averaging standardized initiative prominence scores, implying the most prominent strategies that help the company overcome supplier-related challenges and threats. In our case, the investment and collaboration strategy is the most prominent course of action, followed by the training and auditing strategy; risk-hedging, competitive, and sustainability strategies come after the first two prominent strategies.

Among the initiatives, partnering with the suppliers by investing in shares obtains a higher prominence score; information and capacity sharing with suppliers receives the second higher prominence score. These are followed by designating a third-party auditor to inspect the suppliers' facilities, setting audit visits for the suppliers' facilities with firm inspectors, and organizing training programs for suppliers.

Furthermore, using strategy importance scores, the proposed 4S scorecard determines which strategies and initiatives should be prioritized. Managers can also monitor target values in six dimensions using the proposed BSC.

6. Conclusion

This paper introduces a novel method for a smart and sustainable supplier scorecard. Our approach is based on the BWM-enhanced BSC approach to develop, monitor, and inspect suppliers who impact a company's production and supply chain quality. A supplier scorecard is crucial for assessing a supplier's performance concerning particular metrics, and both small and large businesses use it to manage and monitor the performance of their suppliers. Companies can better understand their suppliers' sustainability and digitization practices by implementing a BSC-based approach.

Our paper's novel smart and sustainable supplier scorecard provides implications for managers and decision-makers in evaluating their suppliers regarding six dimensions: performance, quality management, risk analysis, environmental management, smartness, and legitimacy. Each dimension and its indicators determine the 4S-score; therefore, the insights obtained through implementing the smart and sustainable supplier scorecard guide companies to make better decisions regarding supplier selection processes, leading to a competitive market position.

Despite this paper's contributions to the extant research, our proposed method has some limitations that must be addressed for future research. We implemented our methodology in a company that operates in the HVAC industry and works with 160 suppliers. Upcoming research can broaden the scope to include other businesses from various industries.

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REFERENCES

Al Naimi, M., Faisal, Mohd. N., & Sobh, R. (2020). Prioritization of supply chain reconfiguration variables using balanced score card and analytic network process. *International Journal of Operations and Quantitative Management, 26*(2), 95–119. https://doi.org/10.46970/2020.26.2.2

Aliakbari Nouri, F., Shafiei Nikabadi, M., & Olfat, L. (2019). Developing the framework of sustainable service supply chain balanced scorecard (SSSC BSC). *International Journal of Productivity and Performance Management, 68*(1), 148–170. https://doi.org/10.1108/IJPPM-04-2018-0149

AlMaian, R. Y., Needy, K. L., Alves, T. da C. L., & Walsh, K. D. (2016). Analyzing effective supplier-quality-management practices using simple multiattribute rating technique and value-focused thinking. *Journal of Management in Engineering, 32*(1). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000364

Anjomshoae, A., Hassan, A., & Wong, K. Y. (2019). An integrated AHP-based scheme for performance measurement in humanitarian supply chains. *International Journal of Productivity and Performance Management, 68*(5), 938–957. https://doi.org/10.1108/IJPPM-04-2018-0132

Aqlan, F., Lam, S. S., & Ramakrishnan, S. (2016). Assessment of supply chain readiness for transformation. *International Journal of Business Performance and Supply Chain Modelling, 8*(3), 181–200. https://doi.org/10.1504/IJBPSCM.2016.078562

Asif, M., Searcy, C., & Castka, P. (2022). Exploring the role of industry 4.0 in enhancing supplier audit authenticity, efficacy, and cost effectiveness. *Journal of Cleaner Production, 331*, 129939. https://doi.org/10.1016/j.jclepro.2021.129939

Bae, J., Lund-Thomsen, P., & Lindgreen, A. (2021). Global value chains and supplier perceptions of corporate social responsibility: A case study of garment manufacturers in Myanmar. *Global Networks, 21*(4), 653–680. https://doi.org/10.1111/glob.12298

Barber, E. (2008). How to measure the "value" in value chains. *International Journal of Physical Distribution & Logistics Management, 38*(9), 685–698. https://doi.org/10.1108/09600030810925971

Basu, R., Little, C., & Millard, C. (2009). Case study: A fresh approach of the balanced scorecard in the Heathrow Terminal 5 project. *Measuring Business Excellence, 13*(4), 22–33. https://doi.org/10.1108/13683040911006765

Bigliardi, B., & Bottani, E. (2010). Performance measurement in the food supply chain: A balanced scorecard approach. *Facilities, 28*(5/6), 249–260. https://doi.org/10.1108/02632771011031493

Brege, S., Brehmer, P.O. and Rehme, J. (2008). Managing supplier relations with balanced scorecard. *International Journal of Knowledge Management Studies, 2*(1), 147-161. https://doi.org/10.1504/ijkms.2008.016447

Brewer, P. C. (2002). Aligning supply chain incentives using the balanced scorecard. *Supply Chain Forum: An International Journal, 3*(1), 12-19. https://doi.org/10.1080/16258312.2002.11517094

Burke, J. J., Hoitash, R., & Hoitash, U. (2019). The heterogeneity of board-level sustainability committees and corporate social performance. *Journal of Business Ethics, 154*(4), 1161–1186. https://doi.org/10.1007/s10551-017-3453-2

Cadez, S., & Czerny, A. (2016). Climate change mitigation strategies in carbon-intensive firms. *Journal of Cleaner Production, 112*, 4132–4143. https://doi.org/10.1016/j.jclepro.2015.07.099

Chandra, D., & Kumar, D. (2019). Two-way assessment of key performance indicators to vaccine supply chain system in India. *International Journal of Productivity and Performance Management, 68*(1), 194–230. https://doi.org/10.1108/IJPPM-02-2018-0078

Chang, H. H. (2009). An empirical study of evaluating supply chain management integration using the balanced scorecard in Taiwan. *The Service Industries Journal, 29*(2), 185–202. https://doi.org/10.1080/02642060802294961

Chang, H. H., Hung, C.-J., Wong, K. H., & Lee, C.-H. (2013). Using the balanced scorecard on supply chain integration performance—a case study of service businesses. *Service Business, 7*(4), 539–561. https://doi.org/10.1007/s11628-012-0175-5

Chang, T.-W., Pai, C.-J., Lo, H.-W., & Hu, S.-K. (2021). A hybrid decision-making model for sustainable supplier evaluation in electronics manufacturing. Computers & Industrial Engineering, 156, 107283. https://doi.org/10.1016/j.cie.2021.107283

Chen, P. S., & Wu, M. T. (2013). A modified failure mode and effects analysis method for supplier selection problems in the supply chain risk environment: A case study. *Computers & Industrial Engineering, 66*(4), 634-642. https://doi.org/10.1016/j.cie.2013.09.018

Chen, T., & Hu, L. (2022). *Enterprise supplier evaluation model based on entropy weight method in calculus learning* (pp. 440–447). https://doi.org/10.1007/978-3-031-04809-8_39

Chia, A., Goh, M., & Hum, S. (2009). Performance measurement in supply chain entities: Balanced scorecard perspective. *Benchmarking: An International Journal, 16*(5), 605–620. https://doi.org/10.1108/14635770910987832

Chorfi, Z., Benabbou, L., & Berrado, A. (2018). An integrated performance measurement framework for enhancing public health care supply chains. *Supply Chain Forum: An International Journal, 19*(3), 191–203. https://doi.org/10.1080/16258312.2018.1465796

Cinnirella, V., Carpitella, S., Coco, A., Frangiamore, D. D. M., & de Geronimo, R. P. (2022). Sustainable suppliers evaluation in the waste management sector: The case of a leading Sicilian enterprise. *IFAC-PapersOnLine, 55*(11), 66–71. https://doi.org/10.1016/j.ifacol.2022.08.050

Coşkun, S. S., Kumru, M., & Kan, N. M. (2022). An integrated framework for sustainable supplier development through supplier evaluation based on sustainability indicators. *Journal of Cleaner Production, 335*, 130287. https://doi.org/10.1016/j.jclepro.2021.130287

Cunha Callado, A. A., & Jack, L. (2015). Balanced scorecard metrics and specific supply chain roles. *International Journal of Productivity and Performance Management, 64*(2), 288–300. https://doi.org/10.1108/IJPPM-05-2014-0071

Cunha Callado, A. A., & Jack, L. (2017). Relations between usage patterns of performance indicators and the role of individual firms in fresh fruit agri-food supply chains. *Journal of Applied Accounting Research, 18*(3), 375–398. https://doi.org/10.1108/JAAR-04-2016-0037

De Giovanni, P., & Cariola, A. (2021). Process innovation through industry 4.0 technologies, lean practices and green supply chains. Research in Transportation Economics, 90, 100869. https://doi.org/10.1016/j.retrec.2020.100869

de Moura, R. L., Gonzalez, A., Franqueira, V. N. L., Neto, A. L. M., & Pessin, G. (2021). Geographically dispersed supply chains: A strategy to manage cybersecurity in industrial networks integration. In A*dvances in Cybersecurity Management* (pp. 97–116). Springer International Publishing. https://doi.org/10.1007/978-3-030-71381-2_6

Designing Buildings. (2023, March 7). *Heating ventilation and air conditioning HVAC*. Retrieved May 12, 2023, from https://www.designingbuildings.co.uk/wiki/Heating_ventilation_and_air_conditioning_HVAC

Dhiaf, M. M. , Benabdelhafid, A., & Jaoua, F. (2012). Supply chain flexibility and balanced scorecard: Conceptual model and empirical study in Tunisian companies launched upgrading program. *Polish Journal of Management Studies, 5*(1), 34–58.

Doolen, T., Traxler, M. M., & McBride, K. (2006). Using scorecards for supplier performance improvement: Case application in a lean manufacturing organization. *Engineering Management Journal, 18*(2), 26–34. https://doi.org/10.1080/10429247.2006.11431691

Esmaeilian, B., Sarkis, J., Lewis, K., & Behdad, S. (2020). Blockchain for the future of sustainable supply chain management in Industry 4.0. *Resources, Conservation and Recycling, 163*, 105064. https://doi.org/10.1016/j.resconrec.2020.105064

Expert Market Research. (2023). *Global HVAC market report and forecast 2023-2028*. Retrieved May 16, 2023, from https://www.expertmarketresearch.com/reports/hvac-market

Fernandes, A. C., Vilhena, E., Oliveira, R., Sampaio, P., & Carvalho, M. S. (2022). Supply chain quality management impact on organization performance: Results from an international survey. *International Journal of Quality & Reliability Management, 39*(2), 630–646. https://doi.org/10.1108/IJQRM-05-2020-0159

Ferreira, L. M. D. F., Silva, C., & Azevedo, S. G. (2016). An environmental balanced scorecard for supply chain performance measurement (Env_BSC_4_SCPM). *Benchmarking: An International Journal, 2*3(6), 1398–1422. https://doi.org/10.1108/BIJ-08-2013-0087

Foerstl, K., Reuter, C., Hartmann, E., & Blome, C. (2010). Managing supplier sustainability risks in a dynamically changing environment—sustainable supplier management in the chemical industry. *Journal of Purchasing and Supply Management, 16*(2), 118–130. https://doi.org/10.1016/j.pursup.2010.03.011

Franceschini, F., & Turina, E. (2012). Proposal for a performance dashboard for the monitoring of water and sewage service companies (WaSCs). *Water Resources Management, 2*6(1), 63–80. https://doi.org/10.1007/s11269-011-9901-3

Frederico, G. F., Garza-Reyes, J. A., Kumar, A., & Kumar, V. (2020). Performance measurement for supply chains in the Industry 4.0 era: A balanced scorecard approach. *International Journal of Productivity and Performance Management, 70*(4), 789–807. https://doi.org/10.1108/IJPPM-08-2019-0400

Fu, H., Li, K., & Fu, W. (2020). Investing in suppliers with capacity constraints in a decentralized assembly system. *Computers & Industrial Engineering, 142*, 106332. https://doi.org/10.1016/j.cie.2020.106332

Galankashi, M. R., Helmi, S. A., & Hashemzahi, P. (2016). Supplier selection in automobile industry: A mixed balanced scorecard–fuzzy AHP approach. *Alexandria Engineering Journal, 55*(1), 93–100. https://doi.org/10.1016/j.aej.2016.01.005

Gao, L. (2015). Collaborative forecasting, inventory hedging and contract coordination in dynamic supply risk management. *European Journal of Operational Research, 245*(1), 133–145. https://doi.org/10.1016/j.ejor.2015.02.048

Golrizgashti, S. (2016). Effect of knowledge management on supply chain value, empirical evidence from Iran. *International Journal of Business Performance and Supply Chain Modelling, 8*(2), 97–129. https://doi.org/10.1504/IJBPSCM.2016.077165

Gonzalez-Padron, T. L. (2016). Ethics in the supply chain: Follow-up processes to audit results. *Journal of Marketing Channels, 23*(1–2), 22–33. https://doi.org/10.1080/1046669X.2016.1147341

Govindan, K., Kaul, A., Darbari, J. D., & Jha, P. C. (2023). Analysis of supplier evaluation and selection strategies for sustainable collaboration: A combined approach of best–worst method and TOmada de Decisao Interativa Multicriterio. *Business Strategy and the Environment*. https://doi.org/10.1002/bse.3374

Govindan, K., Rajendran, S., Sarkis, J., & Murugesan, P. (2015). Multi criteria decision making approaches for green supplier evaluation and selection: A literature review. *Journal of Cleaner Production, 98*, 66–83. https://doi.org/10.1016/j.jclepro.2013.06.046

Ho, W., Xu, X., & Dey, P. K. (2010). Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *European Journal of Operational Research, 202*(1), 16–24. https://doi.org/10.1016/j.ejor.2009.05.009

Hosseinnezhad, D., Nugroho, Y. K., & Heavey, C. (2023). Horizontal collaboration between suppliers to mitigate supply chain disruption: A secure resource sharing strategy. *Computers & Industrial Engineering, 177*, 109088. https://doi.org/10.1016/j.cie.2023.109088

Hudnurkar, M., Rathod, U., Jakhar, S. K., & Vaidya, O. S. (2018). Development of a balanced scorecard-based supplier collaborative performance index. *International Journal of Productivity and Performance Management, 67*(2), 401–425. https://doi.org/10.1108/IJPPM-05-2016-0084

ISKID. (2023, April 28). *2022 Turkey HVAC'R Industry report*. ISKID. Retrieved May 17, 2023, from https://iskid.org.tr/en/2022-turkey-hvacr-industry-report/

Jalali Naini, S. G., Aliahmadi, A. R., & Jafari-Eskandari, M. (2011). Designing a mixed performance measurement system for environmental supply chain management using evolutionary game theory and balanced scorecard: A case study of an auto industry supply chain. *Resources, Conservation and Recycling, 55*(6), 593–603. https://doi.org/10.1016/j.resconrec.2010.10.008

Jochem, R., Menrath, M., & Landgraf, K. (2010). Implementing a quality-based performance measurement system. *The TQM Journal, 22*(4), 410–422. https://doi.org/10.1108/17542731011053334

Khaleeli, M., Faisal, R., & Anwar, S. (2021). The effect of green marketing, green supply chain and green human resources on business performance: Balanced scorecard approach. *Uncertain Supply Chain Management*, 133–138. https://doi.org/10.5267/j.uscm.2020.11.001

Khan, S. A. R., Dong, Q. L., & Yu, Z. (2016). Research on the measuring performance of green supply chain management: In the perspective of China. *International Journal of Engineering Research in Africa, 27*, 167–178. https://doi.org/10.4028/www.scientific.net/JERA.27.167

Kilubi, I. (2016). The strategies of supply chain risk management – a synthesis and classification. *International Journal of Logistics Research and Applications, 19*(6), 604–629. https://doi.org/10.1080/13675567.2016.1150440

Kim, J., & Rhee, J. (2012). An empirical study on the impact of critical success factors on the balanced scorecard performance in Korean green supply chain management enterprises. *International Journal of Production Research, 50*(9), 2465–2483. https://doi.org/10.1080/00207543.2011.581009

Klassen, R. D., & Vachon, S. (2009). Collaboration and evaluation in the supply chain: The impact on plant-level environmental investment. *Production and Operations Management, 12*(3), 336–352. https://doi.org/10.1111/j.1937-5956.2003.tb00207.x

Knotts, T. L., Jones, S. C., & Udell, G. G. (2006). Using a "balanced approach" to measure merchandising supplier performance. *Measuring Business Excellence, 10*(1), 4–13. https://doi.org/10.1108/13683040610652177

Kumar, S., C. Clemens, A., & W. Keller, E. (2014). Supplier management in a manufacturing environment. *International Journal of Productivity and Performance Management, 63*(1), 127–138. https://doi.org/10.1108/IJPPM-12-2012-0137

Liang, Y.-H. (2015). Performance measurement of interorganizational information systems in the supply chain. *International Journal of Production Research, 53*(18), 5484–5499. https://doi.org/10.1080/00207543.2015.1026614

Lin, F., Qin, X., Pu, X., Zhu, W., & Zhuo, X. (2021). Effects of in-house production on channel structures in a co-opetitive supply chain under supply uncertainty. *Omega, 103*, 102426. https://doi.org/10.1016/j.omega.2021.102426

Lin, Y., Tseng, M.-L., Chiu, A. S. F., & Wang, R. (2014). Implementation and performance evaluation of a firm's green supply chain management under uncertainty. *Industrial Engineering and Management Systems, 13*(1), 15–28. https://doi.org/10.7232/iems.2014.13.1.015

Liu, W., Long, S., Wei, S., Xie, D., Wang, J., & Liu, X. (2022). Smart logistics ecological cooperation with data sharing and platform empowerment: An examination with evolutionary game model. *International Journal of Production Research, 60*(13), 4295–4315. https://doi.org/10.1080/00207543.2021.1925173

Lo, H.-W., Liaw, C.-F., Gul, M., & Lin, K.-Y. (2021). Sustainable supplier evaluation and transportation planning in multi-level supply chain networks using multi-attribute- and multi-objective decision making. *Computers & Industrial Engineering, 162*, 107756. https://doi.org/10.1016/j.cie.2021.107756

Lu, M., Huang, S., & Shen, Z.-J. M. (2011). Product substitution and dual sourcing under random supply failures. *Transportation Research Part B: Methodological, 45*(8), 1251–1265. https://doi.org/10.1016/j.trb.2010.09.005

Matthess, M., Kunkel, S., Xue, B., & Beier, G. (2022). Supplier sustainability assessment in the age of Industry 4.0 – insights from the electronics industry. *Cleaner Logistics and Supply Chain, 4*, 100038. https://doi.org/10.1016/j.clscn.2022.100038

More, D., & Babu, A. S. (2012). Strategic approach to manage supply chain flexibility: A proposal. *International Journal of Logistics Systems and Management, 11*(4), 492–521. https://doi.org/10.1504/IJLSM.2012.046703

Nazari-Ghanbarloo, V. (2022). A dynamic performance measurement system for supply chain management. *International Journal of Productivity*

and Performance Management, 71(2), 576–597. https://doi.org/10.1108/IJPPM-01-2020-0023

Núñez-Merino, M., Maqueira-Marín, J. M., Moyano-Fuentes, J., & Martínez-Jurado, P. J. (2020). Information and digital technologies of Industry 4.0 and Lean supply chain management: A systematic literature review. *International Journal of Production Research, 58*(16), 5034–5061. https://doi.org/10.1080/00207543.2020.1743896

Pandey, I. M. (2005). Balanced scorecard: Myth and reality. Vikalpa: *The Journal for Decision Makers, 30*(1), 51–66. https://doi.org/10.1177/0256090920050105

Rahimnia, F., Keyvanipoor, S., & Moghadasian, M. (2014). Analysis of BSC perspectives as related to the alignment of environmental uncertainty and supply chain strategy. *Benchmarking: An International Journal, 21*(6), 903–916. https://doi.org/10.1108/BIJ-11-2012-0075

Reefke, H., & Trocchi, M. (2013). Balanced scorecard for sustainable supply chains: Design and development guidelines. *International Journal of Productivity and Performance Management, 62*(8), 805–826. https://doi.org/10.1108/IJPPM-02-2013-0029

Reuter, C., Foerstl, K., Hartmann, E., & Blome, C. (2010). Sustainable global supplier management: the role of dynamic capabilities in achieving competitive advantage. *Journal of Supply Chain Management, 46*(2), 45–63. https://doi.org/10.1111/j.1745-493X.2010.03189.x

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega, 53*, 49–57. https://doi.org/10.1016/j.omega.2014.11.009

Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model. Omega, 64, 126-130. https://doi.org/10.1016/j.omega.2015.12.001

Saidy, C., Pinna, C., Wilson, Z., Panavas, L., Harik, R., & Bayoumi, A. M. (2018). Literature review of current practices of supplier's assessment and valuation of decisions regarding underperforming suppliers. *International Journal of Product Lifecycle Management, 11*(3), 245–267. https://doi.org/10.1504/IJPLM.2018.094719

Saleheen, F., & Habib, Md. M. (2023). Embedding attributes towards the supply chain performance measurement. *Cleaner Logistics and Supply Chain, 6*, 100090. https://doi.org/10.1016/j.clscn.2022.100090

Saroha, M., Garg, D., & Luthra, S. (2022). Analyzing the circular supply chain management performance measurement framework: The modified balanced scorecard technique. *International Journal of System Assurance Engineering and Management, 13*(S2), 951–960. https://doi.org/10.1007/s13198-021-01482-4

Schiffling, S., & Piecyk, M. (2014). Performance measurement in humanitarian logistics: A customer-oriented approach. *Journal of Humanitarian Logistics and Supply Chain Management, 4*(2), 198–221. https://doi.org/10.1108/JHLSCM-08-2013-0027

Schloetzer, J. D. (2012). Process integration and information sharing in supply chains. *The Accounting Review, 87*(3), 1005–1032. https://doi.org/10.2308/accr-10216

Sharma, M. K., & Bhagwat, R. (2007). An integrated BSC-AHP approach for supply chain management evaluation. *Measuring Business Excellence, 11*(3), 57–68. https://doi.org/10.1108/13683040710820755

Shinkevich, A. I., Shaimieva, E. S., Nurgaliev, R. K., & Gumerova, G. I. (2021). *The modeling of operating activities of petrochemical and fuel and energy enterprises in industry 4.0. 27*(4), 1–11.

Sillanpää, I., Shahzad, K., & Sillanpää, E. (2015). Supplier development and buyer-supplier relationship strategies - a literature review. *International Journal of Procurement Management, 8*(1/2), 227–250. https://doi.org/10.1504/IJPM.2015.066283

Silva, P. M., Gonçalves, J. N. C., Martins, T. M., Marques, L. C., Oliveira, M., Reis, M. I., Araújo, L., Correia, D., Telhada, J., Costa, L., & Fernandes, J. M. (2022). A hybrid bi-objective optimization approach for joint determination of safety stock and safety time buffers in multi-item single-stage industrial supply chains. *Computers & Industrial Engineering, 168*, 108095. https://doi.org/10.1016/j.cie.2022.108095

Simić, D., Kovačević, I., Svirčević, V., & Simić, S. (2017). 50 years of fuzzy set theory and models for supplier assessment and selection: A literature review. *Journal of Applied Logic, 24*, 85–96. https://doi.org/10.1016/j.jal.2016.11.016

Sislian, L., & Jaegler, A. (2018). A sustainable maritime balanced scorecard applied to the Egyptian Port of Alexandria. *Supply Chain Forum: An International Journal, 19*(2), 101-110). https://doi.org/10.1080/16258312.2018.1481716

Şişman, T., Kiriş, S. B., & Yilmaz, D. (2022). Sustainable supplier evaluation in an automotive company using fuzzy multi-criteria decision-making methods. *International Journal of Information Technology & Decision Making*, 1–47. https://doi.org/10.1142/S0219622022500833

Sperber, W. H. (1998). Auditing and verification of food safety and HACCP. *Food Control, 9*(2–3), 157–162. https://doi.org/10.1016/S0956-7135(97)00068-6

Sundtoft Hald, K., & Ellegaard, C. (2011). Supplier evaluation processes: the shaping and reshaping of supplier performance. *International Journal of Operations & Production Management, 31*(8), 888-910. https://doi.org/10.1108/01443571111153085

Susanty, A., Bakhtiar, A., Puspitasari, N. B., & Mustika, D. (2018). Performance analysis and strategic planning of dairy supply chain in Indonesia. *International Journal of Productivity and Performance Management, 67*(9), 1435–1462. https://doi.org/10.1108/IJPPM-10-2017-0250

Taifa, I. W. R., Hayes, S. G., & Stalker, I. D. (2020). Development of the critical success decision criteria for an equitable order sharing in an extended enterprise. *The TQM Journal, 32*(6), 1715–1742. https://doi.org/10.1108/TQM-05-2019-0138

Thanki, S., & Thakkar, J. (2018). A quantitative framework for lean and green assessment of supply chain performance. *International Journal of Productivity and Performance Management, 67*(2), 366–400. https://doi.org/10.1108/IJPPM-09-2016-0215

Tolooie, M., Alvandi, M., & Arani, M. S. (2022). Sustainable supplier evaluation and selection in developing countries: An integrated fuzzy framework. *International Journal of Integrated Supply Management, 15*(2), 151–183. https://doi.org/10.1504/IJISM.2022.121952

Trade Map - List of exporters for the selected product: *8415 air conditioning machines comprising a motor-driven fan and elements for changing the temperature and humidity, incl. Those machines in which the humidity cannot be separately regulated; parts thereof.* (2023). ITC Trade Map. Retrieved May 17, 2023, from https://www.trademap.org/Country_SelProduct_TS.aspx?nvpm=1%7c%7c%7c%7c%7c%7c8415%7c%7c%7c%7c4%7c1%7c1%7c2%7c2%7c1%7c2%7c1%7

Varma, S., Wadhwa, S., & Deshmukh, S. G. (2008). Evaluating petroleum supply chain performance. A*sia Pacific Journal of Marketing and Logistics, 20*(3), 343–356. https://doi.org/10.1108/13555850810890093

Vörösmarty, G., & Dobos, I. (2020). A literature review of sustainable supplier evaluation with Data Envelopment Analysis. *Journal of Cleaner Production, 264*, 121672. https://doi.org/10.1016/j.jclepro.2020.121672

Yin, Z., & Wang, C. (2018). Strategic cooperation with a backup supplier for the mitigation of supply disruptions. *International Journal of Production Research, 56*(12), 4300–4312. https://doi.org/10.1080/00207543.2017.1410246

Yu, V. F., Qiu, M., & Gupta, J. N. D. (2022). Improving supplier capability through training: Evidence from the Chinese Automobile Industry. *Computers & Industrial Engineering, 163*, 107825. https://doi.org/10.1016/j.cie.2021.107825

Zhang, L.-J., Liu, R., Liu, H.-C., & Shi, H. (2020). Green supplier evaluation and selections: A state-of-the-art literature review of models, methods, and applications. *Mathematical Problems in Engineering, 2020*, 1–25. https://doi.org/10.1155/2020/1783421

Zheng, M., Li, Y., Su, Z., Fan, Y. Van, Jiang, P., Varbanov, P. S., & Klemeš, J. J. (2022). Supplier evaluation and management considering greener production in manufacturing industry. *Journal of Cleaner Production, 342*, 130964. https://doi.org/10.1016/j.jclepro.2022.130964

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Appendix 1. Risk matrix

	Production Technologies	**On-time Delivery Performance**					
Level of suppliers	Transformation of the entire production process on new production technologies, new supplier	They cause huge deficits in production	**M**	**H**	**H**	**H**	
	New technology is used in production	Problematic on-time deliveries	**L**	**M**	**H**	**H**	
	At the stage of installation of proven new production technology	Several problems have occurred during on-time deliveries so far	**L**	**M**	**M**	**H**	
	Proven production technology is used	On-time deliveries have been carried out without any problems so far	**L**	**L**	**M**	**M**	
			Standard parts and services such as catering and cleaning	Basic parts	More complex parts	System/module safety-related parts	Expected/desired level from the supplier in terms of technical know-how
			Simple manufacturing supply parts	Simple supply parts with low complexity to manufacture	Parts with medium complexity to manufacture	Parts with complex production processes	At what stage of the production chain?
			The effect of deviations on function/visuality is very low	The effect of deviations on function/visuality is low	The effect of deviations on function/visuality is moderate	The effect of deviations on function/visuality is significant	Department requests - Technical requirement: functional risk, materials - Visual requirements: voids, surface roughness, color

Location of supplied part/ module at the production level

H. Division/Supplier: High-Risk Initiation
M. Division/Supplier: Medium Risk Initiation
L. Division/Supplier: Low-Risk Initiation

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RESEARCH ARTICLE

Prediction of Airline Ticket Price Using Machine Learning Method

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ABSTRACT

Airline ticket pricing is a complex and dynamic process influenced by various factors, including demand fluctuations, seasonal variations, and competitive strategies. Accurate price prediction is crucial for both airlines, to maximize revenue, and customers, to secure the best deals. Traditional methods often fall short of capturing the intricate and rapidly changing patterns of airfare pricing. With the advent of machine learning algorithms, there is a growing potential to enhance the accuracy and reliability of ticket price predictions. This paper aims to predict ticket prices based on airline flight data using ML algorithms and to compare the performance of ML algorithms. The secondary objective of this paper is to identify the main factors affecting airline ticket prices. The flight and ticket price datasets of THY and PGS that were obtained from open-access sources are used in this paper. The final dataset consists of 962 records for three months from June 1st, 2022 to August 30th, 2022 and includes 19 different variables. Statistical tests and ML algorithms were applied to the final dataset. This paper compares various ML models to predict airline ticket prices, considering performance metrics such as MAE, MSE, RMSE, and R2 during training and test phases. According to the model training and test results, the best algorithm is GPR with R2: 0.86 (training) and R2: 0.90 (test). The findings are consistent with existing literature, further validating the superior efficacy of certain models in specific contexts and demonstrating significant progress in the field. This paper contributes to the literature by comparing the effectiveness of various machine learning algorithms in predicting airline ticket prices, providing new and valuable insights into model performance and key price-determining factors.

Keywords: Price Prediction, Ticket Price, Airfare Price, Machine Learning, Intelligent Transportation Systems

1. Introduction

In today's highly competitive airline industry, ticket pricing is crucial in attracting customers and maximizing revenue. Airline ticket prices are influenced by a multitude of factors including demand, seasonality, route popularity, fuel costs, and competitor pricing strategies (Wang et al., 2019). Given the dynamic nature of these factors, accurately predicting ticket prices is a complex and challenging task. Traditional pricing models often fall short of capturing the intricate patterns and rapid changes in the market (Deng, 2024).

Recent advancements in Machine Learning (ML) offer promising tools and techniques for addressing this challenge. ML models can analyze vast amounts of historical data and identify hidden patterns that can improve the accuracy of price predictions. These models can be trained to consider a wide range of variables simultaneously, adapting to new data and refining their predictions over time.

This paper aims to explore the application of various ML methods for predicting airline ticket prices. By leveraging ML algorithms, we seek to develop a robust predictive model that can assist airlines in optimizing their pricing strategies. The paper evaluates different ML techniques, including regression models, decision trees, and neural networks, to determine their effectiveness in forecasting ticket prices. The objectives of this research are threefold: (1) to identify the key factors influencing airline ticket prices, (2) to develop and compare the performance of various ML models in predicting these prices, and (3) to provide insights and recommendations for airlines to enhance their pricing strategies using the developed models.

In the following sections, we review the relevant literature on airline pricing and ML applications, describe the methodology and data used in our study, present the results of our model comparisons, and discuss the implications of our findings for the airline industry. This research contributes to the growing body of knowledge on dynamic pricing and offers practical solutions for one of the most critical aspects of airline revenue management.

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2. Related Work

The prediction of airline ticket prices has been an area of significant research interest, with various approaches and methodologies being explored to enhance accuracy and efficiency. Predicting airline ticket prices is a complex task due to the dynamic nature of pricing influenced by numerous fluctuating factors. Over the past decade, researchers have increasingly employed ML algorithms and Data Mining (DM) techniques to model these prices more accurately (Abdella et al., 2021; Aliberti et al., 2023; Groves & Gini, 2015; Kumar, 2023; Sherly Puspha Annabel et al., 2023; Zhao et al., 2022). This section reviews key studies and their contributions to the field, focusing on the methods employed and their performance outcomes.

Janssen et al. (2014) aimed to predict the lowest ticket price before departure using a linear quantile mixed regression model. While their model demonstrated reasonable short-term performance, its long-term efficiency was found to be inadequate. In this study, multiple LR models were compared to determine the best fit for advising passengers on whether to purchase a ticket immediately or wait for a better price. The authors recommended linear quantile mixed models for predicting the lowest fares, termed "real bargains." This study, however, was limited to economy-class tickets on flights from San Francisco to John F. Kennedy Airport. Tziridis et al. (2017) evaluated eight regression ML models to identify the optimal fare prediction algorithm. Among these, the Bagging Regression model achieved an accuracy of 87.42%, and the Random Forest (RF) Regression Tree achieved 85.91%. On the other hand, Gordiievych and Shubin (2015) utilized the ARIMA model to predict future ticket price drops, although specific performance results were not provided. Another study Santana et al. (2017) proposed Deep Regressor Stacking, which combines RF and Support Vector Machine (SVM) for more accurate predictions, demonstrating the applicability of these techniques across similar domains. Furthermore, Wohlfarth et al. (2011) focused on predicting the best time to buy tickets using Classification And Regression Trees (CART) and RF models, suggesting that these models could offer preliminary advice to customers during pre-registered purchase periods.

Beyond flight-specific features, other factors such as market demand significantly impact ticket pricing. For instance, Huang (2013) used Artificial Neural Network (ANN) and Genetic Algorithm (GA) to predict air ticket sales revenue for a travel agency, incorporating variables like international oil prices and stock market indices. The GA optimized input features for the ANNs, resulting in a Mean Absolute Percentage Error (MAPE) of 9.11%. Another study Kalampokas et al. (2023) examines airfare price prediction by comparing the pricing policies of different airlines using AI techniques. Specifically, it extracts features from over 136,000 flights from Aegean, Turkish, Austrian, and Lufthansa Airlines across six popular international destinations. AI models from three domains—ML, DL, and Quantum ML (QML)—comprising 16 different architectures, were employed to predict ticket prices. The findings indicate that at least three models from each domain achieved accuracy rates between 89% and 99% for this regression problem, demonstrating the effectiveness of AI in airfare price prediction.

Early research explored classification models to predict price trends. For instance, Ren et al. (2014) developed an ensemble model incorporating Linear Regression (LR), Naive Bayes, Softmax Regression, and SVM to predict the lowest ticket price before departure. The training errors for Naive Bayes and Softmax Regression were reduced to 24.88% and 20.22%, respectively, with SVM also showing an approximate 1% reduction in error. However, their SVM regression model underperformed, leading them to use an SVM classification model to differentiate prices as "higher" or "lower" than the average.

Gui et al. (2020) applied an ensemble model combining random tree models with Deep Learning (DL) to predict flight delays. The Long Short-Term Memory (LSTM) network effectively handled aviation sequence data, while the RF model achieved a 90.2% accuracy for binary classification, thereby mitigating overfitting issues. Likewise, Shih et al. (2019) proposed a DL model utilizing an attention mechanism for multivariate time series prediction, which incorporated frequency domain information for forecasting. Their TPA-LSTM model outperformed others in experimental tests, demonstrating the effectiveness of integrating attention mechanisms with DL techniques for improving prediction accuracy.

Lai et al. (2018) explored multivariate time series prediction using DL models, specifically Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), to extract short-term local dependency patterns among variables. Their results indicated superior performance across three out of four experimental datasets. Similarly, Yujing et al. (2020) focused on predicting flight passenger load factors with a CNN model incorporating a multi-granularity temporal attention mechanism (MTA-RNN), which demonstrated the best performance in their experiments. In the realm of stock time series prediction, Qin et al. (2017) applied a dual-stage attention-based RNN (DA-RNN), which showed superior performance on the SML 2010 and NASDAQ 100 datasets compared to other models. Additionally, Chen et al. (2018) developed a dual-stage attention-based RNN for sales volume forecasting in a commercial scenario, integrating trend alignment with dual-attention, multi-task RNNs, and their trend alignment with dual-attention model yielded the best prediction results in their studies. Collectively, these studies highlight the effectiveness of advanced DL techniques in various predictive tasks, demonstrating their potential for superior performance across different domains.

The collection and processing of airline ticket data, often sourced from web crawling or private collaborations, pose significant challenges. This variability makes it difficult to replicate studies and compare model performances. On the other hand, these studies

illustrate the breadth of approaches and techniques applied to airline ticket price prediction, from traditional regression models to advanced ML and DL frameworks. Each method has its strengths and limitations, contributing to the ongoing development of more accurate and efficient prediction models in this dynamic field.

3. Method

This paper aims to predict ticket prices based on airline flight data using ML algorithms and to compare the performance of ML algorithms. The secondary objective of this paper is to identify the main factors affecting airline ticket prices. The flight and ticket price datasets from Turkish Airlines (THY) and Pegasus Airlines (PGS) are used in this paper. The data obtained were analyzed using DM. DM allows the study data to be analyzed accurately and reduces the error rate. Thus, time and performance losses are prevented. Statistical tests and ML algorithms were applied to the final extracted dataset and airline ticket price prediction was performed.

3.1. Data Preprocessing

The dataset used for the analysis in this paper was obtained from open-access sources. The final dataset consists of 962 records for 3 months from June 1st, 2022 to August 30th, 2022. The dataset includes flight and ticket price data of THY and PGS airlines. There are 19 different variables in the dataset.

In this paper, some sub-processes were performed within the scope of data preprocessing. These are: removing columns with out-of-scope and missing values, completing missing data, extracting outliers and repeated values, data editing, normalization, and standardization. In general, identifying missing data, extracting outliers, and cleaning the dataset improves the accuracy of the models and makes the results more reliable.

Data editing, in general, can be expressed as cleaning categorical variables and re-expressing them with a standard. The data editing phase was completed with two approaches which are called one-hot encoding and label encoding. Data editing can be defined as the rescaling and standardization of numerical variables in general. First, the data were arranged, and then normalization and standardization were performed. On the other hand, the categorical variables were transformed to numerical classification, labelled, and categorized by removing the textual expressions in the dataset.

Normalization and standardization are two important techniques used in data preprocessing. Normalization rescales the data between 0 and 1, while standardization rescales the data to have the same mean (0) and the same standard deviation (1) (Karataş, 2021). The min-max scaler method which is one of the most popular normalization methods was used in this paper. Notations of normalization and standardization are presented in Table 1.

Table 1. Notations of normalization and standardization

	Notation	Explanation
Normalization	$X_{new} = \frac{X - X_{min}}{X_{max} - X_{min}}$	X_{new} : new normalized value X_{max} : maximum value in variable X_{min} : minimum value in variable
Standardization	$Z = \frac{X - \mu}{S}$	Z : new standardized z-score X : number of observations μ : mean of observations S : standard deviation

3.2. Data Analysis

Some statistical analyses were performed on the final dataset. Statistical analysis is a type of analysis using statistical methods to make sense of the data, identify patterns, understand the relationships between variables, and predict future events. In this paper, descriptive analysis and correlation analysis were performed within the scope of statistical analysis.

Descriptive analysis is used to understand the general characteristics of the dataset, to identify important patterns and trends, and to provide a basis for further analysis. Descriptive analysis aims to reveal the general characteristics of the variables related to flight and ticket price in the final dataset in detail. The study dataset and the results of the descriptive analysis are shown in Table 2.

Table 2. Study dataset and descriptive analysis results

Variable Name	Description	Data Type	Unique Value Count	Min.	Max.	Range	Mean	Median	Mode	Standard Deviation	Variance
AirlineCode	The commercial code of the airline	Categorical	2	1	2	1	1,25	1	1	-	-
FlightDay	The day of flight	Numerical	30	1	31	30	12,77	11	1	8,96	80,35
FlightMonth	The month of flight	Numerical	3	6	8	2	6,99	7	6	0,82	0,68
FlightYear	The year of flight	Numerical	1	2022	2022	0	2022	2022	2022	0	0
DepCode	The commercial code of departure airport	Categorical	29	1	29	28	12,83	12,5	1	-	-
DesCode	The commercial code of arrival airport	Categorical	9	21	37	16	31,62	33	21	-	-
DepHour	The departure time in hours	Numerical	22	0	23	23	10,44	10	11	5,17	26,69
DepMin	The departure time in minutes	Numerical	12	0	55	55	23,57	20	0	17,79	316,35
ArrHour	The arrival time in hours	Numerical	24	0	23	23	12,93	14	7	6,15	37,79
ArrMin	The arrival time in minutes	Numerical	12	0	55	55	26,37	25	30	17,62	310,55
Day	Whether the arrival was the same day or next day	Categorical	2	1	2	1	1,11	1	1	-	-
Duration(min)	The flight duration	Numerical	132	55	1465	1410	314,96	280	230	184,72	34120,63
BoughtDay	The day that the ticket was bought	Numerical	3	16	18	2	16,54	16	16	0,75	0,56
BoughtMonth	The month that the ticket was bought	Numerical	1	2	2	0	2	2	2	0	0
BoughtYear	The year that the ticket was bought	Numerical	1	2022	2022	0	2022	2022	2022	0	0
Stop	The number of flight stops	Numerical	3	1	3	2	1,85	2	2	0,49	0,24
DayDiffer	The day difference between date of flight and ticket sale	Numerical	82	103	194	91	146,38	144	136	27,12	735,73
PriceEx	The price exchange between date of flight and ticket sale	Numerical	20	0	99	99	74,46	81	98	28,26	798,72
Price(₺)	The price of airline ticket	Numerical	148	279	1212	933	935,85	1005	1159	250,33	62663,68

Correlation analysis is a statistical technique that measures the relationship between two or more variables and the strength of this relationship. Correlation analysis is usually performed using the Pearson Correlation Coefficient (Miles & Banyard, 2007). Pearson correlation is a parametric measure of the linear relationship between two continuous variables (Gibbons, 1997; Howell, 1992). Its values vary between -1 and +1 (Cohen, 2013). +1 is a full positive correlation, meaning that when one variable increases, the other variable increases linearly. 0 means that there is no correlation between the two variables. -1 means full negative correlation, meaning that when one variable increases, the other variable decreases linearly. According to the results of the correlation analyses, the variables with a correlation between them and the related values are presented in Table 3.

Table 3. Correlation analysis results

	AirlineCode	FlightDay	FlightMonth	FlightYear	DepCode	DesCode	DepHour	DepMin	ArrHour	ArrMin	Day	Duration(min)	BoughtDay	BoughtMonth	BoughtYear	Stop	DayDiffer	PriceEx	Price(₺)
AirlineCode	**1,00**																		
FlightDay	0,09	**1,00**																	
FlightMonth	-0,03	0,04	**1,00**																
FlightYear	0,00	0,00	0,00	**1,00**															
DepCode	0,06	-0,12	-0,04	0,00	**1,00**														
DesCode	0,02	0,03	0,00	0,00	-0,04	**1,00**													
DepHour	0,22	-0,02	0,03	0,00	0,10	0,02	**1,00**												
DepMin	-0,15	0,17	0,04	0,00	-0,18	0,00	-0,13	**1,00**											
ArrHour	-0,06	0,02	-0,04	0,00	0,15	0,01	0,23	-0,21	**1,00**										
ArrMin	-0,02	0,02	0,02	0,00	-0,02	-0,09	-0,01	-0,03	-0,08	**1,00**									
Day	0,18	-0,06	0,05	0,00	0,07	-0,03	0,53	0,08	-0,61	0,06	**1,00**								
Duration(min)	-0,04	-0,09	-0,01	0,00	0,33	-0,08	0,11	-0,10	0,13	0,09	0,37	**1,00**							
BoughtDay	0,43	-0,28	-0,07	0,00	0,58	-0,03	0,27	-0,25	0,06	-0,03	0,26	0,33	**1,00**						
BoughtMonth	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**1,00**					
BoughtYear	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**1,00**				
Stop	-0,14	-0,07	0,00	0,00	0,24	-0,18	-0,05	-0,04	0,15	0,05	0,12	0,69	0,13	0,00	0,00	**1,00**			
DayDiffer	-0,01	0,38	0,94	0,00	-0,09	0,01	0,01	0,10	-0,04	0,03	0,02	-0,04	-0,18	0,00	0,00	-0,03	**1,00**		
PriceEx	0,49	0,21	0,01	0,00	-0,15	0,05	0,13	0,08	-0,07	-0,02	0,06	-0,22	0,04	0,00	0,00	-0,35	0,08	**1,00**	
Price(₺)	-0,29	0,05	0,09	0,00	0,22	-0,09	-0,07	0,02	0,22	0,08	0,00	0,56	-0,02	0,00	0,00	0,80	0,10	-0,36	**1,00**

Correlation analysis was applied to the final dataset variables used in this paper. According to the correlation matrix presented in Table 3, correlations less than -0.50 and greater than 0.50 are highlighted in red. According to the analysis results, it was found that there were high positive correlations between some variables. There is a positive linear relationship of 0.94 between the DayDiffer and FlightMonth variables and 0.80 between the Price(£) and Stop variables. In this case, the Multicollinearity problem arises. Multicollinearity refers to a situation where there is a high correlation or relationship between independent variables in a predicting model (Farrar & Glauber, 1967). In other words, one or more independent variables are strongly correlated with other independent variable(s). This may cause problems in the prediction model. At this point, the variables the FlightMonth and Stop which cause positive correlation and are also considered to negatively affect the model performance were removed from the model to perform the prediction accurately.

3.3. Modelling

This paper requires a supervised regression ML technique according to the dataset structure and the problem addressed. Regression algorithms, which are used in cases where the dependent variable should take a continuous value, stand out with their data analysis and prediction capabilities. In this study, regression algorithms are used within the scope of supervised learning on a labelled dataset. In this paper, various regression algorithms such as Linear Regression (LR), Decision Tree (DT), Support Vector Machines (SVM), Efficiently Linear Regression (ELR), Gaussian Process Regression (GPR), Kernel Approximation Regression (KAR), Ensemble Tree (ET), and Neural Networks (NN), which are widely used in the literature, were used and their performances were compared.

LR is a simple, yet powerful statistical method used for modeling the relationship between a dependent variable and one or more independent variables. It assumes a linear relationship between the variables and aims to find the best-fitting straight line (or hyperplane in higher dimensions) through the data points. DT is a type of decision tree used for regression tasks. They recursively partition the feature space into smaller regions and fit a simple model (usually a constant value) to each region. This allows for non-linear relationships to be captured in the data. SVM is a powerful supervised learning algorithm used for classification and regression tasks. It works by finding the optimal hyperplane that best separates the data into different classes while maximizing the margin. SVM can also be used for regression tasks by finding the hyperplane that best fits the data within a margin of tolerance. ELR is an optimization approach that combines stochastic gradient descent with L1 and L2 regularization to efficiently solve linear regression problems. It aims to minimize the sum of squared errors while penalizing large coefficients to prevent overfitting. GPR is a non-parametric probabilistic approach to regression tasks. It models the relationship between input and output variables as a joint Gaussian distribution, allowing for uncertainty estimation in predictions. GPR is flexible and can capture complex relationships without assuming a specific parametric form. KAR is a regression method that approximates the kernel trick used in Support Vector Machines. It maps input features into a higher-dimensional space using a kernel function, allowing linear models to capture non-linear relationships efficiently. ET, commonly known as Random Forests or Gradient-Boosted Trees, are ensemble learning techniques that combine multiple decision trees to improve predictive performance. They work by training multiple trees independently and averaging their predictions (or combining them in a weighted manner) to make more accurate predictions. NN is a class of ML models inspired by the structure and function of the human brain. They consist of interconnected nodes organized in layers and are capable of learning complex patterns and relationships from data. Neural networks have been successful in various tasks, including regression, classification, and pattern recognition.

LR serves as the fundamental basis for many regression techniques, including ELR, which enhances LR's optimization process. SVM builds upon LR's principles, providing a robust framework for both classification and regression tasks, with ELR borrowing optimization strategies from SVM. DT offers a different approach, utilizing tree-based structures to capture non-linear relationships, close to ET which leverages multiple decision trees for improved accuracy. GPR diverges by employing a probabilistic framework, allowing for uncertainty estimation in predictions, contrasting KAR which efficiently approximates non-linear relationships using kernel functions, reminiscent of SVM's kernel trick. NN stands as a versatile paradigm, capable of learning intricate patterns and relationships from data, with the potential to encompass aspects of all aforementioned methods within their deep architectures. The regression algorithms used in this paper and their notations are presented in Table 4.

Table 4. Regression algorithms and notations

Algorithm	Notation	Explanation
LR	$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \epsilon$	y : dependent variable x_n : independent variable β_n : regression coefficient ϵ : error term
DT	$\hat{y} = f(x) = \sum_{m=1}^{M} c_m \cdot I(x \in R_m)$	$\hat{y}$: predicted value of dependent variable x : vector of dependent variable M : total number of leaf nodes R_m : region corresponding to the m-th leaf node c_m : prediction coefficient at the m-th leaf node $I(x \in R_m)$: function indicating whether x is present in R_m
SVM	$\rightarrow w \cdot x + b = 0$ (hyperplane) $\rightarrow min_{w,b} \frac{1}{2} \|w\|^2$ $\rightarrow y_i(w \cdot x_i + b) \geq 1 \; for \; i = 1,2,\ldots,n$ (constraints)	w : weight vector perpendicular to the hyperplane b : bias term x : input feature vector x_i : feature vector y_i : class label
ELR	$J(w) = \frac{1}{2m} \sum_{i=1}^{m} \left(h_w(x^{(i)}) - y^{(i)}\right)^2 + \lambda_1 \|w\|_1 + \frac{\lambda_2}{2} \|w\|_2^2$	w : weight vector m : number of training samples $h_w(x^{(i)})$: predicted value for the i-th observation $y^{(i)}$: actual value for the i-th observation λ_1 and λ_2: L1 and L2 regularization parameters
GPR	$f(x) \sim GP(m(x), K(x, x'))$	$f(x)$: predicted value of dependent variable $m(x)$: mean function $K(x, x')$: kernel function
KAR	$f(x) = \sum_{i=1}^{n} a_i \cdot K(x, x_i)$	$f(x)$: predicted value of dependent variable x : input value to be estimated x_i : i-th observation in the dataset a_i : coefficient of i-th observation $K(x, x_i)$: kernel function
ET	$y(x) = \frac{1}{B} \sum_{i=1}^{B} T_i(x)$	$y(x)$: predicted output B : number of trees $T_i(x)$: prediction of the i-th tree for x
NN	$y = f\left(\sum_{i=1}^{n} w_i x_i + b\right)$	y : output of a neural cell f : activation function (i.e. sigmoid, ReLU, tanh) x_i : input value w_i : input weight b : bias term

3.4. Performance Measures

R-squared - Determination Coefficient (R^2), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Mean Absolute Error (MAE) metrics were used to measure the performance of the ML algorithms in this paper. R^2 indicates that the independent variable can explain the percentage of total changes in the dependent variable. R^2, which ranges between 0 and 1, indicates that the model performs better as it approaches 1. MSE is another important metric that evaluates the model performance. MSE measures the mean squared error between the actual and predicted values of the model. Lower MSE values indicate that the model makes better predictions. RMSE is the square root of MSE. Calculating the RMSE is a useful way to evaluate the model's accuracy. RMSE measures the error between the actual values and the predicted values. The error rate decreases as the RMSE approaches 0. The performance measures used in this paper and their notations are presented in Table 5.

Table 5. Performance measures and notations

Performance Measures	Explanation	Reference
$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}$	n : number of observations y_i : true responses $\hat{y}_i$: predicted responses $\bar{y}_i$: true responses mean	(Barrett, 2000; Di Bucchianico, 2008)
$MSE = \frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$	n : number of observations y_i : true responses $\hat{y}_i$: predicted responses	(Hyndman & Koehler, 2006; Makridakis et al., 1982)
$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2}$	n : number of observations y_i : true responses $\hat{y}_i$: predicted responses	(Hyndman & Koehler, 2006; Nevitt & Hancock, 2000)
$MAE = \frac{1}{n} \sum_{i=1}^{n} \|y_i - \hat{y}_i\|$	n : number of observations y_i : true responses $\hat{y}_i$: predicted responses	(Hyndman & Koehler, 2006; Sammut & Webb, 2010)

4. Results

In the results section, it is focused on the performance results of the implemented regression-based ML algorithms. MATLAB R2023b was used in the training and test processes of ML algorithms. MATLAB is a widely preferred tool in data analysis and ML applications and played a crucial role in this study. The performance results provide a detailed perspective on the effectiveness, accuracy, and reliability of the models developed to predict airline ticket prices. The findings will provide an important basis for how successful these models can be in practical applications.

According to the model training and test results, the best algorithm is GPR with R^2: 0.86 (training) and R^2: 0.90 (test). The GPR algorithm has lower RMSE, MSE, and higher R^2 values, indicating that this model has a better learning and prediction capability. However, it should be noted that each model may have various advantages and disadvantages in different application and problem contexts. The choice of the best model may vary depending on the requirements and data structure of a particular problem. Figure 1 shows the airline ticket prices and their predicted values from the final dataset. Also, Figure 2 shows the comparison of the observed Price(TL) values in the training data set with the predicted values according to the perfect prediction curve (diagonal).

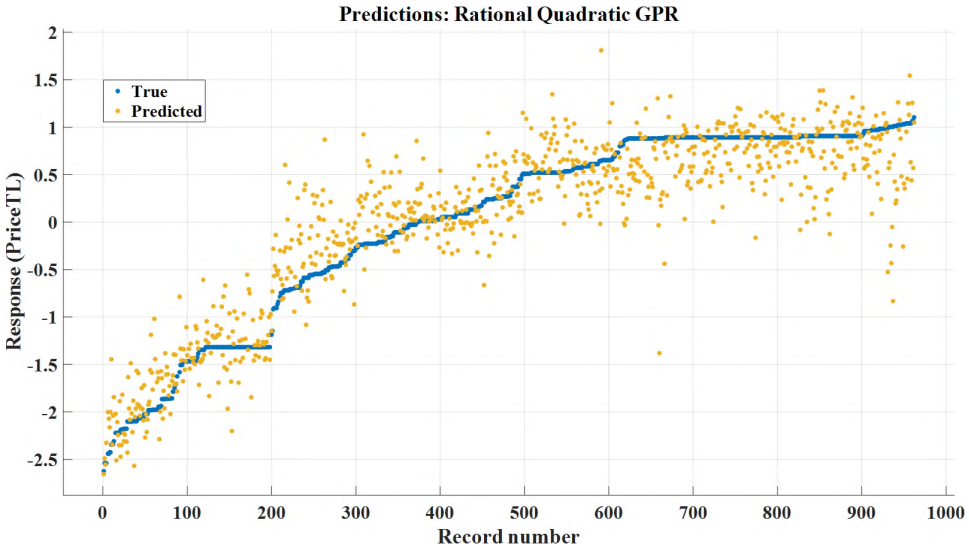

Figure 1. Distribution of true and predicted values by GPR algorithm (Training)

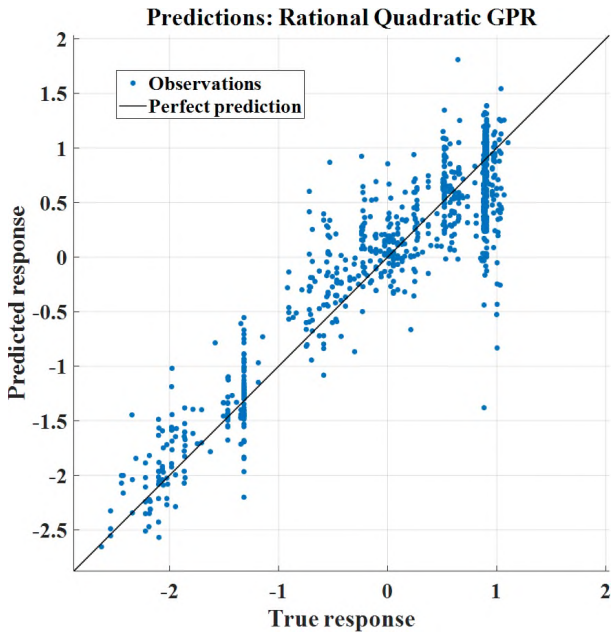

Figure 2. Comparison of true and predicted values by GPR algorithm (Training)

4.1. Training and Test Dataset

The numbers and percentages of the datasets used in the training and testing processes of the implemented ML algorithms are presented in this part. The results obtained are critical for the evaluation of the performance. The final dataset used in this paper is divided into a 90% training set and a 10% test set. The number and proportions of training and test datasets used for ML algorithms are presented in Table 6.

Table 6. The count and percentage of observations for training and test datasets

	Observations	Percentage
Training Data	866	%90
Test Data	96	%10
Total	962	%100

4.2. Performance Optimization

In this paper, different methods are used for the performance optimization of regression-based ML models. These methods are k-fold cross validation, principal component analysis (PCA), and feature selection (FS). A value of 5 was set for k-fold cross validation. 5-fold cross validation is a technique that involves dividing the dataset into five equal parts. One of these parts is used as the test dataset, while the remaining four parts are used as the training dataset. The model is then trained and tested, and this process is repeated five times, each time choosing a different part as the test dataset. The overall model performance is calculated by averaging the performance measures obtained from each test run. PCA analysis was performed as another method. PCA results can be used to assess the significance and predictive power of variables in regression models.

The FS algorithm was implemented to reduce the model complexity, avoid overlearning, and increase the predictive power. As a result of the prediction model experiments, it has been observed that FS analyses affect the prediction performance by about 3-5%. The variables selected, the tests performed and the scores of the variables within the scope of the FS analysis are presented in Table 7. In this paper, F Test scores were used. Accordingly, 13 different variables with scores greater than zero were selected to be used in the training and testing of the models.

Table 7. Feature selection algorithms and importance scores of variables

No.	Features	F Test	No.	Features	MRMR
1	Duration(min)	5.485.005	1	PriceEx	16.096
2	PriceEx	3.893.397	2	DayDiffer	10.713
3	DesCode	2.984.395	3	DesCode	0.8917
4	DepCode	483.303	4	Duration(min)	0.7631
5	BoughtDay	480.109	5	ArrHour	0.6174
6	ArrHour	459.737	6	BoughtDay	0.5873
7	AirlineCode	441.948	7	DepMin	4416
8	DepHour	353.904	8	FlightDay	0.3541
9	FlightDay	134.514	9	ArrMin	0.3432
10	ArrMin	108.690	10	DepHour	0.2586
11	DayDiffer	48.172	11	AirlineCode	0.1939
12	DepMin	40.774	12	DepCode	0.1725
13	Day	0.0362	13	Day	0.0258

4.3. Model Performance Comparison

The results of our experiments aimed at comparing the performance of various ML algorithms are presented in this section. Below, detailed information is provided on the performance error rates (MAE, MSE, RMSE) and R^2 values for each model type on both training and test sets. Additionally, the computation times of the models are compared. This analysis allows us to evaluate the performance of the models in terms of accuracy and computational cost. Comparative training and test results of regression-based ML algorithms are presented in Table 8.

Table 8. Comparative training and testing results

Model Category	Model Type	Training					Test			
		MAE	MSE	RMSE	R^2	Time (obs/sec)	MAE	MSE	RMSE	R^2
LR	Linear	0,40039	0,29095	0,5394	0,70929	3600	0,38031	0,27258	0,52209	0,72375
	Interactions Linear	33,74	87300	295,47	-87227	2000	0,70971	4,2857	2,0702	-3,3435
	Robust Linear	0,36837	0,33751	0,58095	0,66277	3700	0,39339	0,38422	0,61986	0,6106
	Stepwise Linear	0,54087	1,392	1,1798	-0,39087	3500	0,42473	0,83185	0,91206	0,15692
DT	Fine Tree	0,33102	0,31785	0,56379	0,68241	4600	0,29416	0,29696	0,54494	0,69904
	Medium Tree	0,34308	0,28885	0,53744	0,71139	5300	0,36839	0,3555	0,59624	0,63971
	Coarse Tree	0,3962	0,32469	0,56981	0,67558	7200	0,42497	0,38576	0,62110	0,60903
SVM	Linear SVM	0,37302	0,30796	0,55494	0,69229	6600	0,38296	0,31851	0,56437	0,67719
	Quadratic SVM	0,31177	0,21702	0,46585	0,78316	5200	0,29941	0,1584	0,398	0,83946
	Cubic SVM	0,29949	0,17651	0,42013	0,82364	6700	0,23893	0,10542	0,32468	0,89316
	Fine Gaussian SVM	0,76674	0,88528	0,94089	0,11545	6800	0,76768	0,8666	0,93091	0,12171
	Medium Gaussian SVM	0,3146	0,18329	0,42813	0,81686	6400	0,25806	0,11261	0,33558	0,88587
	Coarse Gaussian SVM	0,4651	0,33409	0,578	0,66619	4200	0,41318	0,25137	0,50137	0,74524
ELR	Efficient Linear Least Squares	0,40347	0,29215	0,54051	0,70809	3400	0,38285	0,27045	0,52005	0,7259
	Efficient Linear SVM	0,36477	0,31808	0,56399	0,68218	5200	0,3778	0,33579	0,57948	0,65968
ET	Boosted Trees	0,33362	0,21426	0,46288	0,78592	3400	0,33647	0,23242	0,4821	0,76445
	Bagged Trees	0,31653	0,22443	0,47374	0,77576	2800	0,30259	0,23895	0,48883	0,75783
GPR	Squared Exponential GPR	0,28555	0,14977	0,38701	0,85035	3700	0,24658	0,10322	0,32128	0,89539
	Matern 5/2 GPR	0,27717	0,14430	0,37986	0,85582	4000	0,24469	0,10427	0,32291	0,89432
	Exponential GPR	0,28547	0,15090	0,38845	0,84923	4500	0,25913	0,11794	0,34342	0,88047
	Rational Quadratic GPR	0,27595	0,143	0,37816	0,85712	4800	0,2453	0,10485	0,32381	0,89373
NN	Narrow Neural Network	0,32247	0,22607	0,47547	0,77411	5000	0,26544	0,11378	0,33732	0,88468
	Medium Neural Network	0,44	0,33093	0,57526	0,66934	5300	0,37638	0,25744	0,50738	0,73909
	Wide Neural Network	0,30638	0,16678	0,40839	0,83336	6600	0,31536	0,18774	0,43329	0,80973
	Bilayered Neural Network	0,33344	0,26627	0,51602	0,73395	6000	0,26429	0,13394	0,36598	0,86425
	Trilayered Neural Network	0,31347	0,22775	0,47723	0,77244	4100	0,256	0,15174	0,38953	0,84622
KAR	SVM Kernel	0,34911	0,2167	0,46551	0,78348	4100	0,30353	0,14815	0,38491	0,84985
	Least Squares Regression Kernel	0,38434	0,24147	0,49139	0,75873	3300	0,35455	0,18733	0,43282	0,81014

The RMSE and MAE metrics were used for comparison between the models. Figures 3 and 4 show the performance results obtained by each ML model during the training and test process. The changes and achievements are represented by different colors and symbols are shown on the graph. This graph provides a visual comparison of model performances by showing how successful each model is in the training process. Also, the Interactions Linear algorithm was removed from the graphs due to the presence of outliers.

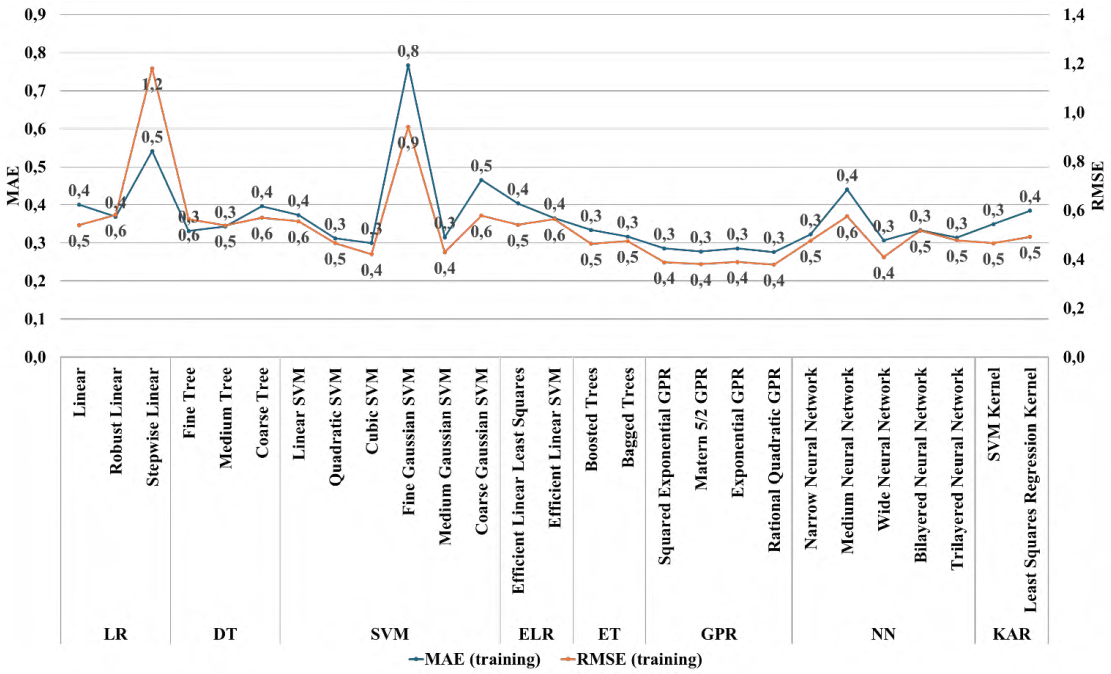

Figure 3. Training performance comparison for ML models

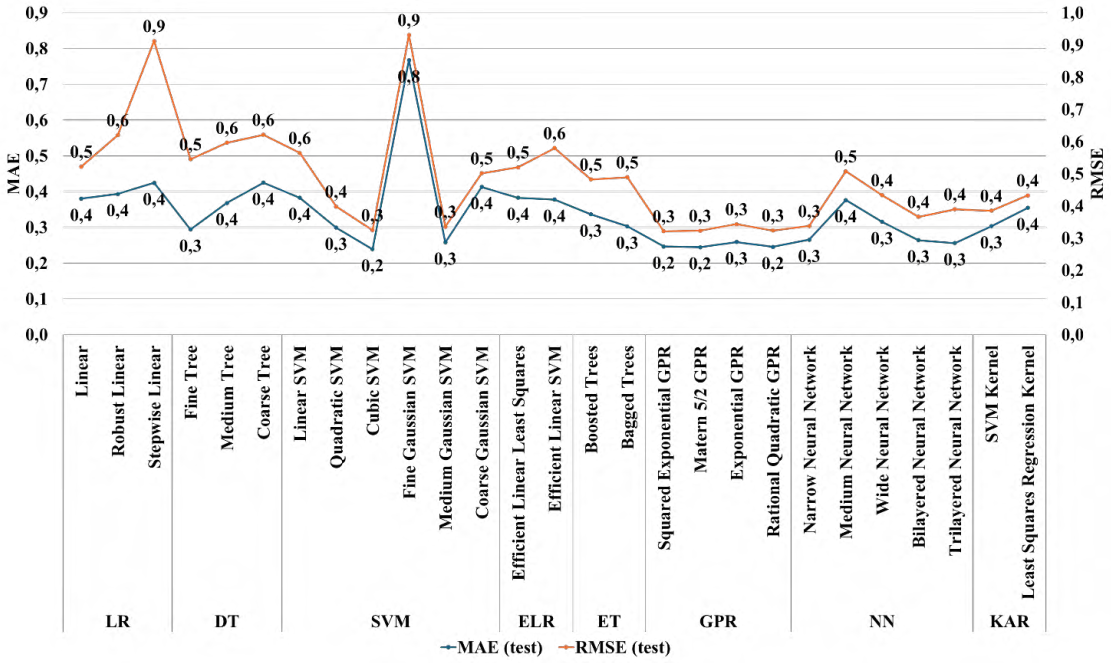

Figure 4. Test performance comparison for ML models

Figure 5 shows the training time of each ML model in observations per second (obs/sec). This figure provides a visual comparison of the variation and differences in the training time of each model. This graph visually highlights the presence of time performance between the models by representing the training times of each model with different columns. This distribution provides an important indication of the computational complexity of each algorithm and its adaptability to the dataset.

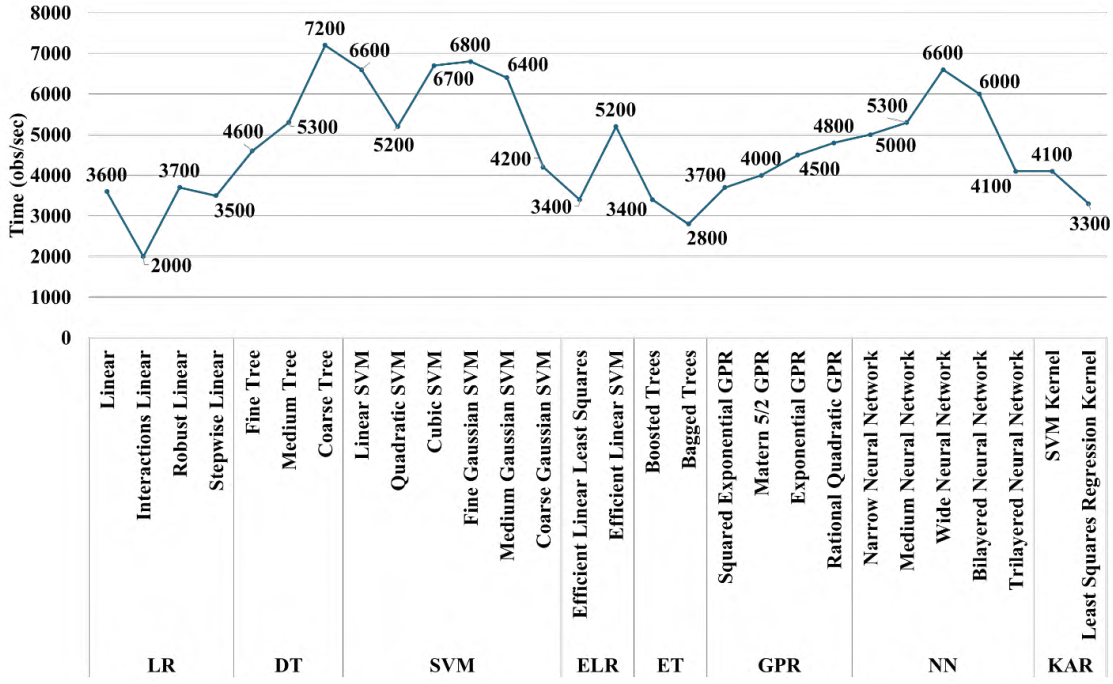

Figure 5. Training time distribution for all ML models

5. Discussion and Conclusion

This paper aims to predict ticket prices based on airline flight data using ML algorithms and to compare the performance of ML algorithms. The secondary objective of this paper is to identify the main factors affecting airline ticket prices. The flight and ticket price datasets of THY and PGS that were obtained from open-access sources are used in this paper. The final dataset consists of 962 records for 3 months from June 1st, 2022 to August 30th, 2022 and includes 19 different variables. In this paper, we compared various ML models to predict airline ticket prices, considering performance metrics such as MAE, MSE, RMSE, and R^2 during both training and test phases. According to the model training and test results, the best algorithm is GPR with R^2: 0.86 (training) and R^2: 0.90 (test). Our findings align with existing literature, reinforcing the efficacy of certain models over others in specific contexts. Below, the performance results concerning previous studies are discussed.

Janssen et al. (2014) used a linear quantile mixed regression model to predict the lowest ticket price before departure, reporting reasonable short-term performance but inefficient long-term results. Our study shows that the standard LR model achieved a reasonable R^2 value of 0.72 during testing, indicating good short-term prediction capabilities. However, the Interactions Linear model performed poorly with a negative R^2 value, suggesting its inefficiency in capturing complex price patterns over the long term.

Wohlfarth et al. (2011) recommended using CART and RF models for predicting the best time to buy tickets. Our results for the Medium Tree model show an R^2 of 0.71 during testing, supporting the effectiveness of decision tree approaches. Fine Tree and Coarse Tree models also performed adequately, though with slightly lower R^2 values. Also, Kalampokas et al. (2023) conducted a study to predict airfare prices using the decision tree model, achieving an average R^2 value of 0.83. Although our R^2 result is lower, it can be said that a result close and parallel to the literature has been obtained. The reason for this low result is mainly related to the quality and size of the dataset used. These findings collectively underscore the robustness and reliability of decision tree models in accurately forecasting airline ticket prices.

Tziridis et al. (2017) found that Bagging Regression Trees and RF models performed best among eight ML models, including SVMs. Similarly, Kalampokas et al. (2023) conducted a study to forecast airfare prices utilizing the RF model, achieving an average R^2 value of 0.87. In our analysis, the Cubic SVM model achieved an impressive R^2 of 0.89 during testing, outperforming other SVM variants. The Medium Gaussian SVM also showed strong performance with an R^2 of 0.88, confirming the potential of SVM models in airfare prediction. Also, Kalampokas et al. (2023) achieved a study to predict airline ticket prices using the SVM model, reaching an average R^2 value of 0.80. Furthermore, Gui et al. (2020) applied an ensemble model combining random tree models with DL for flight delay prediction, achieving high accuracy. Similarly, our study indicates that Boosted Trees and Bagged Trees performed well, with the Boosted Trees model achieving an R^2 of 0.78. These results corroborate the utility of ensemble methods in handling complex, non-linear relationships in airfare data.

DL models, such as those proposed by Tziridis et al. (2017) and various other studies, have shown significant promise. Likewise, Kalampokas et al. (2023) conducted a study to forecast airfare prices utilizing the Multi-Layer Perceptron (MLP) model, achieving an average R^2 value of 0.91. Our Narrow Neural Network model achieved an R^2 of 0.88, and the Bilayered Neural Network performed well with an R^2 of 0.86. These findings are consistent with the literature, indicating that neural networks are highly effective in capturing intricate patterns in ticket pricing data. Our study's GPR models, particularly the Squared Exponential GPR and Matern 5/2 GPR, demonstrated high performance with R^2 values of 0.895 and 0.894, respectively. These results align with existing research suggesting that GPR models are well-suited for regression tasks involving complex, non-linear data.

Across different model categories, this paper confirms that advanced ML techniques, especially ensemble models and neural networks, offer superior performance in predicting airline ticket prices. Models such as the Cubic SVM and GPR variants showed outstanding predictive accuracy, with R^2 values close to or exceeding 0.89. This indicates their robustness and adaptability to the dynamic nature of airfare pricing.

On the other hand, it is possible to note several key factors influencing ticket prices. There is a positive correlation between the distance and duration of the flight and ticket prices; for instance, flights over 300 minutes exhibit an average price increase of 15% compared to shorter duration. Additionally, longer flight durations increase ticket prices due to increased operational costs. Also, seasonal demand can significantly impact ticket prices. Furthermore, three monthly demand fluctuations reveal that prices increase by the day. The presence of competing airlines on the same route reduces ticket prices and our observations indicate that routes served by three or more airlines tend to have lower prices due to increased competition. Besides, fluctuations in fuel prices can directly impact ticket pricing. Macroeconomic factors such as Gross Domestic Product growth and inflation rates also affect ticket prices, as higher disposable incomes during periods of economic growth lead to increased demand for air travel, subsequently driving up prices, while during economic downturns, prices tend to stabilize or decrease. By considering these factors, airlines can better understand and strategically manage their ticket pricing to optimize revenue and market competitiveness.

Based on our analysis, several practical recommendations can be made for airlines to optimize their pricing strategies. Firstly, airlines should adopt dynamic pricing models that adjust ticket prices based on real-time demand and supply conditions. Implementing sophisticated algorithms that consider factors such as booking time, competition, and customer behavior can help maximize revenue. Secondly, strategic route planning is crucial; airlines should strategically plan routes to capitalize on high-demand periods and destinations by offering more flights during peak seasons and reducing frequency during off-peak times, thus optimizing operational efficiency and profitability. To mitigate the impact of volatile fuel prices, airlines can engage in fuel hedging, a financial strategy that involves locking in fuel prices for future purchases, providing cost predictability, and reducing the risk of sudden price hikes. Additionally, developing robust loyalty programs can help airlines retain customers and encourage repeat business; offering incentives such as discounts, upgrades, and exclusive benefits can enhance customer satisfaction and brand loyalty. Lastly, leveraging advanced technologies such as AI and big data analytics can improve operational efficiency; predictive maintenance, optimized flight paths, and automated customer service are areas where technology can significantly reduce costs and improve the quality of service. By implementing these recommendations, airlines can strategically manage their pricing, enhance customer loyalty, and achieve greater operational efficiency.

In conclusion, our findings support the existing literature, demonstrating that ML models, particularly ensemble methods and DL models, significantly enhance the accuracy of airline ticket price predictions. These models provide valuable insights and practical tools for airlines to optimize their pricing strategies, ultimately contributing to more efficient revenue management in the highly competitive aviation industry. Future research should continue exploring these advanced techniques, incorporating larger and more diverse datasets to further refine and validate model performance.

6. Limitations and Future Research

Our analysis has certain limitations and suggests several directions for future research. Firstly, data limitations exist as our analysis was based on data from a limited number of airlines and routes, which may not fully represent the global airline industry. Future studies should aim to include a more comprehensive dataset. Additionally, unforeseen external factors such as geopolitical events, pandemics, and natural disasters can significantly impact ticket prices, and these factors were not fully accounted for in our analysis, and thus should be considered in future research. Moreover, rapid technological advancements in aircraft efficiency and alternative fuels were not deeply explored in this study, yet these factors could have significant implications for future ticket pricing strategies.

Looking ahead, future research should aim to conduct a more comprehensive global analysis, including a broader range of airlines and routes, to provide a more holistic understanding of the factors affecting ticket prices. Additionally, investigating the impact of emerging technologies such as electric aircraft, autonomous flights, and sustainable fuels on ticket pricing can provide valuable insights for the industry. Exploring consumer behavior patterns, including preferences and purchasing behaviors, can help airlines develop more targeted and effective pricing strategies. Furthermore, conducting longitudinal studies to track changes in ticket pricing over time and across different economic cycles can provide deeper insights into the dynamic nature of airline pricing. By addressing these limitations and pursuing these research directions, future studies can offer a more robust and detailed understanding of airline ticket pricing dynamics.

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REFERENCES

Abdella, J. A., Zaki, N., Shuaib, K., & Khan, F. (2021). Airline ticket price and demand prediction: A survey. *Journal of King Saud University - Computer and Information Sciences, 33*(4), 375–391. https://doi.org/10.1016/j.jksuci.2019.02.001

Aliberti, A., Xin, Y., Viticchié, A., Macii, E., & Patti, E. (2023). Comparative analysis of neural networks techniques to forecast Airfare Prices. *2023 IEEE 47th Annual Computers, Software, and Applications Conference (COMPSAC)*, 1023–1029.

https://doi.org/10.1109/COMPSAC57700.2023.00157

Barrett, G. B. (2000). The Coefficient of Determination: Understanding r squared and R squared. *The Mathematics Teacher, 93*(3), 230–234.

Chen, T., Yin, H., Chen, H., Wu, L., Wang, H., Zhou, X., & Li, X. (2018). TADA: Trend Alignment with Dual-Attention Multi-task Recurrent Neural Networks for Sales Prediction. *2018 IEEE International Conference on Data Mining (ICDM)*, 49–58. https://doi.org/10.1109/ICDM.2018.00020

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Routledge.

Deng, T. (2024). International flight fare prediction and analysis of factors impacting flight fare. *Theoretical and Natural Science, 31*(1), 329–335. https://doi.org/10.54254/2753-8818/31/20241079

Di Bucchianico, A. (2008). Coefficient of determination (R 2). *Encyclopedia of Statistics in Quality and Reliability*.

Farrar, D. E., & Glauber, R. R. (1967). Multicollinearity in Regression Analysis: The Problem Revisited. *The Review of Economics and Statistics, 49*(1), 92. https://doi.org/10.2307/1937887

Gibbons, J. D. (1997). Nonparametric methods for quantitative analysis. *Journal of the Operational Research Society, 48*(8), 853.

Gordiievych, A., & Shubin, I. (2015). Forecasting of airfare prices using time series. *2015 Information Technologies in Innovation Business Conference (ITIB)*, 68–71. https://doi.org/10.1109/ITIB.2015.7355055

Groves, W., & Gini, M. (2015). On Optimizing Airline Ticket Purchase Timing. *ACM Transactions on Intelligent Systems and Technology, 7*(1), 1–28. https://doi.org/10.1145/2733384

Gui, G., Liu, F., Sun, J., Yang, J., Zhou, Z., & Zhao, D. (2020). Flight Delay Prediction Based on Aviation Big Data and Machine Learning. *IEEE Transactions on Vehicular Technology, 69*(1), 140–150. https://doi.org/10.1109/TVT.2019.2954094

Howell, D. C. (1992). *Statistical methods for psychology*. PWS-Kent Publishing Co.

Huang, H.-C. (2013). A Hybrid Neural Network Prediction Model of Air Ticket Sales. *TELKOMNIKA Indonesian Journal of Electrical Engineering, 11*(11). https://doi.org/10.11591/telkomnika.v11i11.2762

Hyndman, R. J., & Koehler, A. B. (2006). Another look at measures of forecast accuracy. *International Journal of Forecasting, 22*(4), 679–688. https://doi.org/10.1016/j.ijforecast.2006.03.001

Janssen, T., Dijkstra, T., Abbas, S., & van Riel, A. C. (2014). A linear quantile mixed regression model for prediction of airline ticket prices. *Radboud University, 3*.

Kalampokas, T., Tziridis, K., Kalampokas, N., Nikolaou, A., Vrochidou, E., & Papakostas, G. A. (2023). A Holistic Approach on Airfare Price Prediction Using Machine Learning Techniques. *IEEE Access, 11*, 46627–46643. https://doi.org/10.1109/ACCESS.2023.3274669

Karataş, G. (2021). The Effects of Normalization and Standardization an Internet of Things Attack Detection. *European Journal of Science and Technology, 29*, 187–192. https://doi.org/10.31590/ejosat.1017427

Kumar, A. (2023). *Airline Price Prediction Using XGBoost Hyper-parameter Tuning* (pp. 239–248). https://doi.org/10.1007/978-3-031-28183-9_17

Lai, G., Chang, W.-C., Yang, Y., & Liu, H. (2018). Modeling Long- and Short-Term Temporal Patterns with Deep Neural Networks. *The 41st International ACM SIGIR Conference on Research & Development in Information Retrieval*, 95–104. https://doi.org/10.1145/3209978.3210006

Makridakis, S., Andersen, A., Carbone, R., Fildes, R., Hibon, M., Lewandowski, R., Newton, J., Parzen, E., & Winkler, R. (1982). The accuracy of extrapolation (time series) methods: Results of a forecasting competition. *Journal of Forecasting, 1*(2), 111–153. https://doi.org/10.1002/for.3980010202

Miles, J., & Banyard, P. (2007). *Understanding and using statistics in psychology: A practical introduction*.

Nevitt, J., & Hancock, G. R. (2000). Improving the Root Mean Square Error of Approximation for Nonnormal Conditions in Structural Equation Modeling. *The Journal of Experimental Education, 68*(3), 251–268. https://doi.org/10.1080/00220970009600095

Qin, Y., Song, D., Chen, H., Cheng, W., Jiang, G., & Cottrell, G. W. (2017). A Dual-Stage Attention-Based Recurrent Neural Network for Time Series Prediction. *Proceedings of the Twenty-Sixth International Joint Conference on Artificial Intelligence*, 2627–2633. https://doi.org/10.24963/ijcai.2017/366

Ren, R., Yang, Y., & Yuan, S. (2014). Prediction of airline ticket price. *University of Stanford*, 1–5.

Sammut, C., & Webb, G. I. (2010). Mean absolute error. *Encyclopedia of Machine Learning, 652*.

Santana, E., Mastelini, S., & Jr., S. (2017). Deep Regressor Stacking for Air Ticket Prices Prediction. *Anais Do Simpósio Brasileiro de Sistemas de Informação (SBSI)*, 25–31. https://doi.org/10.5753/sbsi.2017.6022

Sherly Puspha Annabel, L., Ramanan, G., Prakash, R., & Sreenidhi, S. (2023). *Machine Learning-Based Approach for Airfare Forecasting* (pp. 901–912). https://doi.org/10.1007/978-981-19-6634-7_65

Shih, S.-Y., Sun, F.-K., & Lee, H. (2019). Temporal pattern attention for multivariate time series forecasting. *Machine Learning, 108*(8–9), 1421–1441. https://doi.org/10.1007/s10994-019-05815-0

Tziridis, K., Kalampokas, Th., Papakostas, G. A., & Diamantaras, K. I. (2017). Airfare prices prediction using machine learning techniques. *2017 25th European Signal Processing Conference (EUSIPCO)*, 1036–1039. https://doi.org/10.23919/EUSIPCO.2017.8081365

Wang, T., Pouyanfar, S., Tian, H., Tao, Y., Alonso, M., Luis, S., & Chen, S.-C. (2019). A Framework for Airfare Price Prediction: A Machine Learning Approach. *2019 IEEE 20th International Conference on Information Reuse and Integration for Data Science (IRI)*, 200–207. https://doi.org/10.1109/IRI.2019.00041

Wohlfarth, T., Clemencon, S., Roueff, F., & Casellato, X. (2011). A Data-Mining Approach to Travel Price Forecasting. *2011 10th International Conference on Machine Learning and Applications and Workshops*, 84–89. https://doi.org/10.1109/ICMLA.2011.11

Yujing, D., Zhihao, W., & Youfang, L. (2020). Flight passenger load factors prediction based on RNN using multi-granularity time attention. *Computer Engineering, 46*(509), 01.

Zhao, Z., You, J., Gan, G., Li, X., & Ding, J. (2022). Civil airline fare prediction with a multi-attribute dual-stage attention mechanism. *Applied Intelligence, 52*(5), 5047–5062. https://doi.org/10.1007/s10489-021-02602-0

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RESEARCH ARTICLE

Enabling Intelligent Transport in Smart Cities: A 5G Valley in Türkiye

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ABSTRACT

This research examines the integration of smart transportation systems with 5G technologies in a designated pilot area in Ankara as part of the IPA-2 Project. The main objective of this study is to identify the critical factors influencing the practitioners of smart transportation systems in the pilot region. Using the Analytic Hierarchy Process (AHP) methodology, key considerations for achieving "smart" transportation systems are explored. During the study, communication was established with smart transportation experts from every continent, and an AHP-based questionnaire was sent to 10 experts from each continent, totaling 70 experts. The experts were selected from among electrical engineers, transportation engineers, and planners specializing in ITS (Intelligent Transportation Systems). Experts who have worked or are currently working on smart transportation projects formed the sample for this study. The views of transportation system practitioners were collected, and the parameters deemed most important by the experts were identified. The findings emphasize the centrality of environmental awareness among smart transportation system practitioners and highlight the need for eco-friendly transportation solutions. The results also demonstrate that experts consider the "smart environment" parameter the most important. This finding underscores the significance of a clean and sustainable environment for 5G applications in transportation.

Keywords: Smart transportation, Environmental sustainability, Analytical hierarchy process (AHP), 5G, Informatics and Information Technologies in Architecture

1. Introduction

The rapid urbanization of cities has brought forth several challenges, including overcrowding, resource depletion, environmental degradation, and increased air pollution. In response, the smart city concept has gained prominence as an innovative framework for sustainable urban development. This research focuses on the integration of advanced technologies and data-driven strategies into smart cities, highlighting their potential to enhance residents' quality of life, optimize city operations, and contribute to sustainable growth.

As urban populations grow and technological advancements continue, the shift toward smart cities has gained momentum, as discussed by scholars such as Bibri and Krogstie (2020), Liu and Peng (2021), Kumar and Al-Dubai (2020), Giffinger and Gudrun (2021), and Pan and Zhang (2022). Their work emphasizes the transformative capabilities of smart city initiatives, including benefits such as improved sustainability, enhanced governance through artificial intelligence (AI) and the Internet of Things (IoT), and the implementation of data-driven systems to support urban resilience and operational efficiency (Bibri and Krogstie, 2020; Liu and Peng, 2021; Kumar and Al-Dubai, 2020; Giffinger and Gudrun, 2021; Pan and Zhang, 2022).

A core feature of smart cities is their reliance on modern technologies to address urban challenges. Through the deployment of IoT devices, cutting-edge sensors, and advanced data analytics, these cities collect and process data in real time, enabling informed decision-making. This seamless technological integration helps improve urban services and fosters the development of adaptive and responsive environments.

Central to the smart city framework is an aim to enhance residents' quality of life. By leveraging technology to improve public services, transportation, and energy management, smart cities seek to create more livable, sustainable environments. Intelligent transportation systems (ITS) can reduce traffic congestion, improve air quality, and improve public health. Additionally, energy-efficient infrastructure and smart grids align with global sustainability goals, further promoting climate action initiatives. Efficiency gains across sectors such as healthcare, waste management, and transportation further demonstrate the potential of smart cities. By using data-driven strategies, smart cities can optimize resource allocation, reduce operational costs, and enhance governance.

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Predictive analytics and machine learning tools can even prevent disruptions to critical infrastructure, ensuring the reliability of essential services (Liu and Peng, 2021). A critical element of this technological evolution is the implementation of ITS, which plays a pivotal role in transforming urban mobility. ITS integrates advanced technology, data analytics, and communication systems to enhance the efficiency, safety, and sustainability of transportation networks (Khalid et al., 2018). These systems utilize real-time data, sensor networks, and intelligent algorithms to reduce congestion, shorten travel times, improve safety, and reduce environmental impacts (Khalid et al., 2018; Barba et al., 2013).

As urbanization accelerates and the demand for efficient transportation grows, ITS has become increasingly important for shaping future mobility. Governments, private companies, and researchers worldwide are collaborating to implement ITS technologies and develop smarter, more sustainable transportation ecosystems. Recent advances in IoT and 5G communication have accelerated the adoption of ITS (Khalid et al., 2018).

The foundation of ITS lies in the collection, exchange, and analysis of transportation data, which allows for effective monitoring, measurement, and management of urban-transport systems. These technologies aim to optimize road capacity, improve mobility, decrease travel time, and minimize the environmental impacts associated with transportation (Ministry of Transport and Infrastructure, 2021; Wecka et al., 2022).

With the increasing global demand for efficient transport solutions, intelligent systems are becoming more essential than ever to enhance both safety and efficiency. ITS applications span various domains, including traffic management, vehicle safety, public transit information, and emergency response systems. The development of cooperative intelligent transportation systems (C-ITS) emphasizes the importance of real-time data exchange between vehicles and their environments, with 5G technology being a key enabler of these systems (Bojkovic et al., 2020). The development of 5G networks, which are characterized by ultra-low latency and the ability to transmit real-time data, is expected to revolutionize autonomous vehicles and artificial intelligence (AI) applications in transportation (Ministry of Transport and Infrastructure, 2020). As the demand for Connected, Cooperative, and Autonomous Mobility (CCAM) continues to rise, the role of 5G and next-generation communications will become even more critical. Although 5G technologies are still emerging, they hold great promise in terms of enhancing existing services and introducing new innovations in IoT, smart cities, and ITS (Guevara and Cheein, 2020).

Effective communication networks are fundamental to the planning, management, and monitoring of complex transportation infrastructures. Integration and interoperability across different modes of transportation—including highways, urban traffic zones, tunnels, parking facilities, and other systems—are essential for achieving cohesive and efficient transportation strategies.

Technologies such as connected, cooperative, and autonomous mobility (CCAM), IoT, mixed reality (AR/VR), cloud computing, big data, open data, AI, digital twins, blockchain, drones, air taxis, mobility-as-a-service (MaaS), and smart roads are reshaping the future of transportation. The role of communication advancements, particularly 5G, is critical in realizing this transformation (Bertin and Crespi, 2017).

The advent of 5G technology has introduced transformative solutions to transportation, emphasizing both human and environmental considerations. This new paradigm focuses on equitable access while reducing negative impacts such as energy consumption, traffic congestion, and accidents, all of which contribute to broader sustainability conversations (Guevara and Cheein, 2020).

However, there are considerable challenges in the implementation of 5G in transportation. Establishing 5G networks requires substantial investment in infrastructure such as small cell towers, fiber optics and edge computing systems. This investment is not only a one-time expense but also requires continuous maintenance and future upgrades. Case studies from cities such as Vienna and Tianjin illustrate how public-private partnerships have successfully navigated these financial challenges (Bertin and Crespi, 2017).

Concerns about privacy, data security, and the implications of automation for jobs can slow the adoption of such technologies. Addressing these issues through clear policies, public outreach, and education can help build trust and foster acceptance. Pilot programs that gradually introduce these technologies help ease public concerns (Mas and Schuster, 2019).

Costs can be reduced by implementing these systems in phases and encouraging government support through subsidies and tax breaks for private sector partners and telecom providers. Discussing funding options, such as public-private partnerships and government grants, will highlight effective economic strategies (Zhu and Liu, 2021). Expanding pilot programs, especially in varied urban and rural settings, alongside enhanced government support and the development of balanced regulatory frameworks can support sustainable innovation. Collaborations with academic institutions can further drive technological advancements and promote social engagement (Sharma and Li, 2020).

In Türkiye, the Ministry of Transport and Infrastructure (MoTI) is at the forefront of developing smart transportation policies. This includes selecting test sites and trialing 5G technologies for transportation as part of the Instrument for Pre-Accession Assistance (IPA 2) Project. A Presidential Decree issued in 2018 tasked MoTI with creating national strategies, action plans, and

technical criteria for intelligent transportation systems (ITS), in addition to establishing a data management center to handle data generated by public and private entities (Presidential Decree, 2018).

The first tests of 5G technologies in Türkiye's transportation sector occurred within the IPA-2 Project, with Hacettepe University serving as the pilot location. This research examines how 5G technologies can be applied to smart transportation in this pilot area.

Hacettepe University, founded in 1967, is one of Türkiye's leading academic institutions, featuring 16 faculties, 15 institutes, vocational schools, and nearly 100 research centers. The 1604 Street designated on its campus is a test site for 5G transportation innovations.

This study examines smart transportation in the context of 5G technology in Türkiye, focusing on its environmental impacts. The key research questions guiding the study are as follows: "What smart transportation strategy is suitable for Türkiye?" and "Is the current transportation system contributing to environmental pollution?" The proposed hypothesis argues that transforming transportation to prioritize smart transportation principles is necessary to reduce pollution while maintaining operational efficiency.

2. Literarute Review

The rapid growth of urbanization, combined with technological progress, has given rise to smart cities, designed to tackle modern urban issues like congestion, resource scarcity, and environmental damage. Smart cities use cutting-edge technologies to improve quality of life, drive sustainability, and boost operational efficiency. Intelligent Transportation Systems (ITS) play a crucial role in achieving these goals by improving mobility through innovative solutions. When integrated with 5G technology, ITS provides a revolutionary approach to managing transportation, greatly improving efficiency, safety, and environmental sustainability.

