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Two-Echelon Location Selection and Unmanned Aerial Vehicle-Assisted Vehicle Routing Problem

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Abstract In recent years, the potential use of Unmanned Aerial Vehicle (UAV) technology in logistics processes and the rapid developments in this field have made UAV-assisted routing problems an important research topic. In this paper, we consider a two-echelon location selection and UAV-assisted vehicle routing problem. In this problem, trucks leave from the main depot with their packages and UAVs, move through potential service points (mobile depot), and return to the main depot. At each mobile depot, UAVs are launched from the truck to service the customers, and the trucks wait for the UAVs to complete their service and return. The UAVs are capable of making multiple trips between the mobile depot and customers, carrying only one package at a time. The objective is to minimize the maximum tour time. In this paper, a new problem, which involves a multi-truck structure and multiple launches of UAVs from a mobile depot, is investigated for the first time to the best of our knowledge in the literature. A mixed integer linear programming model is proposed to solve the problem. In order to evaluate the performance of the proposed mathematical model, the number of trucks is determined as one and two, experimental analyses are performed and the results are reported in detail.

Keywords UAV Routing · vehicle routing · location · mathematical modeling

Author Note It is the expanded version of the paper selected at the YAEM 2024 Congress.

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Two-Echelon Location Selection and Unmanned Aerial Vehicle-Assisted Vehicle Routing Problem

The exponential growth in technology over the past decade has led to a notable increase in the utilization of Unmanned Aerial Vehicles (UAVs) or "drones", across a diverse range of sectors, including logistics, military operations, public security, and surveillance. It is noteworthy that several leading online retailers, including Amazon, Google, UPS, 7-Eleven, DHL and Walmart, have already started to integrate drones into their parcel delivery services. This reflects a growing interest in UAVs for "last-mile" delivery solutions (Macrina et al., 2020; Rojas Viloria et al., 2021).

The use of UAVs as a mode of transportation is becoming increasingly prevalent, with a variety of applications in the logistics industry (Moshref-Javadi & Winkenbach, 2021). The advantages of drones over conventional vehicles are numerous, including a constant and high travel speed, the absence of the need for physical road infrastructure, the directness of travel, and the avoidance of exposure to traffic and congestion (Macrina et al., 2020; Moshref-Javadi & Winkenbach, 2021; Rojas Viloria et al., 2021). These advantages are expected to result in reduced delivery times and increased responsiveness of logistics systems (Moshref-Javadi & Winkenbach, 2021). In light of ongoing urbanization, rapid growth in direct e-commerce deliveries, and increasing density and congestion levels, the benefits of UAV-based delivery are particularly pronounced in urban environments (Moshref-Javadi & Winkenbach, 2021). The resulting savings in time and cost could benefit both companies and customers in commercial logistics systems. Many prominent industry players, such as Amazon, Google Wing, United Parcel Service (UPS), and Rakuten, are actively working on developing and testing drone delivery models (Moshref-Javadi & Winkenbach, 2021). Given the anticipated growing importance of drones as a means of delivery in the near future, it is crucial to ensure a close and focused alignment between academic research and industrial practice in this field (Macrina et al., 2020; Moshref-Javadi & Winkenbach, 2021).

The use of UAVs for the delivery of last-mile packages is set to transform the structure of the logistics industry. However, before UAVs can be widely deployed in the commercial sector, several significant regulatory and technological challenges must be overcome. These include the capacity of the battery, the payload capacity, the maximum height at which they can fly, the inability to fly in restricted areas, the safety of the UAV and the parcel being transported, and the ability to detect and avoid obstacles. Despite these limitations, numerous researchers are currently engaged in efforts to mitigate the technical shortcomings of UAVs. While a substantial body of research has been conducted to address these technical issues, operational challenges have not been as extensively explored (Murray & Chu, 2015). For example, given the operations proposed by Amazon using UAVs with a direct depots-to-customer range of 16 km, UAV deliveries need to be made from distribution centers located close to customers. In this instance, it would be necessary for the existing distribution centers to be relocated or for new ones to be constructed. To benefit from economies of scale, these distribution centers would likely be located in proximity to densely populated urban areas with high-rise housing.

This paper addresses distribution network design problems where UAV-assisted distribution processes are planned through mobile depots instead of establishing distribution centers close to customers. Although UAV transportation offers great benefits in terms of both time and cost, UAVs have to move from distribution centers located close to customers due to constraints such as battery capacity for last-mile package deliveries. This may require relocating existing distribution centers near densely populated urban areas or building new ones. In this case, firms must incur high installation and operating costs. Moreover, the

customers to be delivered in last-mile delivery vary from day to day. Locating the distribution center at a fixed-point leads to higher delivery times and costs. To overcome the aforementioned disadvantages, this study will focus on a UAV-assisted last-mile delivery network structure over mobile depots.

To overcome the aforementioned disadvantages, this study will focus on a UAV-assisted last-mile delivery network structure over mobile depots. In this structure, high-capacity trucks move from the depot (main depot) where the products to be delivered to the customers are located to the temporary stopping points (mobile depots) to be determined within the city with the products loaded to them and UAVs. Mobile depots can be parking lots of shopping malls, vacant lots, truck garages, etc. where trucks can wait temporarily. Upon reaching the mobile depot, the products loaded onto the UAVs in the trucks are delivered to the customers and the UAVs return to the trucks. After the deliveries to be made from the relevant mobile depot are completed, the trucks move to the next potential mobile depot, perform the same operations there, and return to the main depot at the end of the day. Thanks to this network structure, significant savings are achieved in distribution center installation and operating costs, and problems arising from variability in customer locations will be prevented. For example, when there is a delivery density in a certain region the next day, the mobile depot area that was not used the previous day can be rented with low costs such as daily rent, etc., and can be used as a mobile depot and deliveries can be made. In this proposed approach, it is necessary to determine which of the alternative regions should be selected as mobile depots, how to move between these mobile depots, which customer will be served from which mobile depot, by which vehicle, and on which route.

In this paper, we consider the UAV-assisted vehicle routing problem, where customers are served by drones, while trucks carry only UAVs and packages. This raises new routing variants that use a combination of trucks and drones for delivery. We call these problems two-echelon routing problems with trucks and drones (2ER-TD) and define them as prototypical problems. The main difference between the 2ER-TD and the classical two-echelon vehicle routing problem (2E-VRP) is that drones are used in the second echelon instead of trucks. In addition, because the drones are transported by truck to intermediate depots, the truck after launching the drones must stay at an intermediate depot to wait for the drones to come back. A single-truck version of the problem was previously considered by Vu, Vu, Ha, and Nguyen (2022). In this paper, we extend the work of Vu et al. (2022) by defining a new problem, which is an improved version of this problem with multiple trucks. Thus, the problem is transformed from a two-stage location and UAV-assisted vehicle routing problem to a two-stage location and UAV-assisted vehicle routing problem.

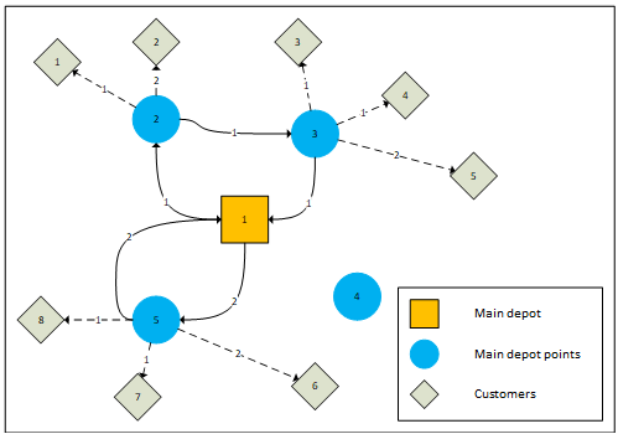
In this paper, a new problem, called “Two-Echelon Location Selection and Unmanned Aerial Vehicle Assisted Vehicle Routing Problem” (2E-UVRP), which involves a multi-truck structure and the ability to launch a UAV more than once from a mobile depot, is investigated for the first time to the best of our knowledge in the literature. The 2E-UVRP problem is shown in Figure 1. The dotted lines represent the back-and-forth transportation by drone and the solid lines represent the transportation by truck. The numbers in the dotted lines represent the drone identities, and the numbers in the solid lines represent the truck identities. For example, while the first truck was waiting at mobile depot 3, drone 1 performed two transportation tasks from this mobile depot to customers 3 and 4, while drone 2 performed only one transportation task to customer 5. In this scenario, no truck was directed to mobile depot point 4 and the depot was not activated. Allowing drones to perform more than one transportation task within the scope of the problem and using more than one truck can reduce the service time. In addition, the simultaneous movement of trucks makes it possible to serve customers in a shorter time compared to the single-truck problem.

The contributions of this study can be summarized as follows: First, a new problem type with a multi-truck structure is introduced to the literature on drone-assisted routing problems. Second, a mixed-integer

linear programming model was developed that allows solving small- and medium-sized problem instances efficiently. The proposed model can be reduced to the 2ER-TD problem when the number of vehicles is one and can also solve single-truck problems efficiently. Third, in the experimental analysis performed using the test data presented by Vu et al. (2022), the number of vehicles was set as one and two, and detailed tests were applied under different configurations. All problems are solved optimally under a time constraint of 10 minutes. Finally, a more commercially viable structure is presented by providing faster delivery to customers within the scope of 2E-UVRP.

Figure 1

Figural representation of the 2E-UVRP



This study is structured as follows: Literature review section provides the main works in the literature on 2E-UVRP. Problem definition and mathematical models part presents the problem definition and the developed mixed integer linear mathematical models in detail. Experimental results chapter is devoted to the experimental studies and their comprehensive analysis. Conclusion and future research directions summarizes the conclusions of the study and makes recommendations for future research.

Literature review

The topic of UAV-assisted routing problems is a relatively new and current area of research within the literature. In one of the earliest works on this topic, Murray and Chu (2015) defined two new problems: the flying sidekick traveling salesman problem (FSTSP) and the parallel drone scheduling traveling salesman problem (PDSTSP). FSTSP is a deployment problem where a UAV and a truck move synchronously together. The problem is considered as a single truck with infinite capacity and multiple stops per route, and a single UAV with infinite capacity and one stop per route, where the truck and UAV move in unison, with the joining and departure points situated at customer locations. In this problem, the objective is to minimize the total tour length. A mathematical model and a heuristic method were developed for solving the problem (Murray & Chu, 2015). Carlsson and Song (2017) demonstrated that the improvement in efficiency resulting from the use of a single truck and a UAV is proportional to the square root of the ratio of the speeds of the trucks and the UAV. In a recent contribution to the field, Ha et al. (2018) proposed a novel variant of the UAV-assisted traveling salesman problem (UAV-GSP) to minimize operating costs. These costs include the total transportation cost and the cost associated with the loss of time incurred when one vehicle must wait for another. Phan et al. (2018) introduced a novel variant of the UAV-GSP, incorporating the use of multiple UAVs. Salama and Srinivas (2020) presented mathematical models for the joint optimization of route completion times for trucks and UAV routes with customer clustering, as part of their study, which considered a truck and a UAV fleet. The objective of this study is to identify the optimal truck route through the application of a standard traveling salesman problem (GSP) model. This model incorporates customer clustering and the

determination of the central points through the k-means method. Subsequently, a truck visits these points. To minimize customer waiting times, Moshref-Javadi, Hemmati, et al. (2020) proposed a model in which multiple UAVs can be launched from a single location but are not expected to return. Conversely, Moshref-Javadi, Lee, et al. (2020) introduced a variation in which the trucks must wait for the return of all UAVs it has launched to continue their route. Morim, Campuzano, Amorim, Mes, and Lalla-Ruiz (2024) studied the drone-assisted vehicle routing problem with robot stations. They proposed a mixed integer linear programming mathematical model and a general variable neighborhood search metaheuristic algorithm for the objective functions of delivery time and operational costs. Jiang, Dai, Yang, and Ma (2024) investigated a multi-visit flexible docking vehicle routing problem that uses a fleet of trucks and drones to fulfill pickup and delivery requests in rural areas. They developed this problem as a mixed-integer linear programming model and solved it with a large neighborhood search metaheuristic. Savuran and Karakaya (2024) addressed the Multi-Capacity Mobile Depot Vehicle Routing Problem, a variant of VRP in which multiple drones with limited flight range operate from a mobile depot. The goal is to maximize the goal coverage while considering flight endurance, depot mobility, and drone multiplicity. They developed a new evolutionary algorithm that generates synchronized routes for the drones, taking into account all constraints.

The 2ER-TD considered in this study has some similarities with the FSTSP, where trucks act as mobile depots and UAVs make deliveries. However, since all locations (customers and depots) in the FSTSP have to be visited, there is no decision regarding the selection of the locations to be visited by trucks. In the 2ER-TD, location decisions, which determine which mobile depot to open based on customer locations, and decisions for assigning customers to these mobile depots are handled together. Another similar problem, PDSTSP, proposed by Murray & Chu (2015), is a distribution problem where a fleet of trucks and a fleet of UAVs move asynchronously from a depot to customers. This model is based on the following assumptions: *i*) the trucks and UAVs move asynchronously; ii) customers can visit by which vehicle is known in advance; *iii*) stops can be made at more than one per route; *iv*) the capacity of the UAV is infinite; *v*) with a single supporting vehicle, stops can be made at one per route; *vi*) the capacity of the supporting vehicle is limited; *vii*) there is a limited number of UAVs; and *viii*) there is a single depot. In this problem, the minimum tour length is taken as the objective function, and a mathematical model is developed to represent the problem. In this problem, customers who are situated outside the UAV's operational range or whose packages exceed the UAV's maximum payload are served by trucks, while other customers are served by either trucks or UAVs. In their study, Nguyen, Dang, Hà, and Pham (2022) extended the PDSTSP problem by incorporating a homogeneous fleet of trucks in addition to the UAV fleet. This problem, which they refer to as the Parallel Drone Scheduling Vehicle Routing Problem (PDSVRP), allows for the servicing of customers from an existing depot by both the truck fleet and the UAV fleet.

A review of the literature reveals that no studies have considered the impact of customer time windows and add-distribute operations on UAV-GSP problems. Furthermore, all studies have assumed that the capacity of trucks is unlimited. With the exception of the study by Gonzalez-R et al. (2020), all studies assume that a UAV is capable of making a single delivery. With the exception of some studies, the capacity of UAVs is not considered. Instead, it is assumed that UAVs can serve all customers (Dayarian et al., 2020; Ha et al., 2018; Murray & Raj, 2020; Song et al., 2018). Moreover, only a limited number of studies have employed energy consumption models (Ferrandez et al., 2016; Gonzalez-R et al., 2020; Jeong et al., 2019; Murray & Raj, 2020).

The second stage of the 2ER-TD considered in this study and the PDSTSP and PDSVRP models have similarities in that deliveries are made from a depot by UAVs and trucks. However, the network structure we propose differs in terms of the use of more than one mobile depot (the PDSVTSP and PDSVRP problems use a single depot), the location decision for the mobile depot in the first stage, and the determination of which customers will be served from these mobile depots. While the FSTSP offers considerable benefits when

customer locations are distant, the PDSTSP provides advantages when customer locations are proximate (Murray & Chu, 2015). The two-stage structure, in which the location of mobile depots is selected in the first stage according to customer locations, and the distribution to customers is carried out in the second stage, allows for the simultaneous utilization of the advantages of FSTSP and PDSTSP. Consequently, the 2ER-TD distribution structure has the potential to mitigate the adverse effects of distance on the solution.

The closest problem to the one considered in this paper is considered by Vu et al. (2022). Vu et al. (2022) considered a new version of the two-stage routing problem in which parcels are delivered from depots to intermediate satellites, which in turn deliver them to customers. They first proposed mixed integer linear programming models to mathematically describe the problem and solve small instances optimally, and a metaheuristic based on the idea of a greedy random adaptive search procedure to handle larger instances. This paper describes the single-truck problem. Because it is a single-vehicle problem, it is closer to the traveling salesman problem. In this paper, we consider the multi-vehicle two-stage UAV-assisted vehicle routing problem, which is closer to the vehicle routing problem.

Problem definition and mathematical models

Problem Definition

In this study, a new problem is proposed to allow deliveries to be made in less time using more than one truck and to make the problem more realistic. In the proposed problem, there is a main depot, multiple high-capacity trucks, and multiple fleets of UAVs traveling with each vehicle. While the trucks serve as mobile depots, the distribution of parcels from the mobile depots to customers is carried out by UAVs. The assumptions of the model developed for this problem are detailed below.

- Each customer has a positive demand and is known.
- The distances between all nodes (main depots, mobile depots, and customers) are known.
- Multiple trucks act as mobile depots and their capacities are sufficient to meet all customer demands.
- Trucks have a certain number of homogeneous UAVs that provide services to customers.
- The set of customers that can be served by the UAVs from each mobile depot is known.
- The truck route starts from the main depot and ends at the main depot after visiting some or all the potential mobile depot points.
- At each mobile depot, the trucks wait for the UAVs' service time.
- UAVs can only serve one customer on the same route.
- UAVs can serve multiple customers from a mobile depot.

Under these assumptions, the aim is to minimize the time it takes for all trucks to leave and return to the main depot after serving all customers. It also aims to determine which mobile depot points are selected, which truck stops at which mobile depot point, and which customer is served by which mobile depot point.

This study addresses a problem that involves the use of both multiple trucks and multiple UAVs, where each UAV operates multiple times from a single mobile depot, integrating both transportation and aerial routing systems.

Mixed-integer linear programming formulations

In developing the MILP model for 2E-UVRP, the MILP model for 2ER-TD presented in Vu et al. (2022) was utilized and defined as follows: Let $G(V, D, A_1, A_2)$ be a connected network. In this network, V represents mobile depot nodes that can be visited by trucks and D represents customer nodes that must be visited

by UAVs. A_1 and A_2 are the set of edges between nodes in cluster ($A_1 = \{(i,j) : i,j \in V \; ve \; i \neq j\}$) and $A_2 = \{(i,j) : i \in V, j \in D\}$ respectively. For each arc $(i,j) \in A_1$ positive movement time for trucks is defined by t_{ij} and for each arc $(i,d) \in A_2$ positive flight time for UAVs is defined by t'_{id}. The set V consists of main depot (0) and mobile depot nodes $(V_D = 1,2,...,n-1)$. Each customer has a positive demand $(d \in D)$, which is delivered by a single visit of the UAV to the customer. UAVs have a limited range due to their battery capacity, and within this capacity, the set of customers $(D_i : i \in V_D)$ that can be served by the UAVs from mobile depot i is known. In the problem, there is a set U of u identical UAVs and a set K of k high-capacity trucks. Each UAV is capable of autonomous flight and has a flight range of *r* units, measured in time. The decision variables for the developed MILP model are explained below.

X_{ijk} : binary variable equals 1 if truck k moves from point i to point j and 0 otherwise.

Y_{ik} : binary variable equals 1 if truck k visits node i, and 0 otherwise.

Z_{uid} : binary variable equals 1 if UAV u visits customer d from mobile depot i and 0 otherwise.

b_i : positive variable representing the visiting sequence of node i by a truck.

S_{ik} : positive variable representing the time truck k waits for UAVs at mobile depot i.

L_k : positive variable representing the time for the k^{th} truck to complete the route.

Objective Function

$$Minimize \; MaksTour \tag{1}$$

Subject to

$$\Sigma_{i \in V} X_{0ik} \leq 1 \quad \forall k \in K \tag{2}$$

$$\Sigma_{i \in V} X_{i0k} \leq 1 \quad \forall k \in K \tag{3}$$

$$\Sigma_{i \in V} X_{ijk} = Y_{jk} \quad \forall j \in V_D \forall k \in K \tag{4}$$

$$\Sigma_{j \in V} X_{jik} = \Sigma_{j \in V} X_{ijk} \quad \forall i \in V_D \forall k \in K \tag{5}$$

$$b_i - b_j + |Nc| \Sigma_{k \in K} X_{ijk} + (|Nc| - 2) \Sigma_{k \in K} X_{jik} \leq (|Nc| - 1) \Sigma_{k \in K} Y_{ik} \quad \forall i \in V_D, \forall j \in V_D, i \neq j \tag{6}$$

$$b_i \leq |Nc| \Sigma_{k \in K} Y_{ik} \quad \forall i \in V_D \tag{7}$$

$$b_i \geq \Sigma_{k \in K} Y_{ik} \quad \forall i \in V_D \tag{8}$$

$$b_i \leq |Nc| - (|Nc| - 1) \Sigma_{k \in K} X_{0ik} \quad \forall i \in V_D \tag{9}$$

$$Z_{uid} \leq \Sigma_{k \in K} Y_{ik} \quad \forall u \in U, \forall i \in V_D, \forall d \in D \tag{10}$$

$$\Sigma_{u \in U} \sum_{d \in D} Z_{uid} \geq \Sigma_{k \in K} Y_{ik} \quad \forall i \in V_D \tag{11}$$

$$\Sigma_{u \in U} \Sigma_{i \in V_D} Z_{uid} = 1 \quad \forall d \in D \tag{12}$$

$$S_{ik} \geq \Sigma_{d \in D} 2 t'_{id} Z_{uid} - M(1 - Y_{ik}) \forall u \in U, \quad \forall i \in V_D, \forall k \in K \tag{13}$$

$$L_k = \Sigma_{i \in V} \Sigma_{j \in V_D} t_{ij} X_{ijk} + \Sigma_{i \in V_D} S_{ik} \quad \forall k \in K \tag{14}$$

$$MaksTour \geq L_k \quad \forall k \in K \tag{15}$$

$$X_{ijk} \in \{0,1\} \quad \forall i,j \in V_D, \forall k \in K \tag{16}$$

$$Y_{ik} \in \{0,1\} \quad \forall i \in V_D, \forall k \in K \tag{17}$$

$$Z_{uid} \in \{0,1\} \quad \forall u \in U, \forall i \in V_D, \forall k \in K \tag{18}$$

$$b_i \geq 0 \quad \forall i \in V_D \tag{19}$$

$$S_{ik} \geq 0 \quad \forall i \in V_D, \forall k \in K \tag{20}$$

$$L_k \geq 0 \quad \forall k \in K \tag{21}$$

The objective function (1) is to minimize the maximum tour time. Constraint set (2) ensures that a truck must move from the main depot before it can be used, while constraint set (3) ensures that each truck leaving the main depot returns to the main depot after completing its tour. Constraint set (4) guarantees that if a truck stops at any mobile depot, this depot is opened. Constraint set (5) guarantees that trucks leave each mobile depot they visit. Constraint sets (6)-(9) are Miller-Tucker-Zemlin (MTZ) sub-tour elimination constraints adapted for the multi-truck problem. Constraint set (10) ensures that no customer is served by a mobile depot that is not opened. Constraint set (11) ensures that if a mobile depot is opened, at least one customer is served from this mobile depot. Constraint set (12) ensures that each customer is served by only one UAV. Constraint set (13) calculates the waiting time of the truck for the UAVs. Constraint set (14) calculates the time it takes for each truck to leave the main depot and return to the main depot. The constraint set (15) ensures that the *MaxTour* parameter is equal to or greater than the tour time of the truck with the longest route. Finally, constraint sets (16)-(21) are known as integrality constraints.

Experimental results

In this section, the test cases generated by Vu et al. (2022) are used to test the effectiveness of the proposed mathematical model for the 2E-UVRP problem. The test cases are generated by first randomizing the mobile depot locations and then randomizing the customer coordinates such that each customer can be served by at least one mobile depot node. Depending on the size of the surface, four different layout combinations were created with different combinations of the number of mobile depots and the number of customers. For $d = 20$ problems, the number of mobile depots and number of customer combinations were 8-14 and 11-11, and for $d = 30$ problems these values were 11-22 and 17-16. When reporting the results, each example is presented in $d - n - m$ format. Where d is the side length of the square, n is the number of mobile depots and m is the number of customers.

The test cases also considered the speed of the UAV and the truck. For each problem, the truck speed is 40 km/h, while the UAV speeds are 40, 50, 60, 70, and 80 km/h, respectively. Since the UAVs can fly directly between the start and end points, the flight time of the UAVs is measured by the (t'_{ij}) Euclidean distance, while the movement time of the trucks between the nodes is calculated by the (t_{ij}) Manhattan distance. The UAV flight time is limited to 30 minutes. In other words, to serve a customer from a mobile depot, the sum of the travel time from the mobile depot to the customer and the arrival time at the customer must be less than or equal to 30 minutes.

In the study, the UAV speeds are different for each problem and the number of UAVs is determined as the minimum required number of UAVs ($u_{\min}$), one, two, and three more than $u_{\min}$. $u_{\min}$value represents the minimum number of UAVs required to be in trucks.

In this test set, 4 different mobile depot-client number combinations (20-8-14, 20-11-11, 30-11-22, and 30-17-16), 5 different UAV speeds (40, 50, 60, 70 and 80 km/h), 4 different UAV numbers$(u_{\min}, u_{\min}+1, u_{\min}+2, u_{\min}+3)$ There are 80 test samples in total.

The mathematical model presented in the section titled “Mixed-integer linear programming formulations” was solved using the GAMS/CPLEX solver on a PC with a 2.30 GHz processor and 16 GB RAM with a run-time limit of 10 min. If the number of trucks is taken as one, the problem is transformed into the study

of Vu et al. (2022). In the developed integer complex mathematical model, the problem proposed by Vu et al. (2022) can be solved faster and more efficiently if the number of trucks is set to one. The same optimal results were obtained for these problems.

Numerical Results

Within the scope of the experimental studies, the number of trucks for 2E-UVRP was determined as one and two, and experiments were carried out on these different configurations. In these problems, the UAVs can only visit a single customer on each route, while they provide service to more than one customer by traveling back and forth from the same mobile depot. A total of 160 problems were solved, 80 for the one-truck problem and 80 for the two-truck problem. In the mathematical model developed by Vu et al. (2022), they obtained optimal results in all problems under the constraint of one hour in the problems with $d = 20$. However, in the problem with $d = 30$, they could not reach optimal results in 20 problems. With the mathematical model proposed in this study, optimal results were obtained for all problems with a constraint of 10 min.

Table 1 shows the results for $d = 20$ problems. Optimum results were found for all test instances in an average of 0.237 s for one-truck problems. In the two-truck problems, optimum results were found for all test instances in an average of 1.42 s. While the objective function value is 1.52 on average in one-truck problems, it decreases to 0.99 on average in two-truck problems. This shows that the use of more than one truck will result in faster deliveries than in the case of a single truck. While the average number of depots opened was 1.73 in one-truck problems, it increased to 2.18 in two-truck problems. In this case, since two trucks are used simultaneously, more mobile depots are visited, and deliveries are made in a shorter time.

The analysis shows that problems with 11 mobile depots and 11 customers require longer solution times than problems with 8 mobile depots and 14 customers. It was found that the increase in the number of mobile depots was more effective on the difficulty level of the problem than the increase in the number of customers. However, the effect of the increase in the number of UAVs on the difficulty level was not found for these problems.

Table 1

Results of one-truck and two-truck problems for d = 20

Problem Name	v_d	u	One- Truck			Two-Truck		
			Number of depots opened	Objective function value	Solution time	Number of depots opened	Objective function value	Solution time
$u = u_{\min}$								
20-8-14	40	2	***3***	2.448	***0.12***	***3***	1.432	***0.45***
20-8-14	50	2	***3***	2.189	***0.16***	***3***	1.300	***0.39***
20-8-14	60	2	***3***	2.015	***0.17***	***3***	1.223	***1.88***
20-8-14	70	2	***3***	1.892	***0.19***	***2***	1.120	***0.50***
20-8-14	80	2	***2***	1.757	***0.17***	***2***	1.036	***0.44***
20-11-11	40	2	***4***	2.162	***0.20***	***4***	1.288	***2.72***
20-11-11	50	2	***2***	1.909	***0.11***	***2***	1.198	***5.99***
20-11-11	60	2	***2***	1.707	***0.12***	***2***	1.039	***4.16***
20-11-11	70	2	2	1.563	***0.20***	2	0.975	***3.48***
20-11-11	80	2	***1***	1.442	***0.25***	***2***	0.934	***1.20***
Mean			*2.5*	*1.908*	*0.17*	*2.5*	*1.155*	*2.12*

Problem Name	v_d	u	One- Truck			Two-Truck		
			Number of depots opened	Objective function value	Solution time	Number of depots opened	Objective function value	Solution time
$u = u_{\min} + 1$								
20-8-14	40	3	***3***	2.028	***0.14***	***3***	1.254	***0.33***
20-8-14	50	3	***3***	1.852	***0.17***	***2***	1.116	***0.30***
20-8-14	60	3	***1***	1.621	***0.38***	***2***	1.009	***0.50***
20-8-14	70	3	***1***	1.454	***0.23***	***2***	0.929	***0.36***
20-8-14	80	3	***1***	1.328	***0.23***	***2***	0.869	***0.39***
20-11-11	40	3	***3***	1.963	***0.33***	***3***	1.211	***2.97***
20-11-11	50	3	***2***	1.563	***0.31***	***2***	1.063	***3.98***
20-11-11	60	3	***1***	1.335	***0.28***	***2***	0.905	***2.02***
20-11-11	70	3	1	1.208	***0.27***	2	0.840	***1.20***
20-11-11	80	3	***1***	1.114	***0.19***	***2***	0.791	***1.12***
Mean			*1.7*	*1.547*	*0.25*	*2.2*	*0.999*	*1.32*
$u = u_{\min} + 2$								
20-8-14	40	4	***3***	1.961	***0.20***	***2***	1.111	***0.25***
20-8-14	50	4	***2***	1.775	***0.22***	***2***	1.019	***0.34***
20-8-14	60	4	***1***	1.330	***0.22***	***2***	0.888	***0.47***
20-8-14	70	4	***1***	1.205	***0.59***	***2***	0.835	***0.52***
20-8-14	80	4	***1***	1.110	***0.19***	***2***	0.791	***0.53***
20-11-11	40	4	***2***	1.864	***0.47***	***2***	1.053	***0.70***
20-11-11	50	4	***1***	1.335	***0.23***	***2***	0.973	***2.72***
20-11-11	60	4	***1***	1.125	***0.27***	***2***	0.888	***2.02***
20-11-11	70	4	1	1.029	***0.17***	2	0.826	***1.95***
20-11-11	80	4	***1***	0.956	***0.24***	***2***	0.779	***1.30***
Mean			*1.4*	*1.369*	*0.28*	*2*	*0.916*	*1.08*
$u = u_{\min} + 3$								
20-8-14	40	5	***2***	1.953	***0.22***	***2***	1.053	***0.16***
20-8-14	50	5	***2***	1.684	***0.23***	***2***	0.972	***0.23***
20-8-14	60	5	***1***	1.158	***0.27***	***2***	0.888	***0.67***
20-8-14	70	5	***1***	1.057	***0.23***	***2***	0.826	***0.41***
20-8-14	80	5	***1***	0.981	***0.19***	***2***	0.779	***0.39***
20-11-11	40	5	***2***	1.800	***0.25***	***2***	1.053	***0.41***
20-11-11	50	5	***1***	1.217	***0.30***	***2***	0.972	***1.02***
20-11-11	60	5	***1***	1.009	***0.36***	***2***	0.888	***5.44***
20-11-11	70	5	1	0.929	***0.19***	2	0.826	***1.66***
20-11-11	80	5	***1***	0.869	***0.22***	***2***	0.779	***1.39***
Mean			*1.3*	*1.266*	*0.25*	*2.0*	*0.904*	*1.18*
Overall mean			***1.7***	***1.522***	***0.24***	***2.2***	***0.993***	***1.42***

Table 2 shows the results for $d = 30$ problems. Optimum results were found for all test instances in an average of 1.95 s for one-truck problems. In the two-truck problems, optimum results were reached for all

test instances in an average of 68 s. While the average value of the objective function is 2.71 in the one-truck problems, it decreases to 1.71 in the two-truck problems. While the average number of depots opened in one-truck problems is 3, it increases to an average of 3.35 in two-truck problems. In this case, because two trucks are used simultaneously, more mobile depots are visited, and deliveries are made in a shorter time.

Table 2

Results of one-truck and two-truck problems for d = 30

Problem Name	v_d	u	One- Truck			Two-Truck		
			Number of depots opened	Objective function value	Solution time	Number of depots opened	Objective function value	Solution time
$u = u_{\min}$								
30-11-22	40	3	***4***	4.243	***1.14***	***4***	2.507	***3.22***
30-11-22	50	3	***3***	3.217	***1.02***	***3***	2.020	***9.38***
30-11-22	60	3	***3***	2.914	***1.09***	***3***	1.861	***8.47***
30-11-22	70	3	***3***	2.698	***0.53***	***3***	1.738	***5.81***
30-11-22	80	3	***2***	2.388	***2.02***	***3***	1.452	***1.17***
30-17-16	40	2	***5***	4.115	***2.30***	***5***	2.398	***65.27***
30-17-16	50	2	***4***	3.235	***2.22***	***4***	1.962	***65.77***
30-17-16	60	2	***4***	2.954	***2.09***	***4***	1.815	***173.84***
30-17-16	70	2	3	2.665	***0.77***	3	1.607	***26.16***
30-17-16	80	2	***2***	2.420	***0.86***	***3***	1.493	***29.94***
Mean			*3.3*	*3.085*	*1.40*	*3.5*	*1.885*	*38.90*
$u = u_{\min} + 1$								
30-11-22	40	4	***4***	3.810	***0.33***	***4***	2.307	***2.72***
30-11-22	50	4	***3***	2.791	***1.30***	***3***	1.817	***4.34***
30-11-22	60	4	***3***	2.559	***0.47***	***3***	1.700	***4.56***
30-11-22	70	4	***3***	2.394	***0.61***	***4***	1.621	***6.53***
30-11-22	80	4	***2***	2.043	***3.06***	***3***	1.290	***1.27***
30-17-16	40	3	***4***	3.734	***2.89***	***4***	2.175	***68.19***
30-17-16	50	3	***3***	2.860	***6.41***	***4***	1.779	***88.47***
30-17-16	60	3	***4***	2.632	***3.88***	***3***	1.670	***180.75***
30-17-16	70	3	3	2.287	***0.81***	3	1.443	***91.39***
30-17-16	80	3	***2***	1.929	***0.92***	***3***	1.242	***21.84***
Mean			*3.1*	*2.704*	*2.07*	*3.4*	*1.704*	*47.01*
$u = u_{\min} + 2$								
30-11-22	40	5	***4***	3.678	***0.31***	***4***	2.253	***2.98***
30-11-22	50	5	***3***	2.641	***0.45***	***3***	1.761	***3.59***
30-11-22	60	5	***3***	2.434	***0.44***	***3***	1.634	***4.69***
30-11-22	70	5	***3***	2.286	***0.50***	***3***	1.543	***4.66***
30-11-22	80	5	***2***	1.841	***0.67***	***3***	1.285	***2.44***
30-17-16	40	4	***4***	3.695	***2.67***	***4***	2.150	***272.92***
30-17-16	50	4	***3***	2.708	***6.62***	***4***	1.735	***246.08***
30-17-16	60	4	***3***	2.492	***4.91***	***3***	1.613	***129.66***

Problem Name	v_d	u	One- Truck			Two-Truck		
			Number of depots opened	Objective function value	Solution time	Number of depots opened	Objective function value	Solution time
30-17-16	70	4	2	2.049	***1.20***	2	1.299	***42.42***
30-17-16	80	4	***1***	1.639	***3.73***	***2***	1.051	***18.22***
Mean			*2.8*	*2.546*	*2.15*	*3.1*	*1.632*	*72.77*
$u = u_{\min} + 3$								
30-11-22	40	6	***4***	3.678	***0.30***	***5***	2.253	***3.69***
30-11-22	50	6	***3***	2.641	***0.48***	***3***	1.761	***5.03***
30-11-22	60	6	***3***	2.434	***0.58***	***3***	1.634	***6.22***
30-11-22	70	6	***3***	2.286	***0.73***	***3***	1.543	***5.95***
30-11-22	80	6	***2***	1.746	***0.78***	***3***	1.285	***2.28***
30-17-16	40	5	***4***	3.695	***3.12***	***4***	2.150	***363.92***
30-17-16	50	5	***3***	2.703	***5.51***	***4***	1.735	***161.86***
30-17-16	60	5	***3***	2.480	***7.58***	***4***	1.613	***322.50***
30-17-16	70	5	2	1.888	***1.69***	2	1.299	***239.58***
30-17-16	80	5	***1***	1.435	***1.00***	***3***	1.051	***25.28***
Mean			*2.8*	*2.499*	*2.18*	*3.4*	*1.632*	*113.63*
Overall mean			***3.0***	***2.708***	***1.95***	***3.4***	***1.714***	***68.08***

Figure 2 shows the objective function value and solution times according to the size of the problem (number of mobile depots and number of customers), UAV speeds, and number of UAVs. Figure 2. a shows the average objective function values of all the problems. While the average value of the objective function is 2.12 for the problems with one truck, the average value of the objective function is 1.35 for the problems with two trucks. When the number of trucks is two, the service time to customers is reduced by approximately 36%. The use of multiple trucks brings the problem closer to real-life scenarios while enabling shorter service delivery times in last-mile delivery processes. This situation improves customer satisfaction and provides a more sustainable and effective solution, especially for real-world applications. Figure 2. b shows the average solution time for all the problems. Problems with one truck were solved in 1.09 seconds on average, while problems with two trucks were solved in 34.75 seconds on average. This result shows that the increase in the number of trucks has a serious impact on the solution time and significantly increases the complexity of the problem. Problems with two trucks require more coordination and synchronization, which dramatically increases the solution time due to the enlargement of the search space and the increase of constraints. This demonstrates the significant impact of increasing the number of resources on the computational load and algorithmic performance in transport and route optimization.

The analysis shows that problems with 17 mobile depots and 16 customers require a longer solution time than problems with 11 mobile depots and 22 customers. It was found that the increase in the number of mobile depots was more effective on the difficulty level of the problem than the increase in the number of customers. Problems with 11 mobile depots and 22 customers were solved in an average of 4.45 s, while problems with the same number of mobile depots but 11 customers were solved in an average of 2.37 s. Although the number of customers doubled, the increase in the solution time was less than double, indicating that the increase in the number of customers has a limited effect on the difficulty of the problem. On the other hand, problems with 17 mobile depots and 16 customers were solved by an average of 131.70 s, while this time reduced to 0.48 s for problems with 8 mobile depots and 14 customers. These results clearly

show that for 2E UVRP problems, increasing the number of mobile depots makes the problem much more complex than increasing the number of customers.

Figure 2

Objective function value and solution times according to the name of the problem, UAV speed, and number of UAVs

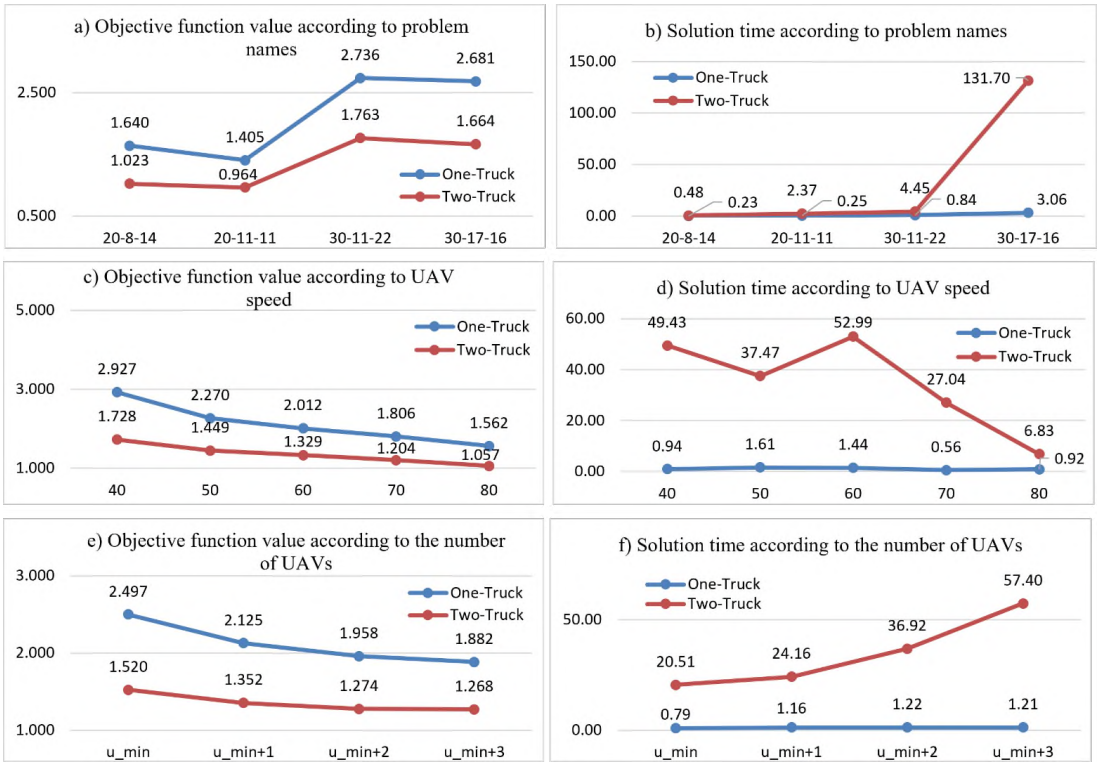


Figure 2c shows that the objective function values for the one-truck and two-truck problems gradually converge as the UAV speeds increase. Similarly, Figure 2e shows that as the number of UAVs used increases, the objective function values become relatively closer to each other. These findings reveal that in scenarios where the number and speed of UAVs are low, two-truck solution approaches are more advantageous than one-truck solutions in terms of the efficiency of logistics operations.

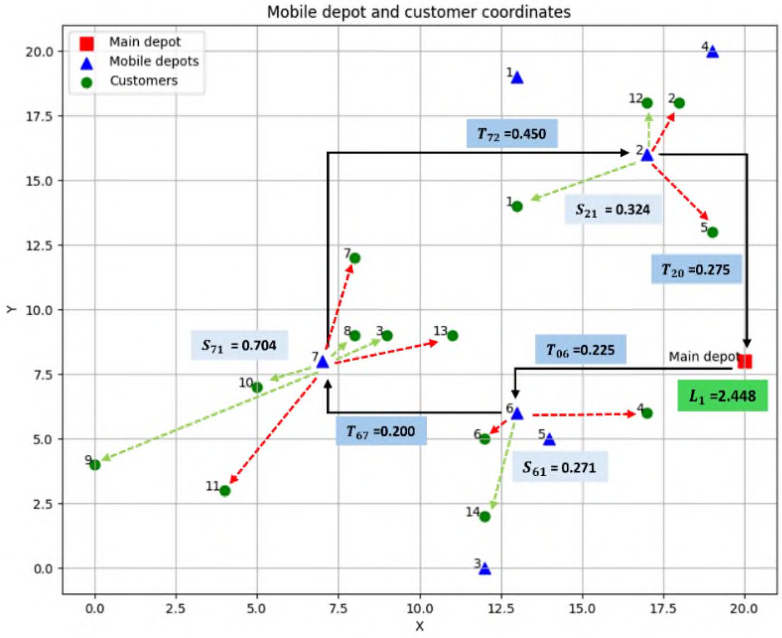
Figure 2d shows the solution time with increasing UAV speeds. In particular, it was found that the solution time was shorter when the UAV speed was 70 km/h or higher than when the speed was 60 km/h or lower. However, it is clearly seen in Figure 2f that the increase in the number of UAVs increases the solution times for the problems.

Graphical representation of the results

In this section, the results for the one-truck and two-truck scenarios for the problem "20-8-14", where the UAV speed is set to 40 km/h and the number of UAVs is set to 2, are analyzed graphically. In Figure 3 and Figure 4, the black solid arrows and blue solid arrows represent the routes of the trucks; the green dashed arrows represent the movements of the first UAV; and the red dashed arrows represent the movements of the second UAV. The term $Truck_{ik}$ refers to the movement time of the truck between the mobile depots; S_{ik} refers to the waiting time of the trucks for the UAVs at the mobile depots; and L_k refers to the return time of each truck to the main depot.

Figure 3

Graphical representation of the problem with one-truck (problem name = 20-8-14, v_d=40, u =2)

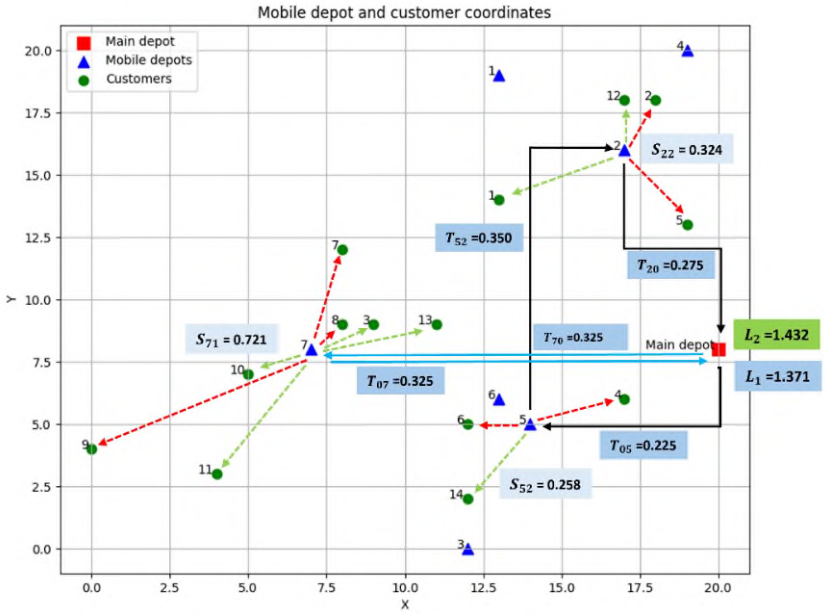


The solution results for the one-truck problem are presented in Figure 3. In this problem, the truck departs from the main depot and visits points 6, 7, and 2, respectively, and returns to the main depot, completing a route with a total length of 1.150 units. The waiting times of the truck at mobile depots 6, 7, and 2 were measured as 0.271; 0.704 and 0.324 units, respectively, and the total waiting time was calculated as 1.298 units. The total route length includes the sum of the waiting times of the truck's route and the UAVs at the mobile depots and was calculated as 2.448 units.

The solution results of the two-truck problem are presented in Figure 4. The first truck, shown with the blue solid arrows, departed from the main depot and reached mobile depot 7, and returned to the main depot, following a route with a total length of 0.65 units. The first truck completed the route in a total time of 1.371 units with a waiting time of 0.72131 units at mobile depot 7. The second truck, indicated by the black solid arrows, visited mobile depots 5 and 2, respectively, after departing from the main depot and returned to the main depot and followed a route of 0.85 units. The waiting times at mobile depot 5 and mobile depot 2 were measured as 0.258 and 0.324 units, respectively, and the total waiting time was calculated as 0.582 units. The total route length of the second truck, including the routes followed by the trucks and the waiting time for the UAVs in the mobile depots, was calculated as 1.432 units in total. In the two-truck problem, the total tour length is the time for both trucks to return to the main depot. This time is calculated as 1.432 units, which is the route length of the second truck and reflects the time to serve all customers.

Figure 4

Graphical representation of the problem with two-trucks (problem name = 20-8-14, v_d=40, u =2)



Conclusion and future research directions

This study examines a logistics model that is expected to provide future benefits in the logistics sector. The model involves the integration of a fleet of high-capacity trucks that depart from a main depot and act as mobile depots and a fleet of UAVs that fly from these trucks. The model integrates the UAV routing problem with the location selection problem by enabling UAVs to depart from mobile depots to serve customers and then return to the same mobile depot for battery replacement and/or package loading. In this context, high-capacity trucks act as mobile depots and depart from the main depot, are positioned at designated alternative mobile depot locations and wait there during the delivery period. UAVs moving from the trucks deliver the packages to customers and return to the trucks after completing the distribution task. When all delivery operations are completed, the trucks and UAVs return to the main depot and end the operation.

The basic structure of the two-echelon location selection and UAV-assisted routing problem was investigated by Vu et al. (2022), and both a complex integer mathematical model and a heuristic approach were developed as solution methods. In their study, Vu et al. (2022) considered two different problems where a truck is involved and UAVs can be used once or multiple times from a mobile depot. In this paper, a mathematical model is proposed for the 2E-UVRP, which is considered for the first time in this paper, where multiple trucks are involved and UAVs can be used more than once from a mobile depot. The proposed model is applied to the test cases created by Vu et al. (2022) and obtains optimal solutions in a very short time.

In the 2E-UVRP problem, if the number of trucks is taken as one, the problem becomes a 2ER-TD problem. In this context, the developed model can solve both the 2E-UVRP problem and the 2ER-TD problem. From a commercial point of view, 2E-UVRP stands out as a more feasible problem. In this study, single-truck and multi-truck problems are compared and the effects of changes in the number of mobile depots, number of customers, number of UAVs, and number of trucks on the solution times of the 2E-UVRP problem and the efficiency of the model are examined. The results show that increasing the number of mobile depots significantly increases the solution time. In particular, it is found that if the number of mobile depots is doubled, the solution time increases by 277 times. On the other hand, the effect of increasing the number of customers on the resolution time was found to be relatively limited. Increasing the number of UAVs

relatively reduces the difficulty of the problem. Increasing the number of trucks makes the problem more complex and requires more coordination and synchronization. However, multi-truck solutions offer a more advantageous option for real-world applications. It can increase customer satisfaction by shortening service times, especially for last-mile deliveries. In conclusion, this study shows that increasing the number of mobile depots and trucks significantly increases the difficulty of the 2E-UVRP problem; however, multi-truck systems offer more efficient and feasible solutions in real-world scenarios.

Future research may focus on addressing UAV routing problems in more complex and dynamic environments. In particular, the integration of factors such as air traffic, weather conditions, energy consumption, and real-time decision-making processes into the model will significantly increase the applicability and practical value of the problem in terms of real-world applications. Additionally, developing new algorithms to enhance the cooperation and coordination of multiple UAV systems could significantly contribute to safety and flexibility while improving routing efficiency. Furthermore, the integration of artificial intelligence and machine learning techniques can enhance the autonomous capabilities of UAVs, enabling more flexible and efficient solutions.

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A Mixed-Integer Programming Model for Optimizing the Distribution Network of a Packaging Company

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Abstract Designing a distribution network for a company is critical as it determines how efficiently and cost-effectively products are transported. An optimized distribution network should minimize costs and delivery times while maximizing service levels. In this context, the location and number of facilities such as warehouses and factories, as well as the choice of transportation modes, play a significant role in the network's performance. This study examines a distribution network design problem experienced by a packaging company. Currently, the company operates a single-warehouse shipment management system for its operations in France. However, the company's sales group in France believes that replacing the single-warehouse system with a two-warehouse system could optimize transportation costs while ensuring on-time deliveries. Therefore, the company analyzes the feasibility of such a transition. To achieve this, mixed-integer linear programming (MILP) models are developed, minimizing total distribution costs between the manufacturing plants and the warehouses while determining the distribution of deliveries through three transportation modes—trucks, trains, and ships—that ensures timely delivery of demands. The results indicate that the company should maintain its current single warehouse policy but can favor reduction in transportation costs by focusing on production lead times and delivery prices of transportation modes.

Keywords Mixed Integer Linear Programming · Distribution Network Design Problem · Transportation Mode Selection · Supply Chain Network Design Problem

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A Mixed-Integer Programming Model for Optimizing the Distribution Network of a Packaging Company

Supply chain network design is a strategic process that determines the optimal configuration and operation of supply chains to ensure the efficient flow of goods from suppliers to end customers (Jahani, Abbasi, Sheu, & Klibi, 2024). It involves critical decisions regarding the location of facilities, transportation modes, inventory levels, and the relationships between supply chain components. Effective supply chain network design minimizes costs, enhances customer satisfaction, and reduces risks while adapting to dynamic market conditions (Khalili-Fard, Sabouhi, & Bozorgi-Amiri, 2024). Despite its strategic importance, designing cost-effective and efficient networks remains a challenge due to the complex interplay between transportation, warehousing, and inventory management.

This study focuses on optimizing the distribution network system of a flexible global packaging company with a significant presence in Europe. The company currently employs a single-warehouse strategy to serve its customers in France but faces challenges due to increasing transportation costs and constraints associated with delivery deadlines. To address these issues, the company is evaluating the feasibility of transitioning to a two-warehouse system to improve cost efficiency and delivery performance. For this task, in this study, a mixed integer linear programming (MILP) model that minimizes the total transportation costs between the manufacturing plants and the warehouses using three different transportation modes—trucks, trains, and ships—is developed. The developed model is applied for the current single-warehouse system and the two-warehouse system together with two different scenario analysis and the results are compared to give insights to the company.

The primary research questions guiding this study are as follows:

- How can the transition from a single-warehouse to a two-warehouse system impact transportation costs and delivery performance?
- What is the optimal transportation strategy that minimizes total transportation costs while meeting delivery deadlines under capacity and mode constraints?
- How can sensitivity analyses provide insights into the effects of varying key parameters such as production time and transportation availability on the supply chain's performance?

This study contributes to the literature by presenting a MILP model that integrates on-time delivery, transportation mode selection, and capacity utilization of the transportation modes. Unlike many studies that treat these aspects separately, this research combines them to provide a comprehensive evaluation of warehouse management strategies. The findings offer valuable insights for both researchers and practitioners by highlighting the cost implications of multi-warehouse systems, and the trade-offs involved in transportation mode selection. The remainder of this study is organized as follows. The next section presents a summary of the existing literature on the distribution network design problem. The Methods section outlines the problem definition for the packaging company of concern together with the proposed MILP approach, and the Results section evaluates the cost-efficiency of the proposed strategy using real-world data. The discussion section provides the implications of the findings, limitations, and directions for future research, and the study is concluded in the Conclusions section.

Existing Studies on the Distribution Network Design Problem

The distribution network design problem is an optimization problem that involves determining warehouse and facility locations and selecting transportation modes to ensure efficient, cost-effective and timely delivery of products from production points to customers (Li, Liu, & Yang, 2024). The problem requires strategic planning of logistics processes with the goal of minimizing total costs and maximizing service levels in a supply chain (Lee, Ko, & Moon, 2024). Inventory and network design in supply chains involved in the above-mentioned problem type is a frequently studied topic in literature. You and Grossmann (2009) developed a MINLP model for inventory management and multi-level supply chain configuration in the chemical industry under stochastic demand. By reformulating the problem into a decomposable concave minimization program, they achieved near-optimal solutions with reduced computational costs. Dündar, Tekin, Peker, Şahman, & Karaoğlan (2022) addressed wheat supply chain optimization with a multi-period, multi-stage model, enhancing efficiency and resilience through real-world applications. Bacchetti, Bertazzi, and Zanardini (2020) improved supply chain distribution planning by optimizing warehouse replenishment and distribution strategies, minimizing costs in complex logistics networks. Moreover, Ayyıldız, Şahin, & Taşkın (2023) explored a supply chain network design issue through a split delivery vehicle routing problem with multi-depot, multi-commodity, and time windows characteristics.

The optimization processes involve multiple objects to be considered in most supply chain networks. Hajmirfattahtabrizi and Song (2019) proposed a mixed-integer nonlinear programming (MINLP) model with a multi-objective function for supply, production, and distribution systems. The model minimizes total costs and integrates supply chains, reducing bottlenecks by 19.73% using MATLAB computations. Similarly, Ghahremani-Nahr, Najafi, and Nozari (2022) focused on optimizing transportation and distribution in perishable product supply chains. Their model integrates multiple vehicles and analyzes demand uncertainties using the Sequential Convex Approximation and Genetic Algorithm, achieving higher efficiency with the former. Qiu et al. (2024) applied game theory to optimize oil substitution, transportation, and pipeline pricing, reducing costs and emissions in China's fuel supply chain.

The selection of transportation modes in distribution systems is also of interest to many researchers. Mogale, Dolgui, Kandhway, Kumara, & Tiwari (2017) and Mogale, Kumar, Kumara, & Tiwari (2018) tackled food grain distribution challenges in India's Public Distribution System. They developed MINLP models addressing vehicle selection, seasonal supply, silo storage, and demand constraints. Using metaheuristics like Improved Max-Min Ant System and Hybrid Particle-Chemical Reaction Optimization, they demonstrated superior efficiency and cost reduction. Zhou and Zhang (2023) focused on multimodal transportation, employing network graph theory and the Dijkstra algorithm to optimize costs and enhance logistics systems. Kravets et al. (2020) optimized grain export cargo flows via a multi-criteria nonlinear programming model, emphasizing time and cost efficiency in rail transport.

Determining the optimal location of the facilities is another major task in supply chain design. Buriticá, Escobar, and Gutiérrez (2018) optimized warehouse location selection for a Colombian soft drink company using k-means clustering and MILP. They minimize the distribution network costs while meeting the capacity constraints. Boujelben et al. (2014) designed multi-product distribution networks for the automotive industry, considering transport and capacity constraints to reduce costs. Kheirabadi et al. (2019) designed a two-tier supply chain network, selecting facility locations and transport modes to minimize costs and enhance product availability. In a similar effort, Kızılkaya, Kevser, Ofluoğlu, Ölçücüer, and Demirel formulated a Euclidean minimum model and p-median model to determine the optimal warehouse location for an electrical home appliances company.

To derive the optimal solutions for the mathematical models constructed to represent the distribution network design problems, diverse optimization techniques such as advanced algorithms and heuristics are employed. Luathep, Sumalee, Lam, Li, and Lo (2011) introduced a global optimization algorithm for mixed transportation network design problems, leveraging Wardrop's user equilibrium. Baller, Fontaine, Minner, & Lai (2022) addressed logistics optimization at the assembly level in the automotive industry using MILP, achieving significant cost reductions and improved transport efficiency. Yang and Zhou (2017) reformulated travel time reliability measures for dynamic transportation networks, demonstrating computational efficiency with MILP.

Strategic and tactical decisions in the supply chain planning horizons are also important study fields. Sadjady and Davoudpour (2012) emphasize strategic facility positioning and transportation mode selection to minimize total network costs, contributing to efficient distribution network design. Bilgen and Ozkarahan (2007) optimized wheat distribution planning for overseas shipments, minimizing costs over a three-month horizon using MILP.

Table 1

Summary of the examined studies

Study	Objective	Key Constraints	Decision Type
Bilgen and Ozkarahan (2007)	Minimize the total transportation, inventory, blending, and loading costs	Blending capacity, loading capacity, vessel capacity, blended product capacity, demand satisfaction.	Tactical
You &Grossmann (2009)	Minimizing the total supply chain design cost	Distribution center selection and assignment, customer demand zone assignment, and linking constraint	Tactical
Luathep, et al. (2011)	Minimizing the total travel time	Budget constraint, capacity expansion, travel time constraints	Tactical
Sadjady and Davoudpour (2012)	Minimizing the product lead time cost, transportation costs, inventory holding costs, opening and operating costs of facilities and warehouses.	Capacity levels for warehouses and plants, capacity on transportation modes, demand satisfaction, and binary nature of decision variables.	Strategic
Boujelben, et al. (2014)	Minimize the total distribution costs	Volume constraints on transport, covering distance constraints, and volume and capacity constraints on distribution centers	Strategic
Mogale, et al. (2017)	Minimize the overall cost	Vehicle capacity, demand satisfaction, silo storage constraints, and seasonal procurement constraints	Tactical
Yang and Zhou (2017)	Minimizing the total travel time	Travel time constraints, transportation network	Tactical
Buriticá, et al. (2018)	Minimize the total cost of the distribution network	Storage capacity, transport capacity, compliance of the demand	Strategic
Mogale, et al. (2018)	Minimize transportation, inventory holding, and operational costs	Demand satisfaction, silo capacity, seasonal procurement constraints, vehicle capacity	Tactical
Hajmirfattahtabrizi and Song (2019)	Minimizing the total cost in the procurement, production, and distribution processes	Supply constraint, demand constraint, inventory level, decision variable bounds, production and distribution	Tactical

Study	Objective	Key Constraints	Decision Type
Kheirabadi, et al. (2019)	Minimize the overall cost	Capacity limitations (demand and raw material), fixed and variable costs of transportation modes, and purchasing costs of raw materials	Strategic
Bacchetti, et al. (2020)	Minimizing the total transportation cost	Inventory level constraints at the production plants and regional warehouses, one-step direct shipping and two-step direct shipping constraints, vehicle capacity constraints, and demand satisfaction.	Strategic
Kravets, et al. (2020)	Maximizing transportation time in the plan	Number of routes and loading stations	Tactical
Dündar, et al. (2022)	Minimize the transportation cost	Capacity limitations and demand satisfaction	Tactical
Ghahremani-Nahr, et al. (2022)	Minimizing the transfer time of perishable fruits and vegetables from cultivation centers to customers	Inventory levels, specific deterioration times, demand constraints, capacity use	Tactical
Zhou and Zhang (2023)	Minimization of the total cost	Transportation cost and time constraints	Tactical
Qiu, et al. (2024)	Maximizing the overall system efficiency	Oil supply and demand capacity, transportation capacity, batch requirements, loading and unloading capacity, oil depot capacity	Strategic
The current study	Minimize the total transportation cost between warehouses and production plants	Demand satisfaction, transportation mode constraints, delivery risk reduction constraints	Strategic

The used methodologies and the key indicators that are considered in the above-mentioned studies are summarized in Table 1. Overall, the existing studies highlight advancements in supply chain optimization through various mathematical models and solution techniques. Common themes include minimizing costs, addressing uncertainties, and enhancing efficiency across supply chain networks. Techniques such as MINLP, MILP, and advanced heuristics are widely applied, while strategic decisions like facility location and multi-modal transportation further enrich the field. Future research could focus on integrating sustainability and resilience into supply chain design to address global challenges. In addition to the existing studies, this study focuses on strategic decision-making with the objective of minimizing the total transportation costs between warehouses and the production plants by considering demand satisfaction, transportation mode selection, and delivery risk reduction constraints.

METHODS

The steps of the proposed method are displayed in Figure 1 and are detailed in the following subsections.

Figure 1

Flowchart of the proposed method

Problem Definition

This study focuses on the design and optimization of a distribution network for a packaging company. The company operates with a centralized structure, comprising a single plant and a warehouse. Customer demands are fulfilled from the warehouse at specific times, with the demand volumes and delivery schedules being predetermined. To transport products from the plant to the warehouse, the company employs three transportation modes: train, ship, and truck.

Each transportation mode has its own cost structure. Specifically, containers can be transported using trains or ships, while trucks are used for smaller volumes that cannot fully use the container capacity. Containers can only be dispatched if they are fully loaded, meaning that the volume of products being transported matches the container's capacity. Otherwise, such unutilized volumes must be transported via trucks, which are less cost-effective than trains and ships. Consequently, the company minimizes the use of trucks to optimize overall transportation costs.

Production at the plant takes approximately two weeks, with an additional two weeks allocated for transportation to the warehouse. However, the production time is variable, averaging around two weeks. This temporal structure necessitates careful planning to align production schedules with delivery deadlines to ensure timely fulfillment of customer demands.