2.1. Smart Cities and Environmental Sustainability

Smart cities use IoT and data-driven technologies to manage urban services such as transportation, energy, and waste. According to Albino, Berardi, and Dangelico (2015), smart city projects place a strong emphasis on environmental sustainability, acknowledging that urban areas are significant contributors to pollution and energy consumption. Recent developments in 5G technology have facilitated real-time data gathering and analysis, greatly reducing energy consumption and carbon emissions by streamlining the management of urban services, including transportation networks. More recent research (Bibri and Krogstie, 2020; Liu and Peng, 2021) underscores the pivotal role of smart city technologies in crafting sustainable urban futures, particularly in terms of improving efficiency and supporting eco-friendly initiatives.

2.2. 5G Technologies and ITS

The incorporation of 5G technologies into smart transportation systems promises to significantly improve urban mobility. With faster data transfer rates, lower latency, and improved connectivity, 5G enables real-time monitoring and management of transportation infrastructures. This innovation supports vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, enhancing traffic management and alleviating congestion. Abbas et al. (2015) and Bae and Lee (2016) examined the effects of 5G on transportation, highlighting its capacity to revolutionize urban mobility by improving safety and efficiency and reducing environmental impacts. More recent research by Kumar and Al-Dubai (2020) and Zhang et al. (2021) has also emphasized that 5G could enable autonomous driving, a crucial step toward future urban transportation, by enhancing real-time communication and decision-making systems (Kumar and Dubai, 2020; Zhang et al., 2021).

2.3. ITS and environmental impacts

Intelligent Transportation Systems (ITS) have the potential to minimize the environmental impact of transportation networks. As noted by Sánchez-González et al. (2019), implementing eco-conscious transportation solutions is essential for mitigating urban pollution (Sánchez-González et al., 2019). Borge-Holthoefer et al. (2017) demonstrated that integrating ITS with 5G technology can streamline traffic, decrease fuel usage, and reduce emissions, thus fostering a cleaner environment. In this context, the present study adds to the existing body of research by examining how professionals prioritize environmental sustainability when deploying ITS.

2.4. Application of AHP in Similar Studies

The analytical hierarchy process (AHP) methodology has been extensively applied to assess and rank decision-making factors in smart cities and Intelligent Transportation Systems (ITS). Caragliu and Nijkamp (2011) used the AHP to evaluate the criteria that influence smart city development, underscoring the importance of sustainability in urban planning (Caragliu and Nijkamp, 2011). Similarly, Sánchez-González et al. (2019) employed AHP to examine key factors in smart transportation, with environmental considerations being a top priority for experts (Sánchez-González et al., 2019). This study expands on previous research by applying AHP to assess expert insights on the most significant factors for implementing 5G-enabled ITS, with a particular focus on environmental impact.

In conclusion, incorporating 5G technology into ITS within smart cities represents a pivotal move toward sustainable urban transportation. By analyzing existing literature on 5G, ITS, and sustainability, this research addresses a gap by considering the specific concerns of professionals engaged in the deployment of these technologies (Abbas et al., 2015; Albino et al., 2015; Bae and Lee, 2016; Borge-Holthoefer et al., 2017; Caragliu et al., 2009; Mousa and Shoaib, 2018; Ratti and Townsend, 2011; Sánchez-González, 2019).

AHPs are frequently used in decision-making frameworks across sectors like ITS, urban development, and sustainability evaluations. It is particularly effective for evaluating multi-criteria decisions in which multiple variables must be considered, making it an ideal method for assessing the integration of 5G into smart transportation systems.

Jing et al. (2020) used AHP to evaluate factors influencing the adoption of autonomous vehicles in smart cities. They identified essential criteria, including safety, infrastructure expenses, public acceptance, and environmental impact, illustrating how the AHP can be used to prioritize these factors according to expert opinion. This research parallels the current study, which identifies key factors impacting smart transportation system practitioners (Jing et al., 2020).

Similarly, Wang et al. (2018) applied AHP to analyze sustainable urban mobility strategies, examining metrics such as air quality, energy usage, and congestion reduction. The study emphasized eco-friendly transport, which is consistent with the results of this research, which underscores the role of environmental consciousness in smart transportation systems (Wang et al., 2018).

Tsamboulas et al. (2007) also used the AHP to evaluate transportation infrastructure investments, ranking various options based on cost, safety, and environmental impact. Their research supports the application of AHP in planning smart transportation systems and demonstrates its value in balancing economic, environmental, and social considerations (Tsamboulas et al., 2007).

These examples demonstrate how AHP can systematically assess stakeholder priorities in smart transportation initiatives. By integrating expert feedback, the AHP provides a structured framework for determining which factors should be prioritized in technological advancements like 5G.

There are key initiatives that play a critical role in Türkiye's transportation infrastructure, including Ulak, Aselsan, and Havelsan:

Ulak: A leading company in Türkiye, Ulak is responsible for developing Turkey's first locally produced 5G base station. It is instrumental in advancing telecommunications infrastructures by offering secure and scalable solutions that support both national and global 5G networks (Ulak Haberleşme A.Ş., 2022).

Aselsan: Renowned for its expertise in defense and electronics, Aselsan has expanded its research into telecommunications, focusing on the development of 5G infrastructure, specifically designing essential hardware components and integrating systems for secure communication (Aselsan, 2022).

Havelsan: A specialist in software-driven solutions, Havelsan plays a vital role in Türkiye's digital transformation by contributing to 5G development, particularly in cybersecurity and network management systems, to ensure the resilience and security of 5G networks (Havelsan, 2023).

3. Research method

The selection of the AHP methodology in this study was based on its ability to determine the significance weights of various parameters. This decision-making approach not only addresses problem-solving but also aids in problem definition, solution modeling, comparison phases, and hierarchical structuring of identified concepts. Given the challenge of establishing significance levels among numerous overlapping concepts, decision support systems are essential. These systems assist decision makers by simplifying the evaluation process, generating effective decision options, presenting and analyzing alternatives, and enhancing the likelihood of making informed decisions across multiple concepts (Oğuztimur, 2008). In this study, expert opinions were consulted, and ethics approval was obtained from the Scientific Research Ethics Committee in Social and Human Sciences at Necmettin Erbakan University (dated 23.04.2023, approval number 196.)

The Analytic Hierarchy Process (AHP) has consistently been a reliable tool for both researchers and decision-makers and is one of the most frequently used multi-criteria decision-making frameworks. A bibliographic review by Steuer (2003) emphasizes AHP's significance among decision-making methodologies. One of AHP's notable strengths is its versatility, which enables its combination with methods such as Linear Programing, Quality Function Deployment, and Fuzzy Logic (Saaty and Ozdemir, 2003).

The key steps of this methodology are as follows:

1. Defining the decision issue.
2. Identifying the criteria that affect decision-making.
3. Structuring a problem in a hierarchical model that includes objectives, criteria, sub-criteria, and alternatives.
4. Pairwise comparisons of the different elements.
5. Calculate the maximum Eigenvalue, Consistency Index (CI), Consistency Ratio (CR), and normalize the values for each criterion and alternative.
6. Assess the CI and CR values. If these fall within acceptable limits, decisions are made based on the normalized results; otherwise, the process is repeated until acceptable values are reached (Saaty, 1987).

Problem Identification: Determining the ideal condition for Türkiye's smart transportation system is of paramount importance. Accordingly, it is essential that policymakers' viewpoints are captured. This study focuses on gathering these insights by using the AHP method as the primary framework for analysis (Haller et al., 1996). The structural outline of this approach is presented in Figure 1.

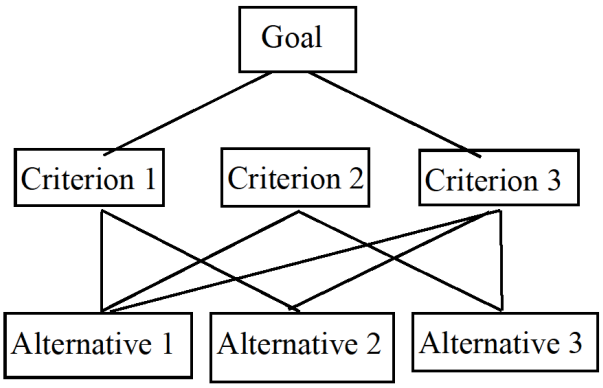

Figure 1. Simple AHP scheme

3.1. Determination of Smart Transportation Criteria

The selection of criteria for smart transportation plays a critical role in decision-making. Presently, the established criteria include "local accessibility, international connectivity, access to ICT infrastructure, sustainable practices, innovation, transportation safety, clean and non-motorized transportation, and a mixed modal approach" (Giffinger, 2007; Cohen, 2010).

3.1.1. Development of a Hierarchical Structure for Decision-Making

This phase involves defining parameters necessary for analyzing the decision problem (Saaty, 2008). It is important to select parameters that enhance the ability of the identified issue within the hierarchical framework. The relationships between the entire system and its components must be thoroughly examined to obtain meaningful insights. Furthermore, the decision hierarchy should encompass all key concerns of the stakeholders (Haller et al., 1996).

3.1.2. Comparison Matrices and Parameter Weight Assignment

The next crucial step in the AHP process is making comparisons, where two options or criteria are evaluated based on the decision-makers' judgments. The relative importance of each criterion is revealed by performing pairwise comparisons. The comparison data is arranged in an "nxn" matrix format (Chandran et al., 2005). At each level of the hierarchy, pairwise comparisons are conducted between elements, and decision-makers indicate their preferences using the Saaty scale for relative importance (Saaty and Vargas, 2006; Saaty, 1980).

The Saaty scale is a key tool for accurate assessment in the AHP methodology, where a score of nine is assigned to the most important concept (Saaty, 2004). When this process is repeated for other evaluation criteria, a corresponding vector for B column (1) is generated for each criterion (Saaty et al., 2003).

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ . \\ . \\ . \\ b_{n1} \end{bmatrix} \tag{1}$$

3.1.3. Creation of parameter comparison matrices and concept weight determination

The pairwise comparison phase constitutes the second fundamental step in the Analytic Hierarchy Process (AHP). This phase entails evaluating and contrasting two options or criteria based on the decision-maker's judgment. The values derived from these pairwise comparisons are organized in an "nxn" matrix, which we refer to as the pairwise comparison matrix. This matrix has a dimensional format of non, corresponding to the number of factors (n) assessed (Table 1) (Chandran et al., 2005).

Table 1. Pairwise comparison matrix for criteria

	Criterion 1	**Criterion 2**	**Criterion n**
Criterion 1	w1/w1	w1/w2	w1/wn
Criterion 2	w2/w1	w2/w2	w2/wn
Criterion n	wn/w1	wn/w2	wn/wn

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{2}$$

A column vector (2), B is generated with the "n" number and "n" components. The B-column vectors are calculated using the following formula: (3)

$$b_i j = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{3}$$

Once the relative importance of the concepts has been established, the next stage is to calculate the consistency ratio (CR) of the comparison matrix. (Hafeez et al., 2007).

If the constructed hierarchy consists of n criteria, a total of n(n-1)/2 pairwise comparisons are necessary, excluding self-comparisons. As a result, when each step of the construction process is repeated with other evaluation factors, a column vector B equals the number of vailable factors. Expressing unit B column vector in matrix format yields the following formation of matrix C (4).

$$C = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ C_{n1} & C_{n2} & \cdots & C_{nn} \end{bmatrix} \tag{4}$$

3.1.4. Assessment of comparison consistency

The consistency evaluation stage is a crucial part of the Analytic Hierarchy Process (AHP). The term "quality of the outcome" refers to how well the decision-maker's judgments align with the consistency criterion, which directly impacts the entire decision-making process (Russo and Camanho, 2015).

For a comparison matrix to be considered consistent, the largest eigenvalue (λmax) must equal the matrix size (n). The consistency index and consistency ratio were calculated using this relationship (Saaty and Ozdemir, 2003).

To determine the consistency index (CI), the following formula was applied (Zhou and Shi, 2009; Ömrüberk and Şimşek, 2014).

$$CI = \frac{\lambda - n}{n - 1} \tag{5}$$

When the ratio is equal to "0," it indicates that the decision-maker has complete consistency in her/his judgments. As the ratio approaches "1," it signifies an inconsistency in the decision-maker's judgments.

3.1.5. Conclusion-Decision

The final step of the AHP process involves determining the hierarchy (Saaty, 2004). This is achieved by multiplying decision matrix K (6) by column vector W, also referred to as the priority vector. The result is a column vector L composed of m elements. This vector L reflects the percentage distribution of decision points and helps establish the relative significance of each decision point (Saaty and Vargas, 2006).

$$K = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ S_{m1} & S_{m2} & \cdots & S_{mn} \end{bmatrix} \quad L = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ S_{m1} & S_{m2} & \cdots & S_{mn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ \cdot \\ \cdot \\ \cdot \\ w_n \end{bmatrix} = \begin{bmatrix} l_{11} \\ l_{21} \\ \cdot \\ \cdot \\ \cdot \\ l_{m1} \end{bmatrix} \tag{6}$$

3.2. Determination of Expert Group

The experts were selected from among electrical engineers, transportation engineers, and planners specializing in ITS. Experts who have worked or are currently working on smart transportation projects formed the sample for this study. The experts were contacted via email. The purpose of the article was explained to them, and they were invited to contribute. A total of 70 experts (10 from each continent) who accepted the invitation participated in the study.

3.3. Purpose of the Stage Activities

- **Literature Review:** This study comprehensively examines existing literature related to smart transportation and the environmental effects of current transportation systems in Türkiye. This will provide a comprehensive understanding of smart transportation strategies and their potential environmental consequences.
- **Data Collection:** We acquired data on this condition of transportation in Türkiye, covering various modes of transportation, infrastructure, and their environmental repercussions. These empirical data will aid in evaluating current transportation systems and their impacts on the environment.
- **Analysis:** The gathered data were evaluated to identify patterns, trends, and correlations between transportation behaviors and environmental pollution. This analysis provides insights into the current state of transportation in Türkiye and its environmental implications.
- **Comparative study:** Smart transportation strategies in other countries and current practices in Türkiye. Identify successful models and best practices to guide the creation of a customized smart transportation strategy for Türkiye.
- **Formulation of Recommendations:** Develop specific recommendations for a smart transportation strategy that addresses the unique needs and challenges facing Türkiye. Provide actionable insights for policymakers and stakeholders to improve transportation and reduce environmental pollution.
- **Hypothesis Testing:** The collected data are tested against the developed hypothesis to determine its validity. Validate or refute the hypothesis based on the findings of the literature review, data analysis, and comparative study.

The proposed framework outlines a systematic approach to the study, encompassing a literature review, data collection, analysis, comparative study, recommendation formulation, and hypothesis testing. Each phase is designed to effectively address the research questions and evaluate the hypothesis.

4. Findings

According to the results, the importance rankings were as follows:
- Clean and engine-free transportation with a weight degree of 0.354,
- Sustainable, innovative, and safe transportation system with a weight degree of 0.238,
- Mixed model of transportation system with weight degree of 0.109,
- Local accessibility with weight degree of 0.103,
- Access to ICT Infrastructures with a weight degree of 0.101,
- International accessibility was ranked 6th with a weight degree of 0.095.

The results of this study suggest that stakeholders and decision-makers prioritize clean and engine-free transportation as the most important criterion, followed by a sustainable, innovative, and safe transportation system. Additionally, the mixed model of transportation systems, local accessibility, access to ICT infrastructures, and international accessibility are recognized as important factors, although with decreasing levels of significance (Table 2).

Table 2. Article Findings

SUB-CRITERIA	The people, who works in In the Ministry and take part in the smart transportation 5G Valley project.	Ranking
Local accesibility	0,103	4
International accesibility	0,095	6
Access to ICT Infrastructures	0,101	5
Clean and engine-free transportation	**0,354**	**1**
Sustainable, innovative and safe transportation system	0,238	2
Mixed model in transportation system	0,109	3
TOTAL	1	

The results of the study support the hypothesis, demonstrating a shared agreement among participants that the transportation system needs to be redefined according to smart transportation principles, with a key focus on reducing pollution. The emphasis on clean and engine-free transportation is the most vital sub-criterion for smart transportation. This highlights the strong priority that decision makers place on promoting non-motorized and non-fossil fuel vehicles to address environmental challenges.

The significance attributed to sustainable and innovative transportation systems, which are ranked second, underscores the urgent need for research and development in this area. Sustainable transportation is essential for reducing the carbon footprint linked to mobility, particularly as the transportation sector is a major contributor to global carbon emissions. This study emphasizes the critical role of sustainable transportation planning in alleviating the negative impacts of climate change, especially in urban settings that contribute to the climate crisis.

Local accessibility is the third most important factor, underscoring its role in fostering livable urban environments. This study reveals that accessibility, which extends beyond conventional transportation policies, is considered a fundamental aspect of human-centered transportation applications. The idea of "accessibility" is positioned as a cornerstone for sustainable transportation planning, in line with the goal of creating an inclusive transportation system (MoTI, 2021).

Although there are challenges in attaining the desired level of local accessibility, the study acknowledges ongoing initiatives, affirming its critical place on the policy agenda. This suggests that achieving an accessible transportation system requires specific objectives that align with the vision of fostering sustainable and livable cities.

In summary, the findings provide important insights into the priorities and views of decision makers regarding smart transportation in Türkiye. The emphasis on clean and engine-free transportation, sustainable and innovative systems, and local accessibility reflects a collective acknowledgment of the need for transformative changes in the transportation sector. These findings have broader implications for policy development, stressing the importance of harmonizing transportation strategies with environmental sustainability and human-centered approaches to improve urban livability.

Based on the results of this study, we prioritize the essential components of smart transportation systems in urban areas as follows:

Clean and Engine-Free Transportation: The highest priority, reflecting a commitment to minimizing pollution.

Sustainable, Innovative, and Safe Transportation Systems: Recognizing the need for research and development.

Mixed Model for Transportation Systems: Integrating various transportation modes for greater efficiency.

Local Accessibility: Essential for creating livable urban environments.

Access to ICT Infrastructures: Promoting technological integration.

International Accessibility: Enhancing connectivity with broader networks.

The recommended steps for advancing smart transportation in cities are as follows:

Raising Awareness:

- Objective: To increase public awareness of the importance of smart and sustainable transportation.
- Rationale: Fostering awareness is fundamental for gaining public support and engaging in adopting environmentally friendly and accessible transportation practices.

Enhancing the Structure of Governance:

- Objective: To strengthen the governance framework overseeing transportation policies and initiatives.
- Rationale: An effective governance structure is vital for coordinating and implementing strategic measures and ensuring alignment with broader developmental goals (Smith, 2017).

Enhancing Regulations and Supervision:

- Objective: To improve regulatory frameworks and supervisory mechanisms in the transportation sector.
- Rationale: Robust regulation and supervision are crucial for ensuring compliance, safety, and the overall effectiveness of transportation systems (Forkenbrock, 2016).

Developing Institutional Capacity:

- Objective: To build institutional capacity within relevant organizations to manage and implement smart transportation initiatives.
- Rationale: Institutional capacity development is integral for sustaining long-term planning and effective execution of transportation strategies (Litman, 2014).

Enhancing Vehicle Accessibility through Infrastructure and Superstructures:

- Objective: To improve vehicle accessibility by enhancing both infrastructure and superstructures.
- Rationale: Enhancing accessibility promotes inclusivity and accommodates diverse mobility needs within the population (Dablanc et al., 2019).

Enhancing Integration Across Different Modes of Transportation:

- Objective: To facilitate seamless integration of various transportation modes.
- Rationale: Integrated transportation systems can optimize efficiency and improve overall accessibility for commuters (Hall, 2019).

Accessing Information Technology:

- Objective: To enhance access to information technology and improve transportation services.
- Rationale: Implementing technology ensures real-time information, efficient operations, and improved user experience in transportation systems (Zheng et al., 2018).

International Access:

- Objective: To strengthen international connectivity and accessibility in transportation networks.

- Rationale: International access fosters economic, cultural, and social exchanges and contributes to sustainable development (Cattaneo et al., 2020).

These objectives collectively represent a holistic approach to addressing the developmental needs of the transportation sector, prioritizing sustainability, inclusivity, and effective governance.

To improve the generalizability of the findings from the 5G-enabled smart transportation system study in Türkiye's 5G Valley, it is essential to acknowledge the wider relevance of the insights. Critical elements, such as environmental sustainability and technological infrastructure, are pertinent to urban mobility challenges across the globe. The results of this study can benefit cities worldwide that are grappling with similar issues, including rapid urbanization and the need for sustainable transportation solutions. Conducting comparable research in a variety of urban settings—such as well-established smart cities (e.g., Singapore) and emerging regions (e.g., parts of Africa)—could uncover common trends and unique challenges.

Reproducing the study in different contexts will enhance our understanding of how 5G technologies can be effectively incorporated into transportation systems. Comparative studies across countries can highlight differences in policy frameworks and infrastructure readiness.

The results should be adapted to local circumstances and priorities while focusing on pertinent factors that reflect regional needs. Forming strong collaborations among government entities, the private sector, and research institutions can expedite the advancement of smart transportation systems. The findings should be developed into flexible solutions that can be implemented in both large and small urban areas through pilot projects.

5. Discussion

The outcomes of this study offer essential insights into the elements impacting the implementation of smart transportation systems within the 5G Valley in Ankara, Türkiye. The integration of 5G technology into transportation infrastructure was analyzed using the Analytic Hierarchy Process (AHP), which highlighted environmental sustainability as a key consideration for professionals in the field.

A key finding from the research is the significant emphasis placed on the "smart environment" parameter by experts. This result reflects the growing trend of smart transportation practitioners to prioritize environmentally friendly solutions. The focus on maintaining a clean and sustainable environment aligns with global initiatives aimed at combating climate change and minimizing carbon emissions. This underscores the need for transportation systems that incorporate green technologies and practices, such as electric vehicles, renewable energy sources, and efficient traffic management systems designed to reduce emissions.

Furthermore, the role of 5G technologies in smart transportation systems is another critical component discussed in this study. The rapid connectivity and low latency offered by 5G networks facilitate real-time data exchange and enhanced communication among vehicles, infrastructure, and traffic management systems. This connectivity is vital for the creation and implementation of intelligent transport systems (ITS), which can optimize traffic flow, enhance safety, and alleviate congestion. This study provides a thorough assessment of 5G applications that align with the priorities identified by practitioners, especially those focused on environmental sustainability.

The application of the analytical hierarchy process (AHP) methodology enabled a structured evaluation of the perspectives and priorities of transportation system professionals. By identifying and ranking crucial factors, the AHP enables a deeper understanding of the relative significance of various parameters in the realm of smart transportation. This methodological approach created a solid framework for decision making, ensuring that the most critical considerations were considered in the rollout of 5G-enabled transport solutions.

While the findings are encouraging, they also uncover challenges that need to be addressed for effective implementation. Transitioning to 5G-enabled smart transportation requires significant investments in infrastructure, technology, and training. Policymakers must prioritize funding and incentives to foster the adoption of green technologies, ensuring that environmental sustainability becomes a core element of transportation planning rather than an ancillary consideration.

Ensuring interoperability among different systems and technologies is also a technical challenge. Future research should focus on establishing standards and protocols that enable seamless integration across diverse platforms and technologies. Collaborative efforts among technology providers, urban planners, and policymakers are essential for creating an ecosystem that supports innovation while addressing interoperability issues.

Future studies should also examine the long-term effects of 5G integration on transportation efficiency and environmental outcomes, specifically exploring how these technologies impact traffic patterns, emission reductions, and urban mobility. Moreover, the social implications of these changes—such as public acceptance, equitable access to smart transportation, and potential job displacement—should be studied to provide a comprehensive understanding of the effects of 5G-enabled transportation systems.

In summary, this study enhances the existing knowledge of smart transportation and 5G technology integration, emphasizing environmental sustainability. By underscoring the importance of eco-friendly practices and offering a detailed evaluation of practitioner priorities, this research provides valuable insights for developing intelligent transport systems in smart cities. This highlights the necessity for ongoing research that addresses not only technical challenges but also the social and economic aspects of these transformative technologies.

6. Conclusion

This article offers a thorough examination of transportation systems in Türkiye, focusing on their intelligent features and environmental implications. This research delves into the intricacies of intelligent transportation systems (ITS) and evaluates their minimal negative impact on the environment. The insights derived from this study aim to guide ITS designers and provide essential recommendations for future research and conceptual approaches during the design phase.

By employing the Analytic Hierarchy Process (AHP) methodology, this paper reveals key insights: experts concur that sustainable transportation is a core component of smart transportation. This finding not only validates the efficiency of intelligent transportation systems (ITS) and emphasizes their compatibility with eco-friendly initiatives.

This research pays special attention to the selection of pilot regions and the integration of 5G technology within the ITS framework. The primary focus is the IPA-2 project, and Hacettepe University's campus has been designated as a significant pilot area. Within this 5G test zone, an advanced transportation system is being developed that leverages 5G technology to enable real-time data exchange among vehicles. The study also underscores the essential role of urban greenery, particularly trees, in reducing the environmental footprint of transportation systems.

Continuous monitoring activities in the 5G test zone—including daily traffic assessments, carbon emissions tracking, and evaluation of the emission-absorbing capacity of trees—offer crucial insights into the environmental impact of transportation systems. Authored by the IPA-2 Project team, this article provides an in-depth analysis of Türkiye's intelligent transportation systems. The importance of the study lies not only in its informative conclusions but also in its potential to shape future research in this dynamic area. With a strong focus on sustainability and the adoption of innovative technologies, this article highlights the importance of forward-thinking transportation planning and design approaches to support urban development and environmental protection.

According to the findings of this study, clean and engine-free options are the foremost parameters in smart transportation, highlighting its critical importance to users. Surveys conducted as part of the research identified sustainable, innovative, and safe transportation systems as the second most vital parameter, suggesting that users prioritize reliability over sustainability. The next significant aspect identified is the mixed model for transportation systems, which indicates that users expect a combination of transportation modes in smart solutions. Although local accessibility, access to ICT infrastructure, and international accessibility are recognized, they are deemed less significant by users than the other parameters.

In summary, this study acts as a driving force for enhancing discussions surrounding intelligent transportation systems, establishing a foundation for informed decision-making, policy development, and further exploration of smart and sustainable urban mobility.

Ethics Committee Approval: Ethics approval was obtained from the Scientific Research Ethics Committee in Social and Human Sciences at Necmettin Erbakan University (dated 23.04.2023, approval number 196.)

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REFERENCES

Abbas, R., Michael, K., & Mutawa, A. (2015). The privacy implications of behavioral profiling in smart transportation systems. *IEEE Intelligent Transportation Systems Magazine, 7*(3), 38-54. https://doi.org/10.1109/MITS.2015.2406691

Albino, V., Berardi, U. and Dangelico, R. M. (2015). Smart Cities: Definition, Dimension, Performance, and Initiatives. *Journal of Urban Technology, 22*(1), 3–21. https://doi.org/10.1080/10630732.2014.942092

Aselsan (2022). *Telekomünikasyon teknolojileri ve 5G altyapı geliştirme. Aselsan yıllık raporu.* 19 Mayıs 2024 tarihinde. https://www.aselsan.com.tr addressinden erişildi.

Bae, J. H., & Lee, H. J. (2016). A study of smart city infrastructure development for sustainable urban areas. *Journal of Environmental Policy and Planning, 18*(4), 443-461. https://doi.org/10.1080/1523908X.2015.1128363

Barba, C. T., Mateos, M. Á., Soto, P. R., Mezher, A. M., and Igartua, M. A. (2013). Smart city for VANETs using warning messages, traffic statistics, and intelligent traffic lights. *IEEE Xplore.* https://doi.org/10.1109/IVS.2012.6232229

Bertin, E., & Crespi, N. (2017). *Evolution of telecommunication services: The convergence of telecom and Internet.* Springer.

Bibri, S. E., and Krogstie, J. (2020). Emerging data-driven smart cities and innovative applied solutions for sustainability: The cases of London and Barcelona. *Energy Informatics, 3*(5), 1-20. https://doi.org/10.1186/s42162-020-00108-6

Bojkovic, Z., Bakmaz, B., & Bakmaz, M. (2020). 5G wireless networks: Concepts, technologies, and applications. *IEEE Access*, 8, 113498-113515. https://doi.org/10.1109/ACCESS.2020.2999472

Borge-Holthoefer, J., González-Bailón, S., & Moreno, Y. (2017). Smart cities, big data, and the future of urban development. *Journal of Complex Systems, 25*(2), 73-89. https://doi.org/10.1142/S0219525917500037

Cattaneo, A., Bianchi, C., & Di Matteo, G. (2020). Smart urban mobility: The role of 5G networks in urban transport infrastructure. *Sustainable Cities and Society, 54*, 101942. https://doi.org/10.1016/j.scs.2020.101942

Caragliu, A., Del Bo, C., & Nijkamp, P. (2009). Smart Cities in Europe. (*VU University Amsterdam, Faculty of Economics, Business Administration and Econometrics, Serie Research Memoranda, 18*. https://doi.org/10.1080/10630732.2011.601117

Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart Cities in Europe. *Journal of Urban Technology, 18*(2), 65–82. https://doi.org/10.1080/10630732.2011.601117

Chandran, B., Golden, B., & Wasil, E. (2005). Linear programing models for weight estimation in the analytic hierarchy process. *Computers and Operations Research, 32*(9), 2235–2254. https://doi.org/10.1016/J.COR.2004.02.010

Cohen, B. (2012). *What exactly is a Smart City*. 21 Haziran 2024 tarwhine https://www.fastcompany.com/1680538/what-exactly-is-a-smart-city addressinden erişildi.

Dablanc, L., Giuliano, G., Holliday, K., & O'Brien, T. (2019). Best practices in urban freight management: Lessons learned from an international survey. *Transportation Research Procedia, 39*, 500-512. https://doi.org/10.1016/j.trpro.2019.06.051

Forkenbrock, D. J. (2016). Transportation finance: The essential role of user charges. *Public Budgeting & Finance, 36*(4), 47-62. https://doi.org/10.1111/pbaf.12137

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Milanović, N., & Meijers, E. (2007). *Smart cities: Ranking of European medium-sized cities.*

Giffinger, R., & Gudrun, H. (2021). Smart city frameworks Assessing challenges and opportunities for cities. *Urban Planning International, 36*(2), 67-83. https://doi.org/10.1016/j.upln.2021.04.005

Guevara, C., & Cheein, F. A. (2020). Intelligent transportation systems and smart mobility: The rise of autonomous vehicles in urban environments. *Sustainable Cities and Society, 53*, 101911. https://doi.org/10.1016/j.scs.2020.101911

Hafeez, K., Malak, N., and Zhang, Y. B. (2007). Outsourcing non-core assets and competences of a firm using analytic hierarchy process. *Computers and Operations Research, 34*(12), 3592–3608. https://doi.org/10.1016/J.COR.2006.01.004

Hall, P. (2019). Cities of tomorrow: An intellectual history of urban planning and design in the twentieth century. *Wiley-Blackwell.*

Haller, W., Tiedeman, E., & Whitaker, R. (1996). Expert choice-user manual. Pittsburgh, PA: *Expert Choice.*

Havelsan (2023). *Türkiye'nin 5G gelişiminde Havelsan'ın rolü.* 9 Nisan 2024 tarihinde https://www.havelsan.com.tr addressinden erişildi.

Jing, X., Zhang, S., & Li, T. (2020). Application of AHP to the adoption of autonomous vehicles in smart cities. *Journal of Advanced Transportation, 2020,* 1-15. https://doi.org/10.1155/2020/8960631

Khalid, T., A. N. Khan, M. Ali, A. Adeel, A. Ur Rehman Khan, A., & Shuja, J. (2018). Fog-based security framework for intelligent traffic light control system. *Multimedia Tools and Applications, 78*(17), 24595-24615. https://doi.org/10.1007/s11042-018-7008-z

Kumar, P. and Al-Dubai, A. Y. (2020). Smart city development: Internet of things and emerging technologies. *IEEE Access*, 8, 223542-223556. https://doi.org/10.1109/ACCESS.2020.3041296

Litman, T. (2014). Transportation cost–benefit analysis: Techniques, estimates and implications. *Victoria Transport Policy Institute.* 11 Haziran 2024 tarihinde https://www.vtpi.org/tca/tca01.pdf adressinden erişildi

Liu, Y., and Peng, Y. (2021). Digital transformation in smart cities: The role of big data and AI in urban management. *Journal of Urban Technology, 28*(4), 1-18. https://doi.org/10.1080/10630732.2021.1878069

Mas, E., & Schuster, C. (2019). Public perceptions and acceptance of smart city technologies: A review. *Sustainability, 11*(20), 5596. https://doi.org/10.3390/su11205596.

MOTI (2021). *Erişilebilir Ulaşım Stratejisi ve Eylem Planı (2021-2025)*. 22 Haziran 2024 tarihinde https://sgb.uab.gov.tr/uploads/pages/yayin-sunum-ve-tablolar/erisilebilir-ulasim-stratejisi-ve-eylem-plani-2021-2025.pdf addressinden erişildi.

Mousa, S. M., and Shoaib, M. (2018). Integrating 5G networks into smart cities: A review and future perspectives. *Wireless Personal Communications, 100*(2), 401-415. https://doi.org/10.1007/s11277-018-5952-x

Oğuztimur, S. (2008). Denizyolu yük taşımacılığında küresel liman rekabet koşullarının Mersin limanı örneğinde değerlendirilmesi (Doktora Tezi). Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.

Ömürbek, N., & Şimşek, A. (2014). Analitik hiyerarşi süreci ve analitik ağ süreci yöntemleri ile online alişveriş site seçimi. *Journal of Management and Economics Research, 12*(22), 306–327.

Pan, H., & Zhang, T. (2022). Smart city development and urban sustainability: A systematic literature review. *Sustainable Cities and Society, 79*, 103673. https://doi.org/10.1016/j.scs.2022.103673

Presidential Decree No. 3032. (2018). Presidential decree approving the national broadband strategy and action plan. *Official Gazette of the Republic of Türkiye.* (in Turkish)

Ratti, C., & Townsend, A. (2011). The social nexus of the smart city. *Scientific American, 305*(3), 42-49. https://doi.org/10.1038/scientificamerican0911-42

Russo, R. D. F. S. M., & Camanho, R. (2015). Criteria in AHP: A systematic review of literature. *Procedia Computer Science,* 55, 1123–1132. https://doi.org/10.1016/j.procs.2015.07.081

Saaty, T. L. (1980). Analytic Hierarchy Process, Mcgraw Hill, New York. *Agricultural Economics Review*, 70, 34.

Saaty, T. L. (1987). *Analytic Hierarchy Process,* McGrawHill.

Saaty, T. L. (2004). Decision making—the analytic hierarchy and network processes (AHP/ANP). *Journal of Systems Science and Systems Engineering,* 13, 1–35.

Saaty, T. L. (2008). Decision-making using the analytic hierarchy process. *International Journal of Services Sciences, 1*(1), 83–98.

Saaty, T. L., & Ozdemir, M. S. (2003). Why is the magic number seven plus or minus two. *Mathematical and Computer Modeling, 38*(3–4), 233–244. https://doi.org/10.1016/S0895-7177(03)90083-5

Saaty, T., Vargas, L. G., & Dellmann, K. (2003). Allocation of intangible resources: An analytic hierarchy process and linear programing. *Socio-Economic Planning Sciences, 37* (3), 169–184.

Saaty, T. L., and Vargas, L. G. (2006). Decision-making using the Analytic Network Process. In *International Series in Operations Research & Management Science (ISOR)* (Vol. 95). https://link.springer.com/book/10.1007/0-387-33987-6

Sánchez-González, P. L., García-García, F., & Navarro, F. (2019). Eco-friendly smart cities: A survey on initiatives and implementation strategies. *International Journal of Sustainable Development and Planning, 14*(4), 315-326. https://doi.org/10.2495/SDP-V14-N4-315-326

Sharma, N., & Li, Y. (2020). 5G technology and smart city development: Opportunities and challenges. *Telecommunications Policy, 44*(8), 102001. https://doi.org/10.1016/j.telpol.2020.102001

Smith, A. (2017). Transportation and technology: Impacts of new transportation systems on urban planning. *Journal of Urban Planning and Development, 143*(2), 04017005. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000382

T.C. Çevre Şehircilik ve İklim Değişikliği Bakanlığı. (2019). 2020-2023 *Ulusal Akıllı Şehirler Stratejisi ve Eylem Planı.* Retrieved from https://www.akillisehirler.gov.tr/wp-content/uploads/EylemPlani.pdf.

Tsamboulas, D., Yannis, G., & Vagiokas, E. (2007). AHP methodology for prioritizing transportation infrastructure investments. *Transportation Research Part A: Policy and Practice, 41*(4), 346-366. https://doi.org/10.1016/j.tra.2006.09.001

Ulak Haberleşme A.Ş. (2022). *Ulak baz istasyonu ve milli 5G şebeke*. Twelve Mayıs 2024 tarihinde https://www.ulakhaberlesme.com.tr adresinden erişildi.

Wang, Y., Chen, Z., & Luo, H. (2018). Multi-criteria decision-making for sustainable urban mobility solutions: An AHP-based study. *Sustainable Cities and Society, 37*, 155-164. https://doi.org/10.1016/j.scs.2017.09.016

Wecka, M., Blake Jacksonb, E., Sihvonena, M., Pappel,I. (2022). Building smart living environments for aging societies: Decision support for cross-border e-services between Estonia and Finland, *Technology in Society,71*(2022), https://doi.org/10.1016/j.techsoc.2022.102066.

Zhang, X., Wang, Y., & Li, J. (2021). 5G-enabled smart transportation: Challenges and opportunities. *IEEE Transactions on Intelligent Transportation Systems, 22*(3), 1498-1509. https://doi.org/10.1109/TITS.2020.2983950

Zheng, Y., Capra, L., Wolfson, O., & Yang, H. (2018). Urban computing: Concepts, methodologies, and applications. *ACM Trans Intell Syst Technol., 5*(3), 10. https://doi.org/10.1145/2629481

Zhou, Y., & Shi, M.-L. (2009). *Rail Transit Project Risk Evaluation Based on AHP Model.* https://doi.org/10.1109/ICIC.2009.265

Zhu, J., & Liu, W. (2021). 5G investment strategies and economic benefits: Analysis of public-private partnerships. *Journal of Telecommunications Policy, 45*(2), 102122. https://doi.org/10.1016/j.telpol.2020.102122

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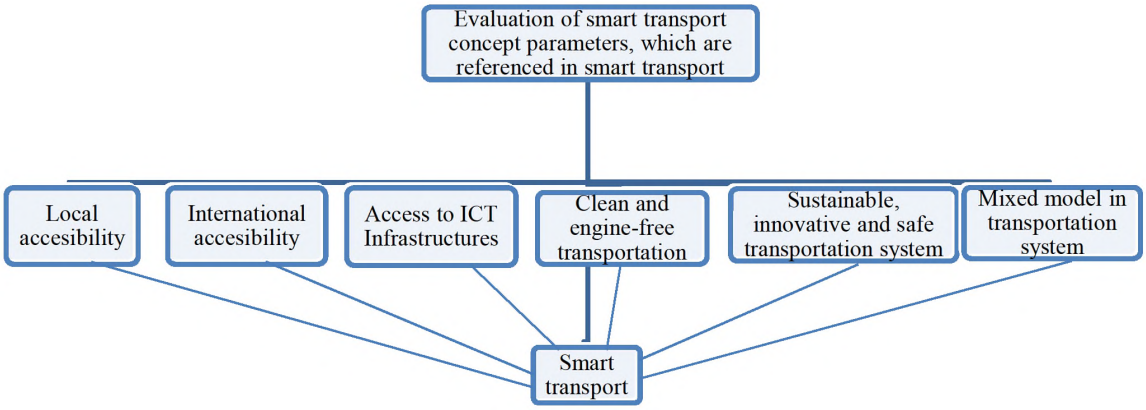
QUESTIONNAIRE ON ENABLING SMART TRANSPORTATION IN SMART CITIES: A CASE STUDY OF THE ANKARA 5G VALLEY



Which parameter is more important for smart transport?

Local accessibility	9	7	5	3	1	3	5	7	9	International accessibility
Local accessibility	9	7	5	3	1	3	5	7	9	Access to ICT Infrastructures
Local accessibility	9	7	5	3	1	3	5	7	9	Clean and engine-free transportation
Local accessibility	9	7	5	3	1	3	5	7	9	Sustainable, innovative, and safe transportation systems
Local accessibility	9	7	5	3	1	3	5	7	9	Mixed-model transportation system

International accessibility	9	7	5	3	1	3	5	7	9	Local accessibility
International accessibility	9	7	5	3	1	3	5	7	9	Access to ICT Infrastructures
International accessibility	9	7	5	3	1	3	5	7	9	Clean and engine-free transportation
International accessibility	9	7	5	3	1	3	5	7	9	Sustainable, innovative, and safe transportation systems
International accessibility	9	7	5	3	1	3	5	7	9	Mixed-model transportation system

Access to ICT Infrastructures	9	7	5	3	1	3	5	7	9	Local accessibility
Access to ICT Infrastructures	9	7	5	3	1	3	5	7	9	International accessibility
Access to ICT Infrastructures	9	7	5	3	1	3	5	7	9	Clean and engine-free transportation
Access to ICT Infrastructures	9	7	5	3	1	3	5	7	9	Sustainable, innovative, and safe transportation systems
Access to ICT Infrastructures	9	7	5	3	1	3	5	7	9	Mixed-model transportation system

Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	Local accessibility
Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	International accessibility
Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	Access to ICT Infrastructures
Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	Sustainable, innovative, and safe transportation systems
Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	Mixed-model transportation system

Sustainable, innovative, and safe transportation systems	9	7	5	3	1	3	5	7	9	Local accessibility
Sustainable, innovative, and safe transportation systems	9	7	5	3	1	3	5	7	9	International accessibility
Sustainable, innovative, and safe transportation systems	9	7	5	3	1	3	5	7	9	Access to ICT Infrastructures
Sustainable, innovative, and safe transportation systems	9	7	5	3	1	3	5	7	9	Clean and engine-free transportation
Sustainable, innovative, and safe transportation systems	9	7	5	3	1	3	5	7	9	Mixed-model transportation system

Mixed-model transportation system	9	7	5	3	1	3	5	7	9	Local accessibility
Mixed-model transportation system	9	7	5	3	1	3	5	7	9	International accessibility
Mixed-model transportation system	9	7	5	3	1	3	5	7	9	Access to ICT Infrastructures
Mixed-model transportation system	9	7	5	3	1	3	5	7	9	Clean and engine-free transportation
Mixed-model transportation system	9	7	5	3	1	3	5	7	9	Sustainable, innovative, and safe transportation systems

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RESEARCH ARTICLE

A Research on The Opportunities of Autonomous Unmanned Marine Vehicles to Enhance Maritime Safety and Security*

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ABSTRACT

Today, technology affects every aspect of life. In recent years, one of the most important technological developments in the field of maritime transportation has been "autonomous/unmanned marine vehicles". With the rapidly developing technology in the "Industry 4.0" era, these vehicles have begun being used in the maritime field. These vehicles are expected to provide further efficiency in both civilian and military maritime operations in a safer and more secure manner. This study aims to examine and determine the usage opportunities (concepts) of autonomous/unmanned marine vehicles to enhance maritime safety and security. With this aim, a Delphi research with 18 participating experts was conducted in addition to the literature review (document analysis). Because of the Delphi research, 18 usage concepts, eight of which reached consensus at the end of three Delphi sessions, were found based on expert opinions. The results of this study are expected to contribute to the maritime literature and future projects to enhance maritime safety and security.

Keywords: Autonomous Unmanned Marine Vehicle, Maritime Security, Maritime Safety, Transportation Safety, Logistics Safety

1. Introduction

A look at the technological development history of the maritime industry shows that there have been significant transformations, such as the transition from sail to steam, to diesel from coal to oil, and the development of complex automated power/engine control systems and navigational equipment of ships, including the gyro compass, radar/ARPA and terrestrial navigation systems, GMDSS, VDR, AIS, and ECDIS. It also shows that many new technologies provide improvements in safety or working/living conditions onboard ships (IMO, 2018). Today, with the rapid development of technology in the era process called Industry 4.0, autonomous/unmanned vehicles have begun to take their place in our lives. They have also begun to be developed as an alternative to conventional marine vehicles, and their use has become widespread. It is possible to handle the developments regarding autonomous/unmanned marine vehicles over the last decade from two perspectives: civilian maritime and military maritime. Examples of autonomous/unmanned marine vehicle development projects in the field of civilian maritime are "ARAGON" which is an unmanned surface vehicle for ocean observation and sea surveillance by the South Korea Research Institute of Ships and Ocean Engineering, "Maritime Unmanned Navigation Through Intelligence in Networks (MUNIN)" by the European Union (EU), "Marine Autonomous and Robotic Systems (MARS) fleet" by the Natural Environment Research Council of UK National Oceanography Centre, "Advanced Autonomous Waterborne Applications (AAWA)" by Rolls-Royce, and other projects based in Finland and Norway such as "Revolt ", "Yara Birkeland", "Falco" etc. (Emad et al., 2020; ThinkTech, 2021; NOC, 2022; Yılmaz & Önaçan, 2019). Examples of autonomous/unmanned marine vehicle development projects in the military field are "ULAQ" armed unmanned marine vehicle by Turkiye (Ares & Meteksan, 2022), "REMUS 600" autonomous underwater vehicle for mine search and identification operations by the US Office of Naval Research (NATO/OTAN, 2019) and "KATANA" autonomous surface ship by Israel Aerospace Industries Ltd. (IAI, 2022), etc. Figure 1 shows the classification of autonomous marine vehicles.

*This article has been produced from M.Sc. Thesis entitled "*Otonom/İnsansız Deniz Araçlarının Deniz Emniyeti ve Güvenliği Alanında Kullanım İmkanlarının İncelenmesi / Investigation of the Usage Opportunities of Autonomous/Unmanned Marine Vehicles in the Field of Maritime Safety and Security*" which was prepared at the Ministry of Internal Affairs Gendarmerie & Coast Guard Academy Security Sciences Institute Maritime Safety & Security Department, Ankara, Turkiye.

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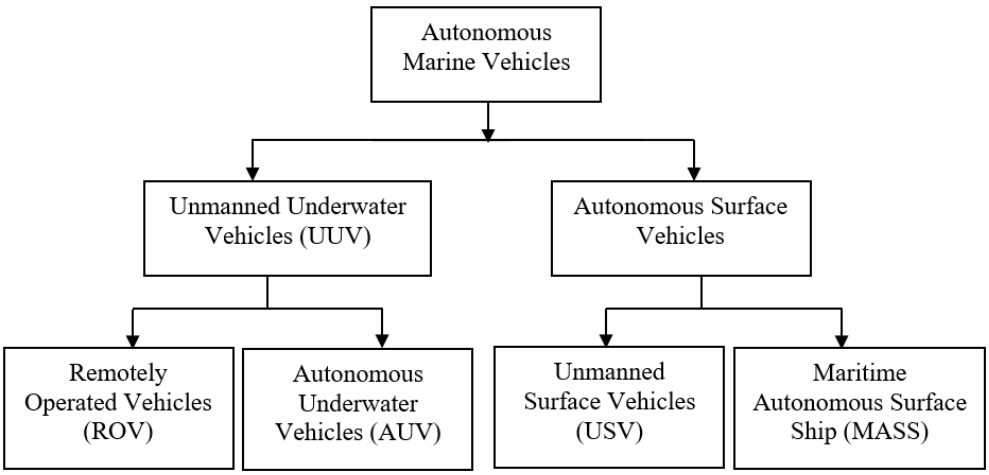

Figure 1. Classification of autonomous and unmanned marine vehicles (NAP, 2020)

ROVs are underwater robots used to explore the deep sea and oceans. It can also be used for shallow water operations. ROVs are attached to a ship via cables and controlled with a joystick. It sends its data directly through a communication cable. ROVs; It can be equipped with tools such as instruments, cameras, water samplers, lights, claws, robotic arms, and cutting blades that measure salinity, depth, and temperature. Cameras capture videos and photos of the underwater environment. Robotic arms pick up attach hooks, cut lines, or small objects to larger objects (Wilson, et al., 2021). AUVs are programmable robots that can move through water or are battery-powered without an operator guiding them. Unlike the ROV, there is no cable providing the connexion between the AUV itself and the research vessel. Similar to ROVs, they perform underwater missions such as detecting and mapping sunken ships, examining the deep seafloor, and finding obstacles that may be dangerous to ships. AUVs are efficient and productive due to their propulsion and navigation systems that allow them to move independently and accurately in any direction in the water. AUVs can also be equipped with a variety of instruments and sensors that provide information and make measurements as they move through water. AUVs survey depths ranging from 16 feet to approximately 20,000 feet below the surface (Wilson, et al., 2021). USVs can be defined as a comprehensive vessel designed to operate without a human operator on board (Burdziakowski & Stateczny, 2019). USVs can be operated by human operators via remote control, or they can be operated as autonomous vehicles that can make decisions on their own according to the conditions in which human control is minimal, using artificial intelligence and various operating systems (Bolat & Koşaner, 2021). MASS is defined as "*a ship capable of operating independently of varying degrees of human interaction*." by the United Nations International Maritime Organisation (IMO). According to MSC.1/Circ.1638 published by the IMO in 2021, the autonomy levels of marine vehicles are determined as follows (IMO, 2021):

"Level 1. Ship with automated processes and decision support: Seafarers operate and control the ship's systems and functions. Some operations are automated, but seafarers are ready to take control at any time.
Level 2. Remotely controlled ship with the seafarer on board: The ship is controlled and operated from another area. Seafarers are on board the ship to take control and operate the ship's systems and functions.
Level 3. Remotely controlled ship without the seafarer on board: The ship is controlled from a remote-control centre and its operation is ensured. The seafarer is not on the ship.
Level 4. Fully autonomous ship. "The operating system of the ship is based on autonomous decision-making and reaction."

In terms of this study, the "autonomous/unmanned marine vehicle" refers to vehicles with an autonomy level determined by IMO as Level 3 and Level 4; that is; it refers to marine vehicles that are unmanned and can perform their functions fully autonomously.

On the other hand, ensuring and enhancing maritime safety and security is a critical issue for the international maritime community, which aims to achieve safer, more secure, and sustainable maritime transportation. It is possible to use autonomous/unmanned marine vehicles as the new marine technology of the Industry 4.0 era to increase maritime safety and security. However, such usage opportunities/concepts have not been properly addressed; hence, this study will provide good insights. In this context, this study examines and determines the usage opportunities (concepts) of autonomous/unmanned marine vehicles to enhance maritime safety and security. With this aim, a Delphi research with 18 participating experts was conducted in addition to the literature review (document analysis) in the study.

2. Literature

During the literature review, it is observed that previous studies covering both topics "*autonomous/unmanned marine vehicles*" and "*maritime safety & security*" related to the subject of this study are quite limited in the civilian field and are mainly concentrated in the military field, as summarised below. De vs et al. (2021) performed a statistical analysis and concluded that applying autonomy

to small cargo ships under 120 m in length may provide the greatest safety benefit because these ships account for the majority of recorded casualties and ship losses. Agarwala (2022) addressed the great opportunity and need for employing micro-ROVs in port security. The NAP (2020) stated that the use of unmanned technologies in tasks such as reconnaissance, surveillance, intelligence gathering, drug smuggling, immigrant smuggling, illegal fishing, search and rescue, and oil spill response can increase maritime awareness and permanence. Savitz et al. (2013) stated that USVs are suitable for many missions of the US Navy such as characterising the physical environment, defence against small vessels, search and rescue, support of other unmanned vehicles, testing and training, electronic warfare/information operations/military deception, mine warfare, and collection and observation of enemies. The US Coast Guard (USCG) aims to use autonomous/unmanned marine vehicles to combat drug, immigrant smuggling, maritime search and rescue, combat illegal fishing, collect ocean and environmental data, map surface/underwater/under-ice oil spills, and provide navigational aids (buoys and beacons). It also develops various projects for using lighthouses and responding to marine pollution incidents (TRB, 2020). The South Korea Coast Guard aims to use autonomous/unmanned marine vehicles for purposes such as surface surveillance, mine detection, preparation training support, environmental research at sea, inspection of underwater objects, search and rescue operations at sea, 24-hour uninterrupted coastal and port security, fire extinguishing, and illegal fishing boats for civilian purposes such as monitoring their operations (Lee, 2022) and to monitor the illegal operations of fishing boats (Sae-jin, 2017). The Singapore Police Coast Guard aims to use autonomous/unmanned marine vehicles for coastal defence, port protection, search and rescue, marine logistics and oceanographic research purposes (Heo et al., 2017 ; HST, 2023). The Australian Maritime Border Command (MBC) aims to use autonomous/unmanned marine vehicles for wide-area reconnaissance, surveillance, and oceanographic purposes (Mugg et al., 2016). The Brazilian Navy uses autonomous/unmanned marine vehicles to clean oil spills and search for mines or submarines. (Savitz, 2021). The UK Royal Navy aims to use autonomous/unmanned marine vehicles for the purposes of detecting and neutralising naval mines (Thales, 2021) and for reconnaissance and surveillance (Royal Navy, 2021). The Royal Norwegian Navy and the Royal Danish Navy aim to benefit from unmanned marine vehicles, especially for neutralising sea mines (Hagen et al., 2003; Lauv, 2022). ULAQ, Turkiye's first armed unmanned marine vehicle, aims to protect critical bases and ports by gaining patrol boat characteristics by integrating remote-controlled combat systems (Şahin, 2021). Because of the literature review, the usage concepts of autonomous/unmanned marine vehicles observed in the literature are shown in Figure 2.

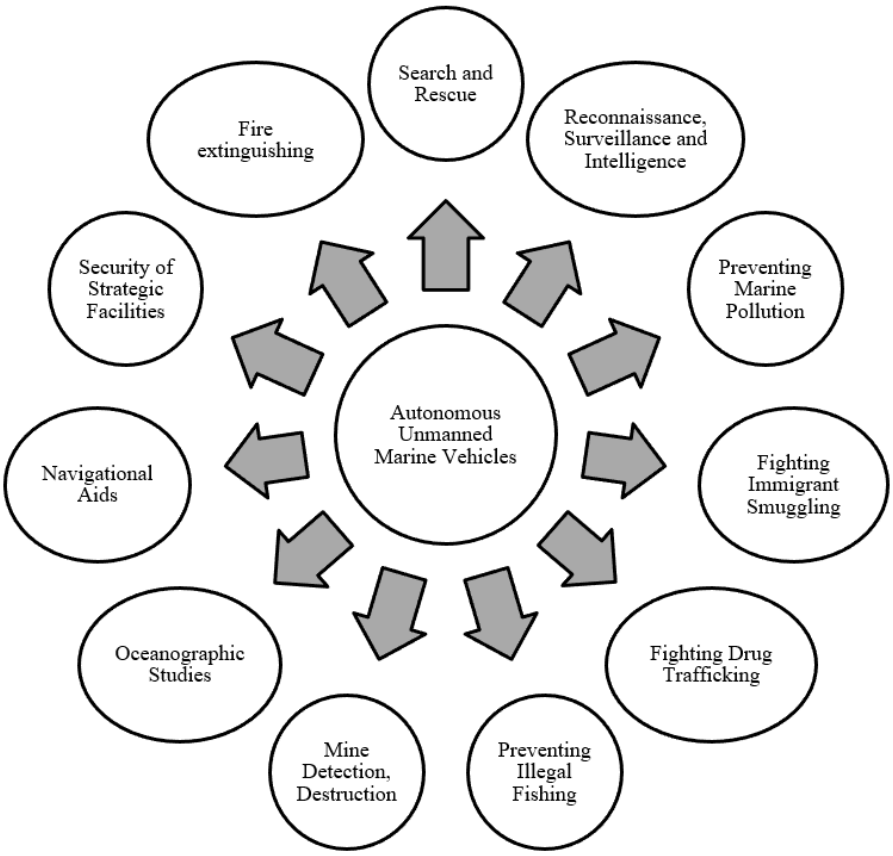

Figure 2. Usage concepts of autonomous/unmanned marine vehicles in the literature (*Figure has been created by the Authors based on Hagen et al., 2003; Mugg et al., 2016; Heo et al. 2017; Sae-Jin, 2017; Thales, 2019; TRB, 2020; Royal Navy, 2021; Savitz, 2021; Şahin, 2021; Lauv, 2022; Lee, 2022; HST, 2023.*)

These usage concepts observed in the literature were also brought to the attention of the Turkish experts in the 1th Delphi session.

3. Materials and Methods

This study is exploratory in terms of its purpose and qualitative in terms of its data collection and analysis method. Qualitative research is a research method in which data collection methods such as observation, interview, and document analysis are used, and situations are presented realistically or close to reality in their natural environment. Qualitative research examines the research problem using an interpretive approach by adopting the holistic (inductive) method (Karataş, 2015). The main research question of this study was "*Can autonomous/unmanned marine vehicles be used to increase maritime safety and security?" For what purposes can they be used?*". At the beginning of the study, a literature review (document analysis) was conducted, and then the data collection and analysis process based on expert opinions was started using the Delphi technique.

3.1. Methodology of the Delphi Technique

The Delphi technique, developed by Dalkey and Helmer in the 1950s, is a technique used by experts to express their own opinions on a predetermined topic and to make predictions about the future by reaching consensus on these opinions, especially in order to form a common opinion and reach a decision on complex issues (Dalkey & Helmer, 1963; Atasoy et al., 2021). The steps of Delphi research that are followed in this study are shown in Figure 3.

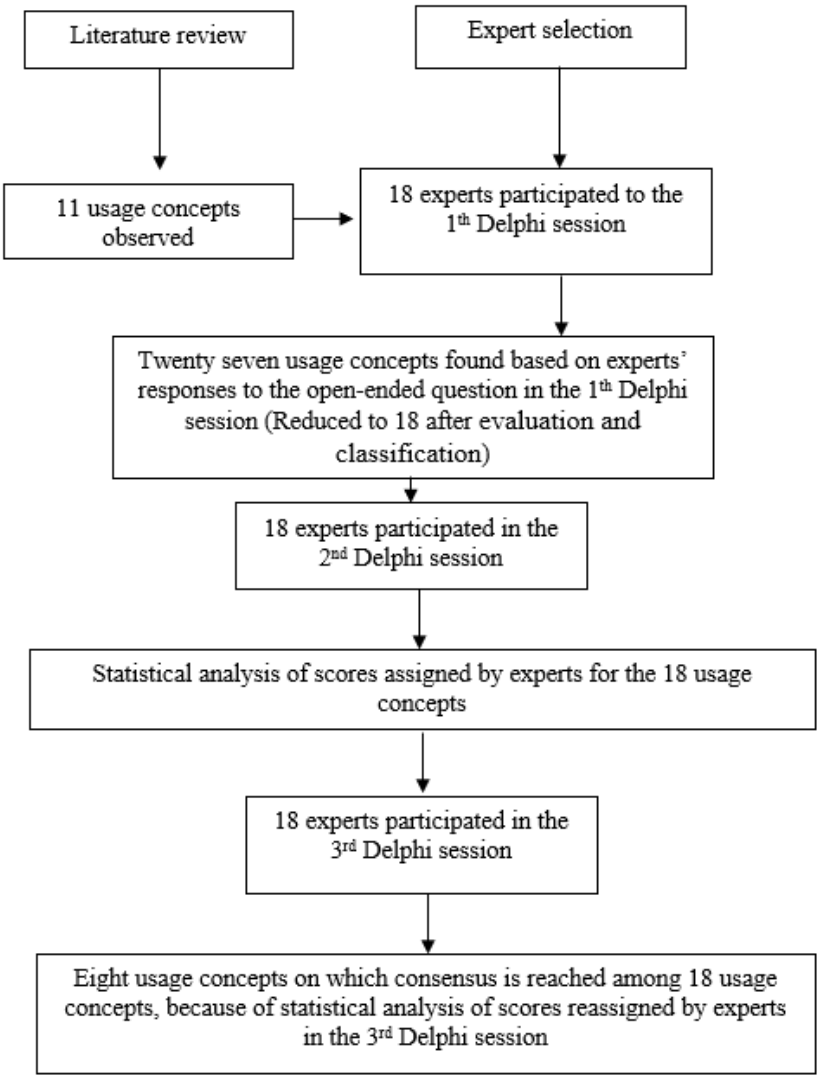

Figure 3. The steps of Delphi research that are followed in this study

Within the scope of Delphi research, 18 experts with undergraduate or graduate education in at least one of these two fields, who are knowledgeable about maritime safety and security and have experience in determining how technological developments will affect these fields, participated in the Delphi sessions. Participating experts have worked or are currently working in institutions

operating in the fields of maritime safety and security. The characteristics and participation status of the experts who participated in the Delphi research within the scope of this study are shown in Table 1.

Table 1. Characteristics and status of participating experts in Delphi research

Expert (E) No.	Profession	Sector in which he/she works	Title	Experience/ Seniority (years)	1. Delphi session	2. Delphi session	3. Delphi session
E1	Maritime Safety and Security	Special	Project Manager	32	√	√	√
E2	Maritime Safety and Security	Special	Business Development Manager	22	√	√	√
E3	Maritime Safety and Security	Public	Programme Manager	20	√	√	√
E4	Maritime Safety and Security	Public	Prof. Dr.	23	√	√	√
E5	Maritime Safety and Security	Public	Dr. Lecturer	18	√	√	√
E6	Maritime Safety and Security	Public	Ship/Boat Commander	16	√	√	√
E7	Maritime Safety and Security	Public	Ship/Boat Commander	18	√	√	√
E8	Maritime Safety and Security	Public	Ship/Boat Commander	11	√	√	√
E9	Maritime Safety and Security	Public	Ship/Boat Commander	9	√	√	√
E10	Maritime Safety and Security	Public	Ship/Boat Commander	11	√	√	√
E11	Maritime Safety and Security	Public	Ship/Boat Commander	8	√	√	√
E12	Maritime Safety and Security	Public	Ship/Boat Commander	8	√	√	√
E13	Maritime Safety and Security	Public	Ship/Boat Commander	8	√	√	√
E14	Maritime Safety and Security	Public	Ship/Boat Commander	33	√	√	√
E15	Maritime Safety and Security	Public	Maritime Pilot	20	√	√	√
E16	Maritime Safety and Security	Public	Maritime Pilot	20	√	√	√
E17	Maritime Safety and Security	Public	VTS Operator	12	√	√	√
E18	Maritime Safety and Security	Public	Ship Captain	15	√	√	√
				TOTAL	18	18	18

The Delphi study was conducted in three sessions, and a 5-point Likert scale was used in the second and third sessions, as shown in Table 2.

Table 2. Likert score scale used in the second and third Delphi sessions

Point	Score Scale
1	I do not agree at all.
2	I do not agree
3	Partially Agree
4	I agree
5	Absolutely, I agree

The Delphi study was conducted via email with 18 participating experts. In the 1st session, an open-ended question "*In what fields can Autonomous/Unmanned Marine Vehicles be used within the scope of maritime safety and security?*" had been asked of the participating experts; therefore, 27 usage concepts were found based on the responses of the participating experts. After the evaluation and classification, the 18 usage concepts shown in Table 3 were determined, and the 2nd Delphi session was started.

Table 3. Usage concepts found in the 1st Delphi session (regardless of prioritisation)

No	Concept
1	Use for reconnaissance, surveillance, and intelligence
2	Use for protection of strategically important facilities/security of critical coastal facilities, bases, and ports
3	Use for combating illegal fishing (detection, identification)
4	Use for Fighting immigrant smuggling (detection, identification)
5	Use for search and rescue activities at sea
6	Use for combating marine pollution (detection, diagnosis)
7	Use for escorting cruise (passenger) ships
8	Use as a navigation aid in bad weather conditions (lights, buoys, meteorological sensors)
9	Use for marine traffic management/mobile traffic observation station
10	Use as a surface/underwater marine vessel for special purpose services (scientific research, hydrocarbon exploration, cable and pipe laying, etc.)
11	Use for explosives/mine detection, reconnaissance, and destruction
12	Use for underwater ship survey/observation
13	Use for ship backup purposes (autonomous/unmanned tugboat, etc.)
14	Use in oceanographic studies
15	Use for surveillance of “Blue Homeland” borders, detection of border violations, and demonstration of uninterrupted presence (flag)
16	Use to ensure the safety of civilian ships in military training and exercise firing areas
17	Use for fire extinguishing purposes on ships/coastal facilities
18	Use for combating smuggling activities (humans, drugs, weapons, fuel, etc.)

3.2. Consensus Criteria

In the 2nd Delphi session, participating experts were asked to assign a score to these 18 usage concepts on a 5-point Likert- type scale with a score of 1-5. For each usage concept, statistics including 1st Quartile (Q1), 3rd Quartile (Q3), Interquartile Range (R), and Median (MD) values were calculated. In the 3rd Delphi session, participating experts were asked to re-assign their scores by presenting the calculated statistics in the 2nd session. The consensus criterion was set as “MD as 4 or more” and “CR as 80% or more” and “R as equal to or less than 1”.

1st Quartile (Q1) means the value that includes 25% of the answers to the left and 75% to the right. In other words, the median of the first half of the series, which is divided into two parts by the median, is called the 1st Quarter. 3rd Quartile (Q3) is the value that includes 25% of the answers to the right and 75% to the left. In other words, the median of the second half of the series, which is divided into two parts by the median, is called the 3rd Quarter. Interquartile Range (R) indicates the difference between Q1 and Q3. If R is equal to or less than 1 ($R=Q3-Q1\leq1$), it indicates that there is a consensus. If R is more than 1 ($R=Q3-Q1>1$), it indicates that there is no consensus. Consensus Rate (CR) is the percentage that indicates the level of consensus. It is calculated as the sum of the percentages of those who responded "4 point: I agree” and “5 point: I absolutely agree” on a 5-point Likert scale in the 2nd and 3rd sessions (Bahar& Somuncu Demir, 2021).

4. Findings and Discussion

At the end of the 3rd session, it was found that there are eight usage concepts in Table 4 on which a consensus has been reached in compliance with the consensus criterion.

Table 4. Usage concepts on which consensus has been reached after 3rd Delphi session

Usage Concepts		MD	Q1	Q3	R	CR (%)
1	Use for reconnaissance, surveillance, and intelligence purposes	5	5	5	0	99
2	Use for explosives/mine detection, reconnaissance, and destruction	5	5	5	0	96
3	Use for surveillance of “Blue Homeland” borders, detection of border violations, and for demonstrating uninterrupted presence (flag)	5	5	5	0	96
4	Use for protection of strategically important facilities/security of critical coastal facilities, bases, and ports	5	4	5	1	89
5	Use for combating illegal fishing (detection, identification)	4.5	4	5	1	87
6	Use for underwater ship survey/observation purposes	4	4	5	1	85
7	Use for oceanographic studies	4	4	5	1	85
8	Use for combating immigrant smuggling (detection, identification)	4	4	5	1	84

The concept of “Use for Reconnaissance, Surveillance and Intelligence Purposes” is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 5, R of 0, and CR of 99%. Huntsberger and Woodward (2011) states that autonomous surface and underwater vehicles could perform several missions, such as surveillance, reconnaissance, and intelligence, in both military and civilian operations. Reconnaissance, surveillance, and intelligence activities in the field of military and security are of great importance and provide power to countries; therefore, autonomous/unmanned marine vehicles can also be used for these purposes.

The concept of "Use for Explosives/Mine Detection, Reconnaissance, and Destruction Purposes" is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 5, R of 0, and CR of 96%. Yılmaz (2012) states that naval mines are used by terrorist organisations and states because of their low cost and high destructive power. With different types, these are dangerous elements of naval warfare, and it is difficult to detect them at sea. For this reason, focussing on explosives/mine detection, reconnaissance, and destruction activities through autonomous/unmanned marine vehicles can prevent terrorist activities and prevent the loss of human life in any adverse situation. For this reason, some countries that are aware of this opportunity have accelerated their efforts to develop autonomous/unmanned marine vehicles (Yılmaz, 2012). Members of the US Office of Naval Research (ONR) launched the REMUS 600 autonomous underwater vehicle for mine search and identification operations in the Baltic Sea in 2018 (NATO OTAN, 2019). KATANA, developed by Israel Aerospace Industries (IAI), performs mine countermeasure duties (IAI, 2022). Silver Marlin, USV (Unmanned Surface Vehicle), was developed in 2007 for coastal reconnaissance, port security, minesweeping, and combat purposes and has been used by the Israeli Navy since November 2009 (Heo et al., 2017). Three LAUVs (Light Autonomous Underwater Vessel) were projected to be delivered to the Danish naval base in 2022 to neutralise naval mines (Lauv, 2022). It is considered that autonomous/unmanned marine vehicles can also be used for explosives/mine detection, reconnaissance, and destruction purposes.

The concept of "Use for the Purpose of Surveillance of the Blue Homeland Borders, Detection of Border Violations, and Display of Uninterrupted Presence (Flag)" is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 5, R of 0, and CR of 96%. “Blue Homeland” is the homeland territory that covers maritime jurisdiction areas such as Turkiye’s territorial waters, exclusive economic zone, and continental shelf in the Black Sea, Mediterranean and Aegean Sea, and all living and non-living beings found there (Aydın, 2022). Protecting Turkiye’s Blue Homeland borders is of great importance, and it is important to detect border violations and display our uninterrupted flag in the "Blue Homeland". Today, this duty is carried out by the Naval Forces Command and the Coast Guard Command. However, in cases of border violations, it may take time for the notification to be received, for the ships/boats to react, and for the incidents to be detected. In this context, autonomous/unmanned marine vehicles can be positioned in certain places at certain distances within Turkiye’s Blue Homeland borders to detect and record border violations and display the flag uninterruptedly 24/7.

The concept of “Protection of Strategically Important Facilities/Use for Security Purposes of Critical Coastal Facilities, Bases and Ports” is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD value of 5, R of 1, and CR of 89%. For example; Katana was designed by Israel Aerospace Industries (IAI) for use in a wide range of missions, including port security, surveillance, and protection of oil, gas, and other critical assets in coastal waters, shallow waters, and

territorial waters (IAI, 2022). Strategically important facilities/critical facilities and ports are places of critical importance where intelligence activities are conducted today. The main threats to these areas are maritime terrorism, piracy, and wars. Therefore, the measures to be taken here are of great importance for states and countries. Such facilities protect 24 h a day by their own private security teams and law enforcement forces. It is considered that autonomous/unmanned marine vehicles can also be used by law enforcement forces for this purpose.

The concept of "Use for the Purpose of Combating Illegal Fisheries Fishing (Detection, Identification)" is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 4.5, R of 1, and CR of 87%. Fighting illegal seafood hunting is important for protecting sustainable marine resources. Illegal seafood hunting is one of the most important duties of coast guard organisations. Autonomous underwater vehicles can be actively used to prevent illegal aquaculture hunting (TRB, 2020). To take legal action against a boat/ship due to illegal fishing, it is first necessary to prove that that boat/ship is engaged in this activity. Real-time images of ships/boats suspected of being involved in illegal aquaculture fishing can be taken with autonomous/unmanned underwater vehicles, especially in bad weather conditions and in cases requiring confidentiality, and the image can be instantly transmitted to the relevant control centre.

The concept of "Underwater Ship Survey / Use for Observation Purposes" is the concept on which consensus was reached in the 3rd Delphi session, with an MD of 4, R of 1, and CR of 85%. One of the reasons for the emergence of autonomous/unmanned marine vehicles is to minimise the loss of life by performing the activities performed by humans by vehicles. Underwater ship survey/observation is not among the duties of coast guard organisations or military forces of countries, but falls within the field of maritime safety within the scope of maintenance, attitude, and inspection required for the safety of ships. The DNV GL uses ROVs to conduct underwater surveys of ships (DNV GL, 2020). It is considered that the survey and inspection activities carried out by flag States, port states, and/or classification societies using divers to observe the underwater situation of the ship can be carried out safely by autonomous/unmanned underwater vehicles.

The concept of "Use for Oceanographic Study Purposes" is the concept on which consensus has been reached in both 3rd Delphi sessions, with an MD of 4, R of 1, and CR of 85%. Autonomous/unmanned marine vehicles use in oceanographic studies, especially by the USCG, Australian Border Protection Command, and Singapore Coast Guard Police. Mugg et al. (2016) stated that unmanned marine vehicles are used as patrol boats for wide-area reconnaissance, surveillance, and oceanographic purposes. Vigilant Class Independent Unmanned Surface Vessel (IUSV) is used by the Singapore Police Coast Guard in tasks such as coastal defence, port protection, search and rescue, marine logistics, and oceanographic studies (Heo et al., 2017). It is considered that autonomous/unmanned marine vehicles can also be used for oceanographic studies.

The concept of "Use for the Purpose of Combating Immigrant Smuggling (Detection, Identification)" is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 4, R of 1, and CR of 84%. Immigrant smuggling incidents, due to their nature, are events that can turn into search and rescue incidents at any time. This extremely important task, which concerns human life, is performed by institutions such as the naval force command or the coast guard command in countries. Because it constitutes one of the primary duties of the United States Coast Guard Command, it is considered that studies on autonomous/unmanned marine vehicles cover this usage concept (TRB, 2020). It is considered that autonomous/unmanned marine vehicles can also be used to combat immigrant smuggling.

It is estimated that the idea of "*There must be seafarers onboard the marine vehicle for this operation, absolutely!*" may have been influential in the scoring of another 10 usage concepts on which consensus has not been reached by the experts. However, these concepts are also important and should be examined by future studies for comparison with the findings of this study.

5. Conclusion

The aim of this study is to examine and determine the usage opportunities (concepts) of autonomous/unmanned marine vehicles to enhance maritime safety and security. With this aim, a Delphi research with 18 participating experts was conducted in addition to the literature review (document analysis) in the study.

As a result of the literature review, it is observed that autonomous/unmanned marine vehicles have begun to be used in many countries in the fields of civilian maritime, military maritime, and coast guard operations, and various projects are still being developed to expand their usage areas. Therefore, their use will become widespread as they offer important opportunities to increase maritime safety and security in both civilian maritime and military maritime. It is also observed from the literature that research and development (R&D) research regarding the use of unmanned/autonomous marine vehicles to enhance maritime safety and security has been mainly conducted in the field of military maritime.

Because of Delphi research conducted in this study, a total of 18 usage concepts, 8 of which consensus is reached by experts, have been found, as shown in Tables 3 and 4. According to the key findings of this study, it can be stated that autonomous/unmanned marine vehicles can be used for the following purposes:

- "Reconnaissance, surveillance and intelligence",
- "Explosives/mine detection, reconnaissance and destruction",
- "Surveillance of "Blue Homeland" borders, detection of border violations",
- "Demonstrating uninterrupted presence (flag)",
- "Protection of strategically important facilities/security of critical coastal facilities, bases and ports",
- "Combating illegal fishing (detection, identification)",
- "Underwater ship survey/observation purposes", "oceanographic study purposes", and
- "Combating immigrant smuggling (detection, identification)".

These concepts have been compared and discussed with other studies. As observed from the literature, autonomous/unmanned marine vehicles have already begun to be used in some countries by institutions responsible for the protection of maritime jurisdictions under their sovereignty. Therefore, it has been concluded that autonomous/unmanned marine vehicles can be used for enhancing maritime safety and security and for other missions.

The results of this study are expected to contribute to the maritime literature and future projects to be developed with the aim of enhancing maritime safety and security. However, these dynamic topics are open to new technological developments every day and require close monitoring. Therefore, it would be useful to examine the usage concepts presented in this study separately and in more detail in future studies by comparing with the findings of this study as well.

Finally, because autonomous/unmanned marine vehicles are a newly developing technology, the literature in this field is limited by the insufficient number of scientific publications or the inability to access sufficient information due to the degree of commercial/military secrecy. Therefore, the data collection and analysis process based on expert opinions using the Delphi technique is critical for this study. There was a limitation that experts in the field whose opinions would be consulted tended to keep their opinions confidential for commercial or security reasons or to give superficial answers. To overcome this limitation, it was well explained to the experts that the necessary confidentiality and ethical rules would be strictly adhered. On the other hand, the reliability of the Delphi technique depends on the qualifications, knowledge, and experience of the participating experts; more time is spent than the planned process while receiving feedback from the participants; and heterogeneous large groups cooperate and reach a consensus. Therefore, if similar research is conducted with more heterogeneous and larger expert groups over longer periods of time in the future, it is possible to obtain more reliable findings.

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REFERENCES

Agarwala, N. (2022). Integrating UUVs for Naval Applications. *Maritime Technology and Research, 4*(3), 254470-254470.

Ares, & Meteksan. (2022), *ULAQ Turkey's First Armed Unmanned Marine Vehicle*, Retrieved from: https://www.ulaq.global/tr on 15 December 2022.Atasoy, B., Güyer, T., Ünal, M., Yüksel, AO & Aydoğdu, Ş. (2021). Determining Critical and Priority Learning Analytics Indicators Using the Delphi Technique. *Gazi University Gazi Faculty of Education Journal, 4* (2), 697-728. DOI: 10.17152/gefad.876541

Aydin, E. (2022). Meanings and Formation Methods of Phrases Blue Homeland, Sky Homeland and Cyber Homeland. *The Journal of Turkic Language and Literature Surveys (TULLIS), 7* (3), 167-178. DOI: 10.30568/tullis.1203759

Bahar, M. & Somuncu Demir, N. (2021). A Sample Study on the Delphi Technique Application Process: Multifunctional Agricultural Literacy. *Abant İzzet Baysal University Faculty of Education Journal*, 21(1), 35-53. DOI: 10.17240/aibuefd.2021.21.60703-814729

Bolat, F., & Koşaner, Ö. (2021). İnsansız Gemilerin Güncel Statüleri. *Avrupa Bilim ve Teknoloji Dergisi, (23)*, 341-358.

Burdziakowski, P. & Stateczny, A. (2019). Universal Autonomous Control and Management System For Multipurpose Unmanned Surface Vessel. *Polish Maritime Research, 26*(101), 30-39.

Dalkey, N., & Helmer, O. (1963). An Experimental Application of the DELPHI Method to the Use of Experts. *Management Science, 9* (3), 351-515. DOI:10.1287/mnsc.9.3.458

De Vos, J., Hekkenberg, R. G., & Valdez Banda, O. A. (2021). The Impact of Autonomous Ships on Safety at Sea – A Statistical Analysis. *Reliability Engineering and System Safety, 210*, 107558.

DNV GL. (2020). *DNV GL's remote in-water ship surveys using ROV mark a world first, Retrieved from*: https://www.dnv.com/news/dnv-gl-s-remote-in-water-ship-surveys-using-rov- mark-a-world-first-184199 on 12 February 2023.

Emad, G., Khabir, M., & Shahbakhsh, M. (2020). *Shipping 4.0 and Training Seafarers for the Future Autonomous and Unmanned Ships*, Retrieved from: https://www.researchgate.net/publication/338395285_Shipping_40_and_Training_Seafarers_for_the_Future_Autonomous_and_Unmanned_Ships on 15 October 2022.

Hagen, P., Storkersen, N., Vestgard, K., Kartvedt, P., & Sten, G. (2003). *Operational military use of the HUGIN AUV in Norway*, Retrieved from: https://static.aminer.org/pdf/PDF/000/259/991/on_onboard_navigation_system_for_autonomous_underwater_vehicles.pdfon 02 February 2023.

Heo, J., Kim, J., & Kwon, Y. (2017). Analysis of Design Directions for Unmanned Surface Vehicles (USVs). *Journal of Computer and Communications 5* (7), 92-100. DOI:10.4236/jcc.2017.57010

Homeland Security Technology (HST). (2023). *Vigilant Class IUSV*, Retrieved from: https://www.homelandsecurity-technology.com/projects/vigilant-class-iusv on 27 December 2023.

Huntsberger, T., & Woodward, G. (2011). *Intelligent Autonomy for Unmanned Surface and Underwater Vehicles*, Retrieved from: https://www.researchgate.net/publication/254012851_Intelligent_autonomy_for_unmanned_surface_and_underwater_vehicles on 27 December 2023.

International Maritime Organization (IMO). (2018). *MSC 99/INF.5 - Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS) - Nautilus Federation's Report of a survey on what maritime professionals think about autonomous shipping - Submitted by IFSMA and ITF*. Retrieved from: https://www.itfglobal.org/sites/default/files/node/resources/files/2018%20MSC%2099-INF.5%20-%20Report%20of%20a%20survey%20on%20what%20maritime%20professionals%20think%20about%20autonomous%20shipping%20%28IFSMA%20and%20ITF%29_1.pdf

International Maritime Organization (MO). (2021). *MSC.1/Circ.1638 on Outcome of The Regulatory Scoping Exercise for The Use of Maritime Autonomous Surface Ships (MASS)*, Retrieved from: https://wwwcdn.imo.org/localresources/en/MediaCentre/PressBriefings/Documents/MSC.1-Circ.1638%20-%20Outcome%20Of%20The%20Regulatory%20Scoping%20ExerciseFor%20The%20Use%20Of%20Maritime%20Autonomous%20Surface%20Ships...%20(Secretariat).pdf on 15 October 2022.

Israel Aerospace Industries Ltd. (IAI). (2022). *KATANA-USV System*. Retrieved from: https://www.iai.co.il/p/katana on 17 September 2022.

Karataş, Z. (2015). Qualitative research methods in the social sciences. *Journal of Spiritually Based Social Work Research, 1* (1), 62-80.

Lauv. (2022). *Three LAUV Units Delivered To The Danish Navy*, Retrieved from: https://www.oceanscan-mst.com/2022/02/14/three-lauv-units-delivered-to-the-danish-navy/ on 25 October 2022.

Lee, D. (2022). *LIG Nex1 Unveils Sea Sword-V USV For ROK Coast Guard*, Retrieved from: https://www.navalnews.com/naval-news/2022/07/lig-nex1-unveils-sea-sword-v-usv-for- rok-coast-guard/ on 22 September 2022.

Mugg, J., Hawkins, Z., & Coyne, J. (2016). *Special Report on Australian border security and unmanned maritime vehicles*, Retrieved from:https://ad-aspi.s3.ap-southeast-2.amazonaws.com/import/SR91_UMV.pdf?VersionId=b2an.wlPGRnpYBur5wGIYq3MYCcywH1O on 03 January 2023.

National Academies Press (NAP). (2020). *Leveraging Unmanned Systems for Coast Guard Missions*. Washington, DC: The National Academies Press. Retrieved from: doi:10.17226/25987.

National Oceanography Center (NOC). (2022). Autonomous Vehicles, Retrieved from: https://noc.ac.uk/technology/technology-development/autonomous-vehicles on 05 January 2023.

North Atlantic Treaty Organization (NATO/OTAN). (2019). *NATO Maritime Unmanned Systems*. Retrieved from: https://www.nato.int/nato_static_fl2014/assets/pdf/pdf_2019_09/20190909_190909-NMUS.pdf?source=content_type%3Areact%7Cfirst_level_url%3Aarticle%7Csection%3Amain_content%7Cbutton%3Abody_ on 13 September 2022.

Royal Navy. (2021). *Royal Navy launches missile from autonomous vessel in NATO exercise*, Retrieved from: https://www.royalnavy.mod.uk/news-and-latest-activity/news/2021/october/14/211014-madfox-at-nato- exercise on 13 September 2022.

Sae-jin, P. (2017). *S. Korea's first unmanned spy boat showcased for surveillance along sea border*, Retrieved from: https://ajudaily.com/view/20170428154755035 on 22 September 2022.

Savitz, S. (2021). *Opportunities for the Brazilian Navy to Employ Additional Unmanned Systems*, Retrieved from: https://doi.org/10.7249/PEA787-1 on 18 January 2023.

Savitz, Scott, Irv Blickstein, Peter Buryk, Robert W. Button, Paul DeLuca, James Dryden, Jason Mastbaum, Jan Osburg, Phillip Padilla, Amy Potter, Carter C. Price, Lloyd Thrall, Susan K. Woodward, Roland J. Yardley, and John Yurchak (2013). U.S. Navy Employment Options for Unmanned Surface Vehicles (USVs). Santa Monica, CA: RAND Corporation. Retrieved from: https://www.rand.org/pubs/research_reports/RR384.html.

Şahin, A.E. (2001). Delphi Technique and Its Use in Educational Research. *Hacettepe University Journal of Educational Research, 20*, 215-2020.

Şahin, A. (2021). *Defense Industrialist*. Retrieved from: https://www.savunmasanayist.com/ulaqin-us-liman-savunma-botu-konfigurasyon-gelistirildi/ on 17 February 2023.

Thales (2021). *The Maritime Mine Countermeasures Programme: The French and British Navies Blaze the Trail Towards a Global First With Their Revolutionary Autonomous System*, Retrieved from: https://www.thalesgroup.com/en/worldwide-defence/naval-forces/magazine/maritime - mine-countermeasures-programme-french-and-british on 19 January 2023.

Transportation Research Board (TRB). (2020). *Transportation Research Board Special Report 335 on Leveraging Unmanned Systems for Coast Guard Missions - A Strategic Imperative*. Washington, DC: The National Academies Press. DOI: 10.17226/25987

ThinkTech STM Center for Technological Thought. (2021). *Future of Unmanned Marine Vehicles and Usage Concepts II Technology and Future Foresight*, Retrieved from: https://thinktech.stm.com.tr/tr/insansiz-deniz-araclarinin-gelecegi-ve-sosyalim-konseptleri-i-askeri-ticari-ve-sivil-alanlarda-insansiz-deniz-araclari on 07 September 2022.

Turan, E., Manav, G., & Baran, G. (2021). Delirium detection form in children: Research with Delphi technique. *Journal of Psychiatric Nursing, 12* (1), 50-58. DOI: 10.14744/phd.2020.36693

Wilson, M., Bailey, D., Maung-Douglass, E., Partyka, M., Sempier, S., & Skelton, T. (2021). Oil spill modelling: From the ocean to humans: Integrated modelling of oil spill impacts, Retrieved from: https://repository.library.noaa.gov/view/noaa/34204

Yılmaz, A.E. (2012). Soldiers in the Blue Unmanned Underwater Vehicles, Retrieved from https://e-dergi.tubitak.gov.tr/edergi/yazi.pdf;jsessionid=FQmDJc3II2fH9c4BU3yDI0pY?dergiKodu=4&cilt=45&sayi=779&sayfa=60&yaziid=33510#:~:text= 02 January 2022.

Yılmaz, F. & Önaçan, MBK (2019). A Qualitative Research on Developments in Autonomous Ship Technology and Its Effects on the Turkish Maritime and Shipbuilding Sector. *Dokuz Eylül University Maritime Faculty Journal 11* (1), 57-86. DOI: 10.18613/deudfd.614836

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RESEARCH ARTICLE

Evaluation of Sustainable Transportation in 25 European Countries Using GRA and Entropy MABAC

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ABSTRACT

The increasing demand for sustainable transportation systems has driven researchers and policymakers to investigate new methodologies. European countries, with their diverse landscapes and varying population densities, have been particularly focused on optimizing transportation systems under the aim of achieving sustainability goals. This study evaluates the sustainable transportation practices in 25 European Union member countries through the implementation of grey relational analysis (GRA) and the entropy-multi-attributive border approximation area comparison (entropy-MABAC) methodology. The proposed study specifically examines the sustainability of the transportation system in these European countries. Twelve criteria have been established, providing a comprehensive analysis of various aspects of the sustainability of transportation systems. The utilization of GRA and entropy-MABAC methodology offers a robust framework for decision-makers to make informed choices regarding transportation policies and investments, ensuring a more sustainable and efficient future for European transportation systems. The findings rank Sweden and Germany first and second, respectively. Poland ranks last in both. The correlation analysis produced a coefficient of 0.8218, which is near 1 and implies a substantial correlation between the outcomes generated by GRA and entropy-MABAC, indicating that the outputs from both approaches are consistent. The findings indicate that the two methods are reliable and yield similar results.

Keywords: Entropy-MABAC, Grey Relational Analysis, Sustainable Transportation

1. Introduction

A nation's transportation systems profoundly affect its economic, social, and environmental dimensions. Transportation activities, though, consume a substantial amount of energy and produce a significant amount of greenhouse gas emissions, both of which makes them a great source of environmental degradation (Rogers & Weber, 2011). The relationship between sustainability and transportation is essential and intricate, deeply connected to the ecological, societal, and economic dimensions of modern society. Transportation is crucial to our daily lives, facilitating the connection of people, goods, and services. However, it also carries substantial implications for the well-being and future of our planet. The concept of sustainability in transportation pertains to the capacity to fulfill present transportation requirements while safeguarding the potential of future generations to fulfill their own needs. The concept entails the comprehensive evaluation of the environmental, social, and economic repercussions associated with transportation systems, with the aim of mitigating adverse consequences and optimizing advantageous outcomes (Illahi, U., & Mir, 2019). In the literature, there are several studies which consider sustainable transportation systems by taking into account greenhouse gas emissions (Rehman et al., 2023; Soni et al., 2022), air and water quality (Johnson & White, 2010; Lev-On et al., 2005), safety (Babaei et al., 2022), the social dimension (Karjalainen & Juhola, 2019), energy efficiency (Palander et al., 2020), and many other concerns.

There is a growing consensus among scholars and experts that a sustainable transportation system should possess certain key attributes, ensuring safety, efficiency in facilitating accessibility and mobility, and promoting economic productivity, all while minimizing harm to the environment (Amekudzi et al., 2009). The present study investigates the transportation-related parameters of European countries from a sustainability perspective via grey relational analysis (GRA) and the entropy-multi-attributive border approximation area comparison (entropy-MABAC) methodology. The GRA method was selected for its capacity to effectively manage systems that involve uncertain and imprecise information. This approach demonstrates exceptional proficiency in examining intricate systems by converting qualitative data into quantitative metrics (Hsiao et al., 2017; Liu et al., 2009). Its versatility in managing multiple datasets makes it appropriate for assessing the multidimensional character of sustainability in transportation

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across different European countries. In addition, the entropy-MABAC methodology provides a methodical strategy for managing difficulties related to decision-making with numerous criteria. This method ensures a fair and comprehensive evaluation of transportation systems by utilizing entropy to quantify the uncertainty and information content of specific criteria. In this way, we have considered several factors, including: freight transportation, public transportation, transportation types, energy consumption, passenger car rate, renewable sources in transportation, electric consumption in transportation, and greenhouse gas emissions (GHG). These criteria have previously been considered in the literature separately (Kraus, 2021). However, this study considers these criteria together for the first time. In addition, the reason behind selecting these criteria derives from the motivation of usage of energy source that affects GHG and effective utilization of transportation type. Limiting the study to 25 countries achieves an appropriate balance between the scope and thoroughness of the analysis. It enables a limited range of study while still offering enough data points to make significant inferences regarding sustainable transportation practices throughout Europe.

The primary objectives of this study encompass: 1) Proposing a systematic approach towards the evaluation of European countries based on their transportation sustainability profiles, 2) Applying and comparing the GRA and entropy-MABAC methodologies, 3) Evaluating the sustainability of the transportation systems in European countries by examining diverse parameters, including energy consumption and electricity consumption in transportation, renewable sources, and total GHG, 4) Providing a framework that could be utilized for a mutual consensus between European countries based on their strengths and weaknesses with respect to sustainable transportation.

1.1. Contributions of the study:

- One important aspect is the evaluation of transportation sustainability through the comparison of the GRA and entropy-MABAC techniques. This study contributes to knowledge about the applicability and efficacy of various analytical approaches in sustainable transportation assessment by demonstrating their similarities and consistent capacity to produce reliable results.
- The study offers a thorough examination of multiple factors related to sustainable transportation, such as: energy usage, usage of electricity, exploitation of renewable sources, and GHG. This comprehensive methodology allows for a comprehensive analysis of transportation sustainability, encompassing its multifaceted nature and intricacies.

This study provides useful insights for policymakers and stakeholders engaged in transportation planning and decision-making. It examines the strengths and weaknesses of several European countries in terms of transportation sustainability. Following this introductory section, Section 2 provides a literature review of transportation sustainability and multi criteria decision making (MCDM) techniques. Section 3 presents the methodology, which includes preliminaries and background information necessary to understand the proposed investigation. Section 4 outlines the approach employed for data collection and analysis, providing the results obtained from the MCDM methodologies along with a detailed discussion. Finally, Section 5 concludes the paper with a summary of key insights and avenues for future research.

2. Literature Review

The importance of developing sustainable transportation systems has grown significantly in response to the various environmental, social, and economic challenges associated with transportation modes, electricity and energy consumption, and the utilization of renewable energy sources,. The objective of this literature review is to consolidate and evaluate prior research pertaining to sustainability within the realm of transportation.

Gökçekuş et al. (2019) presented a study which aimed to incorporate the theory of MCDM into green transportation, while also promoting the use of public transportation, bicycles, and walking for travel purposes. Furthermore, this research aimed to evaluate and compare traditional sustainable transportation alternatives using a MCDM process.

Marimuthu et al. (2022) wrote an article that provides a revised method for ranking generalized interval type-2 trapezoidal fuzzy numbers. Interval type-2 fuzzy sets are beneficial for representing uncertainty and managing imprecision in decision-making data. The designed ranking method aims to tackle the difficulty of making judgments on sustainable urban transportation when various variables must be taken into account. Prioritization and ranking are important steps in providing a deep insight of the sustainable transportation and accurate decision making.

Concerning this perspective, numerous studies have been presented in the literature. One of the articles introduces a novel approach to applying the concept of shared mobility, wherein postal operators leverage their extensive networks of facilities to act as service providers (Senapati et al., 2023). In this study, the primary inquiry revolves around determining the best environmentally-friendly option that service providers should present. The study also proposes a sophisticated decision support model that utilizes Aczel-Alsina aggregation operators and power operators in the context of intuitionistic fuzzy environment to address this difficulty. The criteria weights are determined using the Shannon entropy-based power weighted technique. Another important study aims

to evaluate and rank the various methods of incorporating the Metaverse into the sharing economy, considering different criteria and uncertainties (Rani et al., 2023). It presents a decision-making strategy consisting of four stages, specifically designed for the interval-valued Pythagorean fuzzy context. The first step involves proposing a new scoring function to compare interval-valued Pythagorean fuzzy numbers. Next, several interaction aggregation operations for the Individual Value Preference Function have been suggested to consolidate the knowledge of each individual in the process of group decision-making. Furthermore, a comprehensive weighing procedure is introduced to determine the objective weights of the criterion via a cross entropy-based method. It is also important to analyze the reliability of the provided ranking on sustainable transportation. Sustainable transportation concerns encompass technical elements and subjective assessments, which can be strategically reported by specialists.