The dataset used for this study includes detailed information about a one-month planning horizon, such as: demand volumes and their corresponding delivery dates to the warehouse, required completion dates for production to meet delivery deadlines, the capacity of containers, transportation costs per unit product via trucks, transportation costs per container for trains and ships, and so on. The problem includes key operational challenges, including demand scheduling, mode selection for transportation, and cost minimization. This study develops mathematical models to address these challenges, aiming to optimize the company's distribution network by minimizing costs while ensuring timely delivery.

Assumptions for Choosing the Transportation Modes

The packaging company meticulously plans its order and delivery processes to ensure operational efficiency and cost minimization. Orders are processed through sales representatives and production planning, where raw material procurement and production schedules are coordinated. Completed products are dispatched from İstanbul warehouse to warehouses in France using the most suitable transportation method (road, rail, or sea). As mentioned previously, the company currently operates a single warehouse in Paris, France. However, the new system proposes two warehouses, located in Marseille and Strasbourg. This transition involves evaluating the most efficient transportation modes and routes for deliveries from İstanbul to these locations, considering transportation times and costs.

Road transport using trucks provides a fast and flexible delivery option, with shipments to Paris, Marseille, and Strasbourg. In contrast, rail transport using trains is an economical and environmentally friendly option for long distances. Transportation by sea using ships is more economical than other modes of transportation. However, the transportation times may be longer than the other methods. Containers are used in ships and trains, while products are sent without containers via trucks.

The selection of transportation modes in the packaging company's delivery processes is guided by specific rules to ensure cost efficiency, operational reliability, and customer satisfaction. It is assumed that deliveries must reach the warehouse by the specified deadline, and no backlogging is allowed. In addition, train and ship departures occur once a week on designated days, while road transport operates three times a week. Here, transportation mode selection must prioritize minimum cost while meeting deadlines. Moreover, train and ship containers must be fully loaded, while this restriction does not apply to trucks. Furthermore,

for security reasons, no more than 80% of a delivery can be transported by train or ship. This regulation is assumed to be necessary by the company as it provides risk reduction to prevent delays in deliveries due to interruptions in sea or rail transportation. It is also assumed that separate routes and ports/stations are used for the eastern and western regions of France in the two-warehouse system, while loads from different warehouses cannot be combined. Last but not least, orders assigned to a specific warehouse must be delivered there, with no transfers between the warehouses.

A MILP model was developed to optimize the distribution network system and minimize the total transportation cost. The reason why this model is preferred is that the adopted decision variables consist of integers and real numbers. The assumptions that will enable the adoption of the model are as follows: Production time is β days for each order, and there are no delays due to production capacity. The deadline time of the deliveries is γ days for each order, and deliveries are made only on specified days a week for each transportation mode. Even if there is an emergency, express shipping is not possible and transportation times are deterministically known. The locations of the warehouses will be opened at the points determined by the sales group, and the customers are assigned to a single warehouse closest to them. In addition, there is no capacity limit in the warehouses and all products in the container occupy the same volume of space. That is, the only capacity issues in the model are related to the capacities of the transportation modes.

Mathematical Model

Based on the problem definition and the assumptions, the MILP model is constructed to find the optimal distribution network design as follows:

Sets and Indices:

T Set of days $t \in T = \{1,2,...,H\}$

tr Truck

sh Ship

$turn$ Train

Parameters:

D_t Demand volume at time t

C_{tr} Transportation cost per unit product for using a truck

C_{sh} Transportation cost per container using a ship

C_{trn} Transportation cost per container using a train

Cap_{sh} Capacity of a container for a ship

Cap_{trn} Capacity of a container for a train

atr_t 1 if it is possible to use a truck for starting the shipment from the plant to the warehouse at time t; 0 otherwise

ash_t 1 if it is possible to use ship for starting the shipment from the plant to the warehouse at time t; 0 otherwise

$atrn_t$ 1 if it is possible to use a train for starting the shipment from the plant to the warehouse at time t; 0 otherwise

β Days necessary to complete the production processes after receiving the order

γ Deadline time for an order

θ Risk reduction scalar for transportation by train or ship

months maximum number of containers that can be loaded on a ship for the company

contr maximum number of containers that can be loaded on a train for the company

Decision variables:

z Objective function

xtr_t Number of products started to be transported from the plant to the warehouse by trucks at time *t*

xsh_t Number of containers started to be transported from the plant to the warehouse by ships at time *t*

$xtrn_t$ Number of containers started to be transported from the plant to the warehouse by trains at time *t*

Objective Function:

$$z = \sum_{t=1}^{H} c_{tr} * xtr_t + \sum_{t=1}^{H} c_{sh} * xsh_t + \sum_{t=1}^{H} c_{trn} * xtrn_t \quad (1)$$

Constraints:

$$atr_{t+\beta} * xtr_{t+\beta} + ash_{t+\beta} * Capsh * xsh_{t+\beta} + atrn_{t+\beta} * Captrn * xtrn_{t+\beta} = D_t, \forall t \in \{\gamma+1, \gamma+2, ..., H\} \quad (2)$$

$$Capsh * xsh_{t+\beta} \leq \theta * D_t, \forall t \in \{\gamma+1, \gamma+2, ..., H\} \quad (3)$$

$$Captrn * xtrn_{t+\beta} \leq \theta * D_t, \forall t \in \{\gamma+1, \gamma+2, ..., H\} \quad (4)$$

$$xsh_t \leq contsh, \forall t \in \{1, 2, .., H\} \quad (5)$$

$$xtrn_t \leq conttr, \forall t \in \{1, 2, .., H\} \quad (6)$$

$$xtr_t, xsh_t, xtrn_t \geq 0 \quad (7)$$

$$xsh_t, xtrn_t \; Integer \quad (8)$$

The objective function in Equ. (1) minimizes the total transportation cost. Equ. (2) ensures demand satisfaction on time for each order using three different transportation modes. Equ. (3) and Equ. (4) stand for risk reduction constraints, which provide an upper limit on the proportion of products transported via trains or ships for each order considering safety issues. These risk reduction constraints ensure the company's regulation that not all of the products are delivered through using only trains or only ships. Equ. (5) and Equ. (6) limit the number of containers loaded on each train and ship to be less than the company's allowed space for these transportation modes per travel. Equ. (7) and Equ. (8) are nonnegativity and integer constraints.

Here, as can be seen in Equ. (5) and Equ. (6), capacity restrictions only exist for ship and train modes. In addition, the parameters atr_t, ash_t, and $atrn_t$ take the value of 1 if it is possible to start shipments using these transportation modes on day *t*, considering the order day, production time (β), and delivery day.

RESULTS

Because of our negotiations with the company, order numbers, order dates, order quantities, warehouse location, delivery dates, delivery methods, and delivery costs were obtained. Apart from the current Paris location, two separate warehouse locations planned to be used were determined. Then, the MILP model is solved using the CPLEX solver in GAMS Studio 47 software.

About the Input Data

The company performs sea shipment and rail shipment deliveries by the container leasing method, and one container has a capacity of 24000 kg in both delivery methods. According to the data received from the company, in the current delivery method used for sea shipment, the order arrives at the port of Paris in 13 days and €3120 is paid for each container. Delivery occurs once a week on Tuesdays. Rail shipment takes 11 days to reach the Paris warehouse and €3840 is paid for each container. Delivery occurs once a week on Thursdays. Road shipment delivery to the warehouse takes 6 days. Payment is made at € 0.24/kg. All of these monetary values are provided by the company and they are scaled from the real values into these amounts based on a scalar whose exact value is unknown to the authors for confidentiality. Delivery occurs three times a week on Tuesdays, Thursdays, and Sundays. For the implementation, it is decided to choose a four-week period from the 2023 October actual order data. The reason for this selection is that this period is closest to the 2023 whole year average values and it is the period with the least divergence from seasonal factors such as agriculture, inflation, etc. Demand levels in kg are given in Table 2 for the single-warehouse case for the 2023 October period. Likewise, Table 3 displays the demand levels for the same period for the two-warehouse case: one warehouse for the eastern regions and one warehouse for the Western Regions.

Table 2

Demand levels for October 2023 for the single-warehouse case

Day	Demand	Day	Demand	Day	Demand	Day	Demand
1	0	8	0	15	0	22	0
2	45988	9	63889	16	33513	23	45237
3	0	10	0	17	0	24	0
4	97354	11	15715	18	43034	25	171013
5	0	12	0	19	0	26	0
6	0	13	0	20	0	27	0
7	34432	14	77611	21	97672	28	69330

Table 3

Demand levels for October 2023 for the two-warehouse case

Demands for the Eastern Region Warehouse				Demands for the Western Region Warehouse			
Day	Demand	Day	Demand	Day	Demand	Day	Demand
1	0	15	0	1	0	15	0
2	24789	16	193674	2	21199	16	160161
3	0	17	0	3	0	17	0
4	49573	18	25693	4	47781	18	17341
5	0	19	0	5	0	19	0
6	0	20	0	6	0	20	0
7	13948	21	52569	7	20484	21	45103
8	0	22	0	8	0	22	0
9	38598	23	21946	9	25391	23	23291
10	0	24	0	10	0	24	0
11	5636	25	73251	11	10079	25	97762
12	0	26	0	12	0	26	0
13	0	27	0	13	0	27	0
14	41743	28	34748	14	35868	28	34582

Production time β is 14 days and the deadline γ is 28 days for each order. The risk reduction scalar θ for transportation through train or ship is taken as 0.8 as required by the company. This scalar is embedded in Equation. 3 and Equ. (4) ensures that at most 80% of the demand on a day at the warehouse can be satisfied via trains or ships. As discussed previously, such kind of a scalar is considered necessary by the company to prevent risks due to security and delay concerns. Moreover, the maximum number of containers that can be loaded on a ship and train for the company, *months* and *contr*, are set as 3 and 5, with, respectively.

Numerical Findings

Two separate MILP models are developed considering the single-warehouse case and the two-warehouse case based on the mathematical model defined in the Methods section. The mathematical models generated for both cases are solved optimally in less than 0.01 s in CPLEX time. For the company's current single warehouse system, the total transportation cost is found to be 160293.120 €/month. The delivery times and delivery quantities are provided in Table 4.

Table 4

Deliveries with a single warehouse case

Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships
16	21988		1
18	25354	3	
21	34432		
23	15989		2
25	15715		
28	77611		
30	9513		1
32	19034	1	
35	97672		
37	21237		1
39	51013	5	

For the two-warehouse system, the total transportation costs of the warehouses dedicated to the Eastern and Western regions of France are found to be 121960.320 €/month and 113770.080 €/month, with, respectively. Therefore, the amount paid by the company for monthly transportation with the two-warehouse system is calculated as 235730.4 €/month, which is by far greater than the total transportation costs obtained for the current single-warehouse system. The delivery times and delivery quantity information for the two-warehouse case are displayed in Table 5.

Table 5

Deliveries with a two-warehouse case

Eastern Regions				Western Regions			
Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships	Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships
16	24789			16	21119		
18	25573	1		18	23781	1	
21	13948			21	20484		

Eastern Regions				Western Regions			
Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships	Day	Delivery by trucks (in kg)	Number of containers transported by trains	Number of containers transported by ships
23	14598		1	23	25391		
25	5636			25	10079		
28	41743			28	35868		
30	121674		3	30	88161		3
32	25693			32	17341		
35	52569			35	45103		
37	21946			37	23291		
39	25251	2		39	25762	3	
42	34748			42	34582		

Scenario Analysis

Based on the numerical findings, it is obvious that the two-warehouse system that the company plans to adapt results in greater transportation costs when compared to the current single warehouse system. Thus, the optimal solution among these two can be determined as the current single warehouse system in terms of transportation costs. To see the impacts of changes in several parameter values on the total monthly transportation costs for the company if they continue with the current system, five different scenarios are generated. Different combinations of the effects of changes in the production time and changes in the transportation price parameters are examined in these scenarios, as displayed in Table 6.

The scenarios are generated in the following way: The current production period, which is set to be 14 days, is assumed to be reduced to 12 days by improvements in areas such as raw material supply, production planning and reducing quality problems in Scenario 3, Scenario 4, and Scenario 5; while it is kept as 14 days in Scenario 1 and Scenario 2. In addition, to provide a two-way sensitivity analysis, the impact of a 10% decrease or increase in delivery prices for the three transportation modes on total transportation costs is analyzed within these scenarios. The delivery prices for all three transportation modes are assumed to increase by 10% in Scenarios 1 and 3, while a 10% reduction in delivery prices is considered in Scenario 4. In Scenario 5, it is assumed that there is no change in the delivery prices. Here, it is thought that a reduction in delivery prices may be possible by negotiations with the current logistics company or finding alternative suppliers, whereas an increase in delivery prices may be due to some economic crisis or supply chain disruptions. In all scenarios, all the other parameters are kept constant. The optimal solution of the current single warehouse system when the production period is set as 14 days and current delivery prices are used is also provided in the table as the base scenario for comparison purposes.

Table 6

Comparison of the optimal solution with the solutions of the scenarios

Scenario	Production Time (days)	Delivery Price Change	Orders Shipped by Trucks (kg)	Number of Containers Sent by Ships	Number of Containers Sent by Trucks	Total Transportation Costs
Base Scenario	14	-	458888	5	9	€160293.12
Scenario-1	14	+10%	458888	5	9	€174488.88
Scenario-2	14	−10%	458888	5	9	€146099.36

Scenario	Production Time (days)	Delivery Price Change	Orders Shipped by Trucks (kg)	Number of Containers Sent by Ships	Number of Containers Sent by Trucks	Total Transportation Costs
Scenario-3	12	+10%	338888	9	10	€161238.88
Scenario-4	12	−10%	338888	9	10	€134387.36
Scenario-5	12	-	338888	9	10	€147813.12

The total transportation costs because of each scenario are displayed in the last column of Table 6. Orders shipped by trucks (kg), number of containers sent by ships, and number of containers sent by trucks for each scenario are also given in Table 6. The models generated in each scenario are solved optimally in less than 0.01 s in CPLEX time. Considering the outputs displayed in Table 6, it can be seen that when the production time is reduced to 12 days, the number of containers sent via ships increases from 5 to 9, while the number of containers sent via train increases from 9 to 10. Furthermore, the products sent via trucks decreased from 458,888 kg to 328,888 kg. here, it was found that the change in delivery prices for the transportation modes had no impact on the amount of orders sent through the transportation modes. Furthermore, the total transportation costs are increasing as delivery prices increase and vice versa. The minimum transportation costs are achieved in Scenario 4 when the production time is reduced to 12 days, and the delivery prices for the transportation modes decrease by 10%. Overall, the results show that the total transportation cost could be reduced with possible changes in the values of diverse parameters in the mathematical model.

Discussion

Based on the numerical findings and the results of the scenario analysis, it is suggested that the company should keep its current single warehouse system for its operations in France, instead of introducing a two-warehouse system. However, this decision is based only on the transportation cost analysis, which omits other issues such as service quality improvements or new customer opportunities that the company may favor with a decentralized warehouse system. To incorporate these issues, a new mathematical model that combines multiple objectives and several other constraints must be generated. The proposed model also ignores customer-warehouse allocations for the two-warehouse system, which means that the transportation costs are related only to the deliveries of the products from the manufacturing plants to the warehouses, assuming a fixed delivery network between the warehouses and customers. This network is known to the company but is not shared with the authors. In fact, the transportation costs regarding the deliveries between the warehouses and customers are neglected here because the locations of the warehouses and customer-warehouse allocations have already been determined by the company.

The main reason why the company wants a comparison of single- and two-warehouse systems can be said to be to decrease transportation costs. Using a single warehouse for all deliveries can lead to high transportation costs, especially for distant regions. By utilizing two warehouses, deliveries can be made from closer locations, optimizing overall transportation costs. In the current system, shipments from a single warehouse in Paris result in longer delivery times, particularly for the southern and eastern regions. Establishing warehouses in Marseille and Strasbourg would enable faster deliveries to these areas. Additionally, demand intensity varies across regions, and a two-warehouse system allows for more flexible inventory management, improving responsiveness to fluctuations. Managing large stock volumes in a single warehouse may also create capacity constraints, whereas distributing inventory across two locations enhances storage efficiency. Moreover, relying on a single warehouse poses risks in cases of disruptions such as natural disasters, strikes, or logistical issues. An additional warehouse increases resilience and ensures

a more flexible supply chain. However, it is worth mentioning that most of the above-mentioned issues are not analyzed in this study as the company only focuses on transportation costs because of deliveries between the production plants and warehouses. Nevertheless, this study helps the company in evaluating cost-efficient distribution strategies and enhancing delivery performance from a managerial point of view. Methodologically, it establishes a systematic optimization framework to analyze and compare single with two-warehouse systems, facilitating informed decision-making. Furthermore, it strengthens supply chain resilience by considering risk reductions and improving transportation mode selection processes.

The present study, which uses a MILP model to analyze production and shipment processes in manufacturing firms, is subject to certain constraints and limitations inherent in its methodology. First, the model's reliance on deterministic assumptions regarding production and shipment durations constrains its ability to accurately represent the dynamic and stochastic nature of these processes in real-world settings. In reality, production and shipment durations are subject to variability and uncertainty due to factors such as machine breakdowns, unexpected delays, and fluctuations in demand, which are not fully captured in the deterministic framework.

Second, the assumption of fixed-order quantities for incoming orders overlooks the inherent variability and uncertainty associated with demand patterns. In practice, incoming orders often exhibit stochastic behavior, characterized by fluctuations and deviations from the anticipated quantities. By assuming fixed-order quantities, the model may fail to account for the volatility and unpredictability inherent in the demand forecasting and order fulfillment processes.

Furthermore, while MILP offers computational advantages and facilitates the development of tractable optimization models, its deterministic nature limits its ability to explicitly incorporate uncertainty into the decision-making process. As a result, the model may not adequately reflect the probabilistic nature of real-world uncertainties, potentially leading to suboptimal solutions.

the decision to adopt a deterministic approach was influenced by practical considerations, including time constraints and the complexity associated with developing and solving the stochastic programming models. While the current model serves as a valuable starting point for analyzing production and shipment processes, future research efforts should aim to refine and enhance the model by incorporating stochastic elements to better reflect the inherent uncertainties in manufacturing operations.

In conclusion, while the findings of this study offer valuable insights into production and shipment processes, it is essential to recognize the limitations of the deterministic approach adopted in the modeling framework. Addressing these limitations through further research and model refinement is crucial for advancing our understanding of complex manufacturing systems and improving decision-making processes in practice.

Conclusion

To conclude, optimizing transportation processes and reducing costs play a critical role in increasing operational efficiency for companies by ensuring a more effective use of resources. In order to maintain their market share in competitive markets with changing conditions, the companies must conduct their business at a minimum cost while providing quality service. At the same time, they should keep the costs in production and post-production applications at an optimum level for minimum cost while providing quality service. When all costs are considered, transportation costs have the largest share.

This study was conducted with a flexible packaging manufacturer. The company's existing structure in France plays an important role in its European expansion strategy. In the current system, all orders going to France are sent to a single warehouse; however, the France sales group of the company is examining the

feasibility of converting the current system into a two-warehouse system, one for the Eastern and one for the Western regions of France in terms of transportation costs. Therefore, this study aims to optimize the distribution network system and propose a scenario that minimizes the total transportation cost between the manufacturing plants and the warehouses. The proposed delivery system is based on three different transportation modes: trucks, ships, and trains. In line with these objectives and predictions, information such as necessary parameters and constraints were determined and necessary data were obtained from the company for the October 2023 period. A MILP model is developed and solved separately for the single-warehouse case and the two-warehouse case through the CPLEX solver of GAMS Studio 47 software. The total transportation cost for the one-warehouse system was found to be 160293.120 €/month, while for the two-warehouse system this value was calculated as 235730.4 €/month. As a result, an increase in the transportation costs of 75437.28 €/month was observed; indicating that the transition to a two-storage system has a negative impact on the total transportation costs between the manufacturing plants and the warehouses. The negative impact was observed to be because the ship and train containers were not at full capacity and therefore the more expensive truck had to be used.

In summary, it was found that the intended cost reduction could not be achieved by switching from the current one-warehouse system to a two-warehouse system. As a result of this study, it is recommended that the company remain with the current single warehouse system. At this point, scenario analyses conducted to achieve the targeted cost reduction showed that shortening the production time and decreasing the shipment prices provided a partial cost reduction. After this research, it is recommended that the company should optimize the parameters of the system to improve its warehouse management strategy in France.

Future research efforts should improve and refine the mathematical model to better reflect the uncertainties inherent in manufacturing operations. Although the findings of this study provide valuable insights into the manufacturing and shipping processes, it is important to recognize the limitations of the deterministic approach adopted in the model's methodology. Addressing these limitations through future research and model development is important to advance the understanding of complex production systems and improve decision making in practice.

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Overcoming Logistics Challenges in Large-Scale Disruptions: Dynamic Capabilities in Türkiye's Earthquake Response

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Abstract

Dynamic capabilities (DC) play a critical role in addressing logistics challenges during emergency responses to natural disasters. While researchers in logistics operations (LO) acknowledge this importance, the specific context of major earthquakes remains underexplored. This study aims to analyze logistics challenges in emergency responses to major earthquakes, with a focus on the experiences of Türkiye's recent seismic events.

An exploratory mixed-methods approach that combines qualitative and quantitative methodologies. The research includes a systematic review of 23 academic articles published between 1999 and 2023, supplemented by secondary sources (news, websites, reports) and expert interviews. The Best-Worst Multi-Criteria Decision-Making (BWM) method was employed to identify and prioritize key criteria and alternatives for DC and logistics challenges. The Weighted Sum Model (WSM) prioritizes the other options.

The findings highlight the core logistics challenges in earthquake responses, such as responsiveness and agility. Key DCs— organizational learning, visibility, information flow, robustness, delivery reliability and speed—were essential to mitigating risks for affected populations. This research supports and extends the humanitarian logistics literature by offering a DC framework to address logistics challenges in large-scale disasters, providing practical insights for improving response effectiveness during major earthquakes.

Keywords Logistics Operations · Dynamic Capabilities · Logistics Challenges · Humanitarian Response · Major earthquakes

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Overcoming Logistics Challenges in Large-Scale Disruptions: Dynamic Capabilities in Türkiye's Earthquake Response

The frequency and intensity of major earthquakes have significantly impacted the humanitarian sector in recent decades (Joseph, 2022). In 2000, Walker highlighted that major earthquakes are among the most devastating natural disasters, leading to substantial loss of life and prolonged suffering. For instance, the earthquake in Türkiye on August 17, 1999, which measured 7.4 on the Richter scale, resulted in approximately 18,000 deaths and severely affected the industrial city of Izmit and its surrounding areas. Additionally, many poorly constructed buildings in Istanbul collapsed (Walker, 2000, p.72). More recently, on February 6, 2023, a series of powerful earthquakes struck Türkiye and North of Syria. The main quake, with a magnitude of 7.8 on the Richter scale, was followed by three significant aftershocks, each measuring greater than 5.5, within the next 18 minutes (Maletckii et al., 2023).

These major earthquakes reveal failures in disaster response (Yilmaz et al., 2023; Schiffling et al., 2022; Christopher & Peck, 2004). They worsen existing logistics systems for extended periods, leading to urgent shortages of, for example, health equipment. Health workers often lack preparation and coordination, struggling to fulfill essential needs food, heating, and accommodation (Freddi et al., 2021). Improving coordination emerged as the most urgent challenge (Freddi et al., 2021) during disaster operations (Freddi et al., 2021; Comes et al., 2020; Besiou & Van Wassenhove, 2020). The disaster operations (LO) area, as noted by Besiou and Van Wassenhove (2020), has been the subject of many studies on logistics operations. These studies help to improve the capacity of countries and the international community to get ready for and deal with large-scale natural disasters promptly and efficiently. Logistics operations encounter coordination, efficiency, and capabilities challenges, which are essential for ensuring robust and agile logistics. Additionally, the ability to adapt to change—referred to as dynamic capabilities (DC)—is crucial during responses to major earthquakes (Brusset & Teller, 2017; Teece et al., 1997; Mitrega et al., 2017; Craighead et al., 2020).

Academic and managerial interest in LO has been highlighted as essential for the humanitarian sector's capacity to respond effectively to significant earthquakes (Kovács & Spens, 2007). LO refers to the activities conducted before, during, and after a disruption to minimize its impact on the affected population (Altay & Green, 2006). The occurrence of major earthquakes has underscored the need to reassess the role of LO in managing increasingly complex events that can have far-reaching effects on society's critical infrastructure. Given these challenges, this study defines critical infrastructure in terms of building redundancy and meeting the essential needs of affected individuals, such as food, water, healthcare, housing, and transportation (Suppasri et al., 2021). Therefore, The LO field is viewed as a highly dynamic and efficient system (Besiou & Wassenhove, 2020). Research demonstrates that communication, collaboration, and adaptation in this context cannot be treated as in traditional unidirectional, linear supply chains. Instead, these aspects should be examined as part of a dynamic capabilities system (Teece et al., 1997), a perspective that, to the best of our knowledge, remains understudied.

By examining the scale and timing of recent major earthquakes, we focus on the logistical pressures faced by response systems and how these systems adapt their dynamic capabilities to deliver necessary resources and expertise promptly where required. To achieve this, we use the theoretical framework of DC (Teece et al., 1997). In the humanitarian literature, logistics operations are often challenging (Besiou & Wassenhove, 2020). These challenges arise when adapting to disaster responses globally. By analyzing successful and flawed LO efforts, we can gain valuable in-depth exploration of the DC necessary to effectively address logistical challenges in diverse contexts.

The purpose is to analyze the response to major earthquakes and meet logistics challenges in logistics operations, using the experiences from the major earthquakes that struck Türkiye. To fulfill this purpose, we answer the following RQ:

RQ 1: What dynamic capabilities are critical in addressing the logistics challenges in response to logistics operations during major earthquakes in Türkiye?

In this sense, estimating LO is vital for preventing logistics challenges and achieving a rapid, adaptable, and well-coordinated response. Effectively addressing the logistics challenges posed by a large-scale seismic event in a densely populated urban environment is a capability toward minimizing the impact of an expected earthquake and safeguarding the well-being of a population. As such, Istanbul is one of the cities in Türkiye most vulnerable due to its location, a major weakness in line with houses constructed below adequate standards, posing a significant risk to its population and potentially devastating consequences in the case of a severe earthquake.

This study enhances the literature on logistics operational efficiency by exploring the challenges related to the dynamic capabilities faced by humanitarian logistics providers and responsible organizations. It draws insights from humanitarian responses, critical infrastructures, and operations and supply chain management to develop the concept of logistics challenges. Specifically, it analyzes how dynamic capabilities pose significant challenges to logistics operations in response to major earthquakes.

The remainder of this paper is structured as follows. The subsequent section reviews the relevant literature on logistics operations (LO), dynamic capabilities (DC), and logistics challenges in humanitarian response. Section 3 outlines the methodology of the study. Section 4 reviews the study findings. Section 5 provides a discussion. Section 6 is about the conclusions, implications, limitations and future research.

Literature Review

Logistics operations

Logistics operations (LO) refer to the activities performed before, during and after a disaster to reduce its impact on humanitarian contexts. LO is defined as a "special branch of logistics management response supply chain of critical supplies and services with challenges such as demands, uncertain supplies, critical time windows and vast scope of its operations," (Apte, 2009 p. 17). A definition given by Thomas and Mizushima, (2011 p. 60) to humanitarian response refers to logistics as "the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption to meet the end beneficiaries' requirements". As such, the management of humanitarian response involves many logistics challenges including conflicting interests among stakeholders, issues with coordination and cooperation, substantial uncertainty, and resource shortages. In this study, we offer an outline of LO logistics and its main application areas while outlining current research trends and the major challenges faced in the area today (Çelik, et al., 2012).

LO occurs in a volatile, uncertain, and ambiguous environment that has an impact on response efficiency (Schiffling et al., 2022; Christopher & Peck, 2004). However, current views on LO are believed to be incomplete and not fully aligned with the nature of humanitarian LO, which represents a mismatched paradigm (Adobor, 2020). Interestingly, however, humanitarian actors use "logistics" as a broad term covering various responsibilities handled by the LO. These include managing and maintaining hospitals and feeding centers in collaboration with medical teams; overseeing the supply chain for essential medical supplies, equipment, and other materials (procurement, customs, transportation, and inventory management); installing and maintaining technical equipment; constructing and maintaining water and sanitation (WatSan) facilities; managing computers, communication systems, and IT equipment; overseeing vehicle fleets and fleet oper-

ations; recruiting, training, and supervising national staff; handling data management; preparing security reports, and more. (Medecins Sans Frontieres, 2009; Blecken, 2019).

Dynamic capabilities

Dynamic capabilities (DC) are often referred to for providing the robustness and agility (visibility and velocity) of logistics as well as the ability to adapt to change (Brusset & Teller, 2017; Teece et al., 1997; Mitrega et al., 2017; Craighead et al., 2020). Humanitarian actors have responded to large-scale humanitarian disasters for decades (Kovács & Spens, 2009). The number of actors (organizations) in the field of operation, the relationships between and across actors' boundaries and broader interactions beyond LO have significantly increased (Kaneberg, 2018; Balcik *et al.,* 2010), involving military, governmental, donors, private, public, voluntary, media, and the public (Kovács & Spens, 2009; Balcik et al., 2010). Actors often have different levels of expertise, and their differing views and objectives often have a significant impact on the efficiency of the response operations performance and increasing collaboration (Kaneberg et al., 2016; Heaslip & Barber, 2014). DC are essential for managing and adapting logistics operations efficiency in response to major earthquakes (Craighead *et al.*, 2020; Besiou *et al.*, 2018; Kaneberg, 2018; Brusset & Teller, 2017). As such, early studies have suggested that persistence, adaptation, and transformation can increase flexibility, collaboration, visibility, velocity, technology, communication, and networks, thereby enabling rapid changes (Teece, 2007; Craighead et al., 2020) in humanitarian response.

DC is an area considered when responding to major earthquakes to consider cooperation more than just the performance of individual actors (Kovács and Spens, 2009) and logistical challenges when facing major earthquakes (Barten et al., 2021). During these events, both internal and external disruptions can be expected, requiring regulations to ensure that critical infrastructures like hospitals, housing, and transportation are built to withstand the impact of major earthquakes and minimize their effects on the population (Jafari et al., 2022). In the field of response operations, efficiency is not just about the performance of a single actor (Kaneberg et al., 2016; Heaslip & Barber, 2014). It also has logistical implications when dealing with major earthquakes that need to be quickly resolved (Kovács & Spens, 2009). Major earthquakes can cause both internal and external disruptions, which highlights the need for regulations that ensure infrastructure, such as hospitals, housing, and transportation, are built to withstand the impact of earthquakes and mitigate their effects on the population (Barten et al., 2021). This is especially important as earthquakes can have cascading effects that further disrupt the normal functioning of a region (Ebi & Semenza, 2008; Pescaroli & Alexander, 2016). Dynamic capabilities must be hastily formed under extreme uncertainty and logistical disruptions (Jafari, et al., 2022).

DC are critical for providing the robustness and agility (visibility and velocity) of LO as well as the ability of actors to adapt to change (Brusset & Teller, 2017; Teece et al., 1997; Mitrega et al., 2017; Craighead et al., 2020). Humanitarian actors have responded to large-scale disasters for decades (Kovács & Spens, 2009). The number of actors (organizations) in the field of operation, the relationships between and across actors' boundaries and broader interactions beyond LO have significantly increased (Kaneberg, 2018; Balcik *et al.,* 2010), involving military, governmental, donors, private, public, voluntary, media, and the public (Kovács & Spens, 2009; Balcik et al., 2010). Actors often have different levels of expertise, and their differing views and objectives often have a significant impact on the efficiency of the response operations performance and increasing collaboration (Kaneberg et al., 2016; Heaslip &Barber, 2014; Craighead *et al.*, 2020; Besiou *et al.*, 2018; Kaneberg, 2018; Brusset & Teller, 2017).

DC is a concept referring to the firms' processes—specifically the processes to integrate, build, and reconfigure internal/external competencies to address a rapidly changing environment (Lucien Fobi, 2017). Laaksonen and Peltoniemi, (2018) listed more specific dynamic capabilities such as flexibility, coordination,

and collaboration to the robustness of LO. Wieland and Wallenburg (2012) referred to robustness and agility, which recognize a mixture of operations re-engineering, collaboration, agility, risk awareness, and knowledge management (Alzate, et al., 2022), and developed a system-level approach. Thus, DC could help address logistical challenges when actors (organizations) need to achieve competitive advantage and, at the same time, continuously adapt and reconfigure their operations and resources (Chen et al., 2021). To improve the understanding of LO, we use the dynamic capabilities (DC) lens to address the logistics operations challenges in building and maintaining efficient response to major earthquakes e.g. major earthquakes in Türkiye. This is an established approach (Tatham & Christopher, 2018) that provides a coherent framework for the response operations efficiency (e.g., Lucien Fobi, 2017; Liu, et al., 2021; Teece et al., 1997; Mitrega et al., 2017). Subsequently, this section focuses on logistics operations and the challenges in two major response operations in Türkiye´s context:

Logistics challenges in major earthquakes

Earthquake in Türkiye, 1999

In the response operations during the 1999 earthquake in Türkiye, the lack of coordination was the most widely discussed shortcoming of the disaster response. This included challenges in coordinating the efforts of three government disaster response teams: the fire company department, search and rescue unit, and emergency aid and rescue services. Additionally, there were difficulties in organizing support for providing food and accommodation for the personnel (cf. Altintas & Delooz, 2004). One of the major issues concerning the response operations and rescue phase in Türkiye is that there are several central government agencies with coordinative functions. The ineffectiveness of this system became clear in the aftermath of the August 17, 1999, earthquake (Walker, M., 2000). Despite the willingness of thousands of international and domestic voluntary organizations to assist after the earthquake, their emergency response and rescue efforts were ineffective, partly due to a lack of coordination at the central level (Ganapati, 2008).

The absence of a comprehensive plan and coordination—both crucial for improving the effectiveness of aid in such disasters—led to severe delays in the delivery of food and water. As a result, large quantities of uneaten bread and other perishable food spoiled, accumulating into massive piles of waste in the disaster area (Cetin, 2013). The main issue was the coordination among all parties involved in the disaster response. Effective communication, which is essential for coordination, could not be ensured during the critical phase. Additionally, there was a communication gap due to the shortage of personnel fluent in foreign languages, which would have supported the efforts of international workers (Aslanzadeh *et al.*, 2009). Challenges in accessing and sharing timely and accurate disaster-related information hindered coordination during the Marmara response (Celik & Corbacioglu, 2010). The absence of significant open communication channels between the affected provinces and the central government, combined with chaotic traffic conditions, disrupted the country's information infrastructure during the Marmara earthquake (Corbacioglu & Kapucu, 2006). The restricted flow of information between medical emergency centers, rescue teams, police, military, and volunteers greatly hindered prompt and informed actions, particularly during the initial three days of the Marmara earthquake (Comfort & Sungu, 2001). The transport infrastructure was severely damaged by the earthquake and initially overwhelmed by outsiders trying to drive to the region. This, in turn, prevented the arrival of civil defense rescue units and medical teams until early times (Bibbee et al., 2000).

The relief and rescue efforts were primarily provided by neighbors, family members, individuals, spontaneously organized volunteer groups, political parties, foreign rescue teams, and more established NGOs. The local state authority struggled to manage the crisis, and there was no existing mechanism to coordinate volunteer aid with the needs of the affected population (Jalali, 2002). One of the major problems was

the organization of patients as well as materials transported to hospital units outside the damaged area (especially crushed victims who need dialysis) when most roads were destroyed (Vanholder *et al.*, 2001). Also, the bureaucratic procedures for importing equipment from abroad, customs clearance for communication devices, and legal processes for other equipment and land vehicles led to significant delays. Additionally, the lack of a proper needs assessment prevented international organizations from effectively guiding relief efforts, resulting in challenges in delivering aid materials (Aslanzadeh et al., 2009).

Earthquake in Türkiye, 2023

According to Yilmaz *et al.* (2023), on the first day of the disaster, transportation issues and a shortage of personnel hindered access to affected areas. By the second day, there was a lack of essential medical equipment. By the third day, healthcare workers were unprepared in terms of knowledge and experience to handle the disaster. Furthermore, the deployment of medical personnel was uncoordinated and poorly planned, leaving them unable to meet even their basic needs, such as food, heating, and shelter. Throughout the first week, coordination was consistently reported as the most critical challenge.

Lots of distressed people are perceived and people without homes are living in tents provided efficiently by the state. Moreover, food and water supplies are also sufficient, and the state is providing medical care with charity help. However, both locals and aid workers choose to live in tents fear of the risk of aftershocks (Howard, 2023). The affected region posed challenges in swiftly deploying search and rescue teams to local areas and provinces. Delays in search-and-rescue operations occurred due to transportation and communication disruptions, which hindered the timely arrival of professional teams and logistical support in the immediate aftermath of the disaster (Deger & Ozdinc, 2023). Moreover, the amount of assistance provided by the foreign search and rescue teams fell short of meeting the needs of all earthquake survivors (Supartono *et al.*, 2023).

The degree and duration of the disaster experienced in Türkiye made almost all previous preparations insufficient. Although there are no deficiencies in terms of legislation, there have been serious disruptions in the activities in the field. An earthquake is not a disaster that can be easily detected with early warning systems, but its potential has been mentioned by many experts in the region for a long time. These warnings were taken into consideration based on district administrations, drills were carried out, and disaster action plans were created, but no benefit was achieved because living with the reality of disaster could not be turned into a culture. AFAD, public authority, and civil initiative had a hard time making the first response to the earthquake that spread over a very wide area (cf. Sipal, 2023).

Summary of the literature review

Table 1

The main areas of logistics challenges in the response (logistics) operation context

Response focus	Logistics challenges context
Transportation infrastructure	Concerns with outsiders trying to drive to the region that comprises the logistics challenges. Challenges the arrival of civil defense rescue units and medical teams. Examines the connectivity and ability to large quantity of reinforcement.
Coordination	Concerned with the factors essential to increasing the effectiveness of logistics challenges.Challenges in the delivery of food, water, medical care, and shelter. Examine the coordination between all actors involved in the disaster response
Communication	Concerned communication to the efficiency of logistics challenges.Challenges the coordination and collaboration among the actors.Examines the knowledge of foreign languages facilitating information channels

Response focus	Logistics challenges context
Cooperation of foreign forces	Concerned with logistics challenges in international and national cooperation.Challenges with the balance of demand and supply. Examines logistics knowledge and experience in disaster response.
Lack of medical supplies	Concerned with the preparation and response to logistics challenges. Challenges the medical staff's coordination to deploy health-skilled personnel to the disaster area. Examines immediate response coordination challenges.

Sources: *(Kovács &Spens, 2009; Teece, 2007; Craighead et al., 2020; Brusset & Teller, 2017; Teece et al., 1997; Mitrega et al., 2017; Craighead et al., 2020).*

In summary, focusing on logistics operations (LO) can reveal the challenges faced in disaster response environments (Balcik et al., 2010). **Table 1** provides a summary of these key areas. these areas are interconnected. For instance, the effectiveness of transportation infrastructure is influenced by the coordination among various actors (Kovács & Spens, 2009), as well as their ability to communicate (Teece, 2007; Craighead et al., 2020) and adapt to changes (Brusset & Teller, 2017; Teece et al., 1997; Mitrega et al., 2017; Craighead et al., 2020). This interconnectedness suggests that different actors at various levels of a logistics operation share similar concerns and must collaborate to address the imbalances in demand and supply that arise during response efforts (Kovács & Spens, 2009). While each actor aims to resolve their specific concerns, their actions may inadvertently disrupt the logistics arrangements of similar actors within the broader response operation (cf., Besiou & Wassenhove, 2020).

This study stands out from existing research by providing important insights for logistics operations in both research and practice. It emphasizes how response operations interpret and mediate dynamic capabilities, including transportation infrastructure, coordination, communication, cooperation among foreign forces, and challenges posed by insufficient medical supplies. These logistics challenges hinder the efficiency of responses to major earthquakes. This study makes a unique contribution by specifying the essential roles of various response organizations, such as civil defense, rescue units and medical teams. This creates a comprehensive understanding of the effectiveness of logistics responses. Additionally, it offers valuable insights for public decision-makers, emphasizing the importance of effective communication in achieving intended goals, including the mediation effects identified in the study.

Methodology

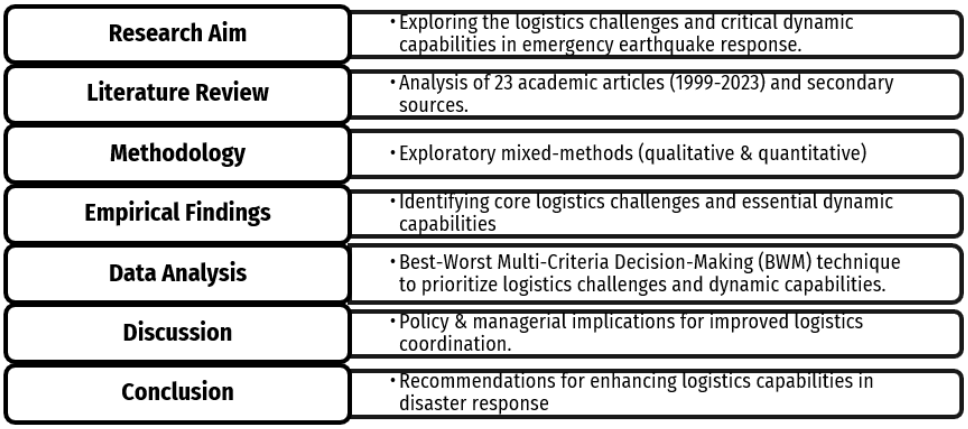
The present study uses exploratory elements to address the humanitarian response efficiency and effectiveness (in Türkiye). Logistics operations (LO) through dynamic capabilities (DC) to reduce logistics challenges, explore the data triangulation (cf. Dezing, 1978) of secondary materials and (one) semi-structured interview **(Table 4)** to estimate requested DC in the response to major earthquakes.

This exploratory study provides a foundation for future research in logistics operations. It creates assumptions that can be tested through quantitative methods and qualitative approaches. Furthermore, using the data gathered from this study in other research projects can enhance the significance of humanitarian research (Ellram 1996, p. 97; Flynn et al. 1990, p. 251). Based on several reasons, this view suggests that using a mixed quantitative and qualitative methodology is ideal for exploring and examining emerging and changing topics. This approach combines the rigor and precision of explorative approaches, as suggested by Miles et al. (2020). *First,* this is particularly valuable in growing research fields such as humanitarian response, LO, and DC. Research on major earthquakes has constantly challenged logistics and is still at an exploratory stage because existing knowledge is scarce, as noted by Kunz et al. (2017), Leiras et al. (2014), L'Hermitte et al. (2016), and Yin (2014). *Second*, the exploratory research design that was used in this study allowed for an in-depth understanding of truthful practices and the collection of empirical data (Eisenhardt

& Graebner, 2007). By analyzing academic and secondary materials, as well as conducting one interview, the study was able to provide a structured data collection process that also allowed for unexpected and new statements to be taken seriously (Döringer, 2021). *Third*, previous research has shown that the approach used in this study is reliable for addressing issues related to LO and logistics challenges in the humanitarian field. Some examples of such studies are Besiou and Wassenhove (2020), Gupta et al. (2019), and Teece et al. (1997). The current study builds upon the work of Eisenhardt and Graebner (2007), which has been used in various studies to examine how organizations from business and service sectors collaborate closely to deal with major earthquakes. However, we also consider the critical role of governments in dealing with LO and supply challenges that may threaten critical infrastructure. Considering the research of Yeow et al. (2018) and Alcaraz and Zeadally (2015), the logistics area is facing challenges, including collaboration, flexibility, transportation, trust, information, management culture, and technology, which are debated in articles focusing on the Türkiye response operation system. This study enhances the generalizability and comparability of LO by exploring the logistical challenges associated with it. The research employed a combination of quantitative data design, which included analyzing 23 academic articles from 1999 to 2023, and in-depth data analysis through secondary materials and an interview. This approach can be used to report different levels of analysis and complement each other, as reported by Lantagne et al. (2021). The research flowchart is illustrated in Figure 1.

Figure 1

Flowchart of the research



Data analysis

The first step is the collection of relevant material for analysis. Academic materials (23 articles), several secondary materials (news, websites, reports), and a single expert with high experience and knowledge with direct responsibility for earthquake response-related activities were carefully chosen as part of our sample. This section provides a detailed discussion of the criteria used for the collection of relevant data for the study.

Consequently, to establish our data criteria, (2015) suggested the Best-Worst Method (BWM), which is a multicriteria decision-making logic that compares the best data criteria (alternative) to the other criteria (alternatives) and all the other criteria (alternatives) to the worst criteria (alternative). According to the BWM, the decision-maker initially identifies the best (most desirable) and worst (least desirable) criteria. Pairwise comparisons are then made between each of these criteria and the others. A maximin problem is subsequently developed and solved to establish the weights of the different criteria. This process is repeated to determine the weights of the alternatives concerning each criterion. By aggregating these weights, the final scores for the alternatives are calculated, facilitating the selection of the best alternative. This process

also makes it possible to use a smaller amount of data in the peer calculation to calculate the weight. The aim was to determine the optimal weights and consistency ratio through our simple optimization model constructed using the comparison system. Moreover, the method can be applied with the participation of a single subject matter expert. The BWM comprises five steps, as shown in **Appendix 1.** Steps of the Best-Words Method (BWM).

Empirical Findings

The Türkiye commitment: A humanitarian dilemma

Investing in logistics capabilities is crucial despite major earthquakes, and it is a critical element for minimizing the impact of expected earthquakes and safeguarding the well-being of the population in Türkiye. However, the anticipated earthquake in Istanbul presents a humanitarian dilemma as there are concerns regarding the ability of Türkiye's emergency system to respond on time. The dilemma lies in balancing the urgent need for structural reinforcements and safety measures to mitigate the impact of the earthquake against the logistical and financial challenges of implementing these measures effectively. Moreover, there is a dilemma in addressing the housing crisis resulting from the large number of residents living in at-risk buildings. Relocation efforts may be complicated by limited resources, the current economic situation, and the need to ensure equitable treatment for all affected individuals.

Türkiye is situated in a seismically active region, making it susceptible to earthquakes, which pose a significant threat to human lives and infrastructure. On *February 6, 2023*, the Kahramanmaras province in Türkiye experienced two significant earthquakes measuring 7.7 and 7.5 in magnitude, followed by two additional earthquakes of 6.4 and 5.8 magnitude on February 20. The impact extended to 11 provinces in the southeast region. The response to these earthquakes was led by the government and coordinated through the Disaster and Emergency Management Authority (AFAD), in collaboration with the Türkiye Red Crescent (TRC). According to the United Nations, an estimated 9.1 million individuals have been affected by the earthquakes. As of March 15, the reported casualties included 48,448 fatalities and over 115,000 injuries across the country (WHO, 2023). Similarly, On *August 17, 1999*, a seismic event with a magnitude of 7.6 struck the Kocaeli and Sakarya districts in northwestern Türkiye. Shortly thereafter, another significant earthquake with a magnitude of 7.2 occurred in the nearby area centered around Duzce. These calamities resulted in a staggering toll, with over 18,000 fatalities and more than 50,000 individuals sustaining serious injuries. A total of more than 51,000 buildings either suffered extensive damage or completely collapsed, rendering over 600,000 people homeless (Akgiray et al., 2004). These two major earthquakes in Türkiye stand as the most severe and extensive natural disasters in the history of the Türkiye Republic. In the aftermath of the earthquake that hit Türkiye in 1999, there has been a widespread acknowledgment of the necessity for comprehensive earthquake preparedness and response planning, grounded in detailed earthquake risk analysis nationwide.

In addition, the predicted Istanbul earthquake has received significant attention because this urban area is located along a significant geological fault. Numerous buildings are being constructed below acceptable standards, with estimates that over 25% of the population is vulnerable to experiencing significant damage to their homes during a significant earthquake (Los Angeles Times, 2023). Istanbul accommodates approximately one-sixth of the country's total population and holds half of Türkiye's industrial potential (Erdik, 2013). Considering the present condition of the building inventory in Istanbul and the elevated likelihood of a substantial earthquake occurring shortly, the city is confronted with enormous logistical challenges, potentially leading to large-scale disruption of unprecedented magnitude (Pyper Griffiths et al., 2007). Moreover, with elevated seismic risk in the Istanbul metropolitan area, accurately predicting the distribution

of damage and casualties across both the European and Asian sides is crucial for the establishment of an effective rapid response system (Zulfikar et al., 2017).

In this sense, disaster operations are vital for ensuring a rapid, adaptable, and well-coordinated response that can effectively address the complex challenges posed by a large-scale seismic event in a densely populated urban environment. Investing in logistics capabilities is assumed to be an imperative step toward minimizing the impact of the expected earthquake and safeguarding the well-being of the population in Istanbul. This is nevertheless also part of the humanitarian dilemma surrounding the anticipated earthquake in Istanbul. For example, the city's vulnerability is due to its location on a major fault line and the high number of buildings constructed below adequate standards. This situation poses a significant risk to the population, with potentially devastating effects.

Findings building from the literature review

Table 2 and Table 3 disclose the most common logistics challenges that appear under the reviewed literature from each earthquake. A large number of academics denoted logistics challenges found in the most prominent literature on disaster operations (preparedness and response). From the review of the Türkiye's response to earthquakes in 1999 and 2023 (23 articles).

Our analysis shows that coordination and communication (11 articles) were the most prominent challenges impacting logistics operations during the response effort shown in **Table 2.,** we use these logistics challenges as criteria for our analysis.

Table 2

Areas challenging the logistics operations during the response to the Türkiye Earthquake in 1999

Logistics Challenges	Reference											
	Vanholder et al., 2001	Caymaz et al., 2013	Bibbee et al., 2000	Baycan, 2004	Altintas& Delooz, 2004	Corbacioglu & Kapucu, 2006	Celik& Corbacioglu, 2010	Comfort& Sungu, 2001	Jalali, 2002	Cetin, 2013	Aslanzadeh et al., 2009	Ganapati, 2008
Transportation infrastructure			*									
Coordination		*			*		*		*	*	*	*
Communication						*	*	*			*	
Food distribution					*							
Accommodation					*							
Transport of the materials	*										*	
Transport of patients	*											
Transport of rubble				*								

During the response to the Türkiye Earthquake in 2023, on the other hand, the transportation infrastructure and coordination (12 articles) were appointed as areas challenging the logistics operations, according to our analysis shown in **Table 3**. We use these logistics challenges as the criteria for our analysis.

Table 3

Areas challenging the logistics operations during the response to the Türkiye Earthquake in 2023

Logistics Challenges	Reference										
	Kolivand et al., 2023	Yilmaz et al., 2023	Howard, 2023	Cinar et al., 2023	Deger& Ozdinc 2023	Supartono et al., 2023	Dal Zilio and Ampuero (2023)	Tabak, 2023	Genc, 2023	Sipal, 2023	Unuvar and El
Transportation infrastructure		*		*	*	*	*		*		
Coordination	*	*		*		*			*	*	
Communication					*						
Cooperation of foreign forces	*										
Lack of medical supplies	*	*									
Lack of compatibility of the aid items	*										
Security and safety of the aid materials	*										
Risk of aftershocks			*								
Transport of rubble								*			
Transport of food											*

Findings building from the expert respondent.

To weigh the criteria and alternatives, **Table 4.** shows the areas resulting from the survey answered by our chosen subject expert. The dynamic capabilities (DC) found in the literature review (section 2.2) we used to structure the survey questions; as such, the most relevant DC were robustness, agility, organizational learning, visibility/information capability, responsiveness and delivery reliability/speed. Table 4 demonstrates the expert-assessed impact of logistics capabilities on logistics challenges, highlighting its role in shaping our findings.

Table 4

Interview findings

Please indicate the impact level of **robustness** (logistics capability) on the **logistics challenges** on the following criteria on a scale of 1-9 (1 refers to "lowest impact" and 9 refers to "highest impact")									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Transportation infrastructure									x
Coordination								x	
Communication								x	
Cooperation of foreign forces	x								
Lack of medical supplies								x	
Risk of aftershocks	x								
Transport of rubble						x			
Transport of food								x	
Please indicate the impact level of **agility** (logistics capability) on the **logistics challenges** on the following criteria on a scale of 1-9 (1 refers to "lowest impact" and 9 refers to "highest impact")									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Transportation infrastructure					x				
Coordination								x	

Communication								x	
Cooperation of foreign forces							x		
Lack of medical supplies									x
Risk of aftershocks						x			
Transport of rubble									x
Transport of food									x
Please indicate the impact level of **organizational learning** (logistics capability) on the **logistics challenges** on the following criteria on a scale of 1-9 (1 refers to "lowest impact" and 9 refers to "highest impact")									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Transportation infrastructure						x			
Coordination									x
Communication									x
Cooperation of foreign forces								x	
Lack of medical supplies							x		
Risk of aftershocks				x					
Transport of rubble	x								
Transport of food					x				
Please indicate the impact level of **visibility/information capability** (logistics capability) on the **logistics challenges** on the following criteria on a scale of 1-9 (1 refers to "lowest impact" and 9 refers to "highest impact")									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Transportation infrastructure								x	
Coordination									x
Communication									x
Cooperation of foreign forces							x		
Lack of medical supplies						x			
Risk of aftershocks	x								
Transport of rubble				x					
Transport of food					x				
Please indicate the impact level of **responsiveness** (logistics capability) on the **logistics challenges** on the following criteria on a scale of 1-9 (1 refers to "lowest impact" and 9 refers to "highest impact")									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Transportation infrastructure									x
Coordination									x
Communication								x	
Cooperation of foreign forces								x	
Lack of medical supplies									x
Risk of aftershocks	x								
Transport of rubble		x							
Transport of food									x
Please indicate the impact level of **delivery reliability/delivery speed** (logistics capability) on the **logistics challenges** on the following criteria on a scale of 1-9 (1 refers to "lowest impact" and 9 refers to "highest impact")									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Transportation infrastructure									x

Coordination					x		
Communication			x				
Cooperation of foreign forces	x						
Lack of medical supplies							x
Risk of aftershocks	x						
Transport of rubble		x					
Transport of food						x	

Criteria and Alternatives

There are many ways of mixing models with different levels of analysis. We employed the Best-Worst Method. This method was introduced by Rezaei (2015) to determine the importance weights of each criterion and used these weights to determine the priority values for each alternative. Here, we describe the steps of our methodology and findings building on the identified logistics challenges and DC required in **Table 5**.

Table 5

Criteria (logistics challenges) and Alternatives (DC) of the MCDM Problem

Alternatives	Criteria
Robustness	Coordination
Agility	Communication
Organizational Learning	Lack of medical supplies
Visibility/Inf. Capability	Transportation infrastructure
Responsiveness	Risk of aftershocks
Delivery Reliability/Speed	Transport of Rubbles
	Transport of Food
	Cooperation of Foreign Forces

Step 1. Identify the criteria and alternatives.

In the first step, we identify the criteria and alternatives for the MCDM problem. Our analysis criteria are concerned with the challenges in the aftermath of an earthquake from the aftermath of the February 6, 2023, earthquake in Türkiye (Ganapati, 2008), while alternatives are concerned with the different capabilities of the "logistics operations" to prompt responding to complex earthquakes reflected in early studies for permitting resilience (Teece, 2007) and the capability to deal with the rapid changes (Craighead et al., 2020).

Step 2. Determine the weight of the criteria by applying the BWM method.

Criteria weights were determined via the BWM method. The criteria were determined from an extensive literature review in section 2. Then, pairwise, a comparison matrix was created.

The Best-Worst Method (BWM) was selected for this study because of its effectiveness in providing reliable and consistent results in multi-criteria decision-making (MCDM) problems. Unlike traditional pairwise comparison approaches such as the Analytic Hierarchy Process (AHP), BWM reduces the number of comparisons required while maintaining a high level of consistency, making it a more efficient and robust method.

According to Rezaei (2015), one of the key advantages of BWM is its ability to minimize inconsistency in decision-making by using only two reference points: the best (most important) and worst (least important) criteria. This approach improves decision reliability by reducing the cognitive burden on experts and ensur-

ing a more structured elicitation of preferences. Additionally, BWM generates an optimal weight distribution with a consistency ratio, allowing for the validation of the decision-making process.

Table 6

Best-to-others (BO) and others-to-worst (OW) pairwise comparison vectors

Criteria	Best	Worst
Coordination	1	9
Communication	2	7
Lack of medical supplies	3	6
Transportation infrastructure	2	8
Risk of aftershocks	6	3
Transport of Rubbles	9	1
Transport of Food	4	2
Cooperation of Foreign Forces	3	4

After determining the pairwise comparison vectors, the criteria weights shown in Table 3 were obtained by solving Eq. (9) in the Appendix using the Excel Solver.

Table 7

Criteria weight according to the BWM method

Criteria	Weights
Coordination	0.283
Communication	0.165
Lack of medical supplies	0.110
Transportation infrastructure	0.165
Risk of aftershocks	0.055
Transport of Rubbles	0.026
Transport of Food	0.082
Cooperation of Foreign Forces	0.110

The third step of the BWM method is applied to determine the importance weights of the criteria. The pairwise comparison consistency was found to be 0.125, which is acceptable and under the threshold value of 0.362. The steps of the BWM method are given in the Appendix. Steps of the Best-Words Method (BWM).

Step 3. Determine the priority of the alternatives. The Weighted Sum Model (WSM) is used to prioritize the alternatives.

Table 8

Collecting data from experts

Alternatives/Criteria	Coordination	Communication	Lack of Medical Supplies	Transportation Infrastructure	Risk of aftershocks	Transport of Rubbles	Transport of Food	Cooperation of Foreign Forces
Robustness	8	8	8	9	1	1	8	1
Agility	8	8	9	5	6	9	9	7
Organizational Learning	9	9	7	6	4	1	5	8

Alternatives/Criteria	Coordination	Communication	Lack of Medical Supplies	Transportation Infrastructure	Risk of aftershocks	Transport of Rubbles	Transport of Food	Cooperation of Foreign Forces
Visibility/Information Capability	9	9	6	8	1	4	5	7
Responsiveness	9	8	9	9	1	2	9	8
Delivery Reliability/ Speed	7	3	9	9	1	2	8	1

Table 9

Normalize the data by dividing the maximum value on each criterion column

Alternatives/Criteria	Coordination	Communication	Lack of Medical Supplies	Transportation Infrastructure	Risk of aftershocks	Transport of Rubbles	Transport of Food	Cooperation of Foreign Forces
Robustness	0.889	0.889	0.889	1.000	0.167	0.111	0.889	0.125
Agility	0.889	0.889	1.000	0.556	1.000	1.000	1.000	0.875
Organizational Learning	1.000	1.000	0.778	0.667	0.667	0.111	0.556	1.000
Visibility/Information Capability	1.000	1.000	0.667	0.889	0.167	0.444	0.556	0.875
Responsiveness	1.000	0.889	1.000	1.000	0.167	0.222	1.000	1.000
Delivery Reliability/ Speed	0.778	0.333	1.000	1.000	0.167	0.222	0.889	0.125

Table 10

Multiply each normalized value by the criterion weights

Alternatives/Criteria	Coordination	Communication	Lack of Medical Supplies	Transportation Infrastructure	Risk of aftershocks	Transport of Rubbles	Transport of Food	Cooperation of Foreign Forces
Robustness	0.252	0.147	0.098	0.166	0.009	0.003	0.074	0.014
Agility	0.252	0.147	0.110	0.092	0.055	0.026	0.083	0.097
Organizational Learning	0.284	0.166	0.086	0.110	0.037	0.003	0.046	0.110
Visibility/Information Capability	0.284	0.166	0.074	0.147	0.009	0.012	0.046	0.097
Responsiveness	0.284	0.147	0.110	0.166	0.009	0.006	0.083	0.110
Delivery Reliability/ Speed	0.221	0.055	0.110	0.166	0.009	0.006	0.074	0.014

Table 11

Find priority values for each alternative by summing up the criteria values

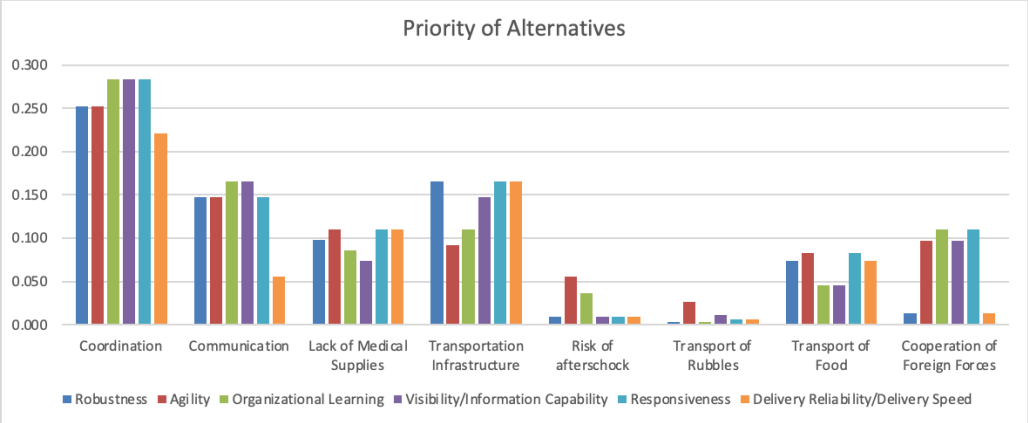
Alternatives/Criteria	Coordination	Communication	Lack of Medical Supplies	Transportation Infrastructure	Risk of aftershocks	Transport of Rubbles	Transport of Food	Cooperation of Foreign Forces	Overall
Robustness	0.252	0.147	0.098	0.166	0.009	0.003	0.074	0.014	0.763
Agility	0.252	0.147	0.110	0.092	0.055	0.026	0.083	0.097	0.863
Organizational Learning	0.284	0.166	0.086	0.110	0.037	0.003	0.046	0.110	0.842

Alternatives/Criteria	Coordination	Communication	Lack of Medical Supplies	Transportation Infrastructure	Risk of aftershocks	Transport of Rubbles	Transport of Food	Cooperation of Foreign Forces	Overall
Visibility/Information Capability	0.284	0.166	0.074	0.147	0.009	0.012	0.046	0.097	0.834
Responsiveness	0.284	0.147	0.110	0.166	0.009	0.006	0.083	0.110	0.915
Delivery Reliability/ Speed	0.221	0.055	0.110	0.166	0.009	0.006	0.074	0.014	0.654

Based on our calculations, the most desired alternative is responsiveness, followed by agility, organizational learning, visibility/information capability, robustness, and delivery reliability/speed. **Figure 2** depicts the priority values of each alternative based on each criterion. The graph also shows the importance of each criterion by plotting each criterion on the bar chart.

Figure 2

Priority of the Alternatives



Analysis And Discussion

Overall, the study analyzed the interview survey (a single expert) along with 23 academic articles published between 1999 and 2023. To structure our findings, we build on our data analysis in Figure 2, showing the most desired alternatives (dynamic capabilities) such as responsiveness, followed by agility, organizational learning, visibility/information capability, robustness, and delivery reliability/speed of the LO. Based on the literature review (Tables 3 and 4), the most emphasized challenges were found in coordination, transportation infrastructure, and communication. We use these findings to explore the answer to our question:

What dynamic capabilities are critical in addressing the logistics challenges in the response to logistics operations during major earthquakes in Türkiye?