In the study conducted by Santos Arteaga et al. (2023), the assessments of multiple experts are presented to illustrate the significance of strategic incentives in the rankings achieved via the implementation of MCDM methodologies. It provides a numerical demonstration of the relationship between the reporting techniques of experts and the formal instruments that decision makers have at their disposal to prevent potential manipulations of the final ranking. Technology is significant regarding sustainable transportation due to its unpredictable nature which necessitates disciplined decision making. In that aspect, Dahooie et al. (2023) conducted a study that analyzes a novel hybrid multi-criteria decision-making approach to identify internet of things (IoT) applications in the urban transportation sector for future investment. The approach utilizes a new portfolio matrix that considers two dimensions: the impact on sustainable development and the feasibility of implementing IoT. Autonomous vehicles are important factors to ensure sustainable transportation due to traffic safety, enabling efficient and effective planning, and providing a dynamic response to any change of actions. From the this point of view, Gamal et al.(2023) presents a framework for selecting autonomous vehicle selection. In this framework, type-2 neutrosophic numbers, removal effects of criteria, and combined compromise solution approaches are included, with the intent of reducing the subjectivity of human judgment.

Considering sustainable transportation, the study of Ecer et al. (2023) introduced a practical and reliable decision-making framework that can effectively address complex uncertainties in order to assess the sustainability performance of micro mobility solutions. In addition, it proposes a new methodological framework called Delphi, Logarithmic Percentage Change-Driven Objective Weighting, and Combined Compromise Solution methods with interval-valued fuzzy neutrosophic number information. This framework serves as a tool for reconciling and establishing the criteria that impact the assessment processes. Another important study was conducted by Antunes et al. (2023) and focuses on the impact of research-development and innovation on transportation sustainability performance. In this study, a novel TEA-IS model is first produced to evaluate the sustainability performance of road transportation. This hybrid DEA-TOPSIS model has the capability to examine the sustainability performance by considering the synergistic impacts among the criteria, in addition to including the advantageous aspects of each individual model. Machine learning approaches are employed to anticipate the performance levels and synergistic nature of provinces in China, based on socioeconomic and demographic factors.

Regarding the performance evaluation, the study of Zhang et al. (2023) assesses the efficiency of railway transportation in China with a systematic approach. The research first establishes the criteria for assessing the performance of railway transportation, encompassing railway safety, infrastructure, equipment, operational efficiency, and environmental sustainability. Furthermore, the weight of each index is determined by employing the intercriteria correlation approach (CRITIC), which assesses the significance of criteria importance. Furthermore, the railway transportation performance is evaluated using an MCDM approach, specifically employing the CRITIC-relative entropy method.

Systematic frameworks and assessments of strategies, systems, and alternatives are crucial to ensure efficiency and effectiveness in sustainable transportation systems. From the this point of view, Kovac et al. (2023) proposes a methodology to handle city logistics concepts. In this study, the ADAM method was applied, considering the city-dry port micro-consolidation centers. Jiang et al. (2023) conducted a study that focuses on sustainable urban road alignment planning. In order to achieve that purpose, the Delphi method and geographic information system based least-cost wide path approaches were utilized. Another study by Korucuk et al. (2023) presented a model for selecting a smart network strategy and determining the weights of criteria used in green transportation indicators. The study was conducted to build an optimal smart network strategy. The authors of the study believe that the proposed model will help businesses and governments achieve their environmental, economic, and social goals by promoting green logistics. This will involve efficiently using limited resources to ensure a sustainable environment for future generations and provide businesses with a competitive edge. In addition, the study of Bouraima et al. (2023) evaluates different railway systems for sustainable transportation, utilizing an integrated IRN SWARA and IRN CoCoSo model. The study proposed by Zagorskas and Turskis (2024) aimed to tackle the difficulty of converting car-oriented industrial parks into places that are hospitable to pedestrians and cyclists. The study aimed to estimate the potential influence on bicycle and pedestrian traffic flows by evaluating various pathway connections using a MCDM approach.

Table 1. Summary of the literature review

Authors-Year	Method	Criteria	Highlight
Gökçekuş et al., 2019	Fuzzy PROMETHEE Method	Toxics gases, climate change, noise, air quality, and capacity	Evaluating and contrasting the traditional sustainable transportation alternatives.
Marimuthu et al., 2022	Interval Type-2 Trapezoidal Fuzzy Number	Reliability, speed, capacity, cost, flexibility, energy, CO2 emissionsReliability, speed, capacity, cost, flexibility, energy, and CO2 emissions	Examines all essential aspects of transportation sustainability, encompassing the efficacy of resilient transportation systems.
Senapati et al., 2023	Intuitionistic fuzzy power Aczel-Alsina model	Cargo and space capacity, GHG emissions, investment cost, market potentialCargo and space capacity, GHG emissions, investment cost, and market potential	The topic of sustainable transportation sharing methods.
Rani et al., 2023	Interval-valued Pythagorean fuzzy model, OCRA approach	12 criteria, including: financial paradigm, Security, Critical mass of users, and the fleets in real-time	Incorporating the Metaverse into the sharing economy specifically in the transportation industry.
Santos Arteaga et al. ,2023	Hesitant fuzzy numbers, TOPSIS	24 criteria, including: Operating costs, GHG emissions, usage of fossil fuels, energy consumption, and travel costs	Converting a MCDM situation into a game-theoretic scenario within the concept of sustainable transportation.
Dahooie et al., 2023	The improved Fuzzy Cognitive Map (FCM) - Best Worth Method (BWM) method, ARAS method	Pollution, energy consumption, GHG emission/climate change, and customer accessibility to transport system	Internet of Things (IoT) in Transportation
Gamal et al., 2023	Type-2 neutrosophic numbers, compromise solution (CoCoSo) method	Price, environmentally friendly, and battery capacity of the autonomous vehicles	Choosing the most suitable autonomous vehicle.
Ecer et al., 2023	Novel IVFNN (interval-valued fuzzy neutrosophic number)-Delphi-LOPCOW (Logarithmic Percentage Change-Driven Objective Weighting)-CoCoSo framework	Land use and infrastructure, land area consumed by public transport facilities m^2, land consumption, and ecosystem degradation	Providing a framework to evaluate the sustainability of small-scale transportation methods.
Antunes et al., 2023	A novel trigonometric envelopment analysis for ideal solutions (TEA-IS)	Labor, capital, energy, GDP, GDP per capita, and population density	Evaluating the sustainability performance of road transportation.
Zhang et al., 2023	Relative entropy evaluation method, the cross-efficiency evaluation method	Railway mileage, labor, freight turnover, passenger turnover, and locomotives	Assessing the efficiency of railway transportation in China with regards to sustainability.
Kovac et al., 2023	Mathematical programming and the axial-distance-based aggregated measurement (MCDM) method	The number of cities, the number of delivery vehicle trips, delivery reliability and flexibility, and availability of traffic infrastructure	Envision an innovative proposal for a potentially sustainable city logistics concept:
Jiang et al., 2023	Systematic literature review, Delphi method, questionnaire surveys for MCDM, GIS	Traffic factors, economic factors, social factors, environmental factors, and engineering factors	Considering digitalization and parsing methodologies, factor evaluation, and road alignment creation in the context of IT development.
Korucuk et al., 2023	Picture fuzzy LBWA (evel based weight assessment)–CoCoSoframework	Economic indicators, environmental indicators, social indicators, and ideal smart network strategies	Developing an optimal smart network strategy.
Bouraima et al., 2023	IRN (interval rough numbers) SWARA and IRN CoCoSo model	National policy, railway network, human and institutional capacity, natural environment, and financial resources	Evaluation of the railway transportation system.
Zagorskas and Turskis, 2024	ARAS-G MCDM Approach	Population, travel distance, and financial savings	Enhance the connectivity of the cycling pathway network, highlighting the possibility of significant growth in cycling and walking.

In conclusion, there exists a body of research that examines the environmental factors in the concept of sustainability with multiple perspectives. Most of the studies only consider a single city or country with limited perspectives. However, in order to analyze sustainable transportation, it is required to consider many factors. Additionally, it is necessary that the method efficiently mitigates the impact of dimensions from both positive and negative viewpoints. In the present study, a total of 12 distinct criteria are taken into account for the purpose of addressing evaluation of European countries, implementing the GRA, Entropy Weight Method (EWM), and MABAC methods.

3. Methodology

3.1. Grey Relational Analysis (GRA)

Deng (J.-L. Deng, 1982) introduced the grey system theory, which specifically addressed the process of decision making when only partial knowledge is available and other aspects remain unclear (Patil et al., 2019). Grey theory is an effective framework employed to address situations characterized by uncertainty. The available information may encompass diverse uncertainties and distortions in the pursuit of novel systems with both internal and external impacts, as well as constraints on human comprehension (Erdemir & Kırkağaç, 2022). The GRA is a significant theory used to evaluate alternatives based on specific criteria (Mondal & Roy, 2022). Considering the GRA, there are a few studies conducted in the literature related to sustainable transportation. One such article aims to determine the most suitable mode or combination of modes for transporting shipments from the starting point to the destination (Fulzele et al., 2019). This is achieved by using an integrated approach that combines grey relational analysis based intuitionistic fuzzy multi-criteria decision-making process and a fuzzy multi-objective linear programming model. Another study presents a method for solving the problem of making decisions in the field of sustainable transportation investments and logistic service providers, where the criteria and expert weight information are unknown (Qadir et al., 2023). The proposed approach utilizes Pythagorean double hierarchy linguistic term sets and hierarchy linguistic term sets with grey relational analysis. Transportation sectors are crucial to guarantee the creation of environmentally friendly towns. In order to achieve this objective, another study constructed a complete assessment index system consisting of three subsystems, seven facets, and 31 indicators (F. Deng et al., 2020). Subsequently, the combination of entropy weight and gray correlation was employed to ascertain the weights of the indices. In this respect, another study accomplished three primary objectives (Yuan et al., 2017): investigation into the links between transportation development, energy consumption, and CO2 emissions in 30 Chinese provinces (determining the specific transportation development mode for each province). The study uncovered policy implications for promoting sustainable transportation development at the provincial level. The 30 provinces can be categorized into eight development modes based on the computed Grey Relational Grades.

The steps of GRA are given as follows (Mondal & Roy, 2022):

Step 1: The decision matrix is formed with n criteria and m alternatives. The value of each alternative for the relevant criterion is recorded in the X_{ij} matrix.

$$X_{ij} = [x_{ij}]_{mxn} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ : & : & \dots & : \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (1)$$

Step 2: In the first step, the normalization process is applied by using Eq. 2 and Eq. 3. Also, xij notation is used to record the value of each alternative for the relevant criterion.

When smaller, the better-quality characteristic, normalized value r_{ij} is given by:

$$r_{ij} = \frac{max_i(x_{ij}) - x_{ij}}{max_i(x_{ij}) - min_i(x_{ij})} \quad (2)$$

When larger, the better-quality characteristic, normalized value r_{ij} is given by:

$$r_{ij} = \frac{x_{ij} - min_i(x_{ij})}{max_i(x_{ij}) - min_i(x_{ij})} \quad (3)$$

where $max_i(x_{ij})$ and $min_i(x_{ij})$ are the maximum and minimum values of the original sequence r_{ij}.

Step 3: During the second stage, the deviation sequence is acquired by applying the subsequent equation:

$$\Delta_{ij} = max_i(r_{ij}) - r_{ij} \tag{4}$$

Step 4: The grey relational coefficient (GRC) is computed by Eq. 5.

$$\gamma_{ij} = \frac{min_i(\Delta_{ij}) + \gamma max_i(\Delta_{ij})}{\Delta_{ij} + \gamma max_i(\Delta_{ij})} \tag{5}$$

where γ is the resolving coefficient, $\gamma \epsilon [0,1]$.

Hence, the estimation of the grey relational grade (GRG) is as follows:

$$\delta_i = \Sigma_j w_j \gamma_{ij}, \forall i, \tag{6}$$

where w_j is the weight of j_{th} criterion, and $\sum_j w_j = 1$.

Therefore, The GRA method gives each indicator the same weight.

3.2. Entropy Weight Method (EWM)

The Entropy Weight Method (EWM) was proposed by Shannon (1948) in order to determine objective weights. EWM has a significant benefit over subjective weighting models as it eliminates the influence of human variables on indicator weights, hence improving the objectivity of the comprehensive evaluation results (Zhu et al., 2020). Entropy, which has its basis in probability theory, is utilized to evaluate ambiguous information. This method employs the entropy values of each indicator to calculate the weights of the indicators, making it an objective weighing approach (Madenoğlu, Ünlüsoy, & Yilmaz, 2022). Considering EWM, several studies in the literature have considered the transportation and sustainability perspectives. One such study aimed to produce a multi-objective model for optimizing the passenger transportation system, taking into account carbon emissions, transit costs, and resource usage (W. Zhang et al., 2023). Furthermore, the optimal solution was achieved by combining the ideal point approach with EWM. Another article constructs an evaluation index method for the urban comprehensive carrying capacity by selecting nine indicators from the population, economy, construction, and transportation aspects (Han et al., 2022). The urban comprehensive carrying capacity of the five provinces was calculated using the EWM and the Linear Weighted Sum Method. Another relevant paper analyzes the development of green transportation in Zhoushan as an example, selecting the data from three aspects: basic indicators, means of transportation, and road construction (Shen et al., 2021). The entropy weight method was used to determine the entropy value and weight of each index, establishing the index evaluation system. The steps of the EWM are outlined below.

Step 1: The decision matrix is formed with n criteria and m alternatives. The value of each alternative for the relevant criterion is recorded in the X_{ij} matrix, as in Eq. 1.

Step 2: Normalization matrix is calculated using Eq.7 to normalize the decision matrix for both minimization and maximization criteria.

$$e_{ij} = \frac{x_{ij}}{\Sigma_{i=1}^{m} x_{ij}} \tag{7}$$

Step 3: Entropy values of the criteria are calculated using Eq.8.

$$E_j = \frac{\Sigma_{i=1}^{m} e_{ij} ln(e_{ij})}{ln(m)} \tag{8}$$

Step 4: The weight of each criterion is calculated as follows:

$$w_j = \frac{1 - E_j}{\Sigma_{j=1}^{n}(1 - E_j)} \tag{9}$$

3.3. Multi-Attributive Border Approximation Area Comparison Method (MABAC)

MABAC is a MCDM method proposed by Pamucar et al. (2015). The approach considers the possible values of both loss and gain, with the outcomes not being affected by the dimensions or positive/negative angles of the criterion. Unlike other MCDM approaches, the MABAC method effectively counteracts the influence of dimensions from both positive and negative perspectives in the decision-making process (Shi et al., 2024). For the MABAC method, the existing literature focuses on transportation without considering sustainability. Other studies have also considered the MABAC method related to transportation. One of these works introduces a novel approach in the field of multi-criteria decision-making to identify optimal route criteria for the transportation of hazardous materials (Noureddine & Ristic, 2019). The weight coefficients of these criteria were derived using the Full Consistency Method. The evaluation and selection of vendors were carried out via the TOPSIS and MABAC methodologies. Another research focuses on the development of a selection strategy for hybrid automobiles utilizing the entropy-based MABAC approach (Biswas & Das, 2018). This study emphasizes the most optimal hybrid car that effectively mitigates air pollution in urban areas, while also providing notable environmental advantages, decreasing reliance on foreign energy imports, and minimizing annual fuel expenses. One of the studies related to MABAC application on transportation considers railway management (Veskovic et al., 2018). In this article, the railway management models in Bosnia & Herzegovina were examined. To assess these models, a novel hybrid model was utilized, namely a model that combines the Delphi, Step-Wise Weight Assessment Ratio Analysis, and MABAC methodologies. The last relevant study that we observed presents a thorough and sophisticated approach to data analytics for rating commercial service airports (Zhou et al., 2023). The methodology includes data envelopment analysis, the best-worst method, and the MABAC comparison method to provide a robust ranking framework.

Steps of MABAC method is as follows:

Step 1: Decision matrix is introduced. Eq. 6 demonstrates the first step.

Step 2: Normalization process is applied.

For a criterion that is beneficial and follows a “larger-the-better” criterion:

$$d_{ij} = \frac{x_{ij} - min(x_i)}{max(x_i) - min(x_i)} \tag{10}$$

For a criterion that is non-beneficial (cost) and follows a “smaller-the-better” criterion:

$$d_{ij} = \frac{x_{ij} - max(x_i)}{min(x_i) - max(x_i)} \tag{11}$$

Step 3: The weighted matrix is calculated using Eq. 12.

$$u_{ij} = w_j(d_{ij} + 1) \tag{12}$$

Step 4: The border approximation matrix is generated.

$$g_j = \frac{1}{m\sqrt{\prod_{i=1}^{m} u_{ij}}} \tag{13}$$

The border approximation area matrix (G) has been generated in a 1 × n format.

$$G = [g_1\, g_2\, \ldots g_n] \tag{14}$$

Step 5: Determine the distance between the alternatives and the border approximation area.

$$r_{ij} = u_{ij} - g_j \tag{15}$$

$$R = [r_{ij}]_{mxn} \tag{16}$$

where R indicates the distance matrix, the variable r_{ij} represents the distance between the i_{th} alternative and the j_{th} criterion, measured from the border approximation area.

Step 6: Ranking of the alternatives.

$$CF_i = \Sigma_{j=1}^{n} r_{ij} \tag{17}$$

where CF_i represents the value of the criteria function for the ith alternative, with a higher value indicating a better result.

4. Applications and Discussion

We have ranked European countries according to the sustainability of their transportation. Due to the availability of data, 25 out of 27 European countries have considered and compared under 12 criteria. The GRA and entropy MABAC methods were applied in order to rank the countries. Figure1 below shows the flowchart of the present research.

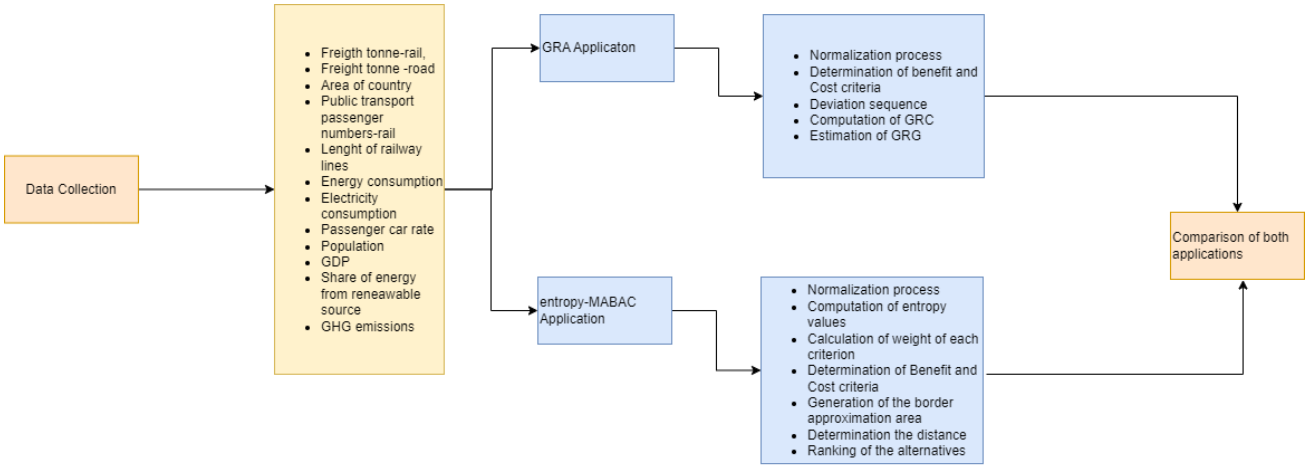

Figure 1. Flowchart of the present study

The data utilized has been acquired from multiple databases, as indicated in Table 2 below.

Table 2. Characteristics of data

Criteria	Database	Date / Reference	Relevance
Freight tonne-km by rail	OECD	2021/ (da Fonseca-Soares et al., 2024)	A decrease in the necessity of traveling in order to minimize the quantity of journeys.
Freight tonne-km by road	OECD	2021/ (Farid et al., 2024)	Reduced use of cars is required.
Area of country (sq.km)	European Union	2022/ (Di Martino et al., 2024)	Relevance of population density related to the social aspect of sustainable transportation.
Public transport passenger numbers by rail	OECD	2021 / (Kraus, 2021), (Şener; et al., 2023)	Reduced use of cars is required.
Length of railway lines (km)	UNECE	2021/ (Kraus, 2021)	Decreasing the necessity of travel to minimize the frequency of travels and the distance covered per trip
Energy consumption in transport	Eurostat	2021 / (Gulcimen et al., 2023)	Environmental aspect of sustainable transportation due to low carbon emission
Electricity consumption in transport (road)	Eurostat	2021 /(Armenta-Déu, 2024)	Environmental aspect of sustainable transportation due to low carbon emission

Table 2. Continued

Passenger car rate (per 1000 inhabitants)	UNECE	2021 / (Gulcimen et al., 2023)	Developing the concept of shared car ownership and promoting the use of reduced emission vehicles
Population size	World Bank	2021/ (Al-Shammari & Al-Jameel, 2023), (Antunes et al., 2023)	Developing the social and environmental relevance to transportation
Gross Domestic Product (GDP)	World Bank	2021 /(Antunes et al., 2023)	GDP has a crucial role in fostering the advancement of transportation due to investment opportunities.
Share of energy from renewable sources used in transport	Eurostat	2021/ (Kraus, 2021)	Environmental aspect of sustainable transportation due to low carbon emission
Total greenhouse gas emissions (GHG) (kt of CO2 equivalent)	World Bank	2019/ (Kraus, 2021)	Environmental aspect of sustainable transportation due to low carbon emission

A set of 12 indicators was employed to assess the sustainability of transportation in European countries. Criteria that provide benefit include: "Freight tonne-km by rail," "Public transport passenger numbers by rail," "Length of railway lines," "Electricity consumption in transport," "GDP," and "Share of energy from renewable sources used in transport." Non-benefit criteria (cost) were chosen as: "Freight tonne-km by road," "Area of country," "Energy consumption in transport," "Passenger car rate," "Population size," and "Total greenhouse gas emissions."

The basic data set is demonstrated in Table 3 below.

Table 3. Data set of the proposed study

	Freight tone km-rail	**Freight tone km-road**	**Area of country**	**Public transport passenger numbers-rail**	**Length of railway lines**	**Energy consumption in transportation**	**Electricity consumption in transportation**	**Passenger car rate**	**Population per area**	**GDP**	**Share of energy from renewable source**	**Total GHG emission**
Austria	21781	19564	83858.	218850	5603	7975.724	14.011	574	8955797	480368.4	9.355	76917.89
Belgium	6698	36199	30528	235000	3578	8531.358	254.4	511	11592952	594104.18	10.262	108064.9
Bulgaria	4658	35161	110993	17147	4031	3433.309	39.545	412	6877743	84056.31	7.613	51283.43
Croatia	3172	13629	56542	13541	2617	2147.878	7.1	454	3899000	68955.08	6.983	22257.68
Czech Republic	16326	63756	78866	135318	9523	6879.881	75.917	569	10505772	281777.89	7.492	116590.9
Denmark	1986	15354	43094	123918	1998	4009.141	234.951	476	5856733	398303.27	10.546	43200.04
Estonia	2124	5237	45228	6077	1167	841.386	16.859	621	1330932	37191.17	11.236	12873.96
Finland	10749	29618	338015	55009	5918	4023.794	236	657	5541017	297301.88	20.512	51478.64
France	35751	167247	55150	894397	27057	42693.98	792.64	568	67749632	2957879.76	8.209	414036
Germany	123067	307277	35703	2880871	38394	52299.14	1386	583	83196078	4259934.91	7.972	749708.7
Greece	490	20903	131957	10029	2339	5530.448	18.836	527	10641221	214873.88	4.31	78502.91
Hungary	11347	37101	93030	100730	7889	4897.618	84	414	9709891	181848.02	6.159	60586.46
Ireland	70	12485	70273	36892	2045	3709.981	63.195	460	5033165	504182.6	4.296	61475.62

Table 3. Continued

Italy	24262	144986	301337	491782	16832	35290.31	440.485	673	59109668	2107702.84	10.001	389003.8
Latvia	7367	15103	64589	11194	1859	1077.062	28.999	403	1884490	39853.5	6.436	11704.76
Lithuania	14566	57755	65300	3948	1910	2144.972	46.6	574	2800839	66445.26	6.462	18934.41
Luxemburg	207	6550	2586	16595	271	1770.925	21.585	686	640064	85506.24	7.962	10481.21
Netherlands	7188	70227	41526	207165	3041	9187.53	1071.285	503	17533044	1012846.76	8.991	172231.2
Poland	54387	379820	312685	240022	19287	23537.388	63.73	678	37747124	679444.83	5.665	353140.2
Portugal	2336	32075	91982	120702	2527	5474.286	17.537	547	10325147	253663.14	8.609	61380.97
Romania	13625	61848	238391	54937	10764	6879.222	179.229	398	19119880	284087.56	7.669	101236.3
Slovakia	8580	30138	49012	46345	3626	2619.259	25	458	5447247	116527.1	8.753	38063.21
Slovenia	4937	24968	20253	11860	1209	1799.603	3.731	564	2108079	61748.59	10.641	16463.32
Spain	10299	270172	505992	418501	16280	30350.056	350	526	47415750	1427380.68	9.194	306947
Sweden	23449	42685	449964	164490	10912	6850.677	1433	479	10415811	635663.8	30.426	46188.53

The GRA method was first implemented, employing equal weighting for all indicators. The grey degrees of relationships are defined by considering Equations 1-6. Figure 2 below demonstrates the ranking of European countries based on their GRA scores.

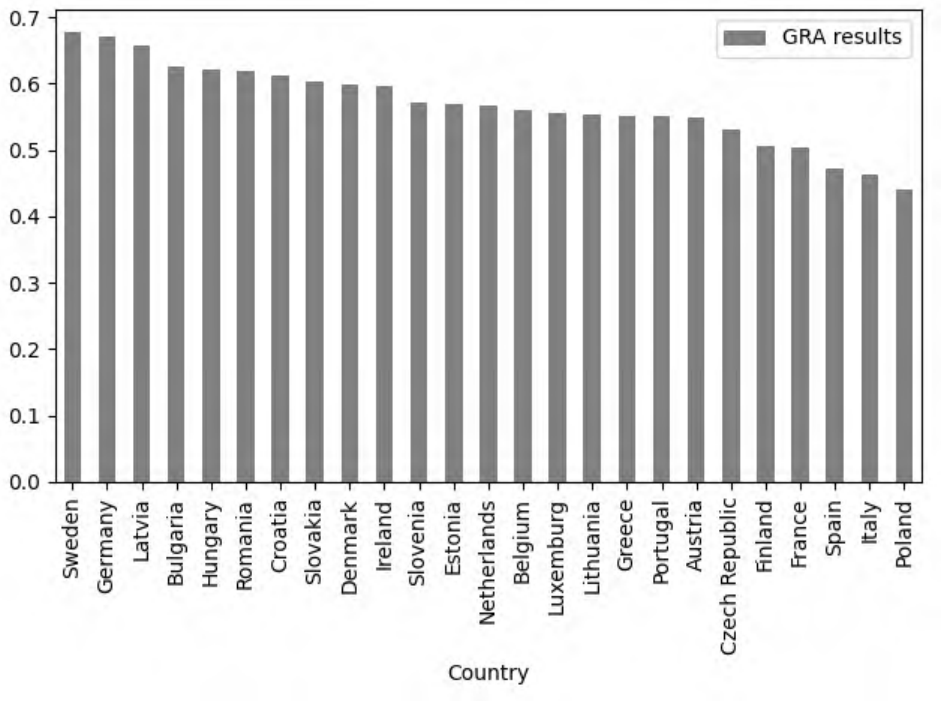

Figure 2. GRA results

As seen from Figure 2, Sweden in in the top position, whichs demonstrates a significant emphasis on the issue of sustainability in transportation. Germany and Latvia are not far from Sweden in terms of sustainability, followed by such countries as Bulgaria, Hungary, Romania, Croatia, and Slovakia, which all prioritize sustainability in transportation. Spain, Italy, and Poland appear are the lowest in terms of sustainability rankings. Following the implementation of the GRA method, the entropy MABAC approach was utilized for a comparative analysis. The weights of the criteria were determined using the entropy method (see Table 4). Equations 7, 8, and 9 were used for this purpose. The MABAC method was applied to rank the countries after determining the weights. The weights obtained from the entropy approach were then provided as input for the MABAC method. The ranking scores of the MABAC approach were derived using Equations 10-17. Figure 3 below displays the outcomes of the entropy-MABAC technique.

Table 4. The weights obtained via the Entropy method

W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
0.052	0.103	0.099	0.098	0.082	0.102	0.120	0.042	0.049	0.099	0.049	0.104

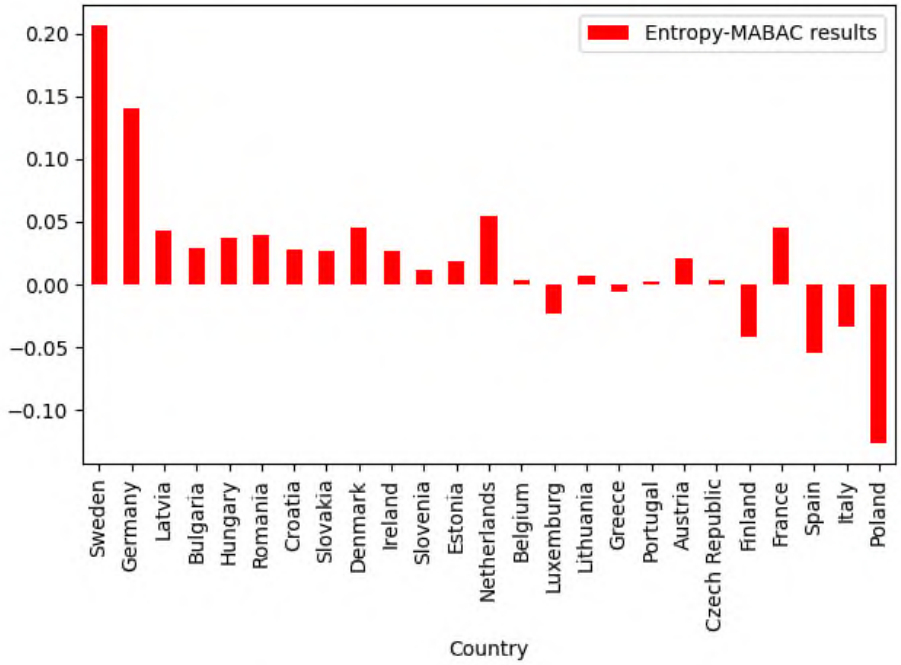

Figure 3. Results of the entropy-MABAC method

The ranking clearly shows that Sweden and Germany are at the top, followed by Latvia, Bulgaria, Hungary, and Romania, as depicted in Figure 3. Conversely, Spain, Italy, and Poland are ranked at the bottom. Luxemburg, Greece, Finland, Spain, Italy, and Poland belong to the lower approximation area. Sweden, Germany, Latvia, Bulgaria, Hungary, Romania, Croatia, Slovakia, Denmark, Ireland, Slovenia, Estonia, Netherlands, Belgium, Lithuania, Portugal, Austria, the Czech Republic, and France are in the upper approximation area. That said, Belgium, Greece, Portugal, and the Czech Republic are positioned nearer to the border approximation area.

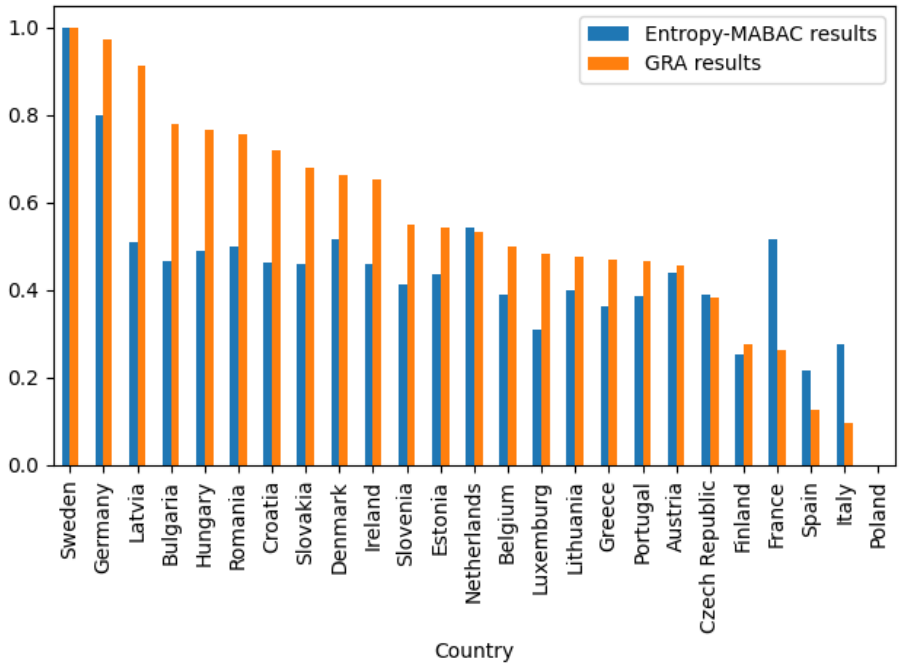

Figure 4. Comparison of the GRA and entropy-MABAC methods

Table 5. Ranking scores for both methods

Country	GRA Scores	Ranking	Entropy-MABAC Scores	Ranking
Sweden	0.677672984	1	0.206114279	1
Germany	0.671453793	2	0.140075211	2
Latvia	0.656852384	3	0.043343855	6
Bulgaria	0.625476172	4	0.028955110	9
Hungary	0.622181711	5	0.036776235	8
Romania	0.619843557	6	0.040024224	7
Croatia	0.611199333	7	0.028111785	10
Slovakia	0.602009995	8	0.026648492	11
Denmark	0.598231028	9	0.045847793	4
Ireland	0.595832747	10	0.026352755	12
Slovenia	0.571035146	11	0.011496918	15
Estonia	0.56972317	12	0.019146209	14
Netherlands	0.56755178	13	0.054080758	3
Belgium	0.559279733	14	0.003746736	17
Luxemburg	0.555484983	15	-0.023347558	21
Lithuania	0.553393229	16	0.0069819407	16
Greece	0.551904939	17	-0.0051815584	20
Portugal	0.551330777	18	0.0026556879	19
Austria	0.548821688	19	0.0204861352	13
Czech Republic	0.531790046	20	0.0030515801	18
Finland	0.506155845	21	-0.0416358529	23
France	0.503617347	22	0.04530044124	5
Spain	0.471180761	23	-0.05396344832	24
Italy	0.463661207	24	-0.03360571062	22
Poland	0.440949769	25	-0.12591610324	25

As illustrated in Figure 4, the min-max scale application was implemented on the data in order to compare the GRA and entropy-MABAC results. When compared to the results of the GRA and entropy-MABAC methods, it can be seen from Figure 4 and Table 5 that the ranking is similar to each other. The implementation of a correlation analysis between the GRA scores and entropy-MABAC scores was also carried out. The correlation study yielded a coefficient of 0.8218, which is near to 1. This indicates a significant relationship between the results produced from GRA and entropy-MABAC, suggesting that the outputs from both methods are consistent. According to both results, Sweden and Germany rank first and second, respectively. Poland is ranked at the bottom for both methods. While there may be variations in the ranking of the top, intermediate, and bottom countries, their alignments display similar attributes. On the other hand, France and Netherland attain a higher ranking in the entropy-MABAC method as opposed to the GRA approach, which ranks them near the bottom. Both approaches demonstrate that Sweden and Germany prioritize sustainability in the transportation category, while Poland, Spain, and Italy lag behind in this regard.

4.1. Managerial implications

- Decision makers can utilize these results as a standard to compare their country's performance with that of other countries. Countries such as Sweden and Germany, that ranked high in both the GRA and entropy-MABAC scores, might be considered as models for implementing effective strategies in sustainable transportation. This can facilitate the identification of areas for improvement.
- Policy and investment decisions can be prioritized by decision-makers using the criteria provided in the study. For example, countries such as Latvia and Bulgaria demonstrate reasonably GRA rankings but rank lower in entropy-MABAC scores, highlighting the necessity for targeted efforts to address the identified vulnerabilities.
- Countries that have higher rankings can utilize their expertise and capabilities to encourage the transfer of knowledge and collaboration with countries that have lower rankings. This can result in the use of the right techniques and expedite advancements towards objectives of sustainable transportation.

5. Conclusion

GRA is extensively utilized for the examination of complicated situations. In addition, the entropy weight method offers a notable advantage compared to subjective weighting models by removing the impact of human factors on indicator weights, hence enhancing the objectivity of the comprehensive evaluation outcomes. In addition, the MABAC method successfully mitigates

the impact of dimensions, whether positive or negative, in the decision-making process, distinguishing it from other MCDM approaches. Given the effective handling of uncertainties by all these methods, the present research compared the GRA and Entropy-MABAC methodologies. This paper describes several uses of the GRA and entropy-MABAC approaches. Researchers and policymakers are exploring new techniques in response to the growing demand for sustainable transportation systems. European countries, characterized by their varied terrains and differing population densities, have placed significant emphasis on enhancing the transportation infrastructure to attain sustainability objectives. This research examines the significance of using both GRA and entropy-MABAC methods in the transportation system of European countries, with a particular focus on sustainability.

The proposed research involves a comparison of 25 European countries based on 12 criteria, with data gathered from diverse sources. As can be understood from the results of the present analysis, there are similarities in the ranking of the GRA and entropy-MABAC methods. According to the results of the two methods, both Sweden and Germany demonstrate a strong commitment to sustainability in the transportation category, while Poland, Spain, and Italy rank at the bottom. Further studies can expand the range of data and enable comparisons across a greater number of countries.

To summarize, although this study provides vital insights on sustainable transportation practices in European countries and presents a strong evaluation methodology, it is important to recognize certain limitations. The findings of the study depend on the presence and accuracy of data about transportation sustainability indices in the chosen European countries. Differences in the availability and reliability of data between countries can lead to biases or restrictions in the study. The analysis of the study relies on a singular temporal representation of facts at a precise point. Transportation systems and sustainability practices are dynamic and susceptible to modification throughout time. Therefore, the results may not accurately represent the long-term patterns or changing dynamics related to transportation sustainability.

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REFERENCES

Al-Shammari, A., & Al-Jameel, H. (2023). Evaluation of the Selected Sustainable Indicators for Urban Roads Network: Al-Kufa City as a Case Study. *IOP Conference Series: Earth and Environmental Science, 1232*(1). https://doi.org/10.1088/1755-1315/1232/1/012051

Amekudzi, A. A., Jotin Khisty, C., & Khayesi, M. (2009). Using the sustainability footprint model to assess development impacts of transportation systems. *Transportation Research Part A: Policy and Practice, 43*(4), 339–348. https://doi.org/10.1016/j.tra.2008.11.002

Antunes, J., Tan, Y., Wanke, P., & Jabbour, C. J. C. (2023). Impact of R&D and innovation in Chinese road transportation sustainability performance: A novel trigonometric envelopment analysis for ideal solutions (TEA-IS). *Socio-Economic Planning Sciences, 87*(PA), 101544. https://doi.org/10.1016/j.seps.2023.101544

Armenta-Déu, C. (2024). Improving Sustainability in Urban and Road Transportation: Dual Battery Block and Fuel Cell Hybrid Power System for Electric Vehicles. *Sustainability (Switzerland)* , 16(5). https://doi.org/10.3390/su16052110

Babaei, A., Khedmati, M., & Jokar, M. R. A. (2022). A New Model for Evaluation of the Passenger and Freight Transportation Planning Based on the Sustainability and Safety Dimensions: A Case Study. *Process Integration and Optimization for Sustainability, 6*(4), 1201–1229. https://doi.org/10.1007/s41660-022-00272-0

Biswas, T. K., & Das, M. C. (2018). Selection of hybrid vehicle for green environment using multi-attributive border approximation area comparison method. *Management Science Letters, 8*(2), 121–130. https://doi.org/10.5267/j.msl.2017.11.004

Bouraima, M. B., Qiu, Y., Stević, Ž., & Simić, V. (2023). Assessment of alternative railway systems for sustainable transportation using an integrated IRN SWARA and IRN CoCoSo model. *Socio-Economic Planning Sciences, 86*(November 2022). https://doi.org/10.1016/j.seps.2022.101475

da Fonseca-Soares, D., Eliziário, S. A., Galvincio, J. D., & Ramos-Ridao, A. F. (2024). Greenhouse Gas Emissions in Railways: Systematic Review of Research Progress. *Buildings, 14*(2), 1–22. https://doi.org/10.3390/buildings14020539

Deng, F., Fang, Y., Xu, L., & Li, Z. (2020). Tourism, Transportation and Low-Carbon City System Coupling Coordination De-

greeA Case Study in Chongqing Municipality, China. *International Journal of Environmental Research and Public Health, 17*(3). https://doi.org/10.3390/ijerph17030792

Deng, J.-L. (1982). Control Problems of Grey Systems. *Systems & Control Letters, 1*(5), 288–294.

Di Martino, A., Longo, M., & Foiadelli, F. (2024). Increasing transportation sustainability from scratch: Small city context. *Energy Conversion and Management, 304*(February), 118211. https://doi.org/10.1016/j.enconman.2024.118211

Ecer, F., Küçükönder, H., Kayapınar Kaya, S., & Faruk Görçün, Ö. (2023). Sustainability performance analysis of micro-mobility solutions in urban transportation with a novel IVFNN-Delphi-LOPCOW-CoCoSo framework. *Transportation Research Part A: Policy and Practice, 172*(April). https://doi.org/10.1016/j.tra.2023.103667

Erdemir, Ö. K., & Kırkağaç, M. (2022). A Comparative Study on Performance of Insurance Companies with Grey Relational Analysis and Analytic Hierarchy Process. *Alanya Akademik Bakış, 6*(3), 2627–2645. https://doi.org/10.29023/alanyaakademik.1070741

Farid, H. M. A., Dabic-Miletic, S., Riaz, M., Simic, V., & Pamucar, D. (2024). Prioritization of sustainable approaches for smart waste management of automotive fuel cells of road freight vehicles using the q-rung orthopair fuzzy CRITIC-EDAS method. *Information Sciences, 661*(July 2023), 120162. https://doi.org/10.1016/j.ins.2024.120162

Fulzele, V., Shankar, R., & Choudhary, D. (2019). A model for the selection of transportation modes in the context of sustainable freight transportation. *Industrial Management and Data Systems, 119*(8), 1764–1784. https://doi.org/10.1108/IMDS-03-2019-0169

Gamal, A., Abdel-Basset, M., Hezam, I. M., Sallam, K. M., & Hameed, I. A. (2023). An Interactive Multi-Criteria Decision-Making Approach for Autonomous Vehicles and Distributed Resources Based on Logistic Systems: Challenges for a Sustainable Future. *Sustainability (Switzerland), 15*(17). https://doi.org/10.3390/su151712844

Gökçekuş, H., Ozsahin, D. U., & Al-Othman, D. (2019). Evaluation of the impact of sustainable transportation alternatives on environment using fuzzy PROMETHEE method. *International Journal of Innovative Technology and Exploring Engineering, 8*(8), 3254–3259.

Gulcimen, S., Aydogan, E. K., & Uzal, N. (2023). Robust Multicriteria Sustainability Assessment in Urban Transportation. *Journal of Urban Planning and Development, 149*(2), 4090. https://doi.org/10.1061/jupddm.upeng-4090

Han, C., Zheng, J., Lu, B., & Yu, D. (2022). Analysis on Influencing Factors of urban comprehensive carrying capacity: a case study of five provinces in Northwest China. *International Conference on Geoinformatics, 2022-Augus*, 1–6. https://doi.org/10.1109/Geoinformatics57846.2022.9963843

Heidary Dahooie, J., Mohammadian, A., Qorbani, A. R., & Daim, T. (2023). A portfolio selection of internet of things (IoTs) applications for the sustainable urban transportation: A novel hybrid multi criteria decision making approach. *Technology in Society, 75*(May), 102366. https://doi.org/10.1016/j.techsoc.2023.102366

Hsiao, S. W., Lin, H. H., & Ko, Y. C. (2017). Application of grey relational analysis to decision-making during product development. Eurasia Journal of Mathematics, *Science and Technology Education, 13*(6), 2581–2600. https://doi.org/10.12973/EURASIA.2017.01242A

Illahi, U., & Mir, M. S. (2019). *Sustainable Transportation: Indicators, Frameworks, and Performance Management.* Springer-Verlag, Heidelberg, Germany.

Jiang, F., Ma, L., Broyd, T., Li, J., Jia, J., & Luo, H. (2023). Systematic framework for sustainable urban road alignment planning. *Transportation Research Part D: Transport and Environment, 120*(May), 103796. https://doi.org/10.1016/j.trd.2023.103796

Johnson, B. J., & White, S. S. (2010). Promoting Sustainability through Transportation Infrastructure? Innovation and Inertia in the Kansas City Metropolitan Area. *Journal of Urban Planning and Development, 136*(4), 303–313. https://doi.org/10.1061/(asce)up.1943-5444.0000027

Karjalainen, L. E., & Juhola, S. (2019). Framework for assessing public transportation sustainability in planning and policy-making. *Sustainability (Switzerland)*, 11(4). https://doi.org/10.3390/su11041028

Korucuk, S., Aytekin, A., Ecer, F., Pamucar, D. S. S., & Karamaşa, Ç. (2023). Assessment of ideal smart network strategies for logistics companies using an integrated picture fuzzy LBWA–CoCoSo framework. *Management Decision, 61*(5), 1434–1462. https://doi.org/10.1108/MD-12-2021-1621

Kovač, M., Tadić, S., Krstić, M., & Veljović, M. (2023). A Methodology for Planning City Logistics Concepts Based on City-Dry Port Micro-Consolidation Centres. *Mathematics, 11*(15). https://doi.org/10.3390/math11153347

Kraus, L. (2021). Sustainable Urban Transportation Criteria and Measurement — A Systematic Literature Review. *Sustainability, 13*(7113).

Lev-On, M., Shapiro, E., & Cox, R. (2005). The partnership for clean fuels and vehicles: A new approach to helping countries achieve environmental sustainability in the transportation sector. *SAE Technical Papers*, 114(2005), 196–205. https://doi.org/10.4271/2005-01-0538

Liu, S., Forrest, J., & Vallee, R. (2009). Emergence and development of grey systems theory. *Kybernetes, 38*(7), 1246–1256. https://doi.org/10.1108/03684920910976943

Madenoğlu, F. S., Ünlüsoy, Ö. F., & Yılmaz, Ç. (2022). Performance Evaluation of Energy Companies With a Novel Integrated Multi-Criteria Decision Making Method. *Kafkas Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 13*(26), 640–658. https://doi.org/10.36543/kauiibfd.2022.027

Mondal, A., & Roy, S. K. (2022). Application of Choquet integral in interval type-2 Pythagorean fuzzy sustainable supply chain management under risk. *International Journal of Intelligent Systems, 37*(1), 217–263. https://doi.org/10.1002/int.22623

Noureddine, M., & Ristic, M. (2019). Route planning for hazardous materials transportation: Multi-criteria decision-making approach. *Decision Making: Applications in Management and Engineering, 2*(1), 66–85. https://doi.org/10.31181/dmame1901066n

Palander, T., Haavikko, H., Kortelainen, E., & Kärhä, K. (2020). Comparison of energy efficiency indicators of road transportation for modeling environmental sustainability in "green" circular industry. *Sustainability (Switzerland), 12*(7), 1–22. https://doi.org/10.3390/su12072740

Pamučar, D., & Ćirović, G. (2015). The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison (MABAC). *Expert Systems with Applications, 42*(6), 3016–3028. https://doi.org/10.1016/j.eswa.2014.11.057

Patil, A. N., Walke, G., & Gawkhare, M. (2019). Grey Relation Analysis Methodology and its Application. RESEARCH REVIEW International

Journal of Multidisciplinary, 3085(February), 409–411. https://doi.org/10.5281/zenodo.2578088

Qadir, A., Alghaffari, S. N., Abosuliman, S. S., & Abdullah, S. (2023). A three-way decision-making technique based on Pythagorean double hierarchy linguistic term sets for selecting logistic service provider and sustainable transportation investments. *AIMS Mathematics, 8*(8), 18665–18695. https://doi.org/10.3934/math.2023951

Rani, P., Alrasheedi, A. F., Mishra, A. R., & Cavallaro, F. (2023). Interval-valued Pythagorean fuzzy operational competitiveness rating model for assessing the metaverse integration options of sharing economy in transportation sector. *Applied Soft Computing, 148*, 110806. https://doi.org/10.1016/j.asoc.2023.110806

Rehman, F. U., Islam, M. M., & Miao, Q. (2023). Environmental sustainability via green transportation: A case of the top 10 energy transition nations. *Transport Policy, 137*(April), 32–44. https://doi.org/10.1016/j.tranpol.2023.04.013

Rogers, M. M., & Weber, W. L. (2011). Evaluating CO2 emissions and fatalities tradeoffs in truck transport. *International Journal of Physical Distribution and Logistics Management, 41*(8), 750–767. https://doi.org/10.1108/09600031111166410

Santos-Arteaga, F. J., Di Caprio, D., Tavana, M., & Tena, E. C. (2023). A Credibility and Strategic Behavior Approach in Hesitant Multiple Criteria Decision-Making With Application to Sustainable Transportation. *IEEE Transactions on Fuzzy Systems, 3*1(2), 460–474. https://doi.org/10.1109/TFUZZ.2022.3188875

Senapati, T., Simic, V., Saha, A., Dobrodolac, M., Rong, Y., & Tirkolaee, E. B. (2023). Intuitionistic fuzzy power Aczel-Alsina model for prioritization of sustainable transportation sharing practices. *Engineering Applications of Artificial Intelligence, 119*(November 2022), 105716. https://doi.org/10.1016/j.engappai.2022.105716

Şener, F., Aydoğan, S., & Akay, D. (2023). Urban Mobility Patterns with Linguistic Summarization: Insights from the Bicycle- Sharing System. *Erciyes University Journal of Institue Of Science and Technology, 39*(3), 538–547.

Shen, Z., Zhao, Q., & Fang, Q. (2021). Analysis of green traffic development in zhoushan based on entropy weight topsis. *Sustainability (Switzerland)*, 13(14), 1–13. https://doi.org/10.3390/su13148109

Shi, M., Li, X., & Xu, C. (2024). Two-stage site selection of hydrogen refueling stations coupled with gas stations considering cooperative effects based on the CRITIC-ITFAHP-MABAC method: A case study in Beijing. *International Journal of Hydrogen Energy*, 49, 1274–1292. https://doi.org/10.1016/j.ijhydene.2023.09.168

Soni, A. R., Amrit, K., & Shinde, A. M. (2022). COVID-19 and transportation of India: influence on infection risk and greenhouse gas emissions. *Environment, Development and Sustainability*, 0123456789. https://doi.org/10.1007/s10668-022-02311-9

Veskovic, S., Stevic, Ž., Stojic, G., Vasiljevic, M., & Milinkovic, S. (2018). Evaluation of the railway management model by using a new integrated model delphi-swara-mabac. *Decision Making: Applications in Management and Engineerin*g, 1(2), 34–50. https://doi.org/10.31181/dmame1802034v

Yuan, C., Wu, D., & Liu, H. (2017). Using grey relational analysis to evaluate energy consumption, CO2 emissions and growth patterns in China's provincial transportation sectors. *International Journal of Environmental Research and Public Health, 14*(12).

Zagorskas, J., & Turskis, Z. (2024). Enhancing Sustainable Mobility: Evaluating New Bicycle and Pedestrian Links to Car-Oriented Industrial Parks with ARAS-G MCDM Approach. *Sustainability (Switzerland) , 16*(7). https://doi.org/10.3390/su16072994

Zhang, L., & Hua, X. (2023). Evaluating efficiency of railway transportation based on cross-efficiency evaluation method and relative entropy evaluation method in China. *IET Intelligent Transport Systems, 17*(12), 2410–2418. https://doi.org/10.1049/itr2.12420

Zhang, W., Song, Y., Zhou, G., Song, Z., & Xi, C. (2023). Multiobjective-Based Decision-Making for the Optimization of an Urban Passenger Traffic System Structure. *Sustainability (Switzerland), 15*(18). https://doi.org/10.3390/su151813644

Zhou, Y., Kundu, T., Goh, M., Chakraborty, S., & Bai, X. (2023). A multi-stage multi-criteria data analytics approach to rank commercial service airports. *Journal of Air Transport Management, 111*(December 2021), 102410. https://doi.org/10.1016/j.jairtraman.2023.102410

Zhu, Y., Tian, D., & Yan, F. (2020). Effectiveness of Entropy Weight Method in Decision-Making. *Mathematical Problems in Engineering*, 2020, 1–5. https://doi.org/10.1155/2020/3564835

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RESEARCH ARTICLE

Assessment of the Logistics Performance Index of OPEC Countries with ENTROPY, CRITIC and LOPCOW-based EDAS Methods

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ABSTRACT

The aim of this study is to examine the Logistics Performance Index (LPI) of the Organization of the Petroleum Exporting Countries (OPEC) using the ENTROPY, CRITIC, and LOPCOW-based EDAS method. Data were obtained from the "2018 report of LPI" issued by the World Bank (WB). To evaluate the logistics performance of the selected countries, six key dimensions—customs, infrastructure, international shipments, logistics quality and competence, tracking and tracing, and timeliness—were utilized. The weight of the criteria was calculated using three different weighting methods: ENTROPY, CRITIC, and LOPCOW. Subsequently, the countries were ranked using the EDAS method. The results from ENTROPY, CRITIC, and LOPCOW indicated that the most significant criteria were infrastructure, international shipments, and timeliness, respectively. The outcomes of the EDAS method revealed that the United Arab Emirates (UAE) and Angola exhibited the highest and lowest logistics performance, respectively. Additionally, the robustness and validity of the results were confirmed through comparative analysis.

Keywords: LPI, OPEC, ENTROPY, CRITIC, LOPCOW, EDAS

1. Introduction

The OPEC was founded in Baghdad in 1960. The member countries of OPEC are Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the UAE, and Venezuela. The main goal of OPEC is to provide an efficient, economic, and regular supply of petroleum to consuming nations (OPEC, 2010). In particular, OPEC plays a critical role in the sustainability of the economy, energy, and environment. In this context, a large amount of research has been carried out on the OPEC. Existing literature on the OPEC countries has been largely focused on economic growth (Ftiti et al., 2016; Onoh et al., 2018; Ostic et al., 2022), energy consumption (Dabachi et al., 2020; Onifade et al., 2021; Iorember et al., 2022), carbon emissions (Acar et al., 2018; Nazlioglu et al., 2021). However, a limited number of studies have examined the OPEC countries within the scope of logistics.

The role of logistics in the world economy is becoming increasingly important. The logistics industry contributes significantly to facilitating trade, decreasing transportation costs, and promoting economic growth. Additionally, sustainable growth and trade efficiency depend on the quality and efficiency of logistics services (Devlin and Yee, 2005; Bugarčić et al., 2020). As stated by Rashidi and Cullinane (2019), effective logistics operations in international trade have a significant role in the development of the reliability of the supply chain and improvement of trade relations between countries. On the contrary, inefficient logistics operations could damage the balance of foreign trade and cause interruptions in the functioning of all economic sectors (Isik et al., 2020, p.549-550). Accordingly, it is important to analyse the logistics performance of nations. The WB has been publishing the LPI report since 2007. In this report, logistics performance across more than 160 countries is measured by six main indicators, which are customs, infrastructure, international shipments, logistics quality and competence, tracking and tracing and timeliness. The LPI plays a vital role in global initiatives aimed at enhancing the understanding of logistics performance amid increasingly intricate supply chains. It is derived from a comprehensive worldwide survey targeting on-the-ground operators, including global freight forwarders and express carriers, who provide insights into the logistics "friendliness" of the nations in which they operate and those with which they engage in trade. It incorporates both qualitative and quantitative metrics, facilitating the development of logistics friendliness profiles for these nations. It assesses performance throughout the logistics supply chain within a country, offering both international and domestic viewpoints. It has been released every two years from 2010 to 2018, with the most recent edition published in 2018 (Arvis et al., 2018). In the preparation of this report, over 1,000 experts involved in international logistics

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operations from various countries contributed significantly. In this regard, LPI is considered as a Multi-Criteria Decision Making (MCDM) problem (Yıldırım and Mercangöz, 2020, p.28).

MCDM is one of the most accurate decision-making methods (Aruldoss et al., 2013). Since the 1950s, a variety of empirical and theoretical researchers have concentrated on MCDM methods to investigate their mathematical modeling potential. Their objective has been to create a framework that facilitates the organization of decision-making challenges and the formulation of preferences from a range of alternatives (Hajduk,2021; Taherdoost and Madanchian, 2023). Accordingly, this paper investigates the logistics performance of OPEC countries using the integrated MCDM methods. In this study, three objective weighting methods, namely ENTROPY, CRITIC and LOPCOW are used for determining the criteria weights. Logistics performance of countries is evaluated by EDAS method. Since each weighting method has its own unique formulation and approach, multiple weighting methods are employed in this study. This approach aimed to examine the impact of different weighting methods on the ranking results. Accordingly, it can be stated that the combination of ENTROPY, CRITIC, and LOPCOW with EDAS offers a novel approach that merges the advantages of these weighting techniques with the efficient distance-based assessment of EDAS. This integration has the potential to establish a stronger and more reliable decision-making process. For instance, the ENTROPY method quantifies information content per criterion to minimize bias in weighting, the CRITIC method leverages criteria correlation, and the LOPCOW method provides a structured approach for managing criteria hierarchy, resulting in increased consistent and reliable in outcomes (Diakoulaki et al., 1995; Alinezhad and Khalili, 2019; Ecer & Pamucar, 2022). The EDAS method assesses alternatives by measuring their proximity to the average solution, taking into account both favorable and unfavorable deviations (Keshavarz Ghorabaee et al., 2015).

The current study contributes to existing literature in two ways. First, this study allows the comparison of three types of objective method for determining criteria weights and their implementation to analyze the logistics performance of OPEC countries. Second, so far there has been little discussion about the logistics performance of OPEC countries with MCDM methods. Previous research is largely focused on other economic organizations such as The Organization for Economic Co-operation and Development (OECD) and the European Union (EU). Therefore, the current study is designed to address these research gaps and research question is formulated as follows:

Research Question: What is the logistics performance of OPEC countries and does their performance ranking differ according to MCDM methods?

The remaining part of the research proceeds as follows: Section 2 presents the studies related to logistics performance evaluation. Section 3 describes the integrated MCDM methodology. Section 4 illustrates the weights of the criteria and logistics performance ranking of countries. Section 5 explains conclusions, limitations, and recommendations for further study. Additionally, the editing and proofreading of the manuscript is completed by Artificial Intelligence tool (ChatGPT).

2. Literature Review

This section provides an overview of previous research conducted on logistics performance. There has been a notable increase in research aimed at evaluating the logistics performance of countries in recent years. Table 1 presents a brief summary of the relevant literature in this field.

Table 1. Previous research

Author(s)	Year	Methods	Topic
Cakir	2017	CRITIC-SAW-Peter's Fuzzy Regression	Measuring the LPI of OECD countries via fuzzy linear regression
Marti et al.	2017	DEA	Examine the logistics performance of the countries using DEA method
Rezaei et al.	2018	BWM	Evaluate the relative importance of LPI indicators with BWM method
Gök Kısa & Ayçin	2019	SWARA-EDAS	Analysis the LPI of OECD countries with SWARA-based EDAS methods
Karaköy & Ölmez	2019	ENTROPY-OCRA	Investigate the LPI of Balkan countries using Entropy-OCRA methods
Ulutaş & Karaköy	2019	CRITIC-SWARA-PIV	Examine the LPI of European Union (EU) countries by integrated MCDM methods
Mešić et al.	2020	CRITIC-MARCOS	Assessment of the LPI of Western Balkan countries using CRITIC-MARCOS methods
Isik et al.	2020	SV-MABAC	Evaluate the LPI of CEE countries with SV-MABAC methods
Yalcin & Ayvaz	2020	FAHP-FTOPSIS	Analyze the LPI of selected countries by Fuzzy AHP-Fuzzy TOPSIS methods
Adıgüzel Mercangöz et al.	2020	COPRAS-G	Investigate the LPI of EU and candidate EU countries based COPRAS-G method
Ulutaş & Karaköy	2021	Grey SWARA-Grey MOORA	Assessment of the LPI of Transition Economies countries with grey MCDM methods
Miškić et al.	2023	MEREC-MARCOS	Examine the LPI of EU countries using MEREC-MARCOS methods
Oğuz	2023	EDAS-TOPSIS	Measuring of Customs, Infrastructure and Logistics Service performance for selected countries with EDAS-TOPSIS methods
Pehlivan et al.	2024	TOPSIS-Clustering Analysis	Analysis the logistics performance of G20 countries using decision-making methods
Akbulut et al.	2024	SD-PSI-MEREC-MARA	Measuring the LPI of G20 countries based on integrated MCDM methods
Kale & Tilki	2024	ENTROPY-TOPSIS	Comparison the LPI of World countries with Entropy-TOPSIS methods

As depicted above, a considerable amount of literature has published that analyze the LPI of countries such as EU, OECD or Balkan countries using various MCDM methods. Despite the extensive research conducted utilizing hybrid MCDM methodologies, no single study has been identified that assesses the LPI of OPEC countries with Entropy, CRITIC, LOPCOW-based EDAS methods. Therefore, this study seeks to fill this gap by proposing a new MCDM model.

3. Methodology

3.1. ENTROPY

The concept of Entropy was introduced by the German physicist R. Clausius in 1865. The Entropy method is employed to assess the relative significance of various attributes and their capacity to convey decision-making information. In information theory, it primarily utilizes the Entropy value to quantify the uncertainty associated with information. As the weight of the evaluated information criterion increases, the Entropy associated with that criterion diminishes (Chen, 2021, p.9). The procedure for applying the Entropy method is outlined as follows (Alinezhad and Khalili, 2019):

Step 1. In the initial decision matrix, "*m*" number of alternatives and "n" number of criteria will be set, as shown by Eq. (1).

$$x = \begin{bmatrix} X11 & X\ 12 & \dots & X1n \\ X\ 21 & X\ 22 & \dots & X\ 2n \\ . & . & \dots & . \\ . & . & . & . \\ . & . & . & . \\ X\ m1 & X\ m2 & . & X\ mn \end{bmatrix} \tag{1}$$

Step 2. Based on Eq. (2), the normalized decision matrix is formed.

$$r_{ij}^{-} = \frac{r_{ij}}{\Sigma_{i=0}^{n} r_{ij}}; \qquad j = 1, \dots\dots\dots, n \tag{2}$$

Step 3. The degree of entropy (e_j) is determined using Eq. (3), the divergence degree (d_j) of the entropy value is generated by Eq. (4) and the entropy weight (w_j) is computed by Eq. (5).

$$E_j = -\frac{1}{lnn} \sum_{i=1}^{n} \bar{r}_{ij} * ln\bar{r}_{ij}; \qquad j = 1, \dots\dots\dots\dots.., n, 0 \leq E_j \leq 1 \tag{3}$$

$$d_j = 1 - E_j; j = 1, \dots\dots\dots\dots.., n \tag{4}$$

$$w_j = \frac{d_j}{\Sigma_{j=1}^{n} d_j} \tag{5}$$

3.2. CRITIC

In 1995, Diakoulaki, Mavrotas, and Papayannakin introduced the Criteria Importance Through Intercriteria Correlation (CRITIC) method. This approach is primarily employed to determine the weights of various attributes and is recognized as an objective weighting technique. The attributes considered in this method are non-conflicting, and the decision matrix serves as the basis for calculating these weights. The steps of the CRITIC method is outlined as follows (Diakoulaki et al., 1995; Alinezhad and Khalili, 2019):

Step 1. Eqs. (6) and (7) are used to normalize the positive and negative attributes of decision matrix, respectively.

$$x_{ij} = \frac{r_{ij} - r_i^{-}}{r_i^{t} - r_i^{-}}; \qquad i = 1, \dots\dots., m \ \ j = 1, \dots\dots., n \tag{6}$$

$$x_{ij} = \frac{r_{ij} - r_i^{+}}{r_i^{-} - r_i^{+}}; \qquad i = 1, \dots\dots., m \ \ j = 1, \dots\dots., n \tag{7}$$

Step 2. Eq. (8) is used to determine the correlation coefficient among attributes.

$$\rho_{jk} = \Sigma_{i=1}^{m}(x_{ij} - \bar{x}_j)(x_{ik} - \bar{x}_k) / \sqrt{\Sigma_{i=1}^{m}(x_{ij} - \bar{x}_j)^2 \Sigma_{i=1}^{m}(x_{ik} - \bar{x}_k)^2} \tag{8}$$

$\bar{x}_j$ is calculated from Eq. (9).

$$\bar{x}_j = \frac{1}{n}\sum_{j=1}^{n} x_{ij}; \qquad i = 1, \ldots\ldots\ldots\ldots\ldots\ldots, m \tag{9}$$

Step 3. The standard deviation of each attribute is estimated by Eq. (10)

$$\sigma_j = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(x_{ij} - \bar{x}_j)^2}; \qquad i = 1, \ldots\ldots\ldots\ldots\ldots\ldots, m \tag{10}$$

Eq. (11) is used to calculate the index (C)

$$C_J = \sigma_j \sum_{k=1}^{n}(1 - \rho_{jk}); \qquad j = 1, \ldots\ldots\ldots\ldots\ldots\ldots.., n \tag{11}$$

Step 4. Eq. (12) is utilized to determine the weights of attributes.

$$w_j = \frac{C_j}{\Sigma_{j=1}^{n} C_j}; \qquad j = 1, \ldots\ldots\ldots\ldots\ldots\ldots., n \tag{12}$$

For the final ranking, the attribute weights are ranked in descending order.

3.3. LOPCOW

The Logarithmic Percentage Change-driven Objective Weighting (LOPCOW) method was introduced by Ecer and Pamucar in 2022. It has emerged as a novel approach to objective weighting. The steps for implementing the LOPCOW method are outlined as follows (Ecer & Pamucar, 2022):

Step 1. The decision matrix is formed.

Step 2. According to Eqs. (13-14), the decision matrix is normalized.

$$r_{ij} = \frac{x_{max} - x_{ij}}{x_{max} - x_{min}}, \text{if } j \text{ is a cost criterion} \tag{13}$$

$$r_{ij} = \frac{x_{ij} - x_{min}}{x_{max} - x_{min}}, \text{if } j \text{ is a benefit criterion} \tag{14}$$

Step 3. Percentage values (PV) of each criterion is determined based on Eq. (15).

$$PV_{ij} = \left| ln\left(\frac{\sqrt{\frac{\Sigma_{i=1}^{m} r_{ij}^2}{m}}}{\sigma} \right).100 \right| \tag{15}$$

Step 4. Calculate the weights of the criteria using Eq. (16).

$$w_j = \frac{PV_{ij}}{\Sigma_{i=1}^{n} PV_{ij}} \tag{16}$$

3.4. EDAS

In 2015, Keshavarz Ghorabaee, Zavadskas, Olfat, and Turskis developed the Evaluation based on Distance from Average Solution (EDAS) method. This method proves to be highly effective in scenarios characterized by conflicting attributes, allowing for the selection of the most suitable alternative by calculating the distance of each option from the optimal value. The steps of the EDAS method is outlined as follows (Keshavarz Ghorabaee et al., 2015; 2017; Alinezhad and Khalili, 2019):

Step 1. Eq. (17) is used to calculate each attribute's average solution.

$$AV_J = \frac{\sum_{i=1}^{m} r_{ij}}{m}; j = 1, ..., n \tag{17}$$

Step 2. Eqs. (18) and (19) are used to determine the positive distances from average (PDA) and negative distances from average (NDA) of the positive attributes based on the positive and negative types of attributes.

$$PDA_{IJ} = \frac{max(0, (r_{ij} - AV_j))}{AV_j}; \qquad i = 1, ...m, j = 1, ..., n \tag{18}$$

$$NDA_{IJ} = \frac{max(0, (AV_j - r_{ij}))}{AV_j}; \qquad i = 1, ...m, j = 1, ..., n \tag{19}$$

Additionally, Eqs. (20) and (21) are used to calculate the PDA and NDA values of the negative attributes.

$$PDA_{IJ} = \frac{max(0, (AV_j - r_{ij}))}{AV_j}; \qquad i = 1, ...m, j = 1, ..., n \tag{20}$$

$$NDA_{IJ} = \frac{max(0, (r_{ij} - AV_j))}{AV_j}; \qquad i = 1, ...m, j = 1, ..., n \tag{21}$$

Step 3. Eqs. (22) and (23) are used to calculate the weighted PDA and weighted NDA values for each alternative, considering the weight of attributes.

$$SP_I = \sum_{j=1}^{n} PDA_{IJ}.w_j; \qquad i = 1, ..., m \tag{22}$$

$$SN_I = \sum_{j=1}^{n} NDA_{IJ}.w_j; \qquad i = 1, ..., m \tag{23}$$

Step 4. The values of weighted PDA and weighted NDA are normalized using Eqs. (24) and (25), respectively.

$$NSP_I = \frac{SP_i}{\max\limits_i(SP_i)}; \qquad i = 1, ..., m \tag{24}$$

$$NSN_I = \frac{SN_i}{\max\limits_i(SN_i)}; \qquad i = 1, ..., m \tag{25}$$

Step 5. Eq. (26) is used to compute each alternative's appraisal score.

$$AS_i = \frac{1}{2}(NSP_i + NSN_i); \qquad i = 1, ..., m \tag{26}$$

The appraisal scores of the alternatives are ranked in descending order to determine the final ranking of the alternatives.

4. Results

In this section, the results of the ENTROPY, CRITIC and LOPCOW-based EDAS methods are presented. Initially, the weight of the criteria was calculated with the ENTROPY, CRITIC and LOPCOW methods, separately. Once the determination of the criteria weight, logistics performance of the alternatives was ranked using the EDAS method. In the current study, the six criteria,

which are customs, infrastructure, international shipments, logistics quality and competence, tracking and tracing and timeliness, were used to evaluate the logistics performance of OPEC countries. All criteria were considered beneficial. The 2018 LPI data for OPEC countries were retrieved from the WB. Table 2 and 3 demonstrates the description of the criteria and initial decision matrix, respectively (Arvis et al., 2018, p.8).

Table 2. Summary of the Criteria

Criterion	Code	Definition	Source
Customs	C1	The efficiency of customs and borders	World Bank (LPI-2018)
Infrastructure	C2	The quality of trade and transport infrastructure	
International Shipments	C3	The ease of arranging competitively priced shipments	
Logistics Quality & Competence	C4	The competence and quality of logistics services	
Tracking & Tracing	C5	The ability to track and trace consignments	
Timeliness	C6	The frequency with which shipments reach consignees within scheduled or expected delivery times	

Table 3. The Decision Matrix of OPEC Countries

Country	C1	C2	C3	C4	C5	C6
Algeria	2,13	2,42	2,39	2,39	2,60	2,76
Angola	1,57	1,86	2,20	2,00	2,00	2,59
Congo	2,27	2,07	2,87	2,28	2,38	2,95
Equatorial Guinea	1,91	1,88	2,88	2,25	2,13	2,75
Gabon	1,96	2,09	2,10	2,07	2,07	2,67
Iran	2,63	2,77	2,76	2,84	2,77	3,36
Iraq	1,84	2,03	2,32	1,91	2,19	2,72
Kuwait	2,73	3,02	2,63	2,80	2,66	3,37
Libya	1,95	2,25	1,99	2,05	1,64	2,77
Nigeria	1,97	2,56	2,52	2,40	2,68	3,07
Saudi Arabia	2,66	3,11	2,99	2,86	3,17	3,30
United Arab Emirates	3,63	4,02	3,85	3,92	3,96	4,38
Venezuela	1,79	2,10	2,38	2,21	2,29	2,58

4.1. Results of the ENTROPY Method

The normalized values of the decision matrix were computed using Eq. (2) and shown in Table 4.

Table 4. The Normalized Decision Matrix

Criteria	C1	C2	C3	C4	C5	C6
Algeria	0,0734	0,0753	0,0705	0,0748	0,0800	0,0703
Angola	0,0541	0,0577	0,0650	0,0627	0,0616	0,0661
Congo	0,0783	0,0642	0,0846	0,0713	0,0731	0,0751
Equatorial Guinea	0,0658	0,0583	0,0849	0,0704	0,0653	0,0700
Gabon	0,0674	0,0650	0,0620	0,0649	0,0635	0,0681
Iran	0,0904	0,0860	0,0814	0,0888	0,0850	0,0855
Iraq	0,0634	0,0632	0,0687	0,0597	0,0673	0,0693
Kuwait	0,0939	0,0939	0,0776	0,0875	0,0817	0,0858
Libya	0,0673	0,0699	0,0587	0,0640	0,0503	0,0705
Nigeria	0,0677	0,0796	0,0745	0,0750	0,0825	0,0781
Saudi Arabia	0,0916	0,0966	0,0882	0,0894	0,0975	0,0840
United Arab Emirates	0,1251	0,1250	0,1136	0,1226	0,1217	0,1114
Venezuela	0,0616	0,0652	0,0703	0,0690	0,0705	0,0657

According to Eqs. (3), (4) and (5), the entropy value (ej), divergence degree (d_j) and the final weights (w_j) for all criterions were generated. The final weights obtained from the Entropy method should be in the range of 0 and 1, and the sum of the resulting weights should give the value 1. In this case, number of alternatives n = 13. Therefore, $K = 1/\ln(n) = 1/\ln(13) = 0.3899$. The results obtained from all calculation is presented in Table 5 and 6.

Table 5. The Degree of Entropy

Criteria	C1	C2	C3	C4	C5	C6
Algeria	-0,1917	-0,1947	-0,1870	-0,1939	-0,2021	-0,1867
Angola	-0,1579	-0,1647	-0,1777	-0,1736	-0,1717	-0,1795
Congo	-0,1994	-0,1763	-0,2090	-0,1884	-0,1912	-0,1944
Equatorial Guinea	-0,1791	-0,1657	-0,2094	-0,1868	-0,1782	-0,1862
Gabon	-0,1817	-0,1777	-0,1724	-0,1775	-0,1751	-0,1829
Iran	-0,2173	-0,2110	-0,2042	-0,2150	-0,2096	-0,2102
Iraq	-0,1748	-0,1746	-0,1839	-0,1682	-0,1817	-0,1849
Kuwait	-0,2221	-0,2222	-0,1983	-0,2131	-0,2046	-0,2107
Libya	-0,1816	-0,1860	-0,1665	-0,1759	-0,1503	-0,1870
Nigeria	-0,1824	-0,2014	-0,1935	-0,1943	-0,2058	-0,1992
Saudi Arabia	-0,2190	-0,2258	-0,2141	-0,2159	-0,2269	-0,2081
United Arab Emirates	-0,2600	-0,2599	-0,2471	-0,2573	-0,2563	-0,2445
Venezuela	-0,1716	-0,1780	-0,1866	-0,1845	-0,1870	-0,1790

Table 6. The Entropy Weight

Criteria	C1	C2	C3	C4	C5	C6
Entropy (e_j)	0,9897	0,9895	0,9941	0,9920	0,9905	0,9955
Divergence degree (d_j)	0,0103	0,0105	0,0059	0,0080	0,0095	0,0045
Weights (w_j)	0,2101	0,2158	0,1218	0,1646	0,1954	0,0923
rank	2	1	5	4	3	6

The ENTROPY results showed that infrastructure (C2) and timeliness (C6) are the most and least important criteria, respectively. The general ranking of criteria is as follows: C2 > C1 > C5 > C4 > C3 > C6.

4.2. Results of the CRITIC Method

According to Eq. (6), the decision matrix was normalized and presented in Table 7.

Table 7. The Normalized Decision Matrix

Criteria	C1	C2	C3	C4	C5	C6
Algeria	0,2713	0,2607	0,2144	0,2401	0,4169	0,1000
Angola	0,0000	0,0000	0,1147	0,0477	0,1585	0,0074
Congo	0,3404	0,0966	0,4719	0,1855	0,3193	0,2049
Equatorial Guinea	0,1645	0,0083	0,4767	0,1699	0,2104	0,0938
Gabon	0,1865	0,1085	0,0590	0,0827	0,1857	0,0504
Iran	0,5114	0,4203	0,4131	0,4623	0,4865	0,4313
Iraq	0,1301	0,0815	0,1806	0,0000	0,2391	0,0770
Kuwait	0,5602	0,5382	0,3434	0,4416	0,4399	0,4381
Libya	0,1855	0,1809	0,0000	0,0681	0,0000	0,1049
Nigeria	0,1919	0,3246	0,2869	0,2438	0,4512	0,2711
Saudi Arabia	0,5287	0,5775	0,5359	0,4732	0,6607	0,4003
United Arab Emirates	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
Venezuela	0,1048	0,1108	0,2101	0,1484	0,2832	0,0000

Based on Eqs. (8) and (9), the mean values of each attribute were computed and shown in Table 8.

Table 8. The Correlation Coefficient

Criteria	C1	C2	C3	C4	C5	C6
C1	1,0000	0,9457	0,8460	0,9631	0,8845	0,9670
C2	0,9457	1,0000	0,7578	0,9561	0,9105	0,9538
C3	0,8460	0,7578	1,0000	0,8832	0,8774	0,8637
C4	0,9631	0,9561	0,8832	1,0000	0,9380	0,9703
C5	0,8845	0,9105	0,8774	0,9380	1,0000	0,9001
C6	0,9670	0,9538	0,8637	0,9703	0,9001	1,0000

The standard deviation of each attribute was calculated by using Eqs. (10) and (11). The index for all attributes presented in Table 9.

Table 9. The Index (C)

Criteria	C1	C2	C3	C4	C5	C6
C1	0,0000	0,0543	0,1540	0,0369	0,1155	0,0330
C2	0,0543	0,0000	0,2422	0,0439	0,0895	0,0462
C3	0,1540	0,2422	0,0000	0,1168	0,1226	0,1363
C4	0,0369	0,0439	0,1168	0,0000	0,0620	0,0297
C5	0,1155	0,0895	0,1226	0,0620	0,0000	0,0999
C6	0,0330	0,0462	0,1363	0,0297	0,0999	0,0000

By using Eq. (12), the weight of the criteria was calculated and shown in Table 10.

Table 10. The Weight of Criteria

	C1	C2	C3	C4	C5	C6
W_j	0,1424	0,1842	0,2721	0,1051	0,1679	0,1284
rank	4	2	1	6	3	5

The CRITIC results showed that international shipments (C3) and logistics quality and competence (C4) are the most and least important criteria, respectively. The general ranking of criteria is as follows: C3 > C2 > C5 > C1 > C6 > C4.

4.3. Results of the LOPCOW Method

Based on Eq. (14), the decision matrix was normalized and shown in Table 11. Then, *PV* of each criterion and weight of criteria was determined using Eqs. (15-16), respectively. The results of the LOPCOW method are presented in Table 12.

Table 11. The normalized decision matrix

Country	C1	C2	C3	C4	C5	C6
Algeria	0,2718	0,4126	0,3981	0,3981	0,5000	0,5777
Angola	0,0000	0,1408	0,3058	0,2087	0,2087	0,4951
Congo	0,3398	0,2427	0,6311	0,3447	0,3932	0,6699
Equatorial Guinea	0,1650	0,1505	0,6359	0,3301	0,2718	0,5728
Gabon	0,1893	0,2524	0,2573	0,2427	0,2427	0,5340
Iran	0,5146	0,5825	0,5777	0,6165	0,5825	0,8689
Iraq	0,1311	0,2233	0,3641	0,1650	0,3010	0,5583
Kuwait	0,5631	0,7039	0,5146	0,5971	0,5291	0,8738
Libya	0,1845	0,3301	0,2039	0,2330	0,0340	0,5825
Nigeria	0,1942	0,4806	0,4612	0,4029	0,5388	0,7282
Saudi Arabia	0,5291	0,7476	0,6893	0,6262	0,7767	0,8398
United Arab Emirates	1,0000	1,1893	1,1068	1,1408	1,1602	1,3641
Venezuela	0,1068	0,2573	0,3932	0,3107	0,3495	0,4903

Table 12. The results of LOPCOW

Criteria	C1	C2	C3	C4	C5	C6
Mean Square	0,3223	0,4395	0,5030	0,4320	0,4529	0,7043
σ	0,2684	0,3012	0,2366	0,2634	0,2868	0,2414
PV	18,2801	37,8042	75,4080	49,4789	45,7160	107,0689
W_j	0,0548	0,1133	0,2259	0,1482	0,1370	0,3208
rank	6	5	2	3	4	1

The LOPCOW results showed that timeliness (C6) and customs (C1) are the most and least important criteria, respectively. The general ranking of criteria is as follows: C6>C3>C4>C5>C2>C1.

4.4. Results of the ENTROPY-based EDAS Method

The average solution of each attribute was obtained using Eq. (17) and shown in Table 13.

Table 13. The Average Solution

Country	C1	C2	C3	C4	C5	C6
Algeria	2,13	2,42	2,39	2,39	2,60	2,76
Angola	1,57	1,86	2,20	2,00	2,00	2,59
Congo	2,27	2,07	2,87	2,28	2,38	2,95
Equatorial Guinea	1,91	1,88	2,88	2,25	2,13	2,75
Gabon	1,96	2,09	2,10	2,07	2,07	2,67
Iran	2,63	2,77	2,76	2,84	2,77	3,36
Iraq	1,84	2,03	2,32	1,91	2,19	2,72
Kuwait	2,73	3,02	2,63	2,80	2,66	3,37
Libya	1,95	2,25	1,99	2,05	1,64	2,77
Nigeria	1,97	2,56	2,52	2,40	2,68	3,07
Saudi Arabia	2,66	3,11	2,99	2,86	3,17	3,30
United Arab Emirates	3,63	4,02	3,85	3,92	3,96	4,38
Venezuela	1,79	2,10	2,38	2,21	2,29	2,58
Average	2,2331	2,4744	2,6047	2,4596	2,5033	3,0206
w_j	0,2101	0,2158	0,1218	0,1646	0,1954	0,0923

The values of the PDA and NDA solution for each alternative was calculated by Eqs. (18-21), and shown in Table 14 and 15, respectively.

Table 14. Values of the PDA

Country	C1	C2	C3	C4	C5	C6
Algeria	0,0000	0,0000	0,0000	0,0000	0,0406	0,0000
Angola	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Congo	0,0178	0,0000	0,1003	0,0000	0,0000	0,0000
Equatorial Guinea	0,0000	0,0000	0,1038	0,0000	0,0000	0,0000
Gabon	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Iran	0,1755	0,1181	0,0584	0,1539	0,1052	0,1110
Iraq	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Kuwait	0,2205	0,2212	0,0086	0,1370	0,0620	0,1150
Libya	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Nigeria	0,0000	0,0345	0,0000	0,0000	0,0725	0,0158
Saudi Arabia	0,1914	0,2557	0,1460	0,1628	0,2670	0,0925
United Arab Emirates	0,6262	0,6252	0,4771	0,5935	0,5820	0,4488
Venezuela	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Table 15. Values of the NDA

Country	C1	C2	C3	C4	C5	C6
Algeria	0,0460	0,0214	0,0834	0,0278	0,0000	0,0859
Angola	0,2963	0,2495	0,1545	0,1851	0,1993	0,1409
Congo	0,0000	0,1650	0,0000	0,0725	0,0501	0,0236
Equatorial Guinea	0,1446	0,2422	0,0000	0,0852	0,1511	0,0896
Gabon	0,1243	0,1546	0,1943	0,1565	0,1741	0,1153
Iran	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Iraq	0,1763	0,1782	0,1075	0,2241	0,1245	0,0995
Kuwait	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Libya	0,1251	0,0912	0,2363	0,1684	0,3465	0,0829
Nigeria	0,1193	0,0000	0,0317	0,0248	0,0000	0,0000
Saudi Arabia	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
United Arab Emirates	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Venezuela	0,1996	0,1525	0,0865	0,1027	0,0836	0,1453

The values of the weighted PDA and weighted NDA of each alternative were obtained using Eqs. (22) and (23), and the results are presented in Table 16.

Table 16. Values of the SP and SN

Country	SP	SN
Algeria	0,0079	0,0370
Angola	0,0000	0,2173
Congo	0,0160	0,0595
Equatorial Guinea	0,0126	0,1345
Gabon	0,0000	0,1536
Iran	0,1256	0,0000
Iraq	0,0000	0,1590
Kuwait	0,1404	0,0000
Libya	0,0000	0,1779
Nigeria	0,0231	0,0330
Saudi Arabia	0,2007	0,0000
United Arab Emirates	0,5774	0,0000
Venezuela	0,0000	0,1320

Eqs. (24) and (25) was used to normalize the values of the weighted PDA and weighted NDA, respectively and shown in Table 17.

Table 17. Values of the NSP and NSN

Country	NSP	NSN
Algeria	0,0137	0,8299
Angola	0,0000	0,0000
Congo	0,0276	0,7262
Equatorial Guinea	0,0219	0,3812
Gabon	0,0000	0,2934
Iran	0,2175	1,0000
Iraq	0,0000	0,2684
Kuwait	0,2431	1,0000
Libya	0,0000	0,1816
Nigeria	0,0399	0,8482
Saudi Arabia	0,3475	1,0000
United Arab Emirates	1,0000	1,0000
Venezuela	0,0000	0,3925

Based on Eq. (26), the AS for each alternative was computed and the AS of alternatives were arranged in a descending order. Table 18 presents the final ranking of the alternatives.

Table 18. Values of the AS and Final Ranking

Country	AS	Rank
Algeria	0,4218	6
Angola	0,0000	13
Congo	0,3769	7
Equatorial Guinea	0,2016	8
Gabon	0,1467	10
Iran	0,6088	4
Iraq	0,1342	11
Kuwait	0,6216	3
Libya	0,0908	12
Nigeria	0,4440	5
Saudi Arabia	0,6738	2
United Arab Emirates	1,0000	1
Venezuela	0,1962	9

According to results obtained by the ENTROPY-based EDAS methods, the UAE has the highest logistics performance, followed by Saudi Arabia and Kuwait. On the other hand, Angola has the lowest logistics performance, followed by Libya and Iraq.

4.5. Results of the CRITIC-based EDAS Method

The average solution of each attribute was obtained using Eq. (17) and presented in Table 19.

Table 19. The Average Solution

Country	C1	C2	C3	C4	C5	C6
Algeria	2,13	2,42	2,39	2,39	2,60	2,76
Angola	1,57	1,86	2,20	2,00	2,00	2,59
Congo	2,27	2,07	2,87	2,28	2,38	2,95
Equatorial Guinea	1,91	1,88	2,88	2,25	2,13	2,75
Gabon	1,96	2,09	2,10	2,07	2,07	2,67
Iran	2,63	2,77	2,76	2,84	2,77	3,36
Iraq	1,84	2,03	2,32	1,91	2,19	2,72
Kuwait	2,73	3,02	2,63	2,80	2,66	3,37
Libya	1,95	2,25	1,99	2,05	1,64	2,77
Nigeria	1,97	2,56	2,52	2,40	2,68	3,07
Saudi Arabia	2,66	3,11	2,99	2,86	3,17	3,30
United Arab Emirates	3,63	4,02	3,85	3,92	3,96	4,38
Venezuela	1,79	2,10	2,38	2,21	2,29	2,58
Average	2,2331	2,4744	2,6047	2,4596	2,5033	3,0206
w_j	0,1424	0,1842	0,2721	0,1051	0,1679	0,1284

Eqs. (18-21) were used to determine the positive distance from average (PDA) and negative distance from average (NDA) values for each alternative, and the results are displayed in Tables 20 and 21, respectively.

Table 20. Values of the PDA

Country	C1	C2	C3	C4	C5	C6
Algeria	0,0000	0,0000	0,0000	0,0000	0,0406	0,0000
Angola	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Congo	0,0178	0,0000	0,1003	0,0000	0,0000	0,0000
Equatorial Guinea	0,0000	0,0000	0,1038	0,0000	0,0000	0,0000
Gabon	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Iran	0,1755	0,1181	0,0584	0,1539	0,1052	0,1110
Iraq	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Kuwait	0,2205	0,2212	0,0086	0,1370	0,0620	0,1150
Libya	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Nigeria	0,0000	0,0345	0,0000	0,0000	0,0725	0,0158
Saudi Arabia	0,1914	0,2557	0,1460	0,1628	0,2670	0,0925
United Arab Emirates	0,6262	0,6252	0,4771	0,5935	0,5820	0,4488
Venezuela	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Table 21. Values of the NDA

Country	C1	C2	C3	C4	C5	C6
Algeria	0,0460	0,0214	0,0834	0,0278	0,0000	0,0859
Angola	0,2963	0,2495	0,1545	0,1851	0,1993	0,1409
Congo	0,0000	0,1650	0,0000	0,0725	0,0501	0,0236
Equatorial Guinea	0,1446	0,2422	0,0000	0,0852	0,1511	0,0896
Gabon	0,1243	0,1546	0,1943	0,1565	0,1741	0,1153
Iran	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Iraq	0,1763	0,1782	0,1075	0,2241	0,1245	0,0995
Kuwait	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Libya	0,1251	0,0912	0,2363	0,1684	0,3465	0,0829
Nigeria	0,1193	0,0000	0,0317	0,0248	0,0000	0,0000
Saudi Arabia	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
United Arab Emirates	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Venezuela	0,1996	0,1525	0,0865	0,1027	0,0836	0,1453

The values of the weighted PDA and weighted NDA of each alternative were obtained using Eqs. (22) and (23), and the results are presented in Table 22.

Table 22. Values of the SP and SN

Country	SP	SN
Algeria	0,0068	0,0471
Angola	0,0000	0,2012
Congo	0,0298	0,0494
Equatorial Guinea	0,0282	0,1110
Gabon	0,0000	0,1595
Iran	0,1107	0,0000
Iraq	0,0000	0,1444
Kuwait	0,1141	0,0000
Libya	0,0000	0,1854
Nigeria	0,0205	0,0282
Saudi Arabia	0,1879	0,0000
United Arab Emirates	0,5518	0,0000
Venezuela	0,0000	0,1235

Eqs. (24) and (25) was used to normalize the values of the weighted PDA and weighted NDA, respectively and the results are shown in Table 23.

Table 23. Values of the NSP and NSN

Country	NSP	NSN
Algeria	0,0123	0,7657
Angola	0,0000	0,0000
Congo	0,0541	0,7543
Equatorial Guinea	0,0512	0,4481
Gabon	0,0000	0,2071
Iran	0,2006	1,0000
Iraq	0,0000	0,2823
Kuwait	0,2067	1,0000
Libya	0,0000	0,0782
Nigeria	0,0372	0,8598
Saudi Arabia	0,3405	1,0000
United Arab Emirates	1,0000	1,0000
Venezuela	0,0000	0,3861

Based on Eq. (26), the appraisal score (AS) for each alternative was computed and the AS of alternatives were arranged in a descending order. Table 24 illustrates the final ranking of the alternatives.

Table 24. Values of the AS and Final Ranking

Country	AS	Rank
Algeria	0,3890	7
Angola	0,0000	13
Congo	0,4042	6
Equatorial Guinea	0,2496	8
Gabon	0,1036	11
Iran	0,6003	4
Iraq	0,1411	10
Kuwait	0,6034	3
Libya	0,0391	12
Nigeria	0,4485	5
Saudi Arabia	0,6702	2
United Arab Emirates	1,0000	1
Venezuela	0,1930	9

According to results obtained by CRITIC-based EDAS method, UAE has the highest logistics performance, followed by Saudi Arabia and Kuwait. On the other hand, Angola has the lowest logistics performance, followed by Libya and Gabon.

4.6. Results of the LOPCOW-based EDAS Method

The average solution of each attribute was obtained using Eq. (17) and presented in Table 25.

Table 25. The Average Solution

Country	C1	C2	C3	C4	C5	C6
Algeria	2,13	2,42	2,39	2,39	2,60	2,76
Angola	1,57	1,86	2,20	2,00	2,00	2,59
Congo	2,27	2,07	2,87	2,28	2,38	2,95
Equatorial Guinea	1,91	1,88	2,88	2,25	2,13	2,75
Gabon	1,96	2,09	2,10	2,07	2,07	2,67
Iran	2,63	2,77	2,76	2,84	2,77	3,36
Iraq	1,84	2,03	2,32	1,91	2,19	2,72
Kuwait	2,73	3,02	2,63	2,80	2,66	3,37
Libya	1,95	2,25	1,99	2,05	1,64	2,77
Nigeria	1,97	2,56	2,52	2,40	2,68	3,07
Saudi Arabia	2,66	3,11	2,99	2,86	3,17	3,30
United Arab Emirates	3,63	4,02	3,85	3,92	3,96	4,38
Venezuela	1,79	2,10	2,38	2,21	2,29	2,58
Average	2,2331	2,4744	2,6047	2,4596	2,5033	3,0206
w_j	0,1424	0,1842	0,2721	0,1051	0,1679	0,1284

Eqs. (18-21) were used to determine the positive distance from average (PDA) and negative distance from average (NDA) values for each alternative, and the results are displayed in Table 26 and 27, respectively.

Table 26. Values of the PDA

Country	C1	C2	C3	C4	C5	C6
Algeria	0,0000	0,0000	0,0000	0,0000	0,0387	0,0000
Angola	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Congo	0,0162	0,0000	0,1012	0,0000	0,0000	0,0000
Equatorial Guinea	0,0000	0,0000	0,1051	0,0000	0,0000	0,0000
Gabon	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Iran	0,1773	0,1190	0,0590	0,1545	0,1066	0,1123
Iraq	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Kuwait	0,2221	0,2200	0,0091	0,1382	0,0627	0,1156
Libya	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Nigeria	0,0000	0,0342	0,0000	0,0000	0,0707	0,0163
Saudi Arabia	0,1908	0,2564	0,1473	0,1626	0,2664	0,0924
United Arab Emirates	0,6250	0,6240	0,4773	0,5935	0,5821	0,4500
Venezuela	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Table 27. Values of the NDA

Country	C1	C2	C3	C4	C5	C6
Algeria	0,0465	0,0224	0,0829	0,0285	0,0000	0,0863
Angola	0,2972	0,2486	0,1558	0,1870	0,2010	0,1426
Congo	0,0000	0,1638	0,0000	0,0732	0,0492	0,0234
Equatorial Guinea	0,1450	0,2405	0,0000	0,0854	0,1490	0,0896
Gabon	0,1226	0,1557	0,1942	0,1585	0,1730	0,1161
Iran	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Iraq	0,1763	0,1799	0,1098	0,2236	0,1251	0,0996
Kuwait	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Libya	0,1271	0,0911	0,2364	0,1667	0,3448	0,0830
Nigeria	0,1181	0,0000	0,0331	0,0244	0,0000	0,0000
Saudi Arabia	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
United Arab Emirates	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Venezuela	0,1987	0,1516	0,0868	0,1016	0,0851	0,1459

The values of the weighted PDA and weighted NDA of each alternative were obtained using Eqs. (22) and (23), and the results are presented in Table 28.

Table 28. Values of the SP and SN

Country	SP	SN
Algeria	0,0053	0,0557
Angola	0,0000	0,1807
Congo	0,0238	0,0437
Equatorial Guinea	0,0237	0,0970
Gabon	0,0000	0,1527
Iran	0,1101	0,0000
Iraq	0,0000	0,1371
Kuwait	0,1053	0,0000
Libya	0,0000	0,1693
Nigeria	0,0188	0,0176
Saudi Arabia	0,1630	0,0000
United Arab Emirates	0,5248	0,0000
Venezuela	0,0000	0,1212

Eqs. (24) and (25) was used to normalize the values of the weighted PDA and weighted NDA, respectively and the results are shown in Table 29.

Table 29. Values of the NSP and NSN

Country	NSP	NSN
Algeria	0,0101	0,6915
Angola	0,0000	0,0000
Congo	0,0453	0,7584
Equatorial Guinea	0,0452	0,4629
Gabon	0,0000	0,1548
Iran	0,2097	1,0000
Iraq	0,0000	0,2413
Kuwait	0,2007	1,0000
Libya	0,0000	0,0631
Nigeria	0,0358	0,9028
Saudi Arabia	0,3106	1,0000
United Arab Emirates	1,0000	1,0000
Venezuela	0,0000	0,3291

Based on Eq. (26), the appraisal score (AS) for each alternative was computed and the AS of alternatives were arranged in a descending order. Table 30 demonstrates the final ranking of the alternatives.

Table 30. Values of the AS and Final Ranking

Country	AS	Rank
Algeria	0,3508	7
Angola	0,0000	13
Congo	0,4018	6
Equatorial Guinea	0,2541	8
Gabon	0,0774	11
Iran	0,6049	3
Iraq	0,1206	10
Kuwait	0,6003	4
Libya	0,0315	12
Nigeria	0,4693	5
Saudi Arabia	0,6553	2
United Arab Emirates	1,0000	1
Venezuela	0,1645	9

According to results obtained by LOPCOW-based EDAS method, the UAE has the highest logistics performance, followed by Saudi Arabia and Iran. On the other hand, Angola has the lowest logistics performance, followed by Libya and Gabon. Additionally, a comparison of ranking results with different weighting methods is presented in Figure 1. Based on the comparison of ranking results obtained by ENTROPY, CRITIC and LOPCOW-based EDAS method, the logistics performance of the top five countries is the same in all approaches. The UAE is the best ranked in LPI, followed by Saudi Arabia, Kuwait, Iran, and Nigeria. However, some differences have been observed in the rest of the ranking. For instance, the logistics performance rankings of Algeria, Congo, Gabon, and Iraq are relatively different, as illustrated in Figure 1.

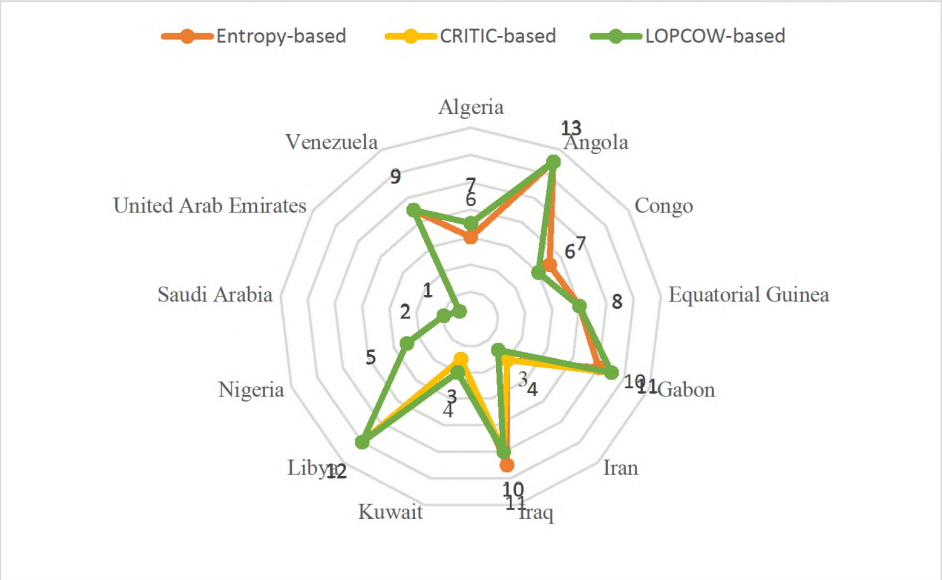

Figure 1. Comparison of ranking results

5. Comparative Analysis

Mešić et al. (2022) pointed out that it's important to carried out consistency analysis of results based on the changes of methods. In this study, a comparative analysis was conducted to assess the robustness of the results obtained from the proposed model. Initially, the geometric mean of the criteria weights was calculated. Subsequently, the outcomes obtained from the proposed model were compared with those obtained by applying other MCDM methods, including ARAS, TOPSIS, COPRAS, MAIRCA, WASPAS, and CoCoSo. These methods were selected due to their distinct calculations and approaches. Table 31 and Figure 2 presents the results obtained by different MCDM methods, respectively.

Table 31. Comparative Analysis Results

Country	EDAS	ARAS	TOPSIS	COPRAS	MAIRCA	WASPAS	CoCoSo
Algeria	7	7	7	9	7	7	7
Angola	13	13	13	13	13	13	13
Congo	6	6	6	5	6	6	6
Equatorial Guinea	8	8	8	6	8	8	8
Gabon	11	11	11	11	11	11	10
Iran	3	4	4	4	4	4	4
Iraq	10	10	10	12	10	10	11
Kuwait	4	3	3	3	3	3	3
Libya	12	12	12	7	12	12	12
Nigeria	5	5	5	8	5	5	5
Saudi Arabia	2	2	2	2	2	2	2
United Arab Emirates	1	1	1	1	1	1	1
Venezuela	9	9	9	10	9	9	9

The comparative analysis results showed that the ranking obtained from the EDAS method is almost the same as in the ranking order obtained from the ARAS, TOPSIS, MAIRCA, WASPAS and CoCoSo methods. However, the ranking differs in relation to COPRAS method. The comparative analysis showed that the UAE and Angola have the best and worst logistics performance, respectively. It can be concluded that the countries with the highest and lowest logistics performance are constant for all methods. The overall ranking of countries obtained by the comparative analysis is presented in Figure 2.

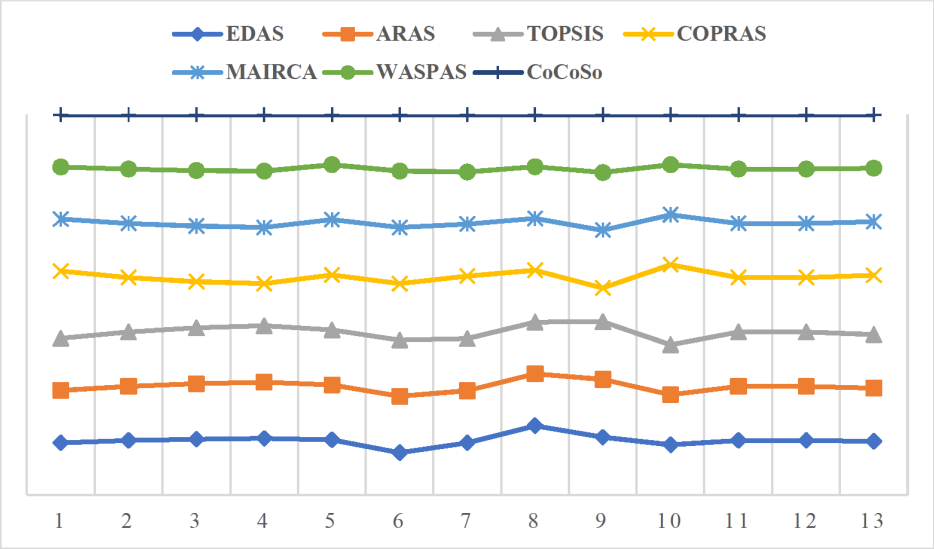

Figure 2. Comparison of ranking results

6. Discussion and Conclusions

The logistics is one of the important industries in facilitating trade, decreasing transportation costs, and stimulating economic growth. Logistics services are crucial in terms of sustainable growth and trade efficiency. In addition, it has a positive effect on economies of scale, production activities, and distribution of goods (Bugarčić et al., 2020). Therefore, measuring the logistics performance of countries is quite important. In this context, the WB has been publishing LPI reports since 2007. LPI is an interactive benchmarking tool created to help countries identify the challenges and opportunities they face in their performance on trade logistics and what they can do to improve their performance (WB, 2023). Parallel to this, a large and growing body of literature has investigated the logistics performance of nations with various MCDM methods. For instance, the logistics performance of OECD (Çakır, 2017; Gök Kısa & Ayçin, 2019; Yıldırım & Adıgüzel Mercangöz., 2020; Arıkan Kargı, 2022; Çalık et al., 2023), the logistics performance of EU (Ulutaş & Karaköy, 2019a; Isik et al., 2020; Adıgüzel Mercangöz et al., 2020), the logistics performance of Balkans countries (Bugarčić et al., 2020; Mešić et al., 2022), the logistics performance of G20 members (Ulutaş & Karaköy, 2019b and the logistics performance of Gulf Cooperation Council (GCC) (Stojanović & Puška, 2021) has been reviewed by many researchers. However, there has been a limited number of studies on the logistics performance of GCC and OPEC members in relevant literature. Accordingly, this study examines the logistics performance of OPEC countries using the ENTROPY, CRITIC and LOPCOW-based EDAS method.

The findings obtained by the ENTROPY, CRITIC and LOPCOW methods showed that the most important criteria were infrastructure, international shipments and timeliness, respectively. The findings of the current study are consistent with those of Ulutaş & Karaköy (2019, 2021), Yıldırım & Adıgüzel Mercan (2020), Isik et al. (2020), Arıkan Kargı (2022), Miškić et al. (2023) who determined the infrastructure, international shipments and timeliness as a most critical criterion. Once the weight of criteria was calculated, the logistics performance of OPEC countries was ranked using the EDAS method. According to results obtained by the ENTROPY, CRITIC and LOPCOW-based EDAS method revealed that the UAE has the highest logistics performance, followed by Saudi Arabia, Iran, Kuwait and Nigeria. These findings seem to be consistent with another research which found that the UAE has the best logistics performance among GCC. However, the logistics performance of Saudi Arabia and Kuwait is relatively low among GCC (Stojanović & Puška, 2021). On the other hand, Angola and Libya have the worst logistics performance, followed by Iraq and Gabon. A possible explanation for these results may be the lack of adequate political and economic stability. In such regions, economic development is relatively low and military administration is more dominant. Based on the LPI Report published by the WB in 2018, the UAE is among the top 20 countries (11^{th} rank), whereas Saudi Arabia and Kuwait are among the top 75 countries (55^{th} and 63^{rd}, respectively). Additionally, Iraq, Gabon, Libya, and Angola are in last place on LPI (147^{th}, 150^{th}, 154^{th} and 159^{th}, respectively).

Overall, the findings from this study make several contributions to the current literature. To the best of the author's knowledge, this is the first study examining the logistics performance of OPEC countries using the ENTROPY, CRITIC and LOPCOW-based EDAS methods. This study also enables a comparison of ranking results with different MCDM methods, such as ARAS, TOPSIS, COPRAS, MAIRCA, WASPAS and CoCoSo. It is anticipated that the results derived from this study will offer valuable insights to policymakers, investors, and businesses operating within OPEC countries concerning logistics performance. Furthermore, this

research has identified priority countries for managers of logistics firms operating within or considering investment in OPEC countries, along with key criteria for market entry. Additionally, several managerial recommendations have been proposed to enhance the logistics performance of these countries: (I) oil and subterranean resources are important sources of revenue for the OPEC countries. To improve connectivity and facilitate effective movement of goods, it would be beneficial to allocate part of their income from transport and logistics infrastructure such as ports, roads, railways or airports. (II) in order to reduce bureaucratic barriers and improve efficiency in their customs and trade activities, OPEC countries can further strengthen contacts with the other countries particularly Europe and Africa. (III) in order to simplify supply chain operations, reduce transaction costs and increase transparency in the logistics network, technological advances such as digitalization, automation, big data, blockchain, artificial intelligence can be adopted. (IV) in order to contribute to environmental preservation and long-term sustainability, while improving overall logistics performance, it is possible to integrate sustainability principles into operations such as the adoption of green logistics practices, optimization of transport routes or reducing carbon emissions. Several limitations of this study need to be acknowledged. For instance, one of the limitations is the observed period and the number of countries. Future research could investigate the logistics performance of other regions, such as Asia, South America, and Africa, over several years and compare the results. Moreover, future research in this field might use different subjective and objective methods, or methods involving fuzzy approaches. It would be interesting to compare the results obtained by fuzzy and gray approaches.

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REFERENCES

Adıgüzel Mercangöz, B., Yıldırım, B. F., & Kuzu Yıldırım, S. (2020). Time period based COPRAS-G method: application on the Logistics Performance Index. *LogForum, 16*(2), 239-250.

Akbulut, E. A., Ulutaş, A., Yürüyen, A. A., & Balalan, S. (2024). Hibrit bir ÇKKV modeli ile G20 ülkelerinin lojistik performansının ölçülmesi. *Business & Management Studies: An International Journal, 1*2(1), 1-21.

Alinezhad, A., & Khalili, J. (2019). *New methods and applications in multiple attribute decision making (MADM)* (Vol. 277). Cham: Springer.

Arıkan Kargı, V. S. (2022). Evaluation of Logistics Performance of The OECD Member Countries with Integrated Entropy and Waspas Method. *Yönetim ve Ekonomi Dergisi, 29*(4), 801-811.

Aruldoss, M., Lakshmi, T. M., & Venkatesan, V. P. (2013). A survey on multi criteria decision making methods and its applications. *American Journal of Information Systems, 1*(1), 31-43.

Arvis, J. F., Ojala, L., Wiederer, C., Shepherd, B., Raj, A., Dairabayeva, K., & Kiiski, T. (2018). *Connecting to Compete 2018: Trade Logistics in the Global Economy.* Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986 /29971. ,

Bugarčić, F. Ž., Skvarciany, V., & Stanišić, N. (2020). Logistics performance index in international trade: Case of Central and Eastern European and Western Balkans countries. *Business: Theory and Practice, 21*(2), 452-459.

Çakır, S. (2017). Measuring logistics performance of OECD countries via fuzzy linear regression. *Journal of Multi-Criteria Decision Analysis, 24*(3-4), 177-186.

Çalık, A., Erdebilli, B., & Özdemir, Y. S. (2023). Novel Integrated Hybrid Multi-Criteria Decision-Making Approach for Logistics Performance Index. *Transportation Research Record*, 03611981221113314.

Chen, C. H. (2021). A hybrid multi-criteria decision-making approach based on ANP-entropy TOPSIS for building materials supplier selection. *Entropy, 23*(12), 1597.

Dabachi, U. M., Mahmood, S., Ahmad, A. U., Ismail, S., Farouq, I. S., Jakada, A. H., & Kabiru, K. (2020). Energy consumption, energy price, energy intensity environmental degradation, and economic growth nexus in African OPEC countries: evidence from simultaneous equations models. *Journal of Environmental Treatment Techniques, 8*(1), 403-409.

Devlin, J., & Yee, P. (2005). Trade logistics in developing countries: The case of the Middle East and North Africa. *World Economy, 28*(3), 435-456.

Ecer, F., & Pamucar, D. (2022). A novel LOPCOW-DOBI multi-criteria sustainability performance assessment methodology: An application in developing country banking sector. *Omega, 112*, 102690.

Ftiti, Z., Guesmi, K., Teulon, F., & Chouachi, S. (2016). Relationship between crude oil prices and economic growth in selected OPEC countries. *Journal of Applied Business Research (JABR), 32*(1), 11-22.

Gök Kısa, A. C. & Ayçin, E. (2019). OECD Ülkelerinin Lojistik Performanslarının SWARA Tabanlı EDAS Yöntemi ile Değerlendirilmesi. Çankırı Karatekin Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 9 (1), 301-325.

Hajduk, S. (2021). Multi-criteria analysis in the decision-making approach for the linear ordering of urban transport based on TOPSIS technique. *Energies, 15*(1), 274.

Iorember, P. T., Gbaka, S., Jelilov, G., Alymkulova, N., & Usman, O. (2022). Impact of international trade, energy consumption and income on environmental degradation in Africa's OPEC member countries. *African Development Review, 34*(2), 175-187.

Isik, O., Aydin, Y., & Kosaroglu, S. M. (2020). The assessment of the logistics Performance Index of CEE Countries with the New Combination of SV and MABAC Methods. *LogForum, 16*(4), 549-559.

Kale, M. V., & Tilki, İ. (2024). Dünya Ülkelerinin Lojistik Performanslarının Çok Kriterli Karar Verme Yöntemi ile Değerlendirilmesi: 2023 Yılı Dünya Bankası Raporu ile Karşılaştırmalı Analizi. *Dumlupınar Üniversitesi Sosyal Bilimler Dergisi(80)*, 13-30.

Karaköy, Ç., & Ölmez, U. (2019). Balkan ülkelerinde lojistik performans endeksi değerlendirilmesi. *Uluslararası Sosyal, Beşeri ve İdari Bilimlerde Yenilikçi Yaklaşımlar Sempozyumu*, 178-180.

Keshavarz Ghorabaee, M., Amiri, M., Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2017). Stochastic EDAS method for multi-criteria decision-making with normally distributed data. *Journal of Intelligent & Fuzzy Systems, 33*(3), 1627-1638.

Keshavarz Ghorabaee, M., Zavadskas, E. K., Olfat, L., & Turskis, Z. (2015). Multi-criteria inventory classification using a new method of evaluation based on distance from average solution (EDAS). *Informatica, 26*(3), 435-451.

Martí, L., Martín, J. C., & Puertas, R. (2017). A DEA-logistics performance index. Journal of applied economics, 20(1), 169-192.

Mercangoz, B. A., Yildirim, B. F., & Yildirim, S. K. (2020). Time period based COPRAS-G method: application on the Logistics Performance Index. *LogForum, 16*(2).

Mešić, A., Miškić, S., Stević, Ž., & Mastilo, Z. (2022). Hybrid MCDM solutions for evaluation of the logistics performance index of the Western Balkan countries. *Economics, 10*(1), 13-34.

Miškić, S., Stević, Ž., Tadić, S., Alkhayyat, A., & Krstić, M. (2023). Assessment of the LPI of the EU countries using MCDM model with an emphasis on the importance of criteria. *World Review of Intermodal Transportation Research, 11*(3), 258-279.

Nazlioglu, S., Payne, J. E., Lee, J., Rayos-Velazquez, M., & Karul, C. (2021). Convergence in OPEC carbon dioxide emissions: Evidence from new panel stationarity tests with factors and breaks. *Economic Modelling, 100*, 105498.

Oğuz, S. (2023). Evaluation of Customs, Infrastructure and Logistics Services with Multi-Criteria Decision-Making Methods: A Comparative Analysis for the Top 10 Countries in the Logistics Performance Index. *Journal of Management Marketing and Logistics, 10*(4), 167-178.

Onifade, S. T., Alola, A. A., Erdoğan, S., & Acet, H. (2021). Environmental aspect of energy transition and urbanization in the OPEC member states. *Environmental Science and Pollution Research, 28*, 17158-17169.

Onoh, J. O., Nwachukwu, T., & Mbanasor, C. A. (2018). Economic growth in OPEC member states: Oil export earnings versus non-oil export earnings. *Journal of Developing Country Studies, ISSN*, 2225-0565.

OPEC. (2010). OPEC Long-Term Strategy Report. Vienna, Austria. Retrieved from: https://www.opec.org/opec_web/en/publications/346.htm (16.03.2023)

Ostic, D., Twum, A. K., Agyemang, A. O., & Boahen, H. A. (2022). Assessing the impact of oil and gas trading, foreign direct investment inflows, and economic growth on carbon emission for OPEC member countries. *Environmental Science and Pollution Research, 29*(28), 43089-43101.

Pehlivan, P., Aslan, A. I., David, S., & Bacalum, S. (2024). Determination of Logistics Performance of G20 Countries Using Quantitative Decision-Making Techniques. *Sustainability, 16*(5), 1852.

Rashidi, K., & Cullinane, K. (2019). Evaluating the sustainability of national logistics performance using Data Envelopment Analysis. *Transport Policy, 74*, 35-46.

Rezaei, J., van Roekel, W. S., & Tavasszy, L. (2018). Measuring the relative importance of the logistics performance index indicators using Best Worst Method. *Transport policy, 68*, 158-169.

Stojanović, I., & Puška, A. (2021). Logistics performances of gulf cooperation council's countries in global supply chains. *Decision Making: Applications in Management and Engineering, 4*(1), 174-193.

Taherdoost, H., & Madanchian, M. (2023). Multi-Criteria Decision Making (MCDM) Methods and Concepts. *Encyclopedia, 3*(1), 77-87.

Ulutaş, A., & Karaköy, Ç. (2019a). An analysis of the logistics performance index of EU countries with an integrated MCDM model. *Economics and Business Review, 5*(4), 49-69.

Ulutaş, A., & Karaköy, Ç. (2019b). G-20 Ülkelerinin lojistik performans endeksinin çok kriterli karar verme modeli ile ölçümü. *Cumhuriyet Üniversitesi İktisadi ve İdari Bilimler Dergisi, 20*(2), 71-84.

Ulutaş, A., & Karaköy, Ç. (2021). Evaluation of LPI values of transition economies countries with a grey MCDM model. In *Handbook of research on applied AI for international business and marketing applications* (pp. 499-511). IGI Global.

World Bank (WB). (2023). LPI 2018 Report. Retrieved from: https://lpi.worldbank.org/ (04.04.2023)

Yalçin, B., & Ayvaz, B. (2020). Çok Kriterli Karar Verme Teknikleri ile Lojistik Performansın Değerlendirilmesi. *İstanbul Ticaret Üniversitesi Fen Bilimleri Dergisi, 19*(38), 117-138.

Yildirim, B. F., & Adiguzel Mercangoz, B. (2020). Evaluating the logistics performance of OECD countries by using fuzzy AHP and ARAS-G. *Eurasian Economic Review, 10*(1), 27-45.

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ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

Türkiye'nin Lojistik Performansına Verdiği Önemin Değerlendirilmesi: Dernek Yayınları Üzerinde İçerik Analizi Uygulaması

Assessing The Importance Attributed by Turkey to Logistics Performance: Application Of Content Analysis on Association Publications

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ÖZ

Dünya Bankası tarafından yayımlanan Lojistik Performans İndeksi (LPI), ülkelerin gümrük işlemleri, altyapı kalitesi ve zamanında teslimat gibi lojistik performans ölçütlerini izlemelerine ve diğer ülkelerle kıyaslamalarına olanak tanır. Türkiye'nin bu indeksteki sıralamasının zaman içinde dalgalandığı gözlemlenmektedir. Bu araştırma, Türkiye'nin lojistik performansına verdiği önemi incelemeyi amaçlamaktadır. Bu amaçla, uluslararası kabul görmüş bir ölçüt olan LPI ve onun bileşenleri kullanılmıştır. Bir sivil toplum kuruluşu olan ÜTİKAD'ın periyodik olarak yayımladığı dergi sayıları üzerinde tümdengelimci içerik analizi gerçekleştirilmiştir. LPI'nın altı bileşeni için belirlenen kelime kökleri, bir önceki LPI'nın 2018'de yayımlanması nedeniyle seçilen 2018-2023 döneminde yayımlanan 24 dergi sayısında taranmıştır. Bulunan frekanslara göre bileşenlere verilen önem değerlendirilmiştir. Ayrıca, taranan dergi sayılarında yer alan bilgiler ışığında SOAR analizi gerçekleştirilmiştir. Gümrük işlemlerinin elektronik ortama aktarılması, altyapı geliştirmeleri, hizmet kalitesi vurgusu, zamanında teslimat önemi, uluslararası sevkiyat ve takip ve izlenebilirlik konularında öneriler sunulmuştur. Çalışma ayrıca LPI bileşenlerinin daha fazla vurgulanması gerektiği sonucuna varmıştır. Özellikle altyapı kriteri üzerinde daha fazla durulması gerektiği, literatürden ve içerik analizinden elde edilen bulgular arasındadır. Bu çalışma, dernek yayınları üzerinden içerik analizi uygulaması ile lojistik performansın önemini değerlendiren ilk çalışma niteliğindedir. Çalışmanın sonuçları, Türkiye'nin lojistik performansının iyileştirilmesi için stratejik yönlendirmeler sağlamaktadır.

ABSTRACT

The Logistics Performance Index (LPI) published by the World Bank allows countries to monitor and compare logistics performance criteria such as customs procedures, infrastructure quality, and on-time delivery. It has been observed that Turkey's ranking in this index has fluctuated over time. This study aims to examine the importance that Turkey places on its logistics performance. For this purpose, the internationally recognized measure LPI and its components have been used. Deductive content analysis was conducted on the periodic journal issues published by UTIKAD, a non-governmental organization. Root words representing the six components of the LPI were identified and analyzed in 24 journal issues published between 2018 and 2023, chosen because the previous LPI was released in 2018. The importance given to these components was evaluated based on the frequencies found. Additionally, a SOAR analysis was also performed based on the information in the analyzed journal issues. Recommendations were made on digitalization of customs procedures, infrastructure improvements, emphasis on service quality, the importance of on-time delivery, international shipment, and tracking and traceability. The study also concluded that LPI components should be emphasized more. Specifically, the infrastructure criterion needs more attention, according to findings from both the literature and content analysis. This study is the first to evaluate the importance of logistics performance through content analysis of association publications. The results provide strategic guidance for improving Turkey's logistics performance.

Anahtar Kelimeler: LPI, Tümdengelimci içerik Analizi, SOAR Analizi

Keywords: LPI, Deductive Content Analysis, SOAR Analysis

EXTENDED ABSTRACT

The increase in global trade volume has led to an increasing emphasis on activities such as transportation, storage, on-time delivery,

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and customs clearance of final products. Since 2007, the Logistics Performance Index (LPI) and its findings have become standard reference material in numerous studies and policy documents on international logistics. The LPI is a worldwide survey conducted by the World Bank. The increasing trend of this important indicator could be a sign that countries will become more attractive in international trade.

The irregular fluctuations in Turkey's score in the Logistics Performance Index have sparked the question of "What is Turkey's importance given to its logistics performance?". To answer this question, the sources were examined first. In the preliminary research phase, the frequency of LPI components in these sources was analyzed, assuming that this frequency could represent the importance of this topic in Turkey. The online sources reached during the preliminary research can be divided into three categories. These are public, private sector, and civil society organizations.

Public sources include reports on the improvement of customs services such as those found on the websites of the General Directorate of Customs, the Ministry of Transport and Infrastructure, and the Ministry of Development, as well as plans such as the 11th Development Plan. Public sources either cover only a certain part of the logistics field, not the entire logistics field, or they cover other fields, not just the logistics field.

Private sector sources include reports from companies with a large logistics sector share, especially those operating internationally. Since many of these reports belong to multinational companies, the data in the reports may not only be related to Turkey. Additionally, a significant portion of private sector businesses may not be able to influence customs procedures or infrastructure investments alone.

The last type of source comes from civil society organizations, also known as the third sector. These sources are publications by associations such as Tüsiad, Loder, and Utikad. In this study, 24 journal issues published periodically since 2018 by Utikad, a non-governmental organization operating in logistics, were used as sources.

After examining data from online sources, content analysis was chosen. In content analysis, category selection can be made with either an inductive or a deductive approach. In the inductive approach, categories are selected or determined before the collected literature is analyzed. In the deductive approach, categories are developed based on generalizations obtained from the collected literature (Goel, et al., 2019). The current study employs deductive content analysis.

During the word selection phase, efforts were made to identify terms representing the six categories of the Logistics Performance Index. The World Bank's survey and LPI resources were utilized as primary references for examining these categories (Çemberci et al., 2015; Gergin and Baki, 2015; Soliani, 2018). Following the categorization of survey questions, keywords from these questions were extracted for content analysis. To ensure reliability, two academics specializing in logistics reviewed the selected keywords.

The 'Full Reader Search' function of Adobe Acrobat Reader Software was employed to determine frequencies. However, each root word discovered was carefully assessed for relevance. If deemed pertinent and not an advertisement, it was considered for frequency analysis. Consequently, frequency numbers for sub-criteria in the journal issues were established, and frequency tables were organized by year.

The selected association journal releases four issues annually. Consequently, a total of 24 journal issues were reviewed spanning the years 2018 to 2023, each containing four issues. SOAR analysis was conducted on the six components of the LPI, taking into account the frequencies and articles within the examined journals.

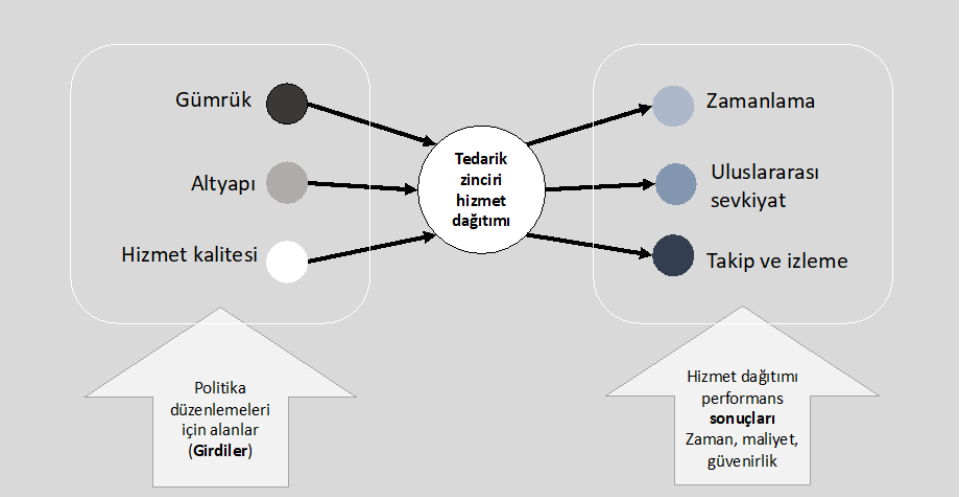
This study highlights the importance of improving Turkey's LPI to attract foreign investment and boost national income. Greater emphasis on all LPI components, particularly infrastructure (including air infrastructure), can significantly enhance Turkey's logistics performance. This research, focusing on publications from a single source, offers valuable insights. Future studies could benefit from including data from the private and public sectors, alongside in-depth interviews, to provide a more comprehensive picture of the importance placed on the LPI in Turkey. By addressing the identified areas for improvement and conducting more in-depth research, Turkey can solidify its position in the global logistics landscape.

1. Giriş

20. yüzyıldan itibaren yaşanan bilgi ve iletişim teknolojilerindeki gelişmeler ile ticarette serbest dolaşım ve rekabetin artması, uluslararası ticarette başarılı olmanın kurallarını büyük ölçüde değiştirmiştir. Küresel anlamda ticaret hacmi artışı, ürünlerin nakliyesi, depolanması, zamanında teslimi ve gümrükleme işlemleri gibi faaliyetlerin her geçen gün önem kazanmasına sebep olmuştur. Dünya Ticaret Örgütü verilerine göre, dünya küresel ticaretinin Gayri Safi Yurt İçi Hasıla'daki (GSYİH) payı 1971'de %25 iken 2021 yılında bu oran yaklaşık %57 civarındadır (DTÖ, 2023). 50 yıl içerisinde gerçekleşen değişim, uluslararası ticaretin artan rolünü vurgulayan önemli bir göstergedir.

2007 yılından bu yana Lojistik Performans İndeksi (LPI) ve bulguları, uluslararası lojistik ile ilgili çok sayıda çalışmada ve politika belgelerinde standart referans materyali haline gelmiştir. LPI, Dünya Bankası tarafından oluşturulan ve dünya çapında yapılan bir araştırmanın sonucudur. Son üç LPI raporu 2016, 2018 ve 2023 yıllarında yayımlanmıştır. 2016 yılındaki LPI'ya ilişkin anket 160 ülkeden, 1052 uluslararası taşımacılık yapan acenteden toplanan verileri içerir. Anketin birinci kısmında, ülkelerin komşu ülkedeki yaşanılan sıkıntıları ve kolaylıkları dikkate alınarak, anketteki ifadelerin çok zor/çok kolay niceleme sıfatları ile değerlendirilmesi istenmiştir. 2018'deki LPI'ya ilişkin anket yine 160 ülkenin verilerini içerir. Dünya Bankası'nın

2023 yılı LPI için yayımladığı rapora göre, son yapılan anket 2018 yılındaki LPI için yapılan anket ile büyük ölçüde aynıdır. Son LPI'da farklı olarak 139 ülkenin verileri mevcuttur. 2023 LPI raporuna göre, indekste yer almayan ülkeler genelde düşük gelirli ülkeler olmuştur (Arvis, vd., 2016; Arvis, vd., 2018; Arvis, vd., 2023). 2018 ve 2023 yıllarında yapılan anketlere göre veriler 6 başlık altında karşılaştırılmıştır. Bunlar: (1) "Gümrük", Gümrük ve sınır yönetimi işlemlerinin etkinliği, (2) "Altyapı", Ticaret ve ulaştırma altyapısının kalitesi, (3) "Uluslararası sevkiyat", Ulaştırmada rekabetçi fiyat düzenleme kolaylığı, (4) "Hizmet kalitesi", Lojistik hizmetlerinin yeterliliği ve kalitesi, (5) "Takip ve İzleme", Sevkiyatları takip etme ve izleme becerisi, (6) "Zamanlama", Teslimatların zamanında yapılabilme sıklığı.



Şekil 1. Lojistik Performans İndeksi Bileşenleri

Kaynak: Arvis, J. F. vd., Connecting to Compete (World Bank, 2023); www.lpi.worldbank.org

LPI raporuna göre, bu 6 unsur iki kategoride toplanmaktadır. (1)Politika düzenleyiciler: Gümrükler, altyapı ve hizmet kalitesi, (2) Hizmetin teslim performansı: Takip ve izleme, zamanlama ve uluslararası sevkiyat. LPI fonksiyonları, uluslararası seviyede ülkelerin lojistikteki zorluklarının tanımlanmasına yardımcı olurken, aynı zamanda ülkelere performanslarını geliştirmek için strateji ve fırsatlar sunmaktadır (Arvis vd., 2016). LPI, birçok ülke tarafından uluslararası gönderilerde ve lojistik stratejilerinde kilit bir performans göstergesi olarak benimsenmiştir. LPI, makro bir gösterge olarak, lojistik fonksiyonlarının ulusal ticaret ve ekonomik büyüme üzerindeki etkisini de ele alır (Martí vd., 2014; Ojala ve Çelebi 2015).

Bu önemli göstergenin giderek artan trend göstermesi, ülkelerin uluslararası ticarette daha cazip hale geleceklerinin göstergesi olabilir. Türkiye'nin aldığı LPI değerlerinin yıllar içerisinde dalgalanma göstermesi, Türkiye'nin bu indekse ne derece önem verdiği sorusunu akıllara getirmiştir. Bu çalışmada öncelikle Türkiye'nin LPI'daki yeri incelenmiştir. Sonraki bölüm LPI kullanılarak yapılmış farklı alanlardaki çalışmaları kapsayan literatür taraması bölümüdür. Takip eden bölümde araştırma metodolojisi verilmiştir. Araştırma metodolojisinde; yöntem, kaynak ve kelime seçimi, veri toplama ve analizi bölümleri yer almaktadır. Sonrasında bulgular, sonuç ve kaynaklar sırasıyla paylaşılmıştır.

1.1. Lojistik Performans İndeksinde Türkiye'nin Yeri

Türkiye, jeopolitik konumu ve genç insan kaynağı ile gelişmekte olan ekonomiler arasından ön plana çıkan bir potansiyele sahiptir. Tablo 1'de Türkiye'nin LPI'ya göre yıllar bazında sıralaması, genel puanı ve diğer alt bileşenlere göre puanlarının değişimi görülmektedir. Genel puan açısından, 2007 ile 2010 arasında gözlenen kısmi artışa kıyasla, 2010 ile 2012 arasında belirgin bir artış dikkat çekmektedir. Ancak, 2014 ile 2018 arasında önemli ölçüde düşüş yaşanmış ve neredeyse başlangıç noktasına dönülmüştür. 2023 yılında ise Türkiye'nin aldığı değer tekrar yükselmiş, fakat 2014 yılını yakalayamamıştır.

Tablo 1'e bakıldığında, Türkiye'nin en güçlü özelliği olarak zamanlama ön plana çıkmaktadır. Bu durum, Türkiye lojistik sektörü tarafından sevkiyatların varış yerine zamanında ulaşılabilirliğinin başarılı bir şekilde yerine getirildiğini gösterir. Gümrük bileşeni ise en düşük değer olan bileşendir. Türkiye'nin LPI'daki genel sıralaması 139 ülke arasından 2023 yılında 38'dir. Bu sıralama 2007 yılında 150 ülke arasından 34, 2010 yılında 155 ülke arasından 39, 2012 yılında 155 ülke arasından 27, 2014 yılında 160 ülke arasından 30, 2016 yılında 160 ülke arasından 34 ve 2018 yılında 160 ülke arasından 47 olarak gerçekleşmiştir.

Tablo 1. Türkiye'nin 2007-2023 Yılları Arasında LPI Performansı

	2007	2010	2012	2014	2016	2018	2023
Türkiye'nin Sıralamadaki Yeri	*34*	*39*	*27*	*30*	*34*	*47*	*38*
LPI puanı	*3,15*	*3,22*	*3,51*	*3,50*	*3,42*	*3,15*	*3,4*
Gümrük	*3,00*	*2,82*	*3,16*	*3,23*	*3,18*	*2,71*	*3*
Altyapı	*2,94*	*3,08*	*3,62*	*3,53*	*3,49*	*3,21*	*3,4*
Uluslararası Sevkiyat	*3,07*	*3,15*	*3,38*	*3,18*	*3,41*	*3,06*	*3,4*
Lojistik Kalite ve Yetkinlik	*3,29*	*3,23*	*3,52*	*3,64*	*3,31*	*3,05*	*3,5*
Takip ve İzleme	*3,27*	*3,09*	*3,54*	*3,77*	*3,39*	*3,23*	*3,5*
Zamanlama	*3,38*	*3,94*	*3,87*	*3,68*	*3,75*	*3,63*	*3,6*

Kaynak: Arvis, J. F. vd., *Connecting to Compete* (World Bank, 2023); www.lpi.worldbank.org

2. Literatür Taraması

Pek çok yazar Dünya Bankası'nın ilk kez 2007 yılında yayımladığı LPI'yı çalışmalarında kullanmışlardır. Bu bölümde çalışmalar ve bulguları yıllar bazında incelenmiştir. Ulaşılan ilk çalışmalardan biri olan Kara vd. (2009) çalışmasına göre, bir ülkenin küresel ticarette lojistik üs olabilmesi için coğrafi, fiziki ve kurumsal altyapısının güçlü olması gerekmektedir. Çalışmada, Türkiye'nin bir lojistik üs olabilmesi için kombine taşımacılık, bilgi teknolojileri, yasal, finansal ve yönetsel alanda iyi olması gerektiği vurgulanmaktadır. Roy (2011), Kanada'nın Lojistik Performans İndeksi ve iş verimliliği arasındaki ilişkiyi analiz etmiştir ve iş verimliliğinin lojistik performansı ve tedarik zinciri yönetimini olumlu etkilediğini belirtmiştir. Çekerol ve Kurnaz (2011), küresel krizin lojistik sektörü üzerindeki etkilerini incelemişlerdir ve kriz ortamında maliyetleri düşüren, bilgi altyapısını geliştiren ve kalifiye eleman ihtiyacını azaltan firmaların lojistik performanslarının artacağını öne sürmüşlerdir.

Lau (2011), Çin ve Japonya'daki üretim firmalarını kullanarak Yeşil Lojistik Performans İndeksi'ni tanımlamış ve ülkelerin performanslarını karşılaştırmıştır. Bayraktutan vd. (2012), Türkiye'nin LPI sıralamasını değerlendirerek, benzer bir çalışmayı Türkiye'nin illeri bazında gerçekleştirmişlerdir. Özellikle Kocaeli'nin lojistik performansını inceledikleri çalışmada, LPI'da olduğu gibi, veri toplamada anket kullanılmıştır. Bu çalışmanın sonuçlarına göre, Kocaeli'nin Türkiye genelinde lojistik performans açısından önemli bir konumda olduğu belirlenmiştir. Guner ve Coskun (2012), ekonomik ve sosyal kriterler ile LPI arasında pozitif yönlü bir korelasyon bulmuşlardır ve LPI'nın ülkelerin GSYİH'si, politik riskleri, demokrasi indeksi ve insani gelişmişlik düzeyi ile ilişkili olduğunu göstermişlerdir.

Burmaoğlu (2012), AB ülkelerinde inovasyon göstergelerinin lojistik performansına etkisini analiz etmiş ve insan kaynakları ve entelektüel varlıkların lojistik performansı üzerinde pozitif etkisi olduğunu ortaya koymuştur. Sofyalıoğlu ve Kartal (2013), Türkiye ile Avrasya Ekonomik Topluluğu ülkelerini lojistik performans indekslerine göre karşılaştırmış ve Türkiye'nin lojistik faaliyetlerindeki nispi üstünlüğüne dikkat çekmişlerdir. Ayrıca Türkiye'nin rekabet gücünü artırabilmesi için demiryolu, denizyolu, havayolu ve boru hatlarından oluşan lojistik altyapıya sahip olmasının gerekliliğini belirtmişlerdir. Martí vd. (2014), LPI'nın uluslararası ticaret üzerindeki etkisini incelemiş ve ticaret akışında LPI ve bileşenlerinin artan öneme sahip olduğunu göstermişlerdir. Jhawar vd. (2014), LPI üzerinde kalifiye işgücünün etkisini incelemişlerdir. Çalışmada altı ana kriter belirleyip LPI'nın gelişimini altyapı, devlet düzenlemeleri ve bilgi teknolojisi olmak üzere üç ana kategori altında toplamışlardır. Daha sonra bu kategorizasyonu tedarik zincirinde analiz için aracı olarak kullanmışlardır.

Çemberci vd. (2015), küresel rekabet indeksinin LPI'nın boyutları üzerindeki etkisini incelemişlerdir. Yu ve Hsiao (2016), veri zarflama analizi yöntemini kullanarak LPI verimliliğini değerlendirmişlerdir. Dünya Bankası'nın veri setini farklı bir metodoloji ile kullanarak her ülkenin gelir düzeyini göz önünde bulundurmuşlardır. Bu çalışmada, OECD ülkelerinden elde edilen büyük veri tabanı kaynak olarak kullanılmış ve oluşturulan yeni indekse meta-LPI adı verilmiştir. Jhawar ve Garg (2018), lojistik performanstaki gelişmenin doğrudan yabancı yatırım ve uzun süreli ekonomik büyüme açısından kritik öneme sahip olduğunu vurgulamışlardır. Yazarlara göre lojistik performansı yüksek olan ülkelere yabancı yatırım daha kolay gelmekte ve ülkenin geliri de buna bağlı olarak artmaktadır. Demirbilek vd. (2018), havayolu kargo taşımacılığının LPI'yı olumlu yönde etkilediği sonucuna varmışlardır. Rezaei vd. (2018), LPI göstergelerini incelemek için best-worst yöntemini kullanarak, altyapı bileşeninin diğer bileşenlere göre daha yüksek ağırlığa sahip olduğunu bulmuşlardır. Ulutaş ve Karaköy (2019), G20 ülkelerinin LPI değerlerini Çok Kriterli Karar Verme (ÇKKV) yöntemlerinden SD ve WASPAS ile kıyaslamışlardır. Çalışmalarının sonucunda gümrükleme süreçlerinin en yüksek ağırlığa sahip olduğunu ortaya koymuşlardır. Oğuz vd. (2019), Asya ülkelerinin LPI skorlarını, ÇKKV yöntemlerinden TOPSIS ile değerlendirmişler ve Dünya Bankası'nın sıralaması ile benzer sonuçlara ulaşmışlardır. Kılınç vd. (2019), Çin, Rusya ve Türkiye'yi LPI ve alt kriterleri üzerinden karşılaştıran bir çalışma yapmışlardır. Karşılaştırmada ülkelerin mevcut durumları, iş birliği alanları, tehdit ve fırsatlar tartışılmıştır. Orhan (2019), Türkiye'nin LPI değerini Avrupa Birliği ülkelerinin LPI değerleri ile karşılaştıran bir çalışma yapmıştır. Karşılaştırma yaparken entropi ağırlıklı EDAS yöntemini kullanmıştır. Yıldız vd. (2020), Türkiye'nin altyapı çalışmalarıyla dikkat çektiği bir kümeleme analizi çalışması yapmışlardır. Pınar ve Diken (2020), LPI kapsamında lojistik üslerin Türkiye ekonomisine katkısını AB ülkeleri ile karşılaştırmışlardır. Cansız ve Ünsalan (2020), yapay zeka teknikleri ve regresyon analizi ile ülkelerin LPI skorlarına etki eden parametreleri incelemişlerdir. Çalışmaya göre, LPI'yı en çok

etkileyen parametre havayolu yük taşımacılığıdır. Cengiz ve Çetinceli (2020), Bilgi ve İletişim Teknolojileri Gelişmişlik Endeksi ile LPI'yı BRICS ülkeleri bazında kıyaslamışlardır. Akandere (2021), Kuşak Yol ülkelerinin LPI ve çevresel performans endeksi değerlerini entropi-TOPSIS yöntemiyle incelemiştir.

Alkan ve Merdivenci (2021), LPI'yı bir alt boyut olarak değerlendirdikleri çalışmalarında, entropi ve EDAS yöntemlerini kullanarak, ülkeleri sürdürülebilir kalkınmaya göre sıralamışlardır. Magazzino vd. (2021), inovasyon, lojistik performans ve çevre kalitesi arasındaki ilişkiyi vurgulamışlardır. Larson (2021), lojistik performansın sürdürülebilirlik boyutlarıyla ilişkisini ele alan kapsayıcı bir çalışma yapmıştır. Manavgat ve Demirci (2021), LPI'yı etkileyen değişkenleri incelemiş ve hava taşımacılığının önemine dikkat çekmişlerdir. Altıntaş (2021a), LPI girdi kriterlerinin çıktı kriterlerine etkisini Yol Analizi ile incelemiştir. Çalışmaya göre altyapı kriteri çıktı kriterlerini en çok etkileyen girdi olarak bulunmuştur. Altıntaş (2021b) bir diğer çalışmasında ise yapay sinir ağları (YSA) ile LPI alt kriterleri arasındaki ilişkiyi analiz etmiştir. Yazarın önceki çalışmasına benzer şekilde, çıktı kriterlerini en çok altyapı kriterinin etkilediği bulunmuştur.

Kahveci (2022), Karadeniz Ekonomik İşbirliği ülkelerinin lojistik performanslarını incelemiş ve LPI'yı pozitif etkileyen faktörleri belirlemiştir. Keskingöz ve Matyar Tanır (2022), lojistik performansı ve sera gazı emisyonlarını konjonktürel olarak değerlendirmişlerdir. Çitil (2022), lojistik performansın ve yeşil lojistik performansın, hukukun üstünlüğü ve politik istikrar gibi yönetişim kalitesi değişkenlerinden etkilenip etkilenmediğini araştırmıştır. Çalışmanın sonucuna göre anlamlı bir etki bulunamamıştır. Pan vd. (2022), Kuşak Yol ülkeleri üzerinde yaptıkları çalışmada Moran indeksini kullanmıştır. Çalışmalarında Çin, Türkiye ve Hindistan'ın, orta-yüksek gelirli grupta olduğunu ve yüksek lojistik performans sergilediğini belirtmişlerdir. Göçer vd. (2022), LPI değeri yüksek olan ülkelerin gelişmekte olan ülkeler için bir model olabileceğinden yola çıkmışlardır. Çalışmalarında nitel ve nicel verileri kullanarak, ülkelerin lojistik politikalarını incelemişler ve önerilerde bulunmuşlardır. Altıntaş'ın (2022a) çalışmasında ülkeler kümeleme analizi ile sınıflandırılmış ve dört kümeye ayrılmıştır. Altıntaş'ın (2022b) bir diğer çalışmasında ise lojistik performansın etkinlik ve verimliliği entropi ve veri zarflama analizi ile değerlendirilmiştir. Türkoğlu ve Duran (2023), ülkeler arası LPI kıyaslaması yaparken gümrük yönetiminin en önemli değişken olduğunu bulmuşlardır. Kaya Samut (2023), LPI'yı arttıran uygulamaların sürdürülebilir kalkınma çerçevesinde ele alınması gerektiğini vurgulamış ve Türkiye için gümrükleme sürecinin kritik bir performans göstergesi olduğunu belirtmiştir. Yücel ve Göncü (2023), Avrupa Birliği geçiş ülkelerinin lojistik performanslarını LPI kriteri ile değerlendiren bir çalışma yapmışlardır. Çalışma sonucuna göre etkin ve verimli ülkeler bulunmuştur. Ayrıca etkin olmayan ülkelerin ideal etkinlik düzeyine çıkabilmeleri için, girdi değişkenlerindeki gerekli iyileştirme oranları hesaplanmıştır.

3. Araştırma Metodolojisi

Türkiye'nin lojistik performans indeksindeki aldığı değerlerin düzensiz bir şekilde değişmesi, "Türkiye'nin lojistik performansına verdiği önem nedir" sorusunu ortaya çıkarmıştır. Öncelikle, bu araştırma sorusuna cevap bulabilmek için sırasıyla nelerin yapılması gerektiği belirlenmiştir. Şekil 2'de araştırmanın çerçevesi gösterilmiştir.

Türkiye'nin lojistik performansına verdiği önemin değerlendirilmesinde, internetten erişilebilir olan kamu, özel sektör ve sivil toplum kuruluşlarının kaynakları incelenmiştir. Lojistik performansa verilen önemin anlaşılmasında, lojistik performansın değerlendirilmesinde uluslararası kabul görmüş bir ölçüt olan LPI kullanılmıştır. Yukarıda belirtilen kaynaklarda, LPI bileşenlerinin yer alma sıklığı incelenmiş ve bu frekansın, Türkiye'de bu konunun ne kadar önemsendiğinin bir göstergesi olarak değerlendirilebileceği varsayılmıştır. Araştırma metodolojisinde yöntem, kaynak ve kelime seçimi, veri toplama ve veri analizi aşağıdaki başlıklarda verilmiştir.

3.1. Yöntem

Yöntem seçimi yaparken, internet üzerindeki kaynaklardan konu ile ilgili elde edilebilecek veriler incelenmiş ve içerik analizinde karar kılınmıştır. İçerik analizi, röportajlar, gözlemler veya mevcut materyallerden elde edilen verileri analiz etmek ve bu analizlerden çıkarımlar yapmak için kullanılan, metin, resim veya ses gibi çeşitli içerikleri kapsayan bir yöntemdir (Darlington ve Scott, 2002; Kahraman ve Kazançoğlu, 2019).

İçerik analizinde veriler kavramsallaştırılır, organize edilir ve sistematik bir şekilde kodlanarak sayısallaştırılır. Kitleyi temsil eden bir örnek kitle seçiminin ardından kategori frekansları belirlenir. Sonrasında frekanslardan çıkarımda bulunma ve yorumlama aşamasına gelinir (Çavuşoğlu ve Denktaş Şakar, 2013). Ayrıca seçilen kaynaktaki veriler arasında anlamlı farklılık olup olmadığının araştırılması için bazı istatistiksel testler kullanılmıştır.

3.2. Kaynak ve Kelime Seçimi

Ön araştırma sırasında ulaşılan çevrimiçi kaynaklar, kamu, özel sektör ve sivil toplum kuruluşlarına ait olmak üzere üç kategoriye ayrılabilir. Bunlardan kamu kaynakları, Gümrükler Genel Müdürlüğü, Ulaştırma ve Altyapı Bakanlığı ve Kalkınma Bakanlığı vb. sitelerde bulunan gümrük hizmetlerinin iyileştirilmesi gibi raporlar ve 11. Kalkınma planı gibi planları içerir. Kamu kaynakları ya lojistik alanın tamamını değil, sadece belli bir bölümünü kapsamakta ya da sadece lojistik alanı değil, daha büyük bir bölümü kapsamaktadır. Özel sektör kaynakları, özellikle lojistik sektöründe büyük pay sahibi olan işletmelerin raporlarını içermektedir.

Şekil 2. Araştırma Çerçevesi

Bu raporların büyük bir kısmı çok uluslu şirketlere ait olduğundan, raporlardaki veriler sadece Türkiye ile ilgili olmayabilir. Ayrıca özel sektördeki işletmelerin büyük bir kısmı tek başına gümrük işlemleri ya da altyapı yatırımlarını etkileme kapasitesine sahip olmayacaktır. Sonuncu kaynak türü ise üçüncü sektör denilen sivil toplum kuruluşlarına ait kaynaklardır. Bu kaynaklar Tüsiad, Loder ve Utikad gibi derneklerin çıkarmış olduğu yayınlardır.

Bu çalışmada üçüncü sektör kuruluşlarından olan, lojistik alanda faaliyet gösteren Utikad'ın 2018 yılından bu yana periyodik olarak çıkardığı 24 dergi sayısı kaynak olarak kullanılmıştır (Utikad, 2023: https://www.utikad.org.tr/UTIKAD-Dergileri).

Kelime seçimi aşamasında lojistik performans indeksinin altı kategorisini ifade eden kelimeler belirlenmeye çalışılmıştır. Bu altı kategoriyi ifade eden kelimeleri bulabilmek için, bu kategorileri inceleyen en güvenilir araç olarak Dünya Bankası'nın LPI için yaptığı anketten ve kaynaklarından yararlanılmıştır (Çemberci vd., 2015; Gergin ve Baki, 2015; Soliani, 2018). Anketteki soruların hangilerinin hangi başlığa ait olduğu belirlendikten sonra, bu sorulardaki anahtar kelimeler çıkarılmış ve içerik analizinde bu kelimeler kullanılmıştır. İçerik analizinde kategori seçimi tümevarım veya tümdengelim yaklaşımıyla yapılabilir. Tümevarımcı yaklaşımında kategoriler, toplanan literatürden elde edilen genellemelere dayalı olarak geliştirilir; tümdengelimci yaklaşımında ise kategoriler, toplanan literatür analiz edilmeden önce seçilir veya belirlenir. Burada kullanılan yaklaşım tümdengelimci içerik analizidir (Deductive content analysis) (Goel, vd., 2019). İçerik analizinin güvenilirliğini sağlamak için anahtar kelimeler lojistik alanında çalışan iki akademisyen tarafından gözden geçirilmiştir. Kullanılan kelimeler Tablo 2'deki gibidir.

3.3. Veri Toplama ve Veri Analizi

Seçilen 24 dergi sayısı, ÜTİKAD sitesinden PDF formatında indirilmiştir. Bu dergi sayılarının sayfa sayıları 27 ile 80 sayfa arasında değişmektedir. Arama yapılırken tüm sayfalar taranmıştır. Kelime araştırma aşamasında Tablo 2'de verilen kelime kökleri ile arama yapılmıştır. Arama yapılırken Adobe programının "Tam Reader Araması" fonksiyonu kullanılmıştır. Ancak her bulunan kelime kökünün olduğu paragraf konu ile ilgisi bakımından incelenmiştir. Eğer ilgili bulunursa ve reklam değilse frekans olarak işlenmiştir. Böylece dergi sayılarında alt kriterlere ait frekans sayıları belirlenmiş ve yıllar bazında frekans tabloları oluşturulmuştur (Tablo 4 – Tablo 9).

ÜTİKAD dergisi yılda dört kez yayımlanmaktadır. Buna göre her yıl dört sayı olmak üzere 2018 ile 2023 yılları arasında toplam 24 dergi sayısı incelenmiştir. Bu 6 yılda konuya verilen önem derecesi arasında istatistiksel olarak anlamlı farklılık olup olmadığı kontrol edilmiştir. Buna göre dergi sayılarına ait frekanslar toplanmış ve her yıl bir grubu temsil edecek şekilde 6 grup oluşturulmuştur.

Analizin bu aşamasında SPSS ve Jamovi programları kullanılmıştır. Öncelikle Kolmogorov Smirnov testi ile verilerin normal dağılıp dağılmadığı kontrol edilmiştir. Buna göre 2018, 2019, 2020, 2021, 2022 ve 2023 verilerinin önem dereceleri %5'in altında çıkmıştır. Buna göre veriler normal dağılmamaktadır. Bunun üzerine Anova yerine non-parametrik testlere geçilmiştir ve Mann-Whitney U testi yapılmıştır.

Tablo 2. Araştırmada Kullanılan Kelimeler ve Kelimelerin Kökleri

KRİTERLER	ALT KRİTER	ARANAN KELİME KÖKÜ
Gümrük	Aranan kelime ya da kelime grupları, ait oldukları makale ve/veya bulundukların paragrafın Gümrük işlemleri ile ilgili olması durumunda sayılır.	
	Gümrük işlemlerinin şeffaflığı	Şeffaf
	Gümrük işlemlerinin hızlılığı	Hız
	Gümrük işlemlerinin kolaylığı	Kolay
	Gümrükte bilgi edinme	Bilgi
	Gümrükte elektronik işlemler	Elektronik, dijital, bilgi sistem, bilgi teknoloji
Altyapı	Aranan kelimenin bulunduğu cümlenin ve paragrafın anlamına göre 6 altyapıdan birinden bahsediyorsa o kategoriye sayılır.	
	Liman altyapısı	Altyapı
	Demiryolu altyapısı	Altyapı
	Karayolu altyapısı	Altyapı
	Havayolu altyapısı	Altyapı
	Bilişim altyapısı	Altyapı
	Depolama altyapısı	Altyapı
Hizmet kalitesi	Aranan kelimenin bulunduğu cümle lojistik sektörünün hizmet kalitesinden bahsediyorsa sayılır.	
	Lojistik hizmetlerin kalitesi	Kalite
Gönderilerin zamanında teslimi	Aranan kelimelerin bulunduğu cümleler zamanında teslimatla ilgili ise sayılır.	
	Süre uzunluğu	Süre
	Gecikme	Gecikme
	Bekleme	Bekleme
Uluslararası sevkiyat	Aranan kelime uluslararası sevkiyat ile ilgili ise sayılır.	
	Rekabetçilik	Rekabet
	Güvenlik	Güvenli
Gönderilerin takip ve izlenebilirliği	Aranan kelime lojistik sistemdeki ürün, hizmet ve bilginin takip ve izlenebilirliği ile ilgili ise sayılır.	
	Takip	Takip
	İzlenebilirlik	İzle
	RFID	RFID
	Barkod	Barkod
	Karekod	Karekod, QR

4. ARAŞTIRMA BULGULARI

Frekansların toplanması esnasında bazı dergi sayılarında, yıllarda ve kriterlerde diğerlerine göre anlamlı bir farklılık olabileceği düşünülmüş ve non-parametrik testler kullanılarak anlamlı farklılık araştırılmıştır. Öncelikle yıllara ait toplam frekanslar arasında

anlamlı farklılık olup olmadığı kontrol edilmiştir. En dikkat çeken farklılaşmanın son senede olduğu frekanslardan dikkati çektiğinden, Jamovi programında "2023 yılında LPI frekansları diğer yılların ortalamasına göre daha düşüktür" hipotezini test etmek için 2018-2022 yıllarının frekans değerlerinin ortalamaları alınmış ve 2023 yılı değerleri ile kıyaslanmıştır. Buna göre Jamovi programının verdiği sonuç tablosu aşağıdaki gibidir (Tablo 3).

Tablo 3. Kurulan Hipotezin Mann-Whitney U Testi Sonuçları

Independent Samples T-Test			
		Statistic	p
F	Mann-Whitney U	167	0.089
Note. H_a $\mu_1 > \mu_2$			

İstatistiksel olarak kurulan hipotezin reddedilmemesi için tablodaki p değerinin 0,05'ten küçük olması beklenir. Değerin 0,05'ten küçük olması, hipotezin %95 güvenle kabul edileceği şeklinde yorumlanır. Burada hipotez reddedilmiştir. Yani 2023 yılı dışındaki yılların ortalaması ile 2023 yılı frekansları arasında anlamlı bir farklılık yoktur. Ancak p değerinin 0,05'e yakın bir değeri olduğuna dikkat edilmelidir. İstatistiksel olarak anlamlı farklılık olmasa da 2023 yılının frekans değerlerine dikkatle bakılmalıdır.

Dergi sayılarından alınan frekanslar Tablo 4-Tablo 9'da verilmiştir.

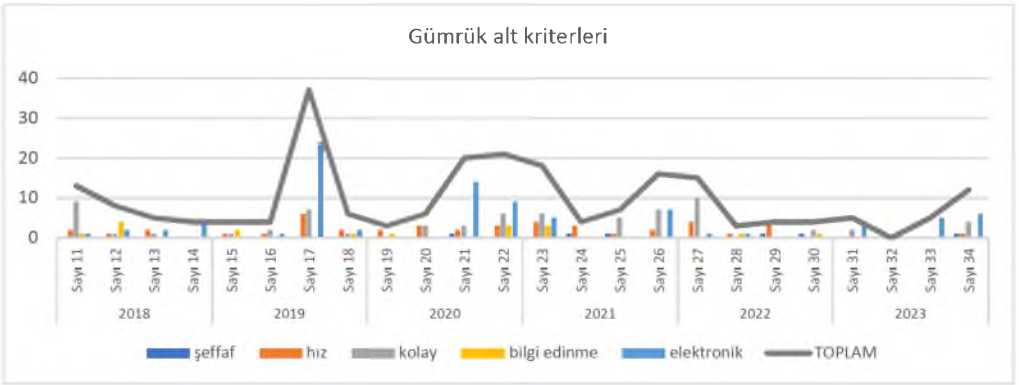
Gümrük kriterinde alt kriterler olarak gümrük işlemlerinin şeffaflığı, gümrük işlemlerinin hızı, gümrük işlemlerinin kolaylığı, gümrük işlemlerinde bilgi edinme ve gümrük işlemlerinin elektronik ortamda yürütülmesi belirlenmiştir. Tablo 4 alt kriterler bazında incelendiğinde, şeffaflık alt kriterinin üzerinde çok az durulduğu görülmüştür. Gümrük işlemlerinin elektronik ortamda yürütülmesi ise üzerinde en çok durulan kriter olmuştur. Bu alt kriteri gümrük işlemlerinin kolay yürütülmesi kriteri izlemiştir. Yıllar bazında gümrük kriterinin ne kadar ele alındığına bakıldığında, en çok 2019 yılında bu kriterden bahsedildiği görülmektedir.

Tablo 4. Gümrük Kriterine Ait Alt Kriterlerin Yıllar Bazında Frekansları

Gümrük kriteri	2018	2019	2020	2021	2022	2023
Gümrük işlemlerinin şeffaflığı	***0***	***0***	***1***	***2***	***2***	***1***
Gümrük işlemlerinin hızı	***5***	***10***	***10***	***10***	***8***	***1***
Gümrük işlemlerinin kolaylığı	***11***	***11***	***12***	***18***	***12***	***6***
Gümrük işlemlerinde bilgi edinme	***5***	***3***	***4***	***3***	***2***	***0***
Gümrük işlemlerinin elektronik ortamda yürütülmesi	***9***	***27***	***23***	***12***	***2***	***14***
Toplam	30	51	50	45	26	22

Şekil 3, gümrük alt kriterlerinin dergi sayılarına göre dağılımını göstermektedir. Şekil 3'te yer alan dağılıma bakıldığında, Sayı 17'de gümrük işlemlerinin elektronik ortamda yürütülmesine, diğer dergi sayılarına oranla daha fazla değinildiği görülmektedir. Ayrıca Sayı 17'de gümrük işlemlerinin hızlılığı ve kolaylığına da vurgu yapılmıştır.

Sayı 17'de özellikle Ticaret Bakanlığı'nın hayata geçirdiği Kağıtsız Gümrük Projesi'ne geniş yer verilmiştir. Gümrük işlemlerini kağıtsız hale getirmek ise dijitalleşme ile mümkündür. Projeye göre kağıt ile eklenen 154 belge dijital ortama taşınacaktır. Ayrıca Sayı 17'de Yetkilendirilmiş Yükümlü Statüsü konusuna değinilmiştir. Ticaret Bakanlığı bu uygulama ile gümrükte hızı ve güvenliği arttırmayı amaçlamıştır. Bu statüye sahip firmaların gümrükten geçişlerinin hızlanacağına vurgu yapılmıştır.



Şekil 3. Gümrük Alt Kriter Frekanslarının Dergi Sayılarına Göre Dağılımı

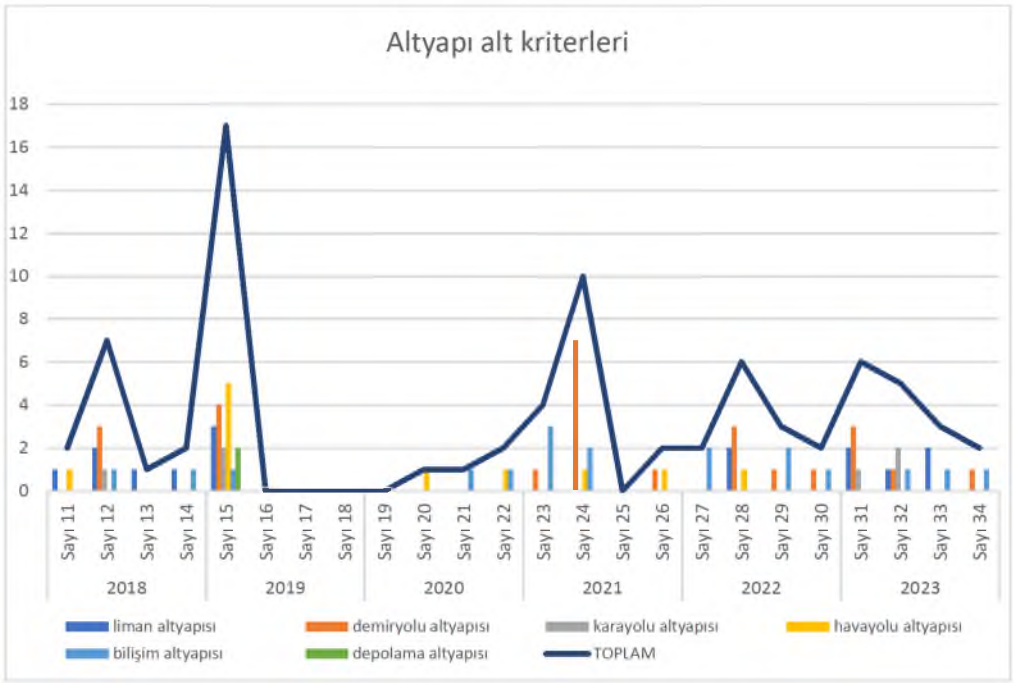
Sayı 21 ve Sayı 22, 2020 yılının ikinci yarısına ait dergi sayılarıdır. Burada pandemi sürecinin etkisiyle, işlemlerinin elektronik ortamda yapılmasının hastalık yayılım hızını azaltacağının bilinciyle, bu alt kriter üzerinde daha çok durulduğu görülmüştür. Ayrıca Sayı 27'de işlemlerin kolaylığı alt kriter frekansı diğer dergi sayılarına göre daha yüksek çıkmıştır. Burada Gümrük İşlemlerinin Kolaylaştırılması Yönetmeliği'ne vurgu yapılmış ve Yetkilendirilmiş Yükümlü Statüsü sahibi olan kişilere verilebilen İzinli gönderici uygulamasından bahsedilmiştir. Özellikle 2023 yılı dergi sayılarının gümrük kriteri alt kriterleri ile ilgili frekanslarının en düşük olması dikkat çekicidir.

Altyapı kriterinde alt kriterler olarak Liman, Demiryolu, Karayolu, Havayolu, Bilişim ve Depolama Altyapısı belirlenmiştir (Tablo 5). Altyapı kriteri ile ilgili aramalarda altyapı eksiklikleri üzerinde çok az durulduğu görülmüştür. En az değinilen altyapı kriteri depolama altyapısıdır. Bu alt kriterden sadece 2019 yılında bahsedilmiştir. En çok değinilen altyapı kriteri ise demiryolu altyapısıdır. 2020 yılında altyapı kriterlerinden diğer yıllara nazaran çok daha az bahsedilmiştir.

Tablo 5. Altyapı Kriterine Ait Alt Kriterlerin Yıllar Bazında Frekansları

Altyapı kriteri	2018	2019	2020	2021	2022	2023
Liman altyapısı	***5***	***3***	***0***	***0***	***2***	***5***
Demiryolu altyapısı	***3***	***4***	***0***	***9***	***5***	***5***
Karayolu altyapısı	***1***	***2***	***0***	***0***	***0***	***3***
Havayolu altyapısı	***1***	***5***	***2***	***2***	***1***	***0***
Bilişim altyapısı	***2***	***1***	***2***	***5***	***5***	***3***
Depolama altyapısı	***0***	***2***	***0***	***0***	***0***	***0***
Toplam	12	17	4	16	13	16

Şekil 4'te verilen grafik bulgularına göre 2019 yılının ilk sayısında tüm altyapı alt kriterleri üzerinde en az bir kez durulmuştur. 2019'da yayımlanan sondan üç sayıda ve 2020 yılının ilk sayısında altyapı kriteri ile ilgili hiçbir bilgi geçmemiştir. Özellikle liman, demiryolu ve karayolu gibi çok kullanılan modların altyapısı ile bilgilerin 2019'un ikinci sayısından 2020 yılı sonuna kadar hiç bahsedilmemiş olması çarpıcıdır. Tüm altyapı kriterlerinin toplam frekansının en yüksek olduğu dergi sayısı, Sayı 15'tir. Burada yeni İstanbul Havalimanındaki altyapı çalışmalarından bahsedilmiştir. Ayrıca çevreye duyarlılık, sürdürülebilirlik ve Endüstri 4.0 gibi konuların lojistiğe etkilerinden bahsedilerek, demiryolu altyapısı ve intermodal taşımacılık için bağlantı çalışmalarına vurgu yapılmıştır. Alt kriterler bazında en yüksek frekans ise Sayı 24'tedir. Bu dergi sayısında demiryolu altyapısı 7 kez geçmiştir. Burada Avrupa Komisyonu'nun 2021 yılını Avrupa Demiryolları Yılı ilan etmesinden bahsedilmiş ve Ulaştırma ve Altyapı Bakanı'ndan demiryolu yatırımlarına ilişkin bilgiler aktarılmıştır.



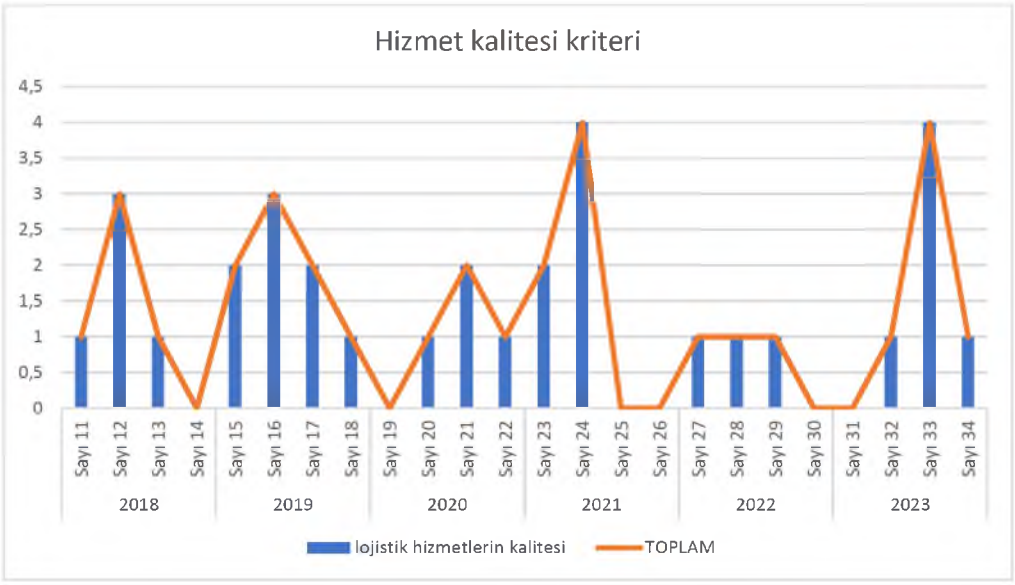
Şekil 4. Altyapı Alt Kriter Frekanslarının Dergi Sayılarına Göre Dağılımı

Hizmet kalitesi çok boyutlu bir kavramdır. Hizmet kalitesi literatüründe hizmetin bütün boyutlarındaki iyileştirme kalite artırımına işaret eder. Bu nedenle hizmet kalitesini ifade eden alt kriterleri seçmek diğer kriterlere göre daha zorlayıcıdır. Bu çalışmada alt kriterlerin seçiminde yararlanılan kaynaklar araştırma metodolojisinde belirtilmiştir. Bu kaynaklardan da destek alarak metinde hizmet kalitesini temsil edecek en iyi alt kriterin lojistik hizmetlerin kalitesi olduğuna karar verilmiştir (Tablo 6). Dolayısıyla hizmet kalitesi diğer kriterlerden farklı olarak tek alt kriterle temsil edilen tek kriterdir. Lojistik hizmetlerin kalitesi ile ilgili en yüksek frekans değeri 2019 yılındadır.

Tablo 6. Hizmet Kalitesi Kriterine Ait Alt Kriterin Yıllar Bazında Frekansı

Hizmet kalitesi kriteri	2018	2019	2020	2021	2022	2023
Lojistik hizmetlerin kalitesi	***5***	***8***	***4***	***6***	***3***	***6***
Toplam	5	8	4	6	3	6

Şekil 5'te Hizmet kalitesi alt kriterinin dergi sayılarına göre dağılımı verilmiştir. Dağılıma bakarak frekans değerinin inişli çıkışlı olduğu söylenebilir. Lojistik hizmetlerin kalitesi bazı dergi sayılarında hiç geçmemiştir. En yüksek frekans değeri ise 4 olarak gerçekleşmiştir. 2021 yılına ait Sayı 24 ve 2023 yılına ait Sayı 33 bu frekansa sahiptir. Bu dergi sayılarında bürokrasinin azaltılarak hizmet kalitesine katkı sağlanabileceğinden, Avrupa Birliği'nin kalite standartlarına uymaktan bahsedilmiş, ayrıca LPI'ya değinildiğinden hizmet kalitesi vurgulanmıştır.



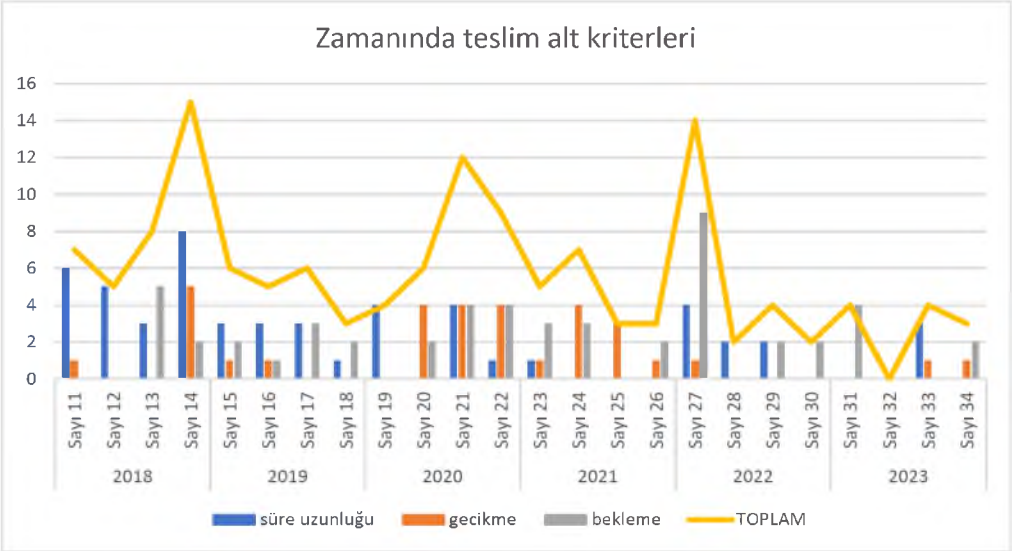
Şekil 5. Hizmet Kalitesi Alt Kriter Frekansının Dergi Sayılarına Göre Dağılımı

Zamanında teslim kriterinde alt kriterler süre uzunluğu, gecikme ve bekleme olarak belirlenmiştir (Tablo 7). Zamanında teslim kriterinde en yüksek frekans süre uzunluğundadır. Yıllar itibariyle bakıldığında yine en yüksek frekansın 2018 yılında süre uzunluğuna ait olduğu tablodan görülebilir. Zamanında teslim kriterinden en az 2023 yılında bahsedilmiştir.

Tablo 7. Zamanında Teslim Kriterine Ait Alt Kriterlerin Yıllar Bazında Frekansları

Zamanında teslim kriteri	2018	2019	2020	2021	2022	2023
Süre uzunluğu	***22***	***10***	***9***	***1***	***8***	***3***
Gecikme	***6***	***2***	***12***	***9***	***1***	***2***
Bekleme	***7***	***8***	***10***	***8***	***13***	***6***
Toplam	35	20	31	18	22	11

Şekil 6'da zamanında teslim alt kriterlerine ait frekansların dağılımı verilmiştir. Dergi içeriklerinde kelime kökü aratılırken, araçların gümrükte beklemeleri, teslimatların gecikmesi konularına bir dergi sayısı içinde, birden fazla makalede değinildiği görülmüştür. Dergi sayıları bazında frekanslara bakıldığında, her dergi sayısında mutlaka zamanında teslim ile ilgili en az bir alt kriterin geçtiği görülebilir. En yüksek toplam frekans ise Sayı 14'tedir. Burada başta Kapıkule olmak üzere sınır kapısındaki beklemeler, fiziki muayenelerin süreci uzatması ve bazı belgelerin elektronik onay sürecindeki aksamalara değinilmiştir.



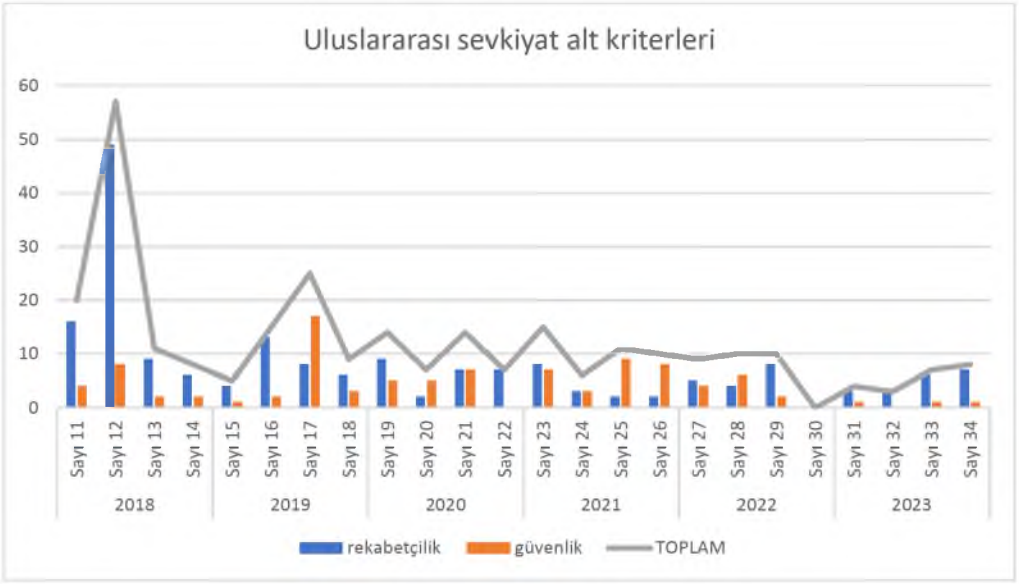
Şekil 6. Hizmet Kalitesi Alt Kriter Frekansının Dergi Sayılarına Göre Dağılımı

Uluslararası sevkiyat kriteri rekabetçilik ve güvenlik alt kriterleri ile incelenmiştir (Tablo 8). Bu alt kriterlerde kullanılan kelime köklerinin uluslararası sevkiyattan farklı konularda birçok yerde geçtiği görülmüştür. Tablo 2'de de belirtildiği gibi, sadece uluslararası sevkiyat ile ilgili kelimeler frekans olarak sayılmıştır. Özellikle "rekabet gücünü arttırma" dergi sayılarındaki birçok makalede geçmektedir. En yüksek frekans 80 ile rekabetçilik alt kriterinde ve 2018 yılındadır. Toplam frekans değerlerinin yıllar içinde azaldığından hareketle, uluslararası sevkiyata verilen önemin yıllar itibariyle azaldığı söylenebilir. Ancak bu iddia yıllar itibariyle anlamlı farklılık arayan bir hipotez olarak test edildiğinde, istatistiksel olarak anlamlı bir farklılık bulunamamıştır. Ancak veri sayısının azlığı da test gerçekleştirmede negatif bir etken olmuştur.

0

Tablo 8. Uluslararası Sevkiyat Kriterine Ait Alt Kriterlerin Yıllar Bazında Frekansları

Uluslararası sevkiyat kriteri	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Rekabetçilik	***80***	***31***	***25***	***15***	***17***	***19***
Güvenlik	***16***	***23***	***17***	***27***	***12***	***3***
Toplam	96	54	42	42	29	22



Şekil 7. Uluslararası Sevkiyat Alt Kriter Frekanslarının Dergi Sayılarına Göre Dağılımı

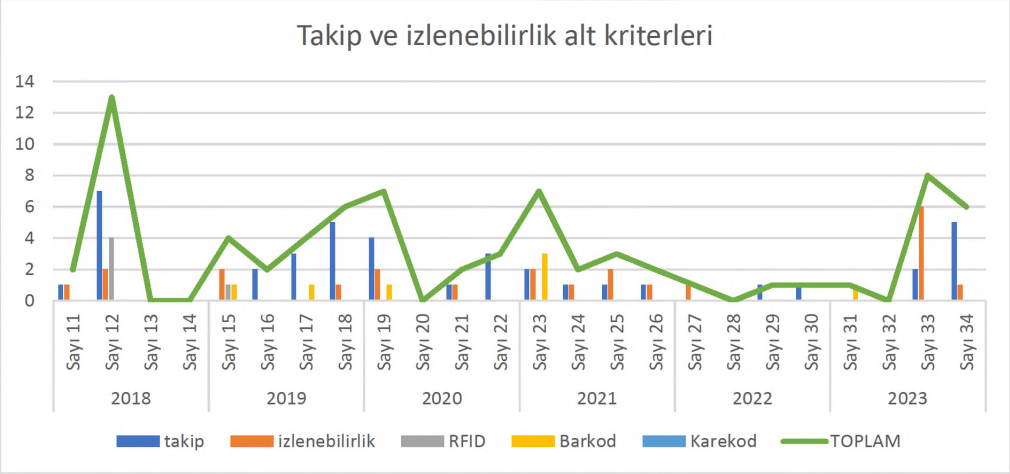
Şekil 7, Uluslararası sevkiyat kriterine ait alt kriterlerin frekans dağılımlarını göstermektedir. En yüksek frekans Sayı 12'dedir. Sayı 12'de serbest piyasa ekonomisinin işlemesi gerektiğinden ve getirilen ücret uygulamalarının rekabet ortamına zarar verdiğinden bahsedilmiştir. Sayı 17 ise güvenlik alt kriterinin frekansının en yüksek olduğu dergi sayısıdır. Bu sayıda dijitalleşmenin ve hızın rekabet gücünü arttırma etkisinden bahsedilmiştir.

Takip ve İzlenebilirlik kriterinde alt kriterler takip, izlenebilirlik, RFID, Barkod ve Karekod olarak belirlenmiştir (Tablo 9). Buradaki ilk iki alt kriter Dünya Bankası'nın anketinden yola çıkılarak eklenmiştir. Son üç kriter ise bu kriteri sağlarken kullanılabilecek teknolojiler ile ilgilidir ve araştırmacı tarafından eklenmiştir. En yüksek frekans takip alt kriterindedir. Karekod alt kriterine ise hiçbir yıl değinilmemiştir. 2022 yılı, takip ve izlenebilirlik kriteri frekanslarının en düşük olduğu yıldır.

Tablo 9. Takip ve İzlenebilirlik Kriterine Ait Alt Kriterlerin Yıllar Bazında Frekansları

Takip ve izlenebilirlik kriteri	2018	2019	2020	2021	2022	2023
Takip	***8***	***10***	***8***	***5***	***2***	***7***
İzlenebilirlik	***3***	***3***	***3***	***6***	***1***	***7***
RFID	***4***	***1***	***0***	***0***	***0***	***0***
Barkod	***0***	***2***	***1***	***3***	***0***	***1***
Karekod	***0***	***0***	***0***	***0***	***0***	***0***
Toplam	15	16	12	14	3	15

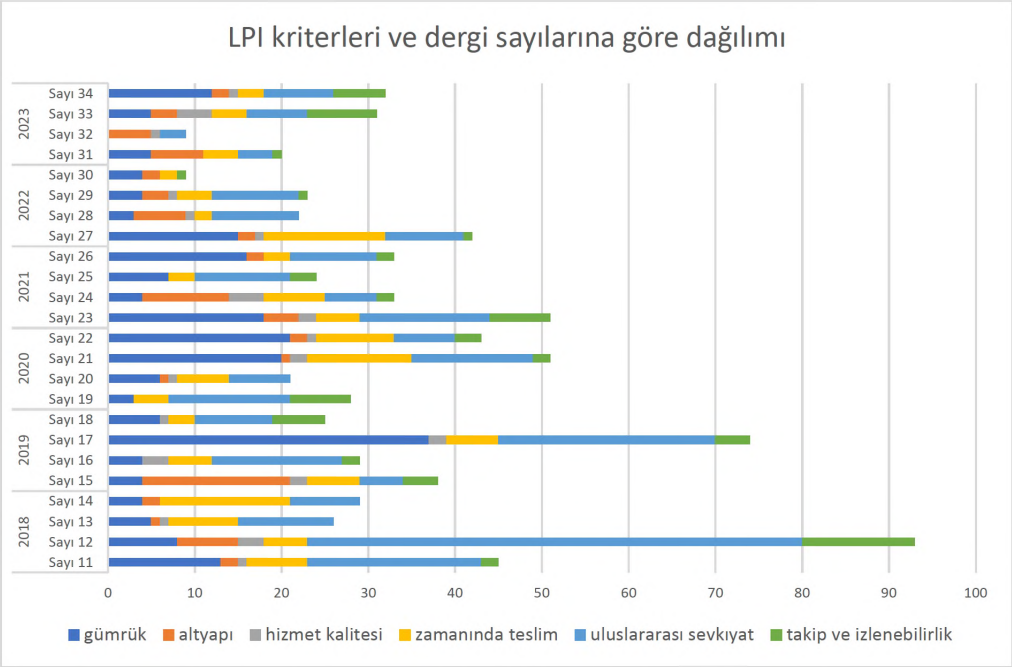
Şekil 8, takip ve izlenebilirlik kriterine ait alt kriterlerin frekans dağılımını göstermektedir. Grafikten de görüldüğü gibi karekod teknolojisinden hiç bahsedilmemiştir. Barkod alt kriterinden çok az bahsedilmiştir. RFID teknolojisinden son dönem dergi sayılarında hiç bahsedilmemiştir. Takip alt kriteri aralarında en yüksek frekansa sahip kriterdir. En yüksek frekansa sahip sayı, Sayı 12'dir. Bu sayıyı ise Sayı 33 takip etmektedir. Sayı 12'de Blockchain teknolojisi sayesinde yük hareketlerinin takip edilebilirliğinin sağlanabildiğine vurgu yapılmıştır. Ayrıca nesnelerin interneti ve RFID etiketlerle de takip ve izlenebilirliğin arttığı konusuna değinilmiştir. Sayı 33'te yine Blockchain teknolojisi ile izlenebilirliğin artacağından bahsedilmiştir. Ayrıca İhracatta Çekilemeyen yükler ile ilgili olarak konteyner izlenebilirliğinin sağlanması gerekliliğinden bahsedilmiştir.



Şekil 8. Takip ve İzlenebilirlik Alt Kriter Frekanslarının Dergi Sayılarına Göre Dağılımı

Şekil 9'da ana kriterlerin dergi sayılarına göre dağılımı verilmiştir. En yüksek frekanslı dergi sayıları sırasıyla Sayı 12, Sayı 17 ve Sayı 21-23'tür. Dergi sayıları sırasıyla 2018, 2019 ve 2020-2021 yıllarına aittir. Yıllar itibariyle en yüksek denilen frekansların giderek azaldığı grafikten gözlemlenebilir. En düşük frekansların son yıllarda yayımlanan Sayı 30 ve Sayı 32'de olduğu görülmektedir. Yine bu sayıların da her biri farklı bir yıla aittir. Yani her yılda yine düşük frekans sayısına sahip sayı da vardır. Bu durum araştırma bulgularının başında verilen hipotez testi sonucunu da destekler niteliktedir. Yani dergi yayınlarında herhangi bir yılda lojistik performansı üzerinde daha çok ya da daha az durulduğu söylenemez.

İncelenen dergi sayılarındaki frekanslar ve makaleler göz önünde bulundurularak, LPI'nın 6 bileşeni için SOAR analizi çalışması yapılmıştır. Tablo 10'da SOAR analizi paylaşılmıştır.



Şekil 9. Tüm Kriter Frekanslarının Dergi Sayılarına Göre Dağılımı

Tablo 10. LPI Bileşenlerine İlişkin Türkiye'nin SOAR Analizi

S (STRENGTHS) (GÜÇLÜ YÖNLER)	*Gümrük:* İşlemlerin elektronik ortama taşınması ile sürecin hızlanması *Altyapı:* Demiryolu altyapısının gelişmiş olması *Hizmet Kalitesi:* Hizmet kalitesinde ilerleme kaydedilmesi *Zamanında Teslim:* Beklemelerin azaltılması ile ilgili yapılan yetkilendirmeler ve elektronik işlemlerin geliştirilmesi *Uluslararası Sevkiyat:* Rekabet gücüne vurgu yapılması *Takip ve İzlenebilirlik:* Takip ve izlenebilirlikte ilerleme kaydedilmesi
O (OPPORTUNITIES) (FIRSATLAR)	*Gümrük:* Anlaşmalar ve özel statüler ile işlemlerin kolaylaşması *Altyapı:* İntermodal taşımacılık olanaklarının geliştirilmesi *Hizmet Kalitesi:* Farklı ölçüm teknikleriyle mevcut durumun tespit edilmesi *Zamanında Teslim:* Farkında olma ve sorunu vurgulamanın iyileştirme çalışmalarına zemin hazırlaması *Uluslararası Sevkiyat:* Dijitalleşmenin hızlanarak rekabetçiliğe katkı sağlaması *Takip ve İzlenebilirlik: B*lockchain teknolojisi ile takip ve izlenebilirliğin artırılması
A (ASPIRATIONS) (HEDEFLER)	*Gümrük:* Dijitalleşme hızına, şeffaflık ve bilgi edinmeye verilen önemin artırılması *Altyapı:* Altyapı çalışmalarının tamamlanması *Hizmet Kalitesi:* Hizmet kalitesinin yükseltilmesi ve müşteri memnuniyetinin artırılması *Zamanında Teslim:* Sınır kapılarındaki beklemelerin azaltılması ve fiziki muayene sürecinin optimize edilmesi *Uluslararası Sevkiyat:* Güvenlik alt kriterine verilen önemin artırılması *Takip ve İzlenebilirlik: İ*zlenebilirlik süreçlerinin geliştirilmesi ve güvenilirliğin artırılması
R (RESULTS) (SONUÇLAR)	*Gümrük:* İşlemlerin kolaylaştırılması ve hızlandırılması ile işlemlerin daha verimli hale gelmesi ve ticaretin kolaylaşması *Altyapı:* Daha etkin ve verimli lojistik ağı ile maliyetlerin azaltılması ve sürecin iyileştirilmesi *Hizmet Kalitesi:* Müşteri memnuniyetinin artırılması *Zamanında Teslim:* Teslimatların planlanan zamanda gerçekleştirilmesi *Uluslararası Sevkiyat:* Uluslararası ticaretin artırılması *Takip ve İzlenebilirlik:* Şeffaf ve güvenilir tedarik zincirinin oluşturulması

5. Sonuç ve Öneriler

Dünya Bankası tarafından sunulan LPI, gümrük, altyapı, hizmet kalitesi, uluslararası sevkiyat, zamanında teslim ve takip ve izlenebilirlik konularında, kamu, özel sektör ve sivil toplum kuruluşlarına bilgi sağlar. 2007 yılından beri 7 kez sunulan bu indeks

sayesinde ülkelerin hem geçmiş performanslarına bakarak hem de diğer ülkelerin performanslarına göre kıyaslayarak durumları görülebilir.

Bu çalışmada LPI'ya verilen önem düzeyi sivil toplum kuruluşları açısından incelenmiştir. Örneklem olarak seçilen dernek olan ÜTİKAD'ın 2018-2023 yılları arasındaki 24 dergi sayısı, tümdengelimci içerik analizi metoduyla incelenmiştir. Bu metotta LPI'yı oluşturan 6 kriterin alt kriterlerini temsil eden kelime kökleri yayınlar içinde aranmıştır. Bu alt kriterlerin frekans sayısı ile önem derecesi arasında doğrusal ilişki olduğu varsayılmıştır. Bu kapsamda kriterlere ilişkin sonuç ve öneriler aşağıdaki gibi sıralanabilir:

- Gümrük, malın ülkeye girişinde ve ülkeden çıkışında gerekli kontrollerin ve vergi tahsilatının yapıldığı yerdir. Gümrükler için ülkelerin ekonomik sınırlarıdır denebilir. Gümrük kriterinin toplam frekans değerlerine bakıldığında, 2019 yılından itibaren giderek azaldığı görülmektedir. Ayrıca gümrük işlemlerinin şeffaflığı üzerinde çok az durulması önemli bir bulgudur. Pandeminin etkisiyle gümrük işlemlerinin elektronik ortama aktarılması süreci hız kazanmıştır. Bu nedenle dergide gümrük işlemlerinin elektronik ortamda yürütülmesi alt kriteri en çok üzerinde durulan ve bu konudaki projelerde yer verilen alt kriter olmuştur. Pandemi geçse bile işlemlerin elektronik ortama aktarılması iş süreçlerini hızlandıracağından, bu sürece devam edilmelidir. Türkoğlu ve Duran'ın (2023) çalışmasına göre Gümrük LPI'daki en önemli kriterdir. Kaya Samut'a (2023) göre ise en düşük performansa sahip kriterdir. SOAR analizinde de belirtildiği gibi işlemlerin kolaylaştırılması ve sürecin hızlandırılmasına devam edilmelidir.