In LO, major earthquakes imply logistics challenges that are, in turn, impeding the evolving critical DC to the response efficiency. However, our findings disclosed that anticipating an earthquake in Istanbul presents a humanitarian dilemma as there are concerns regarding the ability of Türkiye's emergency system to respond on time. The dilemma lies in balancing the urgent need for structural reinforcements and safety measures to mitigate the impact of the earthquake against the logistical and financial challenges of implementing these measures effectively. Moreover, there is a dilemma in addressing the housing crisis resulting from the large number of residents living in at-risk buildings. Relocation efforts may be complicated by limited resources, the current economic situation, and the need to ensure equitable treatment for all affected individuals. Istanbul is one of the cities in Türkiye most vulnerable due to its location, a

major weakness in line with houses constructed below adequate standards posing a significant risk to its population, and potentially devastating consequences in the event of a major earthquake.

One of the foremost challenges in humanitarian logistics is coordination among various stakeholders. In the aftermath of an earthquake, numerous organizations, both local and international, mobilize to aid. However, the lack of coordination mechanisms often leads to duplication of efforts, resource wastage, and gaps in coverage. During disasters, there is a pressing necessity to coordinate logistics resources from both the public and private sector to prevent arbitrary resource allocation. Furthermore, communication breakdowns between relief suppliers, logistics operators, and those in need aggravate the complexity of disaster resource coordination, especially under emergency circumstances (Sheu, 2007). Such disasters also exert significant adverse effects on the physical infrastructure of the affected region, causing widespread destruction to transportation infrastructure like roads, bridges, railways, and airports, as well as disrupting electricity grids and communication networks (Barabaşoğlu et al., 2002). These impediments hamper the timely delivery of aid supplies to affected areas, prolonging the suffering of communities in need. Moreover, the limited availability of vehicles suitable for navigating rugged terrains worsens the problem. By cultivating dynamic capabilities, decision-makers can better address logistical challenges such as coordination, communication, and transportation infrastructure.

Our findings reveal that responsiveness, agility, and organizational learning are DCs that need the most attention by the state and humanitarian organizations. In this sense, our study results align with the literature. *First*, prior research indicates that responsiveness is crucial in the post-disaster setting following sudden-impact events (Naor & Bernardes, 2016). According to Ghosh *et al.* (2004), responsiveness is a vital capability to achieve the efficiency of activities and the seamless integration of processes throughout the chain. Our analysis indicates that responsiveness is crucial in addressing rapidly changing situations and demands when logistics challenges occur.

According to our analysis, both the state and humanitarian organizations and being able to adapt swiftly to evolving circumstances ensure effective and timely responses to large-scale disasters. This is, nevertheless, a humanitarian dilemma surrounding the anticipated earthquake in Istanbul and the ability of Türkiye ´s emergency system to respond in time (cf. Caymaz *et al.,* 2013). The study showed the dilemma in balancing the urgent need for structural reinforcements and safety measures to mitigate the impact of the earthquake against the logistical and financial challenges of implementing these measures effectively. This capability involves not only quick decision-making but also the ability to implement and adjust strategies promptly.

Second, agility is the capacity to detect immediate shifts in the environment and demonstrate swift and adaptable responses to those changes (cf. Alzate, *et al.,* 2022). According to our findings, humanitarian organizations are engaged in disaster relief to enhance the rapid and efficient transport of relief supplies and to save victims. Achieving this goal necessitates the backing of a responsive and agile supply chain network (Dubey *et al.,* 2015). *Third*, our analysis (BWM) indicated that organizational learning is vital to DC. However, according to the study, in more complex and unpredictable logistics challenges, the ability to learn together (from experiences) continues to be a challenging improvement. According to Labib *et al.,* (2019), involved organizations in the response operations (e.g., foreign aid, NGOs, voluntary workers, and national authorities) can enhance their effectiveness by fostering a culture of learning, enabling them to refine their approaches based on past rare events.

The study reveals, on the other hand, that robustness, visibility/information capability, and delivery reliability/speed are the most desired capabilities to overcome logistics challenges. According to Brandon Jones *et al. (2014),* by investing in logistical robustness, organizations can maintain their functions even during sudden demand changes despite disruptions due to major earthquakes. Visibility/information capability

was found to be vital for gathering, analyzing, and disseminating relevant information promptly, according to Francis (2008). The study indicated that for effective coordination, both the state and humanitarian organizations need to invest in robust information systems and processes, ensuring that key stakeholders are well-informed and equipped to make informed decisions. Moreover, delivery reliability/speed also holds significant importance for those involved in logistics challenges. According to Walton et al., (2011), the existing literature on emergency response strongly advocates for speedy logistical processes to deliver goods and services during humanitarian crises.

Conclusions

The purpose of this study was to analyze the response to major earthquakes (natural), meeting logistics challenges in disaster operations using the experiences from the major earthquakes that struck Türkiye. It is essential to acknowledge that logistical challenges during disaster operations are not unique to a single country but are pervasive worldwide. We used dynamic capabilities to explain their critical potential to address logistics challenges when responding to major earthquakes. Examining the LO in response to major earthquakes in Türkiye, our findings showed that several logistics areas pose challenges to the LO. As such, the transportation infrastructure, coordination, communication, cooperation (among foreign forces), and the lack of medical supplies were logistics challenges impeding the efficiency of the response to major earthquakes (e.g., 1999 and 2023). The study showed that humanitarian actors use "logistics" as an umbrella term encompassing a broad variety of tasks covered by the LO, which, in turn, also represent logistics challenges. For instance, coordinating the management and maintenance of hospitals and feeding centers alongside medical teams; overseeing administration and organization; handling health supplies, equipment, and other materials (including procurement, customs, transportation, and inventory management); installing and maintaining technical equipment; managing construction and upkeep; maintaining communication systems and IT infrastructure; overseeing vehicle fleet operations; recruiting, training, and supervising national staff; managing data; and preparing security reports. As we found support for the facilitation of DC to mitigate logistics challenges, we content that during LO, dynamic capabilities would effectively influence the response to complex disruptions (i.e., due to earthquakes that struck Türkiye), and responsible authorities should consider exploiting the coordination and communication capabilities. Hence, our study addresses the associated results from previous research regarding the lack of medical supplies and transportation disruptions. As such, in the mitigation of aftershock risks (e.g., transport of rubble, food, and water), the cooperation involves foreign aid, NGOs, voluntary workers, and national authorities bound by employment mechanisms, as these have been disregarded in early responses.

This study adds to the existing body of literature on logistics operational efficiency by assessing the challenges related to the dynamic capabilities that humanitarian logistics providers and responsible organizations face. It draws upon insights from humanitarian responses, critical infrastructure, and operations and supply chain management to develop the concept of logistics challenges. Specifically, this study analyzes how dynamic capabilities present significant obstacles to logistics operations in the aftermath of major earthquakes. Additionally, we use the logistics operational framework to highlight logistical challenges that could be addressed through the implementation of dynamic capabilities. We emphasize the critical need to improve coordination, communication (including communication channels), and transportation infrastructure to enhance the overall logistics operational efficiency. Our findings also reveal the importance of other specific DCs, such as responsiveness, agility, organizational learning, visibility, and information, robustness, and delivery reliability/speed, to effectively route these logistics challenges. Among these capabilities, responsiveness emerges as highly critical for enabling organizations to promptly adapt to changing circumstances. Additionally, agility is highlighted for its role in maintaining flexibility and

quick adaptability to unforeseen disruptions, providing an asset in overcoming logistical challenges during response operations. In essence, the present study advocates responsiveness, agility, and organizational learning as the key dynamic capabilities to be developed. By doing so, organizations can proactively address coordination, communication, and transportation infrastructure challenges, ensuring a robust and adaptive logistical framework capable of meeting the demands of unpredictable events.

Implications

The various possibilities of doing good research involve, at the same time, implications. One important aspect is the policy implications of this study. That is, regarding the dilemma of balancing the urgent need for structural reinforcements (e.g., The Türkiye response system) and mitigating the logistical challenges (e.g., coordination, communication, and transportation). Policy development would be required as impactful guidance to the humanitarian system involving foreign aid, NGOs, voluntary workers, and the national authorities to efficiently face rapid and challenging changes. Moreover, in line with Türkiye's adaptation process to the EU's Green Deal, responsive and adaptive logistics strategies are not only critical for economic cooperation but also ensure that logistics performance responds swiftly to disasters (Cura & Demir, 2022). The policy can not only provide guidance but also mechanisms to make the response to major earthquakes (e.g., shoving organizations the potential impact of internal and external disruptions) approachable (cf. Barten, et al., 2021). Policy can also support regulations that easily ensure access to vital infrastructures (e.g., hospitals, housing, and transportation) and how these would mitigate the effects on the population (cf. Yeow, *et al.,* 2018).

The other is the managerial implications. The managerial issue in which the role of public and private organizations has been raised at the cost of NGO, voluntary, and national authorities' sectors. Here the implications concern an increasingly specialized work on safety (and security) to protect workers and victims (e.g., as the Türkiye response system appeared to be weak). Responsible managers in the national authorities have to be bound by employment mechanisms for providing conditions and policy guidance to humanitarian workers. However, ultimately, to guarantee a more efficient response, operations work.

Limitations and future research

The Best-Worst Method (BWM) can only be applied with the participation of a single subject matter expert; thus, this study is built on secondary materials and ONE interview. However, future research needs to integrate the analysis of multicriteria decision-making logic by broadening the sample, i.e., different groups of respondents, and research in the area to allow validity and applicability to similar conditions. Using BWM, there is a limited number of expert materials and convenient sample interviews needed to critically establish applicability, following Corbin and Strauss's (1990) on the significance of collecting and analyzing data until redundancy is achieved and additional data only provides slightly new insights. The data-gathering questionnaire was developed based on a comprehensive review of relevant academic literature, ensuring the validity, accuracy, and appropriateness of the selected questions. This approach was chosen for its flexibility, enabling the assessment of various aspects while still aligning with the predefined data collection objectives (Yin, 2014). However, determining from whom data will be collected and where was analogous tour consideration of sampling, is a limitation on representative sampling to generate findings from the sample to the population.

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Appendix

STEPS OF THE BEST-WORDS METHOD (BWM)

BWM is a multicriteria decision-making method that compares the best criteria (alternative) to the other criteria (alternatives) and all the other criteria (alternatives) to the worst criteria (alternative). This process creates a comparison system composed of two comparison vectors. The goal is to find the optimal weights and consistency ratio through a simple optimization model constructed using the comparison system. The BWM comprises five steps (Rezaei, 2015).

Step 1. Determine a set of decision criteria

Step 2. Determine the best (e.g., most desirable, most important) and the worst (e.g., least desirable, least important) criteria.

Step 3. Determine the preference of the best criterion over the other criteria using a number between 1 and 9. The resulting Best-to-Others vector would be:

$A_B = (a_{B1}, a_{B2}, ..., a_{Bn})$

where a_{Bj} indicates the preference of the best criterion C_B over criterion C_j. It is clear that $a_{BB} = 1$.

Step 4. Determine the preference of the criteria over the worst criterion using a number between 1 and 9. The resulting Others-to-Worst vector would be:

$A_W = (a_{1W}, a_{2W}, ..., a_{nW})$

where a_{jW} indicates the preference of criterion C_j over the best criterion C_W.It is clear that $a_{WW} = 1$.

Step 5. Find the optimal weights.

$(w_1^*, w_2^*, ..., w_n^*)$

The optimal weight for the criteria is the one where for each pair of $\frac{w_B}{w_j}$ and $\frac{w_j}{w_W}$, we have $\frac{w_B}{w_j = a_{Bj}}$ and $\frac{w_j}{w_W = a_{jW}}$.To satisfy these conditions for all j, we should find a solution where the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ for all j is minimized. Considering the non-negativity and sum condition for the weights, the following problem results:

$$\begin{gathered} \min \max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right\} \\ s.t. \\ \sum_j w_j = 1 \\ w_j \geq 0, for\ all\ j \end{gathered} \tag{1}$$

Problem (8) can be transferred to the following problem:

$$
\begin{aligned}
&\min \xi \\
&s.t \\
&\left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \xi \; for\; all\; j \\
&\left| \frac{w_j}{w_W} - a_{jW} \right| \leq \xi \; for\; all\; j \\
&\sum_j w_j = 1 \\
&w_j \geq 0, for\; all\; j
\end{aligned}
\tag{2}
$$

Solving problem (9), the optimal weights $(w_1^*, w_2^*, ..., w_n^*)$ and ξ^* are obtained.

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Modeling mode choice behaviors of commuters in car-dependent small country discrete choice models: A case study of Bahrain

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Abstract The aim of this study is to determine the factor affecting the mode choice of travelers in Bahrain, which presents a unique case due to its smaller area size and current dependence on cars. Hence, the need for promoting sustainable modes of transportation is critical for the country. The study used 3864 diverse data records extracted from traveler surveys. This data comprised of revealed preference responses. The variables considered in the modelling included traveler characteristics, and trip information. The logit model and the classification tree models were used to predict the mode choice, considering the currently available modes of transportation currently available (Car and Bus). The accuracy of the models was ascertained through a validation sample collected independently from the initial sample. Trip cost was the most influential factor on mode choice. Other important variables included direct and quick travel, accessibility, and convenience. In terms of model performance, the logit model demonstrated higher accuracy than the classification tree when modeling binary responses. The models and results of this study provide important conclusions for the transportation authorities, which can be utilized for developing and promoting sustainable transportation modes in Bahrain.

Keywords Mode choice · Prediction · Models · Logit Model · Classification Tree · Behavior

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Modeling mode choice behaviors of commuters in car-dependent small country discrete choice models: A case study of Bahrain

Transportation systems in most countries are currently facing serious challenges such as congestion, accidents, and air and noise pollution (Ortúzar and Willumsen, 2011). These challenges arise due to the rapid population growth and increase in car ownership levels, which have consequently led the demand for these systems to surpass the available supply of transportation facilities and services. Therefore, it becomes necessary to establish efficient policies and to have a thorough comprehension of travel demands, travel patterns, and driver characteristics for the development of projects that can facilitate and promote the advancement of transportation systems (Mwale et al., 2022).

Travel forecasting models are a crucial aspect of transportation planning and serve as a measure to identify the travel needs of cities (Sowjanya et al., 2014). These models consist of a set of mathematical equations and algorithms which are employed in a stage-wise or activity-based manner to simulate travel patterns and behaviors (Waghmare et al., 2022). One of the most notable models used for demand forecasting in transportation planning is the modal split model. This modeling operation, also known as mode choice modeling, focuses on predicting and managing the travel demands of different transport modes in a specific system by determining the key variables affecting the mode choice decision-making process (Pineda-Jaramillo, 2019).

In the Kingdom of Bahrain, urban development and population growth have resulted in a substantial increase in car ownership, leading to further congestion on Bahrain's road network. The number of cars in Bahrain increased from approximately 400,000 in 2009 to approximately 700,000 at the end of 2019 (Waleed, 2019). This increase, accompanied by scarcity and the near absence of a public transportation system, made it improbable to navigate through the country without traffic delays, reaching several hours during peak flow conditions.

Most of the efforts related to transportation modeling and innovative planning ventures are directed toward large countries and metropolitan cities. Therefore, this research aims to analyse the mode choice behavior of travelers and determine the factors influencing it in Bahrain. The results of this study are expected to highlight the uniqueness of travel choices in a country such as Bahrain, which has heavy car-dependent travel choices and a smaller size and population, where public transport does not seem to be an economically feasible option. The results could be applied to other countries facing similar challenges.

Literature review

The economic growth of cities, which consequently boosts income and population growth, generates an increase in both passenger and freight demands, which necessitates the improvement of the current transportation system to satisfy the new travel demand while maintaining equilibrium (Modi et al., 2011; Waghmare et al., 2022). Travel demand is defined as the number of persons or vehicles per unit of time that can be predicted to use a certain segment of a transportation system under specific conditions, such as availability, quality, and cost (Ortúzar and Willumsen, 2011). Forecasting travel demand is a vital step in the transportation planning process, and because it is undergoing a continuous increase, more emphasis is given to understanding its relationship with factors affecting it, including mode choice (Hoel et al., 2011).

Factors affecting mode choice

Mode choice and its modeling are considered the most prominent aspects of travel demand. In developing cities, the most commonly available transport modes are private cars, public busses, trains, taxis, walking, and cycling. Commonly, travelers tend to favor transport modes that fit their preferences and traveling habits best; thus, the factors that control their decision can be arranged into three categories (Chen et al., 2013).

These categories are as follows (Ratrout et al., 2014):

• Characteristics of trip makers: These are the socioeconomic and cultural aspects of a traveler, such as automobile ownership, income, employment, gender, age, and personal desires.

• Characteristics of the trip: Mainly concerning the purpose of the trip, the time of the day at which it is made, and the land use of the area in which it is made.

• Characteristics of the transport mode or service: travel time, cost, comfort, safety and availability.

Automobile ownership, public-transport availability and land-use are considered to have a larger influence on travelers' choice than the other factors mentioned above (Convery and Williams, 2019). Considering that the accurate prediction of travelers' mode choice behavior depends on several variables, it is crucial to select the right and most suitable approach to modeling (Chen et al., 2013).

Distinct mode choice modeling

Transportation planning generally relies on discrete choice models to model travelers' mode choice behavior. These models employ the theory of utility maximization and assume that a traveler is most likely to choose the mode that presents the most benefits to its users (Hillel et al., 2019). The logit model, which uses simple mathematical techniques, is considered the most widely used distinct approach for mode choice modeling (Sekhar, 2014). According to this model, the utility function of a mode is demonstrated by a linear equation that links the factors influencing mode choice as independent variables and the utility of a particular mode as the dependent variable.

Equation (1) shows the basic form of the utility function for a traveler's mode choice while Equation (2) is used to calculate the probability of his/her choice (Puan et al., 2019):

$$U_{\mathrm{m}} = C + A_1X_1 + A_2X_2..... + A_{\mathrm{i}}X_{\mathrm{i}} \tag{1}$$

Where:

C=Constant

Ai= vector of coefficients

Xi=Independent Variables

$$P_{\mathrm{mi}} = e^{U_{\mathrm{mi}}}/\left(\sum\nolimits_{\mathrm{j}} e^{U_{\mathrm{mi}}}\right) \tag{2}$$

Generally, based on the number of alternatives included in the model, a logit model can be either of two forms: The Binary Logit model or the Multinomial Logit model.

The binary logit model is used when commuters have two options of travel modes to choose from. The probability of choosing mode "A" in a binary logit model can be obtained through Equation 3, which is a simpler form of Equation 2, while Equation 4 represents the probability of choosing the other alternative (B) (Puan et al., 2019):

$$P_{\mathrm{A}} = e^{U_{\mathrm{A}}}/(1 + e(U_{\mathrm{A}})) \tag{3}$$

$$P_{\mathrm{B}} = 1 - P_{\mathrm{A}} \tag{4}$$

Where:

$P_{(A,B)}$ = Probability of choosing mode A, B

U_A= usefulness of alternative A

When commuters have more than two modes to choose from, the multinomial logit model is used to build the utility functions and estimate probabilities as per Equations (1-2) (Puan et al., 2019). The multinomial logit model is based on the theoretical assumptions that the error elements follow Gumbel distribution rather than normal distribution, that the error elements for each alternative are comparable and independently distributed, and that the error elements are similar and independently distributed for each observation (Hussain et al., 2017).

Machine learning mode choice models

Due to the introduction of new transportation technologies, which allowed a wider range of data collection and remarkable developments in machine learning research, transportation planners began to explore more advanced alternative approaches (Hillel et al., 2019). Machine learning is a term used to refer to a group of algorithms that support computers in mechanizing data and using it to build models. These models overcome the challenges posed by growing travel demands by detecting statistical patterns (Bhavsar et al., 2017).

A key machine-learning approach is Decision trees. These nonparametric methods classify data into groups and model the relationships between features and possible outputs by following a structure identical to a flowchart or a tree (Pineda-Jaramillo, 2019). The most frequently used decision trees are those that use binary splits. To compute each split, the data is classified depending on the specified features, and then for each feature, the possible binary split points were tested (Hillel et al., 2019).

Literature gaps

Most of the above-mentioned literature deals with countries/cities that have various mode choices that are used by a significant proportion of the population. However, Bahrain is a unique case due to its small size and dependence on car mode. Understanding mode choice behavior in such conditions is expected to provide a unique perspective to the research topic. This may also pave the way for the promotion and development of alternative sustainable transportation systems in Bahrain, as well as other car-dependent countries.

Data collection

The previous literature on mode choice shows that information concerning gender, age, nationality, occupation, salary, driver's license, and car ownership appears in many of the previous studies as predictors of mode choice (McCarthy et al., 2017; Geng et al., 2016). Additionally, Origin-Destination, current mode, the purpose of the trip, travel time, and total cost of the trip were also observed to be common features in the previous studies as well as some recent studies such as by Mohamed and Oke (2023) and Ha et al. (2020). Hence, these were the factors considered in this study, and their data were collected in the survey. The details of these variables are given in Table 1. Note that some of the categories for questions needed to be merged due to the lack of responses, for example, responses for age categories above 45 years.

Table 1

Standardization of data items.

Data Item	*Description*
Gender	Binary: Male or Female

Data Item	*Description*
Age	Categorical; “Under 18”, “18 – 25”, “26 – 35”, “36 – 45” or “Above 45”.
Nationality	This data item has two options: Bahraini and Non-Bahraini.
Origin-Destination	Categorical: Capital, Muharraq, Northern and Southern
Occupation	Categorical: employee, student, retired, unemployed, and others
Average Salary	Continuous
Driving License	Binary: Yes or No
Car Ownership	Categorical: 0, 1, 2, 3, and 3+.
Purpose of the Trip	Categorical: work, education, shopping/leisure, and others.
Travel Time	Categorical: “0 – 10”, “11 – 20”, “21 – 30”, “31 – 40”. “41 – 50”, “51 – 60”, “61 – 120” and “120+”.
Total trip cost	Continuous
Current Mode	Categorical: private cars, car-sharing, bus (public busses, school busses and private bus) and non-motorized transportation (walking and cycling).

The data for this data was collected through online surveys which resulted in 3864 samples which could be considered for modelling. From these responses, filtering process was applied to eliminate the responses without the mode choice or those who had missing data for more than one of the variables. This step improved data performance by reducing data insufficiencies and streamlining the process. Table 2 and Figure 1 and Figure 2 highlight the key statistical metrics of the final dataset. The gender representation was almost equal for males and females in the final dataset. The dataset had higher responses from Bahrainis from the age group of 18-35 which could be considered an active population for any country. The dominance of car use among the responses is a true representation of travel mode choice behavior in Bahrain as well as in other neighboring countries (Mahmood et al., 2022). The responses for other modes were merged into one category to avoid model bias due to the large dominance of one mode in the choice set.

Table 2

Key statistical metrics of the final dataset.

Data Item	Statistical Metrics
Gender	M = 51%, F = 49%
Nationality	Bahraini = 61%; non-Bahraini = 39%
Age	Under 18 = 5%
	18–25 = 37%
	26–35 = 29%
	36–45 = 14%
	Above 45 = 15%
Travel Mode	Car = 71%
	Sharing Car = 9%
	Bus = 19%
	Non-motorized Transportation = 1%

Figure 1

Origin Data Percentage

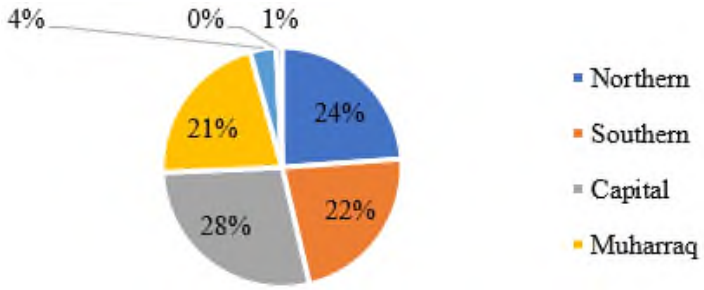
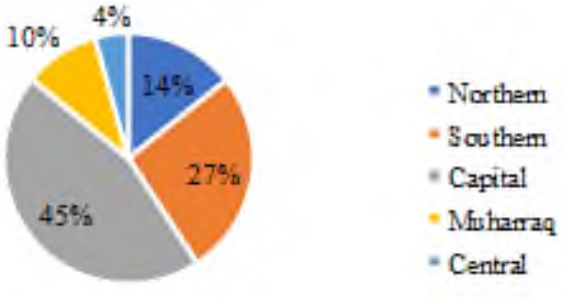


Figure 2

Destination Data Percentages



Model building

Data preparation

Table 3 summarizes the scales used for each category. The categorical variables had to be coded as Minitab was used for modelling which does not take text variables as input for models.

Table 3

Model Variables

Category	*Variable*	*Scale*
Continuous	Age	Continuous Number*
	Travel Time	Continuous Number
	Trip Cost	Continuous Number
	Salary	Continuous Number
Categorical	Gender	1 for males and 0 for females
	Nationality	1 for Bahraini, 0 for non-Bahraini
	Origin	Distinct Numbers (1 - 4) each representing a governorate
	Destination	Distinct Numbers (1 - 4) each representing a governorate
	Current Mode	1 for a car, 2 for Others
	Trip Purpose	1 for Work, 2 for Education, 3 for Shopping, 4 for Other
	Occupation	1 for Employees, 2 for students, and 3 for others
	Driving License	1 for Yes and 0 for No.
	Car Ownership	Distinct Numbers (1 - 4)

*The age categories were replaced with the middle or extreme values in the case of the highest or lowest category, respectively.

The logit model

To develop a binary logit model, several models were built using various variables until an adequate goodness of fit and accuracy was achieved. The optimal model was selected by evaluating and testing different variables until the best combination was identified by the software. The proceeding sections provide more details about this model.

Utility equations

The selected model uses five variables, three of which are of a continuous nature—travel time, trip cost, and salary—and two categorical variables: trip purpose and occupation. Table 4 presents the resulting utility functions for Car and Bus. Note that C12 and C19 refer respectively to the trip purpose and occupation. More details on these variables are presented in Table 3.

Table 4

Utility functions

C12	*C19*	*Car Utility*	*Other Mode Utility*
1	1	Y= 0.4280 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 0.4280 + 0.01267 Average Travel Time - 0.9388 Total Cost of Trip - 0.001054 Average Salary
1	2	Y= 2.111 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 2.111 + 0.01267 Average Travel Time - 0.9388 Total Cost of Trip - 0.001054 Average Salary
1	3	Y= 1.389 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 1.389 + 0.01267 Average Travel Time - 0.9388 Total Cost of Trip - 0.001054 Average Salary
2	1	Y= 1.379 - 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 1.379 + 0.01267 Average Travel Time 0.9388 Total Cost of Trip 0.001054 Average Salary
2	2	Y= 0.3040 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 0.3040 + 0.01267 Average Travel Time - 0.9388 Total Cost of Trip - 0.001054 Average Salary
2	3	Y= 0.4178- 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 0.4178 + 0.01267 Average Travel Time 0.9388 Total Cost of Trip 0.001054 Average Salary
3	1	Y= 2.448 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 2.448 + 0.01267 Average Travel Time 0.9388 Total Cost of Trip 0.001054 Average Salary
3	2	Y= 0.7652 - 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 0.7652 + 0.01267 Average Travel Time 0.9388 Total Cost of Trip 0.001054 Average Salary
3	3	Y= 1.487 - 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 1.487 + 0.01267 Average Travel Time 0.9388 Total Cost of Trip 0.001054 Average Salary
4	1	Y= 3.513 - 0.01267 Average Travel Time + 0.9388 Total Cost of Trip +0.001054 Average Salary	Y'= 3.513 + 0.01267 Average Travel Time 0.9388 Total Cost of Trip 0.001054 Average Salary
4	2	Y= 1.830 - 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 1.830 + 0.01267 Average Travel Time 0.9388 Total Cost of Trip 0.001054 Average Salary
4	3	Y= 2.552 - 0.01267 Average Travel Time + 0.9388 Total Cost of Trip + 0.001054 Average Salary	Y'= 2.552 + 0.01267 Average Travel Time 0.9388 Total Cost of Trip 0.001054 Average Salary
Probability		P(Car) = exp(Y)/(1+exp(Y))	P(Bus) = exp(Y')/(1+exp(Y'))

Coefficients analysis

By thoughtfully examining the coefficients' analysis, the importance of each variable in the model can be assessed. This is accomplished using Wald approximation tests to calculate the Z- and P-values of each variable. The Z-value computes the ratio between the coefficient and its standard error, indicating whether its estimate is large and precise (far from 0) or small and too imprecise (close to 0). In Table 5, it can be concluded that all coefficients have precise estimates that are not statistically equal to 0, since the Z-

values calculated are sufficiently far from 0. Successively, Minitab uses the Z-value to calculate the P-value, which is a probability that suggests that there is no association between the independent variable and the dependent variable. As commonly used in analysis, a 95% confidence level implies that if the P-value is less than or equal to 0.05, the variable is considered statistically significant. Accordingly, based on the P-values shown in Table 5, it can be deduced that there is no evidence for the null hypothesis; therefore, all variables used in the model are significant (Mendenhall et al., 2013).

Table 5

Binary Logit Model Coefficient Analysis

Term	*Coefficient*	*Standard Error*	*Z-Value*	*P-Value*
Constant	−0.428000	0.204	−2.100	0.035
Travel Time	−0.012670	0.004	−3.030	0.002
Total trip cost	0.938800	0.082	11.420	0.000
Salary	0.001054	0.000	4.330	0.000
C12				
2	1.807000	0.674	2.680	0.007
3	2.876000	0.714	4.030	0.000
4	3.940000	1.120	3.520	0.000
C19				
2	−1.683000	0.680	−2.480	0.013
3	−0.961000	0.411	−2.340	0.019

Odds ratios

Odds ratios are prominent in statistical analysis because they can be used to measure the odds of an outcome of interest, occurring with an association to a specific variable. In general, the odds ratios for continuous variables demonstrate the change in the odds of the dependent variable with a unit increase in the independent variable, whereas the odds ratios of categorical predictors compare the odds of the outcome of non-reference categories to that of the reference category. This helps identify the extent of each variable's effect on the outcome and assists informed decision-making. Table 6 and Table 7 display the odd ratios for both continuous and categorical predictors used in the logit model (Kleinbaum et al., 1988). It can be observed that the greatest impact on the mode choice is due to the change in the trip purpose, especially when it changes from traveling to work.

Table 6

Odd Ratios for Continuous Predictors

Term	*Odds Ratio*	*95% CI*
Average Travel Time	0.98	(0.97, 0.99)
Total trip cost	2.55	(2.17, 3.00)
Average Salary	1.00	(1.00, 1.00)

Table 7

Odd Ratios for Continuous Predictors

Reference Level	*Comparison Level*	*Odds Ratio*	*95% CI*
C12			
2	1	6.09	(1.62, 22.84)
3	1	17.74	(4.37, 71.94)

Reference Level	*Comparison Level*	*Odds Ratio*	*95% CI*
4	1	51.46	(5.75, 460.47)
3	2	2.91	(0.57, 14.68)
4	2	8.45	(0.95, 74.80)
4	3	2.90	(0.26, 31.36)
C19			
2	1	0.18	(0.04, 0.70)
3	1	0.38	(0.17, 0.85)
3	2	2.05	(0.61, 6.84)

Goodness of fit

Predominantly, the goodness-of-fit tests' results (Table 8) suggest that the model fits the data well, as both deviance and Pearson's chi-square tests have a high P-value of 1. This implies that the model's estimates are not significantly different from the observed data. However, since the Hosmer-Lemeshow test has a low P-value of 0, suggesting that there is some evidence of a lack of fit, possibly due to the large sample size used in the analysis (Kutner et al., 2004; Hadi and Chatterjee, 2015).

Table 8

Binary Logit Model Goodness-of-fit

Test	Degree of Freedom	Chi square	P–Value
Deviance	1387	842	1.00
Pearson	1387	1162	1.00
Hosmer and Lemeshow	8	50	0.00

Therefore, to better evaluate the model's goodness-of-fit, the normal probability plot and standard errors vs. fits were generated (Figure 3 and Figure 4). Based on the statistical principles and interpretation of diagnostic plots, the approximate linear form of both plots suggests that the model has an acceptable fit to the data and that the linearity assumption between the dependent and independent variables within the utility functions has been met (Kutner et al., 2004; Hadi and Chatterjee, 2015). Subsequently, despite the lack of fit provided by Hosmer-Lemeshow test, the other tests and diagnostic plots do not reject the model generated in this study.

Figure 3

Normal Probability Plot (percentage vs. Residual)

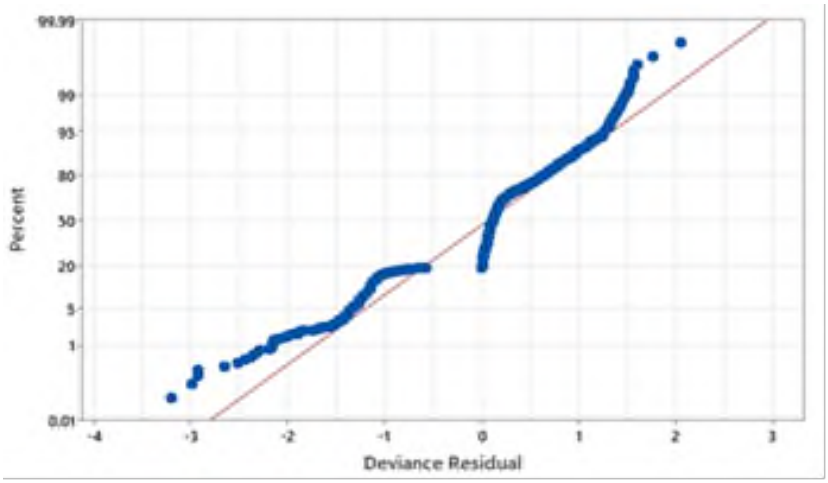
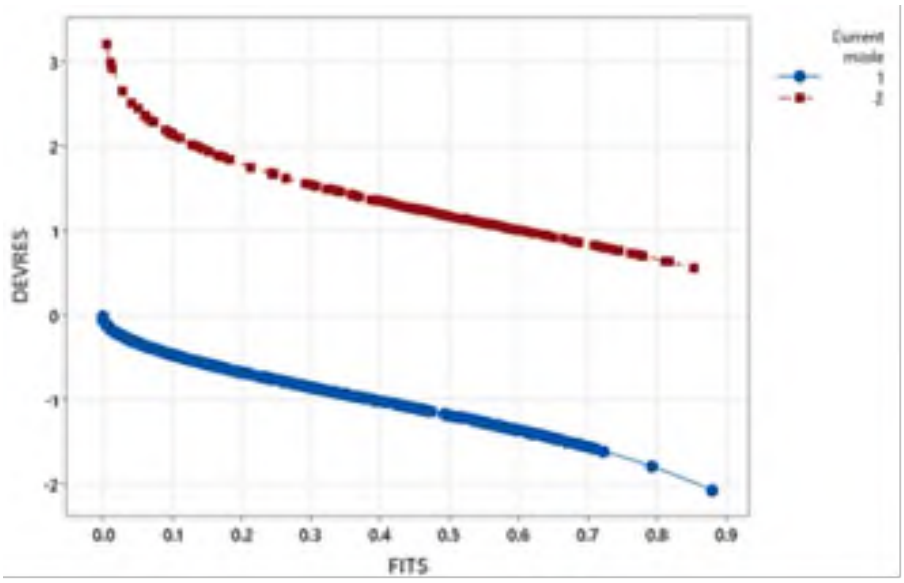


Figure 4

Residuals vs. Fitted Value Plot (Devers vs. Fits)

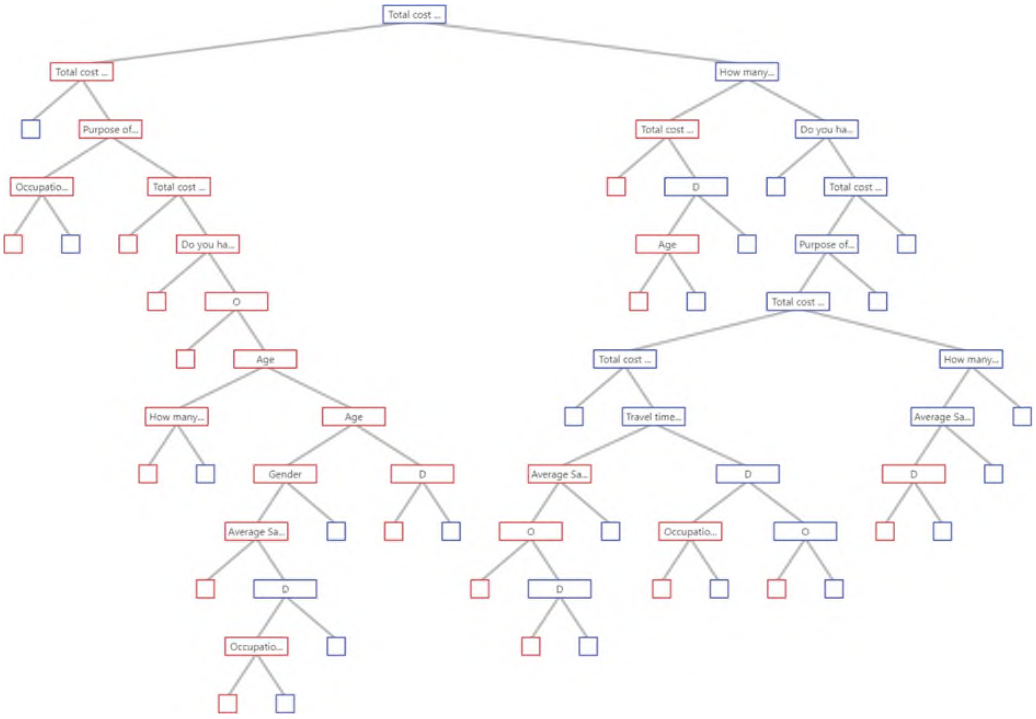


Classification tree model

Similar to the logit model, Minitab was used to develop classification tree models. Various trees were generated using the software algorithm while calculating the misclassification cost (error) of each tree to determine the number of terminal nodes necessary to achieve the optimal model. Finally, the optimal model (35 terminal nodes) was identified to account for a misclassification cost of 0.2472, which is within 1 standard error of the minimum misclassification cost recorded. A simplified view of the classification tree is shown in Figure 5. More details about the extracted tree are provided in the subsequent figures and text.

Figure 5

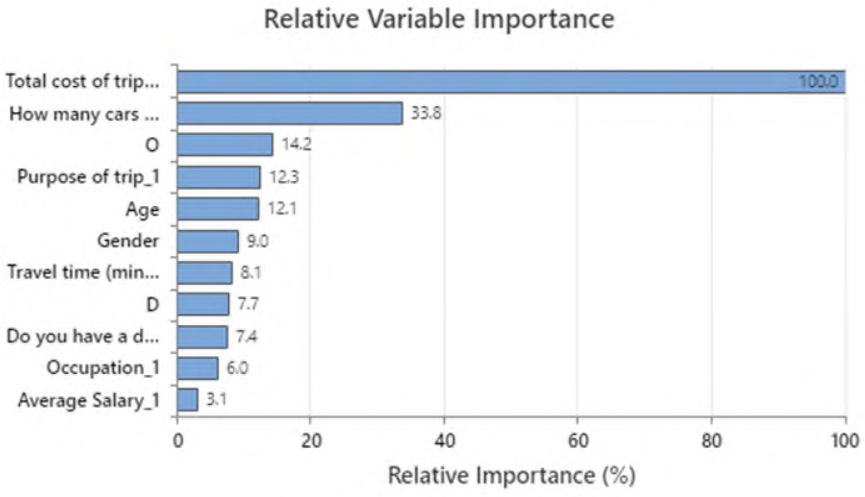
Simplified View of Classification Tree



The model was developed using 3804 responses, 3079 (80.94%) of which belong to Car and the rest for other mode users, respectively. It consists of 35 decisive nodes (out of which 20 represent Car mode and 15 represent other modes). The following variables were found to be affecting the model predictions, namely trip cost, car ownership, Origin-Destination, age, gender, purpose of the trip, travel time, driving license, occupation, and salary. Figure 6 demonstrates the relative variable importance, which is the percentage of improvement achieved when splits are made on a predictor concerning the top predictor (trip cost).

Figure 6

Relative Variable Importance



Variable importance measures model improvement when splits are made on a predictor. Relative importance is defined as % improvement with respect to the top predictor.

Split-half reliability test

The internal consistency of the data is important issue which could greatly influence the model developed from it. One of the methods to check the internal consistency of the data is Split-half reliability test. In this test, the available dataset is randomly divided into two subsets and the correlation between each subset is taken as the measure of consistency. This test also ascertains if the data can be utilized for drawing generalized conclusions about the larger population (Nunnally and Bernstein, 1994).

This analysis was conducted by dividing the data into two samples. The correlation coefficients for each item—current mode, travel time, trip cost, and salary—were computed and found to be 0.63, indicating a moderate to high level of consistency (Nunnally and Bernstein, 1994).

Initial model validation

To evaluate the predictive performance of a model, validation methods are crucial. Therefore, in this study, to ensure that both the logit and classification tree models were generated with adequate accuracy, a 10-fold cross-validation technique was used. This method involves dividing the dataset into 10 equal samples (folds), in which the model is trained on nine and tested on the remaining samples. The process is then repeated 10 times so that each fold serves as the test sample exactly once. As a result, ten varying estimates of the model's performance are generated, and by finding its average for the 10 folds, a more accurate estimate can be computed (Hastie et al., 2009).

The 10-fold cross-validation analysis conducted on the Logit model resulted in a 10-fold deviance R-sq of 34.24% and a 10-fold area under the receiver operating characteristics (ROC) curve of 0.8837. The area under

the curve (AUC) receiver operating characteristic curve (ROC) is commonly used to evaluate the performance of binary classifier models. It measures the model's ability to distinguish between classes by plotting the true positive rate against the false positive rate at each threshold value. The area under this plot ranges from 0 to 1, where a value of 0.5 indicates a model with no predictive power and a value of 1 is considered perfect (Fawcett, 2006). Therefore, despite the relatively low deviance R-sq, the AUC ROC results suggest that the binary model has a good predictive power and can accurately distinguish between the two modes (car and other). In fact, the low deviance R-sq should not necessarily be interpreted as poor performance of the model, as it is a measure that is highly affected by the sample size and is generally used to compare different models alongside other measures rather than evaluating the performance solely on its basis (Fawcett, 2006).

For the classification tree, the 10-fold cross-validation analysis demonstrated that the model can accurately distinguish between positive and negative classes for both the training and testing datasets. The AUC ROC was calculated as 0.9505 for training data and as 0.9236 for testing data. In addition, the percentage of misclassified cases, which is the overall error rate, is largely insignificant, being as low as 11% for training and 13.4% for testing.

Validation survey

The validity of the models was enforced by taking a small survey sample and applying the models to the samples of that survey. 49 diverse responses were collected in this validation survey.

Inputting the data collected from the validation survey into the models, we found that the logit model surpassed the classification tree with an accuracy of 92% compared to an accuracy of 81% for the latter. However, it should be noted that the validation sample only consisted of 49 samples; hence, the superiority of the logit model prediction can be enforced by applying it to a larger sample. Tablo veya Table 9 and Tablo veya Table 10 summarize the findings of the analysis. The accuracy of both models is satisfactory for evaluating the relationships between different variables and mode choices.

Tablo veya Table 9
Logit Model Confusion Matrix (Validation Survey)

Actual/Predict	*Car*	*Other*
Car	41	4
Public Bus	0	3
Total Positive	44	
Accuracy	92%	

Tablo veya Table 10
Classification Tree Model Confusion Matrix (Validation Survey)

Actual/Predict	*Car*	*Other*
Car	37	8
Public Bus	1	2
Total Positive	39	
Accuracy	81%	

Results and Discussion

Logit model results

After reviewing the odds ratios in Tables 6 and 7, the following summarizes the effects of both continuous and categorical variables on the transportation decisions. An increase in the travel time reduces the proba-

bility of choosing car mode over other modes. On the other hand, increased travel costs and salaries increase the odds of choosing a car over other modes. Trips related to education, shopping, and other purposes lead to higher odds of choosing a car over other modes compared to work-related trips. Moreover, shopping and other-purpose trips result in higher odds of choosing a car over other modes than education- related trips. Employees are more likely to choose a car over other modes than students and Others (unemployed, retired and others). Students are more likely to choose other modes when compared to others.

According to these observations, it can be concluded that trip cost is the most significant trip-related factor influencing the mode choice behavior of commuters in Bahrain. Similar findings were noted by (Kumar et al., 2004) in a study that focused on intercity bus services in India, where travel expenses were found to harm bus travelers' utility. Additionally, students have a higher likelihood of traveling by other modes compared to other occupations, and interestingly, trips that are produced for purposes other than work, education, and shopping are 51 times more likely to be done by car than work trips. Similar findings have been reported in previous studies, such as those by Daisy et al. (2018).

Classification tree model results

The node rules extracted from the binary classification tree provided beneficial insights into the attributes of commuters in Bahrain and their trips, which can be used to improve the effectiveness of current transportation policies and systems.

Upon reviewing the rules, the following was noticed. Education and work are the primary purposes for car trips, which are mostly undertaken by commuters who own 1, 2 or 3 cars. Most car trips originate from the capital city. Other modes are mainly used for educational purposes. Surprisingly, most bus users have a driving license. This can be attributed to several reasons:

o Having a driver's license gives individuals the flexibility to choose between different modes of transportation. Some may use a bus to avoid parking problems or high fuel costs but may possess a driving license as an alternative.

o Young individuals who recently obtained their driving license may still prefer to travel by bus, especially if they have limited financial resources.

o They may possess a driving license as a job requirement (taxi drivers, bus drivers, truck drivers, etc.) but cannot financially afford a car for personal use.

Policy implications

These findings lead to some important policy implications that can be used for reducing the dominance of car use, consequently car ownership, and promoting other sustainable modes of transportation in Bahrain. More efforts are required to plan and provide cheap modes of transport that can serve longer distances. In terms of area, the focus should be more on the capital governorate, which also contains the diplomatic and other business-related areas of Bahrain. The results show that young people, especially students, and those with lower salaries have a higher likelihood of using other modes. Hence, future plans should strive to attract high-income people, consequently being older, to use other modes for their work-related trips. These trips eventually cause recurring congestion on highways (Roy et al. 2020). Hence, contemporary solutions, such as metro, autonomous mobility-on-demand, and mobility-as-a-service models, could be more appealing for these types of travelers instead of traditional bus or existing modes of transportation.

Conclusions

This research focused on presenting the demanding need for thorough modeling of the current mode choice in Bahrain. Two types of models used in this research—the logit model and the classification tree model. The findings of this research provide important contributions to construct solid recommendations for promotion of sustainable transportation systems in Bahrain and other neighboring countries who face similar issues of car dominance.

The primary outcomes derived from this research are as follows:

- Trip production is distributed in almost equal proportions among the four governorates.
- The capital governorates most trips for various purposes, including business and diplomatic activities.
- The majority of trips are primarily undertaken for work, followed by shopping and education.
- Trip cost was identified as the most influential factor for mode choice in Bahrain.
- Car is likely to be preferred by commuters with high socioeconomic status.
- The travel time and speed of travel play a considerable role in shaping mode choice decisions; trips by bus account for longer travel times than car trips.
- Other modes of transport are primarily used by students for education-related trips.
- The accuracy of the logit model in modeling binary responses was proven to outperform that of the classification tree in predicting the choices in the validation survey.

The findings of this study identified the traveler groups and areas that are the major causes of the dominance of cars in mode choice. The focus for future planning should be on providing convenient and contemporary solutions, such as metro, autonomous mobility-on-demand, and mobility-as-a-service models, for minimizing recurring congestion on roads due to work trips. The findings also show that young students and people from low-income categories are likely to be more attracted to future alternative modes of transport. The findings of this study are consistent with those of previous studies. Hence, the recommendations of this study can be applied to a wider scale, especially including the neighboring countries.

On the basis of these findings, several future revenues are recommended to be explored. One recommendation is to extend the analysis to incorporate more qualitative variables, such as comfort, safety, and network characteristics. Additionally, studying the effects of transport measures on mode choice, such as public-transport subscriptions, road pricing, parking fees and congestion charges, could provide valuable insights. Another avenue worth investigating is the connection between sustainable transportation and other sustainable objectives such as health, climate change, and energy.

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Research Article

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Geospatial Mapping for Effective Public Infrastructure: A Scenario of Bus Stops in Akure, South Ondo State, Nigeria

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Abstract The bus stop is a designated place where buses stop for passengers to board and alight from. This study aims to map bus stops for effective public infrastructure using Geographic Information Systems (GIS). A total of 73 bus stops were identified within the study area. Data for the bus stops were collected using a hand-held GPS Map 76 CSX, while attribute data was sourced from the Ministry of Transportation and the base map from Google Earth. The study employed ArcGIS 10.3 software, where a database was created and different queries were performed based on attribute data. Two spatial distribution methods were used: the Quadrat method and the Nearest Neighbour method. The Quadrat method yielded a mean of 0.081111, a variance of 2.78145, and a variance/mean ratio of 3.432507, while the Nearest Neighbour method produced a z-score of −9.84310 and a p-value of 0.00000. Buffer analysis at 300 m and density analysis were also performed. Results from both methods indicated that the bus stops were clustered. The study concludes that mapping and analyzing bus stop spatial distribution is essential for optimizing public infrastructure.

Keywords Geospatial Mapping · Infrastructure · Bus Stops

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Geospatial Mapping for Effective Public Infrastructure: A Scenario of Bus Stops in Akure, South Ondo State, Nigeria

A bus stop is a designated place where buses stop for passengers to board or alight from and is a vital component of a successful transportation system (Fatunmibi, 2018, Daudu et al., 2022). Bus stops play an important role as they serve as transit service points of contact between the passenger and the bus (Olowosegun and Okoko, 2012). These are normally positioned on the highway and are distinct from off-highway facilities such as bus stations. The construction of bus stops tends to reflect the level of usage. Stops at busy locations may have shelters, seating, and possibly electronic passenger information systems; less busy stops may use a simple pole and flag to mark the location (Fatunmibi, 2018). Bus stop design and location are recognized as crucial elements in the drive to improve the quality of bus services and public transport in general and also to meet the required convenience and comfort of bus stops, just as the Bus Priority Team (2006) stressed their high level of importance. Any urban area must have an effective and well-planned public infrastructure to operate efficiently. An efficient public infrastructure system is essential for ensuring commuters' accessibility, connectivity, and comfort in the context of transportation. An effective tool for improving public infrastructure, such as bus stops, is provided by geospatial mapping in conjunction with data analysis.

The process of geospatial mapping entails the gathering of pertinent information on current bus stops, the examination of spatial patterns and variables affecting their placement, and the visualization of this data on maps to aid in comprehension and decision-making. Key information on the distribution of bus stops, their proximity to population centres, the demand for transportation, and accessibility to significant facilities like schools, hospitals, and commercial districts can be obtained by geospatial analysis. The management of traffic and congestion depends heavily on bus stops, which are an essential part of the transportation infrastructure (Allison, 2002). The design and placement of bus stops are acknowledged as key components in the effort to enhance the quality of bus services and public transportation in general. The term "Total Journey Quality" refers to the idea that all parts of the journey must be taken into account, including the fact that bus passengers are also pedestrians at both ends of the bus trip. It is important to consider the comfort and convenience of bus stops (Bus Priority Team, 2006). However, the difficulties that make bus use in Nigeria ineffective include illegal parking, abandoned vehicles, and cramped bus stops (Rodrigo and Tyler, 2004), as well as the un-spacious nature of bus stops in Nigeria, which impedes traffic flow along them. These challenges are more prevalent within the city of Lagos (Olaogbebikan et al., 2013).

In Nigeria and the world over, there is no denying the fact that transportation is essential to the fabric of urban life, as it enhances the quality of life of the citizens and delivers dividends to the entire populace. The basis of this assertion is not farfetched, as the study conducted in this context by O'Sullivan (2000) affirms that the quality of life of its citizens is heavily dependent on the efficiency and effectiveness of its transportation system. As good as the system is, there are also some identified threats to it. As such, public transportation is an essential system that helps curb the menace of transportation. The latter is diversified, and each of its components is highly pertinent to the delivery of a sustainable transport system. Among the components or factors that need to be considered for the proper implementation of the public transportation system are bus stops and bus stations.

A further study by Matisziw (2006) stated that to increase urban mobility, bus stops and articulated bus services must be placed in the best possible locations. By doing so, both those who use public transportation and those who own private vehicles will be encouraged to do so. As a result, there may be fewer private

vehicles on the road, which would ease traffic and delays. In addition, research done in this area by Oyedepo (2014) showed that the demise of established public transportation networks has sparked a rapid rise in non-traditional modes of transportation, originally provided by minibuses, shared taxis, and vans, and more recently by commercial motorcyclists.

It is important to keep in mind that bus stops are geographically positioned in various places for various reasons; as a result, using spatial optimization to support strategic planning can help improve the current service. Given precise restrictions on the number of stops to be located, choosing new service stops will allow access to places that do not already have enough access to a facility for servicing vehicles The location of a bus stop is heavily influenced by the volume of traffic in a particular area. This study intends to use the proper tools to evaluate the spatial distribution and mapping of bus stops in the study region. The problem of the spatial distribution of bus stops necessitates the use of digital mapping and Geographic Information Systems (GIS). To evaluate policy objectives and make future improvement plans, it is essential to measure the performance and efficacy of public bus transportation (Murray et al., 1998).

A study conducted by Shatnawia *et al.,* (2020) optimized bus stop locations in Amman, Jordan, using Geographic Information Systems (GIS), Particle Swarm Optimization (PSO), and Genetic Algorithm (GA) to enhance travel time and serviceability. GIS reduced travel time by up to 23.25%, PSO achieved a 39% reduction, and GA yielded a 47.96% reduction in Zahran Street. While increasing the number of bus stops on Al-Quds Street increased the travel time from 12.25 to 50.71 minutes, it improved accessibility by reducing the walking distance from over 2000 m to approximately 400 m. The models demonstrated reliability when applied to other roads, proving useful for urban planning and promoting sustainable, efficient public transportation systems.

This study evaluated public transportation accessibility in Hyderabad, Pakistan, using ArcGIS-10.8 network analysis and a questionnaire survey of 400 participants (Mir et al., 2024). Findings revealed that 53.5% of stops are highly accessible (5-min walk), while 29.3% are moderately accessible (10 min), 11.03% are poorly accessible (15 min), and 6.17% are inaccessible (20+ min). Inner-city areas show better accessibility, with distances ranging from 500 to 800 m, whereas stops 1600 m away require over 20 minutes of walking. Combining GIS analysis with commuter feedback highlights critical accessibility challenges, offering insights for reconfiguring transit systems and supporting sustainable urban development (SDG-11) in Hyderabad and similar urban centres.

Yaiza et al., (2024) combined geography, urban transit planning, and statistical learning to predict bus demand at the top level using a Generalized Additive Model. Incorporating non-linear relationships and spatial dependence, the model achieves a pseudo R-squared of 0.79. GIS processing identifies key factors such as land use, socioeconomic characteristics, and transit supply, with positive impacts from nearby universities, hospitals, and lodging areas. The methodology highlights the spatial dependencies for stops within 1.15 km and provides transferable insights for transit planners. Applications include route design, stop optimization, and urban planning impact assessment, promoting sustainable mobility with environmental and social benefits.

A study conducted by (Lach,2021) presents an evaluative framework to assess neighbourhood safety and transit convenience using indicators like elevation, service areas, crash statistics, and bus stop infrastructure. A case study of the Vine Neighborhood in Kalamazoo, MI, analyzed data with ArcGIS Pro, revealing that high elevations and crash rates compromise transit convenience. Improvements, such as pedestrian amenities or additional stops, were suggested. While further research is needed for practical implementation, this framework offers a foundation for creating safer, user-oriented transit systems that enhance residents' quality of life.

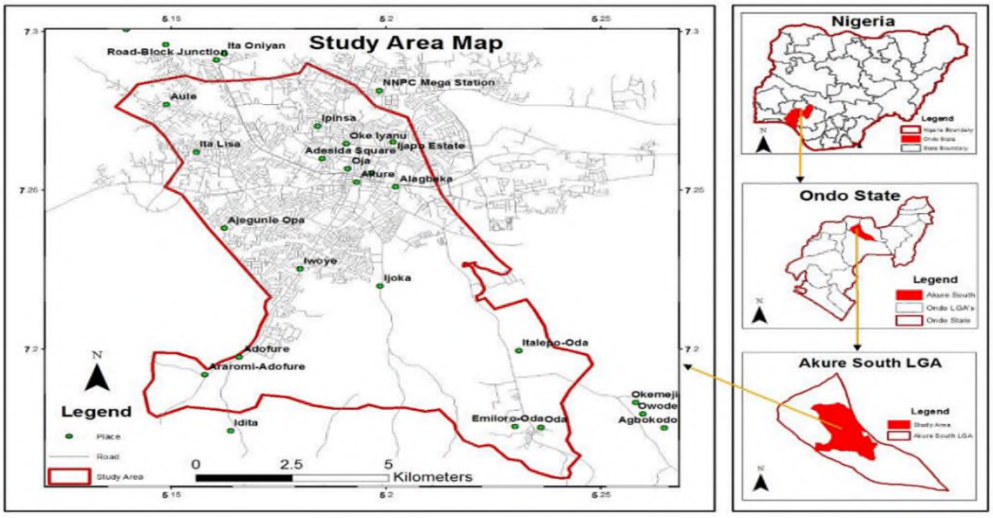
Hakan and Kocaman (2018) conducted a study on GIS Bus Stop Optimization for the Sakarya Public Transportation System. This study addresses the growing demand for urban transportation by analyzing Sakarya Metropolitan Municipality's (SBB) bus routes and stops using GIS. The research evaluates service levels in relation to regional populations and proposes an optimized bus stop model. The alternative model improves the current stop locations, aiming to enhance service efficiency and reduce traffic intensity.

Alamri *et al.*, (2023) evaluated the adequacy and accessibility of public transportation in Melbourne's residential areas using a newly developed measurement model. By analyzing blank spots, transport options, and population density across local government areas (LGAs), the findings reveal that lower-density areas face reduced accessibility, while higher-density areas lack enhanced services like night-time and weekend options. This research highlights gaps in Melbourne's public transportation system, aiming to guide improvements by addressing geographical and demographic disparities, ensuring equitable access and supporting the city's growth.

Study Area

The study area selected for this research is Akure Environs in Ondo State, in the South-Western part of Nigeria. The geographic location is approximately between Latitudes 07°15′N to 07°30′N and Longitude 05°15′E to 05°25′E. The topography of the Basement Complex terrain of Akure is generally undulating with a virtually rugged terrain consisting of hills and valleys, with field recorded elevation varying between 330m above mean sea level in the south-western border (Nigeria Army barracks) and 399 m in the north-eastern border (Shagari Estate) (Michael and Franklin 2017 as cited by Tata and Ono (2018)).

Figure 1
Study Area Map of the Akure Environment
Source: (Tata and Ono, 2018)



Methodology

The attribute data (names and locations of the existing bus stops) were obtained from the Ondo State Ministry of Transportation. The Google Earth Imagery of the study area was clipped out of Google Earth to derive the base map through the digitizing process. The geographic coordinates of the existing bus stops were picked primarily from the field, geocoded, and integrated into the base map using ArcGIS 10.3 software. A GIS database was created, and the spatial and attribute data were encoded and queried (selection by

Location and Attributes). Quadrat and Nearest Neighbor using Microsoft Excel 2010 and ArcGIS 10.3 software, respectively, were used to determine the spatial distribution of the bus stops.

Quadrat analysis was used to estimate how the intensity of a point pattern varies over an area. It is a method suited for investigating first-order effects. The region was partitioned into sub-regions using AutoCAD software of equal area, or quadrats of 1000m 1000m, and superimposed on the bus stops in ArcGIS. The number of events in each quadrat was used to summarize the spatial pattern.

λ = N/A

where λ = intensity

N = number of bus stops

A = area

To describe the degree of spatial clustering of the point distribution, the nearest neighbour distance method uses the average distance from every point to its nearest neighbour point. Nearest neighbour distances provide an estimate of the presence of spatial dependence among events.

Results And Discussion

The variance-to-mean ratio of the event counts in the quadrats was used as a static test for randomness based on the chi-square frequency distribution. We had 90 quadrats. The test statistic is given by: (sum of squared differences)/Mean.

$$\frac{\sum_{i=1}^{n}(X_i - X^-)^2}{X^-} = \frac{\sum_{i=1}^{n} X_i^2 - \left[\frac{(\sum X_i)^2}{N}\right]}{X^-}$$

The values of the test statistics in our cases would be: $\frac{307-59.21111111}{0.8111111} = 319.2820914$

For degrees of freedom: N 1 = 90 1 = 89

Confidence interval 95% = 0.95 = 1 0.95 = 0.05

The value of the chi-square at the 0.95 level is 79.08.

If the variance-mean ratio is above 1, it is a clustered distribution; therefore, we conclude that the bus stops are clustered.

Table 1

Bus stops in each quadrat and the intensity

0	2	0	0	0	0	0	0	0
0	2	0	0	0	0	0	3	0
0	0	4	0	0	0	1	0	2
0	0	0	4	5	2	1	1	1
1	2	0	3	5	11	4	2	0
0	0	2	0	1	3	0	0	0
0	0	0	0	0	2	0	0	0
0	0	0	0	0	4	0	0	0
0	0	2	1	0	1	0	0	0
0	0	1	0	0	0	0	0	0
			intensity λ - number of events/Area					
0	0.000002	0	0	0	0	0	0	0
0	0.000002	0	0	0	0	0	0.000003	0

0	0	0.000004	0	0	0	0.000001	0	0.000002
0	0	0	0.000004	0.000005	0.000002	0.000001	0.000001	0.000001
0.000001	0.000002	0	0.000003	0.000005	0.000011	0.000004	0.000002	0
0	0	0.000002	0	0.000001	0.000003	0	0	0
0	0	0	0	0	0.000002	0	0	0
0	0	0	0	0	0.000004	0	0	0
0	0	0.000002	0.000001	0	0.000001	0	0	0
0	0	0.000001	0	0	0	0	0	0
	area - l^2	area - 1000000M^2						

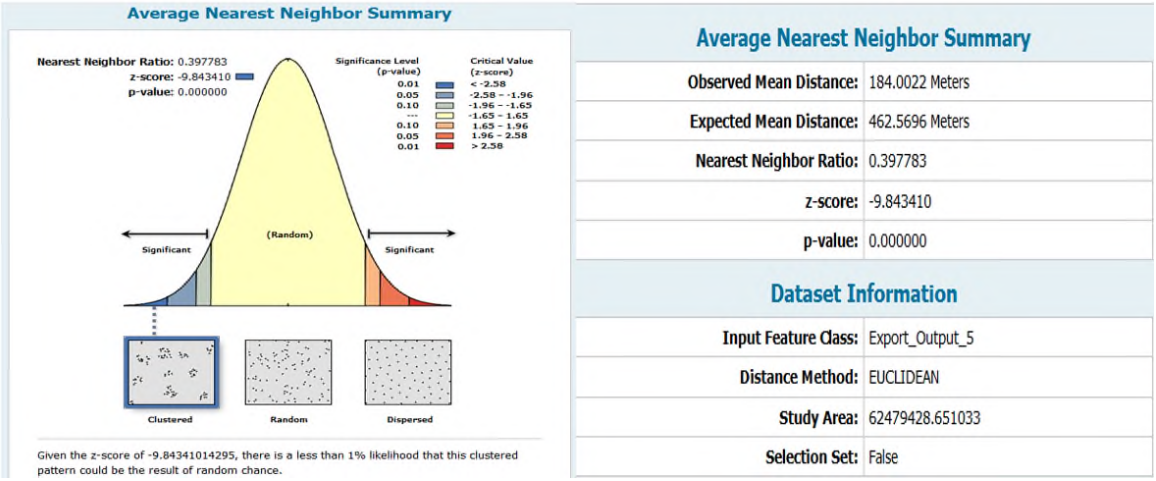
The quadrant method of analysis (Table 1) for bus stops was carried out to ensure equitable and efficient public transportation coverage. This method divides the area into manageable sections (quadrants), enabling a systematic evaluation of bus stop distribution, accessibility, and serviceability. It helps identify underserved areas, optimize stop locations, balance the spacing between stops, and ensure connectivity within neighbourhoods. Additionally, the quadrant method provided actionable insights for transit planning by highlighting high-demand zones, blank spots, and areas with overlapping services. Finally, this analysis boosts traveller accessibility, reduces walking distances, and promotes sustainable urban movement through better design of the transit network.

The ratio of nearest neighbours (Figure 2) serves to establish “how far the bus stops may be congregated or distributed”. A value <1 indicates clustering while >1 indicates dispersion. The Z-Score shows the statistical deviation of randomness from the observed pattern. A Z-Score with a high absolute value indicates either high levels of clustering or dispersion. The P-value complements the hypothesis, verifies the significance of the pattern, and informs if the chance occurred randomly. The spatial distribution of the bus stops, as revealed by the nearest neighbour analysis (Figure 2), indicates a clustered pattern. This is confirmed by a p-value below the significance level and a negative z-score, both of which signify significant clustering of the bus stops as affirmed by (Lach, 2021).

A higher clustering of bus stops can be observed in this data with a Nearest Neighbor Ratio of 0.4 z score of −8 and p value of 0.000 In this case, certain areas might be over-serviced while some have far fewer stops, which indicates that the placement of the stops requires reallocation or fine tuning. Reliable data is provided with this ANN analysis that aids transit planners in developing a better spatial distribution of bus stops and promotes the idea of a well-integrated and accessible public transportation system.

Figure 2

Nearest Neighbor summary

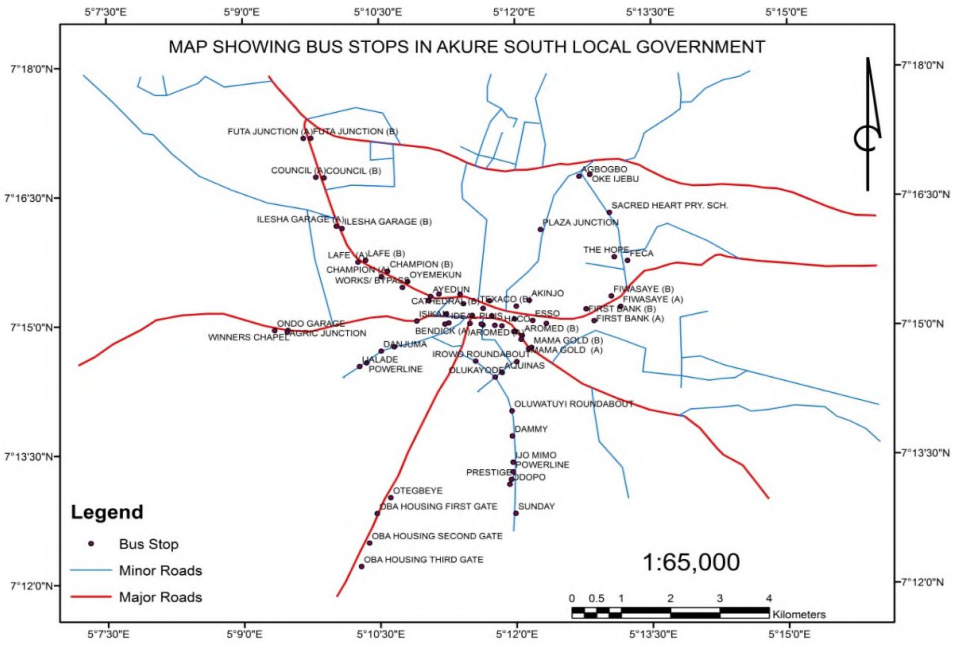


The clustering of bus stops (Figure 3) in urban areas highlights areas of high demand, such as central business districts, schools, or hospitals, enabling planners to enhance services in these zones. However, it may result in unequal coverage, leaving low-density or suburban areas underserved and contributing to traffic congestion and resource redundancy. Urban planning must address these challenges by optimizing stop (Figure 3) locations, balancing high-demand and underserved areas, and integrating bus networks with other transit systems. This ensures equitable accessibility, reduces car dependency, and promotes sustainable urban mobility, supporting goals like the Sustainable Development Goal (SDG-11) for sustainable cities and communities.

The Nearest Neighbor (ANN) analysis is highly suitable for analyzing bus stop distributions because it evaluates the spatial arrangement of points, helping to determine whether bus stops are clustered, randomly distributed, or dispersed across a given area. This is critical for assessing the efficiency, accessibility, and equity of public transportation systems.

Figure 3

Map showing bus stops in the Akure South Local Government



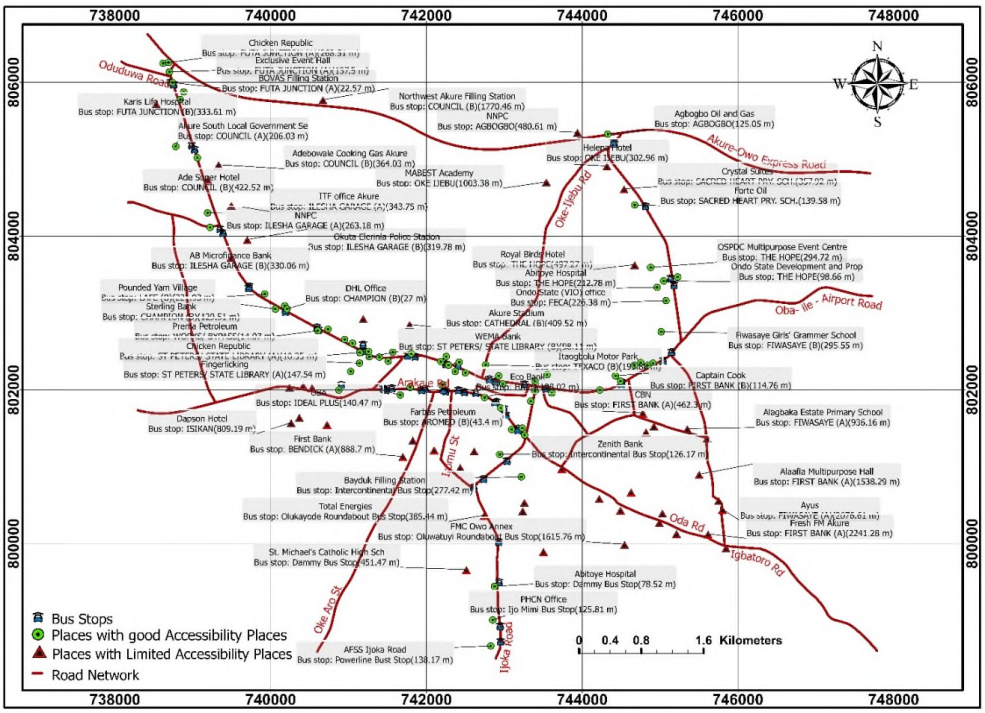
Proximity Analysis

The spatial join and the Near tool were used to allocate the closest bus stop to each chosen location (such as hospitals, churches, schools, hotels, etc.). Based on the spatial proximity, the nearest bus stop attributes to each location in the dataset were linked together using the spatial join. The Near tool was used to conduct a nearby neighbourhood analysis, which involved calculating the distance between each location and its closest bus stop. Equation 1 was used to calculate the travel and walking time (in minutes) between the two nearest bus stops as well as the proximity analysis between the bus stops (Table 1). In this study, 300 m was the maximum permitted walking or travelling distance. Additionally, the permitted walking speed is 4.5 km/h.

$$Walking\ Time\ (T) = \frac{Walking\ Distance\ (km)}{Walking\ Spead\ (km/hr)} * 60\ mins \quad (1)$$

Figure 4

Proximity Analysis Result



The outcome of the proximity analysis is shown in Figure 4. 72 locations were discovered to be just a few minutes walk from bus stations, indicating adequate accessibility to public transportation. Additionally, 48 locations are far from bus stations, which limits their access to public transportation. Considering this, a location for new bus stops was suggested.

Table 2

Walking time between bus stops

From	To	Walking Distance (km)	Walking Time (mins)
Sammy Store (B)	Sammy Store (A)	0.023	0.308
Champion (B)	Champion (A)	0.024	0.320
Mama Gold (B)	Mama Gold (A)	0.025	0.334
Lafe (B)	Lafe (A)	0.025	0.334
First Bank (B)	First Bank (A)	0.027	0.364

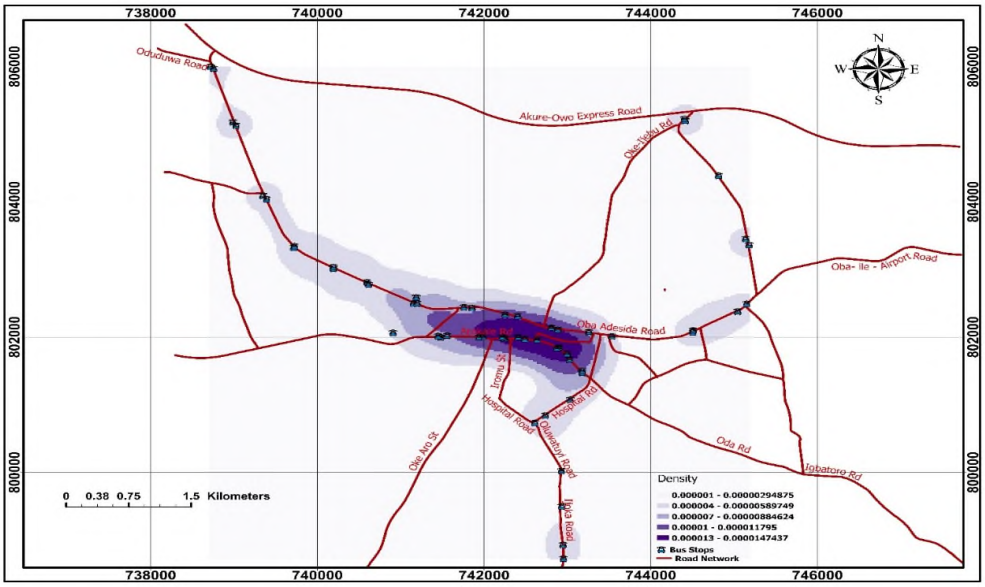
From	To	Walking Distance (km)	Walking Time (mins)
Agbogbo	Oke Ijebu	0.028	0.367
Bendick (B)	Bendick (A)	0.035	0.462
Health Center (B)	Health Center (A)	0.036	0.477
Works/Bypass	Oyemekun	0.038	0.503
Oyemekun	Futa Junction (A)	0.038	0.503
St Peters/State Library (B)	Futa Junction (B)	0.045	0.604
St Peters/State Library (A)	Council (A)	0.045	0.604
Futa Junction (B)	Futa Junction (A)	0.047	0.627
Council (B)	Council (A)	0.065	0.862
Ilesha Garage (B)	Ilesha Garage (A)	0.067	0.889
Ideal Plus	Bendick (A)	0.082	1.092
Texaco (B)	Lafe (B)	0.083	1.110
Texaco (A)	Champion (A)	0.083	1.110
Glober Plaza (A)	Glober Plaza (B)	0.083	1.113
Aromed (B)	Aromed (A)	0.088	1.176
Ayedun	Council (A)	0.088	1.179
Cathedral (B)	Council (B)	0.098	1.303
Cathedral (A)	Ilesha Garage (A)	0.098	1.303
The Hope	Feca	0.098	1.307
Haco	Glober Plaza (A)	0.144	1.925
Post Office (B)	Ilesha Garage (B)	0.154	2.048
Post Office (A)	Lafe (A)	0.154	2.048
Fiwasaye (B)	Fiwasaye (A)	0.156	2.075
Aquinas Bus Stop	Olukayode Round Bus Stop	0.167	2.230
Powerline Bust Stop	Ijo Mimi Bus Stop	0.202	2.694
Adegbemile	Champion (B)	0.284	3.785
Esso	Oyemekun	0.284	3.785
Intercontinental Bus Stop	Aquinas Bus Stop	0.380	5.062
Isikan	Futa Junction (B)	0.496	6.609
Oluwatuyi Bus Stop	Dammy Bus Stop	0.527	7.026
Sacred Heart Pry. Sch.	Oke Ijebu	0.906	12.081

Density Analysis

To visualize the spatial distribution and locate the concentrations of bus stops, Density Analysis was performed. To perform the Density Analysis on the bus stop dataset, which includes the X- and Y- coordinates of each bus stop, the “Kernel Density” tool on ArcGIS Pro software was used.

Figure 5

Density Analysis Result



In Figure 5, the density analysis revealed the concentration of the bus stops. The results show that bus stops are unevenly distributed across the study area. Notably, Mixed-use areas (banks, offices, restaurants, hotels, hospitals, petrol stations, etc.) emerged as prominent hotspots. These high-density cluster areas indicate that this area is well supported by public transportation and serves as an attractive destination for transit riders. However, the density analysis also reveals disparities in the bus stop distribution. Some routes exhibit lower densities of bus stops, while others exhibit no bus stops. The outcomes of the density analysis provide valuable insights for infrastructure decision-making and urban planning. High-density areas around bus stops demand targeted investment in transportation infrastructure and enhanced transit services. Moreover, the identification of low-density areas underscores the need to expand public transportation access and improve connectivity for residents. Addressing these planning considerations can lead to well-integrated urban development and more efficient transit systems.

Buffer Analysis

Buffer analysis involves creating a buffer zone around a point, line, or polygon feature. A buffer zone is a defined area around each feature within a specified distance. In this study, a buffer (which represents a walking distance) of 300 m was created around each bus stop (Figure 6). This is approximately 5 minutes at a walking speed of 4.5 km/h. This analysis was carried out to give a clearer overview of the places that fall within a 300-m walkable distance of each bus stop and to determine the area that is mostly in need of bus stops.

The buffer analysis successfully delineated the service areas around each bus stop, representing the areas within a reasonable walking distance from the stops, and the result is shown in Figure 6. The result reveals that most places along Oba-Adesida and Arakale, the hospital, Oluwatuyi, and Ijoka Road fall within the coverage of each bus stop. Conversely, the buffer analysis also revealed areas with limited service coverage around certain bus stops. It can be seen clearly from Figure 6 that places along the Oke-Aro, Oba-Ile-Airport, Oda, Oke-Ijebu, Igbatoro, and Akure-Owo express roads have limited coverage because there are inadequate or no bus stops along these roads. This reveals that more bus stops are needed in these areas with limited coverage (Underserved areas).

Figure 6

Buffer Analysis Result

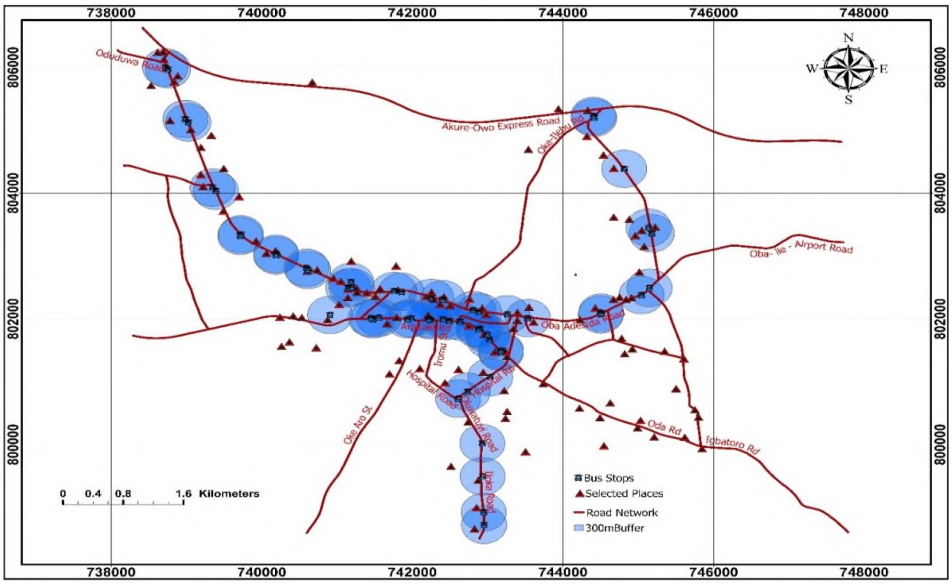
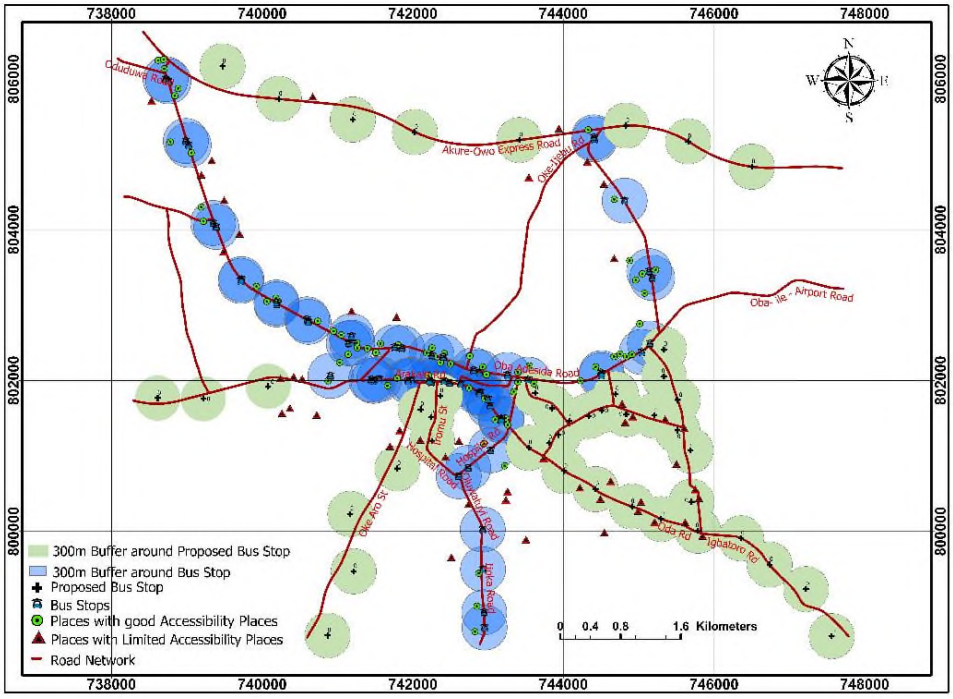


Figure 7 shows the spatial distribution of the bus stops and their accessibility within a 300 m buffer zone in relation to the proposed bus stops in the study area. Areas with good accessibility are shown in blue, while those with limited accessibility are highlighted in green. The results reveal significant gaps in coverage, particularly in marginal areas, where limited accessibility zones dominate. The Proposed bus intends to cover up areas not having access to bus stops, to enhance connectivity and service equity. Furthermore, this analysis reveals the need to optimize bus stop locations to ensure all-inclusive access, reduce walking distances, and improve public transportation service within these areas.

Figure 7

Shows the locations of the proposed bus stops



Conclusion

The study assesses the spatial distribution of Bus Stops in the Akure south local government area of Ondo state through the identification number of bus stops, mapping of the bus stops, generating the attribute data of bus stops, creation of a GIS database for bus stops and, analyzing the spatial distribution of bus stops in the study area. The Quadrat and the Nearest Neighbor analysis results show that the bus stops are Clustered. Furthermore, the proximity analysis between the bus stops at 300 m was the maximum permitted walking or travelling distance. The outcome of the proximity analysis shows that 72 locations were discovered to be just a few minutes walk from bus stations, indicating adequate accessibility to public transportation while 48 locations were far from bus stations, which limits their access to public transportation. The density analysis carried out revealed the concentration of bus stops. The results show that bus stops are unevenly distributed across the study area. Notably, Mixed-use areas (banks, offices, restaurants, hotels, hospitals, petrol stations, etc.) emerged as prominent hotspots. The successful implementation of this study can positively impact the lives of residents by providing a more reliable, convenient, and sustainable public transportation system.

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Exploring Uncertainty in Maritime Collisions: A Qualitative FRAM Approach

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Abstract

This study employs the Functional Resonance Analysis Method (FRAM) to investigate the dynamics of maritime collisions characterized by inherent uncertainties and interdependent operational variables. Through qualitative analysis, FRAM can identify functional variabilities within the system and explore how interactions among operational functions contribute to risk accumulation under complex conditions. The analysis highlights critical points where deviations in timing, environmental factors, and human responses intersected, escalating risks and ultimately leading to the collision. Key findings reveal how delayed command actions, communication gaps, and environmental challenges interact to create cascading effects that amplify safety risks in high-stakes scenarios. By capturing these intricate interactions, the study demonstrates FRAM's effectiveness in analyzing systemic risks and emergent behaviors in complex systems. This approach offers insights into the mechanisms by which operational uncertainties compromise safety and highlights the need for resilient navigational systems. The findings enhance the understanding of maritime collision dynamics and highlight FRAM's suitability for analyzing complex incidents in uncertain environments. By addressing these challenges, the study contributes to improving safety protocols and operational resilience, offering valuable perspectives for managing risks in high-stake maritime operations.

Keywords

Qualitative Safety Evaluation · Maritime Collision Dynamics · Maritime Accident, Systemic Uncertainties · Navigational Risk · Functional Interactions

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Exploring Uncertainty in Maritime Collisions: A Qualitative FRAM Approach

Introduction

Maritime operations are inherently susceptible to a range of risks, including navigational hazards, unpredictable weather, and operational complexities, which collectively contribute to the occurrence of maritime accidents (Latt, 2024). Despite ongoing advancements in safety regulations and navigational technologies, the persistent incidence of maritime collisions highlights a critical gap in understanding and managing systemic risks within these operations (Güler et al., 2024; Bicen et al., 2021). These accidents often stem from the complex interplay among human, technical, and environmental factors, with human error frequently identified as a major contributor. However, issues like fatigue, communication gaps, and decision-making under pressure demonstrate that traditional approaches may fail to capture the underlying dynamics of such incidents (Sheng et al., 2024).

Risk assessment approaches in maritime safety have traditionally aimed to identify specific causal factors through structured methodologies, such as Fault Tree Analysis (FTA) (Senol, 2024), Event Tree Analysis (ETA) (Daas and Innal, 2023), Bow-tie (BT) Analysis (Papageorgiou et al., 2024), Failure Mode and Effects Analysis (FMEA) (Luo et al., 2024), and Bayesian Networks (BN) (Animah, 2024), which often rely on a mechanistic decomposition of systems and a focus on linear causality (Ay et al., 2022). In contrast, the Functional Resonance Analysis Method (FRAM) offers a holistic approach, examining how interactions among various system components contribute to functional outcomes in both expected and unforeseen ways (Hollnagel, 2017). FRAM enables an understanding of how risks arise nonlinearly through system interdependencies, offering a unique perspective in scenarios with high uncertainty and complex interactions (Zheng et al., 2024).

In this study, FRAM was applied to analyze a maritime accident documented in a Marine Accident Investigation Branch (MAIB) report in which a definitive cause could not be determined due to the complexity and inherent uncertainties of the incident. This study aims to bridge the methodological insights and practical outcomes by demonstrating the application of FRAM in a real-world maritime collision scenario. On the methodological side, the proposed method demonstrates how FRAM can systematically capture functional interactions and variability in uncertain operational environments. From a practical perspective, the findings provide actionable recommendations for improving safety protocols and enhancing maritime resilience. This study leverages FRAM's systemic approach to qualitatively examine how functional components within the accident interact, providing a comprehensive perspective on maritime collision dynamics. By highlighting interdependent factors that traditional methods may overlook, this research aims to contribute valuable insights into maritime safety, emphasizing the need for resilience when managing uncertainties in complex operational systems.

The Functional Resonance Analysis Method (FRAM) distinguishes itself from traditional risk assessment methods by examining how a system functions under varied conditions rather than focusing solely on causal chains (Yu et al., 2024). FRAM explores how daily interactions within a system contribute to functional outcomes, offering insight into how flexibility and resilience can prevent accidents when unexpected challenges arise (Yasue and Sawaragi, 2024; Hollnagel, 2017). Unlike approaches that attribute incidents to single-point failures, FRAM uniquely focuses on how systems operate in practice, shedding light on both expected and unexpected functional interactions. While other systemic approaches, such as STAMP, STPA, and CAST, also consider systemic interactions (Patriarca et al., 2022), FRAM emphasizes the emergent nature of risks and explores how they dynamically resonate within a system, rather than merely tracing causal pathways (Viran

and Mentes, 2024). This feature renders FRAM particularly effective for analyzing the dynamic behavior of complex systems under stress (Liu et al., 2024).

FRAM's adaptability has enabled its application across various high-risk industries (Kumar et al., 2024), such as healthcare (Sujan et al., 2024; Saadi et al., 2024), nuclear energy (Fu et al., 2022; Lee and Lee, 2018), aviation (Okine et al., 2024; Tengiz and Unal, 2023; Hollnagel et al., 2008), and rail transport (Rad et al., 2023). In these fields, understanding system dynamics is essential for identifying underlying risks that may not be immediately apparent. FRAM's capacity to reveal intricate interdependencies and emergent risks provides a deeper view of potential failure points within complex operations, especially those that may elude more linear, deterministic methods (Patriarca et al., 2020). Applications in these sectors highlight FRAM's effectiveness in addressing multifaceted operational challenges, offering a holistic approach to risk management and system resilience (Tian and Caponecchia, 2020).

In the maritime sector, FRAM has been employed to address similar complexities, such as operational safety in cargo handling, emergency response coordination, and navigation in constrained waters (Ma et al., 2023). Studies have demonstrated FRAM's capability to account for the intricate interplay among human, technical, and environmental factors in maritime operations, advancing the industry's approach to safety by shifting the focus from isolated causes to a broader view of systemic functionality (Salihoglu and Bal Beşikçi, 2021).

In this study, FRAM was used to investigate a maritime accident where a clear cause could not be identified due to the inherent uncertainties and complexity of the event. This accident, documented in the UK Marine Accident Investigation Branch (MAIB) database, lacked a definitive explanation, presenting an ideal case to explore using FRAM's systemic analysis (MAIB, 2020). By assigning valid data from the MAIB accident report as input variables, FRAM allows for a qualitative examination of the accident, treating each functional component as if it operates independently while contributing to the larger system outcome.

This study's unique contribution lies in its focus on an accident where conventional analyses did not yield a definitive cause. By applying FRAM, this research provides a holistic view of the accident's underlying dynamics, identifying functional interdependencies that traditional methods may overlook. This approach not only contributes to understanding maritime accidents with ambiguous causes but also underscores the importance of systemic resilience in the prevention of future accidents. In doing so, this study offers an innovative approach to maritime safety, enriching the field with insights into handling uncertainties in complex operational systems.

Methodology

This study employs the Functional Resonance Analysis Method (FRAM) to investigate a complex maritime accident characterized by high uncertainty and the absence of a definitive cause. The methodology involves identifying key functions within maritime operation, modeling their interactions using the "FRAM Model Visualizer" (FMV), and examining how variability in these functions affects the system and contributes to control loss and increased risk. By adapting FRAM to address the specific challenges of maritime accidents, this study offers a detailed, qualitative analysis of how complex dynamics within a high-risk operational environment contribute to the outcome of an incident.

Functional Resonance Analysis Method (FRAM)

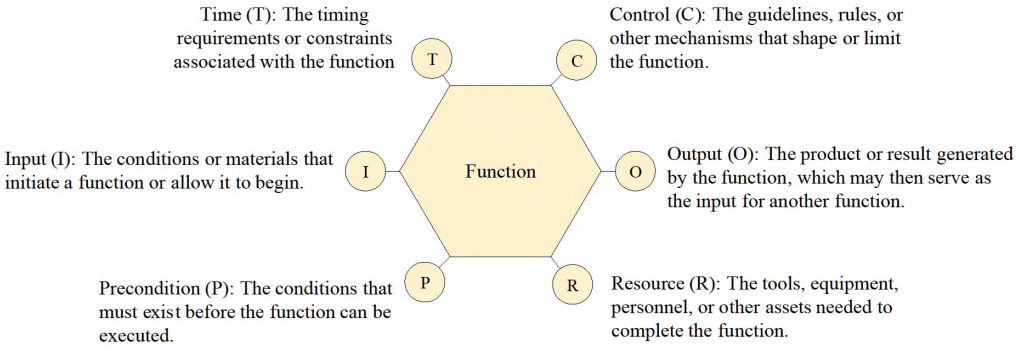
The Functional Resonance Analysis Method (FRAM) is a systemic, nonlinear approach to analyze complex sociotechnical systems (Hollnagel, 2013). Developed by Hollnagel, FRAM seeks to understand not only how systems work under normal conditions but also how interactions between system components can lead to

accidents when variability is introduced (Hollnagel, 2016). Unlike traditional linear accident analysis methods, which focus on cause-and-effect relationships, FRAM views accidents as emergent outcomes resulting from the interaction of multiple, interdependent functions (Hollnagel and Goteman, 2004). By examining these interactions, FRAM enables analysts to assess where system flexibility can be improved and where risks accumulate, which helps prevent future incidents (Hollnagel, 2017).

A key concept in FRAM is the concept of "functions," which represent the essential tasks or activities within a system that contribute to overall performance. Each function is defined by six aspects: Input, Output, Precondition, Resource, Control, and time (Figure 1 (Herrera and Woltjer, 2010).

Figure 1

Overview of functional aspects of FRAM



By evaluating these six aspects, FRAM revealed how each function interacts with others, especially under variable conditions (Tian et al., 2016). The variability in either of these aspects can propagate through the system, shaping the interactions among functions in ways that amplify certain effects, potentially leading to emergent outcomes. This emergent nature of variability rather than individual failures often results in system breakdowns or accidents in complex settings (Hollnagel, 2017).

FRAM is uniquely suited to modeling and managing variability in complex environments where traditional causality is difficult to establish. It acknowledges that variability in routine operations is natural and sometimes necessary because systems often operate in unpredictable environments (Smith et al., 2017). However, when multiple sources of variability interact and amplify each other—or, conversely, dampen certain impacts—the result can be unexpected and significant. FRAM's focus on these dynamic interactions allows for a more nuanced understanding of risk and resilience, particularly in high-stakes industries, such as healthcare, aviation, nuclear energy, and maritime operations (Patriarca et al., 2020).

In the maritime industry, FRAM has demonstrated effectiveness in capturing the multifaceted interactions between human, technical, and environmental factors that contribute to risk (Praetorius et al., 2011; Tian et al., 2016; Kee, 2017; Lee and Chung, 2018; Salihoglu and Bal Beşikçi, 2021; Qiao et al., 2022; Ma et al., 2023; Yu et al., 2024). By identifying how normal variances can combine and resonate, FRAM facilitates a proactive safety approach that emphasizes the importance of system-wide resilience rather than isolating individual error points (Praetorius et al., 2017). The capacity of FRAM to examine the underlying functional dynamics within systems makes it particularly valuable for accident investigations involving high complexity and uncertain causality.

FRAM Model Visualizer (FMV)

In this study, the "FRAM Model Visualizer" (FMV) was used to construct a detailed FRAM model to analyze the functional interactions involved in maritime accidents. Following model creation, the connections

between functions were highlighted manually to represent interactions more clearly, thereby providing a deeper understanding of how the variabilities in one function may propagate through the system.

The FMV, which was written and developed by Rees Hill, is a visual tool based on Hollnagel's FRAM (Hollnagel and Hill, 2020). The proposed platform provides an interactive platform for mapping and analyzing functional interactions, offering valuable analyst support (Patriarca et al., 2017). By representing each function as a hexagon with FRAM's six aspects—Input, Output, Precondition, Resource, Control, and Time—FMV enables analysts to trace how variations in one function influence others, revealing systemic interdependencies that are crucial for understanding risk in complex systems like maritime operations. This visualization approach helps identify potential points where variability in one function may trigger cascading effects, highlighting bottlenecks and hidden dependencies that could affect system stability (Nasur et al., 2025).

In addition to modeling interactions, FMV supports scenario-based modeling, which allows analysts to test different operational conditions to assess potential outcomes. This capability is particularly useful for investigating incidents without a single causative factor, such as the Gülnak and Cape Mathilde accidents examined in this study. By visualizing how variations in specific functions might have contributed to the accident, the FMV offers valuable insights into possible safety interventions and supports a comprehensive understanding of system dynamics, ultimately aiding in the enhancement of safety measures in maritime operations.

Analytical Approach to Complex Maritime Accidents

This study employs FRAM to address the ambiguous and complex nature of the Gülnak–Cape Mathilde collision, which involved a blend of human, technical, and environmental factors. Unlike traditional linear analyses, this systemic approach does not seek a single causative factor but rather examines the layered interactions within the maritime system. FRAM's flexibility allows it to capture the multifaceted interdependencies that characterize maritime operations, especially under uncertain conditions, as highlighted in the Marine Accident Investigation Branch (MAIB) report (Lee et al., 2020).

In this analysis, FRAM focuses on functional interactions and explores potential resonance points rather than direct causal chains. By evaluating how functions like pilot communication, rudder control, and tugboat positioning are performed under variable conditions, this study aims to reveal how minor changes within one function may propagate through the system, escalating the risk (Patriarca and Bergström, 2017). Each function was mapped using FRAM's six aspects (Input, Output, Precondition, Resource, Control, and Time) to visualize how functional variability might influence overall system stability (Praetorius et al., 2017).

A key aspect of this approach is scenario-based modeling, which assesses the reliability of functional aspects, such as the control and resources, during critical stages of the operation. By simulating conditions —such as delays in communication between the bridge team and tugboats—the study evaluates how functional resonance can contribute to adverse outcomes (Yu et al., 2023). This iterative modeling allows continuous refinement of the analysis as new insights are generated, providing a more accurate representation of the accident dynamics (Guo et al., 2023).

Lastly, the analysis identified resonance points where accumulated variabilities among functions led to a loss of operational control, demonstrating that the collision was not the result of a single failure but of a network of interacting functions (Grabbe et al., 2022). This nuanced understanding of accident causation highlights how risks amplify in real-world maritime operations, offering valuable insights into systemic vulnerabilities and informing strategies for safety enhancement and risk mitigation in high-risk maritime environments (Patriarca and Bergström, 2017).

Case Study: Complex Interactions in Gülnak and Cape Mathilde Collision

Accident Description

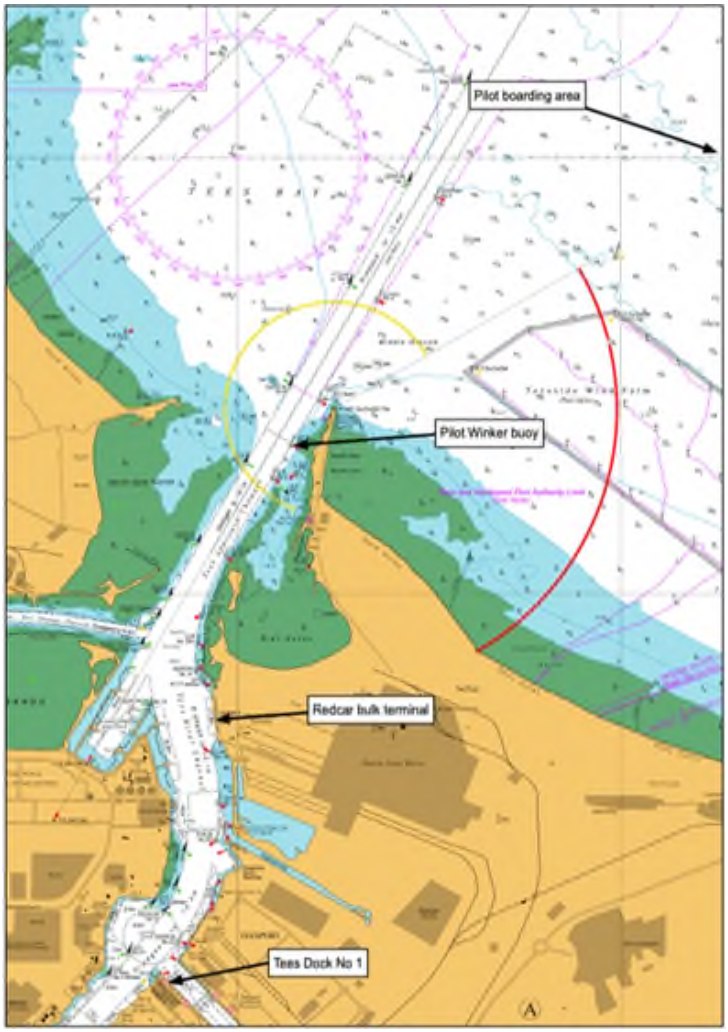
The accident analyzed in this study was based on the Marine Accident Investigation Branch (MAIB) report entitled "Collision between the bulk carrier Gülnak and the moored bulk carrier Cape Mathilde in the River Tees, England." This report provides the foundational data used in the analysis, offering detailed insights into the incident's circumstances and contributing factors as documented by MAIB (MAIB, 2020).

On April 18, 2019, a Turkey-registered bulk carrier "Gülnak" collided with a Panama-registered bulk carrier "Cape Mathilde" in the River Tees, England. The collision occurred as Cape Mathilde was moored alongside the "Redcar Bulk Terminal", and Gülnak was maneuvering along the main navigation channel under the guidance of a harbor pilot.

To provide the spatial context, Figure 2 shows an extract from chart BA2566, indicating the key locations relevant to the collision, including the navigation channel and mooring area. Despite the efforts of the bridge team to control the vessel's direction during a planned turn to port, the turn could not be sufficiently arrested, leading to the collision. Fortunately, the accident did not result in any injuries or environmental pollution; however, both vessels sustained significant structural damage, necessitating repairs.

Figure 2

BA2566 Chart Excerpt Highlighting Critical Locations



Source: MAIB, 2020

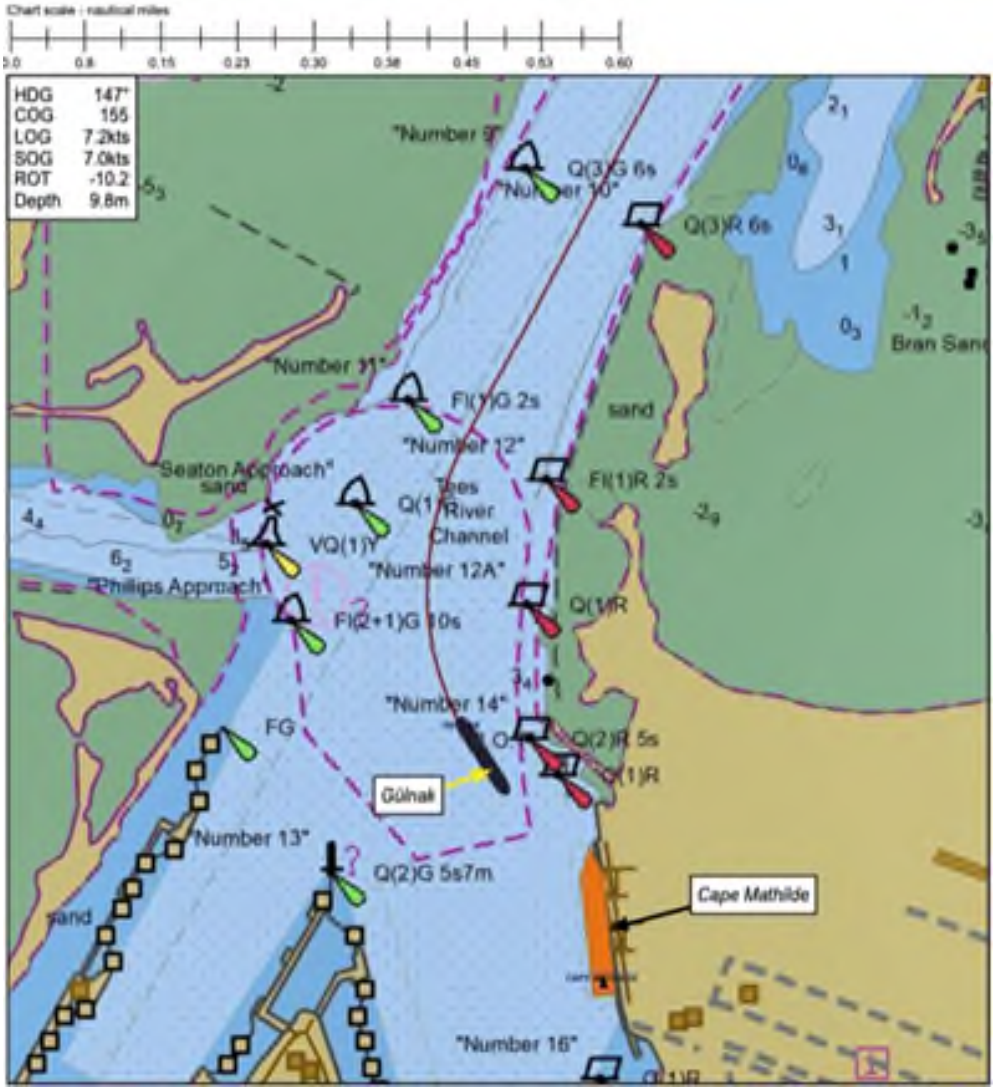
The incident began when Gülnak's pilot initiated a port turn intended to align the vessel with the main channel. As the turn progressed, control of the vessel's heading was lost despite the application of full starboard rudder and eventually full astern power. The turn rate was not adequately reduced, and the ship continued its trajectory toward Cape Mathilde.

Environmental conditions such as tidal flows and limited water depth further amplified the squat effect, reducing the vessel's maneuverability. The fully loaded condition of the vessel also constrained its ability to respond swiftly to navigational inputs, illustrating the compound challenges encountered during maneuvering.

The final moments before impact included attempts by the harbor pilot and master to arrest the turn by using additional maneuvers and increasing engine speed; however, these measures were insufficient. Figure 3 illustrates the positions of both vessels at 03:23:23, shortly before the collision, with Gülnak's engine set to "full astern" in a final attempt to slow down. At approximately 03:24 UT, Gülnak's port bow made contact with Cape Mathilde at an angle of 29°, traveling at a speed of 6.7 knots.

Figure 3

Vessel Positions at 03:23:23

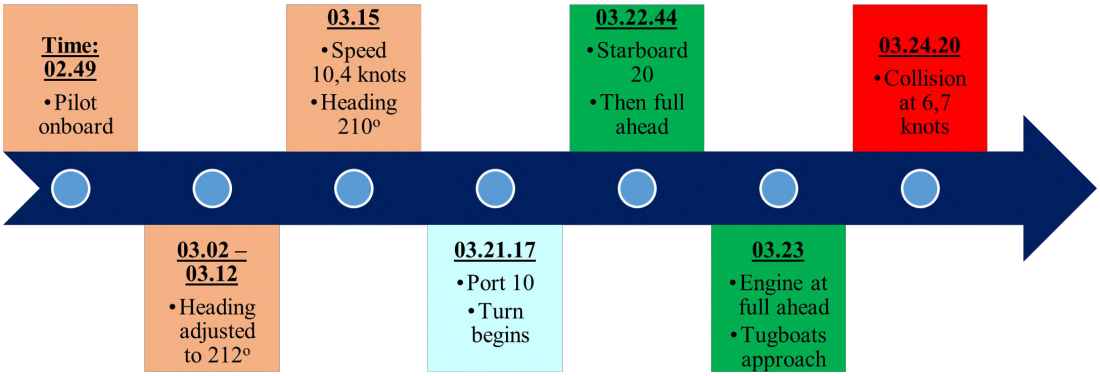


Source: MAIB, 2020

The sequence of critical events leading up to the collision between Gülnak and Cape Mathilde is summarized in Figure 4 , which illustrates the key interactions and decisions that contributed to the incident.

Figure 4

Timelines of Key Events in the Gülnak and Cape Mathilde Collision.



The MAIB report highlights multiple potential contributing factors although it does not identify a single root cause. Key factors considered included the bridge team's actions, the vessel's maneuverability under loaded conditions, possible hydrodynamic effects, and technical malfunctions; however, due to a lack of recorded rudder angle and engine speed data, these factors remain speculative. Additionally, a noted issue with Gülnak's main engine speed indicator, which was behaving erratically following the collision, added to the uncertainty of whether technical faults played a role in the loss of control.

In the wake of the incident, Teesport harbor authorities implemented measures to mitigate similar future occurrences, including enhanced guidelines for pilots regarding tidal flows, increased dredging operations and reinforcement of tugboat positioning procedures. Furthermore, Gülnak's owner, Gülnak Shipping Transport & Trading Inc., was advised to validate the vessel's handling characteristics and ensure the operational reliability of all bridge equipment.

This incident, which is characterized by a complex interplay of human, technical, and environmental factors, serves as an illustrative case for applying the Functional Resonance Analysis Method (FRAM) to uncover how systemic variability and functional interactions contributed to the eventual collision. In the subsequent sections, this case study is analyzed using FRAM to explore how the variability in key functions and their interactions may have amplified risk, ultimately leading to the accident.

FRAM-Based Accident Analysis

FRAM provides a structured framework for analyzing the Gülnak–Cape Mathilde collision by emphasizing the complex interplay of functions contributing to the accident (Hollnagel, 2013). Unlike conventional accident analysis methods, FRAM focuses on how functional variabilities within a system can resonate and create risk.

In this analysis, 15 distinct functions relevant to the incident were identified, and each function was described using the six FRAM aspects—Input, Output, Precondition, Resource, Control, and Time. These functions were selected to represent critical components of maritime operation and their interdependencies within the system, providing a detailed map of how variabilities in one function could propagate through others, ultimately contributing to the accident.

Table 1 provides an overview of these functions, including their type, time, and precision, to establish their relevance within the operational framework. Building on this foundation, Table 2 presents a detailed description of each function's six aspects. This structured description ensures consistency and clarity in

the understanding of how each function operates and interacts. To enable accurate modeling, consistent terminology was applied across interconnected aspects, emphasizing the systemic nature of the accident and the propagation of variability within the system.

Table 1

Overview of Functions: Type, Time, and Precision Variability

Functions	Function Type		Time Variability		Precision Variability	
	Type	Reasoning	Time	Reasoning	Precision	Reasoning
F1: Pilot's Initial Maneuvering Commands	Human	This function involves real-time decision-making and physical inputs by the pilot, which are human-dependent.	On time: should be typical	The pilot's commands should ideally be timely to effectively control vessel maneuvering.	Acceptable: Typical	Note that precision is important; however, slight variability in the precision of commands is likely acceptable given human factors.
F2: Third Officer's Execution of Commands	Human	This function relies on the Third Officer's physical response to execute commands accurately.	On time: should be typical	Timely execution is crucial for maintaining maneuvering accuracy.	Acceptable: Typical	The human response is typically within acceptable limits, but minor imprecisity is expected.
F3: Speed Indicator Functionality	Technological	This function depends on the speed indicator.	On time: Normal, expected	Speed indicators should provide real-time feedback; delays are unlikely unless there's a system issue.	Precise: Normal expected	Technological equipment like a speed indicator typically provides precise data.
F4: Rudder Control Response	Technological	The rudder response is an equipment-based function controlled by the bridge team's input.	On time: Normal, expected	The operator should respond promptly to ensure vessel control.	Precise: Normal expected	The precision of the rudder angle adjustments.
F5: Environmental conditions: Water depth and currents	Organizational	Monitoring environmental conditions is based on organizational guidelines and external data.	On time: Likely	Environmental data should be timely, but minor delays may occur due to observational variability.	Acceptable: Possible	Environmental data only need to be reasonably precise to realize effective navigational awareness.
F6: Squat Effect on the Vessel	Technological	The squat effect is a physical response influenced by vessel design and operational speed.	On time: Normal, expected	The squat effect will occur predictably with changes in speed; thus, the timing is naturally aligned.	Acceptable: Unlikely	Slight variations in squat precision do not critically affect immediate maneuvering decisions.
F7: Communication with Tugboats	Human	Communication with tugboats requires human judgment and coordination.	On time: should be typical	Timely communication is necessary for effective assistance.	Acceptable: Typical	Communication precision is typically acceptable; minor inaccuracies can be managed.
F8: Tugboat Positioning and Readiness	Organizational	Operational planning manages tugboat positioning and readiness.	On time: Likely	Tugs should be in position on time; delays could affect maneuvering support.	Acceptable: Possible	Acceptable precision in the positioning of tugboats provides effective assistance.
F9: Pilot Adjustment to Vessel Speed	Human	The pilot's speed adjustments are based on real-time assessments.	On time: should be typical	Speed adjustments should be made in a timely manner to ensure effective control.	Acceptable: Typical	The precision of speed adjustment is generally within acceptable bounds.
F10: Bridge Equipment Readiness Check	Organizational	The readiness of equipment is an organizational procedure.	On time: Likely	Checks must be completed before departure to avoid delays.	Acceptable: Possible	Precision in readiness checks is acceptable; minor inaccuracies do not significantly affect safety.
F11: Monitoring of Vessel Position and Drift	Technological	Monitoring involves GPS and other navigation technologies.	On time: Normal, expected	Continuous real-time monitoring is expected for effective control.	Precise: Normal expected	High precision is expected from navigation systems to maintain the planned route.
F12: VDR (Voyage Data Recorder) Data Accuracy	Technological	VDR is a technological function that is responsible for data recording.	On time: Normal, expected	Data should be recorded in real time for post-incident review.	Precise: Normal expected	Accurate data are essential for post-incident analysis.
F13: Harbor Control Coordination	Organizational	Harbor coordination is managed through organizational protocols.	On time: Likely	Timely coordination is critical for maintaining traffic flow and safety.	Acceptable: Possible	Coordination precision is usually acceptable, with slight variability tolerable.

Functions	Function Type		Time Variability		Precision Variability	
	Type	Reasoning	Time	Reasoning	Precision	Reasoning
F14: Pilot's Communication with Harbor Control	Human	Communication is dependent on the pilot's interaction with the harbor control.	On time: should be typical	Timely communication is expected to ensure safe maneuvering.	Acceptable: Typical	In general, communication precision is acceptable for safe operations.
F15: Detection of Environmental Hazards (e.g., Shallow Areas)	Technological	The detection is based on radar and other monitoring technologies.	On time: Normal, expected	Real-time hazard detection is essential for immediate response.	Acceptable: Unlikely	Precision in hazard detection is ideal but not critical in cases in which observation can be confirmed.

Table 2

Functional Aspects of Functions

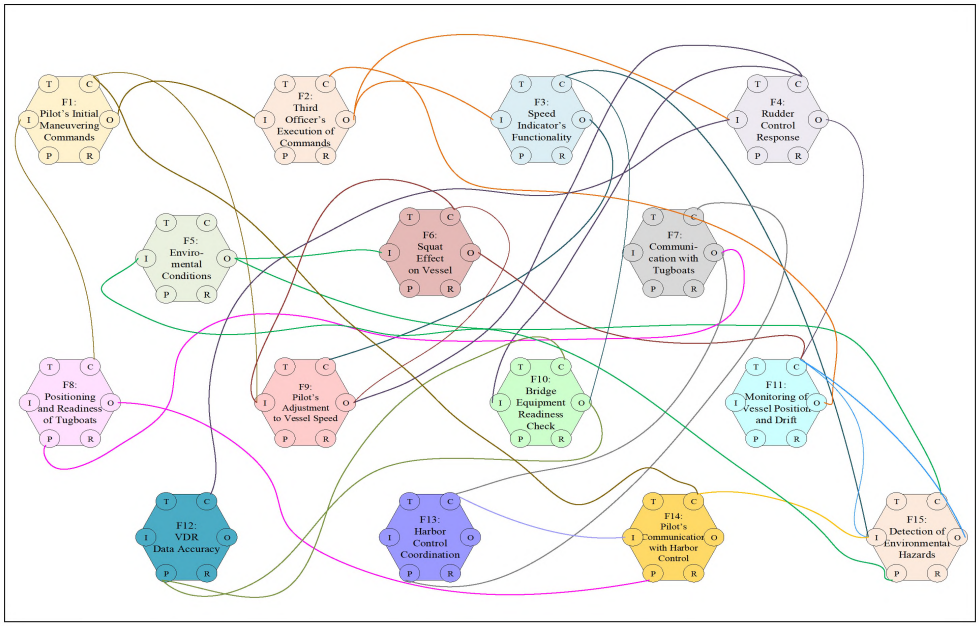
Functions	Functional Aspects					
	Input	Output	Requirement	Resource	Control	Time
F1: Pilot's Initial Maneuvering Commands	Tugboat position as input for initial maneuvering.	Pilot maneuvering commands for heading and speed adjustment. Command directives for speed adjustment.	Tugboat readiness enables pilot communication.	Maneuvering commands requiring bridge team response.	Command directives for speed adjustment. Pilot communication with harbor control supporting maneuvering.	Timing command issuance is critical for course alignment.
F2: Third Officer's Execution of Commands	Pilot maneuvering commands for heading and speed adjustment.	Third Officer's execution of heading and speed adjustments. Command implementation for rudder adjustment.	Accurate input from the pilot for command execution.	Rudder and engine settings for course adjustments.	Position monitoring is used as command execution control.	Execution timing is critical for immediate course correction
F3: Speed Indicator Functionality	Third Officer's execution of heading and speed adjustments.	Speed indicator for accurate adjustments.	Equipment readiness supporting speed indicator accuracy.	Real-time speed feedback for situational awareness.	Speed data support for hazard detection. Equipment readiness supporting speed indicator accuracy.	Continuous speed monitoring to support adjustments.
F4: Rudder Control Response	Command implementation for rudder adjustment. VDR data for rudder control validation.	Rudder response affects vessel position and drift.	Verified VDR data for accurate rudder control.	Rudder systems are responsive to command adjustments.	Verification of bridge equipment readiness. Speed adjustment for rudder control response.	Timely rudder response for navigation adjustments.
F5: Environmental conditions: Water depth and currents	Awareness of environmental conditions.	Environmental conditions influencing squat effect. Environmental data for hazard detection.	Continuous monitoring of real-time environmental input.	Real-time environmental data for situational awareness.	Environmental factors affecting vessel dynamics.	Immediate data needed during high-risk navigation.
F6: Squat Effect on the Vessel	Environmental conditions influencing squat effect.	The squat effect influences vessel position and drift.	Environmental awareness to anticipate squat impact.	Squat data for speed and rudder adjustments.	Squat effect as input for speed adjustment. Speed changes influence the squat effect.	Timely squat data to support navigation choices.

Functions	Functional Aspects					
	Input	Output	Requirement	Resource	Control	Time
F7: Communication with Tugboats		Tugboat communication ensures readiness. Communication for harbor control coordination.	Established protocol for tugboat readiness.	Communication channels with tugboats.	Communication for the coordination of tugboat actions.	Timely communication to secure tugboat support.
F8: Tugboat Positioning and Readiness	Tugboat communication ensures readiness.	Tugboat readiness enables pilot communication with harbor control.	Tugboat communication ensures readiness. Clear positioning for immediate tugboat response.	Tugboat availability for maneuvering support.	Tugboat position as input for initial maneuvering.	Tugboat readiness timing is critical for effective support.
F9: Pilot Adjustment to Vessel Speed	Command directives for speed adjustment. Squat effect as input for speed adjustment.	Speed adjustment for rudder control response. Speed changes influence the squat effect.	Accurate speed data for adjustments.	Engine power adjustments for speed control.	Speed indicator for accurate adjustments.	Timely adjustments to manage vessel speed.
F10: Bridge Equipment Readiness Check	Verification of bridge equipment readiness.	Equipment readiness supporting speed indicator accuracy. Verified bridge equipment for reliable data.	Functional check before departure.	Operational bridge equipment.	VDR accuracy depends on equipment readiness.	Pre-departure timing for equipment checks.
F11: Monitoring of Vessel Position and Drift	Position data for environmental hazard detection.	Position monitoring is used as command execution control.	Reliable data for position and drift monitoring.	Real-time monitoring systems.	Rudder response affects vessel position and drift. The squat effect influences vessel position and drift. Position data for environmental hazard detection. Hazard detection control and drift monitoring.	Continuous monitoring is required during navigation.
F12: VDR (Voyage Data Recorder) Data Accuracy	Equipment accuracy as requirement for VDR data accuracy.		Verified bridge equipment for reliable data. VDR accuracy depends on equipment readiness.	Data recording systems.	VDR data for rudder control validation.	Continuous recording for post-incident review.
F13: Harbor Control Coordination	Harbor control as input for pilot communication.	Harbor control coordination required for tugboat communication.	Communication for the coordination of tugboat actions. Established protocols with harbor control.	The harbor control contact systems.	Communication for harbor control coordination. Harbor control as input for pilot communication.	Timely coordination is critical during the approach.
F14: Pilot's Communication with Harbor Control	Harbor control as input for pilot communication.	Pilot communication with harbor control supporting maneuvering.	Tugboat readiness enables pilot communication with harbor control.	Communication systems with harbor control.	Harbor communication as input for hazard detection.	Communication timing during maneuvering.

Functions	Functional Aspects					
	Input	Output	Requirement	Resource	Control	Time
F15: Detection of Environmental Hazards (e.g., Shallow Areas)	Speed data support for hazard detection. Position data for environmental hazard detection. Harbor communication as input for hazard detection.	Hazard detection control and drift monitoring.	Awareness of environmental conditions.	Sensors and monitoring tools.	Environmental data for hazard detection.	Continuous hazard detection for safe navigation.

Figure 5

Vessel Positions at 03:23:23



Source: MAIB, 2020

Extending the scope of this analysis, Table 3 provides a comprehensive representation of the functional interactions identified during FRAM modeling. This table highlights which aspects of each function (e.g., Input, Output, Control) are interconnected, emphasizing the critical pathways through which variabilities propagate within the system. This level of detail provides a foundational understanding of the emergence of systemic risks during the event.

Table 3

Functional Interactions

Function	Connection	Expression
F1	Output (F1) → Input (F2)	Pilot maneuvering commands for heading and speed adjustment.
	Control (F1) → Input (F9)	Command directives for speed adjustment.
F2	Output (F2) → Input (F3)	Execution of speed adjustments for accurate indicator readings.
	Output (F2) → Input (F4)	Command application for rudder response.
F3	Output (F3) → Control (F9)	Speed feedback for pilot adjustments.
	Control (F3) → Input (F15)	Speed data supporting hazard detection.
F4	Output (F4) → Control (F11)	Rudder response influences position and drift monitoring.

Function	Connection	Expression
F5	Control (F4) → Input (F10)	Rudder control input for bridge readiness verification.
	Output (F5) → Input (F6)	Environmental factors impacting squat.
	Output (F5) → Control (F15)	Environmental data for hazard detection.
F6	Output (F6) → Control (F11)	Squat influences position and drift monitoring.
	Control (F6) → Input (F9)	The squat impact is considered in the speed adjustment.
F7	Output (F7) → requirement (F8)	Coordination ensures tug readiness.
	Output (F7) → Control (F13)	Communication point for harbor control coordination.
F8	Output (F8) → requirement (F14)	Tugboat readiness enabling harbor communication.
	Control (F8) → Input (F1)	Tug position as input for pilot's initial maneuvers.
F9	Output (F9) → Control (F4)	Speed adjustments affect the rudder response.
	Output (F9) → Control (F6)	Speed impact as a control factor for squat.
F10	Output (F10) → Control (F3)	Readiness check supporting speed indicator accuracy.
	Output (F10) → requirement (F12)	Equipment readiness ensuring VDR accuracy.
F11	Output (F11) → Control (F2)	Position monitoring is a factor in 3/O's command execution.
	Control (F11) → Input (F15)	Position and drift data are inputs for hazard detection.
F12	Requirement (F12) → Control (F10)	VDR accuracy depends on equipment functionality.
	Control (F12) → Input (F4)	The VDR data ensure the rudder response accuracy.
F13	Requirement (F13) → Control (F7)	The harbor control coordination enables tug communication.
	Control (F13) → Input (F14)	Harbor control as input for pilot communication.
F14	Output (F14) → Control (F1)	Harbor communication supporting maneuver commands.
	Control (F14) → Input (F15)	Harbor control communication for hazard detection.
F15	Requirement (F15) → Input (F5)	Environmental conditions influence hazard detection.
	Output (F15) → Control (F11)	Detected hazards impacting position monitoring.

These interactions are visualized in Figure 2, which was developed using the FMV model to present the FRAM model of functional interactions and their variabilities. By combining the data presented in Table 3 with the visual representation in Figure 2, the analysis provides a multidimensional view of how the collision unfolded due to cascading variability. Building on the FRAM analysis, the critical moments leading to the collision were examined, with a focus on how timing issues, equipment limitations, and communication delays dynamically interacted to compound the risk. The analysis identified key moments at which the variabilities in function alignment escalated into systemic risks, as detailed below:

- Initial Maneuvering Commands (03:02–03:12): Variabilities in the pilot's incremental adjustments (F1) propagated to the Third Officer's execution of commands (F2), leading to minor misalignments. These misalignments were not corrected in subsequent functions, which gradually reduced system stability.
- Escalation of the Turn Rate (03:21:17): Timing delays in the rudder response (F4) and speed adjustments (F9) intensified an unexpected increase in the vessel's turn rate. This created a resonance effect that amplified misalignment and led to an unsustainable turn angle.
- Speed Adjustment and Squat Effect (03:22:44): The "full ahead" command (F9) aimed to stabilize the vessel but amplified the squat effect (F6), reducing rudder efficacy. Variabilities in environmental factors such as water depth (F5) compounded this effect.
- Communication and Tugboat Coordination (03:23): Delays in communication and positioning hindered attempts to engage tugboat support (F7, F8), resulting in a missed opportunity for external assistance.

This missed opportunity for external intervention reduced the system's ability to recover from accumulated risks.

- Final Rudder Adjustments and Drift Monitoring (03:23–03:24): Cumulative delays and misalignments in rudder control (F4) and drift monitoring (F11) confirmed the inevitability of the collision.

Finally, Table 4 summarizes the function interactions, showing how the variabilities led to resonance effects and increased systemic risks during the incident.