- Türkiye'nin LPI'daki altyapı kriterinde 2012 yılından bu yana yaşanan düşüş 2023 yılında tekrar artışa geçmiştir (Bknz: Tablo 1). Bir ülkenin lojistik performansını artırabilmesi için, altyapı geliştirmeleri hız kesmeden devam etmelidir. Dergi sayılarında altyapı ile ilgili frekansların toplamına bakıldığında, en çok demiryolu altyapısından bahsedildiği görülmüştür. Altyapı çalışmalarından bahsederken intermodal taşımacılığa ve bağlantı çalışmalarına vurgu yapılmıştır. Lojistik akışın kesintisiz ve çevresel kaygıyla sürdürülebilmesi için bunlar kuşkusuz önemlidir. Ancak bir yıl süresince altyapı kriterindeki alt kriterlerin herhangi birinden hiç bahsedilmemesi önemli bir bulgudur (bknz: Şekil4 (2019'un ikinci çeyreğinden 2020'nin ilk çeyreğine kadar)). Teknolojinin giderek geliştiği süreçte bilişim altyapısına yapılan vurgunun giderek artması beklenmektedir. Literatür taramasında incelenen çalışmaların önemli bir bölümü altyapı kriterini en önemli kriter olarak görmektedir (bknz: Yıldız vd, 2020; Sofyalıoğlu ve Kartal, 2013; Rezaei vd, 2018, Altıntaş 2021a, Altıntaş 2021b). Yine önemli bir kısım özellikle havayolu taşımacılığının lojistik performansını arttıran en önemli kriterlerden olduğu sonucuna ulaşmıştır (bknz: Manavgat ve Demirci, 2021; Demirbilek vd, 2018; Cansız ve Ünsalan, 2020). Altyapı ile ilgili konuların, özellikle de havayolu altyapısının daha fazla gündeme gelmesi gereklidir.

- Hizmet kalitesi diğer kriterlerden farklı olarak, sadece lojistik sektörüne özgü değil, bütün sektörlerde bulunan bir kriterdir. Hizmet kalitesini ölçmek ve geliştirmek için hemen her işletme çaba göstermektedir. Aksi halde müşterilerini rakiplere kaybetme riski ile karşı karşıya kalırlar. Hizmet kalitesi algılanan ve beklenen hizmet kalitesi arasındaki farkla ölçülür. Eğer algılanan hizmet kalitesi beklenenin üstündeyse müşteri memnuniyetinden; eğer algılanan hizmet kalitesi beklenenin altındaysa müşteri memnuniyetsizliğinden bahsedilir. Türkiye'nin hizmet kalitesi kriteri 2007 yılından bu yana inişli çıkışlıdır. 2023 yılı indeksine göre ise hizmet kalitesi 2018 yılındaki indekse göre yine artışa geçmiştir. Tek alt kriterle ölçülen tek kriter olan lojistik hizmetlerin kalitesinde lojistikle ilgili görülen her "kalite" kelimesi frekans olarak işlenmesine rağmen, frekans sayısının maksimum dört olması dikkat çekicidir. Lojistik sektörde hizmet kalitesi unsuru üzerinde daha çok durmanın gerekliliği görülmektedir.

- Zamanında teslim kriteri Türkiye'nin 2018'de 3,63 ile en yüksek puan aldığı kriterdir. Dolayısıyla diğer kriterlere göre en güçlü kriter olarak görülürken, 2023 yılındaki indekste düşüş yaşanan tek kriter olması dikkat çekicidir. Süre uzunluğu, gecikme, bekleme alt kriterleri, özellikle pandemi sürecinde aksamalar yaşanması nedeniyle dünya genelinde bir sorun haline gelmiştir. Dergi sayılarında da gecikme ve bekleme alt kriterlerine değinilmiş ve özellikle sınır kapılarından geçiş ile ilgili yeni uygulamalara değinilmiştir. Bu sayede teslimattaki gecikmelerin azaltılabileceği, sınır kapılarındaki beklemelerin kısalması ile sürenin de kısalacağı ile ilgili görüşlere yer verilmiştir. Dünya Bankası'nın 2023 LPI raporunda ise özellikle limanlardaki bekleme süreleri üzerine vurgu yapılmıştır. Yine rapora göre birçok ülkenin limanda bekleme süresi 3-9 gün arasında iken, Türkiye'de limanda bekleme süresi 8-16 gün arasıdır. Özellikle limanlardaki bekleme süreleri üzerinde durulması gerekir.

- Uluslararası sevkiyat kriteri 2018'de en düşük değerindeyken, 2023'te neredeyse en yüksek seviyeye çıkmıştır. Uluslararası sevkiyatın alt kriterleri olan rekabetçilik ve güvenliğin frekans olarak diğer alt kriterlerden yüksek olduğu bulgulardan görülebilir. Dolayısıyla kullanılan metoda göre dernek yayınlarında bu kritere verilen önem diğerlerinden fazladır denilebilir. Ancak yıllar itibariyle frekanslarda düşüş, yani bu konulardan daha az bahsetme görülmektedir. Güvenlik alt kriteri ise rekabetçilik alt kriterine göre daha az ele alınmıştır. Daha çok rekabet gücünü arttırma üzerine vurgu yapılmıştır.

- Takip ve izlenebilirlik kriterinde, lojistik süreç boyunca eşyanın takibi ve izlenebilirliğinin yanı sıra eşya ile ilgili işlemlerin takip ve izlenebilirliği de dikkate alınmıştır. Takip ve izlenebilirlik alt kriterlerinin frekansları düşüktür. Özellikle 2022 yılında toplam frekanslar diğer yıllara göre en düşük seviyededir. Takip ve izlenebilirlikte kullanılabilecek teknolojiler olan RFID, barkod ve karekoda çok az değinilmiştir. Ancak Blockchain teknolojisine vurgu yapılması önemlidir.

Yıllar bazında dernek yayınlarının lojistik performans indeksine gösterdiği önem derecesinin birbirinden farklı olup olmadığının testi de gerçekleştirilmiştir. Test sonuçlarına göre 2018, 2019, 2020, 2021, 2022 ve 2023 yıllarına ait yayınlarda bulunan frekans sayıları arasında anlamlı bir farklılık bulunamamıştır. Ülkelerin lojistik performanslarını arttırmaları önemlidir. Literatürde değinilen Jhawar ve Garg'ın (2018) çalışmalarında da belirtildiği gibi lojistik performansı yüksek olan ülkelere doğrudan ya-

bancı yatırım daha kolay gelmekte ve ülkelerin milli geliri artmaktadır. Etkin olmayan lojistik politikaları iş yapmanın maliyetini arttıracak ve uluslararası ve yerel entegrasyonu azaltacaktır. Bir problemin çözümünden önce doğal olarak problemin kendisinin fark edilmesi gerekir. LPI bileşenlerinin daha fazla vurgulanması, sektördeki tüm tarafların dikkatini çekecek ve böylece performans geliştirmesinin yolu açılacaktır. Bu nedenle LPI'nın daha çok dikkate alınması gerektiği düşünülmektedir. Çalışmada lojistik performans indeksine verilen önemin sadece sivil toplum kuruluşları açısından değerlendirilmesi araştırmanın kısıtını oluşturmaktadır. Gelecek çalışmalarda özel sektör ve kamu tarafından da incelemeler yapılabilir. Yöntem olarak ÜTİKAD dergi sayılarının içerik analizi yapılmıştır. İçerik analizine derinlemesine görüşme gibi farklı veri toplama metotları eklenerek güvenilirlik arttırılabilir. Çalışmada bu kısıtlar dahilinde literatüre yol gösterici olmak hedeflenmiştir. İlerideki çalışmalarda bu noktalar dikkate alınarak bir araştırma yapılması, Türkiye'nin LPI'ya verdiği önemin ölçülmesi açısından daha kapsayıcı olacaktır.

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KAYNAKLAR / REFERENCES

Akandere, G. (2021). Kuşak Yol Ülkelerinin Lojistik ve Çevresel Performansının Analizi. *Gaziantep University Journal of Social Sciences*, 20(4), 1893-1915. https://doi.org/10.21547/jss.927509

Alkan, G. ve Merdivenci, F. (2021). Sürdürülebilir Kalkınma Açısından Lojistik Performans Endeksine Göre Seçilen Ülkelerin Entropi Temeline Dayalı Edas Yöntemi ile Değerlendirmesi. *Gümüşhane Üniversitesi Sosyal Bilimler Enstitüsü Elektronik Dergisi*, 12(2), 627-41. https://doi.org/10.36362/gumus.900118

Altıntaş, F. F. (2021a). Lojistik Performans Endeksi Kapsamında Lojistik Girdi Bileşenlerinin Lojistik Çıktı Bileşenlerine Olan Etkisi: Yol Analizi ile Bir Uygulama. *Journal of Emerging Economies and Policy,* 6(2), 128-138.

Altıntaş, F. F. (2021b). Estimation of Relations Between Logistics Performance Components by Artificial Neural Networks. *Euroasia Journal of Social Sciences & Humanities*, 8(3), 101-112. https://doi.org/10.38064/eurssh.212

Altıntaş, F. F. (2022a). Lojistik Performans Endeksi Kapsamında Ülkelerin K-Ortalamalar Kümeleme Analizi Ile İncelenmesi. *Journal of Yasar University*, 17(68), 878-891. https://doi.org/10.19168/jyasar.955205

Altıntaş, F. F. (2022b). G7 Ülkelerinin Lojistik Etkinlik ve Verimlilik Performanslarının Değerlendirilmesi. *Verimlilik Dergisi*, 1, 78-93. https://doi.org/10.51551/verimlilik.734258

Arvis, J. F., Saslavsky, D., Ojala, L., Shepherd, B., Busch, C., Raj, A., ve Naula, T. (2016). Connecting to compete 2016. *Trade Logistics in The Global Economy—The Logistics Performance Index and Its Indicators*. Washington, DC: World Bank.

Arvis, J. F., Ojala, L., Wiederer C., Shepherd, B., Raj, A., Dairabayeva K., ve Kiiski, T. (2018). Connecting to Compete 2018. *Trade Logistics in the Global Economy - The Logistics Performance Index and Its Indicators*. Washington, DC: World Bank.

Arvis, J. F., Ojala, L., Shepherd, B., Ulybina W. ve Wiederer C. (2023). Connecting to Compete 2023. *Trade Logistics in an Uncertain Global Economy - The Logistics Performance Index and Its Indicators Developing Trade Consultants.* Washington, DC: World Bank.

Bayraktutan, Y., Tüylüoğlu, Ş. Ve Özbilgin, M. (2012). Lojistik Sektöründe Yoğunlaşma Analizi ve Lojistik Gelişmişlik Endeksi: Kocaeli Örneği. *Uluslararası Alanya İşletme Fakültesi Dergisi*, 4(3), 61-71.

Burmaoğlu, S. (2012). Ulusal İnovasyon Göstergeleri ile Ulusal Lojistik Performansı Arasındaki İlişki: AB Ülkeleri Üzerine Bir Araştırma. *Ege Akademik Bakış*, 12(2), 193-208. https://doi.org/10.21121/eab.2012219534

Cansız, Ö. F. ve Ünsalan, K. (2020). Yapay Zekâ ve İstatistiksel Yöntemler ile Küresel Ticarette Rekabet Ölçütü Olan Lojistik Performans İndeksine (LPI) Etken Parametrelerin Ülke Bazlı İncelenmesi ve Tahmin Modellerinin Geliştirilmesi. *Fırat Üniversitesi Müh. Bil. Dergisi*, 32(2), 571-82. https://doi.org/10.35234/fumbd.706406

Cengiz, H. ve Çetinceli, K. (2020). Türkiye ve BRICS Ülkelerinin Bilgi ve İletişim Teknolojileri Gelişmişlik Endeksleri ile Lojistik Performans Endekslerinin Karşılaştırılması. *Süleyman Demirel Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 3(38), 165-85.

Çavuşoğlu, D. ve Denktaş Şakar, G. (2013). İntermodal Limanlar ve Pazarlama İletişimi: Liman Web Sitelerinin İçerik Analizi. *Denizcilik Fakültesi Dergisi*, 5(2), 37-55.

Çekerol, G. S. ve Kurnaz, N. (2011). Küresel Kriz Ekseninde Lojistik Sektörü ve Rekabet Analizi. *Selçuk Üniversitesi Sosyal Bilimler Enstitüsü Dergis*i, 25, 47-59.

Çemberci, M., Civelek, M. E. ve Canbolat, N. (2015). The Moderator Effect of Global Competitiveness Index on Dimensions of Logistics Performance Index. *Procedia - Social and Behavioral Sciences*, 195, 1514-24. https://doi.org/10.1016/j.sbspro.2015.06.453

Çitil, M. (2022). Yeşil Lojistik ve Lojistik Performans ile Yönetişim Kalitesi Arasındaki İlişkiye Yönelik Bir İnceleme. *Dicle Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 12(24), 322-52. https://doi.org/10.53092/duiibfd.1133548

Darlington, Y. ve Scott, D. (2002). *Qualitative Research in Practice Stories from the Field.* https://doi.org/10.1016/S1361-3111(02)00100-0

Demirbilek, A., Öz, S. ve Fidan, Y. (2018). Lojistik Performans Endeksi ve Havayolu Kargo Taşımacılığı İlişkisi: 2007-2016 Türkiye Örneği. *Ekonomi, İşletme ve Yönetim Dergisi*, 2(1), 1-24.

DTÖ. (2023). *World Trade Report 2023: Re-Globalization for a Secure, Inclusive and Sustainable Future.* Retrieved from https://www.wto.org/english/res_e/reser_e/wtr_e.htm (10.04.2024)

Gergin, R. E. ve Baki, B. (2015). Türkiye'deki Bölgelerin Lojistik Performanslarının Bütünleştirilmiş AHS ve TOPSIS Yöntemiyle Değerlendirilmesi. *Business and Economics Research Journal*, 6, 115-35.

Goel, A., Ganesh, L. S. ve Arshinder, K. (2019). Deductive Content Analysis of Research on Sustainable Construction in India: Current Progress And Future Directions. *Journal of Cleaner Production*, 226, 142-58. https://doi.org/10.1016/j.jclepro.2019.03.314

Göçer, A., Özpeynirci, Ö. ve Semiz, M. (2022). Logistics Performance Index-Driven Policy Development: An Application to Turkey. *Transport Policy,* 124, 20-32. https://doi.org/10.1016/j.tranpol.2021.03.007

Guner, S. ve Coskun, E. (2012). Comparison of Impacts of Economic and Social Factors on Countries' Logistics Performances: A Study with 26 OECD Countries. *Research in Logistics & Production,* 2(4), 329-43.

Jhawar, A., Garg, S. K. ve Khera, S. H. (2014). Analysis of the Skilled Workforce Effect on the Logistics Performance Index—Case Study from India. *Logistics Research*, 7(1), 1-10. https://doi.org/10.1007/s12159-014-0117-9

Jhawar, A. ve Garg, S. K. (2018). Modelling of Critical Factors for Improving Logistics Performance of India Using Interpretive Structural Modeling. *International Journal of Applied Management Sciences and Engineering (IJAMSE)*, 5(1), 29-51. https://doi.org/10.4018/IJAMSE.2018010103

Kahraman, A. ve Kazançoğlu, İ. (2019). Understanding Consumers' Purchase Intentions Toward Natural-Claimed Products: A Qualitative Research in Personal Care Products. *Business Strategy and the Environment*, 28(6), 1218-33. https://doi.org/10.1002/bse.2312

Kahveci, Ş. (2022). Ekonomik ve Kurumsal Faktörlerin KEİ Ülkelerinin Lojistik Performansına Etkisi. *Uluslararası İktisadi ve İdari İncelemeler Dergisi*, 35, 97-112. https://doi.org/10.18092/ulikidince.1039093

Kara, M., Tayfur, L. ve Basık, H. (2009). Küresel Ticarette Lojistik Üslerin Önemi ve Türkiye. *Mustafa Kemal Üniversitesi Sosyal Bilimler Enstitüsü Dergis*i, 6(11), 69-84.

Kaya Samut, P. (2023). OECD Ülkelerinin Yeşil Lojistik Performansı ile Enerji, Sağlık Ekonomisi ve Çevre İlişkisinin Analizi. *Verimlilik Dergisi*, 67-82. https://doi.org/10.51551/verimlilik.1112577

Keskingöz, H. ve Matyar Tanır, Y. (2022). Türkiye ve Avrupa Birliği Ülkelerinin Lojistik Performanslarının Konjonktürel Yaklaşımla Değerlendirilmesi. *KSÜSBD*, 19 (özel sayı), 73-88.

Kılınç, E., Fidan, O. ve Mutlu, H. M. (2019). Türkiye, Çin ve Rusya Federasyonu'nun Lojistik Performans Endeksine Göre Karşılaştırılması. *International Journal of Economic Studies*, 5(2), 17-34.

Larson, P. D. (2021). Relationships Between Logistics Performance and Aspects of Sustainability: A Cross-Country Analysis. *Sustainability (Switzerland)*, 13(2), 1-13. https://doi.org/10.3390/su13020623

Lau, K. H. (2011). Benchmarking Green Logistics Performance with a Composite Index. *Benchmarking: An International Journal*, 18(6), 873-96. https://doi.org/10.1108/14635771111180743

Magazzino, C., Alola, A. A. ve Schneider, N. (2021). The Trilemma of Innovation, Logistics Performance, and Environmental Quality In 25 Topmost Logistics Countries: A Quantile Regression Evidence. *Journal of Cleaner Production*, 322. https://doi.org/10.1016/j.jclepro.2021.129050

Manavgat, G., ve Demirci, A. (2021). Lojistik Performans Endeksi Tutarlılığının Sıralı Lojistik Regresyon Modeliyle İncelenmesi. *Journal of Yasar University*, 16(64), 1856-71. https://doi.org/10.19168/jyasar.934418

Martí, L., Puertas, R. ve García, L. (2014). The Importance of the Logistics Performance Index in International Trade. *Applied Economics*, 46(24), 2982-92. https://doi.org/10.1080/00036846.2014.916394

Oğuz, S., Alkan, G. ve Yılmaz, B. (2019). Seçilmiş Asya Ülkelerinin Lojistik Performanslarının TOPSİS Yöntemi ile Değerlendirilmesi. *IBAD Sosyal Bilimler Dergisi*, 497-507. https://doi.org/10.21733/ibad.613421

Ojala, L. ve Çelebi, D. (2015). *The World Bank's Logistics Performance Index (LPI) and drivers of logistics performance.*Prepared for the Roundtable on Logistics Development Strategies and their Performance Measurements. In Proceeding of MAC-EMM, OECD, 3-30.

Orhan, M. (2019). Türkiye ile Avrupa Birliği Ülkelerinin Lojistik Performanslarının Entropi Ağırlıklı Edas Yöntemiyle Karşılaştırılması. *European Journal of Science and Technology*, 1222-38. https://doi.org/10.31590/ejosat.657693

Pan, W. T., Jiang, B., Wang, Y., Cai, Y. ve Ji, X. (2022). Comparison and Suggestions of Logistics Performance Index of Main Countries of Belt and Road Strategy Based on Bootstrap DEA Model. *Computational Intelligence and Neuroscience*, 2022. https://doi.org/10.1155/2022/2159578

Pınar, A. ve Diken, A. (2020). Lojistik Performans Endeksi Kapsamında Lojistik Üslerin Türkiye Ekonomisine Etkisi Üzerine Bir İnceleme. *İstanbul Ticaret Üniversitesi Sosyal Bilimler Dergisi*, 19(39), 1384-1406. https://doi.org/10.46928/iticusbe.758630

Rezaei, J., Roekel, W. S. ve Tavasszy, L. (2018). Measuring the Relative Importance of the Logistics Performance Index Indicators Using Best Worst Method. *Transport Policy*, 68, 158-69. https://doi.org/10.1016/j.tranpol.2018.05.007

Roy, J. (2011). *Logistics and the Competitiveness of Canadian Supply Chains.* Global Value Chains: Impacts and Implications. Trade Policy Research, 313-33.

Soliani, R. D. (2018). Evaluation of the Brazilian Logistic Performance in the LPI Index. *European International Journal of Science and Technology*, 7(8), 35-48.

Sofyalıoğlu, Ç. ve Kartal, B. (2013). Türkiye ve Avrasya Ekonomik Topluluğu Ülkelerinin Lojistik Performans İndekslerinin Karşılaştırılması ve Bazı Çıkarımlar. *International Conference on Eurasian Economies*, 524-31. https://doi.org/10.36880/C04.00766

Türkoğlu, M. ve Duran, G. (2023). Çok Kriterli Karar Verme Yöntemleri ile Bölgesel Kapsamlı Ekonomik Ortaklık (RCEP) Ülkelerinin Lojistik Performanslarının Değerlendirilmesi. *Ekonomi Bilimleri Dergisi.* 15(1), 45-69 https://doi.org/10.55827/ebd.1247297

Ulutaş, A. ve Karaköy, Ç. (2019). G-20 Ülkelerinin Lojistik Performans Endeksinin Çok Kriterli Karar Verme Modeli ile Ölçümü. *S.C.Ü. İktisadi ve İdari Bilimler Dergisi*, 20(2), 71-84.

UTİKAD. (2023). Retrieved from https://www.utikad.org.tr/UTIKAD-Dergileri (14.03.2023)

World Bank. (2023). Logistics Performance Index. Retrieved from https://lpi.worldbank.org (16.06.2023)

Yıldız, A., Aydoğan, K. ve Kartum, G. (2020). Türkiye'nin Uluslararası Lojistik Performans Endeksindeki Konumunun Kümeleme Analizi ile

Araştırılması. *Turkish Studies-Social Sciences*, 15(3), 1659-79. https://doi.org/10.29228/TurkishStudies.41640.

Yu, M. M. ve Hsiao, B. (2016). Measuring the Technology Gap and Logistics Performance of Individual Countries by Using a Meta-DEA–AR Model.*Maritime Policy and Management*, 43(1), 98-120. https://doi.org/10.1080/03088839.2015.1037372

Yücel, D. ve Göncü, K. K. (2023). Veri Zarflama Analizi ile Avrupa Geçiş Ekonomilerinin Lojistik Performans Endeksi Kullanılarak Değerlendirilmesi. *Trakya Üniversitesi İktisadi ve İdari Bilimler Fakültesi*, 12(1), 30-51. https://doi.org/10.47934/tife.12.01.02

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RESEARCH ARTICLE

Assessment of Profitability of Small-Scale Traditional Taxi Services: A Case Study of a Taxi Stand

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ABSTRACT
Taxis play a pivotal role in urban mobility by offering passengers flexible, comfortable, and door-to-door services. Despite the advent of the sharing economy, ensuring the continuity of traditional taxi services necessitates profitability analyses. For this reason, this study focuses on the economic profitability of trips made at a taxi stand serving the urban arteries of Istanbul. With the aim this, a survey was conducted among the drivers of a taxi stand. Subsequently, a model was developed, incorporating factors such as the number of trips (TRP), total trip distance (DST) and efficiency (EFF), which impact the profitability of taxi services. The modeling approach employed in this study is Response Surface Methodology (RSM). Additionally, contour plots were utilized to provide a more accurate assessment of the effects of factors. The results indicate that the EFF factor is the crucial factor influencing the profitability of traditional taxi services. This underscores the significance of the distance covered with passengers, highlighting its importance for both the economic success of taxi services and the broader network context of urban transportation.

Keywords: Traditional taxis; profitability analysis, response surface methodology, contour plot, sustainability

1. Introduction

Taxis, an integral part of the public transportation system, play a critical role in meeting the mobility needs of urban travelers. However, due to the stochastic nature of taxi ride demand, spatial and temporal differences may arise, leading to imbalances between taxi drivers and passengers. This phenomenon manifests itself as increased demand during peak traffic periods and increased supply during off-peak hours, thus making taxi journeys more complex compared to alternative transportation methods. As a result, the mismatch between taxi driver availability and passenger demand may result in reduced profit efficiency of traditional taxis (Qian and Ukkusuri, 2017).

Traditional taxis distinguish themselves within the urban transportation network by offering flexible and personalized services (Szeto et al., 2019). Concurrently, the advent of the sharing economy has propelled the emergence of ride-hailing services, which coexist with traditional taxis in the urban transportation landscape (Wu et al., 2018). While these systems differ in aspects such as passenger pickup methods, they also share commonalities. Notably, both ride-hailing services and traditional taxis provide 24/7 door-to-door services, affording users flexibility and comfort. However, the two systems engage in competition as they cater to the demand for door-to-door transportation (Cramer & Krueger, 2016; Brodeur & Nield, 2018; Berger et al., 2018), stimulating various discussions in the process. Given these dynamics, a nuanced understanding of passengers' travel behavior becomes indispensable for urban transportation planning to effectively anticipate the demands associated with both service types.

The integration of the sharing economy into urban transportation has significantly impacted the evolution of new services, thereby reshaping the urban transportation, including public transportation and traditional taxi services (Ghaffar et al., 2020; Shaheen et al., 2020; Liu et al., 2022). These emerging services, known as ride-hailing, represent a novel mode of transportation and have experienced notable growth in recent years directly influencing the economic dynamics of traditional taxi services (Bi and Ye, 2021).

Examining the economic efficiency of traditional taxi services as a research question in contemporary literature is very important, especially for metropolises such as Istanbul. Therefore, the main purpose of this study is to model the factors affecting the profitability of traditional taxis operating in urban arteries. Other aim of the study is to reveal the effect of the efficiency parameter, which expresses the occupancy rate, on economic profitability. Thus, the impact of the stochastic structure of taxi

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supply and demand on economic efficiency can be evaluated. For these purposes, a survey was conducted about the trips made at a taxi stand serving on the important arteries of Istanbul. Understanding these factors can help taxi operators make their business more efficient and increase their profit. Additionally, this paper aims to showcase the applicability of response surface methodology as a novel technique for transportation planning in modeling and optimizing transportation systems.

Additionally, the results from this research have the potential to assist decision-makers in urban transportation management by supporting the sustainability of traditional taxi services. Considering that the evaluation of traditional taxi services in the study was conducted using a limited data set, it may not be accurate to generalize these findings. However, it can be argued that this study constitutes an important step for decision makers to create effective strategies for traditional taxi services. The benefits of the obtained results to decision makers are detailed in the results section.

The subsequent sections of this study follow a structured organization. Section 2 provides a concise review of the relevant literature. Section 3 introduces the details of the surveys conducted and the methodology applied in this research. The modeling results are delineated in Section 4. Section 5 succinctly summarizes the study's conclusions. Finally, Section 6 presented the limitations and recommendations of study.

2. Literature Review

Taxi services are an important part of the urban transportation system (Milioti et al., 2015). These services are of great importance in completing urban transportation as they provide time and space flexibility to the passengers. In addition, taxis provide comfortable door-to-door service to the passenger and eliminate the need for parking for the passenger (Christoforou et al., 2012). For this reason, taxi transportation mode, which has an important place within the scope of urban transportation, has been the focus of many studies. In particular, studies are carried out on the economic efficiency of traditional taxi services. Research on the economic efficiency of taxi services shows that many variables affect the economic efficiency of taxis. These variables can be specified as the number of passengers, distance traveled and occupancy rate. Each of these factors should be considered when making important strategic decisions for taxi operators.

Although traditional taxis serve the same urban arteries, their profitability differs from each other. This is due to the fact that the routes preferred by taxi drivers when searching for and transporting passengers are different from each other (Yuan et al., 2011). The time and route used by the taxi to search/carry passengers are important indicators to evaluate the economic efficiency of the taxi (Zhang et al., 2017). Because this time and mileage are potential costs that affect the economic profitability of the taxi (Nian et al., 2022). The time used by taxis to carry passengers and the distance they take during this time are related to the variability of the dynamic environment (weather, traffic density, supply-demand variability, etc.). On the other hand, the time taken by taxis to search for passengers and the route taken during this time are related to the variability of the static environment (the structural environment of the city). This can be explained by the fact that the economic efficiency of taxi services is closely related to external factors (Zong et al., 2019). As a result, this situation causes the economic efficiency of taxis that carry fewer passengers or have a low occupancy rate to decrease (Nquyen-Phuoc et al., 2021). In addition, the increased time and distance to search for passengers causes an increase in the fuel consumption of taxis, emissions and urban traffic (Szeto et al., 2019; Chen et al., 2020).

Traditional taxi services, which stand out by providing more flexibility and comfort compared to public transportation, play an important role in urban transportation by reducing the demand for private vehicles and parking spaces (Aarhaug and Skollerud, 2014; Shaaban and Kim, 2016). Research shows that traditional taxis are predominantly used in regions characterized by low population density or limited public transport infrastructure (Aarhaug and Skollerud, 2014). On the other hand, some studies show that there is a complementary relationship between taxi services and public transportation (Kattan et al., 2010; Welch et al., 2020). This interaction affects individuals' decisions regarding vehicle ownership (Kattan et al., 2010). In particular, Qian and Ukkusuri (2015) investigated the spatial variation of taxi travel in New York and revealed a positive relationship between subway accessibility and taxi travel.

Contemporary evaluations underline the need to investigate the potential impacts of both traditional taxi services and ride-hailing platforms on urban transportation. However, the use of these services and the resulting impact on travel behavior are poorly understood and researched (Ghaffar et al., 2020; Choi et al., 2022). Methodologies developed to investigate and comprehend these services often include data from surveys of both taxi drivers and passengers (Shi et al., 2014; Wong et al., 2015). However, survey-based approaches are both costly and time consuming. This limits a comprehensive understanding of taxi services. As a result, studies based on survey data are especially preferred, especially in small-scale research areas.

3. Methodology

The assessment of transportation performance typically relies on average values of variables. However, such an approach may overlook important nuances in the system. Hence, in this study, the calculation of daily profit for taxis is not based on average values but rather considers the specific values for each taxi, including TRP, DST and EFF (see Table 1). This approach is adopted to cultivate a more accury profit model for traditional taxis, acknowledging the variability inherent in these key factors for individual taxis. Thus, the aim is to develop a model that better reflects the unique characteristics and operational dynamics of each taxi, contributing to a more accurate assessment of their profitability. Flow chart of study methodology is presented in Figure 1.

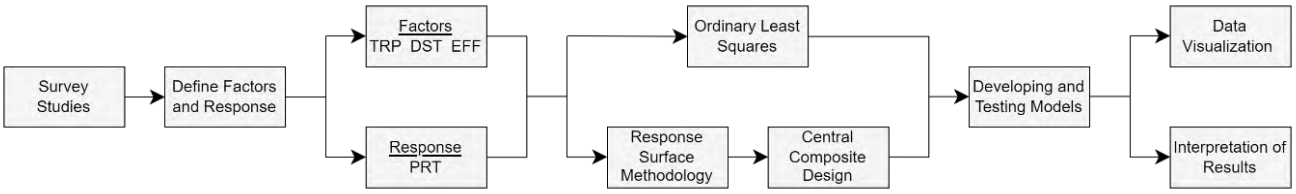

Figure 1. Flow chart of methodology

Table 1. Response and factors details

Response and Factors	Notation	Unit	Definition
Profit	PRT	₺/day	It is defined as the profit earned by the taxi as a result of the service it provides during one day.
Number of trips	TRP	trip/day	The service provided by a taxi during a day is defined as the total number of trips.
Total trip distance	DST	km/day	The distance traveled by a taxi throughout its service during a day is defined as the total trip distance.
Efficiency	EFF	%	The distance traveled by the taxi with the passenger (ride distance) and the ratio of the taxi to the total travel distance during the day (ride distance and cruising distance) were defined as the efficiency of the taxi.

3.1. Material

In the scope of the research, a taxi stand operating in Istanbul arteries was identified. On September 6, 2023, a survey was undertaken at the taxi stand to collect information about traditional taxis. Survey studies were exclusively conducted regarding taxi trips, with a focus on collecting data related to this specific transportation mode. This study was reviewed by the Yıldız Technical University Ethics Committee and approved on 31.10.2024 with the letter numbered 20241003384. All participants were informed and voluntarily involved in this study. This research was conducted in accordance with the principles of protecting the privacy of the participants and ensuring the confidentiality of the data.

3.1.1 Determination of Sample Size

Determining the sample size in research is of critical importance in achieving statistically reliable results. In this study, the sample size calculation formula developed by Cochran (1977) was used to determine the sample size of the survey conducted to investigate the profitability of the taxi transportation mode. Correctly determining the sample size increases the generalizability of the data obtained and the reliability of the research findings. Therefore, the sample size calculation method used in this study was carefully selected to support the scientific aspect of the research results. Cochran's (1977) formula is widely used in many studies and allows the calculation of a statistically significant sample size at a certain confidence level and margin of error (see Eq. 1). Additionally, the sample size approach developed by Cochran provides the possibility of a correction formula for small populations (see Eq. 2).

$$n_0 = \frac{z^2.p.(1-p)}{e^2} \tag{1}$$

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} \tag{2}$$

In this research, 18,395 taxi drivers registered to traffic in Istanbul were determined as the population of the study (IBB, 2023a). Sample size calculations were performed with a 90% confidence level (z) and a 10% margin of error (e). To calculate the sample size (n) from a finite population of 18.395 (population of study). Eq.1 and Eq. 2 were applied as follows:

$$n_0 = \frac{1.645^2.0.50.(1-0.50)}{0.10^2} = 67.65 \text{ drivers}$$

$$n = \frac{67.65}{1 + \frac{67.65-1}{18.395}} = 67.41 \text{ drivers}$$

The parameters used in this calculation for both equations are as follows:

N: finite population of study

n_0: sample size for infinite population

n: sample size

z: confidence level (for a 90% confidence level, z=1.65)

p: The estimated proportion related to the research topic (commonly 0.5 is used)

e: The accepted margin of error (select 10)

As a result, conducting a survey with at least 68 drivers will be sufficient to obtain statistically valid and reliable results in the study.

3.1.2 Survey Design

In the study, surveys were conducted with 70 taxi drivers working in shifts in these taxis. As a result, a survey was conducted covering taxis operated by two different drivers, each operating in shifts. While the first driver provided taxi service between 02:00 and 14:00, the second driver provided taxi service between 14:00 and 02:00. During the data collection process, care was taken to ensure 24-hour availability of taxis. The purpose of this measure was to prevent misrepresentation of the taxi's operational performance due to temporal changes.

All taxis considered in the study were C segment vehicles with identical starting fees (₺19.17/trip) and the same price per kilometer (₺13.75/trip), as per the classification and tariff set by the Istanbul Metropolitan Municipality (IBB, 2023b). To ensure homogeneity in the survey, taxis were required to operate in the similar districts, and surveys were conducted exclusively at one taxi stand. The study involved data collection from 70 taxi drivers.

Throughout the surveys, taxi drivers were queried about income and expenditure parameters, with a focus on key questions such as:

- What is your total number of trips during a day?
- How many kilometers (ride and cruising distance) do you trip in total during a day?
- What percentage of your trip (ride distance) during a day is carried out with passengers?

The response to the question regarding the percentage of the trip covered with passengers was designated as the efficiency variable for the taxis. In this research, taxi efficiency was evaluated based on the total travel distance while providing passenger transportation (distance-based efficiency). The primary inquiries within the survey were oriented toward understanding the daily services provided by taxis. Consequently, the profitability analysis of taxis was conducted in ₺/day unit.

Table 2. Information about the taxi operation

Driver Parameters		
Number of drivers	2	driver/day
Driver shift	12	hour/day
Taxi service duration	24	hour/day
Driver salary	₺ 1.000,00	₺/day
Taxi Parameters		
Number of taxi	1	taxi/day
Taximeter starting fee	₺ 19.17	₺/trip
Fare per km	₺ 13.75	₺/km
Fuel quantity	6	L/100 km
Cost of fuel	₺ 36.00	₺/L
Number of maintenance - repair	4	times/year
Cost of maintenance - repair	₺ 5,000.00	₺/times
Vehicle insurance	₺ 7,500.00	₺/year
Number of vehicle tax	2	times/year
Vehicle tax	₺ 1,000.00	₺/year
Taxi stall rent	₺ 90.00	₺/day

The profitability analysis of the taxi service, obtained from the survey of taxi drivers and calculated based on the individual taxis included in the survey, is presented in Table 2. Important details for a particular taxi are also presented below.

- Total Trips: 48 trips in one day.
- Total Distance: 550 km, including both ride distance and cruising distance, covered during one day.
- Efficiency: The taxi operated with 80% efficiency, calculated based on the ride distance.

Table 3 provide the expenditures and revenues for the taxi service on a daily basis.

Table 3. Expenditure and revenue of any taxi for a day

Expenditures		
Driver salary	₺ 2,000.00	₺/day
Fuel	₺ 1,188.00	₺/day
Maintenance - repair	₺ 54.79	₺/day
Vehicle insurance	₺ 20.55	₺/day
Vehicle tax	₺ 5.48	₺/day
Taxi stall rent	₺ 90.00	₺/day
Revenues		
Taximeter starting fee	₺ 920,16	₺/day
Taxi service	₺ 6,050.00	₺/day

These calculations provide a breakdown of the daily expenditures associated with the taxi service, encompassing various aspects such as driver salary, fuel, maintenance, insurance, vehicle tax, and taxi stall rent. Given that the profitability analysis is conducted on a daily basis, considerations such as maintenance – repair, vehicle insurance and vehicle tax have been transformed into units of measurement on a daily basis. The total daily expenditure is the sum of these individual components, amounting to ₺ 3,358.82 per day (see Table 3).

These calculations provide a breakdown of the daily revenues associated with the taxi service, including the taximeter starting fee and revenue generated from taxi services. The total daily revenue is the sum of these individual components, amounting to 6,970.16 ₺ per day (see Table 3). The taxi generated a total revenue of 6,050.00 ₺ for the services provided during one day. There was an expenditure of 3,358.82 ₺ associated with the operation of the taxi for one day. Thus, the taxi achieved a profit of 3,611.34 ₺ as a result of the services it provided during the day.

It's noteworthy that this profitability analysis provides a comprehensive overview of the financial performance of a specific taxi, taking into account both the income generated and the associated expenses. This methodology was applied to all taxis surveyed, allowing for a comprehensive and systematic assessment of the profitability of the entire taxi fleet in a computerized environment.

3.2. Modelling of Taxi Profit

After calculating the daily profits of the taxi drivers participating in the survey, a modeling study was conducted to investigate the main factors that could have a significant impact on this profit. Ordinary Least Squares (OLS) and Response Surface Methodology (RSM) techniques were used in this study. The purpose here is to compare and verify the results obtained using the RSM technique with the OLS technique.

3.2.1 Ordinary Least Squares (OLS)

After calculating the daily profit of taxis, the ordinary least squares model was used to examine the main factors that could have a significant impact on this profit. The general equation of the ordinary least squares model is presented below (see Eq. 3).

$$y_i = a(X_1) + b(X_2) + c(X_3) + d \tag{3}$$

where y_i is the daily profit of each taxi. X represents the independent variables. While a, b, c represent the model coefficients, d represents the constant term.

3.2.2 Response Surface Methodology (RSM)

RSM, as elucidated by Montgomery and Myers (2002), is a mathematical and statistical technique utilized for the development, improvement, and optimization of processes. Distinguished by several advantages over traditional experimental and optimization methods, RSM stands out for its capacity to extract extensive information from a constrained number of experiments through diverse experimental designs. In light of these strengths, RSM emerges as a valuable tool for modeling the profitability of traditional taxi services. For this reason, RSM technique was preferred since a small-scale data set was used within the scope of the study.

Central Composite Design (CCD):

RSM employs various experimental designs for modeling studies. In this study, the CCD, recognized as one of the most practical experimental designs, was utilized. Introduced by Box and Wilson in 1951, CCD enhances the first-order design with n factors by incorporating axial points, additional factorial points, and center points. Factorial points (β_f), also known as corner or cube points, are coded at levels of ±1, with the number of factorial points determined by the formula 2^n. Center points (β_c) are coded with zero and serve to assess the model's fit or identify errors in the experimental design. Axial points (β_a) are strategically placed outside the cube at a specified distance (usually alpha) from the design center along each axis, aiding in estimating curvature. The formula 2^n calculates the number of axial points in the experimental design. Figure 2 presents the CCD for three different factors. In summary, this study employs for assessing taxi profitability use of RSM technique. The CCD is chosen as the experimental design, showcasing its efficacy in this context. The entire experimental design, modeling process are conducted using Minitab®.

Modeling Taxi Profit with CCD:

To model PRT response and three key factor TRP, DST and EFF are considered, constituting a three-factor experimental design. The experimental design chosen was CCD. It was important in choosing this modeling technique that it could develop models using small-scale data. Because small-scale data from a taxi stand is used in the study. The chosen experimental design is the CCD, requiring a total of 20 experiments (see Table 5). These experiments were selected randomly from 70 drivers, encompassing 8 factorial points, 6 axial points, and 6 central points. CCD configuration details is presented in below.

- Factor Levels: Each factor TRP, DST and EFF is configured with three different levels, as outlined in Table 4.
- Factor Points (β_f): These are the factorial points, also referred to as corner or cube points, and are coded at levels ±1 (see Fig. 2).
- Axial Points (β_a): These points, positioned outside the cube, are coded at a level of ±1.68179 (see Fig. 2). An argument length of 1.68179 is chosen based on the number of factorial points, influencing the coding of axial points.
- Center Points (β_c): Coded at level 0, these points are included to assess the model's fit and identify errors in the experimental design.

In summary, the CCD for three factors involves a set of 20 experiments, incorporating diverse combinations of TRP, DST and EFF. The selection of these 20 experiments is conducted through a random process from the dataset. The strategic use of factorial, axial, and center points, along with appropriate coding, ensures a comprehensive exploration of the experimental space. The CCD is a robust approach to capture the intricate relationships among the selected parameters and model PRT.

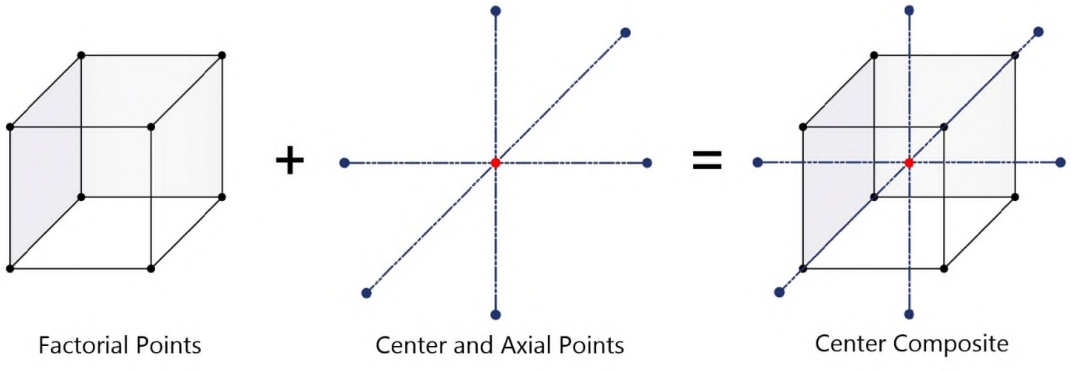

Figure 2. CCD configuration for 3 factors

Table 4. Level of factors for CCD

Factors	Levels		
	-1.68179	0	1.68179
TRP	25	38.50	52
DST	300	470	640
EFF	60	70	80

TRP (trip/day); DST (km/day); EFF(%)

Table 5. Factors and response values

Observation order	Model factors values						Response
	Coded value			Uncoded value			
	TRP	DST	EFF	TRP	DST	EFF	PRT
1	-1	-1	-1	35	350	60	₺1.131,63
2	0	0	0	40	350	60	₺1.227,48
3	0	0	0	40	300	70	₺1.335,48
4	-1	-1	1	25	350	70	₺1.421,18
5	1.68179	0	0	30	370	70	₺1.666,33
6	1	1	1	35	450	60	₺1.740,63
7	1	-1	-1	40	440	60	₺1.775,58
8	0	0	-1.68179	35	380	70	₺1.836,83
9	-1	1	1	40	370	70	₺1.858,03
10	0	0	1.68179	50	450	60	₺2.028,18
11	0	0	0	40	400	70	₺2.081,98
12	-1	1	-1	52	480	60	₺2.249,22
13	0	0	0	50	640	60	₺2.424,23
14	0	-1.68179	0	40	450	70	₺2.455,23
15	-1.68179	0	0	50	550	60	₺2.637,18
16	1	-1	1	40	600	60	₺2.749,98
17	0	0	0	50	480	70	₺2.870,88
18	1	1	-1	40	640	60	₺2.993,58
19	0	0	0	40	540	70	₺3.127,08
20	0	1.68179	0	48	550	80	₺4.111,34

TRP (trip/day); DST (km/day); EFF(%)

4. Results

Two different models have been devised to estimate PRT response using OLS and RSM. These models were constructed by incorporating factors with both linear or square terms, intending to understand the relationship between the factors (TRP, DST, and EFF) and PRT response. The outcomes of these models are expounded upon in this chapter.

Model 1 exclusively incorporates the linear effects of factors on PRT response using OLS. The equation for this model Eq. 4 depicting the relationship with PRT response is presented below:

$$PRT = -6000 + 20.54^{*}TRP + 6.031^{*}DST + 70.04^{*}EFF \quad (4)$$

Model 1 equation indicates that the taxi profit (PRT) response experiences an increase with the increment of the TRP, DST and EFF factors (see Table 6). The adjusted R^2 value for the linear model is computed as 92.51 in the RSM, as detailed in Table 6.

Model 2 encompasses both linear and square effects of the factors on the PRT response using RSM. Model 2 differs from model 1 in this respect because square terms are used. The equation for this model, considering both linear and square terms, is presented as follows Eq. 5 for the PRT response:

$$PRT = 136 + 78.2^{*}TRP + 17.56^{*}DST - 218^{*}EFF - 0.819^{*}TRP^2 - 0.01217^{*}DST^2 + 2.12^{*}EFF^2 \quad (5)$$

The equation for model 2 reveals that the linear and square terms of the factors exert different effects on the PRT response (see Table 6). Both the TRP and DST exhibit a positive impact on taxi profit PRT response, whereas the square terms (TRP^2 and DST^2) have negative effects on PRT response. Conversely, the square term (EFF^2) has a positive effect on PRT response.

Table 6. Results of PRT response

Source	Deggre of freedom	Mean Square (adj)	T-value	F-value	p-value	VIF	R^2	R^2 (adj)
Ordinary Least Squares								
Model	3	3.31E+06		79.21	0.000			
Linear	3	3.31E+06		79.21	0.000			
TRP	1	2.99E+05	2.67	7.15	0.017	1.39	93.69	92.51
DST	1	4.98E+06	10.91	119.02	0.000	1.43		
EFF	1	3.19E+06	8.73	76.28	0.000	1.07		
Constant			40.17		0.000			
Response Surface Methodology								
Model	6	1.72E+06		70.66	0.000			
Linear	3	3.25E+06		133.85	0.000			
TRP	1	1.29E+05	2.31	5.31	0.038	1.75		
DST	1	4.38E+06	13.44	180.51	0.000	1.68		
EFF	1	2.15E+06	9.42	88.71	0.000	1.99	97.02	95.65
Square	3	1.18E+05		4.85	0.018			
TRP*TRP	1	5.06E+04	-1.44	2.08	0.172	1.17		
DST*DST	1	2.35E+05	-3.11	9.69	0.008	1.14		
EFF*EFF	1	8.80E+04	1.90	3.62	0.079	2.52		
Constant			33.73		0.000			

OLS and RSM results for PRT response are summarized in Table 6. The linear coefficient in model 1 demonstrates statistical significance at the 5% level (p_{linear} = 0.000). Besides, the linear and square terms within model 2 exhibit statistical significance at the 5% significance level (p_{linear} = 0.000 and p_{square} = 0.018). Moreover, the Variance Inflation Factor (namely VIF) values for these models were observed to be within acceptable thresholds. The VIF is employed as a statistical metric to evaluate the existence of multicollinearity among factors. Generally, a VIF surpassing 10 is considered indicative of multicollinearity, leading to the removal of the corresponding variables from the model (Qian and Ukkusuri, 2015; Pan et al., 2019).

The goodness of fit of the developed models is evaluated according to the R^2 values presented in Table 6. When the two models developed using OLS and RSM techniques are compared, it is seen that both R^2 and adjusted R^2 values for model 2 are higher than the model 1. Additionally, a lower residual value serves as a positive indicator of the model's goodness of fit; the residual values for the PRT response are detailed in Table 7 for both model 1 and model 2. Statistically, model 2 exhibits better residual values than model 1 (see Table 7). The testing results for models are depicted in Figure 3. This confirmation substantiates that RSM stands as a viable and effective approach for modeling the profitability of traditional taxi services.

Table 7. Estimated of PRT with OLS and RSM

Observation order	Measured	Ordinary Least Squares		Response Surface Methodology	
		Estimasted	Residual	Estimasted	Residual
	PRT	PRT_{est}	PRT - PRT_{est}	PRT_{est}	PRT - PRT_{est}
1	₺1.131.63	₺1.032.33	₺99.294	₺1.085.47	₺46.15
2	₺1.227.48	₺1.135.04	₺92.437	₺1.169.35	₺58.13
3	₺1.335.48	₺1.533.86	-₺198.386	₺1.261.49	₺73.99
4	₺1.421.18	₺1.527.29	-₺106.114	₺1.369.37	₺51.80
5	₺1.666.33	₺1.750.62	-₺84.290	₺1.711.06	-₺44.73
6	₺1.740.63	₺1.635.43	₺105.197	₺1.867.61	-₺126.98
7	₺1.775.58	₺1.677.83	₺97.750	₺1.884.23	-₺108.65
8	₺1.836.83	₺1.913.63	-₺76.807	₺1.920.18	-₺83.35
9	₺1.858.03	₺1.956.03	-₺98.004	₺1.919.76	-₺61.73
10	₺2.028.18	₺1.943.55	₺84.626	₺1.996.38	₺31.80
11	₺2.081.98	₺2.136.96	-₺54.983	₺2.165.35	-₺83.38
12	₺2.249.22	₺2.165.56	₺83.654	₺2.172.87	₺76.35
13	₺2.424.23	₺3.089.44	-₺665.208	₺2.811.70	-₺387.47
14	₺2.455.23	₺2.438.51	₺16.719	₺2.525.99	-₺70.76
15	₺2.637.18	₺2.546.65	₺90.529	₺2.535.06	₺102.12
16	₺2.749.98	₺2.642.78	₺107.195	₺2.668.20	₺81.78
17	₺2.870.88	₺2.824.85	₺46.026	₺2.758.05	₺112.83
18	₺2.993.58	₺2.884.02	₺109.556	₺2.766.81	₺226.77
19	₺3.127.08	₺2.981.30	₺145.782	₺3.021.75	₺105.33
20	₺4.111.34	₺3.906.31	₺205.029	₺4.111.34	₺0.00

TRP (trip/day); DST (km/day); EFF(%)

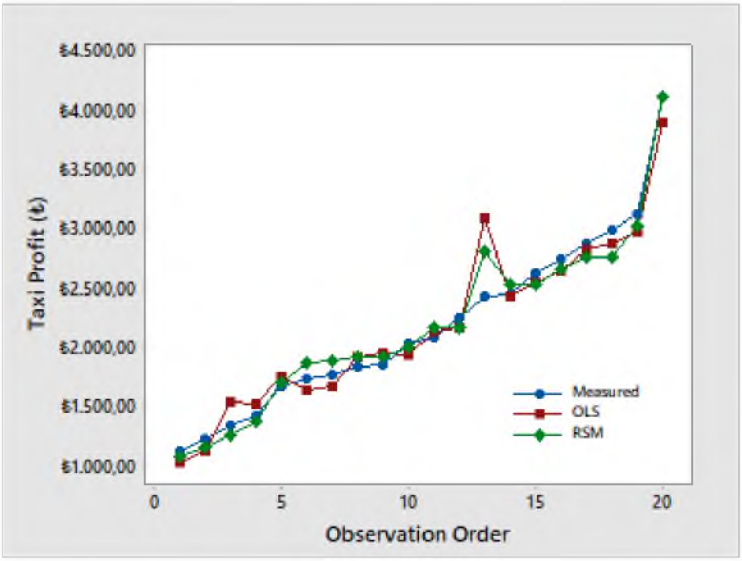

Figure 3. Testing PRT estimated with OLS and RSM

In the contour plot depicted in Figure 4, the variation in PRT response with EFF held constant at 70% is observed for the factors, TRP and DST. The plot illustrates that the minimum PRT response occurs when both the TRP and DST are low. This trend, indicating a positive influence of both the TRP and DST factors on PRT, is consistent with findings from other contour plots.

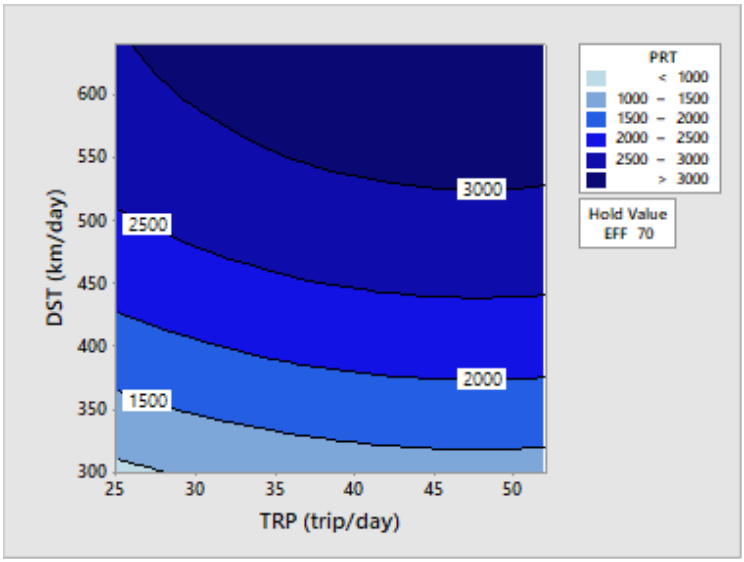

Figure 4. Contour plot of TRP and DST factors

Another contour plot, displayed in Figure 5, delineates the relationship between the factors, TRP and EFF, with DST factor held constant at 470 km. The maximum response for maximum PRT is observed when there is an increase in both the TRP and EFF, as illustrated in Figure 4.

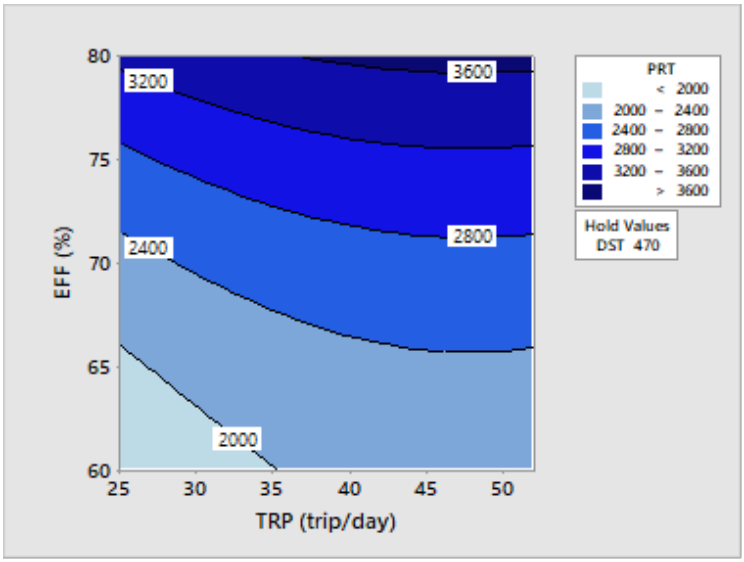

Figure 5. Contour plot of TRP and EFF factors

The final contour plot is depicted in Figure 6, illustrating the relationship between the factors, DST and EFF. The plot maintains a fixed value of 38.50 trips per day for the TRP factor. The maximum daily profit is achieved when the DST is extended. As the taxi drivers cover a greater DST with passengers (indicating a reduced frequency of searching for passengers throughout the day), EFF (ride distance) of the taxi increases, providing to a subsequent rise in daily profit. Consequently, modeling the EFF factor holds significance when conducting profitability analyses of taxi services.

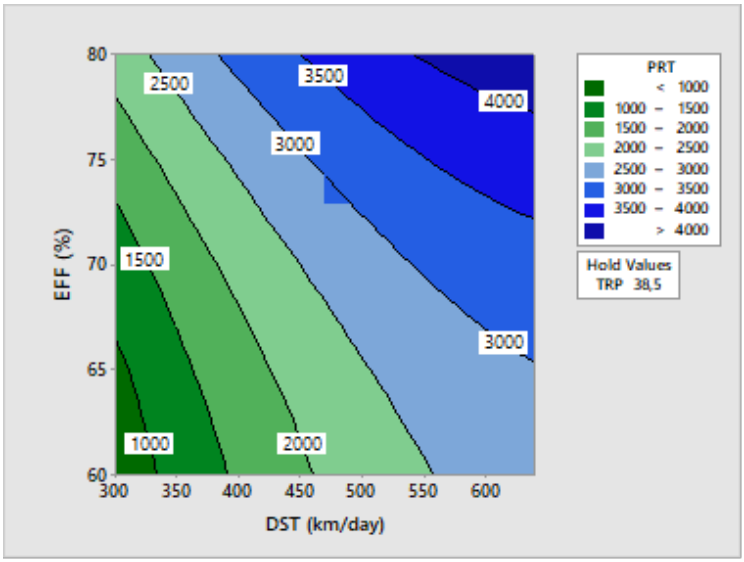

Figure 6. Contour plot of DST and EFF factors

5. Conclusion

This study examines the profitability of traditional taxi services, which constitute a pivotal aspect of urban transportation. The primary objective is to bolster the long-term sustainability of traditional taxis within the expanding realm of the sharing economy by furnishing decision makers with a profitability framework. To achieve this purpose, a survey was conducted on 70 taxi drivers working in shifts within these taxis. Within the scope of the research, small-scale data from a taxi stand was used. However, the results obtained may be an important step in the evaluation of traditional taxi services in urban transportation. The survey inquiries pertaining to taxi trips were subjected to modeling using the Response Surface Methodology. Within the modeling scope, variables such as the number of trips, total trip distance, and efficiency – perceived to impact the profitability of traditional taxi services – were scrutinized as part of the research scope. The ensuing findings gleaned from the study are succinctly outlined below.

- In this paper, CCD was adopted as the foundation for RSM. The CCD was implemented with three different factors, comprising 20 field observations in total, including 8 factorial points, 6 axial points, and 6 center points. Two different models were formulated using RSM, incorporating linear and square terms. Evaluation of the calculated R-square values, ANOVA, and examination of residual plots for each model were conducted. The ANOVA results for the model 2 indicate that all types of terms (linear and square) significantly influence the accuracy of the PRT response estimate. The minimum residual values in model development serve as a reliable indicator of the model's goodness of fit. For the PRT response, residual values in the model 2 range from -₺387,47 and ₺226,77. Consequently, the model 2 demonstrates the most favorable residual values, suggesting superior performance compared to other model. Thus, it is concluded that the model 2 outperforms other in terms of overall performance. Furthermore, this study affirms that RSM serves as an alternative modeling technique for enhancing the profitability of traditional taxi services. Thus, the RSM technique can be recommended to researchers for use within the scope of transportation planning.
- The developed model and contour plots reveal that the TRP, DST and EFF positively contribute to the profitability of taxi services. Furthermore, these outcomes were established as statistically significant at the 5% significance level.
- Notably, EFF factor is an important factor in traditional taxis profitability. This underscores the significance of the distance covered with passengers, emphasizing its importance for both the economic success of taxi services and the broader context of urban transportation. Traditional taxis tend to traverse at lower speeds during passenger search (cruising distance), leading to a decrease in the average traffic flow speed and an increase in travel time. Given the ubiquity of this scenario across all taxis in the city, it adversely impacts the efficiency of the city's transportation network.
- Taxi supply and demand exhibit a stochastic structure, causing traditional taxi drivers to travel long distances in pursuit of passengers. Consequently, the operational efficiency of traditional taxis is on the decline. This decrease can be attributed to the significant loss of time and kilometers incurred by taxi drivers, who dedicate a substantial portion of their working hours to seeking passengers. In such instances, the value of ride-hailing services becomes apparent, offering a streamlined process for matching drivers (supply) and passengers (demand) through a centralized system (mobile applications). The existing literature has demonstrated the superior performance of ride-hailing services over traditional taxis in terms of urban transportation efficiency (Cramer and Krueger, 2016; Jiang et al., 2018). Kong et al. (2020) argue that ride-hailing services exhibit greater

economic efficiency compared to traditional taxis due to their ability to more effectively match drivers with passengers in real-time traffic conditions and employ surge pricing strategies. Consequently, ride-hailing enhances the efficiency of taxi drivers by minimizing the distances traveled in search of passengers, thereby augmenting the overall profitability of taxi services. Furthermore, ride-hailing aligns with decision makers' sustainability objectives for urban transport by mitigating traffic congestion and reducing emissions.

As a result of this study, transportation engineers and decision makers can better understand the potential impacts of implementing new policies or regulations by analyzing the economic efficiency of traditional taxi services. This encourages a knowledge-based approach to decision-making. Additionally, analysis of the economic efficiency of traditional taxi services can evaluate the effects of competition and regulation. For example, topics such as determining taxi prices or how competitive markets work can be examined. Consequently, analyzing the economic efficiency of traditional taxi services provides transportation engineers and decision makers with the data needed to develop a better transportation system and can help make these systems more efficient, economical and sustainable.

6. Limitations and Recommendations

As with any investigation, this study is subject to certain limitations. Firstly, the research was limited to drivers at a single taxi stand. To increase the applicability of the findings to a broader context, the sample size could be expanded by adding a more comprehensive array of taxi stands. Moreover, the incorporation of taxi stands located in rural vicinities within the study's scope would afford a more holistic perspective. Consequently, the assessment of the profitability of traditional taxi services could be extended to encompass various land use typologies. Furthermore, the profitability analysis of traditional taxi services could benefit from the consideration of temporal factors, such as peak travel periods. Evaluating profitability disparities between morning and evening peak hours would facilitate a nuanced understanding of the impact of traffic density on taxi service viability. By addressing these constraints, the study's findings can be bolstered in terms of comprehensiveness and generalizability, thereby enriching scholarly discourse on the subject matter.

Ethics Committee Approval: This study was reviewed by the Yıldız Technical University Ethics Committee and approved on 31.10.2024 with the letter numbered 20241003384.

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REFERENCES

Aarhaug, J., & Skollerud, K. (2014). Taxi: different solutions in different segments. Transportation Research Procedia, 1(1), 276-283. DOI: 10.1016/j.trpro.2014.07.027

Berger, T., Chen, C., & Frey, C. B. (2018). Drivers of disruption? Estimating the Uber effect. European Economic Review, 110, 197-210. DOI: 10.1016/j.euroecorev.2018.05.006

Bi, H., & Ye, Z. (2021). Exploring ridesourcing trip patterns by fusing multi-source data: A big data approach. Sustainable Cities and Society, 64, 102499. DOI: 10.1016/j.scs.2020.102499

Brodeur, A., & Nield, K. (2018). An empirical analysis of taxi, Lyft and Uber rides: Evidence from weather shocks in NYC. Journal of Economic Behavior & Organization, 152, 1-16. DOI: 10.1016/j.jebo.2018.06.004

Chen, F., Yin, Z., Ye, Y., & Sun, D. J. (2020). Taxi hailing choice behavior and economic benefit analysis of emission reduction based on multi-mode travel big data. Transport Policy, 97, 73-84. DOI: 10.1016/j.tranpol.2020.04.001

Choi, Y., Guhathakurta, S., & Pande, A. (2022). An empirical Bayes approach to quantifying the impact of transportation network companies (TNCs) operations on travel demand. Transportation Research Part A: Policy and Practice, 161, 269-283. DOI: https://doi.org/10.1016/j.tra.2022.04.008

Christoforou, Z., Milioti, C., Perperidou, D., & Karlaftis, M. G. (2012). Investigation of taxi travel time characteristics. Advances in Transportation Studies, (27).

Cochran, W. G. (1977). *Sampling techniques*. Canada: John Wiley & Sons.

Cramer, J., & Krueger, A. B. (2016). Disruptive change in the taxi business: The case of Uber. American Economic Review, 106(5), 177-182. DOI: 10.1257/aer.p20161002

Ghaffar, A., Mitra, S., & Hyland, M. (2020). Modeling determinants of ridesourcing usage: A census tract-level analysis of Chicago. Transportation Research Part C: Emerging Technologies, 119, 102769. DOI: https://doi.org/10.1016/j.trc.2020.102769

IBB (2023a), Istanbul Transportation Bulletin. Istanbul Metropolitan Municipality, Retrieved May 21, 2024. https://cdn-uym.ibb.gov.tr/cdn/uym/Bultenlerimiz/istanbul-ulasim-bulteni-2023-2.pdf

IBB (2023b), Taxi Transportation Segments and Fee Tariff. Istanbul Metropolitan Municipality, Retrieved May 21, 2024. https://tuhim.ibb.gov.tr/media/2573/taksi-yay%C4%B1nlama.pdf

Jiang, S., Chen, L., Mislove, A., & Wilson, C. (2018, April). On ridesharing competition and accessibility: Evidence from uber, lyft, and taxi. In Proceedings of the 2018 World Wide Web Conference (pp. 863-872). DOI: https://doi.org/10.1145/3178876.3186134

Kattan, L., de Barros, A., & Wirasinghe, S. C. (2010). Analysis of work trips made by taxi in Canadian cities. Journal of Advanced Transportation, 44(1), 11-18. DOI: 10.1002/atr.102

Kong, H., Zhang, X., & Zhao, J. (2020). Is ridesourcing more efficient than taxis?. Applied Geography, 125, 102301. DOI: 10.1016/j.apgeog.2020.102301

Liu, F., Gao, F., Yang, L., Han, C., Hao, W., & Tang, J. (2022). Exploring the spatially heterogeneous effect of the built environment on ride-hailing travel demand: A geo.graphically weighted quantile regression model. Travel Behaviour and Society, 29, 22-33. DOI: 10.1016/j.tbs.2022.05.004

Milioti, C., Kepaptsoglou, K., Kouretas, K., & Vlahogianni, E. I. (2022). Driver perceptions on taxi-sharing and dynamic pricing in taxi services: Evidence from Athens, Greece. Journal of Public Transportation, 24, 100022. DOI: 10.5038/2375-0901.23.2.4

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. (2016). Response surface methodology: process and product optimization using designed experiments. John Wiley & Sons.

Nguyen-Phuoc, D. Q., Tran, P. T. K., Su, D. N., Oviedo-Trespalacios, O., & Johnson, L. W. (2021). The formation of passenger loyalty: Differences between ride-hailing and traditional taxi services. Travel Behaviour and Society, 24, 218-230. DOI: 10.1016/j.tbs.2021.04.006

Nian, G., Huang, J., & Sun, D. (2022). Exploring built environment influence on taxi vacant time in megacities: A case study of Chongqing, China. Journal of Advanced Transportation, 2022, 1-14. DOI: 10.1155/2022/3096901

Pan, Y., Chen, S., Li, T., Niu, S., Tang, K., 2019a. Exploring spatial variation of the bus stop in fl uence zone with multi-source data: a case study in Zhenjiang, China. J. Transp. Geogr. 76, 166–177. DOI: 10.1016/j.jtrangeo.2019.03.012

Shaheen, S., Cohen, A., Chan, N., & Bansal, A. (2020). Sharing strategies: carsharing, shared micromobility (bikesharing and scooter sharing), transportation network companies, microtransit, and other innovative mobility modes. In Transportation, land use, and environmental planning (pp. 237-262). Elsevier. DOI: 10.1016/B978-0-12-815167-9.00013-X

Szeto, W. Y., Wong, R. C. P., & Yang, W. H. (2019). Guiding vacant taxi drivers to demand locations by taxi-calling signals: A sequential binary logistic regression modeling approach and policy implications. Transport Policy, 76, 100-110. DOI: 10.1016/j.tranpol.2018.06.009

Qian, X., Ukkusuri, S.V., 2015. Spatial variation of the urban taxi ridership using GPS data. Appl. Geogr. 59, 31–42. DOI: 10.1016/j.apgeog.2015.02.011

Qian, X., & Ukkusuri, S. V. (2017). Time-of-day pricing in taxi markets. IEEE Transactions on Intelligent Transportation Systems, 18(6), 1610-1622. DOI: 10.1109/TITS.2016.2614621

Yuan, J., Zheng, Y., Zhang, L., Xie, X., & Sun, G. (2011, September). Where to find my next passenger. In Proceedings of the 13th international conference on Ubiquitous computing (pp. 109-118). DOI: 10.1145/2030112.2030128

Welch, T. F., Gehrke, S. R., & Widita, A. (2020). Shared-use mobility competition: a trip-level analysis of taxi, bike share, and transit mode choice in Washington, DC. Transportmetrica A: Transport Science, 16(1), 43-55. DOI: 10.1080/23249935.2018.1523250

Wu, T., Shen, Q., Xu, M., Peng, T., & Ou, X. (2018). Development and application of an energy use and CO2 emissions reduction evaluation model for China's online car hailing services. Energy, 154, 298-307. DOI: 10.1016/j.energy.2018.04.130

Zhang, W., Ukkusuri, S. V., & Lu, J. J. (2017). Impacts of urban built environment on empty taxi trips using limited geolocation data. Transportation, 44, 1445-1473. DOI: https://doi.org/10.1007/s11116-016-9709-3

Zong, F., Wu, T., & Jia, H. (2018). Taxi drivers' cruising patterns—Insights from taxi GPS traces. IEEE Transactions on Intelligent Transportation Systems, 20(2), 571-582. DOI: 10.1109/TITS.2018.2816938

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ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

Türkiye ve Benzer Özellik Gösteren Avrupa Ülkelerinin Ulaştırma Sistemleri Açısından Karşılaştırmalı Analizi

Comparative Analysis of Türkiye and European Countries with Similar Characteristics in Terms of Transportation Systems

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ÖZ

Ulaştırma sistemleri, sağladığı erişim kolaylığı sayesinde sosyoekonomik gelişme ile yakından ilişkilidir. İyi koordine olmuş bir ulaştırma sisteminin etkinliği sürdürülebilir bir büyüme için önemli rol oynamaktadır. Avrupa'da nüfus ve büyüklük olarak Türkiye ile kıyaslanabilir ülkeler ve Türkiye karayolu, demiryolu, denizyolu ve havayolu ulaşım türleri için ulaşım ağı, yolcu ve yük taşımaları karşılaştırılmıştır. Genel verileri derlenen ülkeler Türkiye'nin yanı sıra Almanya, Fransa, İtalya, İspanya, Polonya ve Birleşik Krallık'tır. Türel dağılımlarda havayolu ve denizyolu modlarına ilişkin verinin analiz yapılan tüm ülkelere ait bilgisi olmadığından dolayı yalnızca kara ulaştırmasındaki (karayolu ve demiryolu) mod payları incelenmiştir. Sonuçlar, Türkiye'nin karayolu taşımacılığında baskın bir pozisyonda olduğunu, ancak demiryolu taşımacılığında gelişim potansiyeline sahip olduğunu göstermektedir. Yıllık veri serileri incelendiğinde 2020 yılında Covid-19 pandemisinin veri yapısını önemli derecede değiştirdiği sonucuna varılmaktadır. Sonuçlar genel olarak ülkelerin gelişmişlik düzeyi ile ilişkilendirilebilir niteliktedir. Türkiye'nin gelişmiş Avrupa ülkelerine göre ne durumda olduğu çalışmada aktarılmaktadır.

ABSTRACT

Transportation systems are closely related to socioeconomic development thanks to the ease of access they provide. The efficiency of a well-coordinated transportation system plays an important role for sustainable growth. Countries in Europe comparable to Türkiye in terms of population and size and Türkiye were compared in terms of transportation network, passenger and freight transportation for road, rail, sea and air transportation types. The countries for which general data were compiled are Germany, France, Italy, Spain, Poland and the United Kingdom, as well as Türkiye. Since the data on airline and sea modes in the modal distributions is not available for all analyzed countries, only the mode shares in land transportation (road and railway) were examined. The results show that Türkiye holds a dominant position in road transportation but has significant potential for development in rail transport. When the annual data series are examined, it is concluded that the Covid-19 pandemic significantly changed the data structure in 2020. The results are generally attributable to the development level of the countries. The study explains Türkiye 's situation compared to developed European countries.

Anahtar Kelimeler: Ulaştırma Sistemleri, Karayolu, Demiryolu, Denizyolu, Havayolu

Keywords: Transportation Systems, Highways, Railways, Seaways, Airways

EXTENDED ABSTRACT

Transportation systems are essential for socioeconomic development by ensuring access and mobility. The efficiency of these systems, particularly in road and rail transport, significantly influences a country's economic growth and environmental sustainability. This study offers a comparative analysis of transportation systems in Türkiye and European countries with similar population sizes and geographical characteristics, such as Germany, France, Italy, Spain, Poland, and the United Kingdom. The objective is to assess Türkiye's current standing in various transportation modes and identify areas for improvement, particularly in rail transport.

This analysis utilizes data from internationally recognized sources, including the OECD, Eurostat, and the World Bank, focusing on the period from 2010 to 2021. It examines transportation infrastructure and modal shares in road and rail transport for both

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passenger and freight movement. The study highlights the role of geographical and political factors in shaping transportation preferences across countries.

The findings reveal that Türkiye relies heavily on road transport, with 99.4% of passenger transportation and 95.1% of freight transportation carried out by road in 2021 when the modal shares in land transportation is analyzed. This level of dependency on a single mode of transport is in stark contrast to the more diversified modal distributions observed in other European countries. For instance, in Germany and France, a more balanced approach is seen, with significant portions of both passenger and freight movement being handled by rail. Germany, in particular, stands out with over 20% of its freight being transported via rail. In Türkiye, by contrast, rail accounts for only 0.6% of passenger transport and 4.9% of freight transport. These figures suggest that Türkiye has significant untapped potential in the rail sector, which could be developed to reduce its overwhelming reliance on road transport.

Geographical conditions and political strategies play a key role in determining transportation infrastructure choices. Türkiye's vast, mountainous terrain has historically favored road transport due to its flexibility. In contrast, flatter landscapes in countries like Germany and France have enabled more effective investment in rail networks, contributing to higher rail usage rates. The role of EU transportation policies, which promote sustainable and integrated transport systems, has also been crucial in shaping the transportation strategies of European countries.

Based on these findings, several recommendations are made to enhance Türkiye's transportation system. First, increasing investment in rail infrastructure is essential to reduce reliance on road transport. Expanding and modernizing the rail network, particularly for freight transport, will improve logistics efficiency. Second, enhancing multimodal transportation systems, especially by integrating road and rail transport, will lead to more efficient logistics operations. This can be encouraged through government policies and incentives that promote the use of rail for long-distance freight. Lastly, promoting sustainable transportation is critical. Prioritizing the development of electric and hybrid vehicles, expanding public transit systems, and investing in green transportation infrastructure will contribute to reduced carbon emissions and align with global sustainability objectives.

This comparative analysis underscores both the strengths and weaknesses of Türkiye's current transportation system. While Türkiye has a dominant position in road transport, its underdeveloped rail sector presents a strategic opportunity for investment and policy reform. By addressing these areas and implementing the suggested improvements, Türkiye can enhance its transportation efficiency, support sustainable development, and strengthen its competitiveness in the global logistics market.

Providing access to more up-to-date data in future studies will contribute to obtaining more accurate and comprehensive results in the analysis of transport systems. Especially with the inclusion of data for the period after 2023-2024 in international databases, the long-term effects of the pandemic on the transport sector and the effects of the investments made in this process can be evaluated more clearly. Making national and international data sources more accessible, improving data collection processes and evaluating the latest developments in countries' transport policies will make an important contribution to future research.

1. Giriş

Ulaşım türleri ve altyapıları, ekonomik kalkınmayı, sosyal etkileşimleri ve kültürel alışverişi destekleyen modern toplumların ayrılmaz bileşenleridir. Karayolu, demiryolu, havayolu ve denizyolu ulaşım türlerinin özellikleri, zorlukları ve etkileşimi, ulaşım ağlarının verimliliğini, erişilebilirliğini ve sürdürülebilirliğini etkilemektedir.

Ulaşımın çok yönlü doğasını anlamak, politika yapıcılar, planlamacılar ve araştırmacılar için ulaşım sistemlerinin karşılaştığı zorlukları ele almak, verimliliği artırmak ve çevresel etkileri en aza indirmek için çok önemlidir. Ulaşım sistemleri, farklı ulaşım türlerinin entegrasyonu ile altyapı gelişimini optimize ederek ve teknolojik gelişmeleri benimseyerek, toplumların gelişen ihtiyaçlarını karşılamak, ekonomik büyümeyi desteklemek ve herkes için yaşam kalitesini iyileştirmek üzere geliştirilebilir.

Ulaştırma sistemlerinin iyileştirilmesi için otoyol, karayolu, havayolu ve denizyolu gibi ulaşım altyapıları geliştirilmeye devam etmektedir. Ayrıca yeni ulaşım teknolojileri (akıllı ulaşım sistemleri, otonom ve akıllı araçlar, hyperloop vb.) geliştirilmekte ve sürdürülebilir ulaşım çerçevesinde iyileştirmelere devam edilmektedir.

Karayolu taşımacılığı ulaşım ağlarının omurgasını oluşturan en yaygın tür olup kesintisiz hareket sağlayan otoyol, devlet yolu, il yolu, kentiçi yolları, köy yolları ve orman yolları ağından oluşmaktadır. Karayolu taşımacılığı esneklik ve kapıdan kapıya hizmet sunması gibi özellikleri sayesinde kısa ve orta mesafeli seyahatler ve son kilometre lojistiği için tercih edilmektedir. Bununla birlikte, trafik sıkışıklığı, karayolu trafik güvenliği ve çevresel etkiler açılarından diğer ulaşım türlerinden daha dezavantajlı konumdadır. Ayrıca karayolu taşımacılığı yaygın yol ağı ile kaynakların ve ilk yardımın hızlı bir şekilde sevk edilmesini sağlayarak acil müdahale ve afet yönetiminde çok önemli bir yere sahiptir.

Özellikle uzun mesafelerde hem yolcu hem de yük hareketleri için verimli ve sürdürülebilir bir tür olan demiryolu taşımacılığı yüksek kapasite, güvenilirlik ve düşük enerji tüketimi yönleriyle öne çıkmaktadır. Demiryolu ağları şehirleri, bölgeleri ve ülkeleri birbirine bağlayarak şehirlerarası ve uluslararası seyahati kolaylaştırmakta olup yüksek hızlı raylı sistemler yüksek hız ve konfor sunarak şehirlerarası hareketlilikte bir iyileşmeye yol açmaktadır. Bununla birlikte, demiryolu altyapısı, artan talebi karşılamak, güvenlik ve verimliliği sağlamak için bakım, genişleme ve iyileştirmeye ihtiyaç duymaktadır.

Havayolu türü şehirler ve ülkeler arasında hızlı bağlantı sağlayan, uzun mesafeli seyahat için çok önemli bir ulaşım türü olup hızlı,

erişilebilir ve coğrafi engelleri aşma özelliklerine sahiptir. Havalimanları, yolcuları ve yükleri birbirine bağlayan ve hareketlerini kolaylaştıran temel merkezlerdir. Uçak tasarım ve teknolojisindeki gelişmeler sayesinde emisyonlar azalmış, yakıt verimliliği ve yolcu konforu artmıştır. Ancak, altyapı verimliliğinin ve sürdürülebilirliğin artırılması için havalimanlarındaki tıkanıklık, gürültü kirliliği ve yüksek karbon emisyonları gibi olumsuzlukların azaltılması gibi konularda çalışmalar yapılması ihtiyacı devam etmektedir.

Diğer ulaşım türlerine göre yüksek taşıma kapasitesi, enerji verimliliği ve birim yük başına daha düşük emisyon avantajlarına sahip olan denizyolu taşımacılığı küresel ticarette ve dökme yüklerin hareketinde çok önemli bir rol oynamaktadır. Limanlar, kara ve su taşımacılığı arasında, malların yüklenmesini, boşaltılmasını ve aktarılmasını kolaylaştıran doğal lojistik merkezler olarak hizmet vermektedirler. Deniz/göl/nehir ekosistemleri üzerindeki potansiyel etkileri ve gemilerden kaynaklı yüksek emisyonlar gibi çevresel kaygılar sebebiyle sürdürülebilir uygulamalar ve teknolojiler konularında çalışmalara ihtiyaç duyulmaktadır.

Ulaşım türleri ve altyapıları, ekonomik kalkınmayı, sosyal etkileşimleri ve kültürel alışverişi desteklemekte olup günümüz yaşamının çok önemli bir bileşenidir. Karayolu, demiryolu, hava ve denizyolu ulaşım türlerinin özellikleri, avantajları, dezavantajları ve birbiriyle olan etkileşimleri mevcut ulaştırma sistemlerinin verimliliğini, erişilebilirliğini ve sürdürülebilirliğini etkilemektedir. Gerekli altyapı iyileştirmeleri ve türler arası bağlantılar ile otonom araçlar ve hyperloop gibi gelişmekte olan teknolojilere yapılan yatırımlar ile ulaştırma sisteminden elde edilecek faydalarda artış sağlanabilir.

Bu çalışmada ulaştırma sektörü ile ilgili genel bilgiler verilmekte, seçilmiş ülkeler ve Türkiye'de, karayolu, demiryolu, havayolu ve denizyolu ulaşım türlerine ilişkin 2010-2021 yılları arasında altyapı ile yolcu ve yük türel ayrım verilerine yer verilmiştir.

Bu çalışmanın amacı, Türkiye'nin ulaştırma altyapısı ve taşıma modlarının, nüfus ve coğrafi özellikler bakımından benzer Avrupa ülkeleriyle kıyaslanarak mevcut durumunu belirlemektir. Çalışma, Türkiye'nin karayolu ve demiryolu taşımacılığına odaklanarak, gelişmiş Avrupa ülkeleriyle kıyaslandığında hangi alanlarda gelişim potansiyeli taşıdığını ortaya koymayı hedeflemektedir. Böylece, Türkiye'nin ulaştırma politikaları ve altyapı yatırımlarının diğer ülkelerle karşılaştırıldığında nasıl bir konumda olduğu değerlendirilecek ve Türkiye'nin ulaştırma sektörüne yönelik iyileştirme önerileri sunulacaktır.

Çalışmanın özgün katkısı, Türkiye'nin ulaştırma sistemlerinin detaylı bir karşılaştırmasını sunarak, özellikle politikacılara ve karar alıcılara ulaşım politikaları ve yatırım stratejileri geliştirmede yol gösterici olacak veri ve analizler sağlamasıdır.

2. Literatür Taraması

Bu çalışmada, Türkiye ve Avrupa ülkelerinin ulaştırma sistemleri üzerine yapılan karşılaştırmalı analizlere odaklanılmıştır. Mevcut literatürde, Türkiye'nin ulaştırma sistemi üzerine odaklanan bazı çalışmalar bulunsa da bu çalışmalar genellikle tek modlu ulaştırma türlerine odaklanmıştır. Örneğin, Özoğlu ve Demirci (2021), Senir ve Büyükkeklik (2023). Türkiye'de karayolu taşımacılığının gelişimini incelemiştir, ancak demiryolu ve diğer modlar arasında karşılaştırmalı bir analiz yapılmamıştır. Avrupa ülkelerindeki benzer çalışmalar ise genellikle gelişmiş ülkelerin ulaştırma sistemlerini kıyaslamış ve Türkiye gibi gelişmekte olan ülkelerle sınırlı karşılaştırmalar yapmıştır (Örneğin, Darby ve Özdemir, 2010). Bu çalışma, Türkiye'nin tüm ulaştırma modları açısından Avrupa ülkeleri ile detaylı bir karşılaştırmasını sunarak literatüre önemli bir katkı sağlamaktadır.

Ulaştırma sistemleri, bir ülkenin ekonomik gelişimi ve toplumsal refahı açısından kritik bir öneme sahiptir. Türkiye'nin ulaştırma yatırımlarının değerlendirilmesine dair önemli bir analiz, 2010 yılında Şafak Bilgiç ve Güngör Evren tarafından yapılmıştır. Bu çalışmada, Türkiye'deki ulaştırma yatırımlarının mevcut değerlendirme yöntemlerinin yetersiz olduğu, resmi olarak tanımlanmış bir değerlendirme sürecinin bulunmadığı ve karar alma süreçlerinin dağınık bir yapıda olduğu vurgulanmaktadır. Yazarlar, Avrupa Birliği ülkelerinin uygulamalarına uygun, katılımcı ve şeffaf bir değerlendirme yöntemi önererek, Türkiye'deki ulaştırma yatırımlarının etkinliğini artırmayı hedeflemektedir (Bilgiç & Evren, 2010).

Karataş'a (2017) göre, Türkiye coğrafi üstünlüğünü mümkün olduğunca etkili şekilde kullanmalı, lojistik sektöründeki sorunları ele almalı ve ülkenin genel ulaşım politikalarını lojistik açıdan gözden geçirmelidir. Türkiye bu fırsatlardan hızlı ve efektif bir şekilde yararlanmazsa, bölgede büyüyen lojistik pazarının, alternatif ulaşım rotalarına sahip Yunanistan ve Bulgaristan gibi ülkeler tarafından domine edilmesine imkan sağlayacaktır. Türkiye'nin, lojistik sektöründeki konumunu ancak ulaşım modları arasında dengeli bir dağılımı garantilemek ve bunları entegre ulaşımla uyumlu hale getirmek için gerekli harcamaları yaparsa koruyabileceği değerlendirilmektedir.

Van Egmond vd (2004) çalışmasında ortaya çıkan kurumsal çerçeveyi gözden geçirmekte ve 22 Avrupa şehrinden oluşan bir örneklemde yerel toplu taşıma sistemleri için başarı koşullarını belirlemeye çalışmaktadır. Kapsamlı saha araştırmasına dayanarak, bu şehirlerdeki kentsel toplu taşıma sistemlerinin sistematik bir performans tablosu oluşturulmuş ve dört kritik başarı faktörü sınıfının bu sistemlerin performansı üzerindeki etkisi araştırılmıştır. Ampirik bölümde, politika ile ilgili sonuçlar elde etmek için hem nitel bir yorumlayıcı analiz hem de yakın zamanda geliştirilen bir yapay zeka aracı olan kaba küme analizi kullanılmıştır.

Şahan (2017) tarafından yapılan çalışmada ise taşımacılık faaliyetlerinin neden olduğu CO_2 emisyonu nedeniyle Türkiye'nin doğal çevreye olan etkisi OECD ortalamasıyla karşılaştırılarak analiz edilmiştir. Ayrıca her bir taşımacılık modu bazında verideki dikkat çeken noktalar belirtilerek Türkiye'nin OECD ortalamasına göre durumu incelenmiştir.

3. Materyal ve Metot

Bu çalışmada, Türkiye ve Avrupa ülkeleri arasındaki ulaştırma sistemlerinin karşılaştırılması için veriler, güvenilir uluslararası veri tabanlarından elde edilmiştir. Kullanılan veriler, OECD ve Eurostat gibi kurumlardan alınan 2010-2021 yılları arasındaki istatistiklerden oluşmaktadır. Karşılaştırmalı analizde, karayolu ve demiryolu taşımacılığına ilişkin veriler incelenmiş ve Türkiye'nin bu iki moddaki durumu Almanya, Fransa, İtalya, İspanya, Polonya ve Birleşik Krallık ile kıyaslanmıştır. Verilerin analizinde karşılaştırmalı analiz yöntemi kullanılmış, her ülkenin taşımacılık altyapısı ve mod payları grafiklerle desteklenmiştir. Bu karşılaştırmalar, ulaştırma altyapısı uzunlukları, yolcu ve yük taşımacılığı verileri gibi çeşitli kriterlere göre yapılmıştır.

Çalışmada seçilen Almanya, Fransa, İtalya, Polonya, İspanya, Türkiye ve Birleşik Krallık, nüfus, coğrafi büyüklük ve ekonomik gelişmişlik bakımından Türkiye'ye benzer özellikler göstermeleri nedeniyle tercih edilmiştir. Ayrıca, bu ülkeler Avrupa'nın farklı bölgelerindeki ulaşım sistemleri ve mod dağılımlarını temsil etmektedir. Almanya ve Fransa gibi Batı Avrupa ülkeleri, gelişmiş ulaşım ağlarına ve ileri düzeyde demiryolu sistemlerine sahipken, Polonya gibi Doğu Avrupa ülkeleri daha gelişmekte olan ulaşım altyapılarıyla dikkate alınmıştır. Türkiye'nin karayolu ağı ağırlıklı ulaşım sistemi, bu çeşitlilik içerisinde önemli bir analiz sunmaktadır. Bu nedenle, karşılaştırma yapılacak ülkelerin temsiliyeti, hem ekonomik hem de ulaşım altyapısı açısından anlamlıdır ve bu ülkelerden elde edilen bulgular, Türkiye'nin ulaşım politikalarını değerlendirmede önemli bir referans teşkil etmektedir.

Bu çalışmada Avrupa ülkelerine odaklanılmasının sebebi, Türkiye ile benzer nüfus ve coğrafi özelliklere sahip ülkeler üzerinden bir karşılaştırma yaparak ulaştırma sistemlerinin etkinliğini değerlendirmektir. Ancak, daha geniş bir coğrafi kapsam ele alınsaydı, sonuçların farklı olabileceği de vurgulanmalıdır. Örneğin, ABD gibi geniş kara parçasına sahip ülkelerde karayolu taşımacılığı dominant bir ulaşım modu olarak öne çıkmakta, demiryolu taşımacılığı ise uzun mesafelerde tercih edilmektedir. Çin gibi büyük nüfusa sahip ülkelerde ise denizyolu taşımacılığı ve demiryolu taşımacılığı önemli bir rol oynamaktadır. Bu ülkelerin çalışma kapsamına dahil edilmesi durumunda Türkiye'nin ulaşım altyapısının daha geniş ölçekli uluslararası kıyaslamalarla karşılaştırılması ve ulaşım modlarının geliştirilmesi için daha fazla perspektif sunulabileceği değerlendirilmektedir. Bununla birlikte, bu çalışmada Avrupa ülkelerine odaklanılması, Türkiye'nin benzer gelişmişlik seviyesindeki ülkelerle karşılaştırılmasını mümkün kılmıştır.

Veri Toplama Süreci ve Kullanılan Kriterler

Bu çalışmada, Türkiye ve Avrupa'daki benzer ülkelerin ulaştırma sistemleri, karayolu ve demiryolu taşımacılığı gibi temel ulaşım modları üzerinden karşılaştırmalı bir analizle incelenmiştir. Veriler, **OECD, Eurostat, World Bank** gibi uluslararası veri tabanlarından temin edilmiştir. Seçilen ülkeler (Almanya, Fransa, İtalya, Polonya, İspanya, Türkiye ve Birleşik Krallık), nüfus ve coğrafi büyüklük açısından Türkiye ile benzerlik göstermekte olup, bu karşılaştırma için uygun bir temel sunmaktadır.

Kullanılan Veri Setlerinin Kalitesi ve Güvenirliği

Bu çalışmada kullanılan veri setleri, OECD ve Eurostat gibi uluslararası kabul görmüş kuruluşlar tarafından toplanan verilerdir. Bu veri tabanları, ülkelerin ulaştırma politikaları, altyapı yatırımları ve taşımacılık faaliyetlerine ilişkin resmi istatistikler sunmaktadır. Verilerin toplanma süreci, uluslararası standartlara uygun olup, ülkeler arasında karşılaştırılabilir niteliktedir. Ayrıca, veriler çeşitli dönemlerde güncellenmekte ve güvenilirlikleri resmi kaynaklar tarafından düzenli olarak denetlenmektedir.

Veri Setlerinin Kullanımı ve Karşılaştırma Kriterleri

Veri setleri, 2010-2021 yıllarına ait ulaştırma verilerini içermekte olup, yolcu ve yük taşımacılığı oranları üzerinden analiz edilmiştir. Karayolu, demiryolu, denizyolu ve havayolu taşımacılığına ilişkin yıllık veriler, her ülkenin ulaştırma performansını göstermektedir. Verilerin analizinde, her ulaşım modunun yıllar içindeki değişim oranları, yatırımların etkileri ve uluslararası trendler dikkate alınmıştır. Bu kriterler doğrultusunda, Türkiye'nin ulaşım modlarındaki güçlü ve zayıf yönleri belirlenmiş ve ülkeler arası karşılaştırmalar yapılmıştır.

4. Türkiye'de ve Avrupa'da Ulaştırma Sektörüne İlişkin Genel Verilerin Karşılaştırılması

Bu çalışmada Avrupa'da ve Türkiye'de ulaştırma sektörüne ilişkin her bir ulaşım türü için genel veriler ve türel ayrım verileri derlenmiştir. Genel verileri derlenen ülkeler Almanya, Fransa, İtalya, İspanya, Polonya, Türkiye ve Birleşik Krallık'tır. Yolcu ve yük türel ayrım verileri ise karşılaştırma olması açısından ve veri mevcudiyetine göre Almanya, Fransa, İtalya, İspanya, Polonya ve Türkiye için verilmiştir. Herhangi bir ülkeye ait verilerin mevcut olmadığı durumda o ülkeye grafikte yer verilmemiştir. Genel olarak bütün verilerin tam olduğu 2010-2021 arası veriler kullanılmıştır. Verilere ulaşılamadığı için karayolu yol uzunlukları verileri olarak 2010-2018 yılları ve Türkiye'ye ilişkin türel ayrım verileri olarak ise 2013-2021 yılları verileri kullanılmıştır.

Söz konusu yedi ülkenin seçilme sebepleri ilgili verilerin resmi kaynaklardan eksiksiz ve uyumlu olarak derlenmesi, tüm ulaşım türlerinin bulunabilmesi, ülkelerin nüfus ve büyüklük olarak Türkiye ile kıyaslanabilir olmalarıdır. Bu ülkelere ilişkin sosyo-demografik veriler Tablo 1'de verilmektedir.