Table 4

Functional Interactions

Function Interaction	Interaction Description	Resonance Effect	Increased Risk
F1: Pilot's Initial Maneuvering Commands → F2: Third Officer's Execution of Commands	Accurate timing between pilot commands and third officer execution is essential for safe maneuvering.	Misalignment in response timing leads to potential resonance, which affects maneuver precision.	Untimely maneuvers increase the turn rate, thus elevating the collision risk.
F2: Third Officer's Execution of Commands → F4: Rudder Control Response	The timely execution of rudder adjustments affects vessel control, especially in critical turns.	Delays create resonance in the rudder control, which reduces maneuverability.	A slow rudder response can cause unexpected deviations, increasing the susceptibility of the engine to environmental factors.
F3: Speed Indicator's Functionality → F9: Pilot Adjustment to Vessel Speed	Accurate speed data are crucial for the pilot's control decisions.	Erroneous speed readings create resonance in speed adjustments, which affects maneuver judgment.	Misjudged speed reduces maneuverability, increasing collision risk in restricted waters.
F4: Rudder Control Response → F11: Monitoring of Vessel Position and Drift	Effective rudder control helps maintain positional accuracy.	Delays in the rudder response resonate during drift monitoring, thereby complicating navigation.	Positional drift increases difficulty in course control, heightening collision risk.
F5: Environmental Conditions → F6: Squat Effect on the Vessel	Water depth and currents amplify squat effects, thereby affecting vessel stability.	Shallow waters or high currents resonate with the squat, reducing the rudder efficacy.	The amplified squat effect decreased maneuverability, thereby increasing the collision risk in narrow channels.
F7: Communication with Tugboats → F8: Tugboat Positioning and Readiness	Effective communication with the tugboats ensures timely intervention.	Miscommunication delays the tug positioning, creating resonance that limits the support.	Delayed tug support increases the collision risk by reducing the available maneuvering assistance.
F8: Positioning and Readiness of Tugboats → F1: Pilot's Initial Maneuvering Commands	Tug readiness affects the pilot's maneuvering strategy.	Poor tug positioning influences the pilot's commands, creating resonant effects in maneuvering adjustments.	Inadequate tugboat support during maneuvering increases the control challenges and collision potential.
F10: Bridge Equipment Readiness Check → F12: VDR Data Accuracy	Verifying the bridge equipment functionality ensures accurate VDR recordings.	Equipment malfunctions resonate within the VDR data, impacting the post-accident analysis.	Inaccurate VDR records hinder event reconstruction, thereby limiting the understanding of causative factors.
F11: Monitoring of Vessel Position and Drift → F2: Third Officer's Execution of Commands	Continuous position monitoring informs Third Officer's actions for timely adjustments.	Delays in monitoring resonate during command execution, reducing response precision.	Lagged responses increase the drift, reducing the vessel control and increasing the collision likelihood.
F13: Harbor Control Coordination → F14: Pilot's Communication with Harbor Control	Coordinated communication with the harbor control system supports real-time navigation alignment.	Delayed communication with harbor control resonates in the pilot's situational awareness, which affects maneuver decisions.	Untimely updates complicate navigation and elevate the risk in restricted maneuvering areas.

By analyzing these interactions, this study identified how variabilities in timing, precision, and response across multiple functions interacted to generate risks. This highlights the systemic nature of risk and the contribution of dependencies and external conditions to the collision.

Through the FMV's functionality, this analysis emphasizes the importance of addressing variability at multiple levels, including the function itself, upstream influences, and external conditions. Such insights are critical for improving maritime operations' resilience under complex and high-risk scenarios.

Findings and Discussions

This section explores the complex interplay of human, environmental, and technical factors contributing to loss control in maritime operations, as revealed through the analysis of the Gülnak–Cape Mathilde collision. By integrating the insights from the FRAM-based assessment with broader maritime safety perspectives, the findings provide a comprehensive understanding of how systemic variabilities interact dynamically under high-stress conditions. These findings are structured under four key themes: human factors and decision-making under stress, environmental conditions and their dynamic impacts, uncertainty and equipment reliability, and preventive recommendations with their potential effects.

Factors and Decision-Making Under Stress

Human factors and decision-making under stress play a pivotal role in maritime safety, as variability in human performance can propagate through interconnected functions, amplifying risks (Ay et al., 2024). The FRAM analysis highlighted how variability in the pilot's commands (F1) and the Third Officer's execution of those commands (F2) contributed to misalignments during critical moments. For instance, delays in the pilot's commands influenced the timing and precision of the Third Officer's responses, creating a cascading effect on downstream functions such as F4 (Rudder Control Response). These misalignments were particularly critical during high-pressure moments, such as the escalation of turn rate.

The early morning timing of the incident (around 03:00) likely intensified these human performance variations. Circadian lows during this period are known to impair cognitive function, reducing alertness and reaction times (Jepsen et al., 2017; Maternová et al., 2023). In this case, the pilot's reactive command escalation—from "port 10°" to "hard-to-starboard"—illustrates decision-making under stress, where high-pressure situations can compromise judgment and lead to suboptimal outcomes (Brooks and Greenberg, 2022; Oraith et al., 2021).

Another critical factor was communication lapse. Variability in F1 and F7 (Communication with Tugboats) introduced delays and inconsistencies, hindering effective coordination between the bridge team and external support. These communication challenges propagated to F8 (Tugboat Positioning and Readiness), reducing the tugboats' ability to assist during critical moments. Studies have consistently emphasized the importance of timely and clear communication in maritime operations to prevent cascading errors (Argüelles et al., 2021; Wahl and Kongsvik, 2018).

Fatigue also likely played a role in amplifying these variabilities. Although specific data on crew fatigue during the incident are unavailable, the timing of the event aligns with circadian rhythm lows, where human performance is typically diminished (Jepsen et al., 2017; Maternová et al., 2023). The FRAM analysis indicates that the fatigue-induced variability in F1 and F2 contributed to slower reaction times and increased the likelihood of errors in high-stake decision-making scenarios.

These findings underscore the need for targeted interventions to address human variability. Training programs that focus on stress management and resilience can help crew members maintain their cognitive performance during high-pressure situations. In addition, standardizing communication protocols and enhancing coordination mechanisms between functions such as F1 and F7 are essential to minimize the cascading effects of variability. By integrating these measures, maritime operations can enhance decision making and overall system stability.

Environmental Conditions and Dynamic Impacts

Environmental factors such as water depth, currents, and the squat effect significantly influence a vessel's maneuverability. The FRAM analysis of F5 (Environmental Conditions) and F6 (Squat Effect) revealed how these factors interacted dynamically, worsening the risks during the collision. Specifically, the pilot's decision to increase speed (F9) in response to the escalating turn rate amplified the squat effect, reducing rudder efficacy and under-keel clearance. This finding aligns with documented hydrodynamic challenges in confined channels, where squat effects are more pronounced (Tezdogan et al., 2016; Maljković et al., 2024).

The analysis highlighted how environmental variability introduced additional uncertainties. For instance, the channel's narrowness and sudden changes in water depth compounded the vessel's maneuverability problems. These variabilities interacted with human decisions, such as the pilot's reactive speed adjustments, creating a cascading effect throughout the system.

Beyond these specific findings, predictive methods and modeling tools have been emphasized in the literature for their potential to mitigate environmental risks. By integrating tools that anticipate hydrodynamic impacts, bridge teams can make more informed decisions under challenging conditions (Yang and el Moctar, 2024). The FRAM model underscores the importance of such tools in capturing and addressing environmental variabilities that pose significant risks to maritime safety.

Uncertainty and Equipment Reliability

Technical equipment reliability is a cornerstone of maritime safety, as even minor malfunctions can cause significant uncertainties. The FRAM analysis identified critical variabilities in functions such as F3 (Speed Indicator) and F4 (Rudder Control Response), demonstrating how these technical failures propagated through the system. For example, the malfunctioning speed indicator provided inaccurate data, which impaired the pilot's ability to make informed decisions. Similarly, delays in the rudder control response reduced the vessel's ability to recover from deviations, amplifying the risks during critical maneuvers.

These findings align with broader concerns about the reliability of onboard systems in high-stake operations. Predictive maintenance strategies, such as those incorporating Bayesian fault detection, have been shown to enhance equipment reliability and reduce uncertainty (Daya and Lazakis, 2024; Rigas et al., 2024). The integration of advanced diagnostic tools into routine operations can provide early warning of potential failures, thereby allowing timely interventions.

The FRAM model also highlighted how equipment-related variabilities interacted with human and environmental factors, emphasizing the need for a holistic approach to managing uncertainty in maritime operations. By addressing these interdependencies, maritime stakeholders can better mitigate risks and enhance operational resilience (Simion et al., 2024; Bicen and Celik, 2023).

Preventive Recommendations and Their Potential Effects

Building on the insights gained from FRAM analysis, this section outlines preventive strategies designed to address the identified variabilities. For example, real-time feedback systems targeting F9 (Speed Adjustments) and F4 (Rudder Control Response) were identified as critical for improving situational awareness and enabling timely corrective actions. Such systems can provide pilots with immediate feedback on vessel responses under various conditions, thus reducing the likelihood of misaligned maneuvers (Aylward et al., 2022).

Furthermore, enhancing the tugboat coordination, as analyzed in F7 and F8, can provide essential external support during emergencies. The proactive positioning of tugboats and standardized communication protocols can mitigate timing delays and improve response readiness (Paulauskas et al., 2021). Scenario-

based training simulations, which replicate high-pressure scenarios, are also emphasized as essential for building stress resilience and enhancing decision-making skills among bridge teams (Dominguez-Péry et al., 2021).

Finally, advanced predictive algorithms for analyzing squat effects and lateral drift (Xiang et al., 2024), as well as upgraded Voyage Data Recorder (VDR) systems, can provide both real-time operational support and valuable data for post-incident analyses (Zhang et al., 2025). These enhancements align with the FRAM model's emphasis on capturing and managing functional variabilities to prevent risk escalation.

Conclusions and Future Directions

This study applied the Functional Resonance Analysis Method (FRAM) to analyze the Gülnak–Cape Mathilde collision, exploring incidents shaped by complex interactions and systemic uncertainties. The FRAM approach effectively captured the detailed interactions and functional variabilities contributing to the accident, illustrating how minor variations can accumulate, leading to control loss in dynamic maritime environments. Unlike traditional linear models, FRAM's capacity to represent the interconnected nature of maritime functions over time highlights its suitability for complex accident analysis, particularly when the causation is ambiguous.

Structuring the FRAM application in an uncertain environment, this study demonstrates a novel approach to understanding accidents where identifying specific causes is challenging, and interactions among multiple functions lead to increasing risks. This perspective demonstrates that FRAM is an adaptable and resilient tool for capturing systemic variabilities that may remain undetected by conventional methods. Such a framework has valuable potential for advancing future accident investigations and enhancing safety management strategies in the maritime domain.

While the proposed framework offers valuable insights, certain limitations should be considered. The qualitative nature of FRAM may constrain its predictive capacity, especially in quantifying risk probabilities, which can be addressed by integrating it with quantitative models. In addition, FRAM's reliance on detailed incident data poses a challenge because maritime accident reports may not always provide the comprehensive documentation necessary for a full analysis. The proposed method also assumes a level of consistency in the functional data, which may not always be realistic in dynamic maritime operations. Variations in the availability and reliability of data—such as incomplete voyage data recorder (VDR) records or limited details on human decision-making processes—can introduce uncertainty into the analysis. Furthermore, the lack of standardized procedures for applying FRAM across different contexts may result in inconsistent outcomes; thus, methodological guidelines should be refined to broaden applicability. Future studies should adopt mixed-method approaches that enhance both the depth and precision of FRAM-based investigations.

Moving forward, future research could build on these findings by incorporating quantitative risk models, such as Bayesian Networks, to introduce probabilistic elements into FRAM analysis, offering a more nuanced understanding of risk accumulation and intervention points. In addition, applying FRAM to a broader dataset of maritime incidents would enhance its generalizability across different types of accident and operational scales. Further advancements in FRAM visualization tools can also support real-time functional analysis, enabling maritime professionals to anticipate and manage variability before it escalates into critical issues. Integrating these tools into bridge operations and training could improve situational awareness and preemptive risk management, ultimately contributing to safer and more resilient maritime practices.

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Taşımacılık ve Dijitalleşme: Uluslararası Taşımacılık Hizmeti Üreten İşletmelerin Dijital Olgunluk Düzeylerinin Belirlenmesi

Transportation and Digitalization: Determining the Digital Maturity Levels of Businesses Providing International Transportation Services

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Öz

Taşımacılık sektörü, teknolojik ilerlemelerle birlikte hızla dijitalleşmekte ve dönüşmektedir. Bu çalışmanın amacı Türkiye'de yer alan uluslararası taşımacılık alanında faaliyet gösteren işletmelerin dijital olgunluk düzeylerinin belirlenmesidir. Uluslararası taşımacılık faaliyetleri, dış ticareti geliştiren önemli faaliyetlerin başında gelmektedir. Bu süreçte yer alan gümrükleme, transit işlemler, liman işlemleri, yükleme süreçleri gibi tüm süreçler doğrudan teknoloji ile bütünleşik süreçler haline gelmiştir. Bu kapsamda ülke dış ticaretinin artmasında önemli bir yere sahip olan taşımacılık faaliyetlerinde dijital olgunluk seviyesinin belirlenmesi önem arz etmektedir. Bu doğrultuda anket uygulaması gerçekleştirilerek, uluslararası taşımacılık sektöründe faaliyet gösteren işletmelerin dijital olgunluk seviyesi ampirik olarak incelenmiştir. Çalışma sonucunda dijital olgunluk strateji alt boyutu ile işletmede çalışan kişi sayısı arasında, örgüt kültürü ve yetenek alt boyutu ile faaliyet gerçekleştirilen ülke sayısı arasında, süreçler alt boyutu ile faaliyet gerçekleştirilen ülke sayısı arasında anlamlı ilişki tespit edilmiştir. Ayrıca teknolojik altyapı alt boyutu ile faaliyet gerçekleştirilen ülke sayısı arasında, teknolojik altyapı alt boyutu ile en fazla hizmet verilen taşımacılık türü arasında, örgüt kültürü ve yetenek alt boyutu ile en fazla hizmet verilen taşımacılık türü arasında da anlamlı bir ilişki bulunmuştur. Taşımacılık sektöründe dijital olgunluk düzeylerinin belirlenmesi, işletmelerin zayıf noktalarını fark edebilmelerine ve bu alanda iyileştirmeler yaparak rekabet avantajı elde etmelerine imkân sağlayacaktır.

Abstract

The transportation sector is rapidly digitalizing and transforming with technological advances. The aim of this study is to determine the digital maturity levels of companies operating in the field of international transportation in Turkey. International transportation activities are one of the most important activities that develop foreign trade. All processes in this process, such as customs clearance, transit operations, port operations, and loading processes, have become processes directly integrated with technology. In this context, it is important to determine the digital maturity level in transportation activities, which have an important place in increasing the country's foreign trade. In this regard, a survey was conducted and the digital maturity level of companies operating in the international transportation sector was empirically examined. As a result of the study, a significant relationship was determined between the digital maturity strategy sub-dimension and the number of people working in the business, between the organizational culture and talent sub-dimension and the number of countries in which operations are carried out, and between the processes sub-dimension and the number of countries in which operations are carried out. In addition, a significant relationship was found between the technological infrastructure sub-dimension and the number of countries in which operations are carried out, between the technological infrastructure sub-dimension and the most serviced transportation type, and between the organizational culture and talent sub-dimension and

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the most serviced transportation type. Determining digital maturity levels in the transportation sector will enable businesses to recognize their weak points and gain competitive advantage by making improvements in this area.

Anahtar Kelimeler Taşımacılık · Dijital Olgunluk · Uluslararası Taşımacılık · Dijitalleşme

Keywords Transportation · Digital Maturity · International Transportation · Digitalization

Extended Summary

Digitalization in the international transportation sector has become an important factor to increase the competitiveness of businesses. However, determining at what stage businesses are in the digital transformation process and managing this process effectively can create difficulties. This study focused on determining the digital maturity levels of companies that produce international transportation services. Based on this issue, the aim of the study is to determine the digital maturity levels of companies producing international transportation services in Turkey. Revealing the digital maturity level with its sub-dimensions and shaping future transportation policies accordingly reveals the importance of the study. In this regard, 714 businesses that are members of UTIKAD, one of the largest non-governmental organizations in terms of the logistics sector in Turkey, represent the population of this study. These businesses constitute the 23 provinces of Turkey: Istanbul, Adana, Antalya, Artvin, Aydın, Ankara, Bursa, Çanakkale, Gaziantep, Hatay, Yozgat, İzmir, Kayseri, Kocaeli, Konya, Mardin, Mersin, Ordu, Samsun, Şanlıurfa, Şırnak, It is distributed in Tekirdağ and Van. Since carrying out the data collection process with the entire population was difficult due to constraints such as time and cost, a sample was chosen for the research. The universe consisting of 714 UTIKAD member businesses is determined by the calculations made by Gürbüz and Şahin (2018) within the scope of "Minimum Acceptable Sample Sizes for Different Universes", and the number of samples must be at least 254 with a 95% reliability level (Gürbüz and Şahin, 2018: 130). For the quantitative analysis carried out in this research, a survey was conducted with 286 logistics business managers.

Following the determination of the sampling method, the survey method was chosen as the data collection method of the study; The survey method is the method in which participants' behaviors, attitudes and thoughts about a determined subject are obtained based on questions asked in a structure and order (Büyüköztürk et al., 2013: 124). The relevant study includes a scale consisting of 38 items and 6 dimensions. 7 questions were asked to the participants within the scope of demographic characteristics, with this title aiming to obtain some information about the participant and his business. Within the scope of the Digital Maturity Scale, participants were asked 38 questions, aiming to reach their opinions on the field of digitalization. The questions asked to the participants in this scale are of the 5-point Likert Scale type. The data collection process was carried out with UTIKAD member businesses operating in various provinces of Turkey. These businesses were contacted via e-mail and telephone and questions were answered. Determining the digital maturity levels of companies that produce international transportation services helps businesses effectively manage the digital transformation process by evaluating their current situation. Determining digital maturity levels enables businesses to recognize their weak points and gain competitive advantage by making improvements in this area. The fact that no study of this scope is found in the literature reveals the necessity of this research.

As a result of the research, a significant relationship was found between the number of employees and the digitalization strategies of companies that carry out international transportation activities. Whether the number of employees is low or high directly affects the digitalization strategies of businesses. Large-scale enterprises are less affected by the costs arising from digitalization and do not hesitate to invest in this regard, while small-scale enterprises are left behind in terms of digitalization strategies, as the costs arising from digitalization take a greater place in their cost items.

A relationship has been determined between the number of countries in which international transportation companies operate and the digitalization processes sub-dimension, organizational culture and talent sub-dimension and technological infrastructure dimension in the digital maturity scale. As the number of countries in which businesses operate increases and their level of internationalization increases, the digitalization dimension of their processes increases. In addition, as the number of countries increases, the phenomenon of digitalization is embedded in the culture of the business and their technological infrastructures develop.

A relationship has been determined between the type of transportation in which the international transportation company operates and the organizational culture and talent sub-dimension and technological infrastructure sub-dimension of the digital maturity scale. There is a relationship between the impact of digitalization on organizational culture according to the type of transportation service provided by international transportation companies. Digital maturity in road and sea transportation is higher than other types of transportation. It has been determined that the digitalization maturity of businesses varies according to transportation types, and competition is more intense in some transportation types, and digitalization maturity is higher in transportation types where competition is intense. High business volumes in road and sea transportation are also one of the important factors that encourage businesses to digitalize.

Taşımacılık ve Dijitalleşme: Uluslararası Taşımacılık Hizmeti Üreten İşletmelerin Dijital Olgunluk Düzeylerinin Belirlenmesi

Yer ve zaman faydası sağlayan taşımacılık faaliyetleri lojistik faaliyetler açısından değer yaratan önemli bir faaliyet olmuştur. Bir yerden bir yere ürünlerin nakledilmesiyle yer faydası sağlanırken, hızlı ve verimli şekilde gerçekleştirerek de zaman faydası sağlanmaktadır (Islam vd., 2013: 6). Zaman ve yer faydasının yanı sıra ekonomik açıdan da önemli bir faaliyet durumuna gelmiştir. Lojistik maliyetler açısından taşımacılık faaliyetleri geniş bir yer kaplamaktadır. İşletmeler açısından ekonomik olarak önemli bir yere sahip olan taşımacılık sektörü ülkeler açısından da gelir sağlayıcı ve ekonomik büyümeye katkı sunan sektörlerin başında gelmektedir.

Taşımacılık aynı zamanda çevre, güvenlik ve genel yaşam kalitesi üzerinde de doğrudan etkiye sahiptir. İşletmeler ve ülkeler açısından bu sistemlerin doğru ve etkin işletilmesi gerekmektedir. Taşımacılık sistemlerinin operasyonel etkinliğini artırmak için bilgi teknolojisi ve dijitalleşmenin kullanımının arttırılması zorunludur (Oladimeji vd., 2023: 1). Uluslararası taşımacılık sektöründe dijitalleşme, işletmelerin rekabet gücünü artırmak için önemli bir faktör haline gelmiştir. Ancak, işletmelerin dijital dönüşüm sürecinde hangi aşamada olduklarını belirlemek ve bu süreci etkin bir şekilde yönetmek zor olabilir.

Dijitalleşme ve dijital olgunluk düzeylerinin belirlenmesi işletmeler açısından kritik öneme sahiptir. Uluslararası taşımacılık hizmeti üreten işletmelerin dijital olgunluk düzeylerinin belirlenmesi, işletmelerin mevcut durumlarını değerlendirerek dijital dönüşüm sürecini etkin bir şekilde yönetmelerine yardımcı olabilmektedir. Dijital olgunluk düzeylerinin belirlenmesi, işletmelerin zayıf noktalarını belirlemelerine ve bu alanlarda iyileştirmeler yaparak rekabet avantajı elde etmelerine olanak tanımaktadır.

Uluslararası taşımacılık faaliyetleri, dış ticaretin kaldıracı durumundadır. Bu süreçte yer alan gümrükleme, transit işlemler, liman işlemleri, yükleme süreçleri gibi tüm süreçler doğrudan teknoloji ile bütünleşik süreçler haline gelmiştir. Bu kapsamda ülke dış ticaretinin artmasında önemli bir yere sahip olan taşımacılık faaliyetlerinde dijital olgunluk seviyesinin belirlenmesi önem arz etmektedir. Lojistik alanında Türkiye'nin en büyük sivil toplum kuruluşlarının başında gelen Uluslararası Taşımacılık ve Lojistik Hizmet Üretenleri Derneği (UTİKAD) üye olan işletmeler üzerinde bu çalışmanın yapılması evren temsili açısından önemlidir. Dijital olgunluk düzeyinin alt boyutlarıyla birlikte ortaya konulması ve ulaştırma politikalarına katkı sunacak olması çalışmanın önemini ortaya koymaktadır.

Araştırmanın hipotezleri "Taşımacılık şirketi çalışanlarının sosyo-demografik özellikleri ile dijital olgunluk ölçeği alt boyutları arasında" ilişkinin tespiti ve "Taşımacılık şirketinin sektörel özellikleri ile dijital olgunluk ölçeği alt boyutları arasındaki" ilişkinin tespiti olmuştur. Bu kapsamda çalışmanın birinci kısmında taşımacılık kavramı ve önemi anlatılırken, ikinci kısımda ise dijitalleşme ve dijital olgunluk kavramları ele alınmıştır. Araştırma kısmında ise anket uygulaması gerçekleştirilerek, nicel araştırma yöntemlerinden

genel tarama modellerinden ilişkisel tarama modeli kullanılarak uluslararası taşımacılık sektöründe faaliyet gösteren işletmelerin dijital olgunluk seviyesi ampirik olarak ele alınmıştır.

Taşımacılık Kavramı

Taşımacılık kavramı literatürde ulaştırma kavramı olarak da kullanılmaktadır. Kavramsal olarak taşımacılık, bir yükün veya yolcunun bir yerden başka bir yere nakledilmesi işlemi olarak tanımlanabilmektedir. Yer ve zaman faydası sağlayan taşımacılık adımları lojistik faaliyetler açısından değer yaratan önemli bir kavramdır. Bir yerden başka bir yere ürünlerin transfer edilmesiyle yer faydası sağlanırken, eylemlerin hızlı ve verimli şekilde gerçekleştirilmesiyle de zaman faydası sağlanmaktadır. Taşımacılık süreçlerinin verimli bir şekilde gerçekleştirilmemesi, müşteri istek ve ihtiyaçlarının doğru zamanda, doğru yerde, doğru miktarda ve eksiksiz bir şekilde gerçekleşmemesi müşteri memnuniyetsizliği başta olmak üzere ilave maliyetlere ve hatta müşteri kayıplarına sebebiyet verebilmektedir (Islam vd., 2013: 6).

Taşımacılık kavramı ekonomide önemli bir yere sahiptir. Özellikle lojistik maliyetler içerisinde etkisi göz ardı edilemeyecek bir alanı kaplayan bu kavram, işletmelerin önemli gider kalemlerinden biridir. Tedarik zinciri üyelerini birbirine bağlayan ve zincirin kesintisiz bir şekilde akışının sağlanması taşımacılık ile gerçekleşmektedir. Doğru bir şekilde kurulan, planlanan ve yönetilen taşımacılık süreçleri tedarik zinciri içinde yer alan paydaşlara maliyet avantajı, rekabet üstünlüğü, hizmet çeşitliliği, operasyonel verimlilik gibi avantajlar yaratırken tedarik zincirini de pozitif açıdan geliştirmektedir (Bentz, 2016: 158).

İşletmeler açısından ekonomik olarak önemli bir yere sahip olan taşımacılık sektörü ülkeler açısından da gelir sağlayıcı ve ekonomik büyümeye katkı sunan sektörlerin başında gelmektedir. Türkiye'de gayrisafi yurt içi hasıla (GSYH) içerisinde taşımacılık faaliyetleri önemli bir yer tutmaktadır. GSYH verilerine baktığımızda 2022 yılında en yüksek pay %22,1 ile imalat sanayi olurken, bu sektörü %13,5 ile toptan ve perakende ticaret, %10,0 ile ulaştırma ve depolama sektörü takip etmektedir (TUİK, 2022). Verilere bakıldığında ulaştırma ve depolama faaliyeti gayrisafi yurt içi hasıla oranlarında 3. sırada yer alırken ekonomiye büyük katkı sunmaktadır. Taşımacılık kavramı belirli araç ve ekipmanlar aracılığıyla gerçekleşmektedir. Temelde taşımacılığın gerçekleştiği türler aşağıda sıralanmıştır (Meindl ve Chopra, 2018: 53):

- Karayolu Taşımacılığı
- Demiryolu Taşımacılığı
- Denizyolu Taşımacılığı
- Havayolu Taşımacılığı
- Boru Hattı Taşımacılığı

İşletmeler yükün niteliğine, cinsine, ağırlığına, ürün miktarına, taşıma hızına ve maliyete göre birçok unsuru ele aldıktan sonra en uygun taşıma türünü seçerek taşıma sürecini gerçekleştirmektedir. Her taşıma türünün kendi içinde sağlamış olduğu birtakım avantajlar ve dezavantajlar bulunmaktadır. İşletmeler bu unsurları dikkate alarak taşıma türünü belirledikleri takdirde taşımacılık süreçlerini etkin ve verimli yönetmektedir.

Dijitalleşme ve Dijital Olgunluk Kavramı

Dijitalleşme tüm iş süreçlerini doğrudan etkileyen teknolojik bir süreçtir. Tanım olarak incelediğinde "sayısallaştırma, analog mesajları (kelimeler, resimler, harfler vb.) ayrı darbelerde iletilebilen, işlenebilen ve elektronik olarak depolanabilen sinyallere dönüştürme işlemi" olarak ifade edilmektedir (Ormanlı, 2012: 33). Teknolojinin insan hayatında aktif rol almasıyla ortaya çıkan dijitalleşme kavramı teknoloji geliştikçe büyümeye ve dönüşmeye devam edecektir. Bu değişim ve dönüşüm iş süreçlerine de doğrudan etki edecek, işletmeler için dijital dönüşüm olgusu gelişim gösterecektir.

Dijitalleşme kavramı, "dijital teknoloji ve sayısallaştırılmış verilerin kullanımı ve doğal olarak dijital veriler ile dijitalleşme; gelir elde etmeyi, işin iyileştirilmesini, iş süreçlerini değiştirmesi/dönüştürülmesinin yanı sıra dijital iş için bir ortam yaratmayı" ifade etmektedir. Dijitalleşme kavramıyla birlikte iletişim süreçleri ve iş süreçleri dijital ortamlarda gerçekleşmektedir. Ayrıca teknolojinin iş süreçlerine dahil edilmesi dijitalleşmenin temel amaçları arasında yer almaktadır (Branca vd., 2020: 2).

Dijitalleşme işletmeler açısından manuel gerçekleştirilen süreçlerin otomasyona alınması, iş süreçlerinde verimlilik olması ve kayıtların dijital ortamlarda tutulması açısından işletme içi verimlilik sağlamaktadır. Ayrıca müşteri talep ve isteklerine hızlı cevap verilmesi, müşteri hizmetlerinin sürekli iyileştirmesi ve gelişen ticari koşullara uygun bir şekilde yeni iş modelleri oluşturması açısından da dış fırsatlar yaratmaktadır (Parviainen vd., 2017: 66).

Dijitalleşme kavramı insanlığın her aşamasında önem arz eden bir konu haline gelmişken işletmeler içinse hayati bir konu durumundadır. Küresel rekabetin çok yoğun olduğu ekonomik koşullarda dijitalleşme işletmeleri sürdürülebilir kılmanın temel yolu haline gelmiştir. İşletmeler açısından dijitalleşme tercih edilebilir bir olgu değil adeta zorunluluk unsuru olmuştur (Ersöz ve Özmen, 2020: 172-173). Dijitalleşme süreçlerini tamamlamayan, bu konuda yeterli olgunluğa erişememiş işletmelerin rakipleriyle baş edebilmesi mümkün gözükmemektedir. Bu noktada işletmelerin tek başına dijitalleşme unsurunu süreçlerine uyarlaması yeterli gelmemekte, ayrıca işletmelerin dijital olgunluğa erişmeleri gerekmektedir (Ribeiro-Navarette vd., 2021: 320).

Dijital olgunluk, "operasyonlar ve insan sermayesinin dijital süreçlere, dijital süreçlerin ise operasyonlar ve insan sermayesine entegrasyonu" olarak tanımlanabilmektedir. Buradaki olgunlukla ele alınan, gelişen teknolojiye ve çevreye uygun bir şekilde yanıt verebilmek için işletmelerin sahip oldukları yetenekleri ifade etmektedir. Dijital olgunluk, dijitalleşme olgusuna yönelik işletmelerin tutumlarını ölçümlerken ayrıca dijital değişime sistematik olarak nasıl bir uyum gösterdiklerini de ortaya koyması açısından önemlidir (Aslanova ve Kulichkina, 2020: 443).

İşletmelerin dijitalleşme düzeylerini belirlemek içi birçok çalışma yapılmıştır. Yapılan çalışmalar dijital olgunluk modelleri veya dijital olgunluk düzeyi olarak isimlendirilmiştir. Bu kapsamda son dönemlerde dijitalleşme kavramının oldukça gelişmesi dijital olgunluk ölçümlemesine doğan ihtiyacı ortaya çıkarmış ve bu konuda birçok çalışma yapılmıştır. Son dönemlerde yapılan dijital olgunluk modellerinde çoğunlukla belirli kriterler analiz edilerek, her bir kriterin gücü saptanmaya çalışılmaktadır. Mevcut kısıtlamalar belirlenerek oluşturulan bu modeller ülkeler, sektörler, işletmeler ve bölgeler için uygulanabilmektedir (Merzlov ve Shilova, 2022: 22).

Olgunluk modelleri, mevcut durumu ortaya koyan ve işletmelerin kendilerini değerlendirmelerine yarayan araçlardır. Özellikle olgunluk modelleri aracılığıyla gerçekleşen dönüşümlere yaklaşımlar ortaya konulurken, bu dönüşümleri nasıl gerçekleştirdiklerini de açıklamaktadır. Dijital olgunluk modelleri ise önceden belirlenen boyutlarda dijital dönüşüme dair çabalarını belirleyen ve yeteneklerini ölçmeyi sağlayan süreçler gerçekleştirmektedir. Günümüzde sektörel bazda ve işletme bazında dönüşüm süreçlerinin yansıması olarak dijital olgunluk modelleriyle ölçümler araştırmacılar tarafından dikkat çeken modeller haline gelmiştir (Leipzig vd., 2017: 521).

Literatür Taraması

Taşımacılıkta dijitalleşme kavramı ile ilgili çalışmalar literatürde giderek artmaktadır. Özellikle yabancı akademik çalışmalarda kavramın çok sık kullanıldığı görülürken yerli literatürde bu anlamda çalışmaların daha kısıtlı olduğuna ulaşılmıştır. Bu kapsamda yapılan bu çalışma ile ilgili literatür özeti literatür taraması başlığı altında verilmeye çalışılacaktır.

Asadamraji vd. (2021) çalışmasında ulaşım faaliyetlerinde dijital dönüşüm için bir olgunluk modeli ortaya koymayı hedeflemiştir. Bu araştırmada, internetteki çeşitli bilimsel veri tabanlarından dijital dönüşüm olgunluğunun farklı modellerini ve aşamalarını incelemek ve olgunluğun boyutları ve aşamalarının kapsamlı bir özetini sunmak için meta-sentez tekniği kullanılmıştır. Tahran'daki 30 nakliye şirketi ve bunların ana faaliyetleri çalışmanın örneklemini oluşturmuştur. Önceki çalışmalarda olgunluğun boyutları ve aşamaları analiz edilerek, bu makalede sunulan olgunluk modelinde ulaştırma alanında beş aşama ve 10 boyuta yer verilmiştir. Bu boyutlar arasında dijital yönetim, bilgi teknolojisi, insan gücü, operasyonlar ve süreçler, kültür, organizasyon yapısı, yenilik ve değişim, yeni stratejiler, akıllı ürün ve hizmetler ile müşteri odaklılık yer almıştır.

Rakoma (2021) çalışmasında denizcilik şirketlerinin dijital olgunluğunu uygun şekilde ölçecek dijital olgunluk modeli geliştirmektedir. Bu araştırma için sistematik bir literatür taraması gerçekleştirilmiştir. Çalışma sonucunda, denizcilikte dijital olgunluk araştırmasının eksik olduğu tespit edilmiştir. Bu doğrultuda araştırmacılar tarafından 8 boyut ve 5 olgunluk seviyesi ile önerilen bir dijital olgunluk modeli geliştirilmiştir.

Tijan vd. (2021) çalışmasında deniz taşımacılığı sektöründeki dijital dönüşümü ele almaktadır. Araştırmada deniz taşımacılığı sektöründe dijital dönüşümün önündeki itici güçler, başarı faktörleri ve engeller hakkında bir literatür taraması gerçekleştirmiştir. Çalışma sonucunda yenilikçi teknolojilerin (blok zinciri veya otonom nakliye gibi) geliştirilmesi, deniz taşımacılığı sektöründe dijital dönüşümü kesinlikle teşvik etmektedir. Çalışmada ayrıca dijital dönüşümün işletmeyi nasıl etkileyebileceğine dair farkındalık eksikliği, paydaşlar arasında standart ve iş birliği eksikliği gibi dijital dönüşümü diğer sektörlere göre yavaşlatan engeller olduğu tespit edilmiştir.

Varol vd. (2022) çalışmasında dijital taşımacılık faaliyetleri için olgunluk ölçümü gerçekleştirmektedir. Bu çalışmada literatürden ve uzmanların deneyimlerinden yararlanılarak yeni bir olgunluk modeli önerilmektedir. Önerilen olgunluk modeli kapsamında beş ana kriter (malzeme akışı, iş kültürü, organizasyon ve strateji, müşteri memnuniyeti ve pazarlama, akıllı lojistik) önerilmektedir. Ayrıca önerilen model, kararsız bulanık analitik hiyerarşi süreci (HFAHP) adı verilen çok kriterli karar verme (MCDM) yaklaşımıyla çözülmektedir. Önerilen model ve metodolojiye Türkiye'deki bir lojistik şirketinde gerçek hayattan bir örnek olay çalışması uygulanmıştır.

Modica vd. (2023) çalışmasında Lojistik 4.0'ın taşımacılık sürecinin tasarımını ve konfigürasyonunu nasıl etkilediğini araştırmaktadır. Sistematik bir literatür taraması kullanan bu çalışma, taşımacılıkta Lojistik 4.0 için böyle bir süreci tasarlarken dikkate alınması gereken süreç boyutlarını içeren bir çerçeve sunmaktadır. Lojistik 4.0 paradigmasını benimsemek için bir olgunluk modeli ortaya konulmuştur.

Jaleta (2023) çalışmasında lojistik ve gümrük alanında dijital dönüşümü kapsamlı bir şekilde ele alarak ortaya dijital olgunluk modeli koymuşlardır. Çalışmada, dijitalleşme uygulamalarının mevcut durumunu değerlendirmek için Dijital Olgunluk Modellerinin en çok alıntı yapılan altı öznel belirleyicisini içeren niceliksel yaklaşımlar uygulanmıştır. 238 gümrük çalışanının ve 384 lojistik hizmet sağlayıcısının anketlere verdikleri cevaplar, tanımlayıcı istatistikler, korelasyon ve göreceli önem endeksi analizi kullanılarak analiz gerçekleştirilmiştir. Çalışma sonucunda dış kullanıcıların gümrüklerin dijital teknolojisini çok gelişmiş olarak görmediğini ortaya koymaktadır. Gümrük çalışanlarının tepkisi ise beklenen nominal ortalamanın biraz üzerinde kalarak ortalama olgunluk seviyesinde konumlanmaktadır. Çalışma, faktörlerin önemini değerlendirmek için iç ve dış dijital teknoloji kullanıcılarının dijital olgunluk algılarını ve göreceli önem endeksi analiziyle desteklenen teknoloji kabul modelini birleştirerek birleşik bir çerçeve önermektedir.

Al Mazroui vd. (2023) çalışmasında denizyolu taşımacılığı sektöründe dijital dönüşümün olgunluğunu ölçümlemişlerdir. Çalışmalarında yöntem olarak Körfez Arap Ülkeleri İşbirliği Konseyi ülkelerindeki işletmeler arasında bir örnek olay incelemesi gerçekleştirmişlerdir. Bu vaka çalışmasında denizcilik sektöründeki

dijital olgunluğa odaklanılmıştır. Bu çalışmada öncelikle nitel bir örnek olay metodolojisi kullanılmış ve üç nakliye şirketinin nakliye yöntemleri, piyasa işletimi, sağlanan hizmetler, teknolojik girişimler ve şirketin teknolojik gelişim hedefleri dikkate alınarak veriler analiz edilmiştir. Daha sonra Scopus veri tabanında bibliyografik tarama yapılarak elde edilen, 2020-2023 yılları arasında uluslararası hakemli dergilerde veya konferans bildirilerinde yayınlanmış 8 makaleden literatür taraması derlenmektedir. Araştırma sonucunda dijital olgunluğun faydalarının, denizcilik şirketlerinin kaynaklarını daha verimli kullanmalarına yardımcı olduğu, bunun sonucunda artan operasyonel verimlilik, gelişmiş müşteri bağlantıları ve artan sürdürülebilirlik sağladığı tespit edilmiştir.

İlgili literatürler incelendiğinde taşıma türleri arasında denizyolu taşımacılığı ile ilgili dijital olgunluk çalışmalarının daha fazla olduğu görülmektedir. Farklı yöntemlerle farklı ölçümlemeler gerçekleştirilmiş, fakat literatürde Türkiye'de yer alan uluslararası taşımacılık işletmelerinin dijital olgunluğu ile ilgili bir çalışmanın bulunmaması çalışmamızın özgün yanını ortaya koymaktadır. Bu kapsamda taşımacılık faaliyetlerinin dijitalleşmesi için öncelikle mevcut durumun ortaya konulması oldukça önem arz eden bir husustur.

Araştırma Metodolojisi

Araştırmanın Amacı ve Önemi

Uluslararası taşımacılık sektöründe dijitalleşme, işletmelerin rekabet gücünü artırmak için önemli bir faktör haline gelmiştir. Ancak işletmelerin dijital dönüşüm sürecinde hangi aşamada olduklarını belirlemek ve bu süreci etkin bir şekilde yönetmek güçlükler yaratabilmektedir. Bu çalışmada, uluslararası taşımacılık hizmeti üreten işletmelerin dijital olgunluk düzeylerinin belirlenmesi üzerine odaklanılmıştır. Bu hususdan yola çıkarak çalışmanın amacı Türkiye'de uluslararası taşımacılık hizmeti üreten işletmelerin dijital olgunluk düzeylerinin belirlenmesidir. Dijital olgunluk düzeyinin alt boyutlarıyla birlikte ortaya konulması ve bundan sonraki taşımacılık politikalarının buna göre şekillenmesi ise çalışmanın önemini ortaya koymaktadır.

Uluslararası taşımacılık hizmeti üreten işletmelerin dijital olgunluk düzeylerinin belirlenmesi, işletmelerin mevcut durumlarını değerlendirerek dijital dönüşüm sürecini etkin bir şekilde yönetmelerine yardımcı olmaktadır. Dijital olgunluk düzeylerinin belirlenmesi, işletmelerin zayıf noktalarını fark edebilmelerine ve bu alanda iyileştirmeler yaparak rekabet avantajı elde etmelerine imkân sağlamaktadır. Literatür taraması incelendiğinde Türkiye'de yer alan uluslararası taşımacılık işletmelerinin dijitalleşme düzeyleri ve dijital olgunluğu ile ilgili anket çalışmasına rastlanılmamıştır. Bu kapsamda taşımacılık işletmelerinin dijitalleşme durumunu ortaya çıkaracağı için çalışmanın önemli bir boşluğu doldurması hedeflenmektedir. Ayrıca bu durumun ortaya konulması sadece özel sektörü değil kamu politikacılarının şekillenmesinde politika yapıcılara da katkı sunacaktır.

Akademik kapsamda yürütülen bilimsel çalışmaların temelinde araştırmaya dair sürecin başlatılabilmesi için ilk aşama araştırma sorusu veya hipotezlerinin belirlenmesidir (Gürbüz ve Şahin, 2018: 51). Bu şekilde çalışma belli bir sistem dahilinde ve mantık çerçevesinde yürütülmektedir (Ali ve Gölgeci, 2019: 807).

Çalışma için etik kurul T.C Tarsus Üniversitesi Sosyal ve Beşerî Bilimler Araştırmaları Etik Kurul Komisyonundan 2024/29 karar sayılı onay raporuyla alınmıştır.

5.2. Evren ve Örneklem

Evren, bir çalışma için ortaya koyulan araştırma sorularına cevap bulabilmek adına ulaşılması gereken veriyi sağlayan canlı veya cansız varlıkların oluşturduğu büyük gruptur (Büyüköztürk vd., 2013: 80). Araştırma kapsamında varılan sonuçlar, evren üzerinde genellenmekte ve araştırma örneklemi evren vasıtasıyla belirlenmektedir (Gürbüz ve Şahin, 2018: 125). Bu doğrultuda Türkiye lojistik sektörü açısından en büyük sivil toplum kuruluşlarından biri olan UTİKAD üyesi 714 işletme bu çalışmanın evrenini temsil etmektedir. Bu

işletmeler Türkiye'nin 23 ilini oluşturan İstanbul, Adana, Antalya, Artvin, Aydın, Ankara, Bursa, Çanakkale, Gaziantep, Hatay, Yozgat, İzmir, Kayseri, Kocaeli, Konya, Mardin, Mersin, Ordu, Samsun, Şanlıurfa, Şırnak, Tekirdağ ve Van'a dağılmış durumdadır. Belirlenmiş olan evrenin tamamı ile veri toplama sürecini yürütebilmek zaman ve maliyet gibi kısıtlar nedeniyle güçlük yarattığından araştırmada örneklem belirleme yoluna gidilmiştir.

Evreni temsil etme kastıyla birtakım metotlarla evren içinden belirlenen ve üzerinde inceleme yapılan grup örneklem olarak ifade edilmektedir (Özen ve Gül, 2007: 397). Örneklem büyüklüğünü ortaya koymak için kesin sayılar belirlemek önemlidir. Örneklem sayısının örneklemi temsil edecek büyüklükte olması ve analiz yönteminin gerekliliklerini karşılayacak kapasitede olması aranmaktadır (Gürbüz ve Şahin, 2018: 127). UTİKAD üyesi 714 işletmeden oluşan evren Gürbüz ve Şahin (2018) tarafından "Farklı Evrenler İçin Kabul Edilebilir Asgari Örneklem Büyüklükleri" kapsamında yapılan hesaplar aracılığıyla %95 güvenilirlik düzeyi ile örneklem sayısının en az 254 olması gerekmektedir (Gürbüz ve Şahin, 2018: 130). Bu araştırmada yürütülen nicel analiz için 286 lojistik işletmesi yöneticisi ile anket çalışması yürütülmüştür.

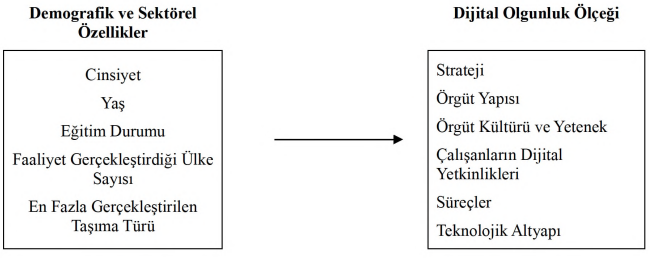
Örneklem sayısının tespit edilmesinin ardından örneklem seçme yöntemleri incelenmiş ve nicel veri toplamak amacıyla olasılığa dayanmayan örnekleme yöntemleri arasından kolayda örnekleme yönteminin çalışmayı nihai hale taşıyacağına karar verilmiştir. Araştırmacının çalışması için ihtiyaç olarak değerlendirdiği büyüklükteki örneklem sayısına varıncaya dek imkanları ölçüsünde kolay ve ulaşılabilir katılımcılarla veri toplama eylemi kolayda örnekleme yöntemi olarak ifade edilmektedir (Gürbüz ve Şahin, 2018: 132).

Örneklem yönteminin belirlenmesinin devamında çalışmanın veri toplama yöntemi olarak anket yöntemi seçilmiştir. Katılımcılara belirlenen bir konu hakkındaki davranış, tutum ve düşüncelerinin bir yapı ve sırada yöneltilen sorulara dayalı olarak elde edildiği yöntem anket yöntemidir (Büyüköztürk vd., 2013: 124). Bu araştırmada Kayabaşı ve Kasımoğlu (2023) tarafından yürütülmüş olan çalışmada yer alan anketten faydalanılmıştır. İlgili çalışma 38 madde ve 6 boyuttan oluşan ölçek içermektedir. Demografik özellikler kapsamında katılımcılara 7 soru yöneltilmiş, bu başlıkla katılımcıya ve işletmesine dair birtakım bilgilerin elde edilmesi amaçlanmıştır. Dijital Olgunluk Ölçeği kapsamında katılımcılara 38 soru sorulmuş, katılımcıların dijitalleşme alanındaki görüşlerine ulaşmak amaçlanmıştır. Bu ölçekte katılımcılara yöneltilen sorular 5'li Likert Ölçeği tipindedir. Veri toplama sürecinde UTİKAD üyesi olan Türkiye'nin çeşitli illerinde faaliyet gösteren taşımacılık işletmelerinden yararlanılmıştır. Bu işletmelere internet ortamında ulaşılmış ve sorulara cevap aranmıştır.

5.3. Araştırma Modeli ve Hipotezleri

Sosyal bilimler altında yürütülen araştırmalarda model, araştırmacı tarafından doğrudan ele alınıp incelenemediği durumlarda anlaşılabilirliği artırmak için kullanılan çerçevedir (Gürbüz ve Şahin, 2018: 76). Model doğrultusunda kompleks kavramların anlamlandırılması mümkün hale getirilmektedir. Bu doğrultuda bu çalışmanın araştırma modeli aşağıdaki gibidir.

Şekil 1
Araştırma Modeli



Araştırma modelinin devamında çalışmaya dair hipotezler oluşturulmuştur. İki veya daha fazla değişken arasında var olduğu öngörülen ilişkinin test edilmesini mümkün hale getiren hipotezler ile (Gürbüz ve Şahin, 2018: 73) ihtiyaç duyulan veri ve bu ihtiyacı karşılamak için izlenecek olan yol tespit edilmektedir (Büyüköztürk vd., 2013: 65).

İşletmelerin dijitalleşme düzeylerini ve olgunluklarını belirlemede üç temel anlayış bulunmaktadır. Birinci anlayışta çalışanların dijital trendlere yanıt verebilecek yetkinlikte olup olmadıkları ve çalışanların yeni süreçlere uygun model kurabilmeleridir. İkinci anlayış örgütlerin yapılarının ve teknolojik altyapılarının buna göre tasarlanması ve üçüncü anlayışta örgütlerin temel kültürlerinin ve stratejilerinin bu uygun dizayn edilmesidir (Ilin vd., 2019: 168-170). Bu kapsamda işletmelerin dijital olgunluğa ulaşabilmesinin tespiti için örgüt stratejilerinin, örgüt kültürlerinin ve yeteneklerinin, çalışanlarının dijital yetkinliklerinin, süreçlerinin ve teknolojik altyapılarının belirlenmesi gereklidir.

Araştırmanın amacına ulaşabilmek için araştırma kapsamında literatür incelenmiş ve "Taşımacılık şirketi çalışanlarının sosyo-demografik özellikleri ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır" hipotezi araştırmanın ana hatlarını oluşturan hipotez olarak kurulmuştur. Alanyazın incelendiğinde dijital olgunluğun sosyo-demografik değişkenler kapsamında cinsiyete bağlı değişkenliği değerlendirildiğinde değişkenler arasında anlamlı farklılık beklenmektedir (Ribeiro-Navarette vd., 2021; Bottalico, 2021; Bozkurt, 2024). Ek olarak yaşa bağlı değişkenliği araştıran çalışmaların sonuçları değerlendiğinde de katılımcıların yaşları ile dijital olgunluk düzeyleri arasında da anlamlı farklılık beklenmektedir (Macky vd., 2008; Bolton vd., 2013; Ribeiro-Navarette vd., 2021; Bozkurt, 2024). Sosyo-demografik değişkenlerden eğitim durumu ile dijital olgunluk ilişkisi değerlendirildiğinde ise Balsmeier ve Woerter (2019), Zaborovskaia vd. (2020) ve Bozkurt (2024)'un yapmış olduğu çalışmalardan yola çıkılarak eğitim durumu ile dijital olgunluk düzeyi arasında anlamlı farklılıkların olması kaçınılmazdır. Bu bağlamda alanyazına dayanarak aşağıdaki hipotezler oluşturulmuştur.

H_1 Taşımacılık şirketi çalışanlarının sosyo-demografik özellikleri ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır.

H_{1a}: Taşımacılık şirketi çalışanlarının cinsiyetleri ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır.

H_{1b}: Taşımacılık şirketi çalışanlarının yaşları ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır.

H_{1c}: Taşımacılık şirketi çalışanlarının eğitim durumu ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır.

Araştırmanın temel amaçlarından olan "Taşımacılık şirketinin sektörel özellikleri ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır" hipotezi araştırmanın ana hatlarını oluşturan ikinci hipotez olarak kurulmuştur. Bu bağlamda değerlendirme yapıldığında alanyazın dijital olgunluk ile sektörel özellikler ele alınmış Eremina vd., (2019), Karaoğlan (2019) ve Bozkurt (2024)'un çalışmalarından yararlanılarak şirketlerin sektörel özellikleri ile dijital olgunluk düzeyleri arasında anlamlı farklılık olması beklenmektedir. Bu bağlamda H2 ana hipotezine bağlı alt hipotezleri oluşturulmuştur.

H_2 Taşımacılık şirketinin sektörel özellikleri ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır.

H_{2a}: Taşımacılık şirketinin faaliyet gerçekleştirdiği ülke sayısı ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır.

H_{2b}: Taşımacılık şirketinin faaliyet gerçekleştirdiği taşıma türü ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır.

Bulgular

Nicel veri toplama yöntemlerinden anket yöntemi ile 286 katılımcıdan elde edilen veriler istatistik paket programı olan free trial version of SPSS Statistics (Statistical Package for the Social Sciences) for Windows 25.0 programı kullanılarak analiz edilmiştir. Analiz sürecine başlanmadan önce çalışmaya konu olan ölçümün geçerli olabilmesi amacıyla güvenirlik testleri yürütülerek İçsel Tutarlılık Analizi doğrultusunda Cronbach's Alfa (α) değeri belirlenmiştir. Likert tipi ölçekte alfa katsayısı 0 ila 1 arasında bir değer almaktadır; güvenilir değerin en az 0,70 olması gerekmektedir (Gürbüz ve Şahin,2018: 333).

Tablo 1

Güvenirlik Analizi

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
,803	,770	38

Çalışmada elde edilen verilerle yapılan analiz sonucunda ise Cronbach alfa değeri ,803 bulunmuştur. Cronbach alfa katsayısı 0,80 ile 0,99 arasında ise ölçek yüksek derecede güvenilir olarak kabul edilmektedir (Özdamar, 2002). Bu doğrultuda çalışmada kullanılan ölçeğin yüksek derecede güvenilir olduğu ifade edilebilmektedir.

Pek çok tesadüfi sürecin dağılımı olarak ortaya çıkan kavrama normal dağılım denmektedir (Can, 2019: 47). Gelişigüzel seçilen bir örnekleme ait olan nicel değişken aldığı değerin dağılımına göre çan eğrisi şeklini alıyorsa normal dağılım sağlanmaktadır. Bu bilgiler doğrultusunda çalışmada ölçek alt boyutları toplam puanlarının normal dağılım gösterip göstermediği kontrol edilmiştir. Araştırmanın örneklem büyüklüğü 286 kişi (n≥50) olduğu için dağılımın normalliği Kolmogorov-Smirnov Testi ile incelenmiştir. Normallik analiz sonuçları aşağıda gösterilmiştir.

Tablo 2

Normallik Testi Sonuçları

Normallik Testi			
	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Strateji	,122	286	,000
Örgüt Yapısı	,132	286	,000
Örgüt Kültürü ve Yetenek	,114	286	,000
Çalışanların Dijital Yetkinlikleri	,147	286	,000
Süreçler	,166	286	,000
Teknolojik Altyapı	,200	286	,000

Çalışmaya dair yürütülen normallik testi sonuçlarına göre alt boyutlar (p=0,000<0,05) normal dağılım göstermemektedir. Normal dağılım göstermeyen verilerin analizi için parametrik olmayan testlerin kullanılması gerekmektedir. Bu kapsamda parametrik olmayan testlerden Mann-Whitney U Testi ve Kruskal-Wallis Testi kullanılmıştır. Çoklu karşılaştırma testlerinde fark yaratan grubu bulmak için Bonferroni Analizi kullanılmıştır.

Tanımlayıcı İstatistikler

Katılımcıların tanıtıcı bilgileri ve çalıştıkları işletme bilgileri doğrultusunda frekans analizleri yapılmıştır. Bu analizlerde değerler sıklık ve yüzdeler ile tablolaştırılmıştır. Çalışmaya dair veriler değerlendirilirken

tanımlayıcı istatistiksel metotlara (sayı, yüzde, ortalama, standart sapma, minimum, maksimum, medyan, sıra ortalaması) yer verilmiştir.

Tablo 3

Katılımcıların Cinsiyet Bilgileri

Cinsiyet	Sıklık	Yüzde (%)
Erkek	180	62,9
Kadın	106	37,1
Toplam	286	100,0

Araştırmaya katılan 286 katılımcının sosyo-demografik özellikleri cinsiyet değişkeni kapsamında ele alındığında katılımcıların 180'i (%62,9) erkek, 106'sı (%37,1) kadın olduğu görülmektedir.

Tablo 4

Katılımcıların Yaş Bilgileri

Yaş	Sıklık	Yüzde (%)
20-30	40	14
31-40	77	26,9
41-50	89	31,1
51-60	53	18,5
61 ve üzeri	27	9,4
Toplam	286	100

Katılımcıların demografik özellikleri yaş değişkeni kapsamında ele alındığında 286 katılımcının 40'ı (%14,0) 20-30 yaş grubunda iken 77'si (%26,9) 31-40 yaş grubu, 89'u (%31,1) 41-50 yaş grubu, 53'ü (%18,5) 51-60 yaş grubu ve 27'si (%9,4) 61 yaş ve üzerinde olduğu görülmektedir.

Tablo 5

Katılımcılara Eğitim Durumu

Eğitim Durumu	Sıklık	Yüzde (%)
İlköğretim	9	3,1
Ortaöğretim/Lise	16	5,6
Ön Lisans	42	14,7
Lisans	122	42,7
Lisansüstü	97	33,9
Toplam	286	100

Sosyo-demografik değişkenlerden eğitim durumunda ise katılımcıların 9'u (%3,1) ilköğretim eğitimi almış olup, 16'sının (%5,6) ortaöğretim/lise mezunu olduğu görülmektedir. Üniversite eğitimini tamamlayanların ise 42'si (%14,7) ön lisans, 122'si (%42,7) lisans ve 97'sinin (%33,9) lisansüstü eğitim seviyesinde bulundukları görülmektedir.

Tablo 6

Katılımcı İşletmelerinin Faaliyet Gerçekleştirdiği Ülke Sayısı

Faaliyet Gerçekleştirilen Ülke Sayısı	Sıklık	Yüzde (%)
1-4 ülke	42	14,7
5-9 ülke	85	29,7
10-14 ülke	94	32,9
15 ülke ve üzeri	65	22,7

Faaliyet Gerçekleştirilen Ülke Sayısı	Sıklık	Yüzde (%)
Toplam	286	100

Katılımcılara yöneltilen "Faaliyet gerçekleştirdiğiniz ülke sayısı kaçtır?" sorusuna verilen yanıtlarda ise 1-4 ülke yanıtını verenler 42 kişi (%14,7), 5-9 ülke yanıtını verenler 85 kişi (%29,7) 10-14 ülke yanıtını verenler 94 kişi (%32,9) ve 15 ülke üzeri yanıtını verenler ise 65 kişi (%22,7) olarak Tablo 6'da belirtilmiştir.

Tablo 7

Katılımcı İşletmelerinin Hizmet Verdiği Taşımacılık Türü

Hizmet Verilen Taşımacılık Türü	Sıklık	Yüzde (%)
Karayolu Taşımacılığı	144	50,3
Denizyolu Taşımacılığı	121	42,3
Demiryolu Taşımacılığı	7	2,4
Havayolu Taşımacılığı	14	4,9
Toplam	286	100

Katılımcıların "En çok hangi taşımacılık türünde hizmet vermektesiniz?" sorusuna 144'ü (%50,3) karayolu yanıtını verirken, 121'i (%42,3) denizyolu, 7'si (%2,4) demiryolu ve 14'ü (%4,9) havayolu yanıtını vermiştir.

Ölçek Puan Dağılımları

Katılımcıların tanıtıcı özellikleri ve işletme bilgilerine dair yürütülen analizlerin ölçek puan dağılımını belirlemek için analizler yürütülmüştür. İlk olarak katılımcıların cinsiyet bilgisine göre Dijital Olgunluk Ölçeği puan dağılımı ele alınmıştır; aşağıda Tablo 8'de gösterilmektedir.

Tablo 8

Katılımcıların Cinsiyetine Göre Dijital Olgunluk Ölçeği Puan Dağılımı

Alt Boyutlar	Cinsiyet	$\overline{X}$	± S.S.	Z	p
Strateji	Erkek (1)	25,7333	2,39553	−0,585	0,558
	Kadın (2)	25,5472	2,01958		
Örgüt Yapısı	Erkek (1)	25,9889	2,24477	−2,463	,014*
	Kadın (2)	25,5094	2,07592		
Örgüt Kültürü ve Yetenek	Erkek (1)	33,9167	2,92337	−0,465	0,642
	Kadın (2)	33,783	2,64036		
Çalışanların Dijital Yetkinlikleri	Erkek (1)	27,6278	4,50454	−2,555	,011*
	Kadın (2)	29,3491	2,37464		
Süreçler	Erkek (1)	23,5444	4,28629	−2,471	,013*
	Kadın (2)	25,1698	2,16233		
Teknolojik Altyapı	Erkek (1)	19,8722	4,29112	−1,257	0,209
	Kadın (2)	21,1604	2,02901		

Katılımcıların cinsiyetine göre Dijital Olgunluk Ölçeğine ilişkin istatistikler Tablo 8'de verilmiştir. Cinsiyete göre strateji, örgüt kültürü ve yetenek ile teknolojik altyapı alt boyutları arasında istatistiksel olarak anlamlı bir fark bulunmaz iken ($p>0,05$); örgüt yapısı, çalışanların dijital yetkinlikleri ve süreçler alt boyutlarında istatistiksel olarak anlamlı fark bulunmaktadır ($p<0,05$).

Tablo 9

Katılımcıların Yaşına Göre Dijital Olgunluk Ölçeği Puan Dağılımı

Alt Boyutlar	Yaşınız	$\overline{X}$	±S.S.	χ^2	p
Strateji	20-30	25,475	2,09991	14,194	,007*
	31-40	25,5455	2,39267		
	41-50	26,3258	2,40159		
	51-60	25,2642	1,83084		
	61 ve üzeri	24,8889	1,98714		
	Toplam	25,6643	2,26164		
Örgüt Yapısı	20-30	25,075	2,17665	7,923	0,094
	31-40	26,0649	1,94894		
	41-50	26,0225	2,28124		
	51-60	25,5849	2,09793		
	61 ve üzeri	25,9259	2,60068		
	Toplam	25,8112	2,19233		
Örgüt Kültürü ve Yetenek	20-30	33,525	2,70789	1,383	0,847
	31-40	33,8312	3,06252		
	41-50	34,1348	2,91622		
	51-60	33,7547	2,2093		
	61 ve üzeri	33,8148	3,10133		
	Toplam	33,8671	2,81783		
Çalışanların Dijital Yetkinlikleri	20-30	28,45	3,14561	34,513	,000*
	31-40	26,0649	5,44914		
	41-50	29,618	2,10792		
	51-60	29,8491	2,33202		
	61 ve üzeri	26,7037	3,77048		
	Toplam	28,2657	3,93892		
Süreçler	20-30	24,75	2,67706	21,135	,000*
	31-40	22,7013	4,91524		
	41-50	25,427	1,99936		
	51-60	25,0755	2,0177		
	61 ve üzeri	21,3333	5,1739		
	Toplam	24,1469	3,7256		
Teknolojik Altyapı	20-30	20,875	149,6	16,521	,002*
	31-40	19,8571	137,33		
	41-50	21,3371	159,64		
	51-60	21,0377	148,82		
	61 ve üzeri	16,3704	88,41		
	Toplam	20,3497			

Katılımcıların yaşına göre Dijital Olgunluk Ölçeğine ilişkin istatistikler Tablo 9'da verilmiştir. Yaşa göre örgüt yapısı ile örgüt kültürü ve yetenek alt boyutu dışındaki diğer alt boyutlarda istatistiksel olarak anlamlı fark saptanmıştır ($p<0,05$).

Tablo 10

Katılımcıların Eğitim Durumuna Göre Dijital Olgunluk Ölçeği Puan Dağılımı

Alt Boyutlar	Eğitim Durumu	$\overline{X}$	±S.S.	χ^2	p
Strateji	İlköğretim	25,6667	2,5	7,478	0,113
	Ortaöğretim/Lise	24,4375	1,67207		
	Ön Lisans	25,2619	2,59511		
	Lisans	25,8361	2,35088		
	Lisansüstü	25,8247	2,00005		
	Toplam	25,6643	2,26164		
Örgüt Yapısı	İlköğretim	27,3333	2,29129	8,151	0,086
	Ortaöğretim/Lise	25,1875	2,6638		
	Ön Lisans	26,0714	2,14582		
	Lisans	25,9262	2,04563		
	Lisansüstü	25,5155	2,25052		
	Toplam	25,8112	2,19233		
Örgüt Kültürü ve Yetenek	İlköğretim	33,8889	3,40751	4,999	0,287
	Ortaöğretim/Lise	34,125	3,0304		
	Ön Lisans	32,9762	2,94244		
	Lisans	34,1721	2,78927		
	Lisansüstü	33,8247	2,68099		
	Toplam	33,8671	2,81783		
Çalışanların Dijital Yetkinlikleri	İlköğretim	26,6667	2	68,042	,000*
	Ortaöğretim/Lise	26,0625	4,26566		
	Ön Lisans	23,2619	5,37864		
	Lisans	29,2131	2,77899		
	Lisansüstü	29,7526	2,32751		
	Toplam	28,2657	3,93892		
Süreçler	İlköğretim	18,8889	3,9826	39,302	,000*
	Ortaöğretim/Lise	22,0625	5,49507		
	Ön Lisans	20,8571	5,62473		
	Lisans	24,8852	2,38174		
	Lisansüstü	25,4742	1,99527		
	Toplam	24,1469	3,7256		
Teknolojik Altyapı	İlköğretim	14,3333	4,5	24,024	,000*
	Ortaöğretim/Lise	16,875	7,06045		
	Ön Lisans	18,8571	5,24321		
	Lisans	21,1475	2,16536		
	Lisansüstü	21,1237	2,25119		
	Toplam	20,3497	3,67019		

Katılımcıların eğitim durumuna göre Dijital Olgunluk Ölçeğine ilişkin istatistikler Tablo 10'da verilmiştir. Buna göre çalışanların dijital yetkinlikleri, süreçler ve teknolojik altyapı alt boyutlarında istatistiksel olarak anlamlı fark bulunurken diğer alt boyutlarda istatistiksel olarak anlamlı fark saptanmamıştır (p<0,05).

Tablo 11

Katılımcı İşletmelerinin Faaliyet Gerçekleştirdiği Ülke Sayısına Göre Dijital Olgunluk Ölçeği Puan Dağılımı

Alt Boyutlar	Faaliyet Gerçekleştirilen Ülke Sayısı	$\overline{X}$	±S.S.	χ^2	p
Strateji	1-4 ülke	25,5476	2,16629	2,236	0,525
	5-9 ülke	25,4941	2,14156		
	10-14 ülke	25,5851	2,39807		
	15 ülke ve üzeri	26,0769	2,27285		
	Toplam	25,6643	2,26164		
Örgüt Yapısı	1-4 ülke	25,8571	1,82892	4,751	0,191
	5-9 ülke	25,5059	2,29712		
	10-14 ülke	25,8085	2,24938		
	15 ülke ve üzeri	26,1846	2,17149		
	Toplam	25,8112	2,19233		
Örgüt Kültürü ve Yetenek	1-4 ülke	33,3571	3,02688	6,694	0,082
	5-9 ülke	33,4353	2,77509		
	10-14 ülke	34,0638	2,41771		
	15 ülke ve üzeri	34,4769	3,16775		
	Toplam	33,8671	2,81783		
Çalışanların Dijital Yetkinlikleri	1-4 ülke	27,7619	5,03068	5,063	0,167
	5-9 ülke	27,5294	4,01363		
	10-14 ülke	28,7872	3,22581		
	15 ülke ve üzeri	28,8	3,87782		
	Toplam	28,2657	3,93892		
Süreçler	1-4 ülke	23,0952	4,23003	10,091	,018*
	5-9 ülke	23,4118	4,11239		
	10-14 ülke	24,8298	3,24829		
	15 ülke ve üzeri	24,8	3,20254		
	Toplam	24,1469	3,7256		
Teknolojik Altyapı	1-4 ülke	19,9286	3,61159	9,791	,020*
	5-9 ülke	19,3765	4,46941		
	10-14 ülke	20,9894	3,00356		
	15 ülke ve üzeri	20,9692	3,15223		
	Toplam	20,3497	3,67019		

Katılımcı işletmelerinin faaliyet gerçekleştirdiği ülke sayısına göre Dijital Olgunluk Ölçeğine ilişkin istatistikler Tablo 11'de verilmiştir. Buna göre süreçler ve teknolojik altyapı alt boyutlarında istatistiksel olarak anlamlı fark bulunurken diğer alt boyutlarda istatistiksel olarak anlamlı fark saptanmamıştır (p<0,05).

Tablo 12

Katılımcı İşletmelerinin En Çok Hizmet Verdiği Taşımacılık Türüne Göre Dijital Olgunluk Ölçeği Puan Dağılımı

Alt Boyutlar	En Çok Hizmet Verilen Taşımacılık Türü	$\overline{X}$	±S.S.	χ^2	p
Strateji	Karayolu Taşımacılığı	25,6319	2,23058	1,151	0,765
	Denizyolu Taşımacılığı	25,7273	2,26569		
	Demiryolu Taşımacılığı	26,2857	2,49762		
	Havayolu Taşımacılığı	25,1429	2,56776		
	Toplam	25,6643	2,26164		
Örgüt Yapısı	Karayolu Taşımacılığı	25,6181	2,14833	8,564	,036*
	Denizyolu Taşımacılığı	26,1405	2,26313		
	Demiryolu Taşımacılığı	25,5714	2,22539		
	Havayolu Taşımacılığı	25,0714	1,73046		
	Toplam	25,8112	2,19233		
Örgüt Kültürü ve Yetenek	Karayolu Taşımacılığı	34,2847	2,68032	8,656	,034*
	Denizyolu Taşımacılığı	33,6198	2,8614		
	Demiryolu Taşımacılığı	32,4286	1,90238		
	Havayolu Taşımacılığı	32,4286	3,45775		
	Toplam	33,8671	2,81783		
Çalışanların Dijital Yetkinlikleri	Karayolu Taşımacılığı	28,8125	3,26663	8,29	,040*
	Denizyolu Taşımacılığı	27,3967	4,58345		
	Demiryolu Taşımacılığı	28,7143	2,36039		
	Havayolu Taşımacılığı	29,9286	3,58339		
	Toplam	28,2657	3,93892		
Süreçler	Karayolu Taşımacılığı	24,7847	2,4585	7,742	0,052
	Denizyolu Taşımacılığı	23,1405	4,82581		
	Demiryolu Taşımacılığı	26,4286	1,27242		
	Havayolu Taşımacılığı	25,1429	2,0702		
	Toplam	24,1469	3,7256		
Teknolojik Altyapı	Karayolu Taşımacılığı	21,4028	2,06645	26,774	,000*
	Denizyolu Taşımacılığı	18,8264	4,73054		
	Demiryolu Taşımacılığı	22,1429	1,34519		
	Havayolu Taşımacılığı	21,7857	1,76193		
	Toplam	20,3497	3,67019		

Katılımcı işletmelerinin en çok hizmet verdiği taşımacılık türüne göre Dijital Olgunluk Ölçeğine ilişkin istatistikler Tablo 12'de verilmiştir. Buna göre strateji ve süreçler alt boyutu dışındaki alt boyutlar arasında istatistiksel olarak anlamlı fark bulunduğu saptanmıştır ($p<0,05$).

Katılımcıların Sektörel Özellikleri ile Dijital Olgunluk Ölçeğinden Aldıkları Puanlara Ait Korelasyon Bulguları

Katılımcıların tanıtıcı bilgileri ve ölçek puan dağılımını belirlemek amacıyla yürütülen analizlerin ardından sektörel özellikler ile Dijital Olgunluk Ölçeğinden elde edilen puanlara ait korelasyon analizine ulaşabilmek için Spearman Korelasyon Analizi yürütülmüştür. İlgili analizle amaçlanan husus parametrik

olmayan testlerde iki değişken arasındaki ilişkiyi değerlendirmektir. Elde edilen sonuçlar Tablo 13'te gösterilmektedir.

Tablo 13

Dijital Olgunluk Ölçeği Alt Boyutları ile Sektörel Özelliklere Ait Korelasyon Analizi

Alt Boyutlar		Faaliyet gösterilen ülke sayısı	En sık kullanılan taşımacılık modu	Strateji	Örgüt Yapısı	Örgüt Kültürü ve Yetenek	Çalışanların Dijital Yetkinlikleri	Süreçler	Teknolojik Altyapı
Strateji	r	0,071	0,001	1	,132*	0,049	,118*	0,096	0,103
	p	0,23	0,986	.	0,026	0,414	0,046	0,104	0,083
Örgüt Yapısı	r	0,112	0,075	,132*	1	0,038	-,137*	-,123*	−0,085
	p	0,06	0,204	0,026	.	0,527	0,02	0,038	0,152
Örgüt Kültürü ve Yetenek	r	,148*	-,160**	0,049	0,038	1	0,105	0,068	−0,008
	p	0,012	0,007	0,414	0,527	.	0,076	0,254	0,893
Çalışanların Dijital Yetkinlikleri	r	0,093	−0,059	,118*	-,137*	0,105	1	,454**	,242**
	p	0,116	0,323	0,046	0,02	0,076	.	0	0
Süreçler	r	,169**	−0,043	0,096	-,123*	0,068	,454**	1	,412**
	p	0,004	0,468	0,104	0,038	0,254	0	.	0
Teknolojik Altyapı	r	,163**	-,174**	0,103	−0,085	−0,008	,242**	,412**	1
	p	0,006	0,003	0,083	0,152	0,893	0	0	.

- Dijital Olgunluk Ölçeği örgüt kültürü ve yetenek alt boyutu ile sektörel özelliklerden faaliyet gerçekleştirilen ülke sayısı arasında istatistiksel olarak anlamlı pozitif yönlü düşük düzeyde bir ilişki vardır (r: 0,148; p<0,05).
- Dijital Olgunluk Ölçeği örgüt kültürü ve yetenek alt boyutu ile sektörel özelliklerden en fazla hizmet verilen taşımacılık türü arasında istatistiksel olarak anlamlı negatif yönlü düşük düzeyde bir ilişki vardır (r: −0,160; p<0,05).
- Dijital Olgunluk Ölçeği çalışanların dijital yetkinlikleri alt boyutu ile süreçler alt boyutu arasında pozitif yönlü orta düzeyde bir ilişki vardır (r: 0,454; p<0,05).
- Dijital Olgunluk Ölçeği çalışanların dijital yetkinlikleri alt boyutu ile teknolojik alt yapı alt boyutu arasında pozitif yönlü düşük düzeyde bir ilişki vardır (r: 0,242; p<0,05).
- Dijital Olgunluk Ölçeği süreçler alt boyutu ile sektörel özelliklerden faaliyet gösterilen ülke sayısı arasında pozitif yönlü düşük düzeyde bir ilişki vardır (r: 0,169; p<0,05).
- Dijital Olgunluk Ölçeği süreçler alt boyutu ile teknolojik altyapı alt boyutu arasında pozitif yönlü orta düzeyde bir ilişki vardır (r: 0,412; p<0,05).
- Dijital Olgunluk Ölçeği teknolojik altyapı alt boyutu ile sektörel özelliklerden faaliyet gerçekleştirilen ülke sayısı arasında istatistiksel olarak anlamlı pozitif yönlü düşük düzeyde bir ilişki vardır (r: 0,163; p<0,05).
- Dijital Olgunluk Ölçeği teknolojik altyapı alt boyutu ile sektörel özelliklerden en fazla hizmet verilen taşımacılık türü arasında istatistiksel olarak anlamlı negatif yönlü düşük düzeyde bir ilişki vardır (r: −0,174; p<0,05).

Bulguların Tartışılması

Taşımacılık Şirketi Çalışanlarının Sosyo-Demografik Özellikleri ile Dijital Olgunluk Ölçeği Alt Boyutları Arasındaki İlişkinin Tartışılması

Araştırmamızın bulgularında taşımacılık şirketi çalışanlarının sosyo-demografik özellikleri ile dijital olgunluk ölçeği ve alt boyutların anlamlı farklılıkların olduğu görülmektedir. Sosyo-demografik değişkenlerden cinsiyet kapsamında değerlendirme yapıldığında dijital olgunluk ölçeği alt boyutlarından örgüt yapısı alt boyutunda erkeklerin lehine, çalışanların dijital yetkinlikleri ve süreçler alt boyutunda ise kadınların yerine anlamlı farklılıkların olduğu ortaya konmaktadır. Teknolojik alt yapı, örgüt kültürü ve yetenek ile strateji alt boyutunda ise anlamlı bir farklılık bulunmamaktadır. Bu bağlamda değerlendirme yapıldığında H_{1a}: Taşımacılık şirketi çalışanlarının cinsiyetleri ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır. Hipotezi kısmen desteklenmektedir.

Sosyo-demografik değişkenlerden yaş değişkeni kapsamında değerlendirme yapıldığında dijital olgunluk ölçeği alt boyutlarından örgüt yapısı ile örgüt kültürü ve yetenek alt boyutlarında anlamlı farklılık saptanmaz iken teknolojik alt yapı, strateji, süreçler ve çalışanların dijital yetkinlikleri alt boyutlarında genel olarak 41-50 yaş aralığındaki katılımcılar açısından anlamlı farklılıkların olduğu görülmektedir. Bu bağlamda değerlendirme yapıldığında H_{1b}: Taşımacılık şirketi çalışanlarının yaşları ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır. Hipotezi kısmen desteklenmektedir.

Sosyo-demografik değişkenlerden eğitim durumu değişkeni kapsamında değerlendirme yapıldığında dijital olgunluk ölçeği alt boyutlarından strateji, örgüt yapısı, örgüt kültürü ve yetenek alt boyutlarında anlamlı farklılık saptanmaz iken teknolojik alt yapı, süreçler ve çalışanların dijital yetkinlikleri alt boyutlarında genel olarak lisansüstü eğitimi tamamlayan katılımcılar lehine anlamlı farklılıkların olduğu görülmektedir. Bu bağlamda değerlendirme yapıldığında H_{1c}: Taşımacılık şirketi çalışanlarının eğitim durumu ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır. Hipotezi kısmen desteklenmektedir.

Genel hatlarıyla sosyo-demografik değişkenler ile dijital olgunluk ölçeği alt boyutları arasındaki ilişki değerlendirildiğinde araştırmamıza katılan katılımcıların sosyo-demografik değişkenleri ile ölçek alt boyutları arasında genel itibariyle anlamlı ilişkinin olduğu söylenebilir. Bu bağlamda araştırmanın ana hipotezlerinden olan H_1:Taşımacılık şirketi çalışanlarının sosyo-demografik özellikleri ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır. Hipotezi alt hipotezlerle birlikte kısmen desteklenmektedir.

Araştırmamız bulgularından yola çıkılarak alanyazın ile karşılaştırması yapıldığında araştırmamız bulgularını genel olarak destekleyen çalışmalar olduğu görülmektedir. Bozkurt (2024)'un gerçekleştirmiş olduğu çalışmada cinsiyet, yaş, eğitim bilgileri ile dijital olgunluk arasında anlamlı bir farklılık bulunmamaktadır. Duncan (2022), Karaoğlan (2019), Eremina (2019), Navarrete vd., (2021)'e göre yaşı ileri yöneticilere sahip olan işletmelerin dijitalleşme düzeyleri daha başarılı iken Macky vd., (2008) ve Bolton vd., (2013)'e göre ise genç yöneticilere sahip olan işletmelerin dijitalleşme düzeylerinin daha yüksek olduğu sonucuna varmışlardır. Dolayısıyla bu çalışmalarda yaş ile dijital olgunluk arasında anlamlı bir farklılık tespit edilirken ilgili literatürler bizim çalışma sonucumuzu desteklemektedir. Balsmeier ve Woerter (2019), 'e göre ise dijitalleşmede eğitimli bireylerin önemli olduğunu vurgulamıştır. Zaborovskaia vd. (2020) ise eğitim seviyesi yüksek kişilerin dijitalleşme konusunda önemli olduğunu tespit etmiştir. Bottalico (2021) 'da yaş ve eğitim seviyesinin dijitalleşme ile ilişkisi olduğunu ifade etmektedir. Bu araştırmada da eğitim durumuyla dijital olgunluk arasında anlamlı bir ilişki tespit edilmiştir. Alanyazın ile araştırmamız bulgularını değerlendirdiğimizde literatürde yer alan çalışmalarda farklı görüşler olsa da büyük çoğunluğunda dijital olgunluk ile sosyo-demografik özellikler arasında ilişkiden söz edilmektedir. Aynı şekilde taşımacılık işletmelerinde çalışan yöneticilerin sosyo-demografik özellikleriyle birlikte dijital olgunluk düzeyleri arasında farklılıklar tespit edilmiştir.

Taşımacılık Şirketinin Sektörel Özellikleri ile Dijital Olgunluk Ölçeği Alt Boyutları Arasındaki İlişkinin Tartışılması

Araştırmamızın bulgularında taşımacılık şirketi sektörel özellikleri ile dijital olgunluk ölçeği ve alt boyutların anlamlı farklılıkların olduğu görülmektedir. Sektörel özelliklerden faaliyet gerçekleştirilen ülke sayısı kapsamında değerlendirme yapıldığında dijital olgunluk ölçeği alt boyutlarından süreçler ve teknolojik alt yapı alt boyutlarında 1-4 ve 5-9 ülke grupları lehine anlamlı farklılık görülmektedir. Bu bağlamda değerlendirme yapıldığında H_{2a}: Taşımacılık şirketinin faaliyet gerçekleştirdiği ülke sayısı ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır. Hipotezi kısmen desteklenmektedir.

Sektörel özelliklerden en çok hizmet verilen taşımacılık türü kapsamında değerlendirme yapıldığında dijital olgunluk ölçeği alt boyutlarından süreçler ve teknolojik alt yapı alt boyutları dışında tüm alt boyutlarda anlamlı farklılıklar görülmektedir. Örgüt yapısı ile örgüt kültürü ve yetenek alt boyutlarında karayolu taşımacılığı lehine farklılıklar bulunurken çalışanların dijital yetkinlikleri ile teknolojik alt yapı alt boyutlarında denizyolu lehine farklılıklar bulunmaktadır. Bu bağlamda değerlendirme yapıldığında H_{2b}: Taşımacılık şirketinin faaliyet gerçekleştirdiği taşıma türü ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır. Hipotezi kısmen desteklenmektedir.

Sektörel özellikler ile dijital olgunluk ölçeği alt boyutları arasındaki ilişki değerlendirildiğinde araştırmamıza katılan katılımcıların görevlerini sürdürdükleri işletmelerin sektörel özellikleri ile ölçek alt boyutları arasında anlamlı ilişkinin olduğu görülmektedir. Bu bağlamda araştırmanın ana hipotezlerinden olan $H_{2:}$ Taşımacılık şirketinin sektörel özellikleri ile dijital olgunluk ölçeği alt boyutları arasında anlamlı ilişki bulunmaktadır. Hipotezi alt hipotezlerle birlikte kısmen desteklenmektedir.

Araştırmamız bulgularından yola çıkılarak alanyazın ile karşılaştırması yapıldığında Song (2021) ile Ahmed ve Rios (2022) faaliyet gösterilen ülke sayısı ile denizyolu taşımacılığının dijitalleşme ile farklılıklarının olduğunu ifade ederken, Zhuravleva ve Kliestik (2023) ise demiryolu taşımacılığının farklılıklarını vurgulamaktadır. Çalışma sonuçları bizim gerçekleştirdiğimiz araştırmada elde ettiğimiz sonuçları destekleyici niteliktedir. Araştırmamızda taşımacılık sektöründe işletmenin faaliyet gösterdiği taşıma moduna göre dijital olgunluk düzeyi arasında farklılık olduğu tespit edilmiştir. Yüksek rekabetin olduğu taşımacılık sektöründe işletmeleri rakiplerinden öne çıkaracak ve yüksek müşteri memnuniyeti sağlayacak en önemli unsurların izlenebilirlik, şeffaflık ve etkinlik olduğu aşikardır. Bu unsurların gerçekleşmesinin temelinde ise dijital olgunluğa erişmeleri yer alacaktır. Ayrıca ihracat yapılan ülke sayısı arttıkça dijital olgunluk düzeyi de artmaktadır. 15 ülke ve üzeri ihracat gerçekleştiren işletmelerin en yüksek orana sahip olduğu görülmüştür. Dijital olgunlukla uluslararası ticarette pazar çeşitlendirmesinin birbirini destekleyici iki ana unsur olduğu vurgulanmaktadır.

Sonuç ve Öneriler

Dijitalleşme son yıllarda işletmelerin en önemli konularının başında gelmeye başlamıştır. Rekabetin çok yoğun olduğu ve işletmelerin birbirine üstünlük kurmaya çalıştığı piyasalarda işletmeleri öne çıkaracak önemli bir olgu haline gelmiştir. Bu kapsamda işletmelerin sadece dijitalleşmesi tek başına yetmemekte dijitalleşme noktasında belirli bir olgunluğa da erişmesi gerekmektedir. Kurumsal işletmeler dijital olgunluğa erişebilmek için ciddi yatırımlar yapmaktadırlar. Yapılan bu yatırımlar karşılığında hangi durumda olduklarını görebilmeleri için ölçümleme yapılması şarttır. Bu çalışmada Türkiye'de yer alan uluslararası taşımacılık işletmelerinin dijital olgunluklarını tespit edilmiştir. Çalışma kapsamında UTİKAD üyelerinin ele alınması ve kullanmış olduğumuz ölçek sorularımız araştırmanın sınırlılıklarını oluşturmaktadır.

Uluslararası taşımacılık işletmelerinin faaliyet gerçekleştirdiği ülke sayısı ile dijital olgunluk ölçeğinde dijitalleşme süreçleri alt boyutu, örgüt kültürü ve yetenek alt boyutu ve teknolojik altyapı boyutu arasında

ilişki tespit edilmiştir. İşletmelerin faaliyet gerçekleştirdikleri ülke sayıları artıkça, uluslararasılaşma düzeyleri yükseldikçe süreçlerinin dijitalleşme boyutu artmaktadır. Ayrıca ülke sayısı artıkça işletmenin kültürüne dijitalleşme olgusu yerleşmekte ve teknolojik altyapıları gelişmektedir. Uluslararası taşımacılık şirketinin faaliyet gerçekleştirdiği taşıma türü ile dijital olgunluk ölçeğinin örgüt kültürü ve yetenek alt boyutu ile teknolojik altyapı alt boyutu arasında ilişki tespit edilmiştir. Uluslararası taşımacılık şirketlerinin vermiş oldukları taşıma türü hizmetine göre dijitalleşmenin örgüt kültürüne etkisi arasında ilişki bulunmaktadır. Taşıma türlerine göre dijital olgunluk düzeylerinde farklılık tespit edilmiştir.

İşletmelerin rekabetçi kalabilmeleri adına dijital olgunluğa erişmeleri ve süreçlere entegre etmeleri şarttır. Bu çalışma kapsamında uluslararası taşımacılık yapan işletmelerin dijital olgunluğa erişebilmeleri için daha fazla ülkeye ithalat ihracat taşıması yapmalarını, uluslararasılaşma düzeylerini artırmalarını ve çalışan kişilerin sayısını ve niteliğini artırmaya yönelik müşteri portföylerini artırmalarını önermekteyiz. Ayrıca nitelikli iş gücünde işletmelerin eğitim düzeyi yüksek personellere ve genç personellere yönelmeleri gerektikleri tespit edilmiştir. Araştırmacılara önerilerimiz ise, farklı ölçekler ve farklı boyutlarla taşımacılık işletmelerinin dijital olgunlukları tespit edilebilir. Sektörün önde gelen sivil toplum kurulu olan UTİKAD üyelerine gerçekleştirilen bu çalışma farklı gruplara yapılabilir ya da aynı gruba farklı sorularla ölçümler tekrarlanabilir. Taşıma türlerindeki dijital olgunluk düzeylerinin arasındaki farkların sebebi araştırılarak detaylandırılabilir. Ayrıca nitel araştırmalar yapılarak konunun uzmanlarıyla derinlemesine mülakatlar yapılabilir.

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Türkiye'de Lojistik Sektörü Çalışanlarının Akıllı Lojistik Teknolojilerine Karşı Tutumu

Attitudes of Employees in the Turkish Logistics Sector Toward Smart Logistics Technologies

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Öz

21. yüzyıl dijital dönüşümün ve teknolojik yeniliklerin toplumsal ve ekonomik alanlarda hızlı bir şekilde yaygınlaştığı bir dönemdir. Bu dönemde lojistik sektörü de büyük veri, yapay zekâ ve otomasyon gibi akıllı lojistik teknolojilerinin etkisiyle dönüşüm geçirmektedir. Bu teknolojiler, lojistik süreçlerin verimliliğini, hızını ve güvenliğini artırarak rekabet avantajı sağlamaktadır. Ancak, bu dönüşüm sadece teknolojik bir ilerleme değil, aynı zamanda insan kaynağının rolünü de yeniden tanımlayan bir süreçtir. Çalışanların bu yeni teknolojilere adaptasyonu, teknolojiyi kabul etmeleri ve yeni yetkinlikler kazanmaları, lojistik sektörünün başarılı bir şekilde dijitalleşmesi için kritik öneme sahiptir. Bu bağlamda gerçekleştirilen çalışma, Türkiye'de lojistik sektöründe görev yapan çalışanların akıllı lojistik teknolojilerine karşı tutumlarını, teknoloji kabul modeli çerçevesinde incelemeyi amaçlamaktadır. TKM, bireylerin bir teknolojiyi kabul etme veya reddetme eğilimlerini analiz etmekte yaygın olarak kullanılan bir modeldir. Araştırma, Türkiye genelinde lojistik alanında faaliyet gösteren işletmelerde çalışan 413 kişiye uygulanan anket verilerine dayanmaktadır. Elde edilen bulgular, akıllı lojistik teknolojilerinin algılanan faydası ve kullanım kolaylığının, çalışanların bu teknolojilere yönelik tutumları ve kullanım niyetleri üzerinde belirgin bir etkiye sahip olduğunu göstermektedir. Çalışma, lojistik sektöründe stratejik planlamalar yaparken ve insan kaynakları politikaları geliştirirken dikkate alınması gereken değerli içgörüler sunmakta olup, Türkiye lojistik sektöründe dijital dönüşüm sürecine katkıda bulunmaktadır.

Anahtar Kelimeler Lojistik sektörü · akıllı lojistik teknolojileri · teknoloji kabul modeli

Abstract

The 21st century is an era in which digital transformation and technological innovations are rapidly spreading across social and economic domains. In this context, the logistics sector is undergoing significant change driven by smart logistics technologies such as big data, artificial intelligence, and automation. These technologies enhance the efficiency, speed, and security of logistics processes, offering a competitive edge. However, this transformation also redefines the role of human resources. The successful digitalization of the logistics sector depends on employees' adaptation, acceptance of new technologies, and development of relevant skills. This study examines the attitudes of logistics employees in Turkey towards smart logistics technologies using the Technology Acceptance Model (TAM), which is widely used to analyze individuals' tendencies to accept or reject a technology. The research is based on survey data collected from 413 employees working in logistics companies across Turkey. The findings reveal that perceived usefulness and ease of use of smart logistics technologies significantly affect employees' attitudes and their intentions to adopt these technologies. The study provides valuable insights for strategic planning and the development of human resources policies, contributing to the digital transformation of Turkey's logistics industry.

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Keywords Logistics sector · smart logistics Technologies · technology acceptance model

Extended Summary

The 21st century is a period in which digital transformation and technological innovations are rapidly spreading across social and economic fields. The logistics sector is also undergoing significant change driven by smart logistics technologies such as big data, artificial intelligence, and automation. These technologies enhance the efficiency, speed, and security of logistics processes, providing a competitive advantage for businesses. However, this transformation not only represents technological advancement but also redefines the role of human resources. Employees' adaptation to these technologies, their acceptance, and acquisition of necessary skills are critical for successful digitalization in logistics.

This study aims to examine the attitudes of employees in Turkey's logistics sector toward smart logistics technologies and identify factors influencing these attitudes. The analysis is conducted within the framework of the Technology Acceptance Model (TAM), which is widely used to understand individuals' tendencies to accept or reject technology. The research is based on survey data collected from 413 employees working in logistics companies across Turkey.

The research model is structured based on TAM, incorporating four core components: perceived usefulness, perceived ease of use, attitude toward use, and behavioral intention. According to TAM, perceived usefulness refers to the functional benefit individuals expect from using a technology, while perceived ease of use indicates how easy they believe the technology is to use. These two components are key antecedents that influence individuals' attitudes and intentions toward a given technology. The study's hypotheses are designed to test the effect of employees' perceptions of the usefulness and ease of use of Logistics 4.0 technologies on their attitudes and behavioral intentions.

A two-part survey developed by the researchers was used to collect data. The first section includes demographic information such as gender, age, and education level. In the second section, TAM-based scales developed by Davis (1989) were used to measure employees' attitudes toward smart logistics technologies. The perceived usefulness and ease of use items were adapted from Davis's original scale, while attitude toward use and behavioral intention items were expanded with statements from other researchers. To ensure reliability and validity, both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were conducted. The results confirmed the validity and reliability of the scales.

The findings reveal that employees' perceptions of the usefulness and ease of use of smart logistics technologies significantly influence their attitudes and behavioral intentions. Higher perceived ease of use leads to a stronger belief in the benefits of the technology, fostering a more positive attitude toward its adoption. The study's hypotheses were largely supported. Correlation analysis indicated strong, positive relationships between perceived usefulness, perceived ease of use, attitude toward use, and behavioral intention. These results suggest that when employees perceive these technologies as useful and easy to use, they are more likely to adopt them with a positive attitude. Employees in Turkey's logistics sector were found to have a positive outlook toward smart logistics technologies. The study emphasizes that the usefulness and ease of use of these technologies significantly affect employees' acceptance and intentions. To facilitate adaptation, supportive strategies should be developed. It is recommended that businesses provide training to employees and offer incentives that encourage technology adoption.

This study contributes to the understanding of how logistics employees adopt smart logistics technologies, reinforcing the TAM framework in the literature. It highlights the importance of perceived usefulness and ease of use in shaping employee attitudes and intentions. Developing strategies that help employees form positive attitudes toward technology can accelerate the digital transformation of the logistics sector. For business leaders, the design and implementation of smart logistics technologies should prioritize user-friendliness. Training programs should be established to support employees' adaptation, and reward mechanisms should be created to promote usage. Furthermore, clearly communicating the benefits of these technologies to the workforce can enhance employees' confidence and willingness to engage with them.

Türkiye'de Lojistik Sektörü Çalışanlarının Akıllı Lojistik Teknolojilerine Karşı Tutumu

Tarih boyunca sanayi devrimleri, öncelikle üretim paradigmalarını ve müşteri taleplerini karşılama biçimini değiştiren yıkıcı teknolojik atılımlardan kaynaklanmaktadır. İleri üretim teknolojilerinin, dijitalleşmenin ve bilgi ve iletişim teknolojilerinin (BİT) giderek daha fazla benimsenmesiyle birlikte, Endüstri 4.0 (dördüncü sanayi devrimi), daha yüksek düzeyde otomasyon ve zekaya ulaşmayı amaçlamaktadır (Qin vd., 2016). Endüstri 4.0, üretim süreçlerinin etkililiği ve verimliliğinden yararlanarak ağırlıklı olarak yeni teknolojilerin yol açtığı paradigma değişimini vurguluyor ancak insani yönlere daha az önem veriliyor (Xu vd., 2021; Nahavandi, 2019; Frederico, 2021). Ancak bunun hem endüstriyel uygulayıcıların hem de akademik çevrenin daha fazla dikkat ve çabasını gerektiren, insanların ve toplumun (Alexa vd., 2021) sürdürülebilir kalkınmasına yönelik bir tehdit olduğu ileri sürülmektedir (Callaghan, 2019). Endüstri 4.0, yeni dijital üretim sistemlerini ve iş süreçlerini kapsayan, üretim süreçlerinin insan gücünden makine gücüne geçerek otomasyonla gerçekleşmesi olarak tanımlanabilir. Bilgi teknolojilerinin gelişimi ve entegrasyonuyla ortaya çıkan bu dönem, lojistik yönetiminde pek çok yeniliğe zemin hazırlamıştır.

"Lojistik" terimi, tedarik zincirinin üreticilerden müşterilere mal, hizmet ve bilgi akışını planlayan, uygulayan ve izleyen kısmını ifade eder (Christopher, 2015; Ballou, 2007). Lojistik operasyonları, malların nakliyesi ve teslimatından daha fazlasını kapsar; aynı zamanda sipariş işleme, depolama, envanter, paketleme ve idari sorumlulukları da içerir (Islam vd., 2013; Christopher, 2016). Bir şirketin veya tedarik zincirinin temel bir işlevi olarak lojistik, son teknolojik gelişmelerden ve yeniliklerden önemli ölçüde etkilenmiştir. Akıllı lojistik operasyonları, akıllı depo yönetiminin, akıllı taşımacılığın, dijital ikizin ve benzerlerinin ortaya çıkmasına yol açan yeni teknolojik çözümlerin artan kullanımıyla mümkün olmaktadır (Sun vd., 2021; Ali ve Phan, 2022). Lojistik sektörü, tedarik zinciri yönetimini kullanırken, taleplerin mevsime ve ekonominin durumuna göre değişmesi nedeniyle iş döngüsünde dalgalanmalar yaşamaktadır. Bu nedenle, iş inovasyonunu desteklemek, müşteri hizmetlerini geliştirmek ve mevcut kaynakları kullanmak için teknolojiyi kullanmak stratejik bir zorunluluktur.

Yeni teknolojiler vasıtasıyla değişen lojistik süreçlerinde insanların rolü ve yerine getirdikleri görevler belirleyici değişikliklere uğramaktadır. Bu açıdan sektör çalışanlarının teknolojiye kabulleri önem arz etmektedir. Chen vd. (2009)'nin belirttiği gibi lojistik sektöründeki işçiler genellikle daha az eğitime sahiptir ve dolayısıyla yeni teknolojiyi keşfetme fırsatı, daha profesyonel sektörlerdeki işçilere göre daha azdır. Bu bakımdan sektör çalışanlarının akıllı lojistik teknolojilerini benimse durumlarının ortaya çıkartılarak strateji geliştirilmesi önemlidir. Bu kapsamda çalışmanın amacı, lojistik sektörü çalışanlarının akıllı lojistik teknolojilerine karşı tutumlarını teknoloji kabul modeli (TKM) ile test etmektir. TKM, kullanıcıların en son teknolojik keşifleri tanıma (veya reddetme) motivasyonunu incelemektedir ve çeşitli araştırma alanlarındaki kullanıcı tepkilerini analiz etmek için yaygın olarak kullanılmaktadır (Do vd., 2020; Xu vd., 2021). Akıllı lojistik teknolojilerinin tüketiciler tarafından kabulüne yönelik çok sayıda çalışma (Cai vd., 2021; Hwang vd., 2019; Kim vd., 2017; Knobloch ve Schaarschmidt, 2020) yapılmış olmasına rağmen teknolojilerin çalışanlar tarafından kabulüne yönelik sınırlı sayıda (Hank ve Selamat, 2023; Alnıpak ve Toraman, 2023) araştırma yapılmıştır. Bu çerçevede çalışmanın literatüre katkı yapması hedeflenmektedir.

Çalışanların akıllı lojistik teknolojilerine yönelik tutumlarını daha derinlemesine analiz edebilmek amacıyla, makale şu şekilde yapılandırılmıştır: İlk olarak, literatür taraması bölümünde akıllı lojistik kavramı ve teknoloji kabul modeli hakkında detaylı bilgi sunulmuştur. Bunu takiben, metodoloji bölümünde araştırmanın yöntemi, amacı, hipotezleri, veri toplama araçları ile araştırmanın evreni ve örneklemi açıklanmıştır.

Araştırma verilerinin analizine ilişkin bulgular ise bulgular kısmında ayrıntılı olarak ele alınmıştır. Son olarak, sonuç ve tartışma bölümünde elde edilen bulgular değerlendirilmiş ve yorumlanmıştır. Bu kısımda ayrıca, gelecekteki araştırmalar için öneriler sunulmuş ve çalışmanın sınırlılıklarına değinilmiştir.

Literatür Taraması

Lojistik 4.0 (Akıllı Lojistik) Teknolojileri

Yeni sanayi devrimi Endüstri 4.0, lojistik dahil tüm iş operasyonlarında dijital dönüşümü gerektirmektedir. Wang (2016), lojistik operasyonlarının gelişimini tarihteki dört sanayi devrimiyle karşılaştırarak, akıllığı ve otomasyonu geliştirmek için Endüstri 4.0 teknolojilerini çeşitli lojistik operasyonlarına entegre eden akıllı lojistik olarak da adlandırılan Lojistik 4.0 kavramını önerdi. Buradaki akıllı kelimesi yüksek teknolojili bir ürün veya hizmeti en iyi şekilde tanımlayacak şekilde olmasını ifade etmektedir. Lojistik ise malların elde edilmesi, depolanması ve varış yerlerine taşınması süreçlerinin birleşimidir (Kenton, 2024). Wong ve Tang'a (2018) göre lojistik, malların üreticilerden tüketicilere taşınmasının bir yoludur ve ticaretin omurgasıdır. Lojistik, eşyaların bir yerden başka bir yere taşınması eyleminin ötesindedir. Bhasin (2021) lojistiğin ana faaliyetlerinin sipariş işleme, malzeme taşıma, depolama, envanter kontrolü, taşıma ve paketlemeyi içerdiğini vurgulamaktadır. Bu nedenle lojistik her işte önemli bir rol oynamaktadır. Akıllı ve lojistiğin ayrı tanımlarından akıllı lojistik kavramı, modern ileri bilgi ve iletişim teknolojisine (BİT) dayanmaktadır. Lojistiğin tüm bölümlerinden gelen bilgilerin gerçek zamanlı olarak işlenip analiz edilmesiyle akıllıca geliştirilen çağdaş bir entegre lojistik sistemidir (Song vd., 2021).

Akıllı lojistik, hızla değişen müşteri taleplerini karşılamak, teknolojinin sunduğu yeni fırsatları değerlendirmek ve yenilikçi iş modellerini desteklemek için etkili bir yaklaşımdır. Akıllı lojistik süreçleri, yük taşımacılığı, depolama ve teslimat gibi temel lojistik faaliyetlerin IoT, büyük veri, bulut bilişim ve yapay zekâ (AI) gibi teknolojilerle entegrasyonu yoluyla gerçekleştirilir. Bu işbirlikçi uygulamalar sayesinde bilgi paylaşımı sağlanarak hızlı yanıt verme yeteneği ve kaynakların verimli kullanımı mümkün hale gelmektedir. Müşteriler açısından değerlendirildiğinde, akıllı lojistik, daha verimli, esnek, doğru ve güvenilir lojistik hizmetleri sunarak müşteri memnuniyetini ve hizmet kalitesini artırmaktadır. Bu bağlamda, akıllı lojistik, lojistik sektörünün dijital dönüşüm sürecinde kritik bir role sahiptir (Ding vd., 2020).

Endüstri 4.0, lojistik süreçlerini daha verimli, esnek ve müşteri odaklı hale getiren bir dönüşüm olarak tanımlanmaktadır. Bu dönüşüm, siber-fiziksel sistemler (CPS), Nesnelerin İnterneti (IoT), hizmetlerin interneti (IoS), büyük veri analitiği, bulut bilişim ve blokzincir gibi ileri teknolojilerle desteklenmektedir (Hofmann ve Rüsch, 2017). Aşağıda bu teknolojilerin lojistik operasyonlarına katkıları detaylandırılmıştır.

Nesnelerin İnterneti (IoT) ve Sensör Teknolojileri; Nesnelerin İnterneti (IoT), fiziksel cihazların, sensörlerin ve diğer nesnelerin bir ağ üzerinden birbirine bağlanarak veri toplamasını ve paylaşmasını sağlayan bir sistemdir. Bu sistem, cihazların internet aracılığıyla insan müdahalesi olmadan iletişim kurmasına olanak tanır (Atzori, vd., 2010). IoT, lojistik süreçlerinde malların takibi, sıcaklık kontrolü, konum belirleme ve filo yönetimi gibi alanlarda önemli bir rol oynamaktadır. IoT cihazları, tedarik zincirinin tüm aşamalarında gerçek zamanlı veri toplayarak şeffaflık ve izlenebilirlik sağlar. Örneğin, bir IoT sensörü, bozulabilir malların sıcaklık ve nem değerlerini sürekli ölçerek lojistik süreçlerin kesintisiz bir şekilde ilerlemesine yardımcı olur (Ding vd., 2020). IoT teknolojisi, lojistik operasyonlar sırasında malzeme ve taşıma süreçlerinin gerçek zamanlı olarak izlenmesini sağlar. Sensörler ve IoT cihazları, tedarik zincirinin her aşamasında veri toplar, bu da malların akışını optimize etmek ve tedarik zinciri boyunca şeffaflık sağlamak için kritik öneme sahiptir. Örneğin, RFID etiketleri ile donatılmış ürünler, depo ve taşıma sırasında kolayca takip edilebilir (Hofmann ve Rüsch, 2017).

Büyük Veri ve Veri Analitiği; Büyük veri, geleneksel yöntemlerle yönetilmesi zor olan, yapılandırılmış ve yapılandırılmamış büyük veri kümelerini ifade eder. Büyük veri yalnızca büyük hacimli veri değil, bu verilerin analiz edilmesiyle çalışma, düşünme ve yaşama şeklimizi değiştiren bir paradigma olarak tanımlamaktadır. Veri analitiği ise bu veri kümelerinden anlamlı bilgi elde etmek için kullanılan matematiksel ve istatistiksel yöntemlerin bir kombinasyonudur (Gandomi ve Heider, 2015). Bu analiz süreçleri, geçmiş verilerden eğilimleri ve modelleri belirleyerek geleceğe dair tahminler yapılmasını sağlar. Büyük veri ve analitiği, sağlık, finans, lojistik gibi sektörlerden günlük yaşamımıza kadar pek çok alanda devrim niteliğinde dönüşümler yaratmaktadır. Lojistikte büyük veri analitiği, geçmiş verilere dayalı olarak gelecekteki talepleri tahmin etmek ve tedarik zinciri süreçlerini optimize etmek için kullanılır. Bu, yalnızca maliyetleri düşürmekle kalmaz, aynı zamanda müşteri memnuniyetini artırır ve tedarik zinciri boyunca kaynakların daha verimli kullanılmasını sağlar (Hofmann ve Rüsch, 2017). Bhasin (2021), büyük veri teknolojilerinin lojistik süreçlerde verimliliği artırmakla kalmayıp, aynı zamanda maliyetlerin azaltılmasına da olanak sağladığını vurgulamaktadır. Özellikle teslimat sürelerinin optimizasyonu ve müşteri memnuniyetinin artırılması gibi hedeflerde büyük veri analitiği kritik bir rol oynamaktadır.

Bulut Bilişim; Bulut bilişim, internet üzerinden veri depolama, işleme ve paylaşımı sağlayan bir hizmet modelidir. Kullanıcılar, fiziksel donanıma ihtiyaç duymadan bilgi işlem kaynaklarına erişebilirler (Mell ve Grance, 2011). Bulut bilişim, IoT ve büyük veri gibi teknolojilerin kullanımı, veri sızıntılarını ve siber tehditleri önlemek için güçlü bilgi güvenliği politikalarını zorunlu kılar. Uluslararası standartlar (örneğin ISO/IEC 27000) bu konuda yol gösterici niteliktedir (Barreto vd., 2017). Bulut bilişim, lojistik süreçlerdeki bilgi akışını kolaylaştırarak veri depolama ve paylaşımını merkezi bir yapıya dönüştürür. Song vd. (2021), bulut bilişimin, lojistik sistemlerindeki operasyonel verimliliği artırdığını ve tedarik zinciri ortakları arasında bilgi paylaşımını hızlandırdığını belirtmiştir. Bu teknoloji, özellikle çok uluslu lojistik operasyonlarında büyük ölçekli verilerin güvenli bir şekilde paylaşılmasını sağlamaktadır.

Yapay Zekâ (AI) ve Makine Öğrenimi; Yapay zekâ (AI), makinelerin insan benzeri akıl yürütme, öğrenme, problem çözme ve karar verme gibi görevleri yerine getirmesine olanak tanıyan bir teknoloji dalıdır (Russell ve Norvig, 2016). Yapay zekâ, lojistik süreçlerin otomasyonu, talep tahmini, rotaların optimizasyonu ve müşteri davranışlarının analizi gibi konularda kullanılmaktadır. Wong ve Tang (2018), yapay zekânın lojistik sektöründe insan müdahalesini azaltarak hata oranlarını minimize ettiğini ve daha hızlı karar alma süreçlerini desteklediğini ifade etmektedir. Ayrıca, makine öğrenimi algoritmaları, taşımacılıkta kullanılan araçların bakım ihtiyaçlarını tahmin ederek kesintisiz bir lojistik akışı sağlar.

Blokzinciri Teknolojisi; Blokzincir, işlemlerin merkezi bir otoriteye ihtiyaç duyulmadan güvenilir ve şeffaf bir şekilde kaydedildiği, zincirleme yapıda düzenlenmiş bir sistem teknolojisidir. Bu teknoloji, verilerin güvenli bir şekilde saklanmasını ve doğrulanmasını sağlamak için kriptografi temelli bir yapı kullanır. Blokzincir, yalnızca kripto para birimlerinin altyapısını oluşturmakla kalmaz, aynı zamanda finans, lojistik, sağlık ve tedarik zinciri gibi farklı alanlarda da güvenilir kayıt tutma ve izlenebilirlik sunar (Nakamoto, 2008; Mougayar, 2016). Blokzincir, lojistikte şeffaflık ve güvenilirlik sağlamak için kullanılmaktadır. Bu teknoloji, uluslararası ticarette belgelerin doğrulanması, teslimat süreçlerinin kaydedilmesi ve sahtecilik riskinin azaltılması gibi konularda etkili bir araçtır (Hofmann ve Rüsch, 2017; Ding vd., 2020). Bu teknoloji, lojistik zincirindeki tüm paydaşlar arasında güveni artırarak süreçlerin daha hızlı ve sorunsuz işlemesini sağlar.

Otonom Araçlar ve Dronlar; Otonom araçlar, sensörler, yapay zekâ ve kontrol sistemleri aracılığıyla insan müdahalesi olmaksızın çalışabilen araçlardır. Dronlar ise uzaktan kumanda ile veya tamamen otonom bir şekilde uçabilen hava araçlarıdır (Thrun, 2010; Floreano ve Wood, 2015). Son yıllarda otonom araçlar ve dronlar, lojistik sektöründe teslimat süreçlerini hızlandırmak için kullanılmaktadır. Otonom araçlar ve dronlar, özellikle son mil teslimat süreçlerinde hız ve maliyet avantajı sağlayarak lojistik operasyonlarında devrim

yaratmaktadır. Bu teknolojiler, lojistik süreçlerin daha verimli hale getirilmesine yardımcı olur (Hofmann ve Rüsch, 2017). Wang (2016), otonom araçların ve dronların lojistik sektörüne kazandırdığı hız ve esneklikle sektörde devrim yarattığını savunmaktadır.

Akıllı Depolama Sistemleri; Akıllı depolama sistemleri, sensörler ve otomasyon teknolojilerini kullanarak depolama süreçlerini optimize eden ve manuel müdahaleyi azaltan entegre sistemlerdir. Akıllı lojistikte, depolama sistemleri de dijital dönüşümden etkilenmiştir. Robotik sistemler, depolama alanlarında ürünlerin yerleştirilmesi ve toplanması süreçlerini hızlandırmaktadır. Bu sistemler, özellikle depo yönetiminde insan kaynaklı hataların önlenmesini sağlar ve envanter yönetimini optimize eder (Bhasin, 2021). Akıllı depolar, RFID sensörleri ve otomatik taşıma araçları gibi teknolojilerle donatılarak, depolama operasyonlarının daha hızlı ve doğru bir şekilde yapılmasını sağlar. Özellikle teslimat sürelerinin optimizasyonu, envanterin doğru yönetimi ve müşteri memnuniyetinin artırılması gibi avantajlar sunar. Depolar, taşıma araçlarıyla entegre olarak "tam zamanında" teslimatları destekler (Barreto vd., 2017).

Siber-Fiziksel Sistemler (CPS); Siber-fiziksel sistemler, fiziksel ve yazılım sistemlerinin bir ağ üzerinden bütünleşmiş bir şekilde çalışarak gerçek zamanlı veri alışverişi ve kontrol sağladığı bir teknolojidir (Lee vd., 2015). CPS, fiziksel ve dijital dünyalar arasındaki etkileşimi kolaylaştırarak lojistik operasyonlarını daha etkin hale getiren temel teknolojilerdir. CPS, sensörler, aktüatörler ve iletişim cihazlarından oluşan ağlarla entegre bir yapı sunar. Bu sistemler, taşıma süreçlerinin izlenmesi, kontrol edilmesi ve optimize edilmesi için gerçek zamanlı veriler sağlar (Barreto vd., 2017). CPS, fiziksel ve dijital dünyalar arasındaki etkileşimi sağlayarak lojistik süreçlerinin otonom, kendi kendini düzenleyen ve gerçek zamanlı kontrol edilen sistemler haline dönüşmesini sağlar. CPS, üretim ve lojistik ağlarında yüksek düzeyde kontrol, izlenebilirlik ve şeffaflık sunar. Bu sistemler sayesinde, lojistik süreçlerin entegrasyonu daha etkin bir şekilde gerçekleştirilebilir (Hofmann ve Rüsch, 2017). Jazdi (2014), CPS'nin sadece fiziksel cihazların internet bağlantısı aracılığıyla veri alışverişi yapmasını değil, aynı zamanda bu verilerin akıllı analizlerini ve gerçek zamanlı karar mekanizmalarını da içerdiğini belirtmiştir. CPS, özellikle lojistik süreçlerde şu katkıları sağlar: *Gerçek Zamanlı İzleme ve Kontrol,* Sensörlerden toplanan verilerin bulut sistemlerinde işlenmesiyle taşıma süreçleri dinamik olarak yönetilebilir. *Önleyici Bakım ve Otomasyon,* CPS, taşıma araçlarının ve depo ekipmanlarının durumlarını sürekli izleyerek arızaları önceden tahmin etme imkânı sunar. *Kaynakların Akıllı Yönetimi,* Sistemler, en uygun rotaları seçerek maliyetleri azaltırken, karbon emisyonunu düşürmeye de yardımcı olur. CPS'nin lojistik sektöründe getirdiği yeniliklere örnek olarak gerçek zamanlı stok takibi ve ürün hareketlerini izlemek için sensörler ve RFID tabanlı çözümler üreten akıllı raf sistemleri, RFID okuyucularla donatılmış ve ürünlerin doğru bir şekilde taşınmasını sağlayan akıllı taşıma arabaları gösterilebilir (Kong vd., 2020).

Ulaşım Yönetim Sistemleri (TYS); Taşıma yönetim sistemleri (TYS), lojistik süreçlerinin izlenmesi ve optimize edilmesi için IoT ve GPS teknolojilerini kullanır. Bu sistemler, filo yönetimini, nakliye planlamasını ve taşıma masraflarının düşürülmesini destekler. Bulut tabanlı TYS çözümleri, işletmelerin esneklik ve maliyet avantajı sağlamasına yardımcı olur. Aynı zamanda akıllı ulaşım sistemleri, sensörler ve VANET ağları aracılığıyla gerçek zamanlı veri toplayarak trafik akışını optimize eder ve çevre dostu taşıma modellerini destekler (Barreto vd., 2017).

Hizmetlerin İnterneti (IoS); Hizmetlerin İnterneti (IoS), hizmetlerin dijitalleşmesini ve internet üzerinden sunulmasını ifade eden bir paradigmadır. IoS, hizmet odaklı bir yaklaşımı teknolojik altyapıyla birleştirir. IoS, lojistik süreçlerinde hizmetlerin internet üzerinden erişilebilir olmasını sağlar. Bu sayede, işletmeler yeni değer yaratan hizmetler oluşturabilir ve iş ortaklarıyla entegrasyonlarını geliştirebilir. IoS sayesinde, tedarik zincirindeki paydaşlar arasındaki işbirliği artırılabilir (Hofmann ve Rüsch, 2017).

Artırılmış Gerçeklik ve Giyilebilir Teknolojiler; Artırılmış Gerçeklik (AR), fiziksel dünyayı dijital bilgilerle zenginleştiren bir teknoloji olarak tanımlanır. Bu teknoloji, gerçek dünya görüntülerinin üzerine bilgisayar

tarafından üretilen ses, video, grafik veya diğer veri katmanlarını ekleyerek kullanıcıların çevrelerini daha anlamlı bir şekilde algılamasını sağlar (Azuma, 1997). AR destekli sistemler, Wi-Fi tabanlı konum belirleme hizmetleriyle birleştirildiğinde, çalışanların depo içinde en verimli rotayı seçmesine yardımcı olabilir. Ayrıca, artırılmış gerçeklik teknolojisi, depolama operasyonlarında eğitim süreçlerini hızlandırmak için sanal simülasyonlarla entegre edilebilir (Nagda vd., 2019). Lojistik operasyonlarında çalışanların yaşadığı fiziksel zorlukları azaltmak ve operasyonel verimliliği artırmak için giyilebilir teknolojiler, akıllı lojistik süreçlerinde önemli bir yer tutmaktadır. Giyilebilir bilgisayarlar, çalışanların ergonomik yüklerini azaltırken, depo ve taşıma süreçlerinde verimliliği artırma potansiyeline sahiptir. Giyilebilir teknolojiler, çalışanların ellerini serbest bırakmasını ve bu sayede daha verimli çalışmalarını sağlar. Lojistik süreçlerinde kullanılan başlıca giyilebilir cihazlar şunlardır; *Baş Monteli Tarayıcılar (Head-Mounted Scanners*)**:** Çalışanların görüş açısını takip ederek barkod tarama işlemlerini optimize eder. Bu cihazlar, ürünlerin otomatik olarak taranmasını sağlarken, ellerin başka işlere odaklanmasını mümkün kılar, *Bilek Monteli Tarayıcılar (Wristband Scanners):* RFID teknolojisiyle entegre edilen bu cihazlar, kullanıcı hareketlerini minimuma indirerek veri toplama süreçlerini kolaylaştırır, *Eldiven Monteli Tarayıcılar (Glove-Mounted Scanners):* RFID veya barkod teknolojisiyle çalışan bu cihazlar, ürün temasını otomatik olarak algılayarak işlem sürelerini hızlandırır. Giyilebilir teknolojilerin gelecekteki gelişmeleri, artırılmış gerçeklik (AR) ve hologram teknolojileri gibi daha ileri düzey işlevler ekleyerek lojistik operasyonlarını dönüştürebilir. Örneğin, başlık monteli tarayıcılar, operatörlere hangi öğeleri alacaklarını ve ne kadar alacaklarını gösteren artırılmış gerçeklik uygulamalarıyla entegre edilebilir. Bu tür teknolojiler, çalışanların eğitim süreçlerini hızlandırabilir ve hatasız operasyonları teşvik edebilir (Mocan ve Draghici, 2018).

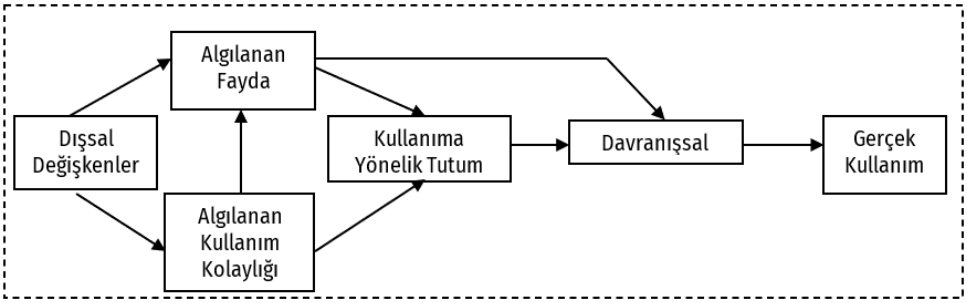
Lojistik 4.0'ın temel unsurları olan bu teknolojiler, lojistik süreçlerin modernizasyonunda yeni fırsatlar yaratmaktadır. Akıllı lojistik teknolojilerinin entegrasyonu, lojistik sektörünün geleneksel yapısını değiştirmekte ve dijital dönüşüm süreçlerini hızlandırmaktadır. Bu teknolojiler, hem tedarik zinciri yönetimi hem de müşteri memnuniyeti açısından sektöre önemli avantajlar sunmaktadır. Endüstri 4.0 ile şekillenen bu yeni lojistik anlayışı, geleceğin lojistik sistemlerinde rekabet üstünlüğü sağlamanın anahtarı olarak görülmektedir.

Teknoloji Kabul Modeli (TKM)

Teknoloji Kabul Modeli (TKM), bireylerin belirli bir bilgi teknolojisini veya bilgi sistemini kabul etme eğilimlerini açıklayan bir modeldir (Davis, 1989). TKM, Fishbein ve Ajzen'in (1975) geliştirdiği ve bireylerin belirli davranışlara yönelik niyetlerini açıklamaya yönelik bir model olan Gerekçeli Eylem Teorisi'nin bir uyarlaması olarak oluşturulmuştur (Davis vd., 1989). Davis ve çalışma arkadaşları (1989), bireylerin davranışlarının arkasında niyet faktörünün yattığı varsayımından hareketle Gerekçeli Eylem Teorisi'ni ele alarak TKM'yi geliştirmiştir. Ancak, iki model arasında bazı farklılıklar bulunmaktadır. Gerekçeli Eylem Teorisi, tüm insan davranışlarını öngörmek ve açıklamak amacıyla oluşturulmuş olup, teknoloji kullanımına odaklanan TKM'den daha genel bir yapıdadır (Zeren, 2014). TKM'ye, Gerekçeli Eylem Teorisi'nde yer almayan "algılanan fayda" ve "algılanan kullanım kolaylığı" gibi değişkenler eklenmiştir. Ayrıca, modeldeki bu iki algıyı etkileyen dışsal değişkenler, kullanıcıların hedef sistemin kullanımını etkileyen çeşitli faktörleri kapsamaktadır (Venkatesh ve Davis, 2000). Bu faktörler, hedef sistemin özelliklerinin yanı sıra kullanıcıların demografik ve kişilik özellikleri ile ilişkilidir (Davis vd., 1989). TKM Şekil 1'de sunulmuştur.

Şekil 1

Teknoloji Kabul Modeli (TKM)



TKM, kullanıcıların en son teknolojik keşifleri tanıma (veya reddetme) motivasyonunu incelemektedir ve çeşitli araştırma alanlarındaki kullanıcı tepkilerini analiz etmek için yaygın olarak kullanılmaktadır (Do vd., 2020; Xu vd., 2021). En yaygın teknoloji benimseme modellerinden biri olan Teknoloji Kabul Modeli (TKM), teknoloji kullanımını ve bireylerin bu teknolojiyi kabul etme eğilimlerini açıklamada sıklıkla başvurulan bir çerçevedir (Nofita ve Sebastian, 2022). TKM, teknolojinin kabul edilmesini etkileyen bilişsel ve duygusal faktörleri temel alarak önceki araştırmalarda tanımlanan ana değişkenleri belirlemek amacıyla oluşturulmuştur. Bu model, teknolojinin kabul edilmesini açıklayan iki temel inanç değişkenine dayanır: 'Algılanan Fayda' (AF) ve 'Algılanan Kullanım Kolaylığı' (AKK)." Bu iki inanç, bireylerin teknolojiye yönelik tutumlarını şekillendirmekte ve kabul düzeylerini belirlemede kritik bir rol oynamaktadır (Rondan-Cataluña vd., 2015).

Teknoloji Kabul Modeli (TKM), bir teknolojinin kullanıcılar tarafından benimsenmesini etkileyen algılanan fayda ve algılanan kullanım kolaylığı gibi temel faktörlere odaklanarak bu süreci açıklayan sade ve etkili bir çerçeve sunmaktadır. Ancak, teknoloji kullanımını etkileyen faktörlerin çeşitliliği ve kullanıcıların bireysel farklılıklarının önemi göz önüne alındığında, bu sürecin daha kapsamlı bir şekilde ele alınması gereği ortaya çıkmıştır. Bu bağlamda, TKM'nin sınırlılıklarını gidermek ve daha geniş bir değişken yelpazesini kapsayarak kullanıcı davranışlarını daha detaylı bir şekilde açıklamak amacıyla Venkatesh ve arkadaşları (2003), Birleştirilmiş Teknoloji Kabul ve Kullanım Teorisi'ni (BTKKT-UTAUT) geliştirmiştir.

Venkatesh ve arkadaşları (2003), bilgi teknolojilerinin kullanıcılar tarafından kabulünü ve kullanımını açıklamak için mevcut sekiz farklı modeli birleştirerek Birleştirilmiş Teknoloji Kabul ve Kullanım Teorisi (BTKKT)' ni geliştirmiştir. BTKKT, bilgi teknolojilerinin benimsenmesi sürecini açıklamak için dört temel faktör içermektedir: performans beklentisi, çaba beklentisi, sosyal etki **ve** kolaylaştırıcı koşullar**.** Model ayrıca, bu temel faktörlerin davranışsal niyet ve kullanım davranışı üzerindeki etkisini açıklayan dört bireysel farklılık değişkenini de kapsar: cinsiyet, yaş, deneyim **ve** gönüllülük. Bununla birlikte, teknolojiye yönelik tutum, öz yeterlilik ve kaygı gibi faktörlerin davranışsal niyet ile doğrudan ilişkisi olmadığı tespit edilmiş ve bu nedenle modelden çıkarılmıştır (Venkatesh vd., 2003). BTKKT'ye göre, performans beklentisi, çaba beklentisi ve sosyal etki**,** bir teknolojiyi kullanma niyetini belirleyen bağımsız değişkenlerdir. Davranışsal niyet ve kolaylaştırıcı koşullar ise kullanıcıların teknoloji kullanım davranışlarını şekillendiren temel belirleyicilerdir. Ayrıca, bireysel farklılık değişkenleri (cinsiyet, yaş, deneyim ve gönüllülük), BTKKT'deki temel değişkenler arasındaki ilişkileri karşılaştırmalı olarak incelemek için kullanılmaktadır.