Tablo 1. Analizi Yapılan Ulkelerin Sosyo-demografik verileri

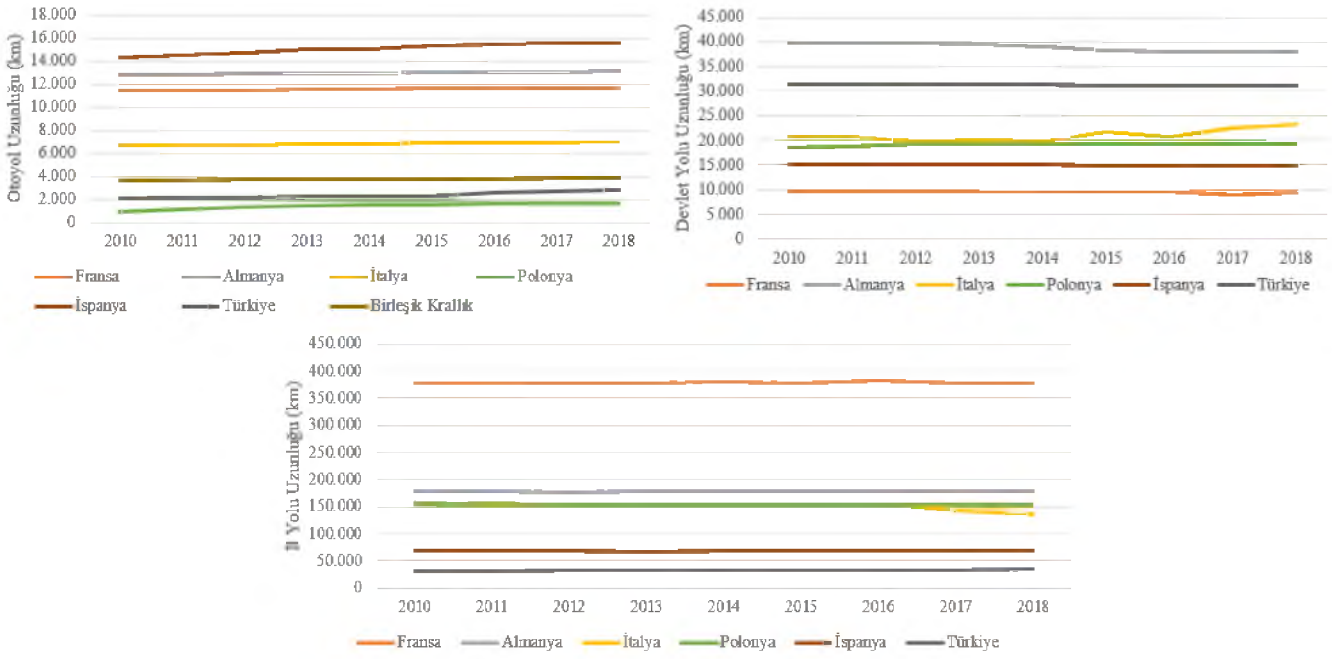
2022	Yüzölçüm (1000 km^2)	Nüfus (milyon)	Nüfus yoğunluğu (kişi/km^2)	GSYİH (Milyar Dolar)	Kişi Başına GSYİH (Dolar)
Almanya	357,59	84,1	235,19	4.072,19	48.421
Fransa	549,09	67,9	123,66	2.782,91	40.985
İtalya	302,07	58,8	194,66	2.010,43	34.191
İspanya	505,96	47,6	94,08	1.397,51	29.359
Polonya	312,71	37,5	119,92	688,18	18.351
Türkiye	785,35	85,3	108,61	905,99	10.621
Birleşik Krallık	243,61	67,0	275,03	3.070,67	45.831

Kaynak: (WorldBank, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

Listenin yüzölçümü açısından en büyük ülkesi 785.350 km^2 ile Türkiye, 549.090 km^2 ile Fransa ikinci, 505.960 km^2 ile İspanya'nın ardından 357.590 km^2 ile Almanya dördüncü sırada yer almaktadır. Nüfusta da benzer şekilde Türkiye, 85,3 milyon ile listedeki lider konuma sahiptir. Almanya ise Türkiye'den az bir farkla 84,1 milyon kişi ile ikinci durumdadır. Bu da Almanya'nın nüfus yoğunluğunun Türkiye'nin iki katından fazla hesaplanması sonucunu doğurmaktadır. Nüfusun yüzölçümüne oranına bakıldığında 275,03 kişi/km^2 ile Birleşik Krallık en yoğun ülkedir. Türkiye, GSYİH açısından 905,99 milyar ABD doları ile Polonya'dan (688,18 milyar ABD Doları) önce fakat listenin sonlarında yer almaktadır. Listenin başında 4.072,19 milyar dolarla Almanya yer alırken, onu 2.782,91 milyar dolarla Fransa takip etmektedir. Ancak kişi başına düşen GSYİH sıralamasında 10.621 dolar ile Türkiye, 18.351 dolar ile 6. sırada yer alan Polonya'nın ardından son sırada yer almaktadır. Karşılaştırmalı analiz yapılan ülkeler arasında kişi başına en yüksek GSYİH (48.421 USD) Almanya'ya aittir.

4.1. Karayolu Ulaştırması

Seçilmiş ülkeler için 2010-2018 yılları arasında otoyol, devlet yolu ve il yolu uzunlukları Şekil 1'de verilmiştir.



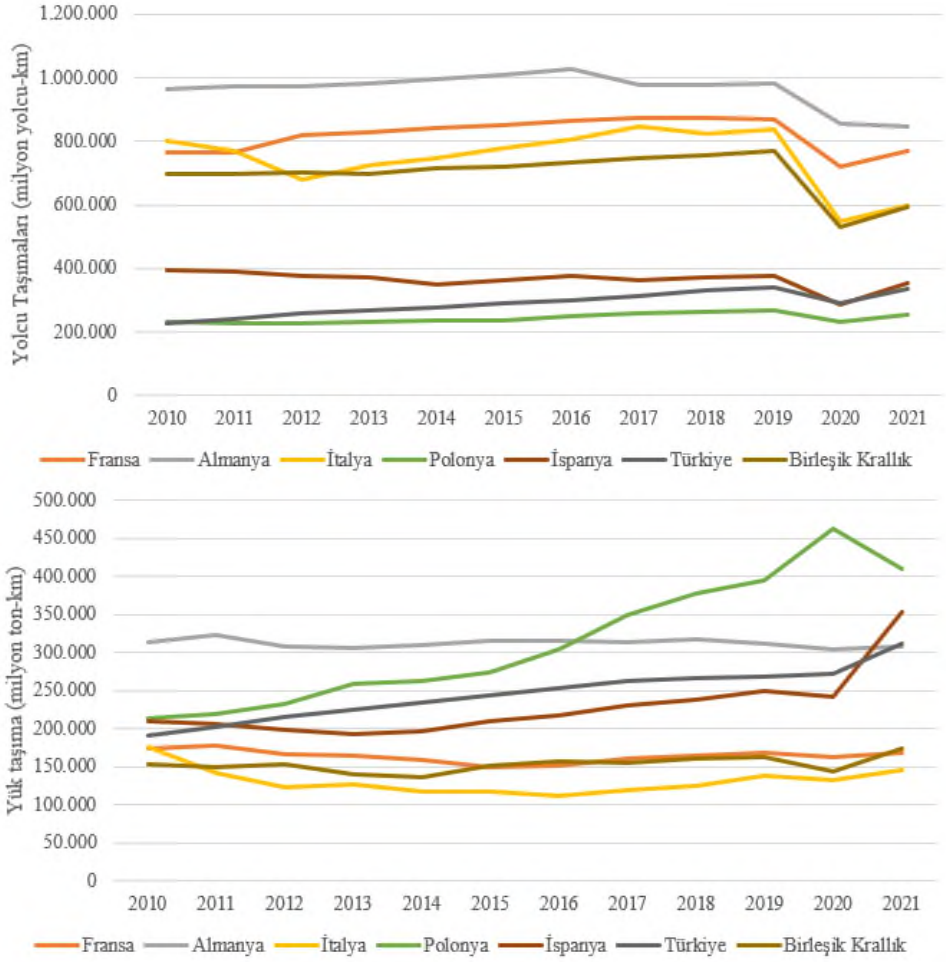
Şekil 1. Seçilmiş Ulkelerde Otoyol, Devlet Yolu ve İl Yolu Uzunlukları (2010-2018) (km)
Kaynak: (OECD, 2023) ve (UNECE, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

Seçilmiş ülkeler içinde 2018 yılında en uzun otoyola sahip ilk üç ülke 15.585 km ile İspanya, 13.141 km ile Almanya ve 11.671 km ile Fransa'dır. Türkiye'nin otoyol uzunluğu ise 2018 yılında 2.842 km ile altıncı sıradadır.

Seçilmiş ülkeler içinde 2018 yılında en uzun devlet yoluna sahip ilk üç ülke 37.879 km ile Almanya, 31.021 km ile Türkiye ve 23.335 km ile İtalya'dır.

Seçilmiş ülkeler içinde 2018 yılında en uzun il yoluna sahip ilk üç ülke 378.401 km ile Fransa, 178.806 km ile Almanya ve 153.497 km ile Polonya'dır. Türkiye'de ise 34.153 km il yolu bulunmaktadır.

Seçilmiş ülkeler için 2010-2021 yılları arasında karayolu ile yapılan yolcu ve yük taşımaları Şekil 2'de verilmiştir.



Şekil 2. Seçilmiş Ülkelerde Karayolunda Yolcu ve Yük Taşımaları (2010-2021) (yolcu-km, milyon ton-km)
Kaynak: (OECD, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

Seçilmiş ülkelerde 2021 yılında karayolu ile en çok yolcu taşımacılığı yapılan ilk üç ülke sırasıyla 846.687 milyon yolcu-km ile Almanya, 769.146 milyon yolcu-km ile Fransa ve 598.582 milyon yolcu-km ile İtalya'dır. Türkiye'de 2021 yılında 336.188 milyon yolcu-km yolculuk yapılmıştır. Covid-19 pandemisi sebebiyle yolcu taşımalarında 2020 yılında 2019 yılına göre ortalama yüzde 22 azalış görülürken Türkiye'de bu azalış yüzde 15 seviyesinde gerçekleşmiştir.

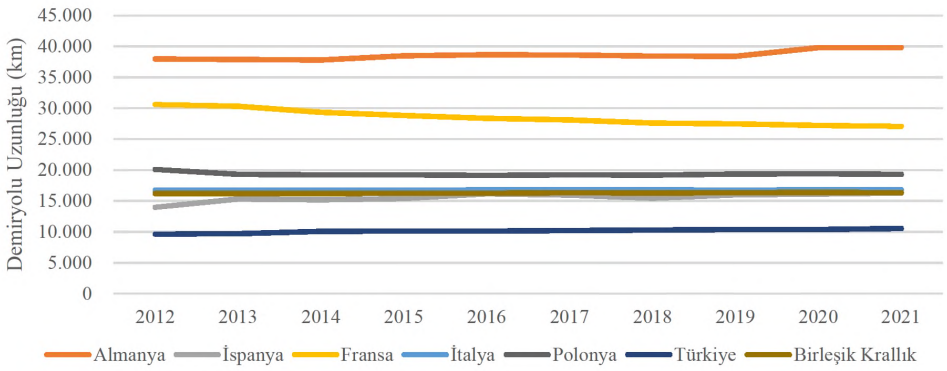
Seçilmiş ülkelerde 2021 yılında karayolu ile en çok yük taşımacılığı yapılan ilk üç ülke sırasıyla 410.224 milyon ton-km ile Polonya, 353.676 milyon ton-km ile İspanya ve 311.818 milyon ton-km ile Türkiye'dir. Yolcu ve yük taşımacılığında ilk üç ülkenin farklı olmasının yolcu taşımacılığının ülkelerin kişi başı GSYH değerleri ile yük taşımacılığının ise ülkelerin transit ülke olmasından kaynaklanabileceği düşünülmektedir. Covid-19 pandemisi sebebiyle yük taşımalarında 2020 yılında 2019 yılına göre yedi ülkenin beşinde azalış görülmüş ancak ortalama yüzde 1,5 artış gerçekleşmiştir. Türkiye'de ise yük taşımalarında 2020 yılında 2019 yılına göre yüzde 2 artış gerçekleşmiştir.

4.2. Demiryolu Ulaştırması

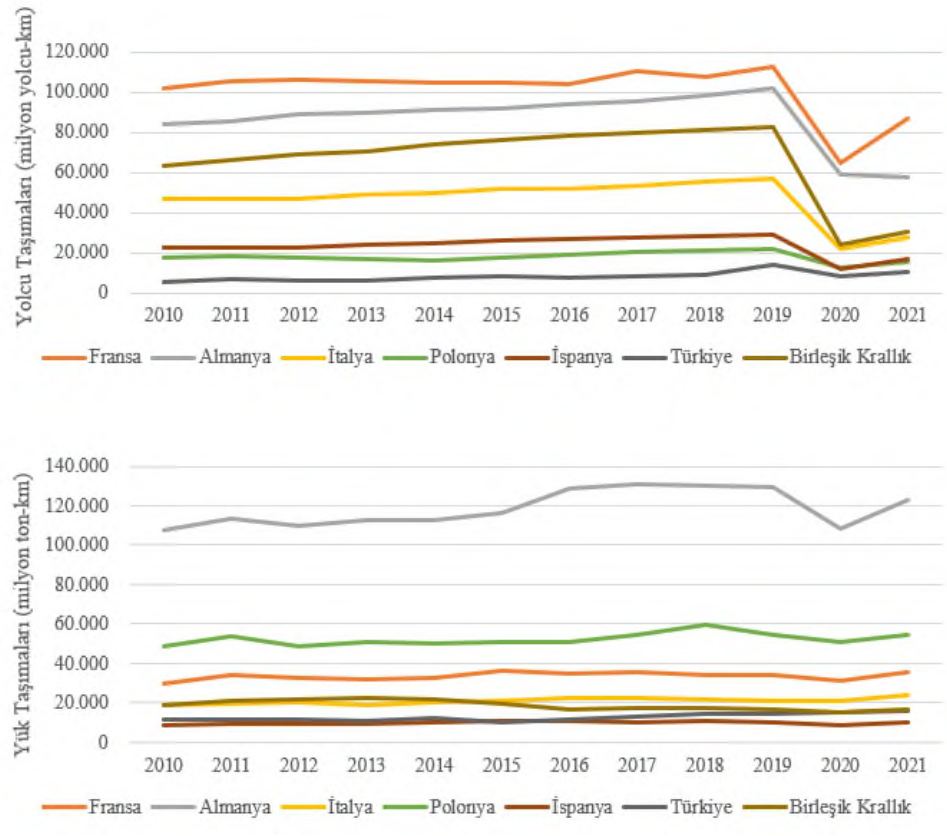
Seçilmiş ülkeler için 2012-2021 yılları arasında demiryolu uzunlukları (güzergâh olarak) Şekil 3'te verilmiştir.

Seçilmiş ülkeler içinde 2021 yılında güzergah olarak en uzun demiryoluna sahip ilk üç ülke 39.799 km ile Almanya, 27.057 km ile Fransa ve 19.287 km ile Polonya'dır. Türkiye'nin güzergâh olarak demiryolu uzunluğu ise 2021 yılında 10.546 km'dir.

Seçilmiş ülkeler için 2010-2021 yılları arasında demiryolu ile yapılan yolcu ve yük taşımacılığı verileri Şekil 4'te verilmiştir.



Şekil 3. Seçilmiş Ülkelerde Demiryolu Uzunlukları (2012-2021) (km)
Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.



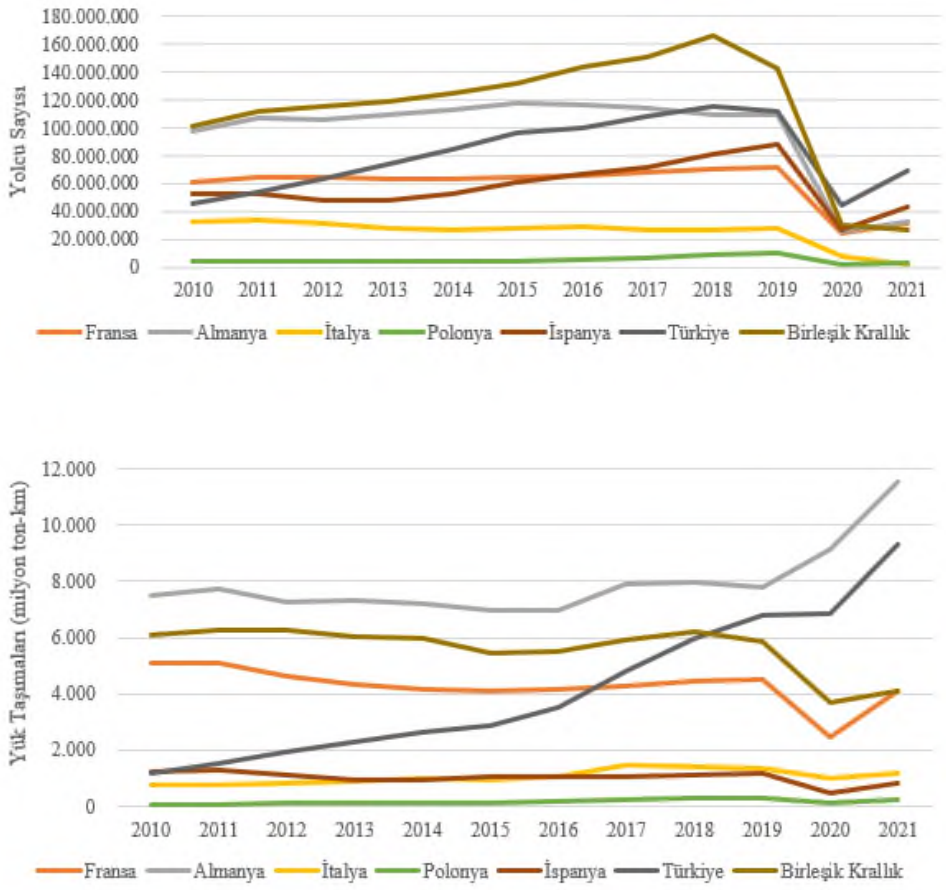
Şekil 4. Seçilmiş Ülkelerde Demiryolunda Yolcu ve Yük Taşımaları (2010-2021) (yolcu-km, milyon ton-km)
Kaynak: (OECD, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

Seçilmiş ülkelerde 2021 yılında demiryolu ile en çok yolcu taşımacılığı yapılan ilk üç ülke sırasıyla 86.853 milyon yolcu-km ile Fransa, 57.518 milyon yolcu-km ile Almanya ve 30.841 milyon yolcu-km ile Birleşik Krallık'tır. Türkiye'de 2021 yılında 10.683 milyon yolcu-km yolcu taşımacılığı yapılmıştır. Covid-19 pandemisi sebebiyle yolcu taşımacılığında 2020 yılında 2019 yılına göre ortalama yüzde 52 azalış görülürken Türkiye'de bu azalış yüzde 42 seviyesinde gerçekleşmiştir.

Seçilmiş ülkelerde 2021 yılında demiryolu ile en çok yük taşımacılığı yapılan ilk üç ülke sırasıyla 123.067 milyon ton-km ile Almanya, 54.387 milyon ton-km ile Polonya ve 35.751 milyon ton-km ile Fransa'dır. Almanya'nın bu sıralamada açık ara önde olduğu görülmektedir. Türkiye'nin demiryolunda yük taşımacılığı 2021 yılında 15.900 milyon ton-km olarak gerçekleşmiştir. Covid-19 pandemisi sebebiyle yük taşımacılığında 2020 yılında 2019 yılına göre yedi ülkenin altısında azalış görülmüş olup bu azalışlar ortalama yüzde 11 seviyesinde gerçekleşmiştir. Söz konusu süreçte yük taşımacılığında artış görülen tek ülke olan Türkiye'de ise 2020 yılında 2019 yılına göre yaklaşık yüzde 5 artış gerçekleşmiştir.

4.3. Havayolu Ulaştırması

Seçilmiş ülkeler için 2010-2021 yılları arasında havayolu yolcu taşımacılığı verileri Şekil 5'te verilmiştir.



Şekil 5. Seçilmiş Ülkelerde Havayolu Yolcu ve Yük Taşımaları (2010-2021)
Kaynak: (WorldBank, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

Seçilmiş ülkeler içinde 2021 yılında en çok havayolu yolcusu olan ilk üç ülke 69.065.868 yolcu ile Türkiye, 43.440.480 yolcu ile İspanya ve 33.073.180 yolcu ile Almanya'dır. Covid-19 pandemisi sebebiyle yolcu sayılarında 2020 yılında 2019 yılına göre ortalama yüzde 71 azalış görülürken Türkiye'de bu azalış yüzde 60 seviyesinde gerçekleşmiştir.

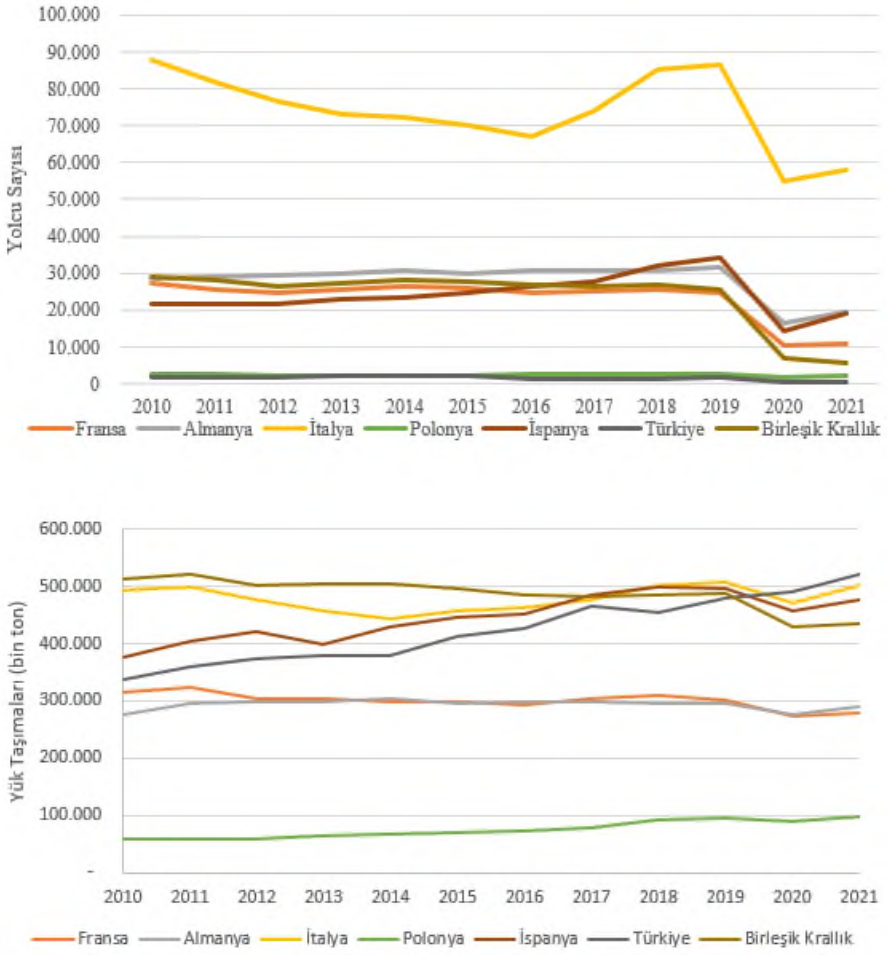
Seçilmiş ülkelerde 2021 yılında havayolu ile en çok yük taşımacılığı yapılan ilk üç ülke sırasıyla 11.533 milyon ton-km ile Almanya, 9.338 milyon ton-km ile Türkiye ve 4.107 milyon ton-km ile Fransa'dır. Covid-19 pandemisi sebebiyle yük taşımalarında 2020 yılında 2019 yılına göre yedi ülkenin beşinde azalış görülmüş olup bu azalma ortalama yüzde 12 seviyesinde gerçekleşmiştir. Yük taşımalarında artış görülen iki ülkeden biri olan Türkiye'de ise 2020 yılında 2019 yılına göre yaklaşık yüzde 1 artış gerçekleşmiştir.

4.4. Denizyolu Ulaştırması

Seçilmiş ülkeler için 2010-2021 yılları arasında denizyolu yolcu taşımacılığı verileri Şekil 6'da verilmiştir.

Seçilmiş ülkeler içinde 2021 yılında en çok denizyolu yolcusu olan ilk üç ülke 57.916.000 yolcu ile İtalya, 19.496.000 yolcu ile Almanya ve 18.881.000 yolcu ile İspanya'dır. İtalya'nın bu sıralamada açık ara önde olduğu görülmektedir. 2021 yılında Türkiye'de denizyolu yolcu sayısı 289.000'dir. Covid-19 pandemisi sebebiyle yolcu sayılarında 2020 yılında 2019 yılına göre ortalama yüzde 49 azalış görülürken Türkiye'de bu azalış yüzde 81 seviyesindedir.

Seçilmiş ülkelerde 2021 yılında denizyolu ile en çok yük taşımacılığı yapılan ilk üç ülke sırasıyla 519.907 bin ton ile Türkiye, 501.603 bin ton ile İtalya ve 477.021 bin ton ile İspanya'dır. Covid-19 pandemisi sebebiyle yük taşımalarında 2020 yılında 2019 yılına göre yedi ülkenin altısında azalış görülmüş olup bu azalma ortalama yüzde 7 seviyesinde gerçekleşmiştir. Yük taşımalarında artış görülen tek ülke olan Türkiye'de ise 2020 yılında 2019 yılına göre yaklaşık yüzde 3 artış gerçekleşmiştir.



Şekil 6. Seçilmiş Ülkelerde Denizyolu Yolcu ve Yük Taşımaları (2010-2021) (bin, bin ton)
Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

4.5. Yolcu Türel Ayrım

Yolculukların ulaşım türlerine göre hangi oranlarda dağıldığı, 'türel ayrım' olarak tanımlanmaktadır. Türel ayrım, belirli bir ulaşım modunun (örneğin, karayolu, havayolu, demiryolu, denizyolu) toplam yolculuklar içindeki oranını analiz etmeyi ve bu oranların zaman içindeki değişimlerini incelemeyi ifade eder. Bu çalışma, farklı ulaşım türlerinin kullanım sıklığını ve eğilimlerini inceleyerek, ulaşım politikalarının geliştirilmesine katkıda bulunmayı amaçlamaktadır.

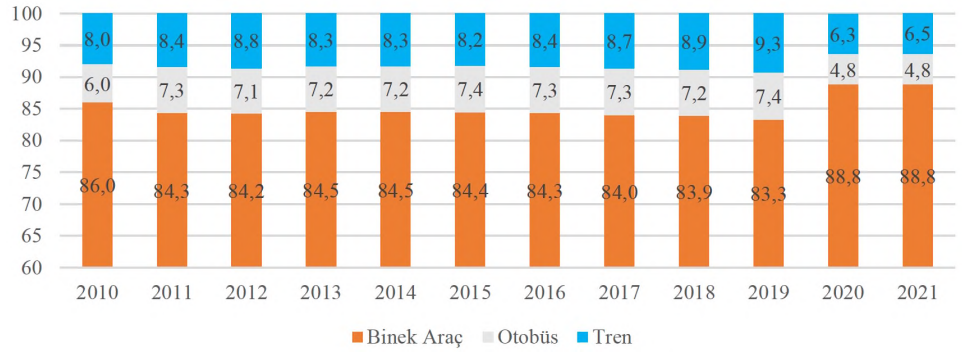
Bu bölümde Avrupa ülkeleri için kullanılan veriler EuroStat verileri olup binek araç, otobüs ve tren araç türleri için türel ayrım değerleri bulunmakta havayolu ve denizyolu verileri bulunmamaktadır. Türkiye verileri Ulaştırma ve Altyapı Bakanlığı verileri olup karayolu, demiryolu, denizyolu ve havayolu ulaşım türlerini içermektedir. Ancak çalışmada bütünlük sağlanması adına kara ulaştırması (karayolu ve demiryolu) türel ayrım verileri kullanılmıştır. Almanya, Fransa, İtalya, Polonya, İspanya ve Türkiye için yolcu türel ayrım değerleri verilmiştir.

2010-2021 yılları arasında Almanya'da ülke içinde gerçekleşen yolcu taşımaları için türel ayrım değerleri Şekil 7'de verilmiştir.

Almanya'da ülke içinde yapılan yolcu taşımalarında en çok binek araç kullanıldığı, binek aracın 2010 yılında yüzde 86 olan payının 2019 yılında en düşük değeri olan yüzde 83,3'e gerilediği, 2020 yılında Pandemi etkisiyle bu payın en yüksek değerine yani yüzde 88,8'e ulaştığı görülmektedir. Söz konusu dönem içinde otobüsün payı 2010 yılında yüzde 6 iken 2019 yılında en yüksek değeri olan yüzde 7,4'e ulaşmış ancak 2020 yılında Pandemi etkisiyle yüzde 4,8 ile en düşük değerine gerilemiştir. Ayrıca, yolcu taşımalarında trenin payı 2010 yılında yüzde 8 iken 2019 yılında en yüksek değeri olan yüzde 9,3'e ulaşmış ancak Pandemi etkisiyle 2020 yılında yüzde 6,3 ile en düşük değerine gerilemiştir.

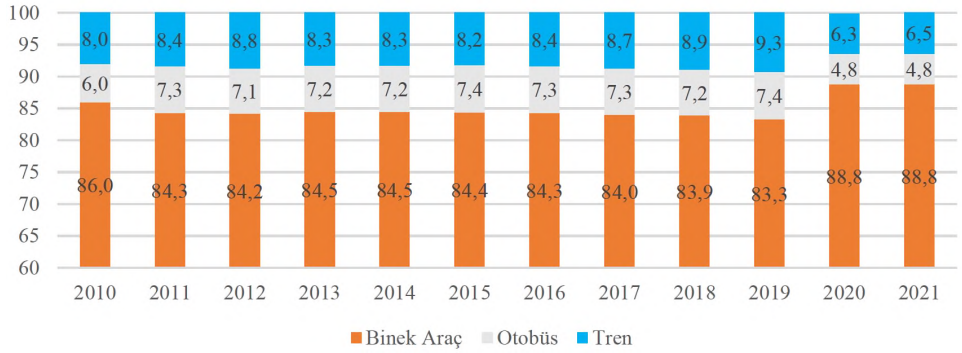
2010-2021 yılları arasında Fransa'da ülke içinde gerçekleşen yolcu taşımaları için türel ayrım değerleri Şekil 8'de verilmiştir.

Fransa'da ülke içinde yapılan yolcu taşımalarında en çok binek araç kullanıldığı, binek aracın 2010 yılında yüzde 85,1 olan payının 2019 yılında en düşük değeri olan yüzde 83,3'e gerilediği, bu payın 2020 yılında Pandemi etkisiyle en yüksek değerine yani yüzde 87'ye ulaştığı görülmektedir. Söz konusu dönem içinde otobüsün payı 2010 yılında yüzde 5,2 iken 2018 yılında en yüksek değeri olan yüzde 6,5'e ulaşmış ancak 2021 yılında Pandemi etkisiyle yüzde 4,9 ile en düşük değerine gerilemiştir. Ayrıca,



Şekil 7. Yolcu Türel Ayrım - Almanya (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

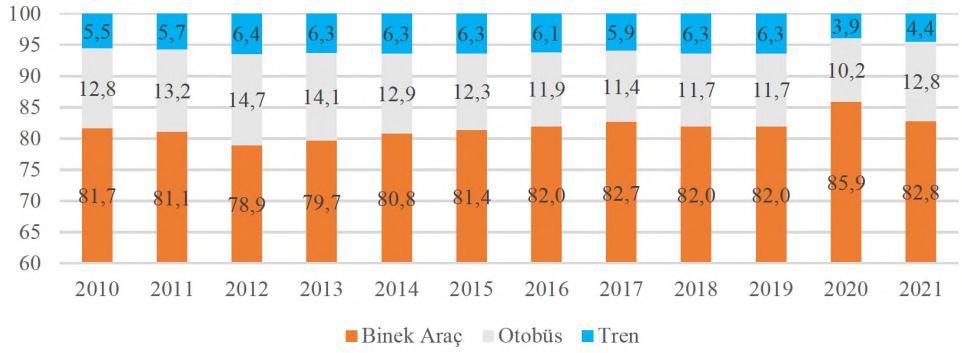


Şekil 8. Yolcu Türel Ayrım - Fransa (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

yolcu taşımacılığında trenin payı 2010 yılında yüzde 9,7 iken 2019 yılında en yüksek değeri olan yüzde 10,3'e ulaşmış ancak Pandemi etkisiyle 2020 yılında yüzde 7,8 ile en düşük değerine gerilemiştir.

2010-2021 yılları arasında İtalya'da ülke içinde gerçekleşen yolcu taşımaları için türel ayrım değerleri Şekil 9'da verilmiştir.



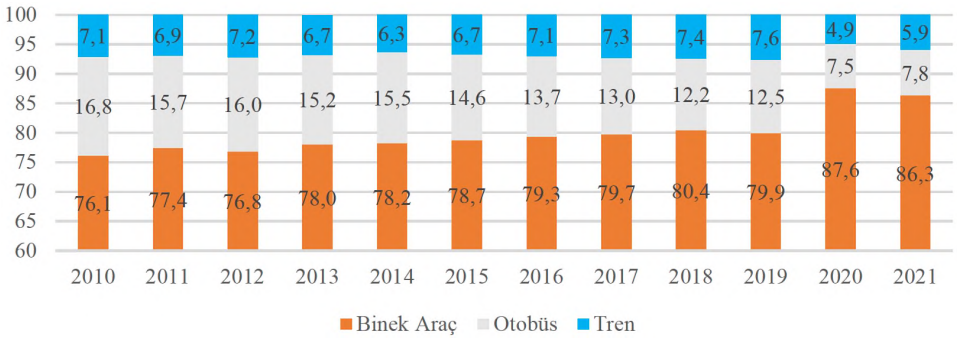
Şekil 9. Yolcu Türel Ayrım – İtalya (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

İtalya'da ülke içinde yapılan yolcu taşımalarında en çok binek araç kullanıldığı, binek aracın 2010 yılında yüzde 81,7 olan payının 2012 yılında en düşük değeri olan yüzde 78,9'a gerilediği ve dalgalı seyri sonrasında 2020 yılında Pandemi etkisiyle bu payın en yüksek değerine yani yüzde 85,9'a ulaştığı gözlenmektedir. Söz konusu dönem içinde otobüsün payı 2010 yılında yüzde 12,8 iken 2012 yılında en yüksek değeri olan yüzde 14,7'ye ulaşmış ancak 2020 yılında Pandemi etkisiyle yüzde 10,2 ile en düşük değerine gerilemiştir. Ayrıca, yolcu taşımalarında trenin payı 2010 yılında yüzde 5,5 iken 2012 yılında en yüksek değeri olan yüzde 6,4'e ulaşmış ancak Pandemi etkisiyle 2020 yılında yüzde 3,9 ile en düşük değerine gerilemiştir.

2010-2021 yılları arasında Polonya'da yurt içinde gerçekleşen yolcu taşımaları için türel ayrım değerleri Şekil 10'da verilmiştir.

Polonya'da ülke içinde yapılan yolcu taşımalarında en çok binek araç kullanıldığı, binek aracın 2010 yılında yüzde 76,1 olan payının 2019 yılına kadar dalgalı seyir izleyerek yüzde 79,9'a yükseldiği ve 2020 yılında Pandemi etkisiyle en yüksek değerine yani yüzde 87,6'ya ulaştığı görülmektedir. Söz konusu dönem içinde otobüsün payı 2010 yılında en yüksek değeri olan yüzde 16,8 iken düşüş eğilimine girerek 2020 yılında Pandemi etkisiyle yüzde 7,5 ile en düşük değerine gerilemiştir. Ayrıca, yolcu

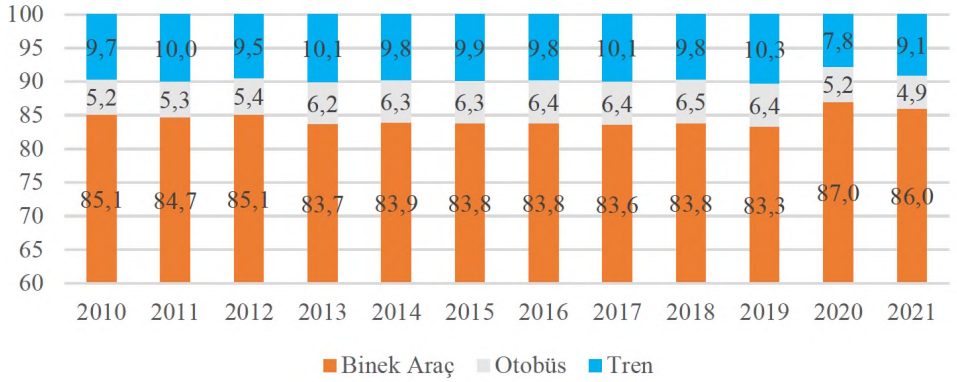


Şekil 10. Yolcu Türel Ayrım - Polonya (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

taşımalarında trenin payı 2010 yılında yüzde 7,1 iken 2019 yılında en yüksek değeri olan yüzde 7,6'ya ulaşmış ancak Pandemi etkisiyle 2020 yılında yüzde 4,9 ile en düşük değerine gerilemiştir.

2010-2021 yılları arasında İspanya'da yurt içinde gerçekleşen yolcu taşımaları için türel ayrım değerleri Şekil 11'de verilmiştir.

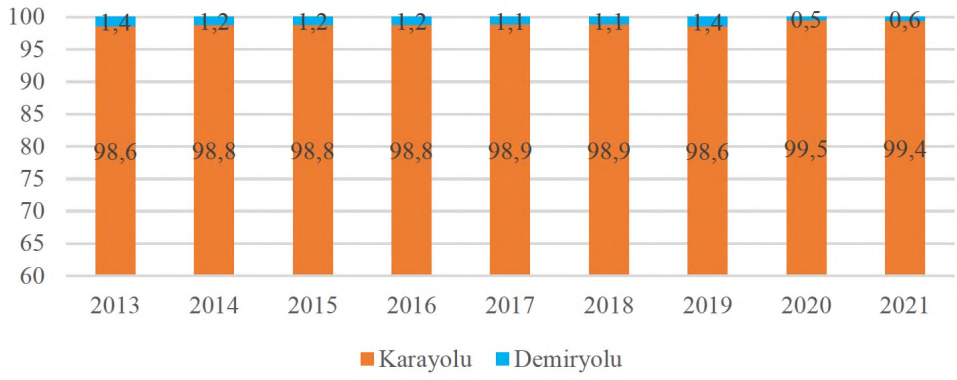


Şekil 11. Yolcu Türel Ayrım – İspanya (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

Yukarıdaki grafikte görüleceği üzere İspanya'da ülke içinde yapılan yolcu taşımalarında en çok binek araç kullanıldığı, binek aracın 2010 yılında yüzde 85,1 olan payının 2019 yılında en düşük değeri olan yüzde 83,3'e gerilediği, 2020 yılında Pandemi etkisiyle bu payın en yüksek değerine yani yüzde 87'ye ulaştığı görülmektedir. Söz konusu dönem içinde otobüsün payı 2010 yılında yüzde 5,2 iken 2018 yılında en yüksek değeri olan yüzde 6,5'e ulaşmış ancak 2021 yılında Pandemi etkisiyle yüzde 4,9 ile en düşük değerine gerilemiştir. Ayrıca, yolcu taşımalarında trenin payı 2010 yılında yüzde 9,7 iken 2019 yılında en yüksek değeri olan 10,3'e ulaşmış ancak Pandemi etkisiyle 2020 yılında yüzde 7,8 ile en düşük değerine gerilemiştir.

2013-2021 yılları arasında Türkiye'de yurt içinde gerçekleşen yolcu taşımaları için türel ayrım değerleri Şekil 12'de verilmiştir. Söz konusu türel ayrım verileri Ulaştırma ve Altyapı Bakanlığı tarafından 2014-2023 yılları arasında yıllık olarak yayımlanan "Ulaşan ve Erişen Türkiye" raporlarından derlenerek oluşturulmuştur. 2012 yılının türel ayrım verileri bulunmadığı için 2013 yılından itibaren türel ayrım verileri verilmiştir.



Şekil 12. Yolcu Türel Ayrım – Türkiye (2013-2021, Yüzde)

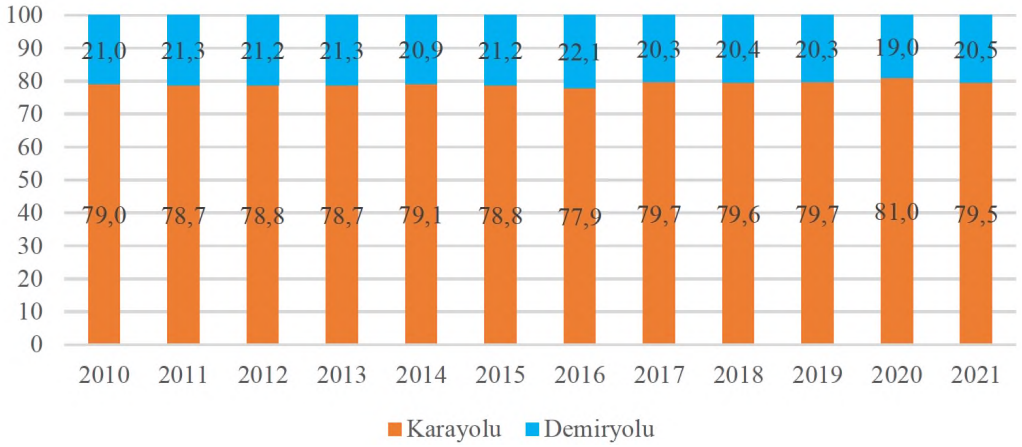
Kaynak: Ulaşan ve Erişen Türkiye (2014-2023) raporlarından yararlanılarak Yazar tarafından oluşturulmuştur.

Yukarıdaki grafikte görüleceği üzere Türkiye'de ülke içinde yapılan yolcu taşımalarında karayolu baskın olup karayolu türünün 2013 yılında yüzde 98,6 olan kara ulaştırmasındaki payı 2020 yılında Pandemi etkisiyle dönem içinde en yüksek değerine yani yüzde 99,5'e ulaşmıştır. Söz konusu dönemde demiryolunun payı 2020 yılına kadar yüzde 1,1 ila yüzde 1,4 arasında değişirken 2020 yılında Pandemi etkisiyle yüzde 0,5 ile en düşük değerine gerilemiştir.

4.6. Yük Türel Ayrım

Bu bölümde Avrupa ülkeleri için kullanılan veriler EuroStat verileri olup karayolu, demiryolu ve iç suyolu türleri için türel ayrım değerleri bulunmakta havayolu verileri bulunmamaktadır. Türkiye verileri Ulaştırma ve Altyapı Bakanlığı verileri olup karayolu, demiryolu, denizyolu ve havayolu ulaşım türlerini içermektedir. Ancak çalışmada bütünlük sağlanması adına kara ulaştırması (karayolu ve demiryolu) türel ayrım verileri kullanılmıştır. Almanya, Fransa, İtalya, Polonya, İspanya ve Türkiye için yolcu türel ayrım değerleri verilmiştir.

2010-2021 yılları arasında Almanya'da ülke içinde gerçekleşen yük taşımaları için türel ayrım değerleri Şekil 13'te verilmiştir.

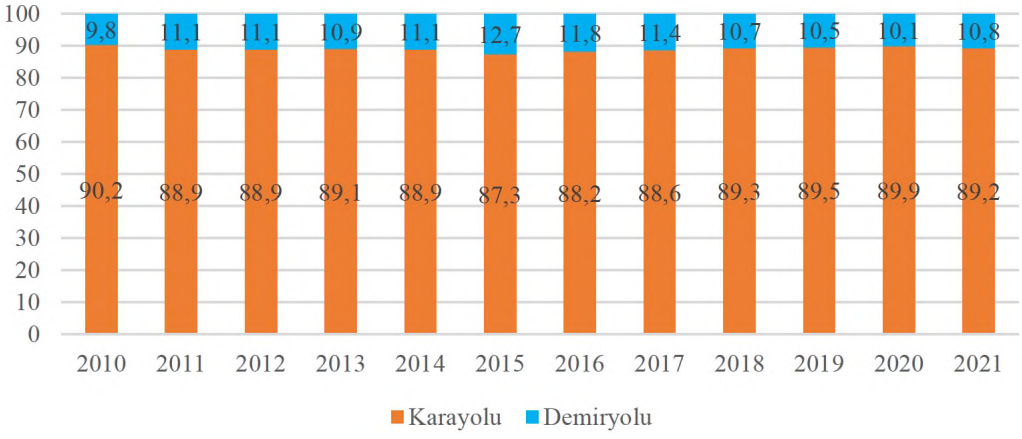


Şekil 13. Yük Türel Ayrım - Almanya (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

Almanya'da ülke içinde yapılan yük taşımalarında en çok karayolunun kullanıldığı, 2010 yılında yüzde 79 olan payın dalgalı bir seyir izleyerek 2020 yılında Pandemi etkisiyle en yüksek değerine yani yüzde 81'e ulaştığı görülmektedir. Söz konusu dönemde demiryolunun payı 2010 yılında yüzde 21 iken 2016 yılında en yüksek değeri olan yüzde 22,1'e ulaşmış ancak 2020 yılında Pandemi etkisiyle yüzde 19,0 ile en düşük değerine gerilemiştir.

2010-2021 yılları arasında Fransa'da ülke içinde gerçekleşen yük taşımaları için türel ayrım değerleri Şekil 14'te verilmiştir.

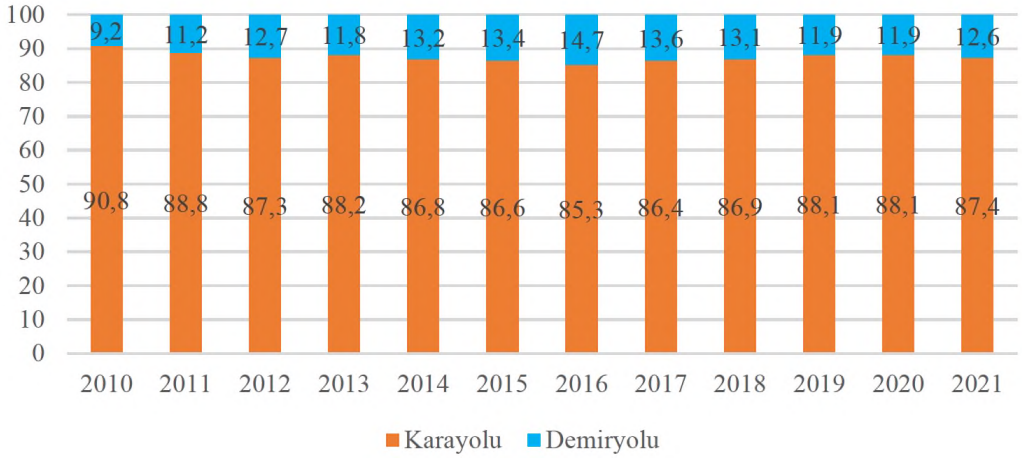


Şekil 14. Yük Türel Ayrım - Fransa (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

Fransa'da ülke içinde yapılan yük taşımalarında en çok karayolunun kullanıldığı, 2010 yılında yüzde 90,2 olan payın dalgalı bir seyir izleyerek 2020 yılında Pandemi etkisiyle yüzde 89,9'a ulaştığı görülmektedir. Söz konusu dönemde demiryolunun payı 2010 yılında yüzde 9,8 iken 2015 yılında en yüksek değeri olan yüzde 12,7'ye ulaşmış ancak sonrasında düşüş eğilimi göstererek 2020 yılında yüzde 10,1'e kadar gerilemiştir.

2010-2021 yılları arasında İtalya'da ülke içinde gerçekleşen yük taşımaları için türel ayrım değerleri Şekil 15'te verilmiştir.

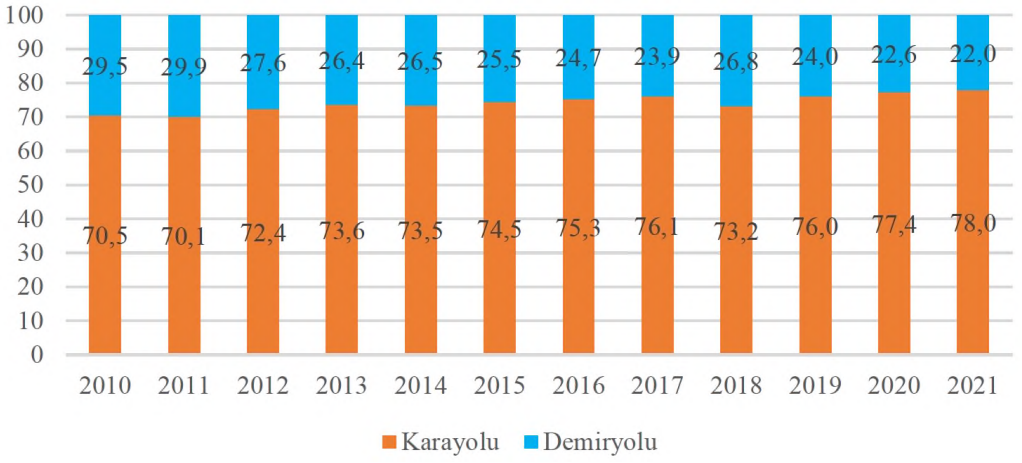


Şekil 15. Yük Türel Ayrım – İtalya (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

İtalya'da ülke içinde yapılan yük taşımalarında en çok karayolunun kullanıldığı, 2010 yılında yüzde 90,8 ile en yüksek değere sahip payın dalgalı bir seyir izleyerek 2016 yılında yüzde 85,3'e gerilediği, 2021 yılında ise yüzde 87,4'e ulaştığı görülmektedir. Söz konusu dönemde demiryolunun payı 2010 yılında yüzde 9,2 iken 2016 yılında en yüksek değeri olan yüzde 14,7'e ulaşmış ancak sonrasında dalgalı bir seyir izleyerek 2020 yılında yüzde 11,9'a kadar gerilemiştir.

2010-2021 yılları arasında Polonya'da yurt içinde gerçekleşen yük taşımaları için türel ayrım değerleri Şekil 16'da verilmiştir.



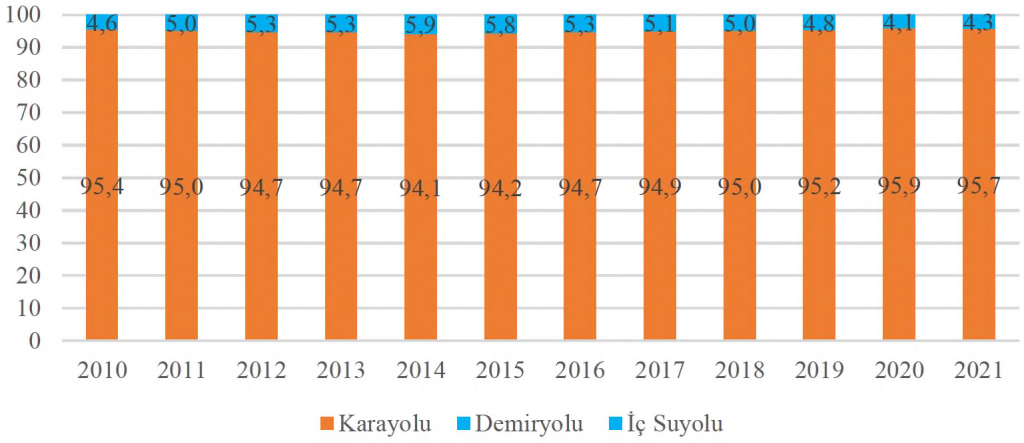
Şekil 16. Yük Türel Ayrım - Polonya (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

Polonya'da ülke içinde yapılan yük taşımalarında en çok karayolunun kullanıldığı, 2010 yılında yüzde 70,5 olan payın dalgalı bir seyir izleyerek 2021 yılında en yüksek değeri olan yüzde 78'e ulaştığı görülmektedir. Söz konusu dönemde demiryolunun payı 2010 yılında yüzde 29,5 iken 2011 yılında en yüksek değeri olan yüzde 29,9'a ulaşmış ancak sonrasında dalgalı bir seyir izleyerek 2021 yılında yüzde 22'ye kadar gerilemiştir.

2010-2021 yılları arasında İspanya'da yurt içinde gerçekleşen yük taşımaları için türel ayrım değerleri Şekil 17'de verilmiştir.

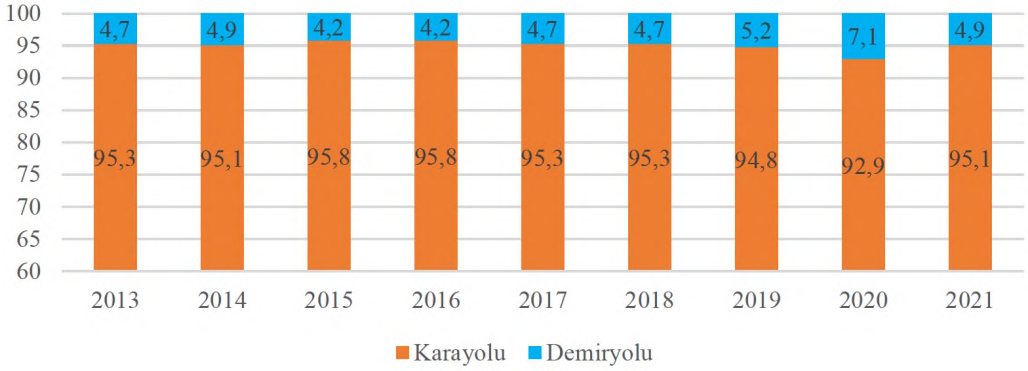
İç suyolu türü bulunmayan İspanya'da ülke içinde yapılan yük taşımalarında en çok karayolunun kullanıldığı, 2010 yılında yüzde 95,4 olan payın söz konusu dönemde yüzde 94,1 ila yüzde 95,9 arasında değiştiği gözlenmektedir. Söz konusu dönemde demiryolunun payı 2010 yılında yüzde 4,6 iken 2014 yılında en yüksek değeri olan yüzde 5,9'a ulaşmış ancak sonrasında düşme eğilimli bir seyir izleyerek 2020 yılında yüzde 4,1'e kadar gerilemiştir.



Şekil 17. Yük Türel Ayrım – İspanya (2010-2021, Yüzde)

Kaynak: (Eurostat, 2023)'den yararlanılarak Yazar tarafından oluşturulmuştur.

2013-2021 yılları arasında Türkiye'de yurt içinde gerçekleşen yük taşımaları için türel ayrım değerleri Şekil 18'de verilmiştir. Söz konusu türel ayrım verileri Ulaştırma ve Altyapı Bakanlığı tarafından 2014-2023 yılları arasında yıllık olarak yayımlanan "Ulaşan ve Erişen Türkiye" raporlarından derlenerek oluşturulmuştur. 2012 yılının türel ayrım verileri bulunmadığı için 2013 yılından itibaren türel ayrım verileri verilmiştir.



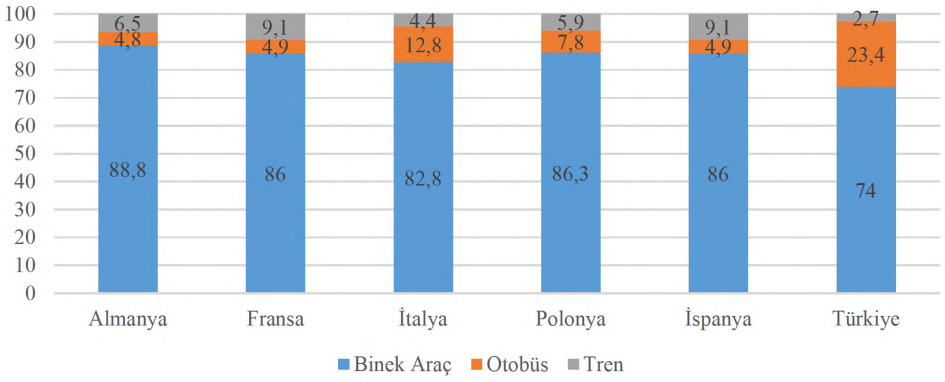
Şekil 18. Yük Türel Ayrım - Türkiye (2013-2021, Yüzde)

Kaynak: Ulaşan ve Erişen Türkiye (2014-2023) raporlarından yararlanılarak Yazar tarafından oluşturulmuştur.

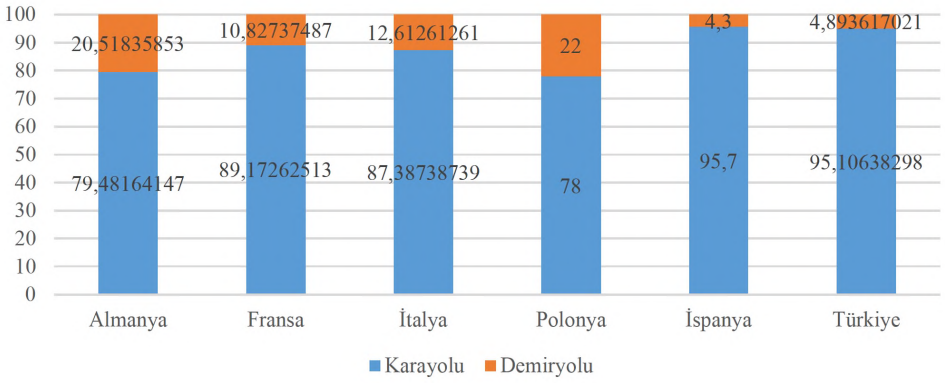
Türkiye'de ülke içinde yapılan yük taşımalarında en çok karayolunun kullanıldığı, 2013 yılında yüzde 95,3 olan payın dalgalı bir seyir izleyerek 2020 yılında en düşük değerine yani yüzde 92,9'a ulaştığı görülmektedir. Söz konusu dönemde demiryolunun payı 2013 yılında yüzde 4,7 iken 2015 yılında en düşük değeri olan yüzde 4,2'ye gerilemiş ancak 2020 yılında Pandemi etkisiyle yüzde 7,1 ile en yüksek değerine ulaşmıştır.

5. Bulgular

Bu çalışmada elde edilen bulgular, Türkiye'nin ulaştırma altyapısının gelişmiş Avrupa ülkeleri ile karşılaştırıldığında hangi alanlarda gelişim potansiyeline sahip olduğunu göstermektedir. Örneğin, Türkiye, karayolu taşımacılığı açısından yolcu ve yük taşıma oranlarında Avrupa'nın önde gelen ülkelerinden biri olmasına rağmen, demiryolu taşımacılığında gelişim için önemli bir potansiyele sahiptir. Karayolu yolcu taşımacılığında Türkiye'nin 2021 yılında %99,4'lük bir pay ile en yüksek değere sahip olduğu, buna karşılık demiryolu kullanım oranının yalnızca %0,6 olduğu belirlenmiştir. Yük taşımacılığında da benzer bir tablo görülmekte, karayolu taşımacılığının %95,1'lik payla baskın olduğu, demiryolunun ise %4,9'da kaldığı gözlemlenmiştir. Bu bulgular, Türkiye'nin ulaştırma politikalarında demiryolu taşımacılığına daha fazla önem verilmesi gerektiğini ortaya koymaktadır. 2021 yılına ait ülkelerin karşılaştırmalarının yapıldığı grafikler Şekil 19 ve Şekil 20'de verilmektedir.



Şekil 19. Yolcu Türel Ayrım – Seçilen Ülkeler (2021, Yüzde)



Şekil 20. Yük Türel Ayrım – Seçilen Ülkeler (2021, Yüzde)

Karayolu Yolcu Taşımacılığı

Seçilmiş 7 ülkenin karayolu yolcu taşımacılığı verileri, Türkiye'nin karayolu taşımacılığına yüksek bağımlılığını net bir şekilde göstermektedir. Türkiye, %99'un üzerinde bir oranla karayolu yolcu taşımacılığında önde gelirken, diğer Avrupa ülkelerinde bu oran daha düşüktür. Özellikle Almanya ve Fransa'da demiryolu kullanımının daha yaygın olması, karayolunun yolcu taşımacılığındaki baskınlığını sınırlamaktadır.

Karayolu Yük Taşımacılığı

Karayolu yük taşımacılığında, İspanya ve Türkiye'nin yüksek oranlara sahip olduğu, özellikle İspanya'nın %95'in üzerinde bir oranla öne çıktığı görülmektedir. Almanya gibi demiryolu kullanımının daha gelişmiş olduğu ülkelerde, yük taşımacılığında karayolunun payı daha düşük kalmıştır.

Demiryolu Yolcu Taşımacılığı

Demiryolu yolcu taşımacılığı açısından Almanya, Fransa ve Birleşik Krallık gibi ülkeler önde gelirken, Türkiye'nin demiryolu yolcu taşımacılığında düşük bir paya sahip olduğu gözlemlenmektedir. Bu durum, Türkiye'nin demiryolu taşımacılığında daha fazla yatırım yapması gerektiğini ortaya koymaktadır.

Demiryolu Yük Taşımacılığı

Almanya, demiryolu yük taşımacılığında %20'yi aşan oranlarla diğer ülkelerden açık ara önde gelmektedir. Türkiye'nin ise demiryolu taşımacılığında %5'in altında kaldığı ve bu alanda büyük gelişim potansiyeli taşıdığı gözlemlenmiştir.

Denizyolu Yük Taşımacılığı

Denizyolu taşımacılığı, özellikle Türkiye için stratejik bir öneme sahiptir. Türkiye, 2021 yılında denizyolu yük taşımacılığında lider ülkelerden biri olarak büyük bir paya sahiptir. Diğer Avrupa ülkelerinde de benzer eğilimler gözlemlenmektedir.

Havayolu Yolcu Taşımacılığı

Havayolu yolcu taşımacılığında Türkiye'nin 2021 yılında en yüksek yolcu taşıyan ülkelerden biri olduğu gözlemlenmiştir. Bu durum, Türkiye'nin havayolu ulaşımına yaptığı yatırımların etkinliğini ortaya koymaktadır.

Ulaşım Modlarının Tercihini Etkileyen Faktörler: Coğrafi Koşullar ve Politik Stratejiler

Ülkelerin ulaşım altyapı tercihleri, yalnızca teknolojik gelişmeler ve ekonomik gerekliliklerle değil, aynı zamanda coğrafi koşullar ve politik stratejiler ile şekillenmektedir. Bu bağlamda Türkiye ve Avrupa ülkeleri arasındaki karayolu ve demiryolu taşımacılığı kıyaslanırken, ülkelerin yüzölçümü, topografyası ve tarihsel olarak geliştirdikleri ulaşım politikaları önemli rol oynamaktadır.

Türkiye'nin geniş yüzölçümü (785.350 km²) ve dağlık bölgeleri, karayolu taşımacılığının daha esnek ve erişilebilir olmasını sağlamış, bu da karayolu kullanımının yüksek oranda tercih edilmesine neden olmuştur. Diğer taraftan, Almanya ve Fransa gibi ülkeler nispeten düz ve ulaşımı kolay arazilere sahip olduklarından, bu ülkelerde demiryolu taşımacılığı hem yük hem de yolcu taşımacılığında ön plana çıkmaktadır. Özellikle Almanya'nın %20'nin üzerinde bir demiryolu yük taşımacılığı oranına sahip olması, ülkenin coğrafi avantajları ile birlikte, demiryolu kullanımını destekleyen stratejik politikaların bir sonucudur.

Avrupa'daki ülkelerde demiryolu altyapısı, çevresel sürdürülebilirlik ve düşük karbon salınımı hedefleri doğrultusunda uzun yıllardır desteklenmektedir. Özellikle Avrupa Birliği politikaları, demiryolu taşımacılığını teşvik eden ve ülkeler arası entegrasyonu güçlendiren önemli düzenlemeler içermektedir. Almanya, Fransa ve İtalya gibi ülkeler, bu bağlamda demiryolu yatırımlarına önemli miktarda kaynak ayırmışlardır. Türkiye'de ise karayolu taşımacılığı tarihi olarak daha baskın bir ulaşım modu olmuştur ve demiryolu yatırımları son yıllarda hız kazanmış olsa da Avrupa ülkeleri ile kıyaslandığında henüz yeterli seviyede değildir.

Bu durum, Türkiye'nin ulaşım politikalarının daha fazla demiryolu yatırımlarına ve ulaşım modları arası entegrasyona yönlendirilmesi gerektiğini göstermektedir. Karayolu taşımacılığı ile demiryolu taşımacılığının entegrasyonu, lojistik maliyetleri düşürebilir ve sürdürülebilir kalkınma hedeflerine katkı sağlayabilir.

6. Sonuç ve Tartışma

İnsanların, malların ve hizmetlerin bir yerden başka bir yere hareketini kapsayan, ekonomik büyümeyi, sosyal etkileşimleri ve kültürel alışverişi destekleyen ulaştırma sektöründe karayolu, demiryolu, havayolu ve denizyolu olmak üzere dört farklı ulaşım türü bulunmaktadır. Karayolu ulaştırması en yaygın ve erişilebilir tür olarak öne çıkarken, demiryolu ulaştırması özellikle uzun mesafelerde hem yolcu hem de yük hareketleri için verimli ve sürdürülebilir bir türdür. Şehirler ve ülkeler arasında hızlı bağlantı sağlayan, uzun mesafeli seyahatler için havayolu ulaştırması öne çıkarken, denizyolu ulaştırması ise küresel ticarette ve dökme yüklerin hareketinde çok önemli bir rol oynamaktadır.

Seçilmiş yedi ülkede (Almanya, Fransa, İtalya, Polonya, İspanya, Türkiye ve Birleşik Krallık) her bir ulaştırma türüne ilişkin genel veriler ile yük ve yolcu taşımacılığına ilişkin veriler verilmiştir.

Karayolu ulaştırmasında altyapı olarak otoyol, devlet yolu ve il yolu uzunlukları, yolcu ve yük taşımaları seçilmiş ülkeler için karşılaştırılmıştır. Türkiye'nin 2021 yılında ilk üçte yer aldığı iki karşılaştırma devlet yolu uzunluğu ile yük taşımacılığıdır. Demiryolu ulaştırmasında demiryolu uzunluğu ile yolcu ve yük taşımaları karşılaştırılmıştır. 2021 yılında Türkiye'nin seçilmiş olan ülkeler arasında ilk üçte yer aldığı herhangi bir karşılaştırma bulunmamaktadır.

Havayolu ulaştırmasında yolcu sayısı ve yük taşımaları karşılaştırılmıştır. 2021 yılında Türkiye seçilmiş olan ülkeler arasında ilk üçte yer aldığı iki karşılaştırma yolcu sayısı ile yük taşımacılığıdır. Denizyolu ulaştırmasında yolcu sayısı ve yük taşımaları karşılaştırılmıştır. 2021 yılında Türkiye seçilmiş olan ülkeler arasında ilk üçte yer aldığı tek karşılaştırma yük taşımacılığıdır.

2019-2022 yılları arasında etkileri görülen Covid-19 pandemisi ulaştırma sektörünü olumsuz yönde etkilemiştir. Kapanmalar ve seyahat kısıtlamaları sebebiyle yolcu taşımacılığında özellikle havayolu yolcu taşımacılığında büyük düşüşler görülmüştür. Ayrıca karayolunun türel ayrım verileri bu yıllarda artış göstermiştir.

Ülkelerdeki yolcu taşımalarında otomobil, otobüs ve tren ile yük taşımalarında ise karayolu ve demiryolu olacak şekilde yıllık kara ulaştırması türel ayrım değişimleri altı ülke (Almanya, Fransa, İtalya, İspanya, Polonya ve Türkiye) için verilmiştir. Yolcu taşımaları için en çok karayolu kullanan ülke Türkiye'den (yüzde 99,4) sonra yüzde 95,6 ile İtalya iken karayolunu en az kullanan

ülke yüzde 90,9 ile Fransa ve İspanya'dır. Yük taşımalarında ise en çok karayolu kullanan ülke yüzde 95,7 ile İspanya iken karayolunu en az kullanan ülke yüzde 79,5 ile Almanya'dır. Türkiye'de 2021 yılında kara ulaştırmasında yolcu taşımalarının yüzde 99,4'ü karayolu, yüzde 0,6'sı ise demiryolu ile yapılmıştır. Diğer taraftan Türkiye'de 2021 yılında kara ulaştırmasında yük taşımalarının yüzde 95,1'i karayolu ve yüzde 4,9'u demiryolu ile yapılmıştır.

Bu çalışmada, Türkiye ve nüfus ve büyüklük açısından Türkiye ile karşılaştırılabilir olan seçilmiş Avrupa ülkelerinin ulaştırma sektörleri 2010-2021 yılları arasındaki verilere dayanarak analiz edilmiştir. Ancak, 2023-2024 yıllarına ait verilere erişilememiş olması, çalışmanın güncelliğini sınırlayan bir unsur olarak karşımıza çıkmaktadır. Özellikle, Covid-19 pandemisi sonrası dönemde ulaştırma sistemlerinde meydana gelen değişikliklerin tam olarak incelenememesi, analizlerin kapsamını etkilemektedir. Pandemi sonrası toparlanma sürecine dair veriler analiz edilmediği için, ulaştırma sektöründeki en güncel gelişmeler bu çalışmada değerlendirilememiştir.

Türkiye'nin demiryolu taşımacılığı, özellikle yük taşımacılığında, Avrupa ülkelerine kıyasla daha düşük bir paya sahiptir. Bu nedenle, Türkiye'nin demiryolu altyapısının genişletilmesi ve modernizasyonu büyük önem taşımaktadır. Özellikle, sanayi bölgeleri ile limanlar arasında demiryolu bağlantılarının güçlendirilmesi, bu modun daha fazla kullanılması için stratejik bir yatırım olarak öne çıkmaktadır. Ayrıca, yük taşımacılığında demiryolu kullanımını teşvik etmek için maliyet avantajları ve teşvik programları uygulanabilir.

Türkiye'de farklı ulaşım modları arasındaki entegrasyonun artırılması, taşımacılık verimliliğini artırabilir ve lojistik süreçlerde zaman ve maliyet etkinliğine katkıda bulunabilir. Karayolu ve demiryolu entegrasyonu başta olmak üzere, multimodal taşımacılık sistemlerinin teşvik edilmesi önemlidir. Bu tür sistemlerin geliştirilmesi, özellikle transit geçiş yollarında Türkiye'nin konumunu güçlendirecektir.

Türkiye'nin ulaşım sektöründe karbon emisyonlarını azaltma hedefleri doğrultusunda daha fazla sürdürülebilir ulaşım uygulamasına geçmesi gerekmektedir. Bu kapsamda, toplu taşıma sistemlerinin genişletilmesi, elektrikli ve hibrit araçların kullanımının yaygınlaştırılması ve fosil yakıtlara olan bağımlılığın azaltılması önemlidir. Türkiye'nin bu alanda attığı adımlar, uzun vadede hem çevresel sürdürülebilirliği artıracak hem de uluslararası standartlarla uyumu sağlayacaktır.

Gelecekteki çalışmaların daha güncel verilere erişim sağlaması, ulaştırma sistemlerinin analizinde daha doğru ve kapsamlı sonuçlar elde edilmesine katkıda bulunacaktır. Özellikle 2023-2024 sonrası döneme ait verilerin uluslararası veri tabanlarına dahil edilmesiyle, pandeminin ulaşım sektörüne uzun vadeli etkileri ve bu süreçte yapılan yatırımların etkileri daha net bir şekilde değerlendirilebilir. Ulusal ve uluslararası veri kaynaklarının daha hızlı erişilebilir hale getirilmesi, veri toplama süreçlerinin iyileştirilmesi ve ülkelerin ulaştırma politikalarındaki son gelişmelerin değerlendirilmesi, gelecekteki araştırmalar için önemli bir katkı sağlayacaktır.

Bu çalışma, Türkiye ve benzer Avrupa ülkelerinin ulaştırma sistemlerinin karşılaştırmalı bir analizini sunarak, Türkiye'nin ulaştırma altyapısının geliştirilmesi gereken alanlarını ortaya koymuştur. Elde edilen bulgulara dayanarak, gelecekteki çalışmalar için birkaç potansiyel araştırma alanı dikkat çekmektedir:

1. **Demiryolu Taşımacılığının Gelişimi ve Entegrasyonu:** Türkiye'nin demiryolu taşımacılığı, Avrupa ülkelerine kıyasla daha düşük seviyede kalmaktadır. Bu alandaki potansiyel araştırmalar, demiryolu altyapısının nasıl geliştirilebileceği, yatırımların nerede yoğunlaşması gerektiği ve diğer ulaşım modlarıyla entegrasyonun nasıl sağlanabileceği üzerine odaklanabilir. Özellikle, yüksek hızlı tren hatları ve yük taşımacılığı için demiryolu ağlarının genişletilmesi gelecekte incelenebilecek konular arasındadır.
2. **Sürdürülebilir Ulaşım ve Çevresel Etkiler:** Türkiye'nin karayolu taşımacılığına olan bağımlılığı, çevresel sürdürülebilirlik açısından çeşitli zorluklar doğurmaktadır. Gelecekteki araştırmalar, Türkiye'nin ulaşım sistemlerinde karbon emisyonlarının nasıl azaltılabileceği, elektrikli araçlar ve alternatif yakıtların ulaşım sistemlerine entegrasyonunun nasıl sağlanabileceği üzerine yoğunlaşabilir. Aynı zamanda, şehir içi toplu taşıma sistemlerinin geliştirilmesi ve çevreci politikaların uygulanması da önemli araştırma konuları arasında yer alabilir.
3. **Pandemi Sonrası Ulaşım Sistemlerinin Yeniden Yapılandırılması:** Covid-19 pandemisinin ulaşım sektörüne olan etkileri büyük olmuştur ve bu etkilerin uzun vadeli sonuçları hala tam anlamıyla incelenmemiştir. Gelecekteki araştırmalar, pandemi sonrası dönemde Türkiye ve Avrupa ülkelerindeki ulaştırma sistemlerinin nasıl değiştiğini, hangi ulaşım modlarının öncelikli hale geldiğini ve yeni normale nasıl uyum sağlandığını araştırabilir. Ayrıca, esnek çalışma modelleri, uzaktan çalışma gibi yeni alışkanlıkların toplu taşıma ve bireysel ulaşım üzerindeki etkileri de önemli bir araştırma alanı olabilir.
4. **Yenilikçi Ulaşım Teknolojilerinin İncelenmesi:** Akıllı ulaşım sistemleri, otonom araçlar ve hyperloop gibi yeni teknolojilerin Türkiye'deki ulaşım sistemine nasıl entegre edilebileceği üzerine yapılan araştırmalar, Türkiye'nin ulaşım geleceği açısından kritik önem taşımaktadır. Gelecekteki çalışmalar, bu teknolojilerin uygulanabilirliği, altyapı gereksinimleri ve olası etkilerini inceleyebilir.

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KAYNAKLAR / REFERENCES

Bilgiç, Ş., & Evren, G. (2002). A suggestion for evaluation of transportation investments in Turkey. Itu Journal, 1(2), 88-89.

Darby, J., & Özdemir, D. (2010). Environmental concerns and sustainable transport systems in the european union and Turkey. Transformation, 10, 12.

Eurostat. (2023, Ekim 1). *Country level - passengers embarked and disembarked in all ports*. Eurostat- Data Browser: https://ec.europa.eu/eurostat/databrowser/view/MAR_MP_AA_CPH__custom_7661203/default/table?lang=en adresinden alındı

Eurostat. (2023, Ekim 6). *Modal split of inland freight transport.* Eurostat - Data Browser: https://ec.europa.eu/eurostat/databrowser/view/TRAN_HV_FRMOD__custom_7726764/default/table?lang=en adresinden alındı

Eurostat. (2023, Ekim 6). *Modal split of inland passenger transport.* Eurostat - Data Browser: https://ec.europa.eu/eurostat/databrowser/view/TRAN_HV_PSMOD__custom_7726750/default/table?lang=en adresinden alındı

Eurostat. (2023, Ekim 1). *Railway transport - length of lines, by number of tracks.* Eurostat Web Sitesi: https://ec.europa.eu/eurostat/databrowser/view/RAIL_IF_TRACKS__custom_7632536/default/table?lang=en adresinden alındı

Eurostat. (2023, Ekim 1). *Sea transport of goods.* Eurostat - Data Browser: https://ec.europa.eu/eurostat/databrowser/view/ttr00009/default/table?lang=en adresinden alındı

Karataş, İ. A. (2017). Bazı Avrupa ülkeleri ile Türkiye'nin lojistik sektörünün karşılaştırmalı analizi. Akademik Yaklaşımlar Dergisi, 8(1), 1-22.

OECD. (2023, Eylül 27). *ITF Transport Statistics.* OECD İLibrary Web Sitesi: https://stats.oecd.org/BrandedView.aspx?oecd_bv_id=trsprt-data-en&doi=2122fa17-en adresinden alındı

Özoğlu, B., & Demirci, S. B. (2021). Turkiye'de karayolu taşımacılığının değerlendirilmesi: Bir literatur taraması. Ömer Halisdemir Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 14(2), 670-687.

Senir, G., & Büyükkeklik, A. (2023). Karayolu taşımacılığında sürdürülebilirlik performansının ölçülmesi: Karşılaştırmalı bir analiz. Business & Management Studies: An International Journal, 11(1), 10-30.

Şahan, D. (2017). Türkiye'de taşımacılığın çevresel sürdürülebilirlik çerçevesinde analizi. Politik Ekonomik Kuram, 1(2), 1-15.

UAB. (2018). Ulaşan ve Erişen Türkiye 2018. Ankara: T.C. Ulaştırma ve Altyapı Bakanlığı.

UAB. (2019). Ulaşan ve Erişen Türkiye 2019. Ankara: T.C. Ulaştırma ve Altyapı Bakanlığı.

UAB. (2020). Ulaşan ve Erişen Türkiye 2020. Ankara: T.C. Ulaştırma ve Altyapı Bakanlığı.

UAB. (2021). Ulaşan ve Erişen Türkiye 2021. Ankara: T.C. Ulaştırma ve Altyapı Bakanlığı.

UAB. (2022). Ulaşan ve Erişen Türkiye 2022. Ankara: T.C. Ulaştırma ve Altyapı Bakanlığı.

UDHB. (2013). Ulaşan ve Erişen Türkiye 2013. Ankara: T.C. Ulaştırma Denizcilik ve Haberleşme Bakanlığı.

UDHB. (2014). Ulaşan ve Erişen Türkiye 2014. Ankara: T.C. Ulaştırma Denizcilik ve Haberleşme Bakanlığı.

UDHB. (2016). Ulaşan ve Erişen Türkiye 2015. Ankara: T.C. Ulaştırma Denizcilik ve Haberleşme Bakanlığı.

UDHB. (2016). Ulaşan ve Erişen Türkiye 2016. Ankara: T.C. Ulaştırma Denizcilik ve Haberleşme Bakanlığı.

UDHB. (2017). Ulaşan ve Erişen Türkiye 2017. Ankara: T.C. Ulaştırma Denizcilik ve Haberleşme Bakanlığı.

UNECE. (2023, Eylül 27). *United Nations Economic Commission for Europe.* https://w3.unece.org/PXWeb2015/pxweb/en/STAT/STAT__40-TRTRANS__11-TRINFRA/ adresinden alındı

Van Egmond, P., Nijkamp, P., & Vindigni, G. (2003). A comparative analysis of the performance of urban public transport systems in Europe. International Social Science Journal, 55(176), 235-247.

WorldBank. (2023, Eylül 27). *The World Bank - Data.* The World Bank Web Sitesi: ttps://data.worldbank.org/indicator/IS.AIR.GOOD.MT.K1?end=2021&start=2000&view=chart adresinden alındı

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RESEARCH ARTICLE

Effects of the Maritime Silk Road on Port Development along the Route of Belt and Road Initiative

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ABSTRACT
The Belt and Road Initiative (BRI) is a comprehensive strategy devised by the Chinese government to promote global connectivity through multiple pathways. The Silk Road Economic Belt (SREB) is primarily concerned with establishing land-based links that stretch across continents. In contrast, the Maritime Silk Road (MSR) is focussed on creating sea-based corridors that connect different maritime hubs. The ports situated along the MSR are not only infrastructural institutions; rather, they play a crucial role in facilitating commerce, fostering economic development, shaping geopolitical strategies, and facilitating cultural interchange. The objective of this research is to not only delineate the existing nodes and ports comprising the MSR but also ascertain prospective sites that might be smoothly included into this maritime infrastructure. A comprehensive comprehension of MSR necessitates an evaluation of the perspectives held by various international stakeholders. The basis of this study is a comprehensive literature analysis that aimed to analyse the development of ports inside the MSR framework since its establishment in 2013. Despite the significance of the programme, there is a notable scarcity of comprehensive studies that expressly examine port involvement in MSR. The existence of this gap serves to highlight the originality and uniqueness of our study. Through an analysis of port ownership patterns, recent investment flows, current political climates, and the extent of MSR's involvement, this report provides a detailed perspective on the marine aspect of China's overarching goal.

Keywords: Maritime Transportation, Port Development, Port infrastructure, Maritime Silk Road, Belt and Road Initiative

1. Introduction

In 2013, the People's Republic of China introduced a proposal for sustained international cooperation, known as the "Silk Road Economic Belt (SREB) and the 21st-Century Maritime Silk Road Initiative," which is a component of the broader Belt and Road, highlighting a significant multinational effort including 65 countries and almost one-third of the worldwide economy Initiative (Wang, 2016; Rolland, 2017; Lam et al., 2018). The Chinese government is now undertaking an ambitious initiative to construct marine infrastructure along the key shipping route between Asia and Europe. This comprehensive endeavour encompasses a wide range of sectors, including energy, telecommunications, healthcare, and education, as well as transportation infrastructure, such as trains, highways, and ports (Çelik et al., 2022; Hughes et al., 2020).

The SREB pertains to the terrestrial segment of the BRI with the objective of establishing connectivity between China, Europe, and other regions in Asia via an extensive network of infrastructure and economic development initiatives. The concept for this endeavour is derived from the renowned Silk Road, an extensive network of trade routes that facilitated connexions between China, Europe, and many other locations over a span of more than two thousand years (Dave and Kobayashi, 2018). The SREB integrates Beijing's current economic investments and security-building efforts, while also initiating novel endeavours to establish stronger connexions between the Central Asia and South Asia with China. In addition, it seeks to expand the sphere of security towards the west and foster the development of a transportation corridor that connects China with Europe (Dave and Kobayashi, 2016: Tracy et al., 2017). The MSR is a contemporary notion that draws inspiration from the historical Silk Road, an intricate system of trade routes that facilitated connexions between China and other regions throughout Asia, Africa, and Europe via both overland and marine channels (Zhang, 2017). The MSR, together with the overland Silk Road Economic Belt, is a comprehensive and interconnected system of commerce, infrastructure, and economic collaboration that extends across many continents. China's BRI

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is widely seen as a strategic approach aimed at advancing its economic interests, augmenting its sphere of influence, and nurturing regional and global economic growth and collaboration (Blanchard, 2017; Lam et al., 2018; Malik, 2020).

According to Van der Putten (2015), China has formulated a strategic initiative known as the "21st Century Maritime Silk Road," which involves the establishment of ports in Southeast Asia, the Indian Ocean region, and the eastern Mediterranean. China's involvement in seaports and other maritime-related facilities is evident via its participation in large-scale transportation infrastructure projects as part of the "BRI". The expansion of sea lanes, road networks, railroads, and aerial transportation systems mutually reinforces one another, thereby facilitating the establishment of novel trade routes connecting different places. The planned marine version of the MSR constructs a maritime corridor by connecting various seaports and infrastructural systems (Çelik and Özer, 2021). The BRI of China functions as a strategic framework guiding the nation's efforts to establish cooperative relationships with novel commercial counterparts. several countries included in this effort exhibit economies characterised by low income levels. Under optimal conditions, they possess a greater capacity to thrive expeditiously. Furthermore, it is plausible that they might foster more organic collaborative partnerships with China, thus opening up possible new markets for Chinese goods and investment. In other words, this expansive and undeveloped region has the potential to become a significant driver of world economic development, facilitating the creation of fresh markets for Chinese products and attracting foreign direct investments from external sources (Huang, 2016; Ohashi, 2018; Tekdal, 2018; Johnston, 2019).

According to Trial et al. (2016), this location is located between the thriving economies of East Asia and West Europe. The efficacy of the new MSR, which aims to facilitate global commerce and marine transit, hinges on the establishment of robust shipping networks and enhanced connectivity. The MSR initiative aims to enhance connectivity between Chinese ports and various developing nations and economic regions, including the Association of Southeast Asian Nations (ASEAN), the Pacific Islands, the Indian Ocean region, the China-Indochina Peninsula Economic (CIPE) Corridor, and Africa (Chung, 2018; Chan, 2018; Lam et al., 2018). Chinese investors historically engaged in FDI by primarily acquiring minority stakes in port shares. COSCO holding now exercises majority control over a limited number of ports, including 85% of Zeebrugge, 100% of Piraeus, 51% of Valencia, and 90% of Abu Dhabi. The acquisition of the port share by the ports of Vad Ligure, Rotterdam, Marseilles, and Antwerp was hindered by the political and regional attitudes of local authorities against Chinese port investments (Duchâtel, 2018).

The primary objective of this study is to conduct a thorough investigation into the many aspects of the Maritime Silk Road (MSR) within the Belt and Road Initiative (BRI), which was put forth by the Chinese government in 2013. The importance of sea-based corridors in boosting global connectivity is emphasised by the MSR, even though the Silk Road Economic Belt (SREB) is largely concentrated on land connexions. In addition to mapping out the current ports and nodes that make up the MSR, possible locations that may easily become part of this maritime network are sought in our study. Furthermore, the viewpoints of different global stakeholders are assessed to obtain a thorough comprehension of the ramifications of the MSR. Due to the scarcity of thorough studies that specifically look at port involvement in the MSR, our research will address this gap.

This study takes a unique approach by thoroughly examining the MSR within the larger context of the BRI, which was proposed by the Chinese government in 2013. A limited number of studies have examined the complex aspects of port involvement and infrastructure development within this marine framework, although prior research has recognised the importance of MSR in improving global connectivity. Our analysis closes a significant gap in the literature by concentrating on the growth of ports inside the MSR since its founding and provides a fresh perspective on China's overall maritime goals. This research provides fresh insight into the current political environment, port ownership patterns, investment trends, and MSR's level of involvement through a thorough examination of all of these factors.

The research provided an analysis of the MSR, focussing on three key aspects: port ownership, infrastructure, and policy. The following section of the report provides concise details about the MSR, including its trajectory and the current situation of pivotal ports situated along its path. The last segment of the investigation entails a discussion and conclusion.

2. Maritime Silk Road

The name "maritime silk road" has traditionally denoted the ancient trade and cultural pathway linking China to many countries throughout Asia, Europe, East Africa, and the Middle East. The objective of Xi's Maritime Silk Road (MSR) initiative is to restore China's historical maritime supremacy and status as a naval force, as documented by Len (2015). In 2013, President Xi Jinping introduced the concept of the MSR as a means to articulate the foreign policy objectives of the country (Guan, 2016). China's oil imports constitute 80% of its total, while its natural gas imports account for 50%. Additionally, 42.6% of China's goods are transported via the maritime routes associated with the MSR. According to Jiang et al. (2018), the implementation of this plan is expected to result in a significant increase in China's import and export trade with countries located along the MSR. Consequently, there will be a corresponding rise in the demand for international logistics and maritime shipping services (Qiu et al., 2018). Hence, the pivotal inquiry pertains to the extent to which China's growing economic participation in these maritime routes will translate

into an escalation of military engagement, as well as the nature of such presence, particularly with regard to the establishment of enduring installations and support bases (Blanchard, 2017). To comprehensively analyse the matter at hand, it is essential to assess the underlying motivations behind China's endeavour to enhance its military presence along the MSR, as well as the many challenges that Beijing will inevitably confront in pursuing this objective. The MSR not only facilitates China's connectivity with three significant economic regions, namely Southeast Asia, South Asia, and the Middle East (Figure 1), but it also plays a crucial role in the production of critical commodities for China, including oil, iron ore, and copper ore. Moreover, the implementation of proactive measures aimed at establishing strategic and economic connexions along the MSR presents a chance, as seen by China, to evade the perceived encirclement and containment resulting from the United States' "pivot to Asia" strategy (Clemens, 2015). The growth rate of China's blue economy is around 7.5% per year, driven by the Chinese government's significant emphasis on the maritime sector as a strategic avenue for national development. The primary factor of utmost importance in this expansion is the augmentation of China's gross domestic product at an average annual rate of 10%. The government of Beijing has expressed its intention to further accelerate this rate to 15% from 2021 to 2035. According to Ghiasy et al. (2018), a significant proportion of Chinese commodities, 90%, are transported via maritime routes. Additionally, sea lanes contribute to approximately 60% of the total value of shipping. Consequently, the Chinese government and enterprises attach great importance to ports and maritime transportation.

Source: Clemens (2015)

Figure 1. Maritime Silk Road and the Silk Road Economic Belt

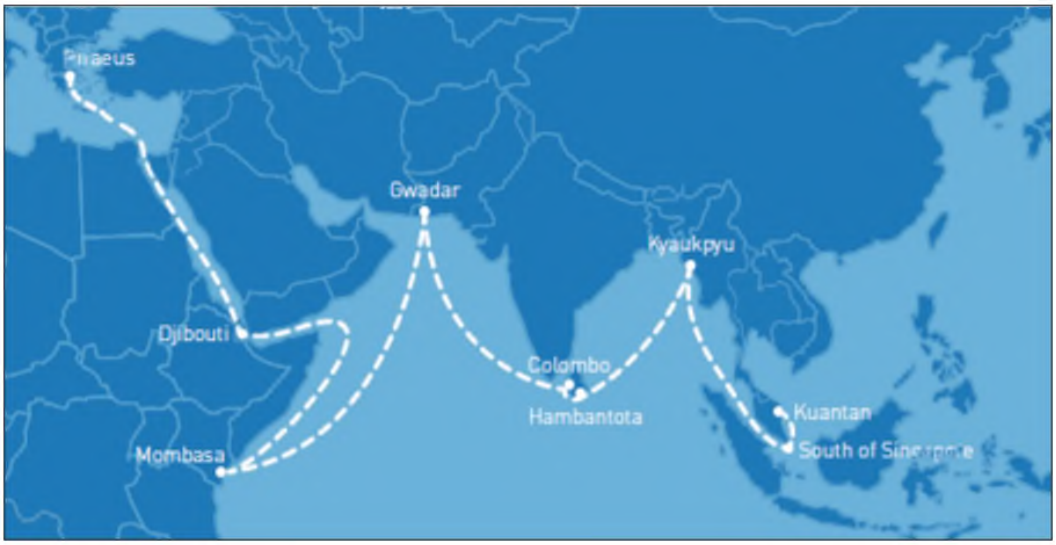
2.1. Route

According to Villafuerte et al. (2016), the main objective of the Maritime Silk Road (MSR) is to establish connectivity between China's coastal port areas and Europe as well as the Southern Pacific Ocean using the South China Sea and the Indian Ocean. The primary port cities along the Maritime Silk Road (MSR) are as follows:

i. Piraeus (Greece)
ii. Mombasa (Kenya)
iii. Djibouti (near the red sea)
iv. Gwadar (Pakistan)
v. Colombo and Hambantota (Sri Lanka)
vi. Jakarta and Batam Island (Indonesia)
vii. Kyaukpyu (Myanmar)
viii. Kuantan (Malaysia) (Figure 2) (LBIA, 2017).

It is important to acknowledge that the Maritime Silk Road did not adhere to a singular, unchanging course, but rather exhibited several branches and modifications along its historical trajectory. Moreover, it assumed a pivotal function in facilitating cultural interchange by enabling the migration of individuals, dissemination of faiths, proliferation of languages, and transmission of

creative influences, alongside the exchange of commercial commodities. The Maritime Silk Road was an integral component of the expansive Silk Road network, facilitating the interconnection between the Eastern and Western regions via land and sea routes. (Chung, 2018; Jiang et al., 2018; Jiang et al., 2022).

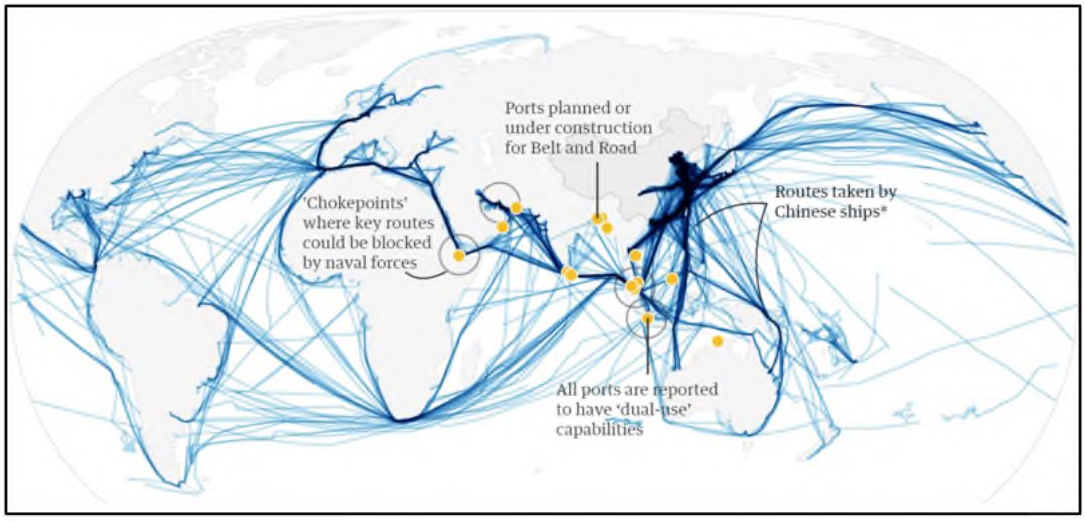


Source: LBIA, 2017

Figure 2. Key port cities of the MSR

2.2. Ports

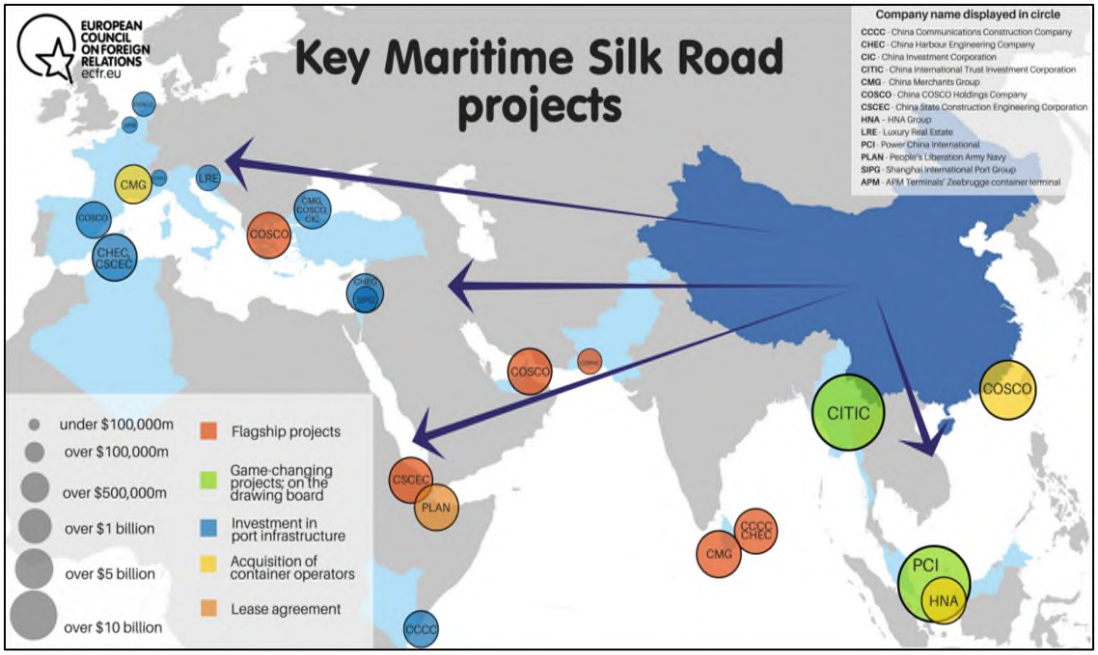
The economic development of nations is heavily dependent on their transportation systems, prompting both developed and developing countries to prioritise the incorporation of their vital transportation infrastructure with global trade routes and import-export networks. Ports play a pivotal role in supporting the integration of nations via marine routes, serving as vital hubs for various types of transportation, as shown in Figure 3 (Wang et al., 2019). The Chinese authorities and member nations place significant importance on improving connectivity and trading capacity between the eastern and western terminals of the ports along the MSR. As a result, there is a significant inclination to accelerate the finalisation of all incomplete connexion ports along the MSR pathway (Celik, 2023). Terminal operators, particularly those originating from China, make conscientious endeavours provide assistance for the project. Since the ports are the primary focal point of the project, the predominant allocation of investment endeavours is aimed at augmenting port infrastructure (Peng, 2018).



Source: Vandenbroeck, 2019

Figure 3. Ports Planned or Under Construction for MSR

The ongoing execution of a comprehensive effort known as the MSR is now being conducted throughout the European region, East Africa, and the Middle East/North Africa region. The project involves many substantial undertakings, including the purchase of shipping enterprises on a worldwide scale, the provision of financial assistance for port management, and the enhancement of port infrastructure. Figure 4 depicts the association existing between the Chinese government and enterprises, along with the major projects associated with the Maritime Silk Road (MSR) initiative (Yin et al., 2020).



Source: Duchâtel and Duplaix, 2018

Figure 4. Key Maritime Silk Road Projects

Ports assume a vital role in the success and importance of the Maritime Silk Road, which constitutes a pivotal element of China's BRI. The significance of ports along the MSR may be comprehended via many perspectives (Wan et al., 2021):

Ports play crucial roles as gateways for facilitating international commerce. International trade plays a crucial role in facilitating the exchange of products between nations, hence assuming a pivotal position in the economic activity of the respective areas it serves. The ports along the MSR serve as vital centres for commerce, facilitating the interconnection of diverse economies and fostering the development of economic collaboration (Lam et al., 2018).

Transshipment hubs are prevalent throughout the MSR and serve as pivotal points for the interchange of commodities between various transportation modes, including ships, trucks, and trains. This phenomenon contributes to the optimisation of global supply chains, resulting in a reduction in transportation expenses (Huang et al., 2021).

Infrastructure development is a crucial aspect of port growth because it requires expenditures in ancillary infrastructure such as road networks, railway systems, and storage facilities. These investments play a significant role in fostering the general development of regions and nations (Liang and Liu, 2020).

Ports play a crucial role in fostering economic development via the stimulation of local enterprises, employment creation, and capital attraction. Port cities and areas often serve as catalysts for the development of local economies, thus promoting economic growth (Zhao et al., 2021).

Cultural movement

Throughout history, ports have served as significant hubs for cultural convergence, facilitating the movement of commodities and ideas, languages, and customs. The MSR facilitates cultural interaction and enhances the cultural fabric of nations by using its port infrastructure (Chan, 2018).

Connectivity

Connectivity is facilitated by ports, which serve as crucial infrastructural nodes that link landlocked areas and the global market. The presence of these infrastructural systems facilitates the connexion of landlocked nations to maritime routes, enabling their engagement in global commerce and mitigating their geographical seclusion (Zhao et al., 2021).

Facilitating Energy Transit Along the Maritime Silk Road

The transit of energy resources, including oil and natural gas, is facilitated by several ports situated along the MSR, which serve as crucial entry points. The aforementioned resources play a pivotal role in the global economy, with ports serving as vital conduits for ensuring a consistent supply to diverse geographical areas (Len, 2015).

Geopolitical Significance

Certain ports situated along the MSR possess strategic positioning, hence facilitating a nation's endeavour to establish influence and safeguard its security interests within the area. These ports have the potential to function as strategic naval bases and provide significant geopolitical benefits (Blanchard and Flint, 2017).

Tourism and Cultural Heritage

Numerous ancient ports and coastal towns situated along the MSR have emerged as popular tourist sites, drawing people with a keen interest in delving into the historical and cultural facets of the area (Winter, 2021).

The aforementioned initiatives include transformational undertakings, investments in port infrastructure, purchases of container ports, and leasing agreements (Duchâtel and Duplaix, 2018). State-owned businesses in China have a significant impact on the investment landscape of ports along the MSR route, which serves as a vital connexion between Asia and Europe. Chinese corporations have made substantial financial commitments to the maritime facilities at Gwadar, Hambantota, Colombo, Malacca, and Piraeus. Based on academic literature, it has been reported that Chinese firms engaged in investments in the foremost 60 container ports throughout 2015, establishing a notable presence in around 65% of these ports (Len, 2017). The inclusion of a red circle in figure 5 denotes the participation of Chinese port investment in the establishment or management of these ports, either via Chinese state-owned firms or other private organisations. The blue circles indicate MSR's genuine objectives, while the yellow circles represent the growing desire of Chinese businesses to invest in ports. The MSR programme has its primary emphasis on the Gulf region, namely the United Arab Emirates, and entails a significant financial investment exceeding $300 million. The primary focus of this effort is the identification and subsequent development of port sites that have strategic significance within the designated area. In addition to the Gulf area, which bears strategic importance for Chinese authorities, Yemen, Israel, Djibouti, Algeria, and Egypt are anticipated to experience heightened relevance in the foreseeable future as a result of the ongoing construction of the MSR. Consequently,

Source: Nouwens, 2019

Figure 5. China's Global Port Ambitions: Chinese company construction and investment

Chinese state-owned enterprises have articulated their ambition to procure a shareholding in or oversee the operations of all ports, with the aim of bolstering this far-reaching endeavour. Nouwens (2019) posits that Djibouti can establish itself as a significant international logistic hub.

The MSR project has influenced and affected numerous ports along its route. The specific impact varies from port to port and depends on various factors, including local government policies, investments, and the strategic importance of the ports. Some notable ports that have been affected by the initiative include (Lam et al., 2018). Hambantota Port has attracted significant investment from China and is now under a leasing agreement with a Chinese corporation (Roy-Chaudhury, 2019). The geographical positioning of the entity in question inside the Indian Ocean has a strategic advantage because it possesses the capacity to evolve into a transshipment centre. However, it has encountered disputes of its economic feasibility. The strategic geographical positioning of Djibouti Port in close proximity to the Bab-el-Mandeb strait, which serves as a vital link between the Red Sea and the Gulf of Aden, has become a significant area of interest for Chinese interests. China has successfully created its first overseas military station in Djibouti, while concurrently seeing substantial growth in the ports of Djibouti (Radwan et al., 2019). The Colombo Port has seen a surge in activity and growth because of its involvement in the MSR initiative. The location serves as a vital transshipment centre within the Indian Ocean region (Park and Dossani, 2020). The Chittagong Port has garnered considerable interest in terms of its prospective development within the BRI framework. This is primarily due to its advantageous position, which provides access to the Bay of Bengal and serves as a strategically significant trading hub within the South Asian region (Monir, 2017). The Mombasa Port has attracted investments and is a component of the envisioned Lamu Port-South Sudan-Ethiopia transport corridor, which aims to enhance transportation and facilitate commerce within the Eastern African region (Gekara and Chhetri, 2013). Although the port of Rotterdam in Europe is not situated immediately along the MSR path, it has seen a surge in traffic and commerce with China. This may be attributed to its significance as a prominent destination for maritime shipments of products (De Langen et al., 2014). The Kuantan Port has seen a notable surge in activity and growth, mostly attributed to substantial investments from China and the establishment of adjacent industrial zones (Yean, 2019).

Following the proclamation of the MSR, Chinese terminal operators operating on a global scale have undertaken the acquisition or expansion of ports across the globe. As an endeavour to advance the objectives of the BRI and strengthen its maritime connectivity, China has made these investments and acquisitions. The following ports have been acquired or are under the management of Chinese global terminal operators:

Piraeus Port

The Piraeus Port Authority in Greece was acquired by the Chinese corporation COSCO (China Ocean Shipping corporation) in the form of a majority interest. This Mediterranean port, situated in a strategic location, has emerged as a highly operational and critical nexus for commodities entering Europe (Chaziza, 2018).

Port of Koper

China Merchants Port Holdings Company, a subsidiary of China Merchants Group, has acquired a 51% interest in the Port of Koper in Slovenia. China is making this expenditure a component of its strategic initiative to enhance its influence in the Adriatic Sea (Rhode, 2022).

Moin Container Terminal

A contract was awarded to a subsidiary of China Harbour Engineering Company for the design and construction of the Moin Container Terminal in Costa Rica. The maritime connectivity in Central America is improved by this endeavour (Baker et al., 2016).

Port of Darwin

Landbridge Group, a Chinese private conglomerate, has obtained a 99-year licence on the strategically located Port of Darwin in Australia, situated in the Asia-Pacific region (Barnes, 2015).

Hambantota Port

Following financial difficulties, the Sri Lankan government entered into a 99-year lease agreement with China Merchants Port Holdings for Hambantota Port, enabling the Chinese company to oversee and advance the development of this strategic port in the Indian Ocean (Kavirarthna et al., 2021).

Gwadar Port

The China Overseas Port Holding Company has played a significant role in the administration and development of Gwadar Port in Pakistan. From its strategic location near the Arabian Sea, this port plays a pivotal role in the China-Pakistan Economic Corridor (CPEC) (Liu et al., 2020).

Doraleh Container Terminal

A legal dispute arose between the government of Djibouti and DP World, a Dubai-based global terminal operator, regarding the administration of the Doraleh Container Terminal, which DP World had previously oversaw. Subsequently, the terminal came under the jurisdiction of the Djiboutian administration (Barton, 2021).

Estonian Ports

Ningbo Zhoushan Port Company, the state-owned port operator of China, has conveyed its prospective investment in multiple Estonian ports with the objective of enhancing maritime connectivity between China and Northern Europe (Wang et al., 2021).

The dep-trap strategy used by the Chinese government is evident in the case of Hambantota Port, where the government acquired equity rights for 99 years, starting from December 2017. Concerns have been raised by authorities in Sri Lanka over the potential use of the Hamnontata port as a naval base, primarily because of its limited economic benefits (Hillman, 2018; Lai et al., 2022). The significance of the Gwadar port in the context of the China-Pakistan Economic Corridor cannot be overstated, as it plays a crucial role in the growth of both China and Pakistan (Ahmed, 2019). The MSR project has had a positive impact on the political and economic collaboration between the authorities of China and Pakistan. Chinese investors are showing a significant focus on the Gwadar port because of its capacity to handle around one million tonnes of cargo annually, including crucial industrial commodities and oil (Gholizadeh et al., 2020). This preference is mostly driven by the limited development opportunities available

at the two other major ports in Pakistan. The construction of this port has generated apprehensions over the maritime expansion of China in the Indo-Pacific area, as seen by significant stakeholders such as India and the United States (Gurmeet, 2018; Liu et al, 2020). The Indian government has formulated a strategic plan to establish the Chabahar Port in Iran as a countermeasure to Chinese endeavours in the area, primarily driven by apprehensions over the expansion of Chinese ports (Pant, 2018). Investment connected to the MSR mostly centres on ports located in Greece and Italy within the European region. The China Ocean Shipping Company (COSCO) has acquired stakes in port facilities located in Turkey and the Netherlands. COSCO acquired a large share of one of the crucial port container terminals in Noatum, Spain, while China Merchant Holding International Limited purchased a 49% stake in the terminals located in France. The latter is recognised as one of the notable Chinese investor in the context of port acquisition under the MSR initiative. Nevertheless, irrespective of the inclusion of these ports in the route, the MSR project is expected to have an influence on many ports, even in the absence of conclusive evidence to support this claim (Nouwens, 2019). The Piraeus Port serves as a central centre for overseeing the transportation operations of the MSR in Europe. However, Cosco Shipping has significantly advanced this network by acquiring Noatum Port, thus establishing a vital connexion between the ports of Piraeus and Valencia. The acquisition of ownership of Spain's principal terminal operator by Cosco enables the establishment of a full connexion between Valencia, the state's foremost container port, and Bilbao, which offers short-sea shipping services to Northern Europe and Rotterdam. The engagement will also include the participation of inland ports in Zaragoza and Madrid, facilitated by Chinese firms. The increasing attraction of Chinese investors to Italian ports such as Genova and Trieste has the potential to significantly shape the European perspective on the Northern Mediterranean region (Ven der Putten et al., 2016; Haralambides, 2020). To facilitate the integration of transportation operations across the European region, Cosco Holding acquired a controlling stake in Kumport, the third-largest container terminal in Turkey. Similarly, COSCO began its investment in the Piraeus port in 2010. Furthermore, Cosco Holding acquired a majority stake of 65 percent in Chancay Port, a minority stake of 20 percent in Antwerp Gateway, and a minority stake of 40 percent in the Noatum Container Terminal (Nouwens, 2019).

The Filyos Project, located in Turkey, is a promising project that is part of the Maritime Silk Road concept. Its goal is to increase trade and connect various maritime routes. Filyos Port, geographically located on the Black Sea coast, is an important point of entry for marine trade and has the potential to grow into a major gateway for commodities, particularly those from the Middle East and Central Asia, travelling from Asia to Europe. By providing a competitive alternative to current ports and integrating smoothly with the Middle Corridor—a crucial transportation route that connects China with Europe via Central Asia and Turkey—China's development might greatly improve connectivity within Eurasia. To ensure sustainable growth and take advantage of the opportunities, however, achieving its full potential will require strong infrastructure development, careful assessment of the environmental and social implications, and coordinated stakeholder engagement. However to fully realise its potential, strong infrastructure development, careful assessment of social and environmental effects, and coordinated stakeholder engagement are required to guarantee sustainable growth and take advantage of the opportunities provided by this important marine gateway (Ceyhan et al., 2017; Günay et al., 2019; Karlı et al., 2021).

2.3. Discussion and Conclusion

The BRI has the potential to reshape the global transportation order. Consequently, it is imperative that scholars thoroughly investigate both the maritime and terrestrial components of this initiative. It is noteworthy to acknowledge that the BRI has engendered much discourse and deliberation. Concerns have been expressed by critics about the sustainability of debt, its environmental consequences, and the possibility that some nations are too reliant on China. The effectiveness and impact of the initiative may differ between participating countries because of variations in individual initiatives, legislation, and local situations. Hence, while the BRI has significant advantages, it also entails certain obstacles and threats.

Maritime transportation is often considered the preferred mode of transportation for facilitating international trade. (Ceylan, 2023). The maritime component of the programme known as the Maritime Silk Road (MSR) was only mentioned in 2013 in the literature. As a result, there is a scarcity of papers and research specifically on MSR. The trajectory of the initiative is variable, allowing for the potential inclusion of a new port in the maritime segment of the project. The objective of the MSR programme is to revolutionise marine transportation through the improvement of infrastructure, the promotion of connectivity, and the use of contemporary technology. These anticipated modifications are projected to result in enhanced efficiency, dependability, and cost-effectiveness in maritime transportation, thus yielding advantages for commerce, economic advancement, and global interconnectedness.

The study highlighted several key ports, including Piraeus in Greece, Mombasa in Kenya, Djibouti near the Red Sea, Gwadar in Pakistan, Colombo and Hambantota in Sri Lanka, Jakarta and Batam Island in Indonesia, Hambantota in Sri Lanka, Djibouti Port in Djibouti, Chittagong Port in Bangladesh, Mombasa Port in Kenya, Kyaukpyu in Myanmar, and Kuantan in Malaysia. However, it should be noted that certain ports may be excluded from the project, whereas additional ports may be considered for inclusion.

The completion of all unfinished link ports along the MSR route is driven by the desire of Chinese authorities and MSR member nations to enhance connectivity and trade capacity between the eastern and western endpoints of the ports.

Global terminal operators and the MSR initiative maintain a collaborative and partnership-oriented relationship. The contribution of these operators in terms of investment, technology, and knowledge to the development of transportation infrastructure and ports along the BRI's route is vital to the initiative's success and its objectives of enhancing trade, economic growth, and connectivity in the regions it spans. Terminal operators try to support the project, with a particular emphasis on those originating from China (Akyar et al., 2023). Chinese state-owned enterprises allocate substantial financial resources towards investments in ports situated along the MSR corridor connecting Asia and Europe. Significant investments have been made by Chinese investors in Gwadar's ports, Hambantota, Colombo, Malacca, and Piraeus. Chinese corporations made investments in the top 60 cargo ports in 2015.

The MSR project has significantly enhanced the political and business ties between Chinese and Pakistani leaders. Chinese investors are primarily interested in the Gwadar port because of its capacity to transport significant volumes of industrial products and oil annually, as well as its ability to handle around one million tonnes of cargo. In contrast, Pakistan's other two largest ports offer limited prospects for expansion. From the vantage point of other prominent nations such as India and the United States, the growth of this port gives rise to concerns over China's maritime expansion in the Indo-Pacific region. The Piraeus Port functions as a pivotal hub for coordinating MSR shipping activities across Europe. However, Cosco has made a notable advancement by purchasing Noatum Port, thus establishing a connexion between the ports of Piraeus and Valencia. Cosco Holding bought Kumport, the third largest container terminal in Turkey, in its entirety. Additionally, in 2010, the China Ocean Shipping Company initiated the acquisition of a portion of the Piraeus port.

In conclusion, the MSR initiative, which is a part of the larger BRI, raises legitimate concerns about the sustainability of debt, its effects on the environment, and its geopolitical ramifications, even though it also offers promising opportunities for increased connectivity and economic growth through maritime transportation. As researchers delve deeper into the complex details of the BRI, it is critical to confront these obstacles while capitalising on the initiative's potential advantages for international trade and connectivity.

By analysing the BRI's maritime and land components, this study adds to the body of knowledge about the initiative and highlights its potential to alter international transportation networks. This study fills a vacuum in the literature by examining the maritime component of the BRI, specifically the MSR, and offers insights into its goals, difficulties, and expected effects on maritime traffic. Analysing the BRI's impact and efficacy compared to other participating countries provides important insights into how different local situations and different legislative frameworks have affected the initiative's execution.

The results of this study can be used by investors, industry participants, and policymakers to develop well-informed strategies for BRI involvement, accounting for potential roadblocks like environmental concerns and debt sustainability. Opportunities for investment and cooperation are presented by the BRI's identification of important ports and the function of international terminal operators. This report emphasises the potential economic benefits of the BRI, such as improved efficiency, dependability, and cost-effectiveness in maritime transportation, by highlighting the initiatives to build connectivity and trade capacity along the MSR route. Anyone with an interest in developing infrastructure and facilitating maritime trade.

The accessibility and accuracy of the data, particularly about port operations, Chinese investments, and the actual execution of the BRI projects, may have placed limitations on the study. The extent of the study and the generalizability of the results may have been constrained by missing or inconsistent data. The study's primary focus is on the BRI's maritime component, specifically the MSR, which may have constrained its examination of the initiative's wider effects. As such, it is possible that some facets of the BRI's land component and how it interacts with the maritime portion have not been thoroughly investigated. It is possible that the study's conclusions cannot be applied to the ports and areas examined. The applicability of the findings to other contexts may be limited by differences in local dynamics, legal frameworks, and geopolitical contexts across the many BRI participating regions. Certain constraints may have been created by the study's methodology, including the choice of important ports and the data processing strategy, which could have an impact on the validity and robustness of the findings. Additional data sources or different methodological approaches may have addressed any biases or offered supplementary insights.

To monitor the long-term effects and evolution of BRI, especially about maritime transportation, future studies may take a longitudinal approach. Researchers can gain a better understanding of the sustainability, efficacy, and consequences of BRI projects for global trade and connectivity by analysing trends across time.

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REFERENCES

Ahmed, Z. S. (2019). Impact of the China–Pakistan Economic Corridor on nation-building in Pakistan. *Journal of Contemporary China*, 28(117), 400-414.

Akyar, D. A., Celik, M. S., & Ceylan, B. O. (2023). Global terminal operators: a competitive strategic position analysis. *Maritime Policy & Management*, 1-19.

Baker, S., Frank, G., Cornett, A., Williamson, D., & Kingery, D. (2016). Physical modelling and design optimizations for a new container terminal at the port of Moin, Costa Rica. In *Ports 2016* (pp. 560-569).

Barnes, P., Bateman, S., Behm, A., Benich, P., Bergin, A., Cronin, P., ... & Zhang, F. (2015). Chinese investment in the Port of Darwin.

Barton, B. (2021). Agency and autonomy in the Maritime Silk Road Initiative: An examination of Djibouti's Doraleh container terminal disputes. *The Chinese Journal of International Politics, 14*(3), 353-380.

Blanchard, J. M. F. (2017). Probing China's twenty-first-century maritime silk road initiative (MSRI): an examination of MSRI narratives. *Geopolitics, 22*(2), 246-268.

Blanchard, J. M. F., & Flint, C. (2017). The geopolitics of China's maritime silk road initiative. *Geopolitics, 22*(2), 223-245.

Celik, M. S. (2023). Determining maritime silk road strategies for ports along the route of belt and road initiative: A case of eastern Aegean ports. Research in Transportation Business & Management, 51, 101056.

ÇELIK, M. S., & ÇAYLAN, D. Ö. (2021). Systematic literature review of 21st century maritime silk road: A bibliometric analysis. *Journal of Management and Economics Research, 19*(3), 35-57.

Çelik, M. S., Akyar, D. A., & Ceylan, B. O. (2022). Bir kuşak bir yol projesinin ortaya çıkışındaki ana etmenler: Çin Halk Cumhuriyeti (ÇHC) bakış açısı. Fırat Üniversitesi Sosyal Bilimler Dergisi, 32(3), 1125-1139.

Ceylan, B. O. (2023). Shipboard compressor system risk analysis by using rule-based fuzzy FMEA for preventing major marine accidents. *Ocean Engineering, 272*, 113888.

Ceyhan, S., Kamacı, A., & Peçe, M. A. (2017). Filyos liman projesinin kruvaziyer gemi turizmi açısından değerlendirilmesi ve bölge ekonomisine katkısı. *Uluslararası Yönetim İktisat ve İşletme Dergisi, 13*(13), 271-283.

Chan, M. H. T. (2018). The belt and road initiative–the new silk road: a research agenda. *Journal of Contemporary East Asia Studies, 7*(2), 104-123.

Chan, Y. K. (2018). Cultural Heritage on China's 21st-Century Maritime Silk Road: The Case of Guangdong Province. *China Report, 54*(2), 159-174.

Chaziza, M. (2018). The Chinese Maritime Silk Road Initiative: The Role of the Mediterranean. *Mediterranean Quarterly, 29*(2), 54-69.

Chung, C. P. (2018). What are the strategic and economic implications for South Asia of China's Maritime Silk Road initiative?. *The Pacific Review, 31*(3), 315-332.

Clemens, M. (2015). The Maritime Silk Road and the PLA. *China Brief, 15*(6), 7-10.

Dave, B., & Kobayashi, Y. (2018). China's silk road economic belt initiative in Central Asia: economic and security implications. *Asia Europe Journal, 16*, 267-281.

De Langen, P. W., & Heij, C. (2014). Corporatisation and performance: A literature review and an analysis of the performance effects of the corporatisation of port of Rotterdam authority. *Transport Reviews, 34*(3), 396-414.

Duchâtel, M., & Duplaix, A. S. (2018). Blue China: Navigating the maritime silk road to Europe. *Policy Brief, 34*.

Gekara, V. O., & Chhetri, P. (2013). Upstream transport corridor inefficiencies and the implications for port performance: a case analysis of Mombasa Port and the Northern Corridor. *Maritime Policy & Management, 40*(6), 559-573.

Ghiasy, R., Su, F., & Saalman, L. (2018). the 21 Century maritime silk road-security implications and ways forward for the European Union.

Gholizadeh, A., Madani, S., & Saneinia, S. (2020). A geoeconomic and geopolitical review of Gwadar Port on belt and road initiative. *Maritime Business Review, 5*(4), 335-349.

Guan, K. C. (2016). The maritime silk road: history of an idea. *Nalanda-Sriwijaya Centre Working Paper*, (23).

Gurmeet, K. (2018). Pakistan's Gwadar Port: A New Naval Base in China's String of Pearls in the Indo-Pacific. *CSIS Briefs, March (Washington, DC: Center for Strategic & International Studies, 2018)*, 1-5.

Günay, E., Çetiner, S., Sevinç, S., & Kütükçü, E. (2019). Tarihi İpek Yolundan Modern İpek Yolu Projesine: Türkiye-Çin Ekonomik İşbirliği Çerçevesinde Orta Koridor ile Kuşak ve Yol Girişimi. *Kahramanmaraş Sütçü İmam Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 9*(2), 157-175.

Haralambides, H. E., & Merk, O. (2020). china's 'belt and road initiative'and global maritime trade flows. In *International Association of Maritime Economists Conference*.

Hillman, J. 2018. "How Big Is China's Belt and Road?" Blog post, Center for Strategic and International Studies, Washington, DC. https://www.csis.org/analysis/how-bigchinas-belt-and-road, (04.09.2020).

Huang, T., Chen, Z., Wang, S., & Jiang, D. (2021). Efficiency evaluation of key ports along the 21st-Century Maritime Silk Road based on the DEA–SCOR model. *Maritime Policy & Management, 48*(3), 378-390.

Huang, Y. (2016). Understanding China's Belt & Road initiative: motivation, framework and assessment. *China Economic Review, 40*, 314-321.

Hughes, A. C., Lechner, A. M., Chitov, A., Horstmann, A., Hinsley, A., Tritto, A., ... & Douglas, W. Y. (2020). Horizon scan of the belt and road initiative. *Trends in Ecology & Evolution, 35*(7), 583-593.

Jiang, B., Li, J., & Gong, C. (2018). Maritime shipping and export trade on "Maritime Silk Road". *The Asian Journal of Shipping and Logistics, 34*(2), 83-90.

Jiang, M., Lu, J., Yang, Z., & Li, J. (2020). Risk analysis of maritime accidents along the main route of the Maritime Silk Road: a Bayesian network approach. *Maritime Policy & Management, 47*(6), 815-832.

Johnston, L. A. (2019). The Belt and Road Initiative: what is in it for China?. *Asia & the Pacific Policy Studies, 6*(1), 40-58.

Karlı, H., Karlı, R. G. Ö., & Çelikyay, S. (2021). Fuzzy AHP Approach to The Determinatıon of Smart Port Dimensions: A Case Study on Filyos Port. *Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 9*(1), 322-336.

Kavirathna, C. A., Hanaoka, S., Kawasaki, T., & Shimada, T. (2021). Port development and competition between the Colombo and Hambantota ports in Sri Lanka. *Case Studies on Transport Policy, 9*(1), 200-211.

Lai, K. P., Lin, S., & Sidaway, J. D. (2020). Financing the Belt and Road Initiative (BRI): research agendas beyond the "debt-trap" discourse. *Eurasian Geography and Economics, 61*(2), 109-124.

Lam, J. S. L., Cullinane, K. P. B., & Lee, P. T. W. (2018). The 21st-century Maritime Silk Road: challenges and opportunities for transport management and practice. *Transport reviews, 38*(4), 413-415.

LehmanBrown International Accountants (LBIA). (2017). The Belt and Road Initiative.

Len, C. (2015). China's 21st Century Maritime Silk Road initiative, energy security and SLOC access. *Maritime Affairs: Journal of the National Maritime Foundation of India, 11*(1), 1-18.

Len, C. (2017). China's Maritime Silk Road and Energy Geopolitics in the Indian Ocean: Motivations and Implications for the Region. *Asia's Energy Security and China's Belt and Road Initiative*, 41-53.

Liang, R., & Liu, Z. (2020). Port Infrastructure connectivity, logistics performance and seaborne trade on economic growth: An empirical analysis on "21st-century maritime silk road". *Journal of Coastal Research, 106*(SI), 319-324.

Liu, Z., Schindler, S., & Liu, W. (2020). Demystifying Chinese overseas investment in infrastructure: Port development, the Belt and Road Initiative and regional development. *Journal of Transport Geography, 87*, 102812.

Malik, J. M. (2020). Myanmar's Role in China's Maritime Silk Road Initiative. In *China's New Global Strategy* (pp. 174-190). Routledge.

Monir, M. M. I. (2017). The role of Port of Chittagong on the economy of Bangladesh. *Erasmus University Rotterdam. https://thesis.eur.nl/pub/40492*.

Ohashi, H. (2018). The Belt and Road Initiative (BRI) in the context of China's opening-up policy. *Journal of Contemporary East Asia Studies, 7*(2), 85-103.

Pant, H. V. (2018). India-Iran Cooperation at Chabahar Port: Choppy Waters.

Park, Y., & Dossani, R. (2020). Port infrastructure and supply chain integration under the belt and road initiative: role of Colombo Port in the apparel industry in South Asia. *Transportation Research Procedia, 48*, 307-326.

Peng, P., Yang, Y., Lu, F., Cheng, S., Mou, N., & Yang, R. (2018). Modelling the competitiveness of the ports along the Maritime Silk Road with big data. *Transportation Research Part A: Policy and Practice, 118*, 852-867.

Qiu, X., Wong, E. Y., & Lam, J. S. L. (2018). Evaluating economic and environmental value of liner vessel sharing along the maritime silk road. *Maritime Policy & Management, 45*(3), 336-350.

Radwan, M. E., Chen, J., Wan, Z., Zheng, T., Hua, C., & Huang, X. (2019). Critical barriers to the introduction of shore power supply for green port development: case of Djibouti container terminals. *Clean Technologies and Environmental Policy, 21*, 1293-1306.

Rhode, G. F. (2022). China's Emergence as a Power in the Mediterranean: Port Diplomacy and Active Engagement. In *Studies in Diplomacy and Statecraft* (pp. 175-196). Routledge.

Rolland, N. (2017). China's "Belt and Road Initiative": Underwhelming or game-changer?. *The Washington Quarterly, 40*(1), 127-142.

Roy-Chaudhury, S. (2019). China, the belt and road initiative, and the Hambantota port project. *St Antony's International Review, 15*(1), 153-164.

Tekdal, V. (2018). China's Belt and Road Initiative: at the crossroads of challenges and ambitions. *The Pacific Review, 31*(3), 373-390.

Tian, W., Yu, M., & Zhang, F. (2016). The exceptional performance of Chinese outward direct investment firms. *China Economic Journal, 9*(2), 209-219.

Tracy, E. F., Shvarts, E., Simonov, E., & Babenko, M. (2017). China's new Eurasian ambitions: the environmental risks of the Silk Road Economic Belt. *Eurasian Geography and Economics, 58*(1), 56-88.

Van der Putten, F. P., & Meijnders, M. (2015). *China, Europe and the maritime silk road*. Clingendael Institute.

Van der Putten, F. P., Montesano, F. S., van de Ven, J., & Ham, P. (2016). *The Geopolitical Relevance of Piraeus and China's New Silk Road for Southeast Europe and Turkey*. Clingendael, Netherlands Institute of International Relations.

Villafuerte, J., Corong, E., & Zhuang, J. (2016, June). The one belt, one road initiative: Impact on trade and growth. In *Proceedings of the 19th Annual Conference on Global Economic Analysis, Purdue University, Washington, DC, USA* (pp. 15-17).

Wan, C., Zhao, Y., Zhang, D., & Yip, T. L. (2021). Identifying important ports in maritime container shipping networks along the Maritime Silk Road. *Ocean & Coastal Management, 211*, 105738.

Wang, C., Haralambides, H., & Zhang, L. (2021). Sustainable port development: The role of Chinese seaports in the 21st century Maritime Silk Road. *International Journal of Shipping and Transport Logistics, 13*(1-2), 205-232.

Wang, Y. (2016). Offensive for defensive: the belt and road initiative and China's new grand strategy. *The Pacific Review, 29*(3), 455-463.

Winter, T. (2021). The geocultural heritage of the Silk Roads. *International Journal of Heritage Studies, 27*(7), 700-719.

Yean, T. S. (2019). The Belt and Road Initiative in Malaysia: Case of the Kuantan Port.

Yin, R., Zhao, B., Zhang, M., & Wang, C. (2020). Analyzing the structure of the maritime silk road central city network through the spatial distribution of financial firms. *Emerging Markets Finance and Trade, 56*(11), 2656-2678.

Zhang, X. (2017). Chinese capitalism and the maritime silk road: A world-systems perspective. *Geopolitics, 22*(2), 310-331.

Zhao, C., Wang, Y., Gong, Y., Brown, S., & Li, R. (2021). The evolution of the port network along the Maritime Silk Road: From a sustainable development perspective. *Marine Policy, 126*, 104426.

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REVIEW ARTICLE

Deciding the Criteria for Software Selection: A Bibliometric Review

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ABSTRACT
With the increase in global competition, there has been an increase in research on how to increase business efficiency and profitability. One area of focus is how businesses choose which software to use. A successful software implementation starts with choosing the right product to meet the organization's specific needs; besides the time, effort, and cost of implementation, poorly chosen software can reduce an organization's market share. However, choosing the right product can be extremely time consuming and daunting. In this study, literature was reviewed using the dimension.ai database, and bibliometric analysis was performed using VOSviewer software. Based on the analysis, the analyzed articles were clustered into groups. The most studied countries in this field were Turkey, the USA, and India. Analytic Hierarchy Process (AHP) was the most frequently used method for evaluating software selection criteria. In addition, Fuzzy and Hybrid methods, which are frequently used in recent years, are also among the methods used. The study also lists the most frequently used criteria, identifies the shortcomings of the studies, and presents new criteria for the current needs of enterprises. Finally, recommendations for future studies and the industry are provided. The findings of this study will both help the marketing and sales teams of software product companies to develop key points and enable end-user organizations to make informed decisions when choosing software packages.

Keywords: Software Selection, Bibliometric Review, VOSviewer

1. Introduction

Outsourcing is defined as the transfer of some of a business's activities to external suppliers or the transfer of business processes from internal sourcing to outsourcing. To gain a competitive advantage, businesses commonly prefer outsourcing because it can improve productivity, basic capabilities, flexibility, and quality, and reduce risks and costs while keeping up with innovations.

In today's intensely competitive business environment, businesses aim to carry out their activities accurately and on time while quickly expanding their market share by increasing customer satisfaction. They can realize this goal by continuously monitoring and effectively managing their systems. These systems have become more complex, so business functions like sales, management, marketing, accounting, procurement, supply, research and development, human resources, and finance use monitorable information technologies to ensure fast, accurate, and reliable flow of information across interconnected processes and units. Businesses can implement this holistic perspective through Enterprise Resource Planning (ERP) software. Since software is generally outside a business's field of activity, outsourcing is preferred.

Choosing a software package is challenging because it entails a thorough analysis of numerous competing factors to satisfy the business's requirements. Therefore, researchers are trying to identify more effective criteria for assessing and choosing software packages. The present study aims to review previous research on evaluating and selecting software packages and provide a basis to improve the software selection process. Accordingly, we address the following research questions:

RQ1: How can the VOSviewer program help to examine the relationship between articles?
RQ2: Which methods do businesses use to select software?
RQ3: How does the literature contribute to evaluating and selecting software packages?
RQ4: How are articles about software selection criteria distributed in the literature? How can these articles be grouped?

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RQ5: What are the software selection criteria based on the literature?

To address these RQs, a detailed literature review was conducted using the dimension.ai database to identify all relevant studies. This search revealed 140 potentially relevant articles regarding software selection, which were then examined in more detail with VOSviewer, a frequently used bibliometric analysis program. This identified several articles to exclude, so the analysis continued with 89 articles. These articles were divided into four groups for further detailed analysis using VOSviewer to address the research questions and provide guidance for future studies. In the second part of the study, the software selection criteria listed in the literature were examined and reorganized to create a standard and address the current needs of businesses.

The rest of this paper is organized as follows. Section 2 describes the research method. Section 3 presents the program applications and detailed analysis. Section 4 lists and analyzes the criteria specified in the reviewed studies. Section 5 concludes.

2. Methodology

This study used publication data sourced from the dimensions.ai database, which was selected for its large dataset, including the number of citations per article, as well as the fact that it gives an API (Application Programming Interface) for doing searches using a particular DSL (Domain Specific Language). The database was searched using the keywords "software selection" and "criteria". The search, which was conducted in August 2023, identified 140 articles.

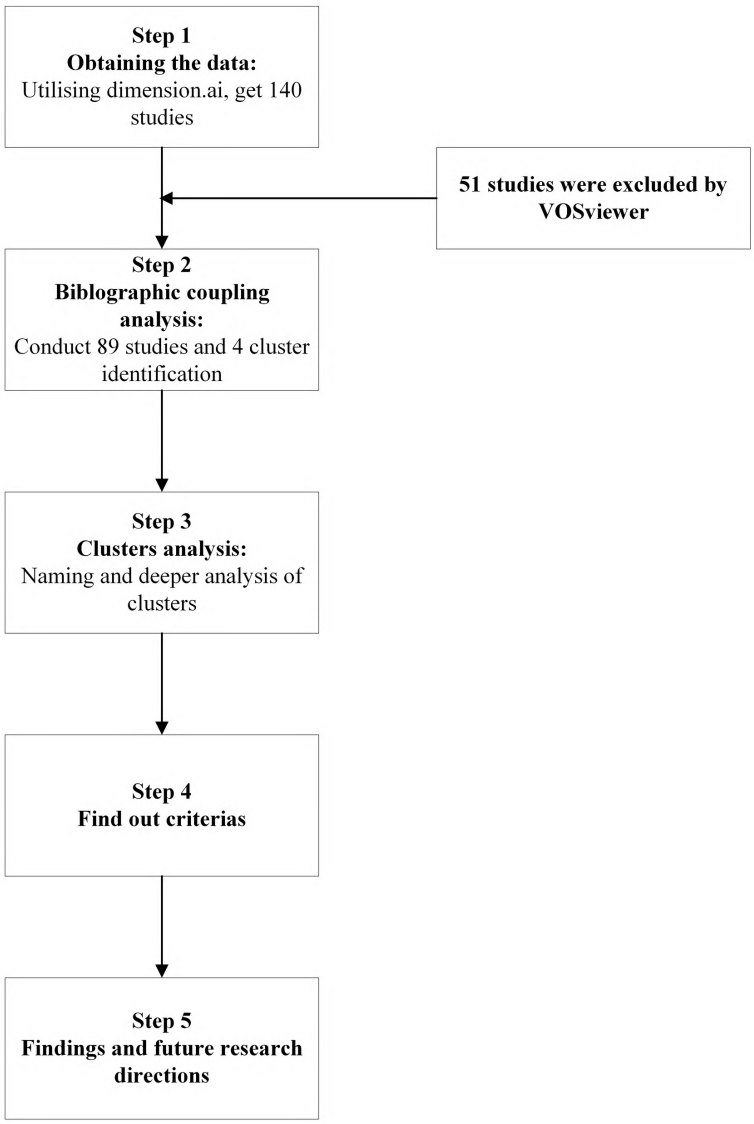

Figure 1. Flowchart of the Systematic Review

As shown in Figure 1, 140 studies were screened using the dimension.ai database during the identification stage, although 51 records were excluded because they fell outside the study's purview. Based on a more thorough review of the relevant literature, 37 additional studies were disqualified at the eligibility stage, leaving 52 studies for the comprehensive literature review. The following sub-sections provide information about the research for the four distinct clusters (Cluster A, Cluster B, Cluster C, and Cluster D).

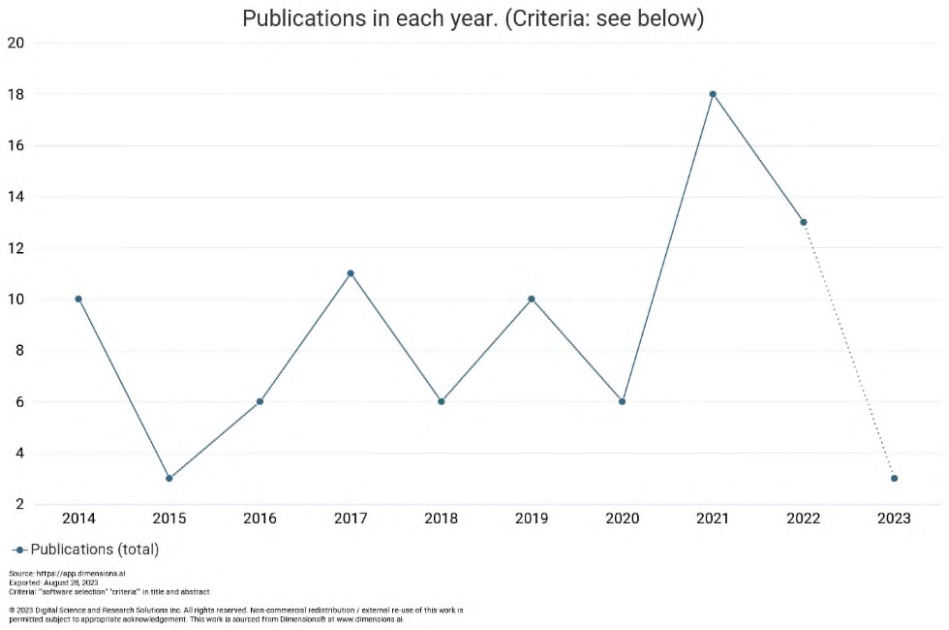

Figure 2. Changes in the Number of Relevant Studies per Year

Figure 2 shows the distribution of studies on software selection criteria by year. Since 2014, the largest number of studies (18) were conducted in 2021, followed by a considerable decrease, probably due to the pandemic period after 2020, which hindered academic research within companies.

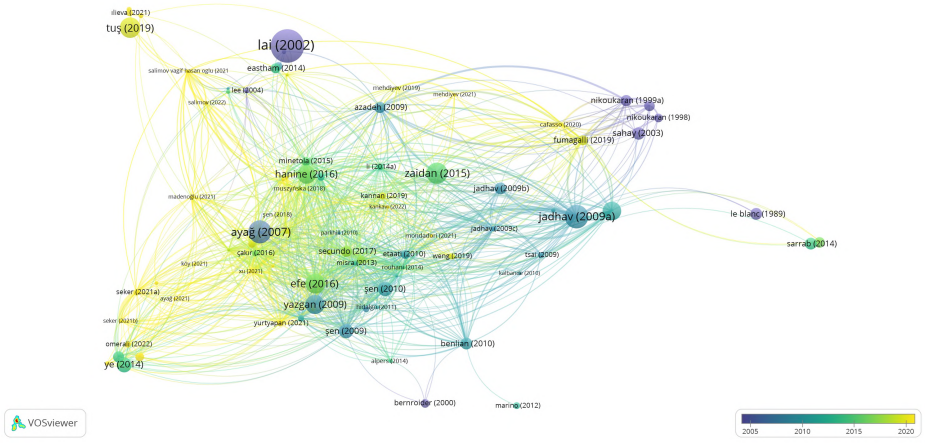

Figure 3. Distribution of Studies by Year

Figure 3 shows the studies color-coded by year of publication, with darker colors representing older articles and lighter colors representing more recent articles. The lines between articles indicate that the articles are related to each other. Articles with a large circle are associated with more articles, while articles with a relatively smaller circle have fewer associations. Looking at the figure, it can be seen that articles written in 2004 and around 2004 are few but are cited by many articles. Articles written after 2010 show that the topic remains popular today.

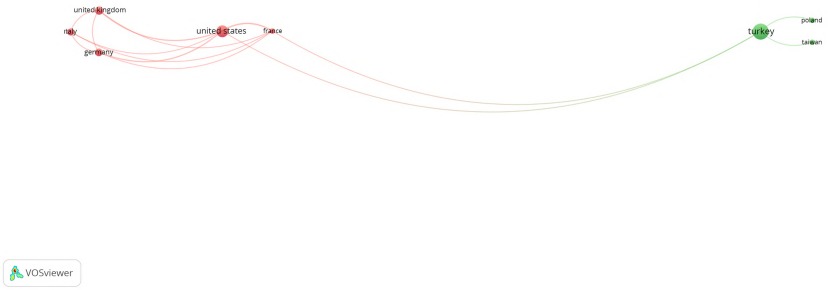

Figure 4. Relationship map of the countries where the studies are based

The countries with the highest number of articles published are Turkey, the USA, India, China, the UK, and Germany—however, the ranking changes when we look at the number of citations. The most cited countries are Turkey, China, India, the USA, UK and Germany, respectively. Figure 4 shows a map of the citation relations of countries. According to the map, the studies conducted in Turkey, Poland, and Taiwan are divided into one group concerning each other, while the other group includes the UK, Germany, Italy, the USA, and France. The relationship between the two groups is not strong. There is a relationship only between Turkey and USA and France. Turkey being the most cited country may affect this.

2.1. Bibliographic coupling analysis

In literature reviews, bibliographic coupling is frequently used to cluster relevant works logically to identify distinct groupings. When two papers cite the same study, this is known as bibliographic coupling (Mollaoglu et al., 2023; Small and Koeing, 1977). This approach assumes that two works that cite a third work are likely to be connected, necessitating their inclusion in the cluster solution generated by a visualization map (Mass-Tur et al., 2021).

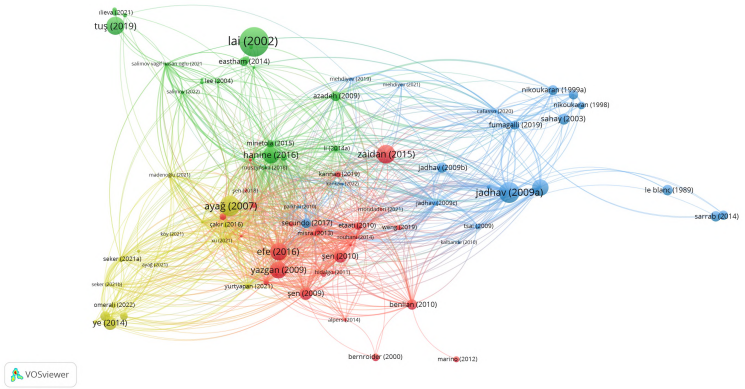

Figure 5. Bibliographic Coupling Network Map for Studies of Software Selection Criteria

Bibliographic coupling analysis was used to identify existing trends and knowledge gaps in the literature on software selection criteria. When the articles from the database were loaded into the VOSviewer program, the program extracted articles from the data pool that were not related to other articles or that differed from other articles for different reasons. As a result, the remaining analysis was completed with 89 studies. Figure 4, which shows the analysis results of the study, shows four clusters coded with red, green, blue, and yellow colors representing clusters A, B, C, and D, respectively. Details on the clusters will be given in the rest of the study. The clustering of the studies is a method offered by the program that facilitates a more detailed examination and

analysis of the studies to be presented to the readers. with this method, trends in the studies can be followed more easily. As in Figure 3, in this figure, each circle represents an article. The size of the circles indicates the strength of the relationship of the studies with other articles. The larger the circle of the study, the more related it is. When we look at the clusters, we see that most of the articles are concentrated in the center and have intense relations with articles from different clusters. this shows us that the articles in the field are generally shaped around the same topics and that they cite each other. There are a few different articles (Bernroider et al. 2020; Marino 2012; Ilieva 2021; Sarrab 2014) that differ from the studies in other clusters.

3. Cluster Analysis

The following subsections examine the four clusters that emerged from the VOSviewer analysis and the articles in these clusters. The clustering process is applied by the VOSviewer program to make the analysis of the articles easier and more systematic. Looking at the general situation of the clusters, it was seen that clustering was made according to the methods applied in the articles. In this context, the AHP method was the most used and was applied in every cluster. The other clusters were interpreted based on the most applied methods other than AHP to help future studies. The articles that were not written in English or Turkish or were not related to the subject were excluded from the analysis.

Cluster A: AHP Method

Cluster A included 16 research papers (15 journal articles and 1 book chapter). This cluster is shown in red color in Figure 5. The AHP method was the most used in this cluster. Therefore, the cluster is located near the center of the map and is strongly connected to all other clusters. Regarding the specific studies, Benlian and Hess (2010) used the Survey method to evaluate software and Office Systems selection criteria. In the study, surveyors were selecting custom ERP systems. They ranked reliability and functionality as the highest priorities. Ease of implementation and support were ranked as the lowest. Also, the cost factor ranked only fifth among the seven factors. Şen et al. (2009) used the Enterprise Software Selection Method (ESSM), a mathematical programming model. This program assists decision-makers in the enterprise software selection process, after that Şen and Baraçlı (2010) used the Fuzzy Quality Function Deployment (QFD) approach that focuses on translating functional requirements formed with linguistic variables into non-functional criteria. Many researchers have used the Analytic Hierarchic Process (AHP) method in this cluster. For instance, the use of the AHP method in research is evident in works by Şen et al. (2019), Efe (2016), Misra (2013), Zaidan (2015), Hidalgo et al. (2011), Kannan (2019), and Çalışkan et al. (2019). Additionally, Çalışkan et al. (2019) employed PROMETHEE to finalize their research, a method favored for assessing binary "YES-NO" questions within the resolution process. Furthermore, Kannan et al. (2019) crafted a hybrid technique for the selection of software packages for a specific firm, integrating the AHP, TLBO, and TOPSIS approaches.

Zahedi et al. (2011) used a Fuzzy Quality Function Deployment (F-QFD) approach to suggest a software selection method. They conducted a case study to choose the best among 10 software companies. In this cluster, there are two articles written by Rohani on this subject. In the first article, Rouhani and Ravasan (2014) used the F-TOPSIS method for software selection. In the second one, Rouhani (2017) used the Fuzzy Superiority and Inferiority Ranking (FSIR) method. Khaled and Idrissi (2011) applied The Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) to express the decision maker's preferences according to the adopted criteria. Lastly, Alpers et al (2014) has issued a conference paper on this topic. In the study, they developed the Selection Approach for ERP systems (SCAPE) method. They also built a comprehensive database covering systems and vendors of ERP software systems.

Cluster B: TOPSIS Method

Cluster B, which contains 13 research articles (10 journal articles and 3 conference proceedings), is shown in green in Figure 5. It is located near the center of the map and appears to be connected to all other clusters. This cluster also contains articles for which the AHP method was used (Lai, et al., 2002; Maram et al., 2019; Okudan, 2007; Azadeh, et al., 2010; Hanine et al., 2016). In addition, the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method stands out as the most widely used method. Hanine et al. (2016) applied Fuzzy TOPSIS to specify the software selection criteria while Zulkifli et al. (2010) and Guezguez et al. (2015) applied TOPSIS to evaluate software selection criteria. Oglu conducted three studies applying different methodologies to functionality, price, usability, and reliability: the Sugeno Integral method (Oglu, 2020); F-AHP (Oglu and Qizi, 2021); and F-TOPSIS (Oglu, 2022). Eastham et al. (2015) applied Hierarchical Decision Modeling (HDM) to project management software selection while Tuş and Adalı (2019) used a new combination of CRITIC and WASPAS methods in a case study of selecting software to meet a company's need for tracking employees' working hours.

Cluster C: Hybrid Methods

Cluster C with 16 research articles is the cluster furthest from the center. It is shown in blue color on the map. Hybrid methods are the most commonly used methods in the cluster. Since it is not a method used in other clusters, it is not very connected to other clusters and is far from the center. Nikoukaran, Hlupic, and Paul (1998) presented a comprehensive list of criteria structured in a hierarchical framework for evaluating simulation software. They categorized issues related to criteria for simulation software

evaluation into seven main groups and several sub-groups. Nikoukaran and Paul (1999) discussed the findings of a literature review on the choice of simulation software. They divided the many research contributions into four groups: strategies for selecting simulation software, procedures for evaluating simulation software, standards to be applied during the evaluation process, and suggestions on the topic. Nikoukaran, Hlupic, and Paul (1999) identified and listed software selection criteria.

Jadhav and Sonar have three studies in this cluster. Jadhav and Sonar (2009a) reviewed research on the evaluation and selection of software packages. They determined that AHP is frequently used and there is no common list of software evaluation criteria. Jadhav and Sonar (2009b) analyzed software selection comparatively using AHP, Weighted Scoring Method (WSM), and Hybrid Knowledge Based System (HKBS). They found that the HKSB method was better than AHP and WSM in terms of computational efficiency, flexibility in problem-solving, reuse of information, and consistency and presentation of evaluation results. Jadhav and Sonar (2011) applied HKBS to software selection. AHP, which is frequently used, as mentioned above, was also used in Cluster C by several researchers (Kankavi and Kocaoglu, 2022; Secundo et al., 2016; Fumagalli et al., 2019; Zakria et al., 2010).

By combining research and practitioner insights, Bjarnason (2023) used method engineering to iteratively design a software selection technique for a specific company, and then validate it through a focus group and implementation. Tsai et al. (2009) investigated ERP software selection criteria as a determiner of software and information quality, and ERP success while Sahay and Gupta (2003) addressed software selection as a supply chain solution. Parkhill et al. (2010) conducted a single-company case study of software selection using Multiple Criteria Decision Analysis (MCDA). Finally, Sarrab and Rehman (2014) conducted a case study to apply their proposed quality criteria to eight different open-source software programs, divided between open-source network tools and learning management systems.

Cluster D: Fuzzy Methods

There were 15 research articles in cluster D. It is shown in yellow color in Figure 5. Fuzzy methods were mostly used in this cluster. Ayağ and Özdemir (2007) used the Fuzzy Analytic Network Process (F-ANP) for software selection rather than the standard method of AHP because the latter cannot accommodate various interactions, dependencies, and feedback between higher- and lower-level elements. Yurtyapan and Aydemir (2021) used MACBETH to suggest a novel strategy for handling uncertainty in ERP software selection. Garg et al. (2022) used SWARA to evaluate criteria weights and COPRAS to rank alternatives using the Complex Intuitionistic Fuzzy Soft (CIFS) context.

Within this cluster, various other methods were used for criterion identification and weighting, including TODIM and TOPSIS (Seker and Kahraman, 2021) MULTIMOORA (Li, 2014), Delphi technique and TOPSIS (Çakır, 2016), Fuzzy COPRAS (Madenoglu, 2021; Omerali and Kaya, 2021), and F-AHP and F-TODIM (Tolga, 2018).

4. Software Selection Criteria

The analysis conducted on the Dimension.ai database identified 140 articles related to software selection criteria. Of these, most aimed at determining the criteria for software selection while the remaining studies mostly applied the criteria. Notably, a detailed analysis of the criteria did not reveal any common list (Jadhav and Sonar, 2009a). Another noteworthy element was that the criteria do not meet the current needs of businesses, with new applications developed to spread sustainable activities, especially in state institutions. The inadequacy of the criteria for meeting these and similar situations prevents businesses from meeting their current needs.

In this study, we aimed to facilitate software selection for businesses by focusing on these two factors. Therefore, the criteria mentioned in the reviewed studies were pooled and simplified to create a common language.

Table 1 shows the articles analyzed and the criteria used. The authors used criteria in different ways but with the same scope. This study aims to bring together and simplify the various criteria in the literature to provide a more streamlined and accessible approach for businesses going through the software selection process. Since it is aimed to create a common language for the criteria, an attempt has been made to group the criteria. It has been observed that the criteria recommended to be used in software selection are generally concentrated in the areas of cost, functionality and ease of use. In addition, there are some studies that add vendor performance to the evaluation criteria.

Figure 6 shows the list of criteria generated. Some studies used 4 criteria, while others used up to 40 criteria. For ease of implementation, the number of criteria was kept at an average number and the criteria were analyzed and grouped under seven main headings. The main criteria given in Table 1 are divided into sub-criteria. This provides an overview of the criteria used in the literature.

Table 1. Criterias Listed From the Literature

Criterias	Authors
Technology	Sahay 2003; Şen 2009; Şen 2010; Fumagalli 2019; Hidalgo 2011; Rouhani 2017; Azadeh 2010; Nikouran 1999; Lai 2002; Efe 2016; Kankavi 2022; Yurtyapan 2021; Seker 2022;
Cost & Pricing	Sahay 2003; Şen 2009; Şen 2010; Zulkifli 2010; Hidalgo 2011; Nikouran 1999; Eastham 2015; Lai 2002; Ayağ 2007; Şen 2019; Benlian 2010; Efe 2016; Khaled 2011; Okudan 2007; Hanine 2016; Oglu 2022; Parkhill 2010; Yurtyapan 2021; Seker 2022; Garg 2022; Madenoglu 2021; Çakır 2016
Features	Sahay 2003; Şen 2009; Şen 2010; Zulkifli 2010; Hidalgo 2011; Azadeh 2010; Eastham 2015; Şen 2019; Benlian 2010; Khaled 2011; Maram 2019; Okudan 2007; Oglu 2022; Oglu 2021; Oglu 2020; Kankavi 2022; Jadhav 2009; Yurtyapan 2021; Omerali 2021;
Customization	Sahay 2003; Şen 2009; Şen 2010; Zulkifli 2010; Fumagalli 2019; Hidalgo 2011; Rouhani 2017; Nikouran 1999; Tolga 2018; Štemberger 2015; Khaled 2011; Misra 2013; Maram 2019; Oglu 2022; Oglu 2021; Oglu 2020; Kankavi 2022; Parkhill 2010; Çakır 2016
Services	Sahay 2003; Şen 2009; Şen 2010; Zulkifli 2010; Fumagalli 2019; Hidalgo 2011; Rouhani 2017; Azadeh 2010; Tolga 2018; Hanine 2016; Seker 2022; Omerali 2021;
Vendor	Sahay 2003; Şen 2009; Şen 2010; Zulkifli 2010; Fumagalli 2019; Rouhani 2017; Azadeh 2010; Lai 2002; Ayağ 2007; Zahedi 2011; Štemberger 2015; Çalışkan 2019; Efe 2016; Hanine 2016; Kankavi 2022; Parkhill 2010; Yurtyapan 2021; Seker 2022; Garg 2022; Omerali 2021; Madenoglu 2021; Çakır 2016
Others	Sahay 2003; Şen 2009; Şen 2010; Zulkifli 2010; Fumagalli 2019; Nikouran 1999; Eastham 2015; Ayağ 2007; Zahedi 2011; Benlian 2010; Khaled 2011; Misra 2013; Maram 2019; Jadhav 2009; Parkhill 2010; Yurtyapan 2021; Garg 2022; Madenoglu 2021; Çakır 2016

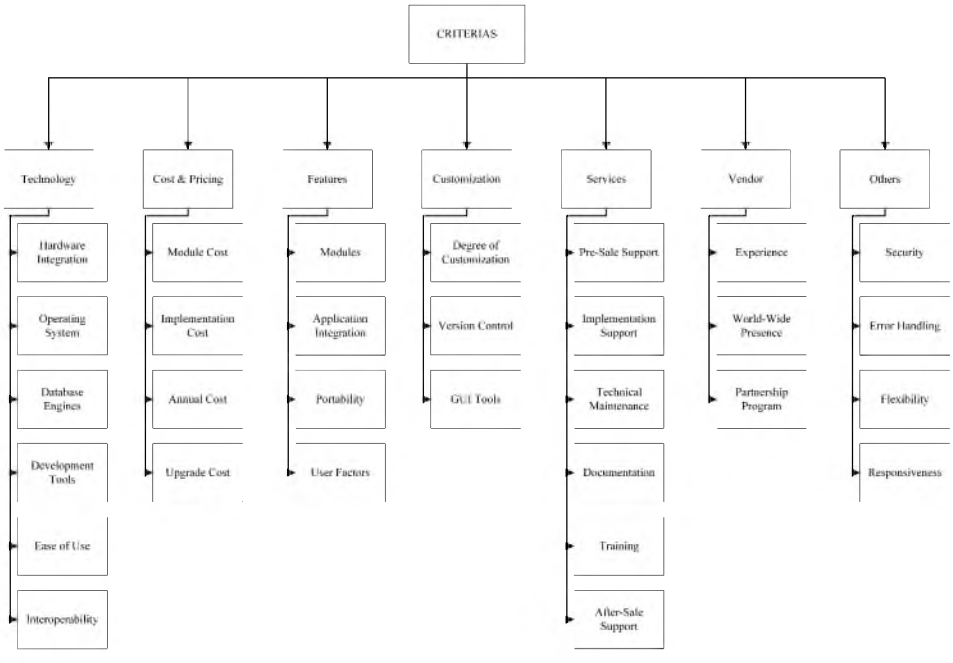

Figure 6. Hierarchical List of Criteria

5. Conclusion

In conclusion, this research provides a comprehensive overview and analysis of software selection criteria and methods. By consolidating and simplifying various criteria from the literature, it offers a more streamlined and accessible approach for enterprises embarking on the software selection process. The emphasis on creating a common language for these criteria further enhances the utility and applicability of this research in practical settings. VOSviewer software was used to analyze the studies. The VOSviewer program groups studies to facilitate the analysis of studies. In this study, the studies were categorized into four groups. As can be seen in Figure 5, the articles are very closely related to each other. This may be due to the frequent use of some methods in the literature. Therefore, it isn't easy to create homogeneous clusters. Looking at the clusters in general, it is seen that the AHP method is the most commonly used method and is used in every cluster. The use of different methods in future studies will diversify the literature. TOPSIS method is expressed as the second cluster. AHP and TOPSIS methods are generally used together in the literature. Hybrid methods and Fuzzy methods were used in the third and fourth clusters formed by researchers who wanted to differentiate from the literature. These methods, which are used to obtain the most comprehensive results by minimizing the influence of the experts assisted in the analysis and which have attracted attention recently, will continue to be used frequently in the future.

This study will be a guideline for future studies. The categorization of the literature will be useful for other researchers interested in the current state of software package selection and evaluation, as well as for practitioners who need information on how to evaluate specific types of software packages. While the software selection methodologies presented in the reviewed studies mostly follow the same procedures, very little work has yet been done to develop a general approach to the selection of all types of software packages. Therefore, a general software selection technique and evaluation criteria are proposed based on the literature review. The most important steps in evaluating software packages are identifying the criteria to be considered, assigning a weight to each criterion, creating a rating scale for each criterion, calculating the score, ranking the options and selecting the best one.

Many papers provide a preferred list of evaluation criteria for evaluating a particular software package; however, there seems to be a lack of a common list. Software evaluation criteria are not clearly defined and explained in the literature. The precise meaning of a criterion depends on the evaluator's interpretation, so authors may use different wording for the same criterion in the same literature, thus creating confusion and uncertainty for the software evaluator. To overcome this problem, we have presented generic lists of evaluation criteria that can be applied in the evaluation of any software program. Future work could create guidelines and develop an expert system to facilitate the decision-making process. This study used articles from a single database. Future work could extend the scope of the analysis by using different databases. In addition to this study, studies can be conducted on the use of software on a sectoral basis.

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REFERENCES

Alpers, S., Becker, C., Eryilmaz, E., & Schuster, T. (2014). A Systematic Approach for Evaluation and Selection of ERP Systems. Lecture Notes in Business Information Processing.

Ayağ & R. G. ÖzdemİR (2007) An intelligent approach to ERP software selection through fuzzy ANP, International Journal of Production Research, 45:10, 2169-2194, DOI: 10.1080/00207540600724849

Azadeh, A., Shirkouhi, S. N., & Rezaie, K. (2010). A robust decision-making methodology for evaluation and selection of simulation software package. Int J Adv Manuf Technol, 47, 381-393.

Benlian, A., & Hess, T. (2011). Comparing the relative importance of evaluation criteria in proprietary and open-source enterprise application software selection – a conjoint study of ERP and Office systems. Info Systems J, 503-525.

Çakır, S. (2016). Selecting appropriate ERP software using integrated fuzzy linguistic preference relations Fuzzy TOPSIS Method. *International Journal of Computational Intelligence Systems*, 9(3), 433-449.

Çalişkan, E., Aksakal, E., Çetinyokuş, S., & Çetinyokuş, T. (2019). Hybrid Use of Likert Scale-Based AHP and PROMETHEE Methods for Hazard Analysis and Consequence Modeling (HACM) Software Selection. *International Journal of Information Technology & Decision Making, 18*(5), 1689–1715.

Eastham, David James Tucker, Sumir Varma & Scott Matthew Sutton (2014) PLM Software Selection Model for Project Management Using Hierarchical Decision Modeling With Criteria From PMBOK® Knowledge Areas, Engineering Management Journal, 26:3, 13-24.

Efe, An Integrated Fuzzy Multi-Criteria Group Decision Making Approach for ERP System Selection, *Applied Soft Computing Journal* (2015)

Fumagalli, Adalberto Polenghi, Elisa Negri & Irene Roda (2019) Framework for simulation software selection, *Journal of Simulation, 13*(4), 286-303.

Garg, H., Vimala, J., Rajareega, S., Preethi, D., & Perez-Dominguez, L. (2022). Complex intuitionistic fuzzy soft SWARA - COPRAS approach: An application of ERP software selection. AIMS Mathematics, 7(4), 5895–5909.

Ghulam Zakria, Z. G. (2010). We are selecting and prioritizing key factors for CAD/CAM software in small- and medium-sized enterprises using AHP. Front. Mech. Eng. China, 5(2), 157-164.

Guezguez, W., Zaini, R., & Quqandi, E. (tarih yok). A multi-criteria decision-making model for software selection to build e-portfolio. 2015 Fifth International Conference on e-Learning.

Hanine, M., Boutkhoum, O., Tikniouine, A., & Agouti, T. (2016). Application of an integrated multi criteria decision making AHP TOPSIS methodology for ETL software selection. SpringerPlus 5.

Hidalgo, A., Albors, J., & Gómez, L. (2011). ERP Software Selection Processes: A Case Study in the Metal Transformation Sector. Intelligent Information Management, 1-16.

Jadhav, A. S., & Sonar, R. M. (2009a). Evaluating and selecting software packages: A review. Information and Software Technology, 51, 555-563.

Jadhav, A., & Sonar, R. (2009b). Analytic Hierarchy Process (AHP), Weighted Scoring Method (WSM), and Hybrid Knowledge Based System (HKBS) for Software Selection: A Comparative Study. Second International Conference on Emerging Trends in Engineering and Technology.

Jadhava, A. S., & Sonar, R. M. (2011). Framework for evaluation and selection of the software packages: A hybrid knowledge based system approach. The Journal of Systems and Software, 84, 1394–1407.

Kannan, A. S., Balamurugan, S. A., & Sasikala, S. (2019). A Novel Software Package Selection Method Using Teaching–Learning Based Optimization and Multiple Criteria Decision Making. IEEE Transactions on Engineering Management.

Khaled, A., & Idrissi, M. A. (2011). A Learning Driven Model for ERP Software Selection Based on the Choquet Integral: Small and Medium Enterprises Context. Communications in Computer and Information Science.

Li, Z.-H. (2014). An Extension of the MULTIMOORA Method for Multiple Criteria Group Decision Making Based upon Hesitant Fuzzy Sets. Hindawi Publishing Corporation Journal of Applied Mathematics.

Madenoğlu, F. S. (2021). Bütünleşik Entropi-COPRAS Yöntemi ile KKP Yazılımının Seçimi. *Yönetim ve Ekonomi Araştırmaları Dergisi, 19*(4), 14-29.

Maram, V., Sultan, S. J., Omar, M. B., & Bommisetty, V. N. (2019). Selection of Software in Manufacturing Operations Using Analytic Hierarchy Process. AIP Conference Proceedings 2138, 040016.

Mas-Tur, A., Roig-Tierno, N., Sarin, S., Haon, C., Sego, T., Belkhouja, M., ... & Merigó, J. M. (2021). Co-citation, bibliographic coupling, and leading authors, institutions, and countries in the 50 years of Technological Forecasting and Social Change. Technological Forecasting and Social Change, 165, 120487.

Misra, S. K., & Ray, A. (2013). Integrated AHP-TOPSIS Model for Software Selection Under Multi-criteria Perspective. Driving the Economy through Innovation and Entrepreneurship, 879-890.

Mollaoglu, M., Altay, B. C., & Balin, A. (2023). Bibliometric Review of Route Optimization in Maritime Transportation: Environmental Sustainability and Operational Efficiency. Transportation Research Record, 03611981221150922.

Nikoukaran, J., & Paul, R. J. (1999). Software selection for simulation in manufacturing: a review. Simulation Practice and Theory, 7, 1-14.

Nikoukaran, J., Hlupic, V., & Paul, R. J. (1998). Criteria for Simulation Software Evaluation. Proceedings of the 1998 Winter Simulation Conference.

Nikoukaran, J., Hlupic, V., & Paul, R. J. (1999). A hierarchical framework for evaluating simulation software. Simulation Practice and Theory, 7, 219-231.

Oglu, S. V. (2020). Software Selection Based of Sugeno Integral. Scholarly Publisher RS Global, 7(59).

Oglu, S. V. (2022). Selectıın of Software on Base of Fuzzy TOPSIS Method. Scholarly Publisher RS Global, 3(75).

Oglu, S. V., & Qizi, D. J. (2021). Software Selection on Base of Fuzzy AHP Method. *International Academy Journal Web of Scholar, 1*(21).

Okudan, G. (2006). A multi-criteria decision-making methodology for optimum selection of a solid modeller for design teaching and practice. *Journal of Engineering Design, 17*(2), 159-175.

Omerali & Tolga Kaya | (2022) Augmented Reality Application Selection Framework Using Spherical Fuzzy COPRAS Multi-Criteria Decision Making, Cogent Engineering, 9:1, 2020610

Rouhani, (2017)," A fuzzy superiority and inferiority ranking based approach for IT service management software selection ", Kybernetes, 46

(4).

Rouhani, A., & Ravasan, A. Z. (2014). A Fuzzy TOPSIS based Approach for ITSM Software Selection. International Journal of IT/Business Alignment and Governance, 5(2).

Secundo, G., Magarielli, D., Esposito, E., & Passiante, G. (2017). Supporting decision-making in service supplier selection using a hybrid fuzzy extended AHP approach. *Business Process Management Journal, 23*(1), 196-222.

Seker, S., & Kahraman, C. (2022). A Pythagorean cubic fuzzy methodology based on TOPSIS and TODIM methods and its application to software selection problems. Soft Computing, 26, 2437–2450.

Small, H. G., & Koenig, M. E. (1977). Journal clustering using a bibliographic coupling method. Information processing & management, 13(5), 277-288.

Stemberger, Vesna Bosilj-Vukšić & Mojca Indihar Jaklić (2009) Business Process Management Software Selection – Two Case Studies, Economic Research- Ekonomska Istraživanja, 22:4, 84-99

Şen, A. Y., Semiz, N., Güneş, B., Algül, D., Gergin, Z., & Dönmez, N. D. (2019). The Selection of a Process Management Software with Fuzzy Topsis Multiple Criteria Decision Making Method. Proceedings of the International Symposium for Production Research 2018, 150-167.

Şen, C. G., & Baraçlı, H. (2010). Fuzzy quality function deployment based methodology for acquiring enterprise software selection requirements. Expert Systems with Applications, 37, 3415–3426.

Şen, C. G., Baraçlı, H., Şen, S., & Başlıgil, H. (2009). An integrated decision support system dealing with qualitative and quantitative objectives for enterprise software selection. Expert Systems with Applications, 36, 5272–5283.

Tolga, C. (2018). Evaluation of ERP software with fuzzy AHP integrated TODIM method. *Sakarya University Journal of Science, 22*(5), 1351-1370.

Tuş, A., & Adalı, E. A. (2019). The new combination with CRITIC and WASPAS methods for the time and attendance software selection problem. OPSEARCH. Yurtyapan, M. S., & Aydemir, E. (2022). ERP software selection using intuitionistic fuzzy and interval grey number-based MACBETH method. Grey Systems: Theory and Application, 12(1), 78-100.

Zaidan, B.B. Zaidan, Hussaen Muzamel, Ahmed Haiqi, M.L. Mat Kiah, Mohamed Abdulnabi, Multi-Criteria Analysis for OS-EMR Software Selection Problem: A Comparative Study, Decision Support Systems (2015)

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REVIEW ARTICLE

Analysis and Comparison of Electric Scooter Crashes: A Review of Crash Characteristics and Health Outcomes in Türkiye

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ABSTRACT

Micromobility, including shared e-scooters, has become a convenient mode of transportation for short-distance trips globally. Türkiye introduced shared e-scooters in 2019, quickly expanding their presence. This study analyses and identifies the crash characteristics and health outcomes of e-scooter crashes in Türkiye. It also seeks to provide recommendations for enhancing safety.

This review focused on e-scooter crashes in Türkiye, a country with a population of 85,279,553. Our narrative analysis examined eight studies and eight media reports on e-scooter incidents in Türkiye, evaluating patient demographics, crash characteristics (user type, fall/collision, speed, time, location), injury types, interventions, hospitalizations, and modifiable risk factors like helmet use and alcohol consumption.

Accidental involvement was slightly higher in men than in women. The rate of helmet usage is quite low. Upper extremity injuries are the most common type, followed by lower extremity injuries. Fatalities have occurred, underscoring public health concerns. E-scooter crashes often involve collisions with pedestrians and vehicles, highlighting the need for adherence to traffic rules and safe riding practices.

E-scooters are a practical transportation solution but pose safety risks. Protective measures such as helmet and other protective equipment use, compliance with traffic rules, and public awareness campaigns are crucial to mitigate these risks. We conclude that e-scooter safety regulations in Türkiye should be enhanced to protect riders and pedestrians and promote a safer micromobility ecosystem.

Keywords: Crashes, micromobility, e-scooters.

1. Introduction

Micromobility is a transportation mode that offers a practical solution for short-distance travel and has been gaining popularity over time. Among micromobility systems, vehicle-sharing systems for e-scooters, which have become increasingly popular worldwide in recent years, were introduced in Türkiye in 2019. This service started in Istanbul and Ankara, but it quickly expanded to other cities. It is estimated that there are around 30,000 shared e-scooters in Istanbul alone (Diken, 2021). The first fatal crash involving a shared e-scooter in Türkiye was recorded in Istanbul in 2020 (Sözcü, 2020). However, it was not until a year later, in April 2021, that the "Electric Scooter Regulation" was published in the Official Gazette (Resmi Gazete, 2021). Following this, there has been a limited increase in education and resources related to safe riding.

Traffic accidents not only affect human life and health but also have negative implications for societies' economic and social structure. They can result in individual consequences, such as the need for care, disability, and loss of the workforce, both financially and emotionally. Additionally, crashes indirectly impact society's overall health and well-being by placing an extra burden on the healthcare system and healthcare workers. A portion of healthcare resources and spending must be allocated to the treatment, recovery, and reintegration of injured individuals. For these reasons, e-scooter crashes are both safety and public health concerns (Masilkova 2017, Singh 2022).

The United Nations has introduced a new hospital code specifically for micromobility vehicle crashes within the NEISS (National Electronic Injury Surveillance System) by, the United States Consumer Product Safety Commission. The NEISS gathers data on patients admitted to emergency services following crashes and uses these data to compile statistics and reports. Between 2014 and 2019, 70,644 micromobility crashes were reported. In 2014, 4,881 crashes nearly sixfold to 29,628 in 2019 (Farley, 2020). Each of these crashes cost the country approximately €3,854. Notably, e-scooter crashes occurred at a rate of 5.2 per 10,000

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miles traveled, car crashes occurred at a rate of 0.1, and motorcycle crashes occurred at a rate of 0.05 per 10,000 miles. Excluding individual vehicles, shared e-scooters have a crash rate of 2.2 per 10,000 miles of travel (Pobudzei 2022).

It is possible to categorize crashes based on their characteristics, such as the time of occurrence, location, involvement of other vehicles, and severity of the impact. When examining their effects, crashes involving e-scooters can be categorized into two main groups: crashes caused by the e-scooter rider (e.g., falls, collisions with objects, collisions with pedestrians) and crashes where the e-scooter rider is involved with other traffic elements (e.g., collisions with other vehicles, where the rider user is the victim) (Mitropoulos, 2023). An example of the first category is a collision between an e-scooter rider and pedestrian on a sidewalk. In contrast, an example of the second category is a crash in which an automobile collides with an e-scooter.

According to recent data (Yılmaz 2022, İğrek & Ulusay 2023), a significant proportion of crashes are more likely to be caused by e-scooter riders than incidents where they are the victims. The impact and consequences of such crashes are directly related to how they occur and the severity of the crash. Obtaining information about the formation of e-scooter crashes in Türkiye is often difficult because crashes resulting from falls or e-scooter-pedestrian collisions are reported to the police only if there are severe injuries; therefore, no records are kept if none of the involved people are sent to the hospital. The inability to determine the characteristics of a crash hinders the development of preventive methods and measures, making it challenging to determine the complete picture.

Although bicycles, one of the oldest forms of micromobility, have been used in Türkiye for many years, a significant portion of the public perceives them more as a means of sport or recreation rather than transportation (Dündar et. al 2022). On the other hand, the inclusion of e-scooters in the transportation system has strengthened the perception among some people that they are more of a recreational vehicle than a mode of transport (Dündar 2023a). Additionally, traffic accidents involving e-scooters and their negative impact on traffic (Dündar, 2023b) have further contributed to the growing negative perception of e-scooters among the public. This perception is not unique to Türkiye; restrictions on e-scooter use have also been implemented in France (Schofield, 2023) and Australia (Wong, 2024).

E-scooters can play an important role in transportation, particularly in journeys defined as the "last mile" or "last kilometer." However, the negative public perception of e-scooters severely undermines this potential. Unlike motor vehicles such as cars, e-scooters do not provide a protective environment around the driver, which means that in the event of an accident, the consequences can be severe. Therefore, the use of protective equipment such as helmets, knee pads, elbow pads, and wrist guards is recommended. In fact, in some countries, the use of such protective gear is a legal requirement (Deveci 2023). Although the literature contains various studies (Kleinertz 2021, Kazemzadeh et al. 2022, Zhao et al 2022) examining the factors and outcomes of accidents in different countries, no study has evaluated these studies and analyzed the factors affecting accident outcomes in this context. Therefore, the objectives are to examine publications and internet news about e-scooter crashes, their characteristics, and outcomes in Türkiye. Thus, this study aimed to support the development of various rules or regulations related to e-scooter usage by evaluating how different factors, such as the use of protective equipment and alcohol consumption, affect accident outcomes. The secondary objective of this study is to develop recommendations to reduce the severity of e-scooter crashes and their consequences in Türkiye.

2. Materials and methods

The present article is a narrative review of the existing literature on e-scooter crashes and their health outcomes. Narrative review is chosen for their ability to provide a wide-ranging exploration of e-scooter accidents and to discuss the outcomes of accidents with respect to factors such as protective equipment or alcohol use. Narrative review is also chosen since the various effects of e-scooter usage are emerging topics, and a more flexible approach is required to integrate diverse findings. A search of the PubMed and Google Scholar electronic databases was undertaken using the search terms “e-scooter crashes," "micromobility crashes," "health outcomes," "health," "hospital," "emergency," "injury pattern," "impact," and “falls” in various permutations and combinations. A total of 142 citations were retrieved using this method. On reviewing the above citations, 134 articles were excluded: 35 because they concerned other types of micromobility vehicles, one because it was a preprint version, one article because we had no access to full text, one because it is a congress paper, one addressed only a single health outcome (ligament injury), 63 because they dealt with other subjects (such as road danger, modeling mobility, emission), and 32 because they dealt with other aspects of e-scooter crashes (such as; safety, sustainability, cost-effectiveness, parking).

As it was not possible to conduct a formal systematic review or meta-analysis given the nature of the above publications, it was instead decided to conduct a narrative review, giving priority to eight studies (Yavuz 2022, Yılmaz 2022, Büyükceran 2023, Demir 2023, Avıncı Taş 2024, İğrek & Ulusoy 2023, Kültür et al. 2023, Baca et al. 2024) from Türkiye and eight media reports briefly summarizing the health outcomes of e-scooter injuries. The news report mining method has been successfully employed in

previous studies (Yang et. al 2020, Scquizzato et. al 2022, Brauner et. al 2022), and we replicate this approach within the context of Türkiye.

Articles were reviewed to assess patient demographics, crash characteristics (e.g., user vs. non-user, fall vs. collision, speed, time of day, and crash location), injury regions and types, interventions, hospitalizations following crashes, and modifiable risk factors that increase the likelihood of crashes, such as helmet use and alcohol consumption. Descriptive data; were expressed as Mean (m), Standard deviation (SD), frequency (%), and number of participants (n).

3. Results

We identified relevant articles and media reports on e-scooter crashes in Türkiye. Our search yielded seven retrospective studies (Yavuz 2022, Yılmaz 2022, Büyükceran 2023, Demir 2023, İğrek & Ulusoy 2023, Kültür et al. 2023, Baca et al. 2024), one prospective study (Avıncı & Taş 2024) from academic sources. Table 1 presents the patient and crash characteristics of the studies, while Table 2 outlines the health outcomes related to e-scooter crashes in these studies. Additionally, we identified eight media reports on the subject (Sözcü 2020, 61Medya 2022, Haber61 2022, Sözcü 2022, Habertürk 2022, TRT Haber 2022, Sabah 2022a, Cumhuriyet 2022b). The compilation of media news records involved gathering data from national news sources in Türkiye published between 2020 and 2023. Although the literature review identified a significantly higher number of e-scooter accidents during these dates, the accidents that made it to the news were those considered newsworthy, involving rule violations or accidents that resulted in fatalities or significant injuries. Therefore, only accidents that appeared in news sources were included in the study. Additionally, accidents covered by multiple news sources were incorporated into the research, with references made to the sources that provided the most detailed information about the incident.

Table 1. The patient and crash characteristics from the studies.

	Mean age m±sd (range)	Patients < 18 years (%)	Female gender (%)	User/non-user (%)	Speed (km/s)	Fall/collision (%)	Alcohol involvement (%)	Helmet use (%)	Day of accident/time of accident (%)	Location of accident (%)
Yavuz 2022 (n=70)	25.82±8.04 (15-57)	8.5%	47.1%	NA	NA	94.2% fall 4.3% collision with an object or person 1.4% collision-with of moving object	2.9% (n=2)	4.3% (n=3)	NA	NA
Yılmaz 2022 (n=117)	27.20±11.90 (5-76)	13.7%	35.9%	96.6%/3.4 %	NA	NA	0%	0%	41.9% weekend	85.5% beach 6% pavement 3.4% road 2.6% sidewalk 2.6% other locations
Büyükercan 2023 (n=99)	NA	49.4%	50.5%	NA	NA	58.5% fall 37.3% collision with moving objects 4.2% collision with an object or person	NA	NA	54.6% 18.00-24.00 31.3% 00.00-06.00 14.1% 12.00-18.00	NA
Demir, 2023 (n=60)	25.3 (6-62)	16.7%	48.3%	1.7% non-user	NA	68.3% fall 18.4% collision with an object or person 11.7% collision with moving objects	0%	1.7%	75% weekdays 51.7% 12.00-18.00 23.3% 06.00-12.00 18.3% 18.00-24.00 6.7% 00.00-06.00	60% urban
Avıncı & Taş 2024 (n=247)	22.93±8.085 (13-44)	0.49%	39%	NA	NA	NA	NA	NA	NA	NA
İğrek & Ulusoy, 2023 (n=62)	34.21 (9-58)	25.8%	27.5%	90.3%/9.7 %	NA	75% fall 14.2% collision with moving objects 10.8% collision with an object or person	19.3%	6.4%	66.1% weekend or weekdays 17.00-08.00 33.9% weekdays 08.00-17.00	45.1% cycling path 35.4% road 19.5% sidewalk
Kültür et al. 2023 (n=43)	35.9 (16-61)	0%	46%	NA	30.2% highest speed (25km/h)	NA	34.9%	4.7%	44.2% 23.00-07.00 25.6% 07.00–15.00 30.2% 15–23.00	37.2% driveway 62.8% sidewalks
Baca et al. 2024 (n=56)	25.01±2.38 (9-52)	35%	32%	NA	NA	67% fall	NA	NA	62.5% weekend 66.1% daytime	NA

This retrospective study analyzed patients who presented to hospital emergency departments in Istanbul. The study by Yavuz et al. (2022) is the first scientific publication to address the clinical and demographic characteristics of patients presenting to the emergency department due to e-scooter crashes in Türkiye. The type and pattern of injuries in e-scooter crashes, use of protective gear, and health-related findings were retrospectively examined and analyzed in 70 cases. Of the cases, 47.1% were female, 52.9% were male, and the average age was 25.82±8.04 (ranging from 15 to 57 years old). According to how the crashes occurred, it was determined that 94.2% involved the rider falling, 4.3% involved colliding with an object or a person, and 1.4% involved colliding with a vehicle. Alcohol was detected in the blood in 2.9% of cases (n=2), and helmet use was recorded in only 4.3% (n=3) of cases.

The most common injuries resulting from crashes were soft tissue trauma (45.7%, n=32), followed by head trauma (40%, n=28), lower or upper limb fractures (8.5%), spinal fractures (2.9%), frontal bone fractures (1.4%), intracranial hemorrhage (1.4%), jaw and facial fractures (11.4%), and injuries requiring stitches (20%). While 94.2% of cases were discharged, 5.7% were admitted to the hospital for treatment (3 to the ward and 1 to the emergency department).

Table 2. The health outcomes related to e-scooter crashes in these studies

	Yavuz 2022	Yılmaz 2022	Büyükercan 2023	Demir 2023	Avıncı and Taş, 2024	İğrek & Ulusoy, 2023	Kültür et al. (2023)	Baca et al. (2024)
Injured body region								
Head/neck	51.4%	36.8%	NA	57.2%	19.51%	0%	0%	NA
Thoracic	0	8.5%	NA	6.3%		NA	0%	NA
Extremities (lower/upper)	8.5%	94.9% (49.6%/45.3%)	86.7% (27.2%/59.5%)	59.4% (29.2%/30.2%)	78.05%	88.5% (36.3%/52.2%)	34.7%/65.3%	NA
Spine	2.9%	1.8%	NA	NA	2.44%	4.5%	0%	NA
The type of injury								
Fracture	24.2%	15.5%	100%	31.7%	24.39%	41.9%	100%	100%
Soft tissue trauma	45.7%	7.7%	NA	100%	75.61%	NA	NA	NA
Hemorage	1.4%	0.9%	NA	NA	NA	NA	NA	NA
Intervention								
Suturing	20%	NA	NA	NA	7.34%	NA	NA	NA
Imaging (MRI, X-ray, etc)	63.3%	NA	NA	100%	NA	NA	NA	NA
Blood test	3.4%	NA	NA	NA	NA	NA	NA	NA
Consultation needed	NA	48.7%	NA	NA	100%	NA	44.2%	NA
Hospitalization								
Discharged	94.2%	96.6%	NA	86%	85.37%	43.6%	16.3% under 4 h 39.5% more than 4 h	NA
Admitted to the hospital	5.7%	3.4%	NA	78%	14.63%	56.4% (m=3.7 days)	44.2%	NA
Surgery	NA	2.6%	NA	13.3%	12.2%	51.6%	44.2%	48.2%
Conservative	NA	NA	NA	NA	NA	38.5%	55.8%	52.8%
Work loss	NA	NA	NA	NA	NA	2.4 months	NA	NA

NA: Not applicable; m: mean; h: hour

Yılmaz et al. (2022) retrospectively analyzed cases presented to the emergency department due to e-scooter crashes. The study included 117 cases, with 35.9% female and 64.1% male patients ranging in age from 5 to 76 years (mean: 27.20±11.90). A total of 13.7% of the cases (n=16) were under 15. 41.9% of the crashes occurred on weekends. Of the injured individuals who reached the hospital, only 1.7% arrived by ambulance, while 98.3% went independently as outpatients. None of the patients showed alcohol in their blood; 23.3% were directed to X-rays, 38.5% to computed tomography (CT) scans, 1.7% to ultrasonography (USG) imaging, and 3.4% had blood tests. In 96.6% of the crashes, the rider was injured, and 3.4% were passengers. Helmet use was not recorded in any crash. The average speed was 24.36±6.28 km/h (ranging from 10 to 30 km/ h), and 85.5% of the crashes occurred on the sidewalk, 85.5% on the beaches, 6% on the pavement, 3.4% on the road, 2.6% in the sidewalks and 2.6% in other locations on the road, and 2.6% in other locations. The most common injuries resulting from crashes were upper extremity injuries (49.6%), followed by lower extremity injuries (45.3%), head/face injuries (35%), thoracic injuries (8.5%), neck injuries (1.8%), and spinal injuries (1.8%). Among these cases, 4.3% (n=5) had lower extremity fractures, 9.4% (n=11) had upper extremity fractures, and 1.8% (n=2) had dental fractures. Moreover, 7.7% of cases (n=9) had soft tissue injuries to the head, and 0.9% had internal bleeding. When the relationship between injury severity and findings was examined, a moderate negative correlation was found between trauma severity and age. Among the included patients, 96.6% were discharged, whereas 3.4% were hospitalized. The study revealed that crashes resulted in minor patient injuries and identified injuries outside e-scooter users due to legal and technical reasons.

Büyükercan et al. (2023) examined orthopedic injuries resulting from e-scooter crashes, focusing on the pediatric population. The study retrospectively analyzed 99 patients admitted to the hospital emergency department with fractures. Almost half of the patients (49.4%) were under 18 years old, and the remaining were adults. Most crashes (58.5%) resulted from spontaneous falls, 37.3% involved collisions with vehicles, and 4.2% were due to striking stationary objects. Upper extremity fractures were more common (59.5%) than lower extremity fractures (27.2%). Crashes occurred most frequently between 18:00 and 00:00 (54.6%), followed by between 00:00 and 06:00 (31.3%). Pediatric patients tended to have more clavicle and humerus fractures, whereas adults had more radial and tibial fractures. Surgical treatment is more common for lower extremity fractures. This study highlighted that e-scooters are popular among pediatric populations and emphasized the importance of public education and awareness to prevent these injuries and associated workforce loss.

Similarly, in a study by Demir et al. (2023), the clinical and crash characteristics of 60 patients requiring surgical intervention were retrospectively analyzed. The majority of respondents were university students, with a slightly higher representation of males.

The average age of the patients was 25.3 years (range, 6–62 years). E-scooter crashes were predominantly observed on weekdays, accounting for 75% of the cases. Non-contact crashes were the most common, constituting 68.3% of the incidents. The peak hours for crashes were between 12:00 and 18:00, representing 51.7% of the cases. All patients in the study sustained soft-tissue injuries (100%), with 13.3% requiring surgical intervention. Notably, extremity fractures were prevalent, occurring in 30% of both the lower and upper extremities, whereas maxillofacial fractures were observed in 25.5% of cases. The results of this analysis shed light on the severity of e-scooter-related injuries, particularly among young individuals, many whom students were. Notably, helmet use was conspicuously absent, and fatal crashes were infrequent. The most common injury was soft tissue trauma to the knee, wrist, and forehead, with a significant incidence of closed distal radius and nasal fractures. Additionally, it is pertinent to highlight the increased occurrence of non-contact crashes. These findings underscore the importance of safety measures and public awareness campaigns to mitigate the risk of such injuries, especially among young e-scooter users. The studies also emphasized the importance of public education and awareness to prevent such injuries and the associated workforce loss.

Study by Avıncı & Taş (2024) revealed that the number of patients admitted to the hospital due to e-scooter accident was 247, with 39% female and 61% male ranging between ages 13 to 44 in Diyarbakır after the first half of 2022. The average age was 22.93±8.085. Most of the patients had extremity-related trauma (78.05%, n=160), 19.51% had neck trauma (n=40), and 2.44% had vertebral trauma (n=5). Similarly, 75.61% had soft tissue-related trauma, whereas 24.39% had fracture in any region. All patients were discharged after treatment. Patients who received inpatient treatment from the hospital (n=30), 4.87% (n=10) were admitted to the intensive care unit, and 9.76% (n=20) were admitted to the relevant clinical service. This study demonstrates the need for protective gear to be advised and worn, and the policies outlined in numerous articles of comparable legislation must be put into action and closely observed.

Again in Diyarbakır (İğrek & Ulusoy 2023) in between January and July 2022, they reported 62 patient admissions to two different hospitals with 105 orthopedic injuries. comprising 72.5% males and 27.5% females, with a median age of 34.21 years. Fifty-six (90.3%) patients were riders and six were pedestrians. All associated e-scooters were rented. There were 44 fractures (41.9% of the total recorded injuries) including 8 (12.9%) open fractures. Surgery was required by 32 patients (51.6%) and 35 (56.4%) required hospital admission, leading to hospitalization for an average of 3.7 days. According to the study findings, the average duration of job loss among working patients after an injury is 2.4 months. This study appears to be the first to examine job loss in this context and in Türkiye, highlighting the potential economic burden that such injuries can impose on countries. Helmet use was detected in 6.4% of the e-scooter users, but no other protective equipment was detected in any of the patients. Furthermore, 19,3% of patients had a blood alcohol level of >10 mg/dl.

Between January 2022 and August 2022, 43 patients who were admitted to the emergency department after an e-scooter accident and developed extremity fractures were included. Patients were divided into 2 groups those treated surgically and conservatively. The mean age of the patients was 35.9 (16–61 years), and 46% were women (n=20). The study revealed that 65.3% of patients had upper extremity injuries, 34.7% had lower extremity injuries, and no patients had pelvic or spinal injuries (Kültür et al. 2023).

According to a study by Baca et al. (2025), among the 4481 upper extremity fractures, finger fractures (27.47%) and distal radius fractures (25.37%) were common, whereas e-scooter-related cases exhibited radius and ulna shaft fractures (23.07%). Of 2400 lower extremity fractures, toe fractures (30.2%) and metatarsal fractures (19.66%) predominated, with e-scooter-related injuries primarily involving metatarsal fractures (30%). The surgery rate in all patients was 8.92%, whereas the surgery rate for e-scooter injuries was 48.2%. The occurrence of lower extremity fractures was significantly greater in e-scooter-related injuries than in upper extremities (p=0.011). Collisions involving stationary or moving objects were linked to lower extremity injuries, whereas falls were primarily associated with upper extremity injuries. Treatment included surgery (48.2%) and conservative management (52.8%), with Open reduction and internal fixation surgery (35.7%) and Closed reduction-internal fixation surgery (10.7%) utilized (Baca et al, 2024).

The first fatal crash with a shared e-scooter in Türkiye was reported in the news for the first time in 2020 (Sözcü, 2020). The incident occurred late at night on a busy street in Istanbul. The incident involved a collision between a car and a 17-year-old boy who was riding an e-scooter. The collision resulted in the young man's death in the scene because he was dragged nearly 30 meters by the vehicle.

In April 2022, in Trabzon, a news report emerged of an incident where a child walking with his family on a sidewalk was struck by an e-scooter carrying two people in the opposite direction. The e-scooter riders and the child were unharmed because of the accident (61Medya 2022). In the same year, in June, another incident occurred in Trabzon, where a 20-year-old rider was severely injured after colliding with a wall. The crash resulted in cracks in various parts of the rider's brain and body, leading to surgical intervention and continued treatment in the intensive care unit. Claims said the crash was due to faulty e-scooter brakes, but no further details were given (Haber61 2022).

In July 2022, a 23-year-old female e-scooter rider was injured in Adana after being hit by a vehicle coming from the opposite direction and dragging her along the road. She was transported to the hospital by ambulance and was discharged after treatment

(Sözcü, 2022). In the same month in Istanbul, another 23-year-old female rider was injured when a vehicle approaching her from behind collided with her as she moved in the left. The rider died in hospital (Habertürk, 2022).