BTKKT'deki kullanım kolaylığı bileşeninin detaylandırılması ile Vankatesh vd. (2012) tarafından, bireysel ve tüketici bağlamlarındaki teknoloji kabulünü açıklama için BTKKT2 (UTAUT2) geliştirilmiştir. Model, BTKKT'nin temel değişkenleri olan performans beklentisi, çaba beklentisi, sosyal etki ve kolaylaştırıcı koşulları koruyarak bunlara hedonik motivasyon, fiyat değeri ve alışkanlık gibi yeni değişkenler eklemiştir. Bu değişkenler, bireylerin teknolojiyi sadece işlevsellik açısından değil, aynı zamanda keyif, maliyet-fayda dengesi ve kullanım alışkanlıkları gibi daha geniş bir perspektiften değerlendirdiğini ortaya koymaktadır. Ayrıca, bireysel farklılıklar (cinsiyet, yaş, deneyim) ve bağlamsal unsurlar (örneğin, gönüllülük) modelde

moderatör değişkenler olarak yer almaktadır. BTKKT2, özellikle mobil uygulamalar, çevrimiçi alışveriş ve kişisel teknoloji ürünlerinin benimsenmesi gibi tüketici odaklı çalışmalarda kullanılarak teknoloji kabulünü daha kapsamlı bir şekilde açıklamayı mümkün kılmaktadır (Venkatesh vd., 2012).

Yeni teknolojiler için kullanıcı kabul davranışları teorisinin çok değerli olduğu ve sürekli geliştirildiği görüşü vardır. Her teorik modelin farklı etki değişkenleri ve nedensel ilişkileri vardır. Bu çalışmada Teknoloji Kabul Modeli (TKM) tercih edilmiştir çünkü model, teknoloji kabulünü etkileyen temel faktörler olan algılanan fayda ve algılanan kullanım kolaylığı gibi unsurlara odaklanarak sade, etkili ve uygulanabilir bir çerçeve sunmaktadır. Araştırmanın odak noktası, kullanıcıların bir teknolojiyi benimseme sürecinde bu temel unsurların rolünü anlamaktır. TKM'nin seçilmesinin bir diğer önemli nedeni, modelin basit yapısının, özellikle spesifik sektörlerde (örneğin, lojistik, eğitim veya sağlık) teknoloji kabulünü açıklamada esneklik sağlamasıdır. Daha karmaşık modeller (örneğin, BTKKT, BTKKT2) geniş bir değişken setine yer verirken, TKM'nin odaklanmış yapısı, bu çalışmanın sınırlı kapsamı içinde daha etkin bir şekilde kullanılabilir. Ayrıca, bu çalışmada araştırma bağlamının (örneğin, belirli bir sektördeki teknoloji adaptasyonu) temel değişkenler olan algılanan fayda ve algılanan kullanım kolaylığı üzerinden açıklanabilir olduğu düşünülmektedir. Dolayısıyla, TKM, bu bağlamda hem teorik hem de pratik olarak yeterli bir çerçeve sunmaktadır.

Çalışmanın Metodolojisi

Çalışmanın Amacı, Modeli ve Hipotezleri

Bu bölümde araştırmanın temel hedefleri, kullanılan modelin yapısı ve oluşturulan varsayımlar ele alınmaktadır. Çalışmanın ana amacı, lojistik sektörü çalışanlarının akıllı lojistik teknolojilerine karşı tutumlarını incelemek ve bu tutumları etkileyen unsurları ortaya koymaktır. Teknoloji Kabul Modeli (TKM), lojistik sektörü bağlamında çalışanların teknolojiye yönelik algılarını ve bu algıların kullanım niyetlerine etkisini anlamak amacıyla teorik bir çerçeve olarak benimsenmiştir. Bu model kapsamında, algılanan fayda ve kullanım kolaylığı gibi faktörlerin çalışanların teknolojiye yönelik tutum ve niyetleri üzerindeki etkisini test etmeye yönelik varsayımlar geliştirilmiştir.

Algılanan fayda, kullanıcıların belirli bir teknolojiyi kullanmaları halinde, iş performanslarında olası bir artış beklentisini ifade eder. Bu, bireylerin teknolojiyi işlevsel bir kazanım olarak görmelerini ve onu kullanma eğiliminde olmalarını sağlayan bir öncüldür (Davis, 1989). Davis (1989) tarafından tanımlanan bu unsur, bireylerin teknolojiyi kullanma kararlarında temel bir motivasyon kaynağı olarak kabul edilir.

Algılanan kullanım kolaylığı ise, kullanıcıların teknolojiyi kullanırken deneyimleyecekleri çaba düzeyine yönelik inançlarını temsil eder. Bu, bireylerin teknolojiyi ne derece zahmetsiz kullanabileceklerini algılamaları ile ilişkilendirilir. Davis'in belirttiği üzere, bir teknolojinin kullanımının kolay algılanması, o teknolojinin kabulünü artırabilir ve kullanıcıların teknolojiye yönelik direncini azaltabilir (Davis, 1989). Chiu ve diğerleri (2009), algılanan kullanım kolaylığının, bilgi sistemleri ve teknolojilerin kullanımında doğrudan ve belirleyici bir etkiye sahip olduğunu vurgulamaktadır. Ngoc ve arkadaşlarının (2023) araştırması, taşıyıcıların elektrikli araç kullanımına yönelik tutumlarının, kullanım kolaylığı algısından olumlu şekilde etkilendiğini göstermiştir. Yapılan çeşitli çalışmalarda, algılanan kullanım kolaylığının, algılanan faydayı önemli ölçüde belirlediği ortaya konulmuştur (Chen vd., 2018; Zhao ve Khan, 2021). Ek olarak, algılanan fayda ve kullanım kolaylığı, bireylerin teknolojiye yönelik tutumları üzerinde güçlü bir etkiye sahiptir (Shin ve Perdeu, 2019; Zhao ve Khan, 2021).

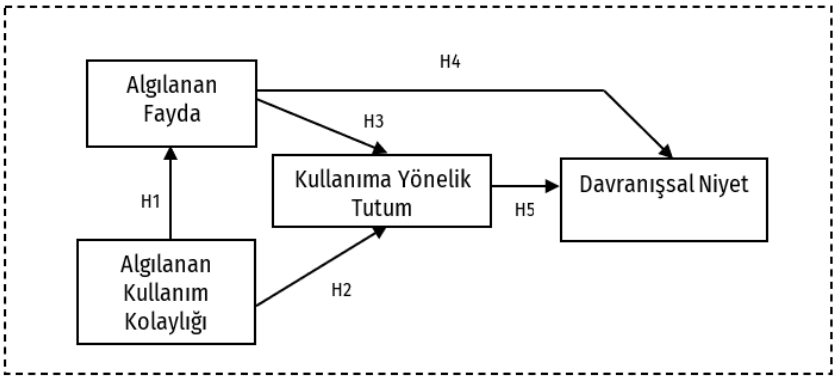
Kullanıma yönelik tutum, bireyin teknolojiyi kullanma isteğini ve bu isteğin davranışa dönüşme potansiyelini gösterir. Taylor ve Todd (1995) tarafından yapılan araştırmalar, bu unsurla ilişkilendirilen pozitif veya negatif değerlendirmelerin, bireylerin teknolojiyi kullanma niyetlerini önemli ölçüde etkilediğini göstermektedir.

Davranışsal niyet, teknolojiyi kullanma konusunda bireyin gösterdiği eğilim ve çabaların somut bir ifadesidir. Bhattacherjee (2001) tarafından dile getirildiği üzere, niyet, bireyin bir teknolojiyi kullanma kararının ve bu kararın eyleme dönüşme olasılığının bir göstergesidir. İnsanlar genellikle, niyetleri ile eylemleri arasında bir tutarlılık sergileme eğilimindedirler.

Yukarıdaki açıklamalar ve araştırmanın amacı doğrultusunda araştırmanın modeli ve hipotezleri oluşturulmuş ve Şekil 2'de sunulmuştur.

Şekil 2

Araştırmanın Modeli



Araştırmanın hipotezleri şu şekildedir;

H1: Çalışanların Lojistik 4.0 teknolojilerine ilişkin kullanım kolaylığı algıları, bu teknolojilere yönelik fayda algılarını olumlu yönde etkilemektedir.

H2: Çalışanların Lojistik 4.0 teknolojilerine dair kullanım kolaylığı algıları, bu teknolojileri kullanmaya yönelik tutumlarını olumlu şekilde etkilemektedir.

H3: Çalışanların Lojistik 4.0 teknolojilerine yönelik fayda algıları, bu teknolojilerin kullanımına yönelik tutumlarını pozitif yönde etkilemektedir.

H4: Çalışanların Lojistik 4.0 teknolojilerine dair fayda algıları, davranışsal niyetlerini olumlu bir şekilde etkilemektedir.

H5: Çalışanların Lojistik 4.0 teknolojilerini kullanmaya yönelik tutumları, davranışsal niyetleri üzerinde olumlu bir etkiye sahiptir.

Katılımcılar

Çalışmanın evrenini Türkiye'de lojistik sektöründe çalışanlar oluşturmaktadır. Kolayda örnekleme yöntemi kullanılarak 440 lojistik sektörü çalışanına anket uygulanmış, bunlar içerisinde analize uygun 413 anket değerlendirme kapsamına alınmıştır. Anket uygulaması öncesinde Bartın Üniversitesi Sosyal ve Beşerî Bilimler Etik Kurulundan 28.05.2022 karar tarihli 2022-SBB-0221 protokol numarası ile etik kurul onay belgesi alınmıştır. Anketler yüz yüze ve çevrimiçi yöntemlerle araştırmacılar tarafından Temmuz 2022-Temmuz 2023 tarihleri arasında gönüllük esasına dayalı olarak uygulanmıştır. Katılımcılara ilişkin tanımlayıcı bilgiler Tablo 1'de sunulmuştur.

Tablo 1
Katılımcıların Tanımlayıcı Bilgileri (n=413)

Değişken		n	%
Cinsiyet	Kadın	124	30
	Erkek	289	70
Yaş	25 yaş ve altı	163	39,5
	26-35 yaş arası	170	41,2
	36-45 yaş arası	59	14,3
	46 yaş ve üzeri	21	5,1
Eğitim durumu	İlköğretim-Ortaöğretim	9	2,2
	Lise	41	9,9
	Önlisans	66	16
	Lisans	249	60,3
	Lisansüstü	48	11,6
Mezun Olunan Bölüm	Uluslararası Ticaret-Lojistik	113	27,4
	Diğer	300	72,6
Mesleki Deneyim	3 yıl ve altı	231	55,9
	3-5 yıl arası	31	7,5
	5-8 yıl arası	40	9,7
	8-11 yıl arası	31	7,5
	11-15 yıl arası	41	9,9
	15 yıl ve fazlası	39	9,4

Tablo 2 incelendiğinde katılımcıların % 70'i erkek, %30'u kadındır, %39,5'u 25 yaş altında % 41,,2'si 26-35 yaş aralığında, %14,3'ü 36-45 yaş aralığında, %5,1'i 46 yaş ve üzerindedir. Katılımcıların % 2,2'si ilköğretim/ortaöğretim, % 9,9'u lise, % 16'sı ön lisans, %60,3'ü lisans, % 11,6'sı lisansüstü mezunudur ve % 27,4'ü uluslararası ticaret/lojistik bölümünden mezundur. Çalışmaya katılan çalışanların % 55,9'u 3'yıl ve altı süre mesleki deneyime sahiptir.

Veri Toplama Araçları

Bu çalışmada veri toplamak için araştırmacılar tarafından hazırlanan ve iki ana bölümden oluşan bir anket formu kullanılmıştır. Anketin ilk bölümünde, katılımcıların cinsiyet, yaş, eğitim düzeyi gibi demografik bilgilerini sorgulayan beş soru bulunmaktadır. İkinci bölümde ise, çalışanların akıllı lojistik teknolojilerine karşı tutumlarını ölçmek amacıyla Davis (1989) tarafından geliştirilen ve geniş bir kullanım alanına sahip olan Teknoloji Kabul Modeli (TKM) uygulanmıştır. TKM çerçevesinde yapılandırılan araştırma modeline uygun olarak, algılanan fayda, algılanan kullanım kolaylığı, kullanım tutumu ve davranışsal niyet olmak üzere dört farklı ölçek kullanılmıştır.

Algılanan fayda ve algılanan kullanım kolaylığı ölçekleri, Davis'in (1989) oluşturduğu ölçek maddelerinden uyarlanmıştır. Kullanıma yönelik tutum ölçeği Heinssen vd. (1987) ile Compeau ve Higgins (1995) tarafından geliştirilen ifadelerden uyarlanırken, davranışsal niyet ölçeği ise Hu vd. (2003)'nin geliştirdiği ifadelerle oluşturulmuştur.

Bu çalışmada kullanılan ölçeklerin faktör yapılarını belirlemek için ilk olarak açıklayıcı faktör analizi (AFA) yapılmıştır. AFA sırasında, örneklem yeterliliği Kaiser-Meyer-Olkin (KMO) testi ile değerlendirilmiş, faktör analizinin uygunluğu ise Bartlett Küresellik Testi ile ölçülmüştür. KMO değeri 0,60'ın üzerinde olduğunda

örneklemin faktör analizine uygun kabul edildiği; Bartlett test değerinin 0,05'ten küçük olması ise verilerin faktör analizine uygunluğunu gösterdiği kabul edilmektedir (Tabachnick ve Fideli, 2001). Tablo 2'deki sonuçlara göre, ölçeklerin KMO ve Bartlett küresellik testi değerlerinin uygun sınırlar içinde olduğu görülmüştür. Ayrıca, faktör analizi sonunda elde edilen faktör yükleri ve varyans değerlerinin 0,40'ın üzerinde olması (Gündüz ve Coşkun, 2012), ölçeklerin yapısal geçerliliğini desteklemektedir.

Tablo 2

Ölçeklerin faktör analizi, geçerlik ve güvenilirlik sonuçları

Ölçekler	İfadeler	KMO/Bartlett Küresellik Testi	Faktör Yükü	Varyans Yüzdesi	Özdeğeri
Algılanan Kullanım Kolaylığı	AKK1	KMO=0,812 Ki-kare=593,305 P=0,001	0,792	66,447	2,658
	AKK2		0,818		
	AKK3		0,835		
	AKK4		0,815		
Algılanan Fayda	AF1	KMO=0,892 Ki-kare=1774,619 P=0,000	0,871	80,107	4,005
	AF2		0,900		
	AF3		0,906		
	AF4		0,913		
	AF5		0,885		
Kullanıma Yönelik Tutum	KYT1	KMO=0,921 Ki-kare=2270,029 P=0,000	0,859	72,107	5,048
	KYT2		0,843		
	KYT3		0,880		
	KYT4		0,884		
	KYT5		0,865		
	KYT6		0,837		
	KYT7		0,769		
Davranışsal Niyet	DN1	KMO=0,894 Ki-kare=1625,750 P=0,000	0,879	78,360	3,918
	DN2		0,881		
	DN3		0,866		
	DN4		0,896		
	DN5		0,905		

Faktör analizi sonrasında ölçeklerin geçerlik ve güvenilirliklerinin belirlenmesi amacıyla Cronbach Alpha, AVE ve CR test değerleri kullanılmaktadır. Araştırmada kullanılan teknoloji kabul modelinde yer alan ölçeklere ilişkin ortalama, standart sapma, cronbach alpha, AVE ve CR değerleri Tablo 3'de sunulmuştur. Cronbach Alpha test değeri 0,70'den yüksek olan ölçekler güvenilir kabul edilmektedir (Pedersen ve Lui, 2003). Bu doğrultuda araştırmada kullanılan ölçeklerin tümü yüksek güvenilirliğe sahiptir. Aynı şekilde AVE ve CR değerleri incelendiğinde ölçeklerin geçerli ve güvenilir olduğu görülmektedir.

Tablo 3

Ölçeklerin ortalama, geçerlik ve güvenilirlik sonuçları

Ölçekler	Ortalama	Standart Sapma	Cronbach Alpha	AVE	CR
Algılanan Kullanım Kolaylığı	3,9558	0,85244	0,831	0,664	0,887
Algılanan Fayda	4,3385	0,87711	0,938	0,801	0,952
Kullanıma Yönelik Tutum	4,1709	0,86293	0,935	0,720	0,947
Davranışsal Niyet	4,2571	0,89074	0,930	0,784	0,947

Tablo 3 incelendiğinde araştırmaya katılan çalışanların genel olarak akıllı lojistik teknolojilerine yönelik tutumlarının yüksek ortalamaya sahip olduğu görülmektedir. Çalışanlar, akıllı lojistik teknolojilerini faydalı (ortalama = 4,33; standart sapma = 0,87) ve kullanımı kolay (ortalama = 3,95; standart sapma = 0,85) olarak değerlendirmektedir. Ayrıca, bu teknolojilere yönelik kullanım tutumu (ortalama = 4,17; standart sapma = 0,86) ve davranışsal niyet (ortalama = 4,25; standart sapma = 0,89) puanları da yüksek bulunmuştur.

Açıklayıcı faktör analizinin ardından faktör yapılarının doğruluğunu test etmek için doğrulayıcı faktör analizi (DFA) uygulanmıştır. TKM modeline uygun olarak yapılan birinci düzey çok faktörlü DFA sonucunda, modifikasyon indeksleri doğrultusunda AF1-AF2, AF1-AF5, AKK2-AKK4, KYT3-KYT5, KYT6-KYT7 ve DN3-DN5 hata terimleri arasında kovaryans eklenmiştir. DFA'nın sonuçları, uyum indeks değerleriyle birlikte Tablo 4'te sunulmaktadır.

Tablo 4

Doğrulayıcı faktör analizi sonuçları

Ölçekler	x^2/df	GFI	AGFI	CFI	NFI	RMSEA
Araştırma Modeli	3,464	0,881	0,845	0,946	0,926	0,077
Uyum Derecesi	x^2/df	GFI	AGFI	CFI	NFI	RMSEA
İyi	≤ 3	≥ 0,90	≥ 0,90	≥ 0,97	≥ 95	≤ 0,05
Kabul Edilebilir	≤ 4-5	0,89-0,85	0,89-0,80	≥ 0,95	0,95-0,90	0,06-0,08

Tablo 4 incelendiğinde, araştırma modelinin doğrulayıcı faktör analizi (DFA) sonuçlarında elde edilen uyum indekslerinin, kabul edilebilir sınırlar içerisinde yer aldığı (Çokluk vd., 2010) görülmektedir.

Bulgular

Araştırmada kullanılan değişkenler arası korelasyon analizi sonuçları Tablo 5'de sunulmuştur.

Tablo 5

Korelasyon Analizi Sonuçları

	1	2	3	4
1.Algılanan Kullanım Kolaylığı	1			
2.Algılanan Fayda	0,676**	1		
3.Kullanıma Yönelik Tutum	0,767**	0,831**	1	
4.Davranışsal Niyet	0,691**	0,805**	0,844**	1

**p<0,01

Algılanan fayda ile algılanan kullanım kolaylığı (r=0,676; p<0,01), kullanıma yönelik tutum (r=0,831; p<0,01) ve davranışsal niyet (r=0,805; p<0,01) arasında güçlü, pozitif yönlü ve istatistiksel olarak anlamlı bir ilişki bulunmaktadır. Ayrıca, algılanan kullanım kolaylığı ile kullanıma yönelik tutum (r=0,767; p<0,01) ve davranışsal niyet (r=0,691; p<0,01) arasında pozitif ve anlamlı bir ilişki olduğu saptanmıştır. Kullanıma yönelik tutum ile davranışsal niyet arasında da pozitif yönlü anlamlı bir ilişki bulunmaktadır (r=0,844; p<0,01, Tablo 5).

Korelasyon analizinin ardından, araştırma modelinin ve hipotezlerin test edilmesi için yapısal eşitlik modeli (YEM) kullanılarak analiz yapılmıştır. YEM analizinde elde edilen uyum iyiliği değerleri ve uyum indeksleri, Tablo 6'da belirtilen kabul edilebilir aralıklarda sunulmuştur.

Tablo 6

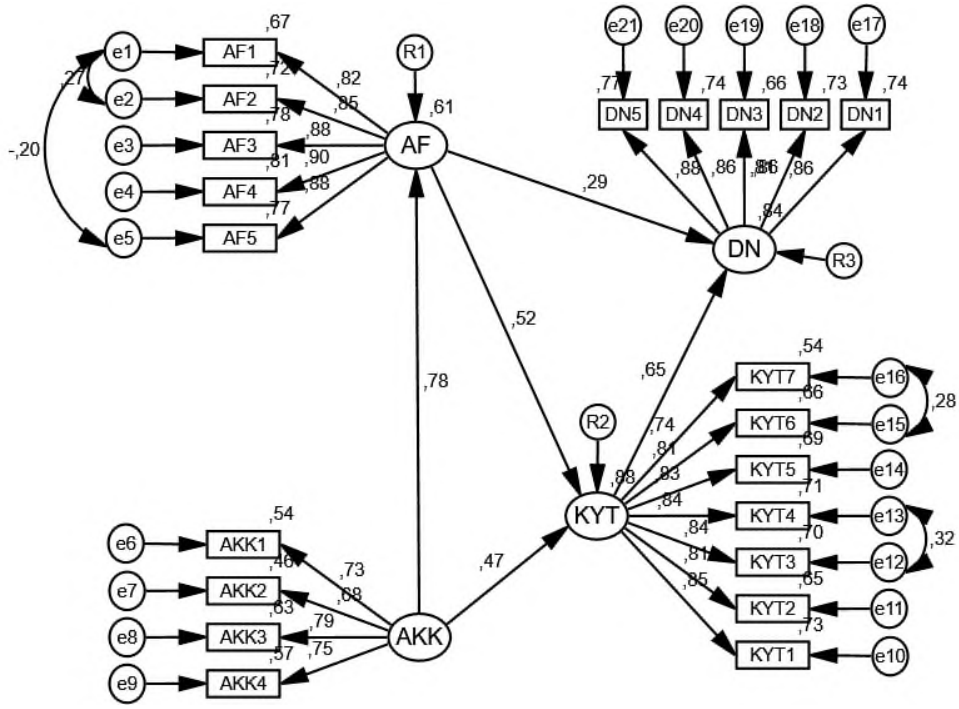
Yapısal Eşitlik Modeline ait uyum iyiliği değerleri

Ölçekler	x²/df	GFI	AGFI	CFI	NFI	RMSEA
Araştırma Modeli	3,528	0,876	0,841	0,944	0,923	0,078
Uyum Derecesi	x²/df	GFI	AGFI	CFI	NFI	RMSEA
İyi	≤ 3	≥ 0,90	≥ 0,90	≥ 0,97	≥ 95	≤ 0,05
Kabul Edilebilir	≤ 4-5	0,89-0,85	0,89-0,80	≥ 0,95	0,95-0,90	0,06-0,08

Tablo 6 incelendiğinde, elde edilen uyum indeks değerlerinin, Hu ve Bentler (1999) tarafından belirtilen iyi ve kabul edilebilir uyum sınırları içinde kaldığı gözlemlenmiştir. Bu bulgu, araştırma modelinin yapısal olarak uygunluğunu doğrulamaktadır. YEM analizinde modifikasyon indeks önerileri doğrultusunda AF1-AF2, AF1-AF5, KYT3-KYT4 ve KYT6-KYT7 maddelerinin hata terimleri arasına kovaryans eklenmiştir. YEM analizi sonrasında elde edilen AMOS çıktısı Şekil 3'de sunulmuştur.

Şekil 3

Yapısal Eşitlik Modeli AMOS çıktısı



Yapısal eşitlik modellemesi (YEM) sonuçları, değişkenler arasındaki ilişkileri ve hipotezlerin test edilmesini içerir. Tablo 5, yapısal ilişkiler için standart regresyon katsayıları (β), standart hata (S.E.), kritik oran (C.R.), belirleme katsayısı (R^2), p-değerleri (P), hipotezler ve hipotez sonuçlarını göstermektedir.

Tablo 7

Araştırma Modeli Yem Sonuçları (n=413)

Yapısal İlişkiler	Stand. Reg. Katsayıları (β)	S.E.	Kritik Oran (C.R.)	R^2	P	Hipotezler	Hipotez Sonuçları
AF<–AKK	0,779	0,064	12,962	0,607	***	H1	Desteklendi
KYT<–AKK	0,472	0,065	8,229	0,879	***	H2	Desteklendi
KYT<–AF	0,522	0,058	9,618		***	H3	Desteklendi
DN<–AF	0,290	0,073	4,023	0,836	***	H4	Desteklendi
DN<–KYT	0,648	0,072	8,587		***	H5	Desteklendi

Tablo 7 incelendiğinde AKK'nin AF üzerindeki etkisinin pozitif ve anlamlı olduğu, AKK'nin AF'yi % 60,7 oranında açıkladığı görülmektedir. AKK ve AF'nin KYT üzerindeki etkisi pozitif ve anlamlıdır. KYT'nin % 87,9'u AKK ve AF tarafından açıklanmaktadır. AF ve KYT'nin DN üzerindeki etkisi pozitif ve anlamlıdır. DN'nin % 83,6'sı AF ve KYT tarafından açıklanmaktadır. Bu sonuçlar doğrultusunda araştırmanın tüm hipotezleri desteklenmektedir.

Genel olarak sonuçlar, modelde yer alan tüm hipotezlerin desteklendiğini göstermektedir. Algılanan kullanım kolaylığı ve algılanan faydanın, kullanıcıların tutumları ve niyetleri üzerinde anlamlı ve olumlu bir etkiye sahip olduğu, özellikle kullanım tutumunun kullanım niyeti üzerinde güçlü bir etkisi olduğu saptanmıştır. Bu bulgular, kullanıcıların bir ürün veya hizmeti benimsemelerinde algıladıkları fayda ve kullanım kolaylığının önemli bir rol oynadığını ve bu faktörlerin kullanıcıların tutumlarını ve niyetlerini şekillendirdiğini göstermektedir.

Sonuç

Lojistik sektörü çalışanlarının akıllı lojistik teknolojilerine yönelik tutumlarını ve bu tutumları etkileyen faktörleri incelemek amacıyla gerçekleştirilen çalışmaya 413 lojistik sektörü çalışanı katılım sağlamıştır. Katılımcıların %70'inin erkek, %30'unun ise kadın olması, cinsiyet dağılımında belirgin bir dengesizliği göstermektedir. Bu durum, sektörde erkek çalışanların daha yaygın olduğu gerçeğini yansıtabilir. Yaş dağılımına bakıldığında, katılımcıların büyük çoğunluğunun (%80,7) 25-35 yaş aralığında yoğunlaştığı görülmektedir. Bu veri, genç ve orta yaş grubundaki bireylerin sektörde daha aktif olduğunu ortaya koymaktadır. Eğitim düzeyinde ise katılımcıların %60,3'ünün lisans mezunu olduğu, bununla birlikte lisansüstü mezun oranının (%11,6) da dikkate değer bir seviyede olduğu gözlemlenmiştir. Bu sonuçlar, sektörde eğitimli iş gücünün önemli bir yer tuttuğunu göstermektedir. Mesleki deneyim açısından değerlendirildiğinde, çalışanların %55,9'unun 3 yıl ve altı mesleki deneyime sahip olması, sektöre yeni giren ya da erken kariyer dönemindeki bireylerin ağırlıkta olduğunu işaret etmektedir. Ayrıca, katılımcıların %27,4'ünün uluslararası ticaret veya lojistik bölümlerinden mezun olması, çalışmanın hedef sektörle doğrudan ilişkili bir katılımcı kitlesine ulaşıldığını göstermektedir. Bu bulgular, çalışmanın katılımcı profili açısından lojistik ve uluslararası ticaret sektörünün genel özelliklerini yansıttığını ortaya koymakta ve elde edilen verilerin sektörel bağlamda değerlendirilebileceğine işaret etmektedir. Çalışmanın katılımcı profiline yönelik elde edilen demografik veriler, sektörün mevcut yapısını ve çalışanların genel özelliklerini yansıtması bakımından önemli ipuçları sunmaktadır. Bu veriler, sektör dinamiklerini anlamak ve bulguların bağlamını doğru şekilde yorumlamak için güçlü bir temel oluşturmaktadır.

Bu çalışmada, Türkiye'de lojistik sektörü çalışanlarının akıllı lojistik teknolojilerine karşı tutumları TKM kapsamında incelenmiştir. Bu doğrultuda algılanan kullanım kolaylığı, algılanan fayda, kullanıma yönelik tutum ve davranışsal niyet arasındaki ilişkilerin ortaya konulması amaçlanmıştır. YEM kullanılarak elde edilen bulgular, araştırma hipotezlerinin tamamının desteklendiğini ve değişkenler arasındaki ilişkilerin güçlü ve anlamlı olduğunu göstermektedir. Araştırmada algılanan kullanım kolaylığının algılanan faydanın % 60,7'sini açıkladığı tespit edilmiştir. Bu sonuç, akıllı lojistik teknolojilerinin çalışanlar tarafından kolaylıkla kullanılabilir olmasının, çalışanların bu teknolojilerden elde edeceği faydayı daha yüksek algılamalarına neden olduğunu göstermektedir.

Araştırmanın bir diğer bulgusu, algılanan fayda ve kullanım kolaylığının birlikte ele alındığında, kullanıma yönelik tutumun %87,9'unu açıklamasıdır. Bu sonuçlar, lojistik sektöründe çalışanların akıllı lojistik teknolojilerine olumlu bir tutum geliştirmelerinde, bu teknolojilerin kullanım kolaylığı ve sağladığı faydanın önemli bir rol oynadığını göstermektedir. Akman ve Mishra'nın (2015) yaptıkları çalışmada, kullanım kolaylığı ve faydanın teknolojinin benimsenmesinde kilit değişkenler olduğu bulunmuştur. Bu çalışma, Türkiye lojistik sektöründe elde edilen bulgularla paralellik göstermektedir ve akıllı lojistik teknolojilerinin benimsenmesi

için kullanıcı dostu arayüzlerin geliştirilmesinin gerekliliğini vurgulamaktadır. Sistem kullanımı ne kadar kolay olursa o kadar yararlı olabilir (Aggorowati vd., 2012).

Araştırmamızın bulguları, lojistik sektöründe çalışanların akıllı lojistik teknolojilerine yönelik algılanan fayda ve kullanım kolaylığı temelinde olumlu tutumlar geliştirdiğini göstermektedir. Bu bulgu, literatürde yer alan Haddad'ın (2024) çalışmasıyla paralellik göstermektedir. Haddad, depo çalışanlarının Lojistik 4.0 teknolojilerini benimseme düzeylerini incelediği çalışmasında, algılanan faydanın teknoloji kabulünde en önemli faktörlerden biri olduğunu ve çalışanların bu teknolojilerin iş performansı, üretkenlik ve etkinliği artıracağına inandığını ortaya koymuştur. Aynı şekilde, algılanan kullanım kolaylığının kullanıcı dostu özellikleri sayesinde teknolojinin benimsenmesini kolaylaştırdığı ve algılanan faydayı güçlendirdiği belirtilmiştir. Bu bağlamda, çalışanların bu teknolojilere daha fazla yönlendirilmesi ve kullanım kolaylığını artırıcı eğitim programlarının uygulanması, hem iş tatminini artırabilir hem de teknolojinin lojistik süreçlerinde daha etkili bir şekilde kullanılmasını sağlayabilir. Dolayısıyla, bu çalışmanın sonuçları, akıllı lojistik teknolojilerinin sektördeki benimsenme sürecini desteklemek için organizasyonel ve eğitimsel stratejilerin geliştirilmesinin önemini vurgulamaktadır.

Araştırmanın diğer bir bulgusu davranışsal niyetin, hem algılanan fayda (β=0,290, $p<0,001$) hem de kullanıma yönelik tutum (β=0,648, $p<0,001$) tarafından olumlu ve anlamlı bir şekilde etkilenmesidir. Ayrıca, kullanıma yönelik tutumun, davranışsal niyet üzerinde daha güçlü bir etkisi olduğu saptanmıştır. Bu bulgu, lojistik sektörü çalışanlarının akıllı lojistik teknolojilerini kullanmaya karar vermelerinde, bu teknolojilere karşı geliştirdikleri olumlu tutumun kritik bir faktör olduğunu ortaya koymaktadır. Algılanan fayda ve kullanıma yönelik tutum birlikte, kullanım niyetinin %83,6'sını açıklamaktadır. Al-Gahtani (2016) tarafından yapılan bir çalışmada, kullanım kolaylığının ve faydanın birlikte ele alınmasının kullanıcıların olumlu tutum geliştirme olasılığını artırdığı belirtilmiştir. Bu çalışma, bireysel düzeyde teknoloji kabulü için tutumun kritik bir faktör olduğunu ve davranışsal niyet üzerinde güçlü bir etkiye sahip olduğunu göstermiştir. Haddad (2024) çalışmasında lojistik sektöründe çalışanların Lojistik 4.0 teknolojilerini gelecekte daha yaygın bir şekilde kullanmaya yönelik yüksek bir niyet taşıdığını vurgulamıştır. Teknolojilerin iş süreçlerine sağladığı katkılar sayesinde çalışanların bu teknolojileri benimsemekte herhangi bir direnç göstermeyeceği sonucuna ulaşmıştır.

Araştırmanın sonuçları, akıllı lojistik teknolojilerinin algılanan faydası ve kullanım kolaylığının, Türkiye'deki lojistik sektöründe kullanıcıların tutumları ve kullanım niyetleri üzerinde kayda değer bir etkiye sahip olduğunu göstermektedir. Bu çalışma, akıllı lojistik teknolojileri ile ilgili stratejik planlama yapılırken ve insan kaynakları politikaları geliştirilirken dikkate alınması gereken önemli içgörüler sunmaktadır.

Teorik Çıkarımlar

Araştırmanın bulgularına dayanarak literatürde mevcut teorileri destekler nitelikte, gelecekteki araştırmalar için de önemli ipuçları sunan çeşitli teorik çıkarımlar yapılabilir. Öncelikle bu çalışma, Davis'in TKM'ni destekler niteliktedir. Algılanan kullanım kolaylığı ve algılanan fayda, kullanıcıların teknolojiye yönelik tutumlarını ve niyetlerini belirleyen önemli faktörler olarak doğrulanmıştır. Akıllı lojistik teknolojilerinin kolay kullanılabilir olması ve kullanıcılara sağladığı faydaların belirgin olması, bu teknolojilere karşı olumlu tutum geliştirilmesine ve kullanım niyetinin artmasına yol açmaktadır. Algılanan kullanım kolaylığı ve algılanan fayda arasındaki güçlü pozitif ilişki, kullanıcıların bir teknolojiyi benimseme sürecinde kullanım kolaylığının önemini vurgulamaktadır. Bu bulgu, yeni teknolojilerin tasarım ve geliştirme süreçlerinde kullanıcı dostu olmasının, teknolojinin benimsenmesini arttıracağını ortaya koymaktadır. Özellikle lojistik sektöründe, akıllı teknolojilerin kullanıcılar tarafından kolayca benimsenmesi, sektörün verimliliğini ve rekabetçiliğini artırabilir. Kullanıma yönelik tutumun, kullanıma yönelik niyet üzerindeki güçlü etkisi, tutumların davranışsal niyetleri şekillendirmedeki kritik rolünü vurgulamaktadır. Bu bulgu, Ajzen'in Planlanmış Davranış Teorisi

(TPB) ile uyumludur. Çalışanların akıllı lojistik teknolojilerine yönelik olumlu tutumlarının, bu teknolojileri kullanma niyetlerini doğrudan etkilediği görülmektedir. Bu da, işletmelerin çalışanlarının teknolojiye yönelik olumlu tutumlarını geliştirmeye yönelik stratejiler geliştirmelerinin önemini göstermektedir.

Çalışmanın bulguları, kullanıcı deneyiminin teknoloji benimseme sürecinde ne kadar önemli olduğunu ortaya koymaktadır. Algılanan kullanım kolaylığı ve faydanın artırılması, kullanıcıların akıllı lojistik teknolojilerine karşı olumlu tutum geliştirmelerine ve bu teknolojileri benimsemelerine katkıda bulunmaktadır. Bu durum, kullanıcı deneyimi tasarımının ve eğitim programlarının teknoloji benimseme süreçlerinde kritik bir rol oynadığını göstermektedir.

Algılanan faydanın ve kullanım kolaylığının kullanıcıların tutum ve niyetleri üzerindeki etkisi, lojistik sektöründe akıllı teknolojilerin benimsenmesini artırmak için pratik uygulamaların ve eğitim programlarının önemini vurgulamaktadır. İşletmeler, çalışanlarına bu teknolojilerin faydalarını ve kullanım kolaylıklarını vurgulayan eğitim programları sunarak, teknolojinin benimsenmesini teşvik edebilirler.

Özetle, bu çalışma, mevcut teorileri desteklemekte ve akıllı lojistik teknolojilerinin benimsenmesi konusunda yeni içgörüler sunmaktadır. Bulgular, lojistik sektöründe teknolojinin benimsenmesini artırmak için kullanıcı dostu tasarımlar ve kapsamlı eğitim programlarının önemini ortaya koymakta ve bu alanda yapılacak gelecekteki araştırmalar için önemli bir temel oluşturmaktadır.

Yönetimsel Çıkarımlar

Araştırmanın bulguları, lojistik sektöründe akıllı teknolojilerin benimsenmesini artırmak isteyen yöneticiler ve karar vericileri için önemli ipuçları sunmaktadır. Algılanan kullanım kolaylığının kullanıcılar üzerindeki etkisi göz önünde bulundurularak, akıllı lojistik teknolojilerinin kullanıcı dostu olacak şekilde tasarlanması ve uygulanması gerekmektedir. Yöneticiler, teknoloji sağlayıcılarıyla iş birliği yaparak, çalışanların bu teknolojileri kolayca öğrenip kullanmalarını sağlayacak basit ve sezgisel arayüzler geliştirmelidir. Algılanan fayda ve kullanım kolaylığının artırılması için çalışanlara yönelik kapsamlı eğitim programları düzenlenmelidir. Yöneticiler, akıllı lojistik teknolojilerinin faydalarını ve kullanım kolaylıklarını vurgulayan eğitim ve geliştirme programları aracılığıyla çalışanların bu teknolojilere olan güvenini artırabilirler. Bu programlar, teknolojinin günlük operasyonlarda nasıl kullanılacağını ve hangi avantajları sağlayacağını açıkça göstermelidir. Çalışanların akıllı lojistik teknolojilerine karşı olumlu tutum geliştirmelerini sağlamak için çeşitli teşvik ve ödül programları uygulanabilir. Örneğin, teknolojiyi etkin bir şekilde kullanan çalışanlara ödüller verilebilir veya başarı hikayeleri paylaşılabilir. Bu tür teşvikler, çalışanların teknolojiye olan ilgisini ve bağlılığını artırabilir. Akıllı lojistik teknolojilerinin faydaları ve kullanım kolaylıkları hakkında düzenli iç iletişim kampanyaları yürütülmelidir. Yöneticiler, bu teknolojilerin işletmeye ve çalışanlara sağlayacağı avantajları net bir şekilde iletişim araçlarıyla (bültenler, toplantılar, seminerler vb.) aktararak, çalışanların bilinç düzeyini ve kabul oranını artırabilirler.

Yeni teknolojilerin benimsenmesi sürecinde pilot uygulamalar gerçekleştirerek, çalışanlardan geri bildirim almak önemlidir. Yöneticiler, belirli bir süre boyunca küçük ölçekli pilot projeler yürütüp, bu süreçte elde edilen geri bildirimleri değerlendirerek teknolojinin eksikliklerini giderebilir ve kullanıcı deneyimini iyileştirebilirler.

Üst yönetim, akıllı lojistik teknolojilerinin benimsenmesine yönelik vizyon ve stratejiyi açıkça belirlemeli ve bunu tüm organizasyona yaymalıdır. Yöneticilerin, teknolojinin potansiyel faydalarını ve işletme üzerindeki olumlu etkilerini vurgulayan bir liderlik yaklaşımı benimsemeleri gerekmektedir. Bu, çalışanların değişime daha hızlı adapte olmalarına ve teknolojiye karşı olumlu tutum geliştirmelerine yardımcı olacaktır.

Akıllı lojistik teknolojilerinin mevcut sistemlere entegrasyonu ve bu süreçte teknik destek sağlanması büyük önem taşır. Yöneticiler, teknolojinin sorunsuz bir şekilde entegrasyonunu sağlamak için gerekli altyapı

yatırımlarını yapmalı ve çalışanlara teknik destek sunmalıdır. Bu, çalışanların teknolojiye adaptasyonunu kolaylaştırır ve benimseme oranını artırır.

Sonuç olarak, bu çalışmanın bulguları, yöneticilere akıllı lojistik teknolojilerinin benimsenmesini artırmak için stratejik adımlar atma konusunda önemli bilgiler sunmaktadır. Kullanıcı dostu tasarımlar, kapsamlı eğitim programları, çalışan motivasyonu ve iç iletişim stratejileri, akıllı lojistik teknolojilerinin etkin bir şekilde benimsenmesini sağlayarak, işletmelerin verimlilik ve rekabet avantajını artırmalarına yardımcı olacaktır. Bu yönetimsel çıkarımlar, çalışmanın bulguları ve teorik temelleri doğrultusunda, yöneticilere akıllı lojistik teknolojilerinin benimsenmesi sürecinde alabilecekleri somut adımlar sunmaktadır.

Kısıtlar ve Gelecekteki Araştırmalara Yönelik Öneriler

Bu çalışmanın kısıtları arasında Türkiye'de yalnızca lojistik sektörü çalışanları üzerinde yapılmış olması, yalnızca TKM (Teknoloji Kabul Modeli) modelinin kullanılması ve lojistik sektördeki rekabet düzeyi, dijitalleşme derecesi gibi dış faktörlerin dikkate alınmaması bulunmaktadır. Bu nedenle, çalışmanın bulgularının farklı sektörlerde ve uzun vadeli koşullarda genellenebilirliği sınırlı kalmaktadır. Gelecekteki araştırmalar için farklı sektörlerdeki çalışanların da dahil edildiği çalışmaların yapılması, uzunlamasına veri toplanarak tutumların zaman içindeki değişiminin izlenmesi ve sektöre özgü dış faktörlerin modele entegre edilmesi önerilmektedir. Ayrıca, demografik özelliklere göre karşılaştırmalı analizlerin yapılması ve TKM dışında alternatif modellerin ya da modellerin birleştirilmesinin kullanılması, akıllı lojistik teknolojilerinin benimsenme sürecine daha kapsamlı bir bakış açısı sunabilir. Bu öneriler, konuya dair daha derin bir anlayış geliştirerek, akıllı lojistik teknolojilerinin çalışanlar tarafından kabul edilmesini etkileyen faktörleri daha geniş bir çerçevede değerlendirmeye katkı sağlayabilir.

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Bilgilendirilmiş Onam	Katılımcılardan bilgilendirilmiş onam alınmıştır.
Hakem Değerlendirmesi	Dış bağımsız.
Yazar Katkısı	Çalışmanın Konsepti/Tasarımı- E.G., M.Ç.; Veri Toplama- M.Ç., E.G.; Verilerin Analizi/Yorumlanması- E.G.; Yazı Taslağı: - E.G.; İçeriğin Eleştirel İncelemesi – E.G., M.Ç.; Son Onay ve Sorumluluk - E.G., M.Ç.
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Deniz Liman İşletmelerinin Strateji Seçimlerinde AHP Modellemesi ile Karar Alma Süreci

In the Strategy Choices of Sea Port Operations Decision Making Process with AHP Modeling

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Öz

Bu araştırmada deniz liman işletmelerinin strateji seçimlerinde üst düzey yönetime yardımcı olacak bir model geliştirmek hedeflenmiştir. Araştırmanın modellemesinde altı boyuttan oluşan deniz liman performans göstergelerinin her birinin ağırlıklarını bulmak için AHP (Analitik Hiyerarşi Süreci) kullanılmış konusunda uzman olan, çeşitli alanlardan seçilen katılımcılardan oluşturulan odak grup görüşmeleri neticesinde anket formalarıyla elde edilen veriler Super Decision Paket Programı ve Microsoft Office Excel Programı kullanılarak analize tabi tutulmuştur. Bu analiz neticesinde öncelikle bir deniz liman işletmesinin performansını etkileyen 6 ana faktörün ve bunların alt boyutlarının ağırlıkları (katsayıları) tespit edilmiştir. Modelde deniz liman performans göstergeleri strateji seçiminde kullanılan kriterler, deniz liman işletmelerinin seçebilecekleri 3 strateji ise alternatifleri oluşturmaktadır. Bu stratejiler maliyet liderliği stratejisi, farklılaştırma stratejisi ve cevap (hızlı yanıt) verme stratejisidir. Araştırmanın son aşamasında iki deniz liman işletmesinin üst düzey yöneticilerine ağırlıklandırılmış kriterleri kendi liman işletmelerini göz önünde bulundurarak Likert ölçeği ile 1'den 9'a kadar değerlerle puanlandırması istenmiştir. İki deniz liman işletmesinin üst düzey yöneticisinin yapmış olduğu puanlama neticesinde her iki deniz limanı da kendileri için en uygun stratejinin farklılaştırma stratejisi olduğu sonucuna varmıştır.

Abstract

In this research, it is aimed to develop a model that will assist senior management in the strategy choices of sea port enterprises. In the modeling of the research, AHP (Analytical Hierarchy Process) was used to find the weights of each of the sea port performance indicators consisting of six dimensions. The data obtained through the survey forms as a result of the focus group discussions held with the participants selected from various fields, who are experts in their field, were analyzed using the Super Decision Package Program and Microsoft Office Excel Program. has been subjected to. As a result of this analysis, the weights (coefficients) of 6 main factors and their sub-dimensions that affect the performance of a sea port enterprise were determined. In the model, sea port performance indicators constitute the criteria used in strategy selection, and the 3 strategies that sea port enterprises can choose constitute the alternatives. These strategies are cost leadership strategy, differentiation strategy and responsive (quick response) strategy. In the final stage of the research, senior managers of two sea port enterprises were asked to score the weighted criteria with values from 1 to 9 on a Likert scale, taking into account their own port enterprises. As a result of the scoring made by the senior managers of the two sea port operators, both sea ports concluded that the most suitable strategy for them was the differentiation strategy.

Anahtar Kelimeler Deniz Liman İşletmeciliği · Anahtar Performans Göstergeleri · Stratejik Yönetim · Analitik Hiyerarşi Prosesi.

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Keywords Sea Port Management · Key Performance Indicators · Strategic Management · Analytical Hierarchy Process.

JEL Sınıflaması M51 · M30 · O18 · R41
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Yazar Notu Çalışma İstanbul Üniversitesi Sosyal Bilimler Enstitüsü Ulaştırma ve Lojistik Yönetimi Doktora öğrencisi olan 1. Yazar Hakan Kılcı'nın, Doç.Dr. Burcu Özge Özaslan Çalışkan danışmanlığında yürütülen henüz yayınlanmamış doktora tezi ile ilgili olarak yapılan bir araştırma niteliği taşımaktadır.

Author Note The study is a research conducted on the unpublished doctoral thesis of the first author Hakan Kılcı, who is a PhD student in Transportation and Logistics Management at Istanbul University, Institute of Social Sciences, under the supervision of Assoc. Prof. Dr. Burcu Özge Özaslan Çalışkan.

Extended Summary

The adoption of the most appropriate strategy to assist seaport operators in gaining a competitive advantage in their management processes is crucial for achieving sustainable growth and enhancing competitive strength. This study aims to develop a model to guide senior management in selecting strategies for seaport companies. The research proposes a model that helps identify the most suitable strategy among three basic approaches used by seaport operators, based on key performance indicators (KPIs) commonly applied in the industry. In the model, the Analytical Hierarchy Process (AHP) was employed to determine the relative weights of six dimensions of seaport performance indicators.

Data was collected through surveys distributed to participants in focus group interviews, comprising experts from various sectors with significant experience in their fields. The experts included four academics, four terminal operator managers, four seaport managers, and four ship transportation business managers. These responses were analyzed using the Super Decision software package. As a result, the weights (coefficients) of the six factors influencing seaport performance were identified. These factors are organized into six primary dimensions, which are further subdivided into 16 sub-dimensions. The weights of both the main dimensions and their sub-dimensions were calculated by comparing the factors on a Likert scale.

In the proposed model, seaport performance indicators serve as the criteria for strategy selection, while the three strategies available to seaport operators represent the alternatives. The three basic strategies for seaport companies are: cost leadership, differentiation, and responsiveness (rapid response).

To weight the main criteria and their sub-dimensions, a group decision-making approach was employed, involving four participants from each of four key stakeholder groups who are directly involved in or impacted by seaport operations. The criteria comparisons provided by each stakeholder were entered into the Super Decision software. After confirming that the inconsistency ratio was below the threshold of 0.10, the weights of the main criteria and their sub-dimensions were calculated by taking the geometric mean of each comparison across all 16 participants.

The analysis revealed that the main criterion with the highest weight was "Terminal and Supply Chain Integration" (0.27), while "Supporting Activities" was the criterion with the lowest weight (0.06). After determining the weights, two seaport operator managers (coded as A and B) were asked to rate the three strategies on a scale from 1 to 10 for each sub-dimension of the main criteria. The weighted scores were then calculated by multiplying the ratings by the corresponding weights of the sub-dimensions and main criteria. The final scores were derived by summing the weighted scores for each sub-dimension.

Seaport operator manager A assigned the highest score (8.48) to the differentiation strategy, indicating that it was the most suitable for their port. The second-highest score (8.28) was given to the responsiveness strategy, while the cost leadership strategy received the lowest score (8.22). Similarly, seaport operator manager B also rated the differentiation strategy highest (8.25), followed by the responsiveness strategy (8.16). The cost leadership strategy received the lowest score (6.80) from manager B. In this study's modeling approach, the key performance indicators (KPIs) of seaport enterprises were utilized as criteria for evaluating strategic alternatives. Consequently, the analytical hierarchy process (AHP) model was structured with the goal positioned at the highest level. The second level includes six primary marine performance indicators as the main criteria. The third level consists of the sub-dimensions of these main criteria, while the lowest level of the model represents the strategic alternatives. In other words, the framework of the study is organized into a four-tier hierarchical structure. In this model, the criteria and goals in

the first three levels are interlinked through nodes. However, the strategic alternatives at the bottom level are not interconnected with the other layers and are independently assessed. This distinctive approach sets our study apart from conventional AHP models, lending it an innovative character.

Deniz Liman İşletmelerinin Strateji Seçimlerinde AHP Modellemesi ile Karar Alma Süreci

Deniz limanları ülkelerin ekonomilerine, dış ticaretine ve lojistik sektörüne önemli ölçüde etki eden önemli yapılardır. Deniz limanları hiç şüphesiz denizyolu taşımacılığının en önemli alt yapı unsurlarından birisidir. Bu alt yapı yatırımı genellikle devletler tarafından yapılmakta ancak son dönemlerde deniz liman işletmeciliğinde bir özelleştirme trendinin de olduğu görülmektedir. Zaten bir deniz limanı sahasında birçok işletme aynı bölgede faaliyette bulunmaktadır ki bu kurumların birçoğu özel sektöre ait işletmelerdir. Deniz liman sahasının büyük ölçüde kamuya ait olduğu durumlarda dahi terminal operatörlüğü ve diğer liman işleri çoğu zaman özel işletmelere alanın kiralanması yoluyla devredilmektedir. Türkiye'de bulunan deniz limanlarının büyük çoğunluğu kamuya ait limanlardır. Ancak bu limanlar kamuya ait olmasına rağmen birçok çeşit işletmenin buralarda faaliyette bulunması neticesinde yönetimde yeknesaklığın ve koordinasyonun sağlanması konusunda bir görüş birliğinin oluşturulması oldukça güçtür. Ancak yine de en üst düzey liman yöneticileri özellikle deniz limanının yönetimi konusunda önemli bir karar olan strateji seçiminde en üst düzey merci olarak karar alabilmeli ve bu stratejiye bağlı olarak işletmelerin liman sahasında faaliyette bulunmalarını isteyebilmelidir. Limanlarda temelde terminal operatörleri faaliyet göstermektedir ki bu işletmeler gemideki yükün aprona, liman sahasına, antrepolara boşaltılması ve/veya diğer ulaştırma modundaki araca aktarılması yani gemideki yükü boşaltma işlemini yaptığı gibi gemiye yüklenecek yüklerin de yüklenmesi işlemini yapmaktadır. Aslında bir deniz limanın en temel işleri olan yüklerin gemiye yüklenmesi ve yüklerin gemiden boşaltılması işlerini terminal operatörleri gerçekleştirmektedir. Terminal operatörlerinin yanı sıra, gümrük müdürlükleri, antrepolar, bankacılık ve sigortacılık işletmeleri, diğer modlarda taşımacılık faaliyetleri gösteren işletmeler vb. tüm işletmeler deniz limanlarında faaliyette bulunmaktadır. Strateji işletme unsurlarının bütünsel anlamda her birinin aynı yöne bakmasını ve aynı doğrultuda kararlar almasını gerektirmektedir. Limanlardaki birçok ayrı kurum yönetiminin bir arada olması bu yeknesaklığı sağlamada bir zorluk meydana getirme ihtimalini içermektedir. Ancak bu araştırmada deniz liman yönetiminin tüm bu kurumların üzerinde bir yönetim merci olarak aldıkları strateji kararları diğer işletme yönetimlerini de bir ölçüde bağlayıcı olduğu varsayılmıştır. Pek tabi ki bu misyona ve vizyona sahip olmayan işletmeler deniz liman yönetimleri tarafından liman sahasından uzaklaştırılabilir. Ancak şunu da belirtmek gerekir ki uzlaşılmış iyi bir strateji deniz limanındaki tüm paydaşların sürdürülebilir rekabet üstünlüğü elde etmelerine önemli ölçüde katkıda bulunacaktır.

Literatür Taraması ve Teorik Çerçeve

Sorun; araştırma, değerlendirme veya çözüm için ortaya konan bir sorudur ve genellikle insanlar mevcut durum ile arzu edilen durum arasında bir fark veya tutarsızlık olduğunu hissettiğinde ortaya çıkar (Shih ve Olsan, 2022:1). Bazı zamanlar sorunu teşhis edip tedaviye başlarken zorluklar yaşanır. İnsanlar tarafından görülebilmesi zor olabilecek gerçek sorunun dikkatlice fark edilmesi daima önemlidir (Clemen, 1996). Problemin ortaya çıktığı çevrenin derinlemesine bilinmesinin yanı sıra alanında uzmanlık bilgisine sahip kişilerin de yardımına ihtiyaç duyulabilir. 5N1K (Ne?, Ne zaman?, Nerede?, Neden?, Nasıl? ve Kim?) sorularına verilecek cevaplar da sorunun tespit ve tedavisinde önemli bir bileşendir (Robertson, 1946). Beyin fırtınası (Osborn,

1953), Ishikawa diyagramı (1968) veya diğer adıyla balık kılçığı diyagramı, sorun bulma odaklı teori (Atsshuller ve Shapiro, 1956) veya diğer yenilikçi teknikler gerçek sorunun bulunmasına yardımcı olabilir. Sorunu net bir şekilde gösteren niceliksel verilerin yanı sıra; niteliksel veriler hatta bazen bir şekil bile mevcut olası sorunları resmedebilir. Tüm bu metotlar ve benzerleri özellikle karar almanın ilk aşamalarında karar alıcıya yardımcı olabilir. Ayrıca hiyerarşik bir yapı veya ağ sorunu ve onunla ilgili unsurları geometrik bir temsil aracılığıyla görselleştirmeye yardımcı olabilir (Saaty ve Shih, 2009). Bir sorun (problem) yapılandırılmış göstergelerin (kriterlerin, delillerin) derecesine göre sınıflandırılabilir (Turban ve diğ., 2006). Bu sınıflandırma yüksek düzeyde yapılandırılmıştan yüksek düzeyde yapılandırılmamışa kadar uzanan bir skala boyunca yer almaktadır. Yapılandırılmış sorun rutindir ve tipik olarak tekrar eder oysa yapılandırılmamış problem yeni veya nadirdir. Bu sınıflandırma kesin sınırları olmasa da sürekliliğin ortasında yer alan yarı yapılandırılmış sorunlar, iki ucun da kısmi özelliklerini taşımaktadır. Her sorunun çözümünden etkilenecek veya o çözümden fayda sağlayacak sahip/-leri vardır. Paydaş; karar vermede sorunun sahibini/lerini veya karar vericileri, sorunun kullanıcısını /-larını, çözümün uygulayıcısını/-larını, problem yaşayan müşteriyi/-leri veya çözümden yararlananları veya sorunun mağdurunu/-larını ve sorunu çözeni veya analisti içeren genel bir terimdir (Daellenbach, 1994). Bu araştırmada deniz liman yönetiminin stratejik yönetim kararından etkilenecek ve/veya sorunun çözümüne katkıda bulunabilecek 4 önemli paydaş grubundan uzmanlar araştırmaya dahil edilerek deniz liman işletmelerinin kendileri için en uygun stratejiyi belirlemelerine yardımcı olabilecek bir model ortaya konulmaya çalışılmıştır. Bu bağlamda deniz liman yöneticileri birinci grubu oluşturmaktadır. İkinci grupta deniz yoluyla taşımacılık yapan işletmelerin yöneticileri yer alır. Hiç şüphesiz deniz liman işletmelerinin birincil müşterileri olan bu kesim deniz yolu taşımacılığı işletmeciliğinde hem karar merci hem de limanın en üst düzey yönetim birimi olarak deniz liman işletmelerinin kararlarından etkilenip bundan memnuniyet duyan ya da tam tersi bundan rahatsız olup bir deniz liman işletmesinin sunduğu hizmetin yerine bir başka deniz limanlarını tercih edebilecek özel veya tüzel kişilerdir. Bu gruptaki işletme yöneticileri deniz liman yönetimlerini etkileyebilme gücüne sahiptir çünkü deniz liman işletmesinin varlık sebebi hiç kuşkusuz gemi taşımacılığı yapan işletmelerdir. Üçüncü grupta ise deniz liman sahalarında terminal operatörü olarak görev yapan işletme yöneticileri bulunmaktadır. Bu işletmeler deniz limanının birincil (temel) faaliyeti olan yükleri gemiye yükleme ve yükleri gemiden boşaltma işlemlerini ifa etmektedir ki aslında bu işlemler deniz limanlarının temel faaliyeti olarak nitelendirilmektedir. Son olarak deniz liman işletmeciliği konusunda teorik bilgiye haiz, bu alanda bilimsel çalışmalar yapmış akademisyenler bu araştırmadaki örnekleme dahil edilmiştir.

Birleşmiş Milletler Ticaret ve Kalkınma Konferansı'nın (UNCTAD 2017) tahminlerine göre, küresel ticaret hacminin yaklaşık %80'i ve ilgili değerin üçte ikisinden fazlası derin deniz gemileri ve limanlar tarafından taşınmaktadır. Deniz liman işletmeleri hizmet sunan işletmelerdir. Buralarda sunulan hizmetin kapsamı ve içeriği ve niteliği limanı kullanan müşterilerin istek ve beklentilerine göre şekillenir. Limanlarda sunulan hizmetleri birçok ölçüte göre sınıflandırmak mümkündür ancak en çok kullanılan sınıflandırmalardan biri yüke ve gemilere sunulan hizmetlere göre yapılan sınıflandırma olacaktır. Deniz limanlarının tarihsel gelişimine bakıldığında gemi ve yüklere verilen hizmetlere insan ve kas gücüyle ve basit düzeneklerle sunulan hizmetlerin günümüzde yüksek teknoloji ve makinelerin kullanıldığı otomasyon düzeyinin yükseldiği ve hatta bazı deniz limanlarında insansız terminallerin de kullanıldığı bir dönüşüme evrildiği görülmektedir (Esmer, 2019:23).

Deniz taşımacılığı yapan işletmeler ile deniz limanları ve terminalleri arasındaki küresel entegrasyon konuları son dönemlerde araştırılan konulardan biridir. Son yıllarda elleçleme ve dağıtım kapasitesi ve konteyner taşımacılığının oranın artmasıyla bu işleri yapanların sayısı birkaç işletmenin eline geçmiş ve bu durum operatörlerin büyük ölçüde yeniden organize olması sonucunu doğurmuştur (Junior ve diğ., 2003:393). Elleçlemede kötü bir performans ürünlerin büyük çapta zarar görmesine neden olabilir (Bowersox ve Closs,

1996:32). Deniz limanlarındaki aktif varlıklar deniz ve kara arasında bir ara yüz olarak uluslararası ticaret bağlantılarını sağlama hizmeti sunmaktadır. Limanlar artan bir şekilde küresel tedarik zincirinin kritik üsleri olarak görülmektedir (Loh, Van ve Thai, 2014). Dawidowicz ve Postan (2015), liman hizmetinin sağlanmasını, malların çıkış noktasından varış noktasına teslim edilmesi süreciyle bağlantılı eylem ve faaliyetlerin yanı sıra organizasyonel, lojistik, teknik, teknolojik, ekonomik ve yasal süreçlerin düzenli bir sırası olarak tanımladılar. Ayrıca yazarlara göre liman hizmetleri dört grupta toplanabilir: Aktarma, depolama ve liman içinde taşıma gibi temel hizmetler birinci grupta yer almaktadır. İkinci gruptaki ek hizmetler arasında kargo ile ilgili işlemler (gümrük kontrolü, konteyner tartımı, konteyner yıkama vb.) yer almaktadır. Üçüncü gruptaki spesifik (özel) hizmetler yükün türüne bağlıdır ve bu nedenle şunları içerir: Sıcaklık kontrolü, veterinerlik ve bitki sağlığı kontrolü, portatif bir jeneratörün konteynere yerleştirilmesi vb. Lojistik hizmetler; sigorta, dağıtım, taşıma işleri komisyonculuğu, danışmanlık, reklam vb. Lojistik hizmetler ise dördüncü grup liman hizmetleridir (Dawidowicz ve Postan, 2015). Deniz limanları hakkındaki temel bilgiler hem Türkiye'deki deniz limanları hem de dünyadaki deniz limanlarının internet sitelerinde yer almaktadır. Buralarda limana ait genel bilgilerin (limanın coğrafi konumu, tarihçesi, liman sahasından fotoğraflar gibi) yanı sıra deniz limanındaki ekipmanların ve buralarda verilen hizmetlerin ayrıntılı bir şekilde belirtildiği de görülmektedir. Bir konteyner terminal işletmesinin internet sitesinde vermiş olduğu hizmetleri şu şekilde sıralamak mümkündür:

- Yükleme/boşaltma ve konteyneri kaydırma.
- Konteyner Terminal Hizmetleri
- Konteyner İşlem İstasyonu Hizmetleri
- Ürünlerin konteynerlerin içine yerleştirme
- Ürünlerin konteynerlerin içinden boşaltma
- Konteynerlerin içlerinin muayene edilmesi ve numune alma.
- Gereken durumlarda konteynerlerin etiketlenmesi
- Konteynerlerin içine gerekli malzeme ile kaplama
- Soğutuculu konteyner hizmetleri
- Tehlikeli madde konulan konteynerlere yönelik hizmetler
- Konteynerleri istifleme ve sabitleme işlemleri (www.marport.com.tr).

Denizcilik ve deniz limanı yönetimi ile ilgili yapılan birçok çalışmada aşağı yukarı aynı hinterlanda sahip ve aynı liman düzleminde yer alan deniz liman yönetimlerinin, liman operatörlerinin arasında pazar payı elde etmek için yoğun bir rekabet olduğunun analizi yapılmıştır. Goss (1990) ve Heaver (1995) liman rekabetini hızlandıran bileşenlerin yerel otoritelerin (merkezi hükümetin rolünün azaltılmasıyla) liman politikaları ile uyumlaştırılması sonucu ortaya çıkacağını savunmuştur. Bu bağlamda, Coeck ve diğ., (1997), liman rekabetinin nadiren bir bütün olarak bir limanla ilgili olduğunu öne sürmüştür. Bir limanın genel rekabetçi konumu, konvansiyonel kargo, konteynerler, kuru yük, sıvı dökme yük ve ro-ro gibi bireysel trafik kategorilerindeki rekabetçi konumu ile belirlenir. Aynı zamanda hem Slack (1994) hem de Fleming (1989) özellikle konteyner taşımacılığında uzmanlaşmış limanların yoğun bir rekabetle karşı karşıya olduğunu gözlemlemişlerdir.

Strateji bir işletmenin misyonunu gerçekleştirmesi için oluşturduğu hareket planadır. Her bir fonksiyonel alan kendi misyonunu ve tüm işletmenin misyonunu da gerçekleştirmesine yardım edecek stratejiye sahiptir. Bu stratejiler fırsatları ve güçlü yanları keşfetmeyi, tehditleri bertaraf etmeyi ve zayıf yönlerden ise kaçınmayı içerir. Firmalar misyonlarını 3 kavramsal yolla başarır: (1) Farklılaştırma, (2) Maliyet Liderliği, (3) Hızlı Yanıt verme. Bu operasyonel yöneticilerin mal veya hizmetleri (1) daha iyi en azından birkaç yönüyle farklı, (2) daha ucuz ve (3) daha hızlı cevap veren bir şekilde teslim etmesi olarak adlandırılır. Bu durum operasyon yöneticilerinin bu stratejik kavramları başarmak için soyut görevlere dönüştürme olarak yorumlanır. Bu

stratejik kavramların biri veya birkaçından oluşan kombinasyonu uygulamak işletmenin rakipleri üzerinde kuracağı emsalsiz bir rekabet avantajına dönüşeceği söylenebilir (Heizer ve Render, 2014:70).

Yukarıda değinilen 3 stratejinin her biri operasyon yöneticilerine rekabetçi avantajı elde etme fırsatını sunacaktır. Rekabetçi avantaj rakipler üzerinde emsalsiz bir avantaj oluşturacak sistemi kurmayı işaret etmektedir. Buradaki temel düşünce etkili ve sürdürülebilir bir şekilde müşteriye bir değer oluşturma iddiasıdır. Bu stratejilerden sadece birinin varlığı yeterli olabilir ancak operasyon yöneticileri genellikle bu 3 stratejinin kombinasyonlarını uygulayacaktır (Heizer ve Render, 2014:71).

Araştırma Metodolojisi

"Deniz Liman İşletmelerinin Strateji Seçimlerinde AHP Modellemesi ile Karar Alma Süreci" başlıklı, 2024/190 dosya numaralı, 10.05.2024 tarih ve 2556128 sayılı başvuru araştırmanın veri toplama süreci ile ilgili İ.Ü. Sosyal ve Beşeri Bilimler Araştırmaları Etik Kurulu'na başvurulmuştur. İ.Ü. Sosyal ve Beşeri Bilimler Araştırmaları Etik Kurulu tarafından 04.06.2024 tarihli ve 2592504 sayılı karar ile adı geçen çalışma etik yönden uygun bulunmuştur. Bu doğrultuda gerçekleştirilen çalışmanın amacı, önemi ve geliştirilen model ve araştırmanın aşamaları aşağıda gösterilmektedir.

Araştırmanın Amacı

Araştırmada deniz liman işletmelerinin strateji seçimlerinde tepe yönetime yardımcı olacak ve tüm deniz liman işletme yönetimlerinin kullanımına uygun bir model ortaya koymak amaçlanmaktadır.

Araştırmanın Önemi

Araştırma, sektörde yer alan deniz liman işletmeleri yöneticilerinin kullanabileceği ve kendi liman işletmelerinin çevre koşullarına uyumlu şekilde puanlama yapmaya olanak tanıyan bir model aracılığıyla kurumsal performansa en fazla katkı sağlayacak en uygun strateji seçimini gerçekleştirebilmek açısından önem taşımaktadır.

Araştırma Modeli

Bu araştırmada amaç; deniz liman işletme yöneticilerinin strateji seçimlerine yardımcı olacak bir model oluşturmaktır. Deniz liman işletmelerinin strateji seçiminde literatür taraması yapıldığında görülmüştür ki 3 temel strateji bulunmaktadır. Bunlar; farklılaştırma, maliyet liderliği ve hızlı yanıt verme stratejisidir (Heizer ve Render, 2014:73). Strateji alternatifleri değerlendirilirken özelde deniz liman işletme yönetimlerinin kullanabilecekleri kriterler ise deniz liman performans göstergelerinden oluşturulmuştur. Deniz liman performans göstergeleri konusunda yapılan çalışmaların literatür taraması sonucunda 6 tane temel faktörün olduğu tespit edilmiştir. Bunlar; temel faaliyetler, destekleyici faaliyetler, finansal güç, müşteri memnuniyeti, terminal tedarik zinciri bütünleşmesi ve sürdürülebilir büyümedir (Yang ve diğ., 2017). Söz konusu kriterlerin ağırlıklarının tespit edilmesinde 16 uzmandan oluşan odak grubuna performans göstergelerinin 6 ana boyutu ve 16 alt boyuttan oluşan kriterleri ikili karşılaştırmalarını içeren bir anket formunu cevaplamaları istenmiştir. Anket formunda 29 adet karşılaştırma yapılmıştır. Verilerin analizinde analitik hiyerarşi sürecini çözümlemede Super Decision Paket Programı kullanılmıştır. Öncelikle araştırmanın sorunsalı belirlenmiştir sorun deniz liman işletmelerinin kendileri için en uygun stratejiyi belirlemesidir. Bunun için kullanılacak 6 ana 16 alt boyut ise programda düğümler (nodes) sayesinde birbiriyle ilişkilendirilmiştir. Araştırmanın ikinci aşamasında ise deniz liman performans göstergelerinin ağırlıklarının belirlenmesinde 16 uzmanın görüşüyle ikili karşılaştırmalar yapılan anket formundaki sorularla tespit edilmiştir. Araştırmanın üçüncü aşamasında katılımcıların yapmış oldukları ikili karşılaştırmaların geometrik ortalaması alınmış ve değerler ondalık kısımları ile beraber Super Decision programında ilgili yerlere girilmiştir. Bu aşamada önemli bir husus

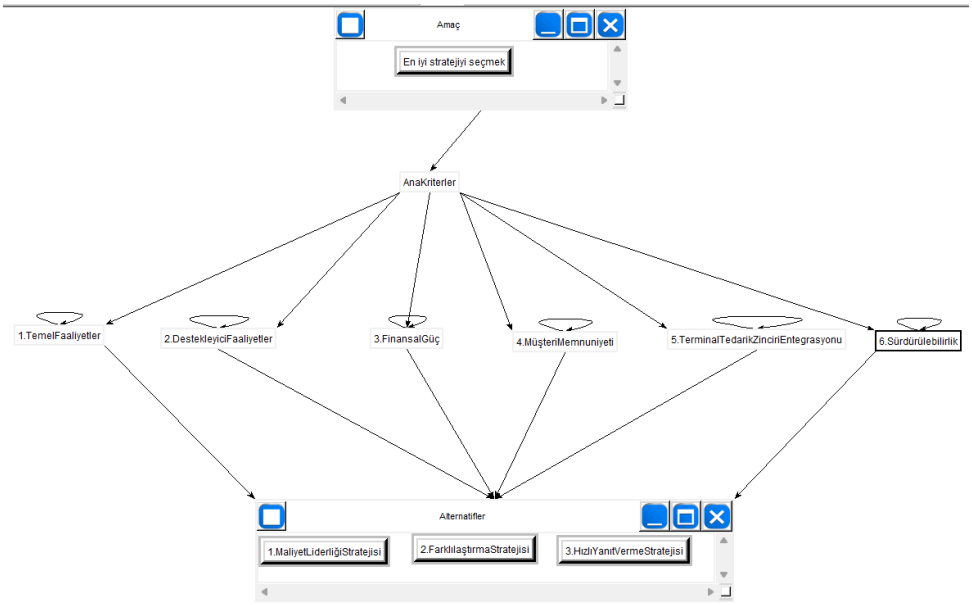
tutarsızlık (inconsitency) oranının 0,10'dan küçük olması gerektiğidir. Son aşama da ise liman stratejisini seçmeye yardımcı olacak deniz liman performans kriterlerinin ağırlıklarının yer aldığı tablo oluşturulmuştur. Bu tabloda her bir deniz liman işletme yöneticisi 9'lu Likert ölçeğini kullanarak her bir ana kriteri ve alt kriteri 1'den 9'a kadar puanlandırmış puanların da ana kriter ve alt kriterlerin katsayıları ile çarpımı sonucu ağırlıklandırılmış puanlar hesaplanmış ve bu puanların toplanması neticesinde en yüksek puana sahip alternatif strateji liman yönetiminin liman stratejisinin belirlenmesinde kullanılabilecek hale getirilmiştir.

Araştırmanın Aşamaları

Araştırmanın ilk aşamasında ana hedef belirlenmiştir. Buradaki ana hedef deniz liman işletmesinin en iyi stratejiyi belirlemesidir. Bu hedefi gerçekleştirmek için stratejilerin değerlendirilmesinde anahtar deniz liman performans göstergeleri ve onların alt boyutları kullanılmıştır. Bu kriterler bağlamında deniz liman işletmelerinin strateji alternatifleri de modelin içinde yer almaktadır. Araştırmanın birinci aşamasında söz edilen işlemleri yapabilmek için AHP kullanımında yaygın olarak tercih edilen Super Decision Paket Programı kullanılmıştır. Şekil 1'de Super Decision ile oluşturulan model çıktıları gösterilmiştir.

Şekil 1

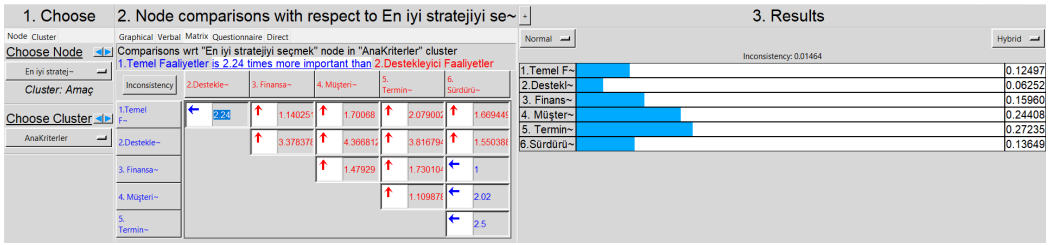
Araştırma Modellemesi



Araştırmanın ikinci aşamasında ana ve alt kriterlerin ağırlıklandırılması için birbirleri ile karşılaştırmaları yapılmış ve ana faktörlerin ve alt faktörlerin ağırlık katsayıları tespit edilmiştir. Bu aşamada öncelikle ana faktörler olan temel faaliyetler, destekleyici faaliyetler, finansal güç, müşteri memnuniyeti, terminal/tedarik zinciri bütünleşmesi ve sürdürülebilirlik faktörlerinin her biri diğeriyle karşılaştırılmış ve ağırlıkları hesaplanmıştır. Analizlerin Super Decision ekran görüntüsü Şekil 2'de gösterilmiştir.

Şekil 2

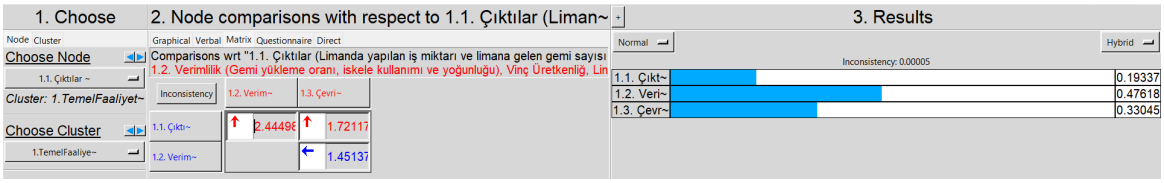
Ana faktörlerin karşılaştırılması ve ağırlıklandırılması



İkinci aşamada ikili karşılaştırma ve ağırlıklandırma işlemi ana faktörlerin alt faktörleri düzeyinde de devam ettirilmiştir. Veri girişinde uzmanlardan gelen yanıtların geometrik ortalaması alınarak çıkan sonuçlar Super Decision Programında oluşturulan ikili karşılaştırmalar kısmına yazılarak işlem yapılmıştır. Burada önemli hususlardan biri tutarsızlık (inconsistency) katsayısının 0,10 değerinden düşük olmasıdır. Bütün karşılaştırmalarda bu katsayının 0,10 değerinden düşük olduğu görülmüştür. Buna göre katılımcıların yaptıkları karşılaştırmaların tutarlılığı oldukça yüksektir (%99,99). Temel faaliyetler ana faktörünün alt faktörleri olan çıktılar (limanda yapılan iş miktarı ve limana bir yıl içinde gelen gemi sayısı), verimlilik (gemi yükleme oranı, iskelelerin kullanışlılığı ve yoğunluğu, vinç üretkenliği, deniz limanındaki alanın kullanımı, iş görenlerin verimliliği) ve çevrim süresi (geminin, tırın, konteynerin limanda kalış süresi).

Şekil 3

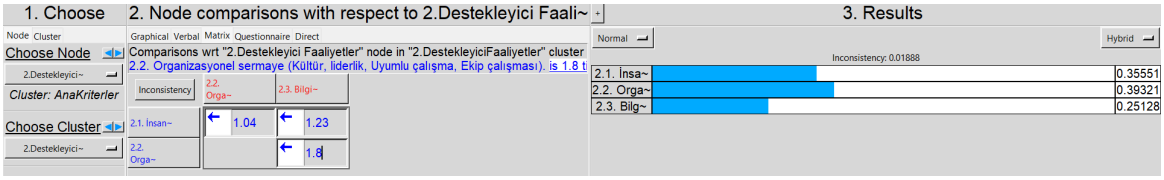
Çıktılar, Verimlilik ve Çevrim Süresi Alt Faktörlerinin Karşılaştırılması ve Ağırlıklandırılması



Destekleyici faaliyetlerin alt faktörleri olan insan kaynakları sermayesi, organizasyon sermayesi ve bilgi sermayesi alt faktörlerinin karşılaştırılması ve ağırlıklandırılması Şekil 4'te gösterilmiştir.

Şekil 4

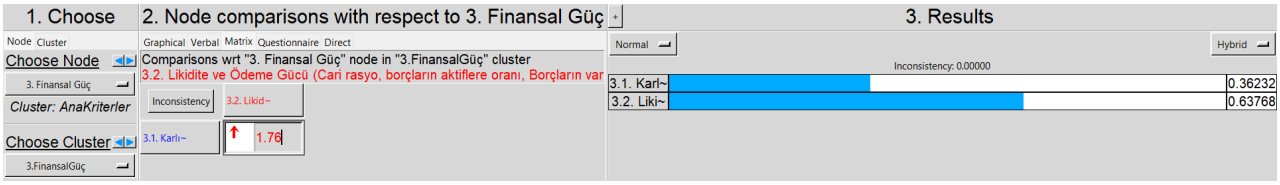
İnsan Kaynakları Sermayesi, Organizasyon Sermayesi ve Bilgi Sermayesi Alt Faktörlerinin Karşılaştırılması ve Ağırlıklandırılması



Finansal güç ana faktörünün alt boyutları karlılık ile likidite ve borçları ödeme gücü alt faktörlerinden meydana gelmektedir. Burada iki alt faktör olduğundan sadece bir karşılaştırma yapılmıştır. Sonuçlar Şekil 5'te gösterilmiştir.

Şekil 5

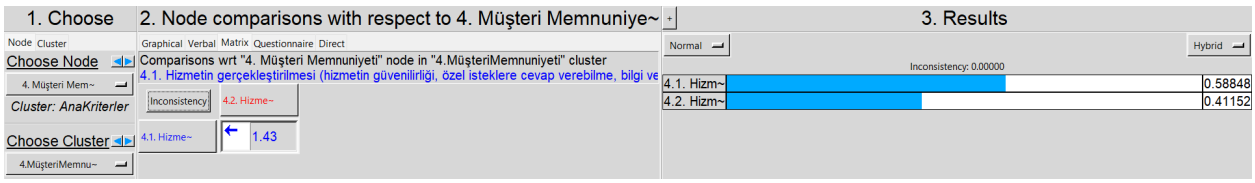
Karlılık ve Likidite Borçları Ödeme Gücü Alt Faktörlerin Karşılaştırılması ve Ağırlıklandırılması



Müşteri memnuniyeti ana faktörünün alt boyutları hizmetin yerine getirilmesi ve hizmetin maliyetidir. Burada da iki alt faktör olduğundan sadece bir karşılaştırma yapılmış sonuçlar Şekil 6'da gösterilmiştir.

Şekil 6

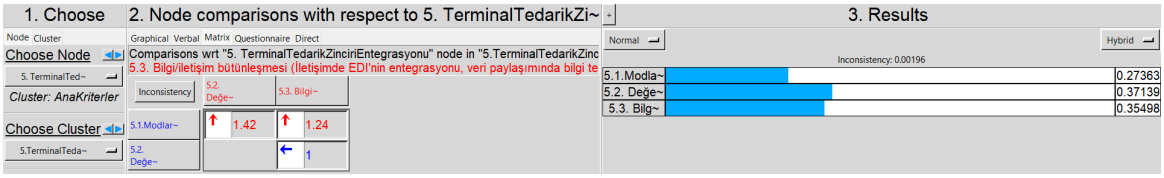
Hizmetin Yerine Getirilmesi ve Hizmetin Maliyeti Faktörlerinin Karşılaştırılması ve Ağırlıklandırılması



Terminal/Tedarik Zinciri Bütünleşmesi ana boyutunun alt boyutları olan modlar arası geçişte ulaştırma sistemleri, değer eklenmiş hizmetler ve bilgi/iletişim bütünleşmesi alt boyutları karşılaştırılmış ve sonuçlar Şekil 7'de gösterilmiştir.

Şekil 7

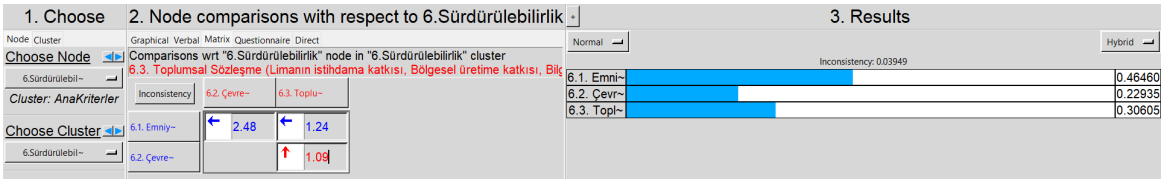
Modlar Arası Ulaştırma Sistemleri, Değer Katılmış Hizmetler ve Bilgi/İletişim Entegrasyonu Alt Faktörlerinin Karşılaştırılması ve Ağırlıklandırılması



Son ana faktör sürdürülebilirliğin alt faktörleri ise emniyet ve güvenlik, çevre ve toplumsal sözleşme alt faktörlerinden oluşmaktadır. Bu alt faktörlerin karşılaştırılmasının sonuçları şekil 8'de gösterilmiştir.

Şekil 8

Emniyet ve Güvenlik, Çevre ve Toplumsal Sözleşme Alt Faktörlerin Karşılaştırılması ve Ağırlıklandırılması



Araştırmanın son aşamasında ana kriterler ve alt kriterlerin katsayılarının yer aldığı ve deniz liman stratejisini seçecek deniz liman işletme yöneticisinin karar vermesinde her bir stratejiyi 1'den 9'a kadar puanlandırabileceği bir tablo oluşturulmuştur. Bu tablo iki deniz liman işletmesinin strateji belirleme konumundaki en üst düzey yöneticilere doldurtulmuş ve sonuçlar ve puanlar Tablo 1 ve Tablo 2'de gösterilmiştir.

Tablo 1

A Deniz Liman İşletme Yöneticisinin Verdiği Puanlar ve Seçtiği Strateji

Ana Kriterler	Katsayısı	Alt Kriterler	Katsayısı	Maliyet Liderliği	Farklılaştırma Stratejisi	Hızlı Yanıt Verme Stratejisi	Maliyet Liderliği Str. Ağırlıklandırılmış Puan	Farklılaştırma Stratejisi Ağırlıklandırılmış Puan	Hızlı Yanıt Verme Stratejisi Ağırlıklandırılmış Puan
1. Temel Faaliyetler	0,14	Limanda Yapılan İş Çıktısı	0,19	9	9	8	0,24	0,24	0,21
		Verimlilik	0,48	10	6	7	0,67	0,4	0,47
		Çevrim Süresi	0,33	9	7	10	0,42	0,32	0,46
2. Destekleyici Faaliyetler	0,06	İnsan Kaynakları Sermayesi	0,36	6	9	10	0,13	0,19	0,22
		Organizasyonel Sermaye	0,39	5	8	9	0,12	0,19	0,21
		Bilgi Sermayesi	0,25	6	8	9	0,09	0,12	0,14
3. Finansal Güç	0,16	Karlılık	0,36	9	8	8	0,52	0,46	0,46
		Likidite ve borçları ödeyebilme gücü	0,64	9	7	6	0,92	0,72	0,61
4. Müşteri Memnuniyeti	0,24	Hizmetin yerine getirilmesi	0,59	7	10	10	0,99	1,42	1,42
		Hizmetin toplam maliyeti	0,41	10	7	6	0,98	0,69	0,59

Ana Kriterler	Katsayısı	Alt Kriterler	Katsayısı	Maliyet Liderliği	Farklılaştırma Stratejisi	Hızlı Yanıt Verme Stratejisi	Maliyet Liderliği Str. Ağırlıklandırılmış Puan	Farklılaştırma Stratejisi Ağırlıklandırılmış Puan	Hızlı Yanıt Verme Stratejisi Ağırlıklandırılmış Puan
5. Terminal ile Tedarik Zinciri Bütünleşmesi	0,27	Modlar arası geçiş	0,27	8	10	10	0,58	0,73	0,73
		Değer Eklenmiş Hizmetler	0,37	9	9	10	0,9	0,9	1
		Bilgi/iletişim Entegrasyonu	0,36	8	10	10	0,78	0,97	0,97
6. Sürdürülebilir Büyüme	0,13	Emniyet ve Güvenlik	0,47	7	9	6	0,43	0,55	0,37
		Çevre	0,23	6	9	5	0,18	0,27	0,15
		Toplumsal Sözleşme	0,3	7	8	7	0,27	0,31	0,27
Toplam	1			125	134	131	8,22	8,48	8,28

A deniz liman işletmesi yöneticisinin yapmış olduğu değerlendirmelere göre işletme için en uygun strateji en yüksek puana (8,48 Puan) sahip olan Farklılaştırma Stratejisidir. İkinci en yüksek puanı (8,28) alan strateji ise Hızlı Yanıt Verme Stratejisidir. Üçüncü sırada ise Maliyet Liderliği Stratejisi 8,22 puan alarak yer almıştır. Tablo 1'de görüleceği gibi deniz liman işletmelerinin performanslarının değerlendirilmesinde en yüksek katsayıya Terminal ile Tedarik Zincirinin bütünleşmesi kriteri sahip olmuştur. İlgili kriter %27'lik ağırlığa sahiptir, ikinci sırada ise müşteri memnuniyeti %24'lük bir ağırlığa sahip olmuştur. Bu iki kriterin ağırlıkları toplamı %51 değerine sahiptir yani deniz liman işletmesinin performans değerlemesinin yarısını bu iki faktör diğer yarısını ise kalan 4 faktör oluşturmaktadır.

B Deniz Liman İşletmesi yöneticisinin strateji alternatiflerine her bir kriter açısından verdiği puanları ise Tablo 2'de görmek mümkündür.

Tablo 2

B Deniz Liman İşletme Yöneticisinin Verdiği Puanlar ve Seçtiği Strateji

Ana Kriterler	Katsayısı	Alt Kriterler	Katsayısı	Maliyet Liderliği	Farklılaştırma Stratejisi	Hızlı Yanıt Verme Stratejisi	Maliyet Liderliği Str. Ağırlıklandırılmış Puan	Farklılaştırma Stratejisi Ağırlıklandırılmış Puan	Hızlı Yanıt Verme Stratejisi Ağırlıklandırılmış Puan
1. Temel Faaliyetler	0,14	Limanda Yapılan İş Çıktısı	0,19	9	6	7	0,24	0,16	0,19
		Verimlilik	0,48	9	6	6	0,6	0,4	0,4
		Çevrim Süresi	0,33	10	9	8	0,2	0,18	0,16
2. Destekleyici Faaliyetler	0,06	İnsan Kaynakları Sermayesi	0,36	7	8	10	0,15	0,017	0,22
		Organizasyonel Sermaye	0,39	6	9	10	0,14	0,21	0,23
		Bilgi Sermayesi	0,25	7	9	9	0,11	0,14	0,14
3. Finansal Güç	0,16	Karlılık	0,36	10	9	8	0,22	0,19	0,17
		Likidite ve borçları ödeyebilme gücü	0,64	7	8	8	0,72	0,82	0,82
4. Müşteri Memnuniyeti	0,24	Hizmetin yerine getirilmesi	0,59	6	10	10	0,85	1,42	1,42

Ana Kriterler	Katsayısı	Alt Kriterler	Katsayısı	Maliyet Liderliği	Farklılaştırma Stratejisi	Hızlı Yanıt Verme Stratejisi	Maliyet Liderliği Str. Ağırlıklandırılmış Puan	Farklılaştırma Stratejisi Ağırlıklandırılmış Puan	Hızlı Yanıt Verme Stratejisi Ağırlıklandırılmış Puan
5. Terminal ile Tedarik Zinciri Bütünleşmesi	0,27	Hizmetin toplam maliyeti	0,41	10	8	8	0,98	0,79	0,79
		Modlar arası geçiş	0,27	7	10	10	0,7	1	1
		Değer Eklenmiş Hizmetler	0,37	7	10	10	0,7	1	1
6. Sürdürülebilir Büyüme	0,13	Bilgi/iletişim Entegrasyonu	0,36	6	10	10	0,58	0,97	0,97
		Emniyet ve Güvenlik	0,47	7	8	8	0,43	0,49	0,49
		Çevre	0,23	6	9	7	0,18	0,27	0,21
		Toplumsal Sözleşme	0,30	5	8	6	0,2	0,31	0,23
Toplam	1			119	137	135	6,8	8,25	8,16

Tablo 2'de görüldüğü üzere B Deniz Liman İşletme Yöneticisi de işletmesi için Farklılaştırma Stratejisini 8,25 puan vererek seçmiştir. Hızlı Yanıt Verme Stratejisi ise 8,16 puanla ikinci sırada yer almaktadır. Üçüncü sırada ise 6,80 puana sahip Maliyet Liderliği Stratejisi yer almaktadır.

Sonuç ve Öneriler

Deniz liman işletmelerinin kendileri için en uygun stratejiyi bulmalarını sağlayacak bir model oluşturma amacıyla yapılan bu araştırmada deniz liman işletmelerinin uygulayabilecekleri stratejileri değerlendirmede deniz liman işletmelerinin anahtar performans göstergeleri kriter olarak kullanılmıştır. Araştırma sonucunda oluşturulan tablo sayesinde deniz liman işletme yöneticileri işletmeleri için en uygun stratejiyi seçebilmelerine yardımcı olacak bir değerlendirme tablosunu kullanmışlar ve işletmeleri için en uygun stratejiyi tespit etmişlerdir. Deniz liman işletmelerinde maliyet liderliği, farklılaştırma ve hızlı yanıt verme stratejileri temel stratejilerdir. Deniz liman işletmelerinin temel ve yardımcı faaliyetleri, deniz liman işletmelerinin finansal gücü, deniz liman işletmesinden hizmet alan müşterilerin memnuniyeti deniz limanındaki terminallerin tedarik zinciri ile bütünleşmesi (hinterlant bağlantısı) ve sürdürülebilir büyüme kriterleri bağlamında değerlendirmeye tabi tutan bu model her bir deniz liman işletmesinin kendine özgü bakış açısıyla kullanabileceği bir formda oluşturulmaya çalışılmıştır. Her bir kriter her bir strateji için puanlandırılmış ve verilen puan kriterin alt kriter ve ana kriter katsayısı ile çarpılıp ağırlıklandırılmış puanı hesap edilmiş en son aşamada ise bütün puanlar toplanıp en yüksek puanı alan strateji bulunmuştur. Böylelikle deniz liman işletmesi için en uygun strateji tespit edilmiştir. Araştırmada kriterlerin ağırlıklarının belirtilmiş olduğu tablo iki ayrı deniz liman işletmesinin en üst düzey yöneticisine doldurtulmuş ve her iki deniz liman işletme yöneticisinin de işletmelerinde Farklılaştırma Stratejisini tercih ettiği görülmüştür.

Deniz liman işletmelerinin en birincil müşterileri hiç şüphesiz deniz yolu taşımacılığı yapan işletmelerdir. Bu işletmeler gemi gibi çok önemli ve yüksek maliyetli duran varlıklara yatırım yapan işletmelerdir. Bu anlamda sözü geçen işletmelerin deniz limanlarından satın aldıkları hizmetlerin maliyeti özellikle duran varlıklara ayrılan amortisman maliyetlerinin yanında çok büyük bir oran oluşturmayacaktır. Deniz taşımacılığında hız ve doğruluk diğer tüm taşıma türlerinde olduğu gibi önemlidir. Ancak deniz liman taşımacılığı daha çok uluslararası taşımacılık modu olduğu için burada taşıma operasyon sürelerinin daha uzun olduğunu söylemek mümkündür. Buna bağlı olarak deniz taşımacılığı yapan işletmelerin bir operasyonun en

önemli ayaklarından biri olan deniz liman işletmelerinde harcayacakları zamanın kısa olması müşteri memnuniyet düzeyinin arttırılmasına katkıda bulunacaktır. Ayrıca deniz limanlarında kısa sürede işlem yapılması özellikle günlük amortisman maliyeti çok yüksek olan gemilerin bekleme sürelerinin uzunluğundan kaynaklı maliyetlerde de büyük azalmalar meydana getirecektir. Hiç şüphesiz her iki durum da deniz taşımacılığı yapan işletmenin deniz limanını tercih sebeplerinden biri haline getirecektir. Deniz liman işletmelerini tercih eden işletmeler onların hızlı, doğru, güvenilir ve emniyetli işlemler yapmasını bilhassa isteyecektir. Bu duruma uygun olarak farklılaştırma stratejisi müşteri odaklı ve ürün kalitesinin yüksek olmasına hususiyetle özen gösterilen bir strateji türüdür. Maliyet liderliği uygulayan işletmelerin sundukları mal ve hizmetlerde ise kaliteden ziyade fiyat (maliyet) odak noktasıdır. Genel anlamda denilebilir ki özellikleri çok önemli olmayan kolayda mal ve hizmetlerde düşük maliyet stratejisi uygulamak daha başarılı sonuçlar doğuracaktır. Oysa deniz liman işletmeciliği hizmeti beğenmeli mallar grubuna dahil edilebilecek türden bir hizmettir. Ve burada müşterinin fiyattan ziyade kaliteyi göz önünde bulunduracağı açıktır buna bağlı olarak deniz liman işletmelerinde ürün fiyatından ziyade ürün kalitesini öncelikleyen farklılaştırma stratejisinin seçilmiş olması beklenen bir durumdur. Hızlı yanıt verme stratejisi ise daha çok özel durumlar ve özel müşteri istek ve ihtiyaçlarını karşılamaya yönelik bir strateji türüdür. Araştırmamızda her iki deniz liman yöneticisi için de hızlı yanıt verme stratejisi oldukça yüksek puan almış her iki liman yöneticisi için de ikinci strateji olarak tercih edilmiştir. Hızlı yanıt verme stratejisi de deniz liman işletme yönetimi için uygun ve müşteri beklenti ve isteklerini anında karşılama anlamında onların memnuniyet derecelerini yükselten bir strateji olması yönüyle farklılaştırma stratejisine de benzemektedir. Ancak hızlı yanıt verme stratejisinde liman sahasında faaliyet gösteren işletme ve yöneticilerin inisiyatif alma, benzersiz çözümler bulma gibi yetenek ve bilgi birikimine sahip olması gerekmektedir. Burada insan kaynakları sermayesi, organizasyon sermayesi ve bilgi sermayesi gibi konular ön plana çıkmaktadır. İlgili konulara yatırım yapan deniz liman işletmeleri elbette ki hızlı yanıt verme stratejisini daha etkin bir şekilde uygulamada daha başarılı olabilecektir.

Araştırmada katılımcıların yapmış oldukları değerlendirmelere göre deniz liman işletmelerinin hinterlandı ile olan bağlantıları onların tercih edilmelerinde en önemli faktör olarak tayin edilmiştir. Terminal/ Tedarik Zinciri Bütünleşmesi ana faktörü uzmanların yaptıkları karşılaştırmalar neticesinde 0,27 katsayı değerine sahip olmuştur. Limanların etkili olabilmeleri onların önemli üretim ve tüketim merkezleri ile (lojistik üsler) bağlantılarının mevcut olmasına bağlıdır. Bu faktör bir ülkenin bütün lojistik yatırımlarından etkilenen bir özelliğe sahiptir. Şöyle ki bir deniz limanın hinterlandındaki noktalarla iç su yolu, kara yolu, demir yolu, boru hattı gibi ulaştırma modları ile bağlantısının sağlanması ve ayrıca hava limanlarına bağlantısının olması da deniz limanın hinterlandı ile bağlantısının gücünü arttıracak böyle terminal ve tedarik zinciri entegrasyonu da sağlanmış olacaktır. Bu noktada deniz liman yönetimlerinin çok etkili olduğunu söyleyemeyiz zira sözü geçen ulaştırma modlarının alt yapı yatırımlarını genellikle devletler gerçekleştirmektedir. Üst yapı olarak nitelendirilebilecek araçlar ve işletmecilik tarafında ise özel ve kamu işletmelerinin faaliyette bulunması da liman işletmelerinin etki edemeyeceği bir faktör olduğunu göstermektedir. Yani bir deniz limanına gelen yüklerin taşınabileceği yolların mevcudiyeti kadar bu modlarda faaliyet gösteren işletmelerin de mevcudiyeti bu faktörü güçlendirecektir. Dünyanın en büyük deniz limanlarına bakıldığında görülecektir ki limana gelen yükleri iç kısımlara (limanın hinterlandına) transfer edecek modlar etkin bir şekilde kullanılmaktadır. Özellikle büyük deniz limanları iç su yolları ve kanal bağlantıları sayesinde çok geniş bir ağa sahiptir.

Bu araştırmada analitik hiyerarşi süreci kullanılmıştır. Bu yöntem seçilmeden önce literatürde benzer konuda yapılmış araştırmalar incelenmiştir. Buna göre liman etkinliğini ölçen ilk çalışmalardan biri Bobrovitch (1982) tarafından yapılmış, çalışmada merkezi ve merkezi olmayan planlamanın liman etkinliğini ne şekilde etkilediği karşılaştırılmıştır. Araştırmacı limanları trafik sıkışıklığına eğilimli sistemler varsayımıyla açıklamaya çalışmıştır. Bu trafik sıkışıklığını aşmada ise Hotelling'in (1929) merkezi ve merkezi

olmamanın dengelendiği matematiksel modelinin kullanılmasını önermiştir. Goss (1990) liman işletme rekabeti konusunu 5 farklı formda kategorize etmiştir: Yazar liman işletmeciliği rekabetlerini; liman kümeleri, farklı ülkeler arasında, ülke içindeki limanlar arasında, liman içindeki terminaller arasında ve ulaştırma modları arasındaki rekabet olarak belirlemiştir. Cullinane ve diğ., (2004) makalelerinde konteyner limanlarında (veya terminallerinde) hizmet üretiminin etkinliğini ölçmede birçok farklı veri zarflama analizinin (DAE) kesit verilerini kullanmış ancak bu modellerin zaman boyutunu dikkate almadığından elde edilen sonuçların tartışmalı olacağını belirtmişlerdir. Bu sebepten dolayı ilgili yazarlar makalelerinde veri zarflama pençeler analizini kullanmışlardır. Araştırma sonucunda konteyner liman etkinliğinin zamanla dalgalanma gösterdiği yargısına ulaşılmıştır. Ayrıca büyük yatırımlardan elde edilen rekabet gücü ve artan etkinlik uzun dönemde liman etkinliğini tahmin etmede mevcut programların yetersiz kaldıkları sonucuna da ulaşılmıştır. Yeo ve Song (2006) Hiyerarşik Bulanık Proses (HFP, Hierarchical Fuzzy Process) modeli ile Asya limanları arasındaki rekabeti ampirik olarak araştırmıştır. Araştırmanın sonucunda Hong Kong ve Singapur limanları en rekabetçi limanlar olarak tespit edilmiştir. Cullinane ve Wang (2012) çoklu bağlantı analizi (MLA, Multiple linkage Analysis) ile Güney Doğu Asya'da faaliyet gösteren en büyük 39 deniz limanının doğrusal iş ağlarını incelemiştir. Sonuçlar limanların hiyerarşik pozisyonu ile birkaç önemli iş ağlarını sağlama konusunda kuvvetli bir bağ olduğunu göstermiştir.

Bu araştırmada kriterlerin değerlendirilmesi safhasında bulanıklık yani belirsizliğin mevcut olduğu çevresel ortamlardaki değişkenlerin belirsizliği modele dahil edilmemiştir. Öznel algıları ve belirsizliği etkili bir şekilde ele almak için bulanık sayılar AHP ile entegre edilip dilsel değerlendirmelerin uygun bir şekilde ifade edilmesi sağlanır (Calabrese ve diğ., 2016). Yapılan literatür taraması sonucunda; araştırmada kullanılan stratejilerin puanlandırılması metodunun kullanıldığı başka bir çalışmaya rastlanmamıştır. Çalışmada, her bir deniz liman işletme yöneticisinin kullanabileceği ve içinde bulundukları çevre koşullarına göre puanlandırma yapabilecekleri bir model geliştirmek amaçlanmıştır. Bu amacı gerçekleştirebilmek üzere stratejilerin puanlaması safhasında daha önce kullanılmamış bir metot uygulanması yönüyle çalışmanın ilgili yazına ve uygulamacılara katkı sağlayacağı düşünülmektedir. Araştırmanın devamı niteliğindeki doktora tez çalışmasında, AHP'ye bulanıklık unsuru da eklenerek, özellikle deniz liman işletme yöneticilerinin seçtikleri stratejilerde bir değişiklik olup olmadığı tespit edilmeye çalışılacaktır.

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Havacılık İşletmelerinde Yöneticilerin Akılcı ve Sezgisel Karar Verme Yeteneği ile Duygusal Zekâları Arasındaki İlişkinin Araştırması

Research on the Relationship Between Rational and Intuitive Decision-Making Ability and Emotional Intelligence of Managers in Aviation Companies

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Öz

Araştırma, havacılık işletmelerinde görev yapan yöneticiler özelinde akılcı ve sezgisel karar verme yeteneği ile duygusal zekâ arasındaki ilişkileri incelemektedir. Araştırma, nicel araştırma yöntemlerine dayalı olarak yapısal eşitlik modeline göre gerçekleştirilmiş ve veriler de SPSS22.0 kullanılarak analiz edilmiştir. Verilerin toplanmasında akılcı ve sezgisel karar verme ölçekleri ile duygusal zekâ ölçeği kullanılmıştır. Araştırmanın örneklemi, kolayda örnekleme yöntemi ile seçilen havacılık yöneticisinden oluşmaktadır.

Araştırma bulgularına göre, duygusal zekâ ölçeğinde yer alan bazı boyutlar, karar verme süreçlerini önemli ölçüde etkilemektedir. Özellikle öz motivasyon, empati ve diğer insanların duygularını yönetme gibi duygusal zekâ boyutlarının, yöneticilerin akılcı karar verme yeteneklerini olumlu yönde etkilediği tespit edilmiştir. Ayrıca, sezgisel karar verme üzerinde de belirgin bir etki gözlemlenmiştir. Kendi his ve duygularını yönetebilme, duyguların farkına varabilme ve etkileşim halinde olduğu kişilerin duygularını yönetebilme gibi duygusal zekâ bileşenlerinin, sezgisel karar verme yetisini oranında artırdığı sonucuna ulaşılmıştır.

Sonuç olarak, duygusal zekâ bileşenlerinin hem akılcı hem de sezgisel karar verme süreçlerinde önemli bir rol oynadığı, havacılık işletmelerinde görev yapan yöneticilerin etkili kararlar alabilmesi için duygusal zekâ becerilerini geliştirmelerinin kritik olduğu görülmüştür. Bulgular, havacılık sektörü gibi dinamik ve stresli ortamlarda çalışan yöneticilerin, karar verme süreçlerinde duygusal zekânın önemli bir katkısı olduğunu ortaya koymaktadır.

Abstract

The study investigates the relationships between rational and intuitive decision-making abilities and emotional intelligence among managers in aviation companies. Utilizing quantitative research methods, the research was conducted using a structural equation model, and the data were analyzed with the SPSS 22.0 software. The data collection tools included rational and intuitive decision-making scales and an emotional intelligence scale. The sample consisted of aviation managers selected through a convenience sampling method.

The findings indicate that certain dimensions of emotional intelligence significantly influence decision-making processes. Specifically, dimensions such as self-motivation, empathy, and managing others' emotions positively impact the rational decision-making abilities of managers. Furthermore, a notable effect on intuitive decision-making was observed. Components of emotional intelligence, such as managing one's emotions, emotional awareness, and managing the emotions of others, were found to enhance intuitive decision-making abilities.

In conclusion, emotional intelligence components play a crucial role in both rational and intuitive decision-making processes. Developing emotional intelligence skills is essential for managers in aviation companies to make effective

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decisions. The findings emphasize the importance of emotional intelligence in decision-making processes, particularly in dynamic and high-stress environments like the aviation sector.

Anahtar Kelimeler Havacılık İşletmeleri · Karar Verme Süreci · Akılcı Karar Verme · Sezgi yolu ile Karar Verme · Duygusal Zekâ

Keywords Aviation Companies · Decision-Making Process · Rational Decision-Making · Intuitive Decision-Making · Emotional Intelligence

Extended Summary

In this research, the relationships between rational and intuitive decision-making ability and emotional intelligence were examined on managers working in aviation companies. The research was conducted in structural equation model according to quantitative research methods. Research data were collected with rational decision making, intuitive decision making and emotional intelligence scale. The research was determined by the convenience sampling method and was conducted on 191 managers working in aviation companies. The obtained data were analyzed in a computer environment with the SPSS22.0 statistical program. As a result of the research; It has been found that the dimensions of self-motivation, empathy and managing others' emotions in the emotional intelligence scale positively affect rational decision-making levels and increase them by 50%. It was concluded that the dimensions of managing one's own emotions, emotional awareness and managing the emotions of others were effective on intuitive decision making and increased it by 47.4%.

The research was designed in the relational survey model, which is a descriptive research model. The study group in the research consists of 191 managers working in aviation companies. The rational and intuitive decision making scale and the emotional intelligence assessment scale were used as data collection tools in the study. The scale consists of a total of 30 items; Five sub-dimensions: Emotional Awareness, Managing Own Emotions, Motivation, Empathy, and Managing Others' Emotions. The data obtained in the study were evaluated on a computer using the IBM SPSS Statistics for Windows, Version 22.0 (SPSS INC., Chicago, IL, USA) statistical program. Frequency and percentage analyzes were used to determine the descriptive characteristics of the participants in the study, and mean and standard deviation statistics were used to examine the scale. Kurtosis and Skewness values were examined to determine whether the research variables showed normal distribution. In the relevant literature, results regarding kurtosis and skewness values of variables between +1.5 and −1.5 (Tabachnick and Fidell, 2013), +2.0 and −2.0 (George and Mallery 2010) are considered normal distribution. It was determined that the variables showed normal distribution. Parametric methods were used to analyze the data. The relationships between the dimensions that determine the scale levels of the participants were examined through Pearson correlation and structural equation path analyses.

The theoretical model for the relationships between rational and intuitive decision-making ability and emotional intelligence was tested with structural equation path analysis. The results are as follows;

Emotional awareness and managing one's own emotions have no effect on rational decision making ($p>0.05$). Self-motivation, empathy and managing others' emotions have a positive effect on rational decision-making ($p<0.05$). 50% of the total variation in rational decision making is explained by emotional intelligence.

Self-motivation and empathy have no effect on intuitive decision making ($p>0.05$). Managing one's own emotions, emotional awareness, and managing the emotions of others have a positive effect on intuitive decision making ($p<0.05$). 47.4% of the total variation in intuitive decision making is explained by emotional intelligence.

The literature confirms that the impact of emotional intelligence on management practices is significant (Ashkanasy and Daus 2002). As a result, managers with high levels of emotional intelligence are believed to contribute to competitive advantage in organizational decision-making and improve managerial procedures (Fernandez, 2007). Research confirms a remarkable correlation between various dimensions of emotional intelligence, including interpersonal skills, intrapersonal skills, general disposition, stress management, and decision-making style (Yılmaz and Altınok 2010).

According to Goleman (Goleman, 2011, p. 15), the adoption of emotional intelligence skills as a management philosophy has led to the organization of manager training programs. Today, organizations that prioritize the emotional intelligence of their managers can make more sensitive decisions than their peers.

In the study, managers' emotional intelligence levels were examined in the dimensions of emotional awareness, managing their own emotions, self-motivation, empathy and managing the emotions of others. It has been determined that managers have a high level of emotional intelligence in all dimensions. It has been observed that managers' rational decision-making and intuitive decision-making levels are also high.

In the study, the relationships between managers' rational and intuitive decision-making abilities and their emotional intelligence were examined by correlation analysis. As a result of the analysis, positive significant relationships were found between all dimensions, while the highest relationship was found to be between rational decision-making and empathy, and the lowest relationship was between rational decision-making and emotional awareness.

In the research, the effect of managers' emotional intelligence levels on their rational and intuitive decision-making levels was examined by establishing a structural equation model. It has been determined that the level of emotional awareness and managing one's own emotions does not affect the rational decision-making levels of managers, while the levels of self-motivation, empathy and managing the emotions of others positively affect the rational decision-making levels and increase them by 50%.

When looking at the effects of emotional intelligence on intuitive decision making; It was concluded that self-motivation and empathy dimensions did not affect the intuitive decision-making levels of managers, and that the levels of managing their own emotions, emotional awareness and managing the emotions of others positively affected the intuitive decision-making levels and increased them by 47.4%.

Havacılık İşletmelerinde Yöneticilerin Akılcı ve Sezgisel Karar Verme Yeteneği ile Duygusal Zekâları Arasındaki İlişkinin Araştırması

Karar verme, yöneticilerin üstlendiği en kritik sorumluluklardan biridir. Bir organizasyonun başarısı veya başarısızlığı büyük ölçüde alınan kararların kalitesine bağlıdır (Simon, 1987). Karar verme süreci, bireylerin ve organizasyonların karşılaştığı sorunlara çözüm bulmak için alternatiflerin analiz edilmesi ve seçim yapılmasını içeren sistematik bir yaklaşımdır (Mintzberg et al., 1976). Özellikle dinamik ve karmaşık sektörlerde, yöneticilerin karar verme süreçleri üzerinde etkili olan çeşitli faktörler bulunmaktadır.

Havacılık sektörü, yüksek stres ve belirsizlikle karakterize edilen, hızlı karar almayı gerektiren bir çalışma ortamıdır (Hoffman & Shatkin, 2011). Bu bağlamda, yöneticilerin duygusal zekâ düzeyleri ve karar verme tarzları, organizasyonel başarının kritik bileşenleri haline gelmiştir. Duygusal zekâ, kişilerin kendi duygularını fark etme, kontrol etme ve diğer insanların duygularını anlama yeteneklerini tanımlar (Goleman, 1995). Bu beceriler hem rasyonel hem de sezgisel karar verme süreçlerinde önemli bir rol oynamaktadır (Salovey & Mayer, 1990).

Araştırmalar, duygusal zekâsı yüksek yöneticilerin daha etkili kararlar alabildiğini ve bu kararların organizasyonel performansa olumlu katkı sağladığını ortaya koymaktadır (Bar-On, 2006). Bununla birlikte, rasyonel ve sezgisel karar verme yeteneklerinin duygusal zekâ ile olan ilişkisi üzerine yapılan çalışmalar sınırlıdır (Sadler-Smith & Shefy, 2004). Bu çalışma, havacılık sektöründe görev yapan yöneticilerin rasyonel ve sezgisel karar verme yetenekleri ile duygusal zekâları arasındaki ilişkiyi incelemeyi amaçlamaktadır.

Araştırma, bu konuda literatürdeki boşlukları doldurmayı ve havacılık sektörü gibi yüksek stresli ortamlarda karar verme süreçlerini daha iyi anlamaya katkıda bulunmayı hedeflemektedir (Kanki et al., 2019). Ayrıca, duygusal zekâ becerilerinin yöneticiler tarafından geliştirilmesinin, organizasyonların karar alma süreçlerine olan etkisini vurgulamaktadır (Goleman, 1998).

Literatür Taraması

Bir organizasyonun her seviyesinde karar verme, yöneticiler için kritik bir sorumluluktur. Kurumun başarısı ya da başarısızlığı bu kararların sonuçlarına bağlıdır ve yöneticilerin yaptığı her eylem özünde bir karardır. Karar verme, bir soruna veya zorluğa çözüm bulmak için eylem planlarını veya çözümleri oluşturma ve seçme aşamasıdır denilebilir. (Najaf Beigi, 2000).

Bir kuruluş içinde etkili kararlar alma söz konusu olduğunda, temel bilgilere sahip olmanın önemi tartışılamaz. Bir toplumun refahı ve hayatta kalması için kan dolaşımının hayati önemine benzer şekilde, bilgi dolaşımı da temel bir rol oynamaktadır. Karar verme, organizasyonlarda merkezi bir süreçtir ve her seviyedeki yöneticilerin önemli bir sorumluluğudur. Yanlış stratejik ve operasyonel kararların alınması, kuruluşların rekabet gücü üzerinde ciddi sonuçlar doğurabilmektedir. Bu nedenle yöneticilerin iyileştirme yapabilmeleri için karar verme süreçlerini kavramaları zorunludur (Heracleous, 1994).

Kurumların uzun vadeli başarısını sağlamak için kurumsal performansı artıran rasyonel yönetsel kararlara öncelik vermeleri gerekmektedir (Alhalalmeh ve Alawamleh, 2017, s 102). Rasyonel karar verme, bilinçli seçimler yapmak için ilgili bilgilerin toplanmasını ve analiz edilmesini içerir. Karar vericiler, farklı seçeneklerin potansiyel sonuçlarını dikkatle değerlendirerek ve olumlu bir risk-fayda dengesi sunan kararları seçerek belirsizliği en aza indirmeye çalışırlar (Kolbe ve diğerleri, 2020). Çok sayıda çalışma, karar verme stilleri ile çeşitli bilişsel veya kişilik özellikleri arasındaki bağlantıyı ve karar vericilerin sonuçlarını incelemiştir.

Allwood ve Salo'ya (Allwood ve Salo, 2012 s. 35) göre yapılan araştırmalar rasyonel tarzın diğer tarzlara göre daha olumlu sonuçlar verme eğiliminde olduğunu göstermiştir.

Karar verme sürecimiz, birikmiş şemalar aracılığıyla topladığımız bilgilere dayanmaktadır. Bu şemalar, belirli alanlara ilişkin bilgilerimizi tutan bilişsel yapılar olarak hizmet etmektedir. (Fiske ve Taylor, 1991). Bu alanlardaki geçmiş deneyimlerimiz anlayışımızı şekillendirmekte ve gelecekteki kararlarımızı büyük ölçüde etkilemektedir. (Juliusson ve diğerleri, 2005). Şemalar, karar vericilerin alternatifler üretmenin ve istenen sonuca ulaşmak için olasılıkları hesaplamanın karmaşıklığını atlamalarına olanak tanıyan zihinsel kısa yollar olarak görülebilmektedir (Tversky ve Kahneman, 1974).

Toplumsal değişimlerin yaşandığı örgütlerde yöneticilere karar verme görevi verilmektedir. Geleneksel olarak yönetimsel karar alma tamamen rasyonel bir süreç olarak görülmüştür. Yöneticilerin, girdileri, çıktıları ve eylemlerinin sonuçlarını tamamen rasyonel bir şekilde hesaplama yeteneğine sahip oldukları ve her zaman önceden belirlenmiş hedeflere ulaşmaya çalıştıkları varsayılmaktadır. Ancak gerçek şu ki, yöneticiler sıklıkla hızlı kararlar alma baskısı altındadır, bu da yanlışların oluşma yüzdesini artırmaktadır. Sonuç olarak bilgi, tecrübe ve duygularla şekillenen sezginin kullanımı artık rasyonelliği aşmıştır (Gigalová, 2017, s. 301). Bazıları, bilgiye sahip olma ve tüm bilgiyi uygulama bilişsel yeteneğine sahip olmaması nedeniyle yalnızca normatif rasyonel karar almaya güvenmenin aldatıcı olduğunu savunmaktadır.

Bireylerin başarıya ulaşabilmesi için yalnızca yüksek düzeyde bilişsel zekaya sahip olmaları yeterli değildir; aynı zamanda yüksek düzeyde duygusal zekaya sahip olmaları gerekir. Bireylerin yaşadıkları deneyimlerin duygusal tesirinin bilincinde olmaları, duyguları tanımlayabilmeleri ve etkin bir şekilde kullanabilmeleri önemlidir (Töremen ve Çankaya 2008). Bu yeteneğe bilişsel zekâ yerine duygusal zekanın geliştirilmesiyle ulaşılabileceği görünmektedir. Hem kişisel hem de mesleki bağlamda bireyler, karar alırken ve görevleri yerine getirirken yalnızca bilişsel zekalarını değil aynı zamanda duygusal zekalarını da değerlendirmelidir. Bu sadece bireyin kişisel başarısı açısından değil, bağlı olduğu kurumun başarısı açısından da büyük önem taşımaktadır.

Çalışanlar ve yöneticilerden oluşan canlı bir varlığa benzetilebilecek bir organizasyonda, çalışanların duygularının yöneticiler tarafından anlaşılması ve yorumlanması büyük önem taşımaktadır. Bu dinamik,

sonuçta çalışanlar ve yöneticiler arasındaki olumlu ilişkileri teşvik ederek kuruluşun zaferini belirlemektedir. Kendi duygularını tanıma, düzenleme ve denetleme yeteneğine sahip yöneticilerin duygusal zekâ konusunda da paralel bir yeterlilik sergilediklerine inanılmaktadır. Bir organizasyonda karar alma ve uygulama süreçleri incelenirken duygusal zekâ becerileri gelişmiş bireylerin karar vericiler arasına dahil edilmesinin organizasyonun başarısını etkileyeceği öngörülmektedir. Bunun nedeni, yöneticiler tarafından belirli anlarda alınan stratejik kararların, organizasyonun başarı öyküsünde önemli bir rol oynamasıdır. Bu süreçler, yöneticilerin alternatifler üretme, örgüt kültürünü anlama, yorumlama ve aldıkları kararların örgüt çalışanları üzerindeki yansımalarını öngörme kapasitelerini kapsar.

Bir kurumun başarısı büyük ölçüde duygusal zekâ düzeyi yüksek bireylere bağlıdır. Bu bireyler, işyerlerinin amaç ve hedeflerini etkili bir şekilde analiz etme ve anlama becerisine sahip olup, önemli katkılar sağlamaktadır. Katkıları normal çalışanlarınkini aşmaktadır (Kılıç ve ark., 2007). Bireylerin gerekli mesleki beceri ve donanıma sahip olmasının yanı sıra iş birliği, iletişim ve meslektaşlarıyla güçlü ilişkiler kurma konularında da başarılı olmaları gerekmektedir. Bu, ekip odaklı bir ortamın teşvik edilmesiyle başarılabilir. Bir ekibin gelişip başarıya ulaşabilmesi için tüm takımı oluşturan parçaların duygusal zekaya sahip olması şarttır (Çetinkaya ve Alparslan 2011). Yaptıkları işin doğası göz önüne alındığında sağlık profesyonellerinin yüksek düzeyde duygusal zekaya sahip olmaları beklenmektedir. Başkalarına yardım etmeye, olumlu ilişkiler sürdürmeye ve iş birliği içinde çalışmaya odaklanmaları, bunu kendi alanlarında bir zorunluluk haline getirmektedir.

Etiklik, mantık ve doğruluğun değerlendirilmesi, duygusal zekanın kolaylaştırdığı karar vermede önemli bir rol oynamaktadır. Bir kararı uygulamadan önce bireyler, seçimlerinin geçerliliğini değerlendirmek için duygusal zekalarına güvenmektedirler. Hayatta kalmak için duyguların göz ardı edilemeyeceği kabul edildiğinde, her kararın bireyin duygusal durumundan etkilendiği açıktır (Trinidad ve ark., 2004). Yenilikçi düşünme, değişen duygulara uyum sağlama ve ortaya çıkan durumları tahmin etme yeteneği, bireylerin karar verme sürecine katkıda bulunduğu temel faktörlerdir. Karar verme stilleri bireyler arasında farklılık göstermektedir (Scott ve Bruce, 1995). Bununla birlikte hem profesyonel hem de sosyal ortamlarda karşılaşılan çeşitli deneyimler, zorluklarla karşılaşıldığında karar vermede farklılıklara yol açmaktadır. Dolayısıyla bireysel farklılıkların karar verme ve problem çözme süreçlerinin ortak yönlerinde önemli bir rol oynadığı sonucuna varılabilir.

Duygusal zekâ kavramı, duygular ve tepkiler arasındaki etkileşimi tanıma, karar verme sürecinde düşüncelerin mi yoksa duyguların mı etkili olduğunu ayırt etme, seçimlerin sonuçlarını tahmin etme ve kritik kararlar alırken bu tahminleri dikkate alma yeteneğini kapsar (Konakay, 2010, s. 8). Duygusal zekanın "duyguların kullanılması" olarak adlandırılan yönü problem çözmeyle yakından bağlantılıdır (Mayer, Caruso ve Salovey, 1999 s. 267). Bireysel farklılıklardan etkilenen problem çözme prosedürü karar verme sürecini yansıtır. Hedeflerimize ulaşmak için hem problem çözme hem de karar verme çabalarında seçenekleri değerlendirmek için duygularımızı kullanmamız çok önemlidir. Bunun nedeni karar vermenin kapsamlı bilgi ve duygusal keskinlik gerektirmesidir.

Verilen kararların kötü karar iyi karar, etik veya değil, akıllıca ya da mantıksız, doğru ya da yanlış değerlendirilmesi duygusal zekâ tarafından kolaylaştırılır. Bu değerlendirmeye dayanarak bireyler duygusal zekalarını kullanarak kararlarını değerlendirip uygulayabilir veya yeni bir kararın gerekliliğini belirleyebilirler. Bireylerin duygularından tamamen kopmasının mümkün olmadığı göz önüne alındığında, her karar farklı derecelerde duygulardan etkilenebilmektedir (Trinidad ve ark, 2004, s. 947).

Karar verme süreci, bireylerin sahip olduğu en güçlü kaynaklar olarak hizmet ettiğinden büyük ölçüde duygulardan etkilenmektedir. Duygular kişinin kendisi, başkaları ve çevredeki fiziksel ve sosyal çevreyle ilgili kararların şekillenmesinde temeldir. Ayrıca duygular, kişisel değerler, arzular, motivasyonel ihtiyaçlar

ve bireysel kontrol ile derinden iç içe olduğundan karar verme tarzlarının belirlenmesinde önemli bir rol oynamaktadır (Pfeiffer, 2001, s. 139).

Duyguların insan deneyimindeki rolü ve karar verme tarzlarıyla bağlantısı, bireysel yeteneklere bağlı olarak değişen kişisel zekanın bir uzantısıdır. Duygusal zekâ ile karar verme arasındaki ilişki, Fallon, Panganiban, Wohleber, Matthews, Kustubayeva ve Roberts (Fallon ve ark., 2014) tarafından da vurgulandığı gibi karmaşık bir yapıdır. Karar verme sürecinin etkinliği hem zekadan hem de duygulardan etkilenebilir. Khona, Kim ve Aidossova (Khona, Kim ve Aidossova 2016) tarafından tartışıldığı gibi duygular, kişinin hem kendi hem de başkalarının duygularını anlama, tanımlama ve yorumlama yeteneğini kapsayan sosyal bir beceri olarak kabul edilmektedir. Sonuç olarak bireyler, duygusal farkındalıkları ve yetenekleri aracılığıyla çeşitli durumları, olayları, ilişkileri ve kararları yönlendirebilir ve yönetebilirler.

Lehrer'e (Lehre, 2011) göre duyguların yokluğu bizi en temel seçimleri bile yapamaz hale getiriyor. İşleyen bir duygusal beyin olmadan karar verme sürecinin imkansızdır. Karar Anı adlı kitabında Lehrer, kökleri antik felsefeye dayanan geleneksel insan doğası perspektifine meydan okuyan, karar verme sürecimizde duyguların oynadığı önemli rolün altını çizmektedir. Beyin görüntüleme tekniklerindeki son gelişmeler, daha önce inanıldığı gibi insanların yalnızca rasyonel varlıklar olmadığının kanıtlarını sağlamıştır.

Baltaş'a (Baltaş, 2005) göre duygular, insanlığın başlangıcından bu yana karar vermede önemli bir pusula görevi görmüştür. Bununla birlikte, dengesiz duyguların, rasyonellikle yumuşatılmadığı takdirde yoldan çıkabileceği, sıkıntıya yol açabileceği ve hatta ortalığı kasıp kavurabileceği de unutulmamalıdır. Bununla birlikte, duygular bireylere eyleme geçmek için gerekli dürtüyü sağladığından, rehberlik etmede, birleştirmede ve etki yaratmada çok önemli bir rol oynarlar.

Bireylerin deneyimlediği sürekli beklenti ve devam eden yenilik arayışı, tercih ettikleri karar verme yöntemlerini kullanma konusunda zorluk teşkil etmektedir. Sonuç olarak kişinin karar alma yaklaşımının ve karar verme tarzı ve yaklaşımının önemi ortaya çıkmaktadır. Her bireyin kendine özgü bir karar verme stili olduğu göz önüne alındığında, problem çözme yaklaşımı ve karar alma