A 44-year-old psychologist fell from an e-scooter in Adana in August and hit his head, sustaining abrasions. He did not immediately seek medical attention but later experienced health deterioration and was hospitalized. It was determined that he had suffered a brain hemorrhage, and as a result, he died (TRT Haber, 2022).

In October 2022, two 18-year-old individuals were traveling together on an e-scooter when they were struck by a motorized vehicle and died (Sabah, 2022a). Most individuals seeking treatment at the emergency unit for jaw and dental trauma were registered as e-scooter crashes, and they presented with severe conditions, such as head-neck fractures, eye globe and jaw fractures, anterior dental fractures, and brain bleeding. While the exact number of cases was not specified, a 40-year-old female traveling on an e-scooter had her wheel stuck in a drain during her ride, causing her to fall forward and hit her jaw on the ground. She underwent orthodontic treatment for her teeth and extensive jaw surgery. Subsequently, during surgery, she experienced partial facial paralysis due to nerve damage. Treatment and recovery took seven months (Cumhuriyet, 2022b).

In addition, according to a report from the Hürriyet website (Hürriyet 2023), there were 2,446 e-scooter crashes in Türkiye in 2023, resulting in 21 deaths and 2,050 injuries. In comparison, 2022 saw 1,840 crashes, with 8 fatalities and 1,554 injuries. Therefore, the rising number of incidents highlights e-scooter crashes as an increasing public safety concern, emphasizing the need for immediate action and the implementation of emergency response plans.

4. Discussion

Our review of eight academic studies and eight media reports on e-scooter crashes in Türkiye identified several common themes. First, falls were the leading cause of accidents, with collisions being less frequent. This could be due to drivers' carelessness or defects on the road surface they are riding on. Most accidents occurred on sidewalks or intersections during the day, often on weekdays. Although using e-scooters on sidewalks is illegal, the concentration of accidents in these areas and their negative impact on pedestrians are significant findings. The majority of patients were young adults, with men being slightly more affected than women. Common injuries included upper and lower extremity fractures, followed by head and facial trauma, and soft tissue injuries. This is not surprising because accidents generally occur in the form of falls. Notably, helmet use was extremely low, recorded in only a small percentage of cases, and some studies have reported alcohol use among riders, although the percentage is quite low. Despite the frequent occurrence of accidents, most injuries were minor and were treated on an outpatient basis, although some required hospitalization or surgery, particularly for fractures. Media reports tended to focus on more severe incidents involving fatalities or significant injuries, often due to rule violations. Both the academic literature and media sources emphasize the growing concern over e-scooter safety, highlighting the need for stricter regulations, public safety campaigns, and better protective measures like helmet, knee pads, elbow pads, wrist guards, and reflective vests, to reduce injuries and fatalities.

In a study conducted in Germany examining the formation and relationship between injuries and micromobility clashes (Kleinertz, 2021), e-scooter and bicycle clashes were compared. Results from 89 e-scooter clashes (mean age: 39.9 ± 14 years) and 435 bicycle clashes (42.5 ± 17) that occurred within a year indicate that e-scooter clashes mainly occurred at night (37%) and under the influence of alcohol (28%). Among these cases, 54% reported head or facial trauma and 18% reported upper extremity injuries. In contrast, bicycle clashes had a lower incidence of occurring at night (14%) and under alcohol influence (6%), with 46% reporting head or facial trauma and 24% reporting upper extremity injuries. Helmet usage was not observed among e-scooter users, whereas 11% of bicycle riders wore helmets. Collisions involving pedestrians accounted for 65% of e-scooter clashes, whereas this rate was 57% for bicycle clashes. The number of cases requiring wound care after e-scooter clashes was 46%, while that for bicycle clashes was 27%. Hospitalization rates were similar in both groups (32%). After e-scooter clashes, 28% of the patients were referred for surgery, whereas the rate was 24% after bicycle clashes. There was no recorded need for intensive care after e-scooter clashes, whereas 2% of cases following bicycle clashes were admitted for intensive care. Only 1% of e-scooter and bicycle clashes required immediate intervention, whereas 7% required immediate intervention. According to the study, using any vehicle under alcohol consumption increases the risk and severity of clashes. Additionally, it is emphasized that the sharp corners of e-scooters, due to their structural characteristics, can cause injuries to the tibialis posterior muscle in the event of a clash.

When comparing e-scooter clashes in Germany to those in Türkiye, the predominance of head injuries (54% in Germany, 40% in Türkiye (Yavuz et al., 2022), and 35% in Türkiye (Yılmaz et al. 2022) stands out. In Germany, none of the drivers wore helmets, whereas in Türkiye, only 4.3% (Yavuz et al. 2022), 6.4% (İğrek & Ulusoy 2023), and 3% Kayaalp et al. (2023) of drivers wore helmets, and none wore helmets (Yılmaz et al., 2022). Given this, it is not surprising that e-scooter clashes occurred more frequently at night and under the influence of alcohol, while in Türkiye, only 2.9% (Yavuz et al. 2022) and 19,4% (İğrek & Ulusoy 2023) of cases involved alcohol or had no alcohol involvement (Yılmaz et al. 2022). This indicates that drivers in Türkiye avoid using e-scooters under the influence of alcohol more than those in Germany. Nevertheless, Yakar and Hancı (2022) published

a case study examining a 30-year-old female patient who was brought to the emergency department due to an e-scooter crash. Laboratory findings indicated alcohol and substance use by the patient, and radiological imaging revealed subdural hematoma, cerebral contusion, and lung contusion. In the initial assessment, the patient's Glasgow coma scale (GCS) score was 5 (indicating severe neurological damage). After a complex treatment process, the GCS remained unchanged, and the patient was discharged to a palliative care center with tracheostomy and home ventilator support. The authors argued that the risks of crashes that could result in outcomes like this one could be reduced in Türkiye through existing regulations related to e-scooter use. We would like to highlight mandatory helmet use and speed limit reductions, as well as organize informative campaigns for the public to discourage the use of e-scooters under the influence of alcohol.

In another study, research from around the world was compiled. The average age was slightly higher than in Türkiye (33.3 ± 3.5), with 58.3% of cases being male and 5.6% under 18 years old. Among the clashes, 74.4% occurred due to falls, and 68.1% of users did not wear helmets. In 39.2% of cases, fractures were reported, with 44.8% being upper extremity-related. Additionally, 22.2% of cases involved neck and head injuries, and 2.5% involved traumatic brain injuries. Moreover, 57.7% of cases were referred to radiology, 54.5% were discharged after initial interventions, and 17.2% were referred for surgery (Singh, 2022). Because of this compilation, which included studies from different parts of the world, it is recommended that equipment that protects the head, neck, and upper extremity areas be legally required. It is predicted that adding sensors and structural supports that reduce the risk of falling to vehicles will decrease the number of crashes related to falling. In contrast to research in Germany and Türkiye, reaching a helmet usage rate of 31.9% resulted in an obvious reduction in neck and head injuries from 40% to 22.2%. This demonstrates that using helmets for e-scooter users significantly reduces the risk of fatal outcomes. Furthermore, in the study conducted by Cakar et al. (2023), the authors examined a cohort of patients aged 18 years who were diagnosed with anterior cruciate ligament (ACL) injuries between January 2019 and June 2021. Their findings revealed that e-scooter crashes accounted for 7% of all ACL injuries during the study period, comprising 80 cases. A detailed analysis of e-scooter-related ACL tears showed that 72.8% (n=58) of these injuries occurred due to non-contact mechanisms, primarily resulting from falls while attempting to halt the scooter. In contrast, 27.2% (n=22) of the injuries were attributed to contact mechanisms, wherein patients fell after colliding with an object. Demographically, the patient population consisted of 52 males (65%) and 28 females (35%), with a mean age of 38.4 years (ranging from 19 to 52 years). Of these patients, 77.5% (n=62) were recommended for ACL reconstruction surgery using hamstring muscle grafts, while the remaining 22.5% (n=18) were managed through functional physical therapy. Remarkably, the study also revealed that 14 of 80 patients had concurrent upper extremity fractures in addition to ACL injuries. These findings highlight the prevalence of ACL injuries following e-scooter crashes and underscore the necessity for stricter regulations and improved safety measures, including the use of knee-specific protective equipment. Such injuries can lead to increased healthcare costs, including medical therapy and medication, and loss of work due to the recovery time required after reconstruction. Therefore, we emphasize the need for comprehensive regulations mandating the use of protective gear for both the head and knees to reduce the incidence of these injuries.

A cohort study analyzing the demographics and injury outcomes of micromobility crashes in China, India, Japan, and the United States was conducted by Zhao (2022). Data on road crashes from the Global Burden of Disease Study by the World Health Organization for 1990-2019 were analyzed. According to the results, mortality and morbidity due to crashes increased in individuals younger than 25 years and older than 60 years. However, crashes are most frequently observed in users aged between 15 and 25. Although there has been a 25.59% decrease in overall traffic crash mortality since 1990, there have been increases of 39.08% and 44.06% in motorcycle and bicycle crash mortality, respectively. Notably, there has been a rapid increase in micromobility crashes, especially from 2015 to 2019. This increase can be attributed to the proliferation of shared e-scooters and e-bicycles in Japan and China as well as the number of two-wheeled motor vehicles in India. Although electric vehicles allow for faster travel, crashes involving electric vehicles tend to be more severe than those involving mechanical vehicles, requiring more extended hospitalization and treatment—for example, one of every ten e-scooter-bicycle collisions in India result in severe injury or death. The authors point out that due to the lack of standardization in the data collected from the four major countries included in the study, changes in regulations and legal requirements over the years, differences in infrastructure and environments in countries, unique individual and societal norms, cultural diversity, and varying driver behavior profiles, determining the overall impact of micromobility crashes and comparing countries is very challenging.

E-scooter crashes often occur at intersections and involve collisions (vehicle-to-vehicle collisions, e.g., motor vehicle-e-scooter or e-scooter-e-scooter collisions). Vehicle-to-vehicle crashes often occur when e-scooters approach the right side of moving cars. Therefore, it is essential to promote adherence to traffic rules and safe riding techniques to prevent crashes when using e-scooters. Increasing public awareness of correct and safe riding techniques is necessary.

In 2023, the Turkish Ministry of Transport and Infrastructure published a scientific study to identify the variables affecting e-scooter crashes and predicting the likelihood of crashes (İnaç 2023). The study used machine learning to use user and ride data from a shared e-scooter application in 15 cities. The results identified variables such as riding area, rental date, rental frequency (experience), travel duration, average speed, and travel distance as the most influential factors in completing a ride without a crash.

Different optimal values for these variables were found for female and male users. For women, the optimal values were a rental frequency of 100, a travel distance of 10.44 km, a travel duration of 48.33 minutes, and a riding speed of 13.38 km/h. For men, the corresponding values were 120, 11.49 km, 52.20 min, and 17.28 km/h, respectively. The study determined an average speed limit of 15.36 km/h for safe and trouble-free rides for both male and female e-scooter users.

The accident reports (collision reports) of 780 e-scooter collisions that occurred in 2021 in Türkiye were examined, and 771 accidents were included. The accident data were obtained from the Traffic Department of the Ministry of Interior (General Directorate of Security. Male e-scooter riders are involved in crashes and injured approximately 4 times more often than female riders. The average age for men injured in e-scooter accidents is 30.4, and the mean age of women was 27.2. For both men and women, most injuries occurred in the 15–20 years age group. Riders under the age of 18 years constitute a significant proportion of accidents (32.5%). Most e-scooter accidents occur on Mondays and during August. Most accidents occurred between 12:00 p.m. and 1:59 p.m. (15.7%) and between 4:00 p.m. and 5:59 p.m. (15.7%), mainly during the daytime. About half of the accidents occurred at intersections. In 10.5% of accidents, the accident occurred at a crosswalk. Approximately one-fifth of the accidents fall, and the most common type of collision was side collision (44.2%). Deaths and injuries caused by road traffic accidents are a public health problem in Türkiye and constitute a significant health burden. If necessary precautions are not taken, this burden is likely to increase (Arıkan Öztürk et al. 2024).

According to the initial regulations, e-scooters traveling on sidewalks now use roads like other vehicles. However, crashes involving e-scooters and other traffic elements can still occur. It is recommended that e-scooters travel on the left side of the traffic, i.e., in the opposite direction, to improve visibility for both e-scooter riders and other drivers. The absence of mirrors and turn signals on e-scooters, which could warn other drivers of the rider's moves, is considered a possible cause of crashes. Approaching e-scooters should reduce their speed and be alert to sudden, signal-less movements (Cumhuriyet 2022a).

According to the Electric Scooter Regulation, authorized operators must inform users that they must wear protective and visibility-enhancing equipment, such as helmets, knee pads, and reflective jackets. Failure to use this equipment is considered a violation of traffic rules, and users not wearing the required equipment may be subjected to fines for inspection. However, from the user's perspective, the fact that shared vehicles do not provide protective equipment is seen as a disadvantage. Therefore, despite discussions about placing protective equipment on or near shared e-scooters, this practice has yet to be implemented due to increased costs for service providers and users and the risk of theft of loose equipment. Users must also show more support when purchasing individual protective equipment because this involves additional costs. Moreover, one of the significant advantages of shared services is the ability to leave the vehicle as desired after use, thus offering the convenience of parking. Therefore, users who wish to avoid carrying protective equipment when their journey is complete may not benefit from this advantage (Sabah 2022b).

However, it should be noted that until a decision is made and implemented, the user bears the responsibility for obtaining and using equipment for safe riding. In any case, the adoption and conscious choice of helmet use are essential. Different designs and features of helmets suitable for various micromobility vehicles can be found in the market. Ideally, separate helmet models should be designed for different micromobility vehicles, considering their distinct riding characteristics and designs (Serra 2021, Wei 2023). For example, e-scooter crashes often involve falling forward onto the chin and upper face (Cumhuriyet 2022b). Therefore, it is appropriate to use a helmet with a chin guard rather than a helmet designed for bicycles.

Lastly, İnaç (2023) aimed to identify variables affecting e-scooter crashes and predict crash probability using machine learning methods based on data from e-scooter drivers in 15 provinces of Türkiye. The results indicate that gender, riding location, rental date, rental frequency, travel duration, average speed, and distance were the most influential factors in completing a ride without a crash. The travel duration had the most substantial impact on the ride, and it was noted that long journeys negatively affected drivers, leading to interruptions in their rides. The optimal values for these factors for female drivers were as follows: rental experience, 100; distance, 10.44 km; travel duration, 48.33 minutes; and travel speed, 13.38 km/h. For male drivers, the corresponding values were 120, 11.49 km, 52.20 min, and 17.28 km/h. It has been reported that the average speed limit for safe and smooth rides for both male and female e-scooter drivers is 15.36 km/h. E-scooter speed limits vary from country to country. According to the study results, reducing the speed limit from 30 km/h to 20 km/h can reduce the severity of injuries in injury-prone crashes by 23%. Although the rate of involvement in crashes among those under 18 years old was an average of 8.4%, the study found minimal interaction between age and driving. Another factor influencing crash outcomes is drivers' knowledge of traffic rules, regulations, and training. In conclusion, the study suggests that micromobility vehicles can smoothly integrate into traffic alongside other vehicles.

5. Conclusions

The findings of this review indicate that e-scooter crashes can impact individuals of all ages, as the studies included individuals aged 5–76 years. Additionally, the frequency of crashes varied by region, with some areas experiencing more crashes on weekdays and others experiencing higher rates on weekends. Males were more commonly involved in crashes than females, and the use of helmets was generally low among victims.

In conclusion, the lack of protective structures in e-scooters makes their users vulnerable to crashes. Crashes can lead to undesirable health outcomes, such as minor scratches and bruises, fractures, neurological damage, jaw and head trauma, and even death. The individual consequences of crashes manifest as disabilities, job loss, reduced quality of life, the need for care, treatment expenses, and psychological and social issues. Societally, allocating healthcare resources to treat these outcomes may hinder investments in other areas that could improve public health. Despite these risks and consequences, e-scooters remain a popular and practical mode of transportation. The most appropriate step to reduce the risks to vulnerable users is to improve and enforce relevant legal regulations.

This study has several limitations. First, as a narrative rather than a systematic review, it may be prone to selection bias. Second, considerable variability exists in the findings and outcome measures across the included studies, making it difficult to draw robust, standardized conclusions. Some studies have focused solely on patients with fractures (Büyükercan et al. 2023, Kültür et al. 2023, Baca et. al. 2024)), those admitted exclusively to orthopedic departments (Iğrek & Ulusoy 2023, Kültür et al. 2023) or those comparing all patients in a department with those involved in e-scooter accidents (Baca et al. 2023), potentially overlooking other injury types and broader patient outcomes. Consequently, we were unable to review all injured patients or comprehensively evaluate the general characteristics of crash-related injuries from e-scooters, which limited the scope of our findings. Additionally, some news reports lacked detailed information on crash characteristics or health outcomes, thereby restricting their use in this review. Despite these limitations, this study represents the first comprehensive effort to consolidate the characteristics of e-scooter crashes and health outcomes. The accumulation of more comprehensive data on e-scooter crashes and health outcomes will enable the development and application of consistent metrics. This will enable more robust comparisons across studies, leading to clearer insights and more actionable conclusions in the field. Finally, longitudinal studies that track e-scooter usage and related incidents over time are valuable for assessing trends and evaluating the impact of regulatory and safety interventions.

Based on our analysis, we propose the following recommendations for reducing e-scooter crash risks and mitigating the severity of consequences:

- Increasing users' awareness about safe driving techniques, rules, and regulations and raising awareness of risky behaviors. Sharing resources about this information openly and freely, organizing educational programs, and transitioning to a driver's license system.
- Organize driving training programs to enhance user driving experiences in controlled environments or simulations.
- Conduct appropriate environmental and infrastructure regulations based on expert opinions.
- Periodically reviewing vehicles' physical conditions and, if available, stations (e.g., annually).
- Determining the variety and quantity of vehicles based on demand and potential usage, revisiting these decisions annually.
- Adding components to vehicles that enhance their visibility on the road and implementing systems that allow users to signal and reduce the risk of falling.
- Updating legal obligations and measures such as speed limits and age restrictions based on scientific research findings.
- Expand the rules to be followed during rides, including issues such as cell phone usage, listening to music, and obeying traffic signals.
- Taking additional precautions and using warning signs in areas with a higher incidence of crashes.
- Enforcement of regulations in addition to deterrent bans.
- Regularly discussing regulations and measures with experts and updating them according to emerging needs.
- Making investments and regulations to establish a safe micromobility network and ensuring the safety of all road users, including pedestrians.

Additionally, evaluating the following recommendations would be beneficial for assessing e-scooter crashes and their impacts in a more objective manner and observing the results of improvements:

- Provide training for law enforcement officers, emergency service workers, and other stakeholders regarding crash documentation.
- Designating a separate unit or authority for in-hospital documentation.
- Adopting a standardized and effective method for recording the formation and outcomes of all crashes in the country and developing a corresponding database.

- Ensuring that data on crashes collected by authorized agencies are reported appropriately at specified intervals so that experts in the field can also benefit from the data.
- Developing policies supporting research addressing the risks, formation, health outcomes, and expenses associated with crashes fosters research in this area.
- Developing algorithms for emergency interventions based on research findings and other data related to clash formation and health outcomes.
- Investigating the proportion of healthcare spending attributable to micromobility crashes, addressing this issue through public health experts, and developing health policies to reduce micromobility crashes.

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REFERENCES

Arıkan Öztürk, E., Karaçor, F., & Bayırtepe, H. (2024). Characteristics of e-scooter accidents reported by police in Türkiye. Traffic injury prevention, 1-9.

Avınca, Ö., & Taş, M. (2024). Prospectıve Analysıs Of E-Scooter Accıdents In Dıyarbakır Cıty, Located In Southeastern Türkiye. Ankara Medical Journal, 24(1).

Baca, E., Kaya, M. G., & Yalın, M. (2024). Unconventional mobility and conventional trauma: a comparative analysis of e-scooter-related fractures. European journal of trauma and emergency surgery, 1-7.

61Medya. (2022). 'Trabzon'da ilk scooter kazası'. Last Access: 3.04.2023. https://www.61medya.com/haber/13308284/trabzonda-ilk-elektrikli-scooter-kazasi.

Brauner, T., Heumann, M., Kraschewski, T., Prahlow, O., Rehse, J., Kiehne, C., & Breitner, M. H. (2022). Web content mining analysis of e-scooter crash causes and implications in Germany. Accident Analysis and Prevention, 178, 106833.

Büyükceran, İ., Ersoy, A., Şay, C. Ş., Coşkun, H. S., and Tomak, Y. (2023). Epidemiology and treatment of fractures caused by electric scooter use: a comparison of pediatric and adult age groups. Cureus, 15.

Cakar, M., Karslioglu, B., Bayraktar, M. K., Dedeoglu, S. S., Imren, Y. and Keskin, A. (2023). A new etiological cause of anterior cruciate ligament injury: e-scooter. acta orthopaedica belgica, 89(1), 112-116.

Cumhuriyet. (2022a). 'Scooter kazaları can alıyor, uzmanından 'ters çizgi' önerisi'. Last Access: 5.04.2023. https://www.cumhuriyet.com/tr/yasam/scooter-kazalari-can-aliyor-uzmanindan-ters-cizgi-onerisi-1995929.

Cumhuriyet. (2022b). 'Uzmanlar uyardı: Elektrikli scooter kazalarına dikkat!'. Last Access: 1.04.2023. https://www.cumhuriyet.com/tr/yasam/uzmanlar-uyardi-elektrikli-scooter-kazalarina-dikkat-1957061.

Demir, N., Dokur, M., Agdoğan, Ö., Koc, S., Karadağ, M., and Dokur, İ. F. (2023). Electric scooters as a silent source of danger for young people: a single-center in-depth accident analysis. Turkish Journal of Trauma & Emergency Surgery, 29(5), 596.

Deveci, S. (2023). Mikromobilite Sistemlerinin Yasal Durumu, Mikromobilite, ed: Dündar, S., Nobel Akademik Yayıncılık, Ankara, 197-238.

Diken. (2021). 'İstanbul'a 75 bin elektrikli scooter'. Last Access: 1.04.2023. https://www.diken.com.tr/istanbula-75-bin-elektrikli-scooter/.

Dündar, S. (2023a). Giriş, Mikromobilite, ed: Dündar, S., Nobel Akademik Yayıncılık, Ankara, 1-4.

Dündar, S. (2023b). Mikromobilite ve Trafik, Mikromobilite, ed: Dündar, S., Nobel Akademik Yayıncılık, Ankara 81-104.

Dündar, S., Günay, G., Karlikanovaite Balıkçı, A., Şentürk Berktaş, A., Ulu, İ.M. (2022). Mikromobilite – Ulaşıma Mucizevi Bir Çözüm Mü, Yoksa Bir Hayal Kırıklığı Mı? İdealkent, 36(13), 576-598.

Farley, K. X., Aizpuru, M., Wilson, J. M., Daly, C. A., Xerogeanes, J., Gottschalk, M. B., & Wagner, E. R. (2020). Estimated incidence of electric scooter injuries in the United States from 2014 to 2019. JAMA network open, 3(8), e2014500-e2014500.

Haber61. (2022). 'Trabzon'da foci kaza! Kiralık Scooter can alıyordu.'. Last Access: 3.04.2023. Available at: https://www.haber61.net/trabzonda-feci-kaza-kiralik-scooter-can-aliyordu.

Habertürk. (2022). 'E-Scooter kazası can aldı'. Last Access: 4.04.2023. Available at: https://www.haberturk.com/video/haber/izle/e-scooter-kazasi-can-aldi/771115.

Hürriyet. (2023). 'Scooter'da acı bilanço'. Last access: 6.09.2024. https://www.hurriyet.com.tr/gundem/scooterda-aci-bilanco-42471682.

İğrek, S., & Ulusoy, İ. (2023). E-scooter-related orthopedic injuries and the treatments applied: are these scooters a new means of transportation or a new source of trauma?. BMC emergency medicine, 23(1), 110.

İnaç, H. (2023). Micro-Mobility Sharing System Accident Case Analysis by Statistical Machine Learning Algorithms. Sustainability, 15(3), 2097.

Kazemzadeh, K., Haghani, M., & Sprei, F. (2022). Electric scooter safety: An integrative review of evidence from the transport and medical research domains. Sustainable Cities and Society, 104313.

Kleinertz, H., Ntalos, D., Hennes, F., Nüchtern, J. V., Frosch, K. H., & Thiesen, D. M. (2021). Accident mechanisms and injury patterns among E-scooter users: a retrospective analysis and comparison with cyclists. Deutsches Ärzteblatt International, 118(8), 117.

Kültür, Y., Tütüncü, M. N. Tütüncü, and S. Ulutaş (2023). Using e-scooters: An easy way to get home or a nightmare? An orthopedic perspective on e-scooter accidents. Turkish Journal of Trauma and Emergency Surgery, 29(10), 1158.

Masilkova, M. (2017). Health and social consequences of road traffic accidents. Kontakt, 19(1), e43-e47.

Ministry of Justice. "Traffic Accidents". Erişim Adresi: https://magdurbilgi.adalet.gov.tr/316/Trafik-Kazalari. Last Access: 10.04.2023.

Mitropoulos, L., Stavropoulou, E., Tzouras, P., Karolemeas, C., & Kepaptsoglou, K. (2023). E-scooter micromobility systems: Review of attributes and impacts. Transportation Research Interdisciplinary Perspectives, 21, 100888.

Pobudzei, M., Tiessler, M., Sellaouti, A. ve Hoffmann, S. (2023). E-Scooter and Bicycle Accidents: Spatial, Temporal, and Demographic Characteristics in Munich, Germany 2.

Resmi Gazete. (2021). 'Elektrikli Skuter Yönetmeliği'. Last Access: 5.04.2023. Available at: https://www.resmigazete.gov.tr/eskiler/2021/04/20210414-3.htm

Sabah (2022a). 'Antalya'da elektrikli skuter kazası' Last Access: 10.04.2023. https://www.sabah.com.tr/galeri/yasam/son-dakika-antalyada-elektrikli-scooter-kazasi-ada-kayahan-ile-mahmut-yagiz-balci-can-verdi.

Sabah (2022b). 'Scooter'da kask ornl olacad mı?'. Last Access: 5.04.2023. https://www.sabah.com.tr/yazarlar/gunaydin/sb-mevlut_tezel/2022/10/29/scooterda-kask-zorunlu-olacak-mi.

Schofield, H., (2023). 'Paris says au revoir to rental e-scooters'. Last Access: 26.08.2024. Available at: https://www.bbc.com/news/world-europe-66682673

Scquizzato, T., Gamberini, L., Stella, F., Paoli, A., Gazzato, A., Forti, A., and Semeraro, F. (2022). Analysis of road traffic accidents involving standing electric scooters reported in Italian newspapers. Clinical and experimental emergency medicine, 9(1), 36.

Serra, G. F., Fernandes, F. A., Noronha, E., & de Sousa, R. J. A. (2021). Head protection in electric micromobility: A critical review, recommendations, and future trends. Accident Analysis and Prevention 163, 106430.

Singh, P., Jami, M., Geller, J., Granger, C., Geaney, L., & Aiyer, A. (2022). Impact of e-scooter injuries: a systematic review of 34 studies. Bone and Joint Open, 3(9), 674-683.

Sözcü. (2020). 'İlk ölümlü kaza. . . '. Last Access: 10.04.2023. https://www.sozcu.com.tr/2020/gundem/ilk-olumlu-kaza-luks-aracin-altinda-kaldi-5646343/.

Sözcü. (2022). 'Elektrikli scooter kazası: Ters yöne giren araç öldürüyordu'. Last Access: 2.04.2023. https://www.sozcu.com.tr/2022/gundem/elektrikli-scooter-kazasi-ters-yone-giren-arac-olduruyordu-7250456/.

Haber, T. (2022). 'Adana'da scooter kazası geçiren psikolog hayatını kaybetti.'. Last Access: 4.04.2023. https://www.trthaber.com/haber/turkiye/adanada-scooter-kazasi-geciren-psikolog-hayatini-kaybetti-703894.html.

Webrazzi teknolojik haber sitesi. (22 Nisan 2022). 'Elektrikli scooter girişimlerinin Türkiye'deki ziyaretçi sayıları'. Erişim Adresi: https://webrazzi.com/2022/04/22/elektrikli-scooter-girisimlerinin-turkiye-deki-ziyaretci-sayilari/ Last Access: 10.04.2023.

Wei, W., Petit, Y., Arnoux, P. J., & Bailly, N. (2023). Head-ground impact conditions and helmet performance in E-scooter falls. Accident Analysis & Prevention, 181, 106935.

Wong, M. H. (2024). "'End the havoc': Another major city has banned e-scooter rentals from its streets". Last Access: 26.08.2024. https://edition.cnn.com/2024/08/15/travel/melbourne-electric-scooter-rental-ban-intl-hnk/index.html

Yakar, M. N, & Hancı, V. (2022). Şiddetli travmatik beyin hasarı ve kötü nörolojik kondisyonla taburculuk: elektrikli skuter kazası. 9. Uluslararası Hipokrat Tıp ve Sağlık Bilimleri Kongresi, pp.400, 2022.

Yang, H., Ma, Q., Wang, Z., Cai, Q., Xie, K., & Yang, D. (2020). Safety of micro-mobility: Analysis of E-Scooter crashes based on mining news reports. Accident Analysis and Prevention, 143, 105608.

Yavuz, B., Temel, T., Satilmis, D., Güven, R., Çolak, Ş. (2022). Analysis of electric scooter injuries admitted to the emergency service. Irish Journal of Medical Science (1971-), 191(2), 915-918.

Yılmaz, S., Akman, G., Ustaalioğlu, İ., Kılıç, M., & Emem, M. K. (2022). Examination of Emergency Department Patients Involved in E-Scooter Related Accidents. Southern Clinics of Istanbul Eurasia, 33(3).

Zhao, Y., Cao, J., Ma, Y., Mubarik, S., Bai, J., Yang D, et al. & Yu, C. (2022). Demographics of road and micromobility injuries among China, India, Japan, and the United States: evidence from an age-period-cohort analysis. BMC Public Health, 22(1), 760.

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REVIEW ARTICLE

Lean Logistics, Lean Supply Chain, And Lean Supply Chain Management For Sustainability: WOS (1987-2024)

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ABSTRACT

To achieve global sustainable development goals, solutions should be developed in environmental, economic, and social areas. Lean logistics is one of them. This study was planned to bibliometrically examine the publications on lean logistics, reveal current trends, and guide future researchers. On 20.07.2024, 267 publications on lean logistics were accessed from the Web of Science database. The collected data were analyzed using a social sciences statistical program. Publications cover the years 1987-2024. Most publications were written in 2022 (219) and received 7000 citations. The subject is lean logistics management (205), and Six Sigma has been examined (117). The majority of publications (114) were WOS. SSCIs were screened. The language of publication is English (260). The country with the most broadcasts is England. This data was scanned in the (114) index. 260 publications were published in English. England ranks first with 38 publications. 161 publications meet sustainable development goals. (92) of these are Responsible Consumption, (47) industry, innovation, and infrastructure, (12) sustainable cities and communities (5) healthy and quality life, (2) healthy and quality life, and (1) zero hunger, quality education and decent It includes work and economic growth. Lean logistics are necessary to achieve sustainability goals.

Keywords: Lean management, lean logistics, bibliometrics, Web of Science

1. Introduction

Logistics have the power to affect both national and international trade. While logistics were only related to the economy until the 2000s, it began to be effective in environmental and social aspects as well. In particular, global sustainability development targets have affected the logistics sector, as in every field, and increased research and applications by states, institutions and researchers have conducted various studies on sustainable logistics activities. Lean logistics plays a key role in ensuring sustainability.

Logistics businesses aim to deliver their products and services to their target locations as quickly and as quickly as possible. They deliver at a low cost. They can achieve this by reducing waste (Mücevver, 2021). Reducing waste provides a competitive advantage to logistics companies (Kılıç, 2022). The concept of leaning emerged in Japanese companies in the 1950s. Lean thinking was first created by Toyota Motor. Lean philosophy is a philosophy that increases business processes efficiency, eliminate waste, and focus on customer value. This philosophy aims to continuously realize value from raw materials to finished products. Essentially, it shows how to identify waste and eliminate it. The indicator of this is the idea of producing the best quality with less cost, less waste, and faster production at affordable prices (Yangınlar and Bal, 2019). Although steps that do not add value are defined as waste, the literature was defined by Ohno in 1988 under the title “Seven Deadly Wastes’ as "unnecessary production, excessive waiting, error in production, excess stock, unnecessary transportation, unnecessary work, and unnecessary movements" (Topuz, 2021). Lean logistics is a working philosophy aimed at identifying and removing waste in the supply chain (Alejandro-Chable, 2022). Lean logistics focus on zero error and continuous improvement in processes (Bowersox et al., 2002). Lean logistics aims to improve processes by eliminating unnecessary costs in logistics processes in lean supply chain management and by abandoning activities that do not create added value (Baudin, 2004).

Lean philosophy around the world; Important production policies such as providing global advantages in competition, ensuring sustainability, adapting to rapid market changes, and expanding the customer base have benefited many businesses. Today, simplification and lean techniques are used along with manufacturing and service systems. These can be cited as examples of business partnerships, such as education, supply, logistics, informatics, and technology (Uçar and Şirin, 2024). Every sector has started to adapt lean management to its business. Logistics activities were also simplified, and lean logistics emerged. If logistics

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businesses want to take their products and services to their target locations in the shortest time and at the lowest cost, they should adopt a simple logistics application approach. For this purpose, businesses should eliminate all unnecessary actions that do not add value to their logistics practices. Avoiding wasteful practices and adopting a lean logistics approach are some primary actions. Only in this way will businesses be able to gain a competitive structure (Mücevher, 2021). Spending less on costs and time is possible by working efficiently in logistics applications and avoiding waste. To avoid waste, unnecessary costs and stocks should be avoided. The essence of lean logistics is controlling raw materials and stocks in storage and transportation steps to achieve the desired service quality (Jordan, 2002).

Lean management is applied in many sectors. With an understanding of its importance in the field of logistics, it has attracted the attention of managers and researchers, and research on this subject has intensified. As in every field, it is extremely important to thoroughly understand the literature to determine the conceptual framework of lean logistics as a research field, as well as its sectoral applications (Raghuram et al., 2010). Bibliometric research is carried out to facilitate, guide, and evaluate opportunities for researchers, students, academicians, and practitioners. Lean logistics applications are quite new; thus, the number of studies is low. In this context, it creates a disadvantageous situation for researchers who want to work in a more specific field of lean logistics, apart from lean production or supply chain.

Sustainable development goals must be implemented for future generations to live in prosperous environments. The main purpose of this study is to emphasize the importance of lean supply chain management and logistics management to achieve sustainable development goals and to bibliometrically examine publications related to the subject. It is anticipated that examining publications that include global sustainable development goals can help achieve these goals. This study includes studies in the Web of Science (WoS) database, which scans academic resources with international field indexes from 1987 to 2024. Publication years, study numbers, and keywords are included. Meso and micro citations, indexes, publication language, links, countries, most influential researchers in the field, most cited studies, most relevant journals, resources, and institutions are shown. This study aims to prepare a roadmap for researchers who want to publish in the field in the future. The study consists of three main sections, apart from the introduction and conclusion sections. In the first section, the literature on lean supply chain, lean supply chain management, and logistics, which are thought to form the basis of this study, is examined. Studies on the subject are also included. In the second section, the method is explained. The findings and results are discussed in the third section.

2. Research Framework

2.1. Sustainability, Sustainable Logistics, Lean Supply Chain Management, and

The danger started when people started using the world's resources, and technological developments accelerated these. In particular, after the Industrial Revolution, a danger began to emerge that threatened scarce resources and therefore the ecosystem. The misuse of resources, rapid consumption, and unconscious activities of people have made "sustainability" mandatory because they threaten nature and future generations (Renner, 2015). Issues such as poverty, migration, inequality, and climate crisis, which continue on a global scale, have moved sustainable development goals from the national level to the international level. Sustainable Development Goals eliminate these negative variables and achieve prosperity for all generations (Örerel and Kağnıcı, (2024).

Sustainable logistics, on the one hand, includes the goal of developing logistics infrastructure and thus creating added value for the country's economy, and on the other hand, it includes the goal of sustainability in growth, development, and development, which concerns all countries in the world. The increasing activities that create added value to the country's economy also lead to the destruction of the natural environment and natural resources. Since the destruction of natural resources and the environment will not allow long-term growth-enhancing activities, it is necessary to create a growth and development model that is sensitive to the environment and natural resources. This model is expressed as sustainable development and guarantees the life and development of today and the future by establishing a balance between economic activities and nature, that is, using resources at a minimum level (Mete, 2020). Sustainable Logistics is an approach that strives to meet the social and economic requirements, along with environmentally friendly logistics activities in material flows between suppliers, manufacturers, and customers, by focusing on creating value for all stakeholders. Figure 1 presents sustainable logistics (Çamlıca and Akar, 2014).

As shown in Figure 1, sustainable logistics includes economic, social, and environmental dimensions, which are also sustainability dimensions. It ensures economic sustainability by limiting costs and eliminating business risks. Social sustainability includes occupational health and safety, corporate image and brand, and occupational health and safety. It covers environmental sustainability and combating air emissions, wastewater, hazardous waste, and toxic substances. (Çamlıca ve Akar, 2014).

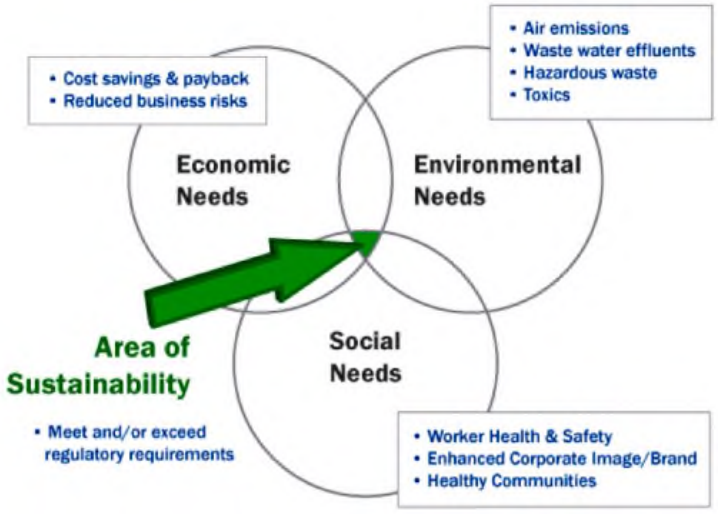

Figure 1. Sustainable Logistics

Çamlıca, Z. & Akar, G. S. (2014). Lojistik sektöründe sürdürülebilirlik uygulamaları*

2.2. Lean Logistics, Lean Supply Chain, and Lean Supply Chain Management

Fuming (2011) noted that the lean logistics approach, which emerged as many new ideas and theories of lean thinking gradually gained ground in the logistics industry, is an innovative and effective method for designing and managing a logistics system, from physical distribution to production control, to information management and supplier support. Socconini (2019) also mentioned that lean logistics is a working philosophy that is used to eliminate waste caused by poor process management or the culture of an organization. The integration of sustainability and lean logistics is important to increase competitive business performance by reducing waste (Sopadang et al.,2014). The basic logic of lean logistics is to plan, organize, execute, and control logistics applications in an effective, efficient, and coordinated manner (Yangınlar and Bal, 2019). In this context, lean logistics is an approach that prevents waste, creates added value for the target audience to which products and services are offered, and spends less time and money on products and services (Kocabaş, 2014).

5S steps, which are a product of the Japanese continuous improvement philosophy, can also be applied to lean logistics. In logistics activities according to 5S (Gapp et al., 2008).
(1) Simplicity
(2) Classification (Seiri),
(3) Placing things in order (section)
(4) Hygiene (season)
(5) Formalization (seiketsu) and control-discipline (shitsuke) steps must be applied

To better understand lean logistics, it is necessary to identify its differences from traditional logistics (Özkan et al., 2015). It is possible to see these differences in Table 1.

Table 1. Differences between Lean Logistics And Traditional Logistics Concepts

Logistics variables	Traditional logistics	Lean logistics
Management	Market-oriented	Self manage
Building	Vertical	Aggregation
Contact	Narrow	Wide
Information transfer	Single-sided	Double-sided
Technology use	Very limited	Extensive
Interactions	Competitive	Collaborative
Relationship focus	Transaction focus	mutual win boiler
Delivery-distribution	Large quantities	Small quantities
Storage	Maximum Level	Minimal level
Production flexibility	Low	High
Quality	Experience/Intensively	Designed
Price applications	Competitive	Based on target cost
Price changes	Increasing	Decreasing
From an external source	benefit Cost-based	Strategic
Selection criteria	Minimum price	Performance
Contract period	Short	Long

Özkan, O., Bayın, G. ve Yeşilaydın, G. (2015). Sağlık Sektöründe Yalın Tedarik Zinciri Yönetimi*

As shown in Table 1, traditional and lean logistics processes are distinguished from each other. While logistics are market-oriented in traditional management, it appears as self-management in lean management. While the structure of traditional logistics is vertical, lean logistics involves agglomeration. While communication is narrow in traditional logistics, it is wide in lean logistics. While information transfer is unilateral in traditional logistics, it is bilateral in lean management. The use of technology in lean logistics is wider than in traditional logistics. While interaction is based on competition in traditional logistics, collaboration in lean logistics. Although traditional logistics interaction is based on competition, lean logistics is based on cooperation. Although the relationship focus in traditional logistics is transaction-oriented, in lean logistics, it is a win-win. While delivery and distribution are performed at the maximum level in traditional logistics, they are performed at the minimum level in lean logistics. Although production flexibility is low in traditional logistics, it is high in lean logistics. In traditional logistics, quality depends on experience. In lean logistics, quality is as designed. Price applications vary. In traditional logistics, prices are based on competition, and price changes are increasing. In lean logistics, price applications are based on target costs, and price changes are decreasing. In traditional logistics, outsourcing depends on cost. Lean logistics have a strategic structure. Although the selection criteria are minimum prices in traditional logistics, they depend on the performance of lean logistics. While contract periods are short in traditional logistics, they are long in lean logistics.

2.3. Studies on Lean Logistics, Lean Supply Chain, and Lean Supply Chain Management

Sustainability is an important factor in this context. Speed and flexibility are considered competitive elements. One lean management application area for businesses is logistics activities (Mücevher, 2021). Due to the ongoing positive value creation of lean logistics, many sectors have taken part in production support activities and are preferred. In the literature, automobile businesses (Liang and Wang, 2013; Silva, 2015; Zhang, 2015), transportation businesses (Vasiliauskas et al., 2014), hospital logistics and healthcare services (Aguilar-Escobar and Garrido-Vega, 2012; Serrou et al., 2016; Khlie et al.,2016; Teng et al.,2019), logistics company (De Haan et al.,2012; Buzdik et al., 2019; Rodrigues and Kumar, 2019), forest industry (Fallas-Valverde et al., 2018), manufacturing and production companies (Dolak and Suchanek,2015); Nowicka-Skowron and Ulewicz, 2017), agricultural product companies (Zhang and Yang, 2010; Szabo et al.,2021), mining sector (Arango Serna et al.,2009), e-businesses (Cao, 2007), urban logistics (Escuder et al., 2020), maritime and port sector (Lyonnet, 2016; Frontoni et al., 2020; Praharsi et al., 2021), vehicle industry (Wang et al., 2006), lean and Six sigma logistics (Carvalho, 2017). Internallogistics (Korytkowski and, Karkoszka, 2016; Grzegorz et al., 2021; Facchini et al., 2024). Management (Gu et al., 2021) and process improvement (Lu et al., 2021).

In Turkey, sustainability means lean logistics (Mücevvher, 2021). Lean management and lean logistics (Yangınlar and Bal, 2019). Lean logistics and value flow (Kocabaş, 2014). Mapping method (Savaş and Kılıç, (2015). Supply chain structure and comparative cost analysis, Uçar and Şirin, use of lean techniques in internal logistics activities, Sönmez and Yağmur (2021), internal logistics optimization, Yalçıner, 2020; Gecü, 2008; Kılıç et al. 2012; Koçan, 2014, Kuvvetli ve Erol, 2017; Küçükoğlu et al., 2018, Patır,2019; Usak ve Selvi, 2019, Topuz, 2021), quality assurance system (Derdiyok, 2019), and process improvement (Kuğu and Köse,2021; Sevgi and Antmen,2019; Turan, 2019).

2.4. Bibliometric Analysis

Unlike systematic literature review, biometric analysis is an analytical method used to obtain formal and quantitative data about the current state of a field and makes it easier to follow academic trends using visualization software. The ultimate goal of the bibliometric approach, which can be confused with concepts such as scientometric, geometric, cybernetic, altimetric, and isometric regarding the age of metrics, is to obtain quantitative data and numerical measurement indicators regarding research performance (Dirik et al., 2023). The term "bibliometrics" was first introduced by Alan Pritchard in 1969. Pritchard defines bibliometrics as the application of mathematical and statistical methods to analyze written communication and provide guidance on the processes of this communication and the reality and development of a branch of science (Lawani, 1981). First, a bibliometric study provides information in a conceptual and intellectual form about the existing literature on specific topics and constructs (Singhania et al., 2022).

Bibliometric indicators are also used as tools to evaluate research performance (Wallin, 2005). These analyses reveal the most productive research and collaborations in the field (Subramanyam,1983). In addition to classical research flows in certain fields, bibliometric analyses are also suitable for determining journal performance, coauthors, and cocitation trends (Baker et al. 2019). Bibliometric mapping is an analysis technique that analyzes and visualizes scientific studies (Arslan, 2022). Bibliometric studies are a quantitative method that evaluates the productivity, growth, and impact of academic literature and can be applied to all disciplines (Yang and Xiu, 2023) and enable the structure of a discipline to be revealed (Arslan et al., 2023). Bibliometric research enables the statistical examination of data such as author, subject, cited author, and cited sources and reveals the general structure of a particular discipline in light of the statistical results obtained (Bozkurt and Çetin, 2016).

The studies examined in the bibliometric analyses were accessed from directories and databases such as Web of Science, Scopus, Dimensions, Google Scholar, Lens, and PubMed (Moral Munoz et al., 2020). At this point, an important data source in the context of the relevant literature is the Web of Science database (Chadegani et al., 2013). VOSviewer is a freely available tool for analyzing and visualizing bibliometric data from the Web of Science database (van Eck and Waltman, 2010). VOSviewer allows data to be quickly examined and visually mapped (Yılmaz and Şahin Yılmaz, 2023). One of the most important critical goals in bibliometric analysis is to obtain a consistent and standardized set of indicators (Van Raan, 2004). Donthu et al. (2021) noted that bibliometric analyses are gaining popularity for interdisciplinary methodologies and processing large volumes of data (Donthu et al. (2021).

3. Methodology

3.1. Purpose of the Research

Logistics, which forms a worldwide network, consists of complex processes that depend on supply transactions and the production and marketing chain. All foodstuffs, clothes, white goods, health products and medicines, furniture, vehicles and construction equipment, raw materials, and semi-finished products, etc. in our environment reach customers as a result of operations related to logistics processes. In the global digital economy, complex transactions, such as supply, purchasing, tendering, and negotiation methods, and management of competitive processes, which constitute a series of transactions interconnected with logistics processes, are carried out through the supply chain network. Therefore, these processes must be managed in the best possible way. Lean logistics is an approach that provides the opportunity to produce the products and services desired by the customer with fewer resources in terms of time and cost, creates value for the customer, and eliminates waste. This study reveals the publication years, country, author, university, and journal productivity, weak and strong research areas, literature gaps, collaboration networks, potential opportunities, and widespread effects of the outputs produced in a field to obtain information about the field through bibliometric analysis in the field of lean logistics. Planned to be removed.

3.2. Method

On 20.07.2024, a search was made from the Web of Science database using the keyword lean logistics, and 2291 publications were found. A search was conducted using the keywords “lean logistics,” “lean supply chain,” and “lean supply chain management,” and 2207 publications were found. The publications were published between 1987 and 2024. Figure 1 shows the research model in detail.

3.3. Research Model

Because of a detailed literature review, the research model shown in Figure 2 was created.

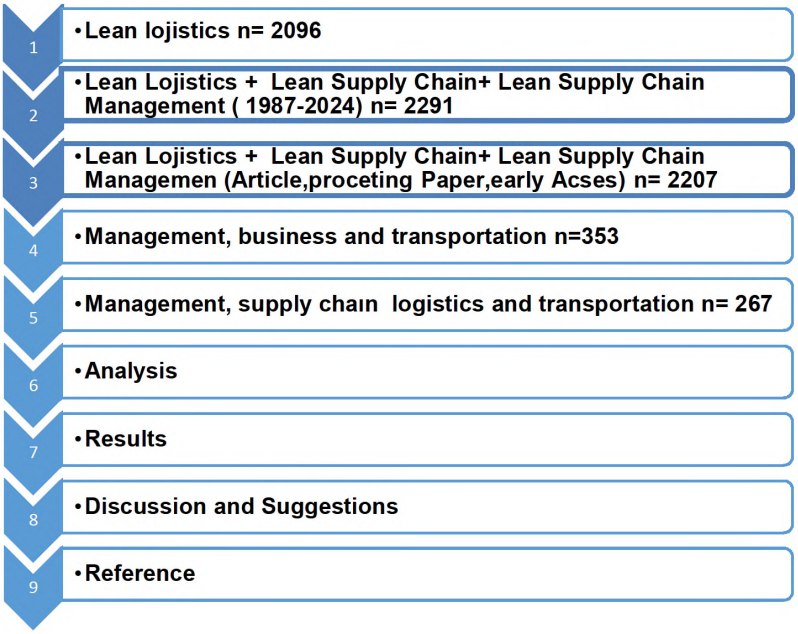

Figure 2. Because of a detailed literature review, the research model shown in Figure 2 was created.

3.4. Research Questions

Question 1. In which years were publications on lean logistics, lean supply chain, and lean supply chain management for sustainability published in the Web of Science database?
Question 2. Which citation topic are related to lean logistics, lean supply chain, and lean supply and chain management for sustainability in the Web of Science database?
Question 3. Which micro-citation topics are related to lean logistics, lean supply chain, and lean supply chain management for sustainability in the Web of Science database?
Question 4. What is the writing language for publications on lean logistics, supply chain, and lean supply chain management for sustainability in the Web of Science database?
Question 5. What is the index of publications related to lean logistics, lean supply chain, and lean supply chain management for sustainability in the Web of Science database?
Question 6. What countries have publications on lean logistics, lean supply chain, and lean supply chain management for sustainability in the Web of Science database?
Question 7. Publishing of publications related to lean logistics, lean supply chain, and lean supply chain management for sustainability in the Web of Science database.
Question 8. Refine by SDG publications on lean logistics, lean supply chain, and lean supply chain management for sustainability in the Web of Science database.
Question 9. What are the affiliations of publications related to lean logistics, lean supply chain, and lean supply chain management for sustainability in the Web of Science database?
Question 10. What is the affiliation with the department of publications on lean logistics, lean supply chain, and lean supply chain management for sustainability in the Web of Science database?
Question 11. What is the country/region count of publications on lean logistics, lean supply chain, and lean supply chain management for sustainability in the Web of Science database?
Question 12. Are the publications on lean logistics, lean supply chain, and lean supply chain management for sustainability in the Web of Science database cited in the last few years?

4. Results

4.1. Number of Publications by Year

Publications and years related to lean logistics are detailed in Figure 3.

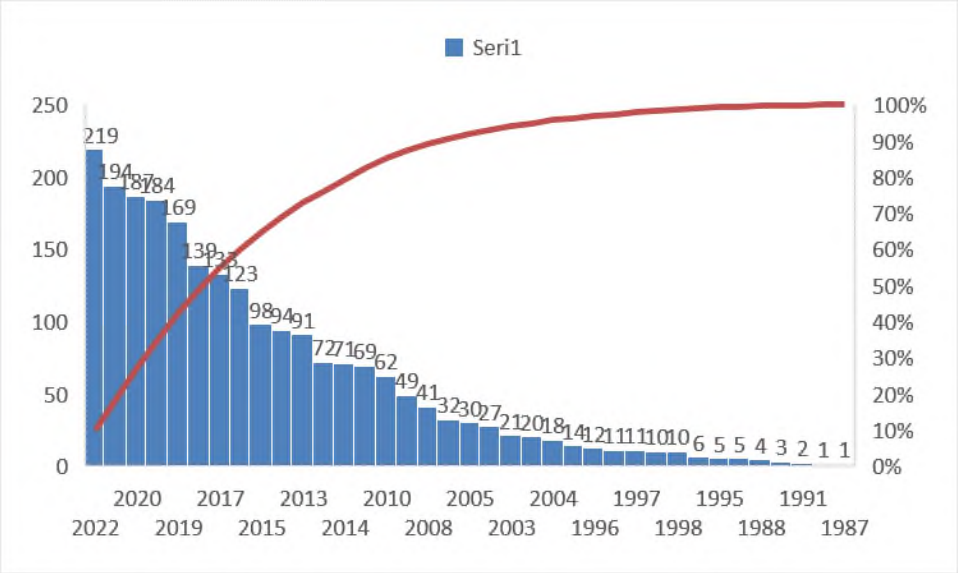

Figure 3. Number of Lean Logistics Publications by Year (Web of Science, 2024)

Figure 1 shows the number of publications with lean logistics by years. The first publication was published in 1987. Although the number of publications was 1 in 1987 and 1988, it increased to 10 in 1997. The number of publications increased to 20 after 2000. After 2010, it rapidly increased and reached 100. With an increase in logistics activities and an understanding of the importance of lean logistics, the number has reached 200 after 2020

4.2. Citation Topics in Lean Logistics Publications

Publications in the fields of lean logistics, management, supply chain and logistics, and transportation have been written. The results are detailed in Table 2.

Table 2. Citation Topics Meso (Web of Science, 2024)

Department	Frekans	%
Management 205	205	76,7
Supply Chain and Logistics	59	22,0
Transportation	3	1,3

As shown in Table 2, the majority of publications related to lean management were published in 205 (76.7%) management, 59 (22%) supply chain and logistics, and 3 (1.3%) transportation.

4.3. Critation Topics Micro

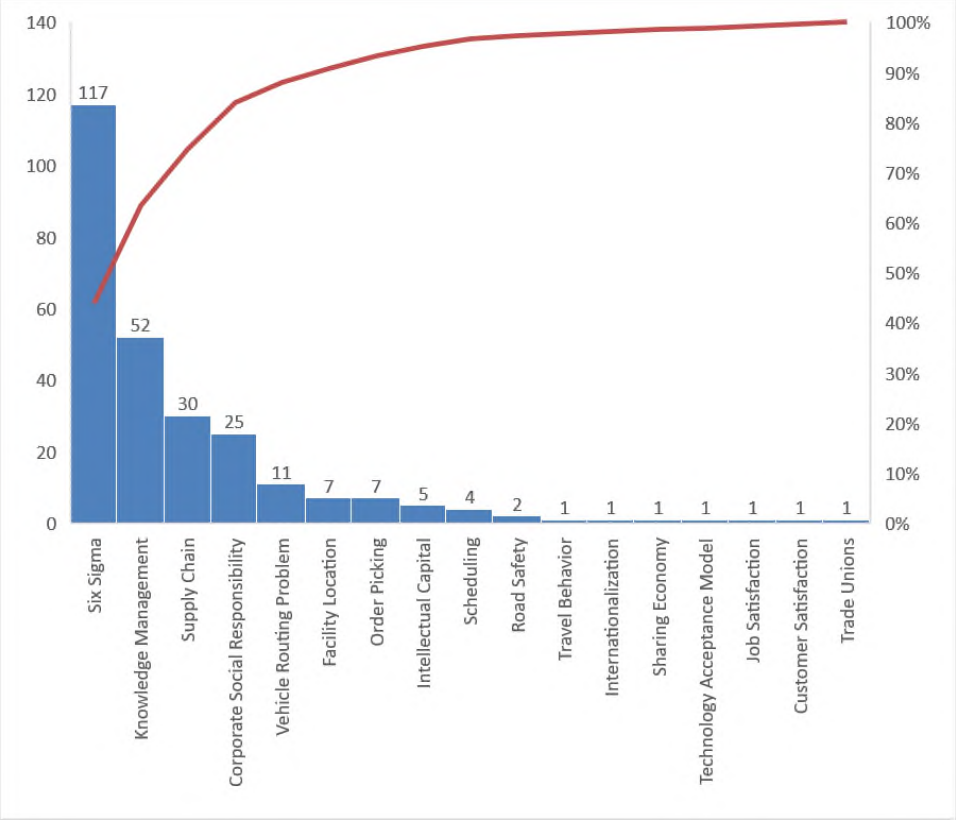

Figure 4. Citation Topics in Micro (Web of Science, 2024)

Figure 2 shows the citation topics of lean management. The number of publications on topics related to at least lean logistics: Trade unions, customer satisfaction, job satisfaction, technology acceptance model, sharing economy, internationalization, and travel behavior, is 1 (% 0, 4). Road safety followed this with 2 (% 0,7), and scheduling was of 4(% 1,4) types. Intellectual capital is 5 (% 2) in order picking, and facility location is 7 (% 2,7). The vehicle routing problem was 11(%4,1), corporate social responsibility is 25 (%9,3) supply chain is 30 (%11,2), maximum Six Sigma score is 117 (% 43,8) This was followed by knowledge management with 52 (% 19,4).

4.4. Grafik Web of Science Index

Web of Science publications are published by various indexes.

Table 3 shows the indices in which lean management publications are published. Publications (at most 114) have been published in the WOS. SSCI index. This was followed by 109 WOS. ESCI. The others were 35 WOS. SCI, 33 WOS. ISSHP, 21 WOS ISTP, 8 WOS. BHCI, 6 WOS BSCI index.

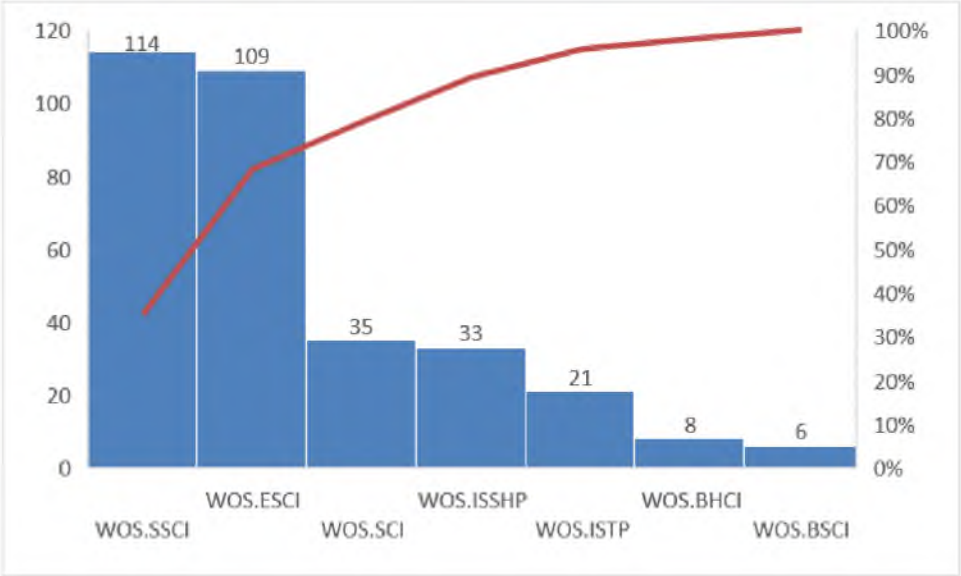

Figure 5. Web of Science Index (Web of Science, 2024)

4.5. Writing Language for Publications

Table 3. Writing language for publications (Web of Science, 2024)

Language	**Frekans**	**%**
English	260	97,3
Spanish	4	1,5
Portuguese	3	1,2

As seen in Table 3, the majority of publications in the field of lean logistics, 260 of them, were written in 97.3% English, 4 of them were written in 1.5% Spanish, and 3 of them were written in 1.2% Portuguese.

4.6. Countries with Publications Written in Lean Logistics Stream

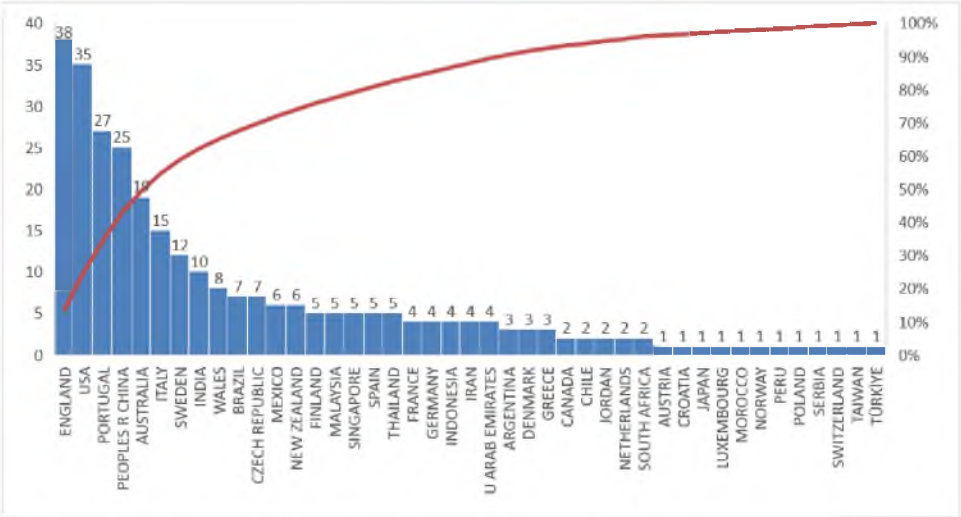

Figure 6. Countries in which publications were written in the lean logistics stream (Web of Science, 2024)

Figure 7 shows the countries where publications were written in the lean logistics stream. England ranks first with the most publications, 38. This is followed by the United States with 34 publications and Portugal with 27 publications. There is 1 publication in Türkiye.

4.7. Publishing

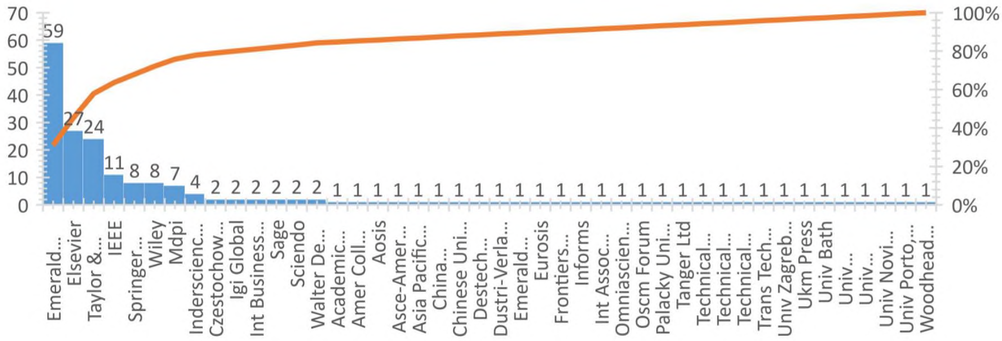

Figure 7. Journals in which lean logistics publications are published (Web of Science, 2024) Figure 5 shows the indexes in which publications on lean supply chain management and logistics were published. The Emerald Group had the most publications, with 59 publications. Elsevier followed with 27 publications, Taylor & Francis with 24 publications, IEEE with 11 publications, Springer Nature and Wiley with 8 publications, Mdpİ with 7 publications, and Inderscience with 4 publications. In the other cases, the number of publications was determined as 1 and 2.)

4.8. Sustainable Development Goals

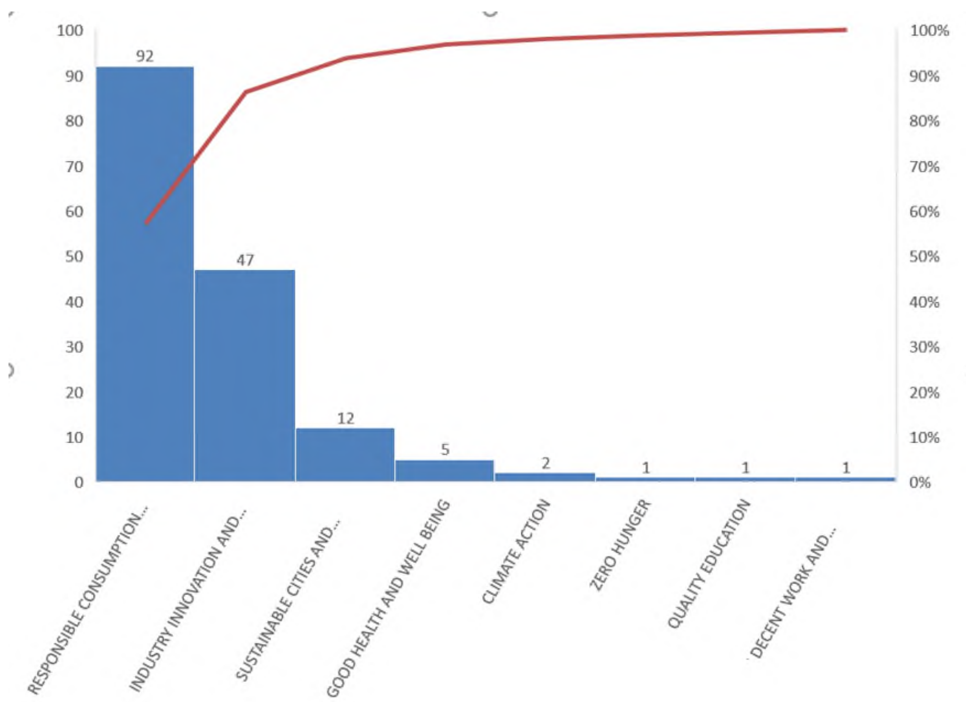

Figure 8. Publications based on sustainable development goals (Web of Science, 2024)

As shown in Graph 6, most of the publications on lean management cover sustainable development goals. In fact, 161 of the 267 articles describe sustainable development goals. Responsible Consumption was one of the sustainable development goals with 92 publications. This was followed by industry, innovation, and infrastructure with 47 publications, sustainable cities and communities with 12 publications, healthy and quality life with 5 publications, climate action with 2 publications, zero hunger, quality education and decent work, and economic growth with 1 publication.

4.9. Affiliation with the Department

Table 4 lists the links to lean logistics publications. Nova University Lisbon School of Science and Technology ranks first with 3 (20%) connections. This was followed by the Massey University College of Sciences, Massey University School of Food

Table 4. Writing language for publications (Web of Science, 2024)

Affiliation with the Department	Frekans	%
Nova University Lisbon School of Science and Technology,	3	20
Massey University College of Sciences,	2	13,3
Massey University School of Food and Advanced Technology,	2	13,3
Department of Mechanical and Industrial Engineering, New University of Lisbon	2	13,3
New University of Lisbon Research And Development Unit for Mechanical and Industrial Engineering	2	13,3
Cranfield University Cranfield School of Management,	1	5,36
Free University of Bozen, Bolzano, Faculty of Science and Technology	1	5,36
Mid Sweden University, Department of Information Systems and Technology,	1	5,36
Mid-Sweden Universıty Faculty of Science Technology and Media	1	5,36
Tianjin Unıversity School of Management	1	5,36
Toplam	15	100

and Advanced Technology, the New University of Lisbon Department of Mechanical and Industrial Engineering, and the New University of Lisbon Research And Development Unit for Mechanical and Industrial Engineering, with 2 (13.3%) connections.

4.10. Times Cited and Publications Over Time

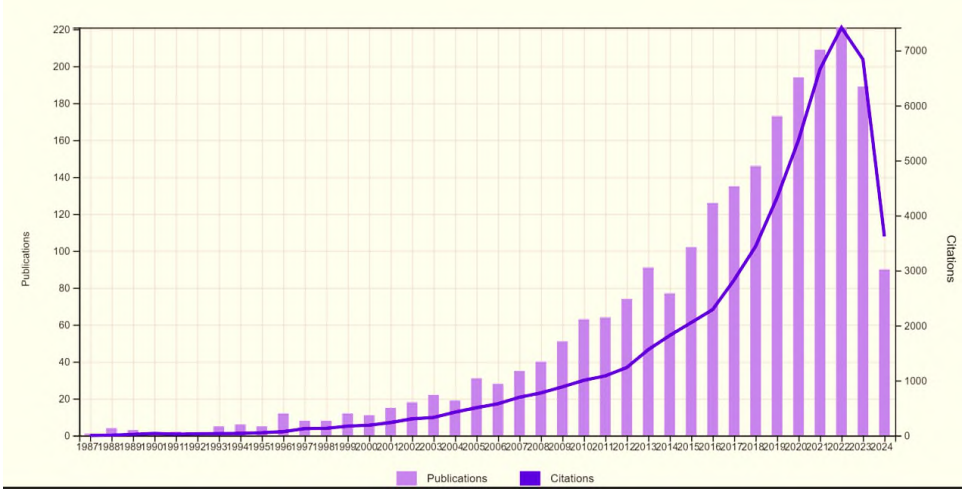

Figure 9. Times cited and publications over time (Web of Science, 2024)

Figure 9 shows the number of citations and publications over time. Although the number of publications was 1 and the citations were at most 1 between 1987 and 1993, the number of publications and citations started to increase after 1996. The number of publications and citations began to increase after the 2000s. 2022 reached its peak with 219 publications and 7000 citations. The study contains 2,291 publications from 1987 to 2024. Citing articles total 48,657 47,993 without self-citations, 57,221 times cited, 54,928 without self-citation, 24.99 average peri tem. H-index = 108.

5. Conclusion and Discussion

Sustainability is the struggle of countries to provide their current economic, social, and environmental good conditions to future generations. Lean logistics, lean supply chain, and lean supply chain management can achieve sustainability goals in economic, social, and strategic terms. Globalization, technological developments, widespread use of the internet, data from international trade, growth of e-commerce, and necessary promotions on websites are changing people's demands, needs, and services. Logistics involves meeting human demands and requirements. International trade, e-commerce, and the logistics sector, which is a great supporter, implement various strategies to continue their activities in an intensely competitive environment. It has registered individuals to prevent resource waste in processes and store logistics data. Lean logistics covers the management of the supply chain with less cost while protecting resource waste. It also highlights the sustainability-oriented effects of lean logistics. In the literature, it is seen that lean logistics, lean supply chain, and lean supply chain management provide sustainability. This study examined the publications related to the keywords "lean logistics, lean supply chain, and lean supply chain management" between 1987 and 2024 in WoS data containing internationally indexed journals and found 267 publications. It can be seen that the number of studies published in this field increased from 1 to 5 between 1987 and 1995 and increased to 100 in 2010. In 2022, 219 publications were reached. 76.7% of the lean logistics publications are in the field of management, and the highest is in the field of

Six Sigma, with 43.8%. The vast majority of the publications are in the 114 WOS. SSCI calendar. This was followed by 109 WOS. ESCI. The vast majority (97.3%) of the publications were written in English. Most of the publications were published by Emerald Group, followed by Elsevier. There are 161 articles on lean logistics, lean supply chain, and the sustainable development goal of lean supply chain management. 92 publications are responsible for consumption, 47 are industry, innovation, and infrastructure, and 12 publications will form the dominance of sustainable cities and communities. 5 of them are healthy individuals, 2 are climate action and 1 explains zero hunger, quality education, decent work, and economic growth. Various bibliometric studies have been conducted on lean logistics, lean supply chain, and supply chain management. Some of these studies are; Öztemiz (2024) conducted bibliometric research on Web of Science (WoS) data logistics. Alp and Akalın (2023) conducted a bibliometric analysis of postgraduate theses in the field of lean management. Toprak et al. (2024) used bibliometric analysis to examine sustainable supply chain management in the automotive sector. Garcia-Buendia et al. (2021), Garcia-Buendia et al., (2022), and Taddeo et al., (2019), "Only supply chain management," and "Only cleaner production, Endler et al., (2018). Lean supply chain, Oliveira-Dias et al., (2021). With the use of information technologies in the supply chain, Wang et al. (2023) conducted bibliometric research on changes in logistics.

The theory of lean thinking, which emerged in the 1940s, changed its dimension in the 21st century and became a sector with added economic value. It is where the increase in globalization, international trade, and e-commerce, on the other hand, the relationships between logistics and technology (Blockchain, Internet of Things, automation systems, etc.) are effective. It is associated with sustainability, which has gained importance, especially in protecting against the negative effects of globalization. It can meet global sustainability goals.

This study shows how working relationships in the field of "lean logistics, lean supply chain, and lean supply chain management" have changed over the years, the degree of global sustainability access, the general programs of current literature, the most relevant journals, institutions, countries, preferred keywords, and the most studied themes in the field. The difference between this study and other publications is that it emphasizes the importance of lean logistics, lean supply chain, and lean supply chain management for sustainable development goals, reveals general trends, determines topics that need to be studied in the future, and is planned to guide researchers, practitioners, and stakeholders. In addition, bibliometric information and summary statistics are presented to new researchers who wish to work in this field.

The findings of this study, which are similar to the results of bibliometric analysis in the literature, especially in terms of researchers and relevant resources in the field, reveal strong research areas, literature gaps, collaboration networks, potential opportunities, and widespread effects of outputs produced in a field. At the same time, it can guide researchers as it can be used as a preliminary step in any research area.

The contribution of this study can then be summarized as follows: This study emphasizes the importance of lean supply chain management and logistics management, which are important factors in achieving sustainable development goals not only nationally but also globally and affecting society economically, socially, and environmentally. 161 of the 267 articles examined cover sustainable development goals. However, this is not sufficient.

The findings of this study, although they show similarities with the results of bibliometric analyses in the literature, especially in terms of researchers and related resources in the field, reveal strong research areas, literature gaps, collaboration networks, potential opportunities, and widespread effects of outputs produced in a field. At the same time, it can guide researchers as it can be used as a preliminary step in any research area.

In this study, 60.3% of the articles explained sustainable development goals. Most publications were responsible for production and consumption 92. This was followed by industry, innovation and infrastructure 47, sustainable cities and communities 12, healthy and quality of life 5, climate action, zero hunger, quality education, decent work, and economic growth 1. No publications were found on poverty, gender inequality, clean water and sanitation, accessible clean energy, reducing inequalities, life below water, peace justice, or strong institutions, goals, or partnerships. It is recommended that future researchers research this subject.

The limitation of this research is that Web of Science database articles books and other documents were not examined. The fact that others (Scobus, TR Index, etc.) were not used is a limitation of the research. Researchers can conduct bibliometric analyses using different keywords from different databases. In addition to the VOSviewer program, programs such as Bibexcel, Pajek, Bibliometrics, and SciMAT can be used.

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REFERENCES

Aguilar-Escobar, V. G., & Garrido-Vega P. (2012). Lean logistics management in healthcare: a case study, *Revista de calidad asistencial: organo de la Sociedad Española de Calidad Asistencial*, 28(1), 42-49. https://doi.org/10.1016/j.cali.2012.07.001.

Alejandro-Chable, J. D., Salais-Fierro, T. E., Saucedo-Martínez, J. A., & Cedillo-Campos, M. G. (2022). A New Lean Logistics Management Model for the Modern *Supply Chain, Mobile Networks and Applications, 1-12.* https://doi.org/10.1007/s11036-022-02018-1.

Alp, F., & Akalın, B. (2023). Yalın yönetim alanında yürütülen lisansüstü tezlerin bibliyometrik analizi (1996-2022), *Sağlık ve Sosyal Refah Araştırmaları Dergisi, 5*(1), 114-125.,

Arango Serna, M. D., H. Gil Gomez, and J. A. Zapata Cortes, J. A. (2009). Lean logistics applied to transport in the miner sector, Boletín *de Ciencias de la Tierra*, (25), 121-136

Arslan, E. (2022). Sosyal bilim araştırmalarında VOSviewer ile bibliyometrik haritalama ve örnek bir uygulama, *Anadolu Üniversitesi Sosyal Bilimler Dergisi*, 22(Özel Sayı 2), 33-56.

Arslan, B. and Akyol, E. M. (2023). Web of Science (WOS) veri tabaninda yer alan örgütsel sessizlik konulu makalelerin bibliyometrik analiz yöntemi ile incelenmesi, *Journal of Business in The Digital Age*, 6(Özel Sayı), 46-56.

Baker, H. K., Kumar, S., & Pattnaik, D. (2019). Twenty-five years of reviews of financial economics: a bibliometric overview. Review *of Financial Economics*. 1-21 https://doi.org/10.1002/rfe.109.

Baudin, M. (2004). Lean logistics: The nuts and bolts of delivering materials and goods. Productivity Press.

Bowersox, D. J. ve Closs, D. J. ve Cooper, M. B. (2002). Supply chain logistics management, ınternational edition, Mc Graw Hill

Bozkurt, Ç. Ö., & Çetin, A. (2016). Girişimcilik ve kalkınma dergisi'nin bibliyometrik analizi. Journal of Entrepreneurship & Development, 11(2).

Cao, C.Z (2007, May).Lean logistics in e-business." 6th Wuhan International Conference on E-Business. Wuhan, China.

Chadegani, A. A., Salehi, H., Yunus, M. M., Farhadi, H., Fooladi, M., Farhadi, M., & Ebrahim, N. A. (2013).A comparison between two main academic literature collections: Web of Science and Scopus databases, arXiv preprint arXiv:1305.0377.

Carvalho, E. Resende, Ana Elaje Azevedo Simões da Mota, G. Maués de Souza Martins, L. dos Santos Lourenço Bastos, and André Cristiano Silva Melo. (2017). The current context of Lean and Six Sigma Logistics applications in the literature: A Systematic Review. *Brazilian Journal of Operations & Production Management,14*(4), 586-602.

Garcia-Buendia, N., Moyano-Fuentes, J., & Maqueira-Marín, J. M. (2022). A bibliometric study of lean supply chain management research: 1996–2020. *Total Quality Management and Business Excellence*, 33(15-16), 1872-1895.

Çamlıca, Z. & Akar, G. S. (2014). Lojistik sektöründe sürdürülebilirlik uygulamaları. Gümüşhane Üniversitesi, *Sosyal Bilimler Elektronik Dergisi*, 11, 100-119.

De Haan, J., Naus, F., & Overboom, M. (2012). Creative tension in a lean work environment: Implications for logistics firms and workers, International Journal of Production Economics, 137(1), 157-164. https://doi.org/10.1016/j.ijpe.2011.11.005.

Derdiyok, T. 2019. Üniversitelerde kalite güvence sistemi kapsamında PUKÖ yönetim döngüsü uygulamasında bir model önerisi. *Ufuk Üniv Sos Bil Enst Dergisi*, 8(15), 173-198.

Dirik, D., Eryılmaz, İ. ve Erhan, T. (2023). Post-truth kavramı üzerine yapılan çalışmaların VOSviewer ile bibliyometrik Analizi. *Sosyal Mucit Academic Review,* 4(2), 164-188. Doi: 10.54733/smar.1271369.

Dolak, R. & Suchanek, P. (2015). Lean company research in manufacturing companies in the Czech Republic. *Proceeding of the 12th International Conference Liberec Economic Forum*. 36-45.

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N. and Lim, W. M. (2021). A bibliometric analysis: An overview and guidelines. *Journal of Business Research*, 133 (2021), 285-296. https://doi.org/10.1016/j.jbusres.2021.04.070.

Endler, K. D., Scarpin, C. T., & Steiner, M. T. A. (2018). A bibliometric analysis of scientific production in lean supply. *International Journal of Logistics Systems and Management*, 31(1), 82-108.,

Escuder, M., Tanco, M., Muñoz-Villamizar, A., and Santos, J. (2020). Can leaning eliminate waste in urban logistics? A field study. International Journal of Productivity and Performance Management, 71(2), 558-575.

Facchini, F., Mossa, G., Sassanelli, C., Digiesi, S. (2024). IoT-based milk run routing for manufacturing system: an application case in an automotive company. Int. J. Product Res. 62(1-2): 536-555.

Fallas-Valverde, P., Quesada, H., and Madrigal-Sánchez, J. (2018). Implementation of lean thinking principles to logistic activities: a case study in a wood forest industry, *Revista Tecnología en Marcha*, 31(3), 52-65.

Frontoni, E., Rosetti, R., Paolanti, M., & Alves, A. C. (2020). HATS project for lean and smart global logistic: A shipping company case study. *Manufacturing Letters*, 23, 71-74. https://doi.org/10.1016/j.mfglet.2019.12.00.

Gapp, R., Fisher, R., & Kobayashi, K. (2008). Implementing 5S within a Japanese Context: An integrated management system, *Management Decision*,42(4): 565-579.

Garcia-Buendia, N., Moyano-Fuentes, J., Maqueira-Marín, J. M., & Cobo, M. J. (2021). 22 years of lean supply chain management: a science mapping-based bibliometric analysis. *International Journal of Production Research*, 59(6): 1901-1921.

Garcia-Buendia, N., Moyano-Fuentes, J., & Maqueira-Marín, J. M. (2022). A bibliometric study of lean supply chain management research: 1996–2020. *Total Quality Management and Business Excellence*, 33(15-16), 1872-1895.

Gecü B. (2008). İç lojistik sistemlerinin yalın üretim bakış açısıylayeniden tasarlanması ve otomotiv sektöründe örnek bir uygulama. Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İstanbul, Türkiye, pp: 117.

Grzegorz B, Izabela N, Arkadiusz G, Zbigniew B. (2021). Reference model of milk-run traffic systems prototyping, Int. J. Product Res, 59(15): 4495-4512.

Gu, S., Zhang, A., Huo, G., Yuan, W., Li, Y., Han J, Shen N. (2021). Application of PDCA cycle management for postgraduate medical students during the COVID-19 pandemic. *BMC Medic Educ*, 21(1), 308.

Jordan, S. M. (2002). Primer on the Supply Chain Logistics Model: *A Working Paper from Trade Dynamics*

Khlie, K., Serrou, D., & Abouabdellah, A. (2016, October). The impact of Lean logistics and information systems on information flow management in the healthcare supply chain ". In 2016 11th International Conference on Intelligent Systems: Theories and Applications(SITA) (pp. 1-5). IEEE.

Kılıç H.S., Durmusoglu M.B., Baskak M. (2012). Classification and modeling for in-plant milk-run distribution systems ". *The International Journal of Applied Materials Technology*, 62: 1135-1146.

Kılıç, F. (2022). Uluslararasi ticaretin önemi kapsaminda sürdürülebilir lojistik. *Uluslararası Ticaret Ve Lojistikte Güncel Yaklaşımlar Ve Değerlendirmeler*-4, 9. Editörler kutlu, A.H; Bakırcı, F; Takım A; karabacak E. Efe Akademi.

Kocabaş, D. (2014). *Yalın lojistik ve değer akışı haritalandırma yöntemi,* Doctoral dissertation, Fen Bilimleri Enstitüsü).

Koçan A.(2014). İç lojistikte setleme/sıralama sisteminin tasarımı ve otomotiv sektöründe bir uygulama, Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İstanbul.

Korytkowski P, Karkoszka R. (2016). Simulation-based efficiency analysis of an in-plant milk-run operator under disturbances. The International Journal of Applied Materials Technology, 82: 827-837.

Kuğu S, Köse R.(2021). "Isı değiştirici üretim hattında değer akış haritalama uygulamasının etkileri", Kırklareli Univ J Eng Sci,7(1): 135-146.

Kuvvetli Y, Erol R. (2017). Ağaç ürünleri üreten bir işletmede malzeme taşıma sisteminin ağaç ürünleri üreten bir işletmede malzeme taşıma sisteminin simülasyon yaklaşımı ile iyileştirilmesi, *Çukurova Üniv Müh Mim Fak Derg,* 32(1): 215-222.

Küçükoğlu İ, Yağmahan B, Çağlıyan MS, Yıldız A, Aktokluk D.(2018). İç lojistik sisteminde malzeme tedariki için geliştirilmiş matematiksel modelleme yaklaşımı: Bir uygulama. *Uludağ Üniv Müh Fak Derg*, 23(4): 159-176.

Lawani, S. M. (1981).Bibliometrics: its theoretical foundations, methods and applications. Libri, 31(1),294-315. https://doi.org/10.1515/libr.1981.31.1.294

Lu, Y., Liu, Z., Min, Q. (2021). "A digital twin-enabled value stream mapping approach for production process reengineering in SMEs". *Int J Comput Integrated Manufact*, 34(7-8): 764-782

Lyonnet, B. (2016). "Assessment of logistic ınformation systems: the contribution of lean management- application case in the maritime and port sector", Proceeding of the 2015 International Conference on Advanced Manufacturing and Industrial Application. 33,57-60.https://doi.org/10.2991/icamia-15.2015.14,

Liang, D., and H. Wang (2013). Study on the development strategy of lean logistics for automobile enterprises under green supply chain environment, *Applied Mechanics and Materials*, 397–400, 2677–2680. https://doi.org/10.4028/www.scientific.net/amm.397-400.2677.

Mete, E. (2020). Sürdürülebilir kalkınma kapsamında yeşil lojistik: Avrupa Birliği ve Türkiye örneği. Karadeniz Sosyal Bilimler Dergisi, 12(23), 383-396.https://doi.org/10.38155/ksbd.790740

Moral-Muñoz, J. A., Herrera-Viedma, E., Santisteban-Espejo, A., & Cobo, M. J. (2020). Software tools for bibliometric analysis: An up-to-date review. *Profesional de la Información*, 29(1), doi:10.3145/epi.2020.ene.03.

Mücevher, M. H. (2021). Sürdürülebilir lojistik için üç öncelikli strateji: Yeşil lojistik, tersine lojistik ve yalın lojistik. *Enderun*, 5(1), 39-54.

Nowicka-Skowron, M. & Ulewicz, R. (2017, November). Lean tools ınfluence on the logistic process ın production company. *Carpathian Logistics Congress. Zakopane*, Poland.

Oliveira-Dias, D., Garcia-Buendia, N., Maqueira-Marín, J. M., & Moyano-Fuentes, J. (2021). Information technologies and lean and agile supply chain strategies: a bibliometric study through science mapping. *International Journal of Business Environment*, 12(4): 338-363.

Örerel, D., & Kağnıcı, D. Y. (2024). Bireyselden küresele sürdürülebilir kalkınma hedefleri bağlamında psikolojik danışman olmak. *Dokuz Eylül Üniversitesi Buca Eğitim Fakültesi Dergisi*, (60), 1173-1196.

Özkan, O., Bayın, G. ve Yeşilaydın, G. (2015). Sağlık sektöründe yalın tedarik zinciri yönetimi. Online Academic Journal of Information Technology,6(18): 71-94.

Öztemiz H. (2024). Yalın lojistik üzerine bibliyometrik bir analiz: wos veri tabanı (1994-2022), *Journal of Transportation and Logistics*, 9(1), 153-174

Patır E. 2019. Otomotiv yan sanayi firmasında yalın üretim ve yalın lojistik uygulamaları. Yüksek Lisans Tezi, *Kocaeli Üniversitesi, Fen Bilimleri Enstitüsü*, Kocaeli, Türkiye.

Praharsi, Y., Jami'in, M. A., Suhardjito, G., and Wee, H. M. (2021). Application of Lean Six Sigma and supply chain resilience in the maritime industry during the COVID-19 pandemic, *International Journal of Lean Six Sigma*, 12(4), 800-834. https://doi.org/10.1108/IJLSS-11-2020-019.

Pritchard, A. (1969). Statistical bibliography or bibliometrics? Journal of *Documentation*. 25, 348-349.

Raghuram, S., Tuertscher, P. and Garud, R. (2010). Research note—mapping the field of virtual work: A cogitation analysis, *Information Systems Research*, 21(4): 983-999.

Rodrigues, V.S. & Kumar, M. (2019). Synergies and Misalignments in lean and green practices: a logistics industry perspective. *Production*

Planning & Control. 30 (5-6). 369-384.

Renner, M. (2015). Modern's seeds Threats. In: State of the World, 2015. Island Press, Washington, DC. https://doi.org/10.5822/978-1-61091-611-0_

Savaş, H., & Kılıç, İ. (2015). Yalın lojistik açısından konaklama işletmelerinin tedarik zinciri yapısı ve karşılaştırmalı bir maliyet analizi. *Anemon Muş Alparslan Üniversitesi Sosyal Bilimler Dergisi, 1*(1):191-220.

D. Serrou, K. Khlie. & Abouabdellah, A. (2016, October). Improvement of lean maintenance by hospital logistics. 2016 4th. *IEE International Colloquium on İnformation Science and Technology.* https://doi.org/10.1109/CIST.2016.7805047.

Sevgili A, Antmen ZF. (2019).Yalın üretim tekniklerinden değer akış haritalandırmanın bir metal işleme fabrikasında süreç iyileştirme amacıyla uygulanması, *Avrupa Bil Teknol Derg*, 16:219 228.

Silva, A. J. V. (2015).Incorporating lean manufacturing techniques in the supply chain of the automotive company: Amelec Jesus Viloria Silva. *In Computing, Control, Information, and Education Engineering*. 843-84.

Singhania, S., Singh, J. and Agrawal, D. (2023).Gender diversity on board and corporate sustainability: a quantitative review based on bibliometric mapping", *International Journal of System Assurance Engineering and Management*, 14(1):267-286.

Socconini, L. (2019). Lean manufacturing. Marge books

Sopadang, A. & Wichaisri, S. (2021).The role of lean sustainable logistics in business operations. *International Journal of Logistics Systems and Management*, 39(1): 111-126. https://doi.org/10.1504/IJLSM.2021.115078.

Sönmez, V., & Yağmur, C. (2021). "Hastane kan toplama merkezinde yalın üretim uygulaması ", *International Journal of Engineering Research and Development*, 13(3): 172-187.

Subramanyam, K. (1983).Bibliometric studies of research collaboration: A review. *Journal of Information Science*, 6(1), 33–38. https://doi.org/10.1177/016555158300600105

Szabo, Ľ., Richnák, P., & Gubová, K. (2021).A new dimension of logistics innovations development in agricultural enterprises in Slovakia. *Agricultural Economics*, 67(4), 136-143. https://doi.org/10.17221/444/2020-AGRICECON.

Taddeo, R., Simboli, A., Di Vincenzo, F., & Ioppolo, G. (2019). A bibliometric and network analysis of Lean and Clean (er) production research (1990/2017). *Science of the Total Environment*, 653: 765-775.

Teng, J., Wang, J. H., & Teng, L. (2019).Application and evaluation of lean logistics management ın the first affiliated Hospital of Xinjiang Medical University. *Fresenius Environmental Bulletin*, 28(8): 5820-5829.

Toprak, B., Katmiş, Ş. Z., Bektaş, D., Çakmak, D., and Nebati, E. E. (2024). Otomotiv sektöründe sürdürülebilir tedarik zinciri yönetiminin bibliyometrik analiz ile incelenmesi, *Sürdürülebilir Çevre Dergisi*, 4(1):1-18. https://doi.org/10.62816/cevder.1479034.

Topuz, T. (2021).Üretim sistemlerinde çekme tipi esaslı iç lojistik sistemi tasarımına yönelik bütünleşik bir metodoloji önerisi: Beyaz eşya sektöründe bir uygulama. Yüksek Lisans Tezi, *İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü,* İstanbul, Türkiye.

Turan, H. (2019). Bulanık ÇKKV metodu kullanarak değer akış haritalama uygulaması, *Uluslararası İİB Derg*, 5(1): 77-93.

Uçar, A., & Şirin, B. T. (2024). İç lojistik faaliyetlerinde yalın tekniklerin kullanılması ve bir uygulama. *Black Sea Journal of Engineering and Science*, 7(3): 423-435. https://doi.org/10.34248/bsengineering.1436910.

Usuk MS, & Selvi İH. (2019). Fabrika içi lojistik sürecinde kablosuz acil parça istek sistemi otomasyonu: bir otomotiv fabrikası uygulaması, *Acta Infologica*, 3(1): 1-12.

Van Eck, N., and Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping; *Scientometrics*, 84(2): 523-538.

Van Raan, A. F. J. (2004). Measuring science. Capita Selecta addresses the current main issues. In: Handbook of quantitative science and technology research. H. F. Moed, W. Glänzel, and U. Schmock. Kluwer (Eds.) Use of publication and patent statistics in studies on S&T systems (pp.19-50). *Academic Publishers, Dordrecht/Boston/London.*

Vasiliauskas, A. V, Macijauskyte, I., Vitk ˙ Unas, R., Zinkeviči ¯ Ut¯ E, V., Pavlova, J. (2014, may). A model of ımplementing lean logistics ˙principles in Lithuanian transport enterprises, *The 8th İnternational Scientific Conference "Business And Management 2014*". Vilnius, Lithuania. Wallin, J. A. (2005). Bibliometric methods: Pitfalls and possibilities. Basic and Clinical Pharmacology & Toxicology, 97(5), 261–275.

J. H. Wang and X. Zhang, & Fang, S. F. (2006, August). Application of lean logistics in the Chinese vehicle industry. Proceeding of the 13th International Conference on Industrial Engineering and Engineering Management. (1-5), 728-733.

Wang, J., Lim, M. K., Wang, C., & Tseng, M. L. (2023). Comprehensive analysis of sustainable logistics and supply chain based on bibliometrics: overview, trends, challenges, and opportunities, *International Journal of Logistics Research and Applications*, 26(10):1285-1314.

Wallin, J. A. (2005).Bibliometric methods: Pitfalls and possibilities", Basic & Clinical Pharmacology and Toxicology, 97(5): 261–275.

Xuming, S. G. (2011). "Optimizing logistics system with lean thinking", *International Conference on Future Information Engineering*. (ICFIE 2011), 8, 148-153

Yalçıner, A. Y. (2020). "Yalın felsefe kapsamında iç lojistik optimizasyonu: araç rotalama problemi uygulaması", In *International Marmara Sciences Congress* (AUTUMN 2020) (p. 640).

Yanginlar, G., and Bal, N. (2019). "Yalin yönetim ve yalin lojistik kavramlarinin irdelenmesi. *Stratejik ve Sosyal Araştırmalar Dergisi*, 3(1): 151-161. Https://Doi. Org/10.30692/Sisad.492188

Yang, C., & Xiu, Q. (2023). A bibliometric review of education for sustainable development, 1992–2022", Sustainability, 15(14),10823. https://doi.org/10.3390/su151410823

Yilmaz, G., & Yilmaz, A. Ş. (2023). Şarap turizmi araştırmalarına bütüncül bir bakış: ağ analizi ile haritalandırma (a holistic view of wine tourism research: mapping with network analysis). *Journal of Tourism and Gastronomy Studies*, 11(2), 1621-1640. DOI: 10.21325/jotags.2023.1259.

Zhang, L. (2015). Lean production "with Chinese characteristics: A case study of China's automobile industry," International *Journal of Sociology*, 45(2), 152-170. https://doi.org/10.1080/00207659.2015.1061861

Zhang, C.L. & Yang, H. J. (2010, November). Study on the value management mode of transport resources in the lean agricultural product logistics proceeding of *2010. International Conference on Information Technology and Industrial Engineering*, 1-2 ().171-174.

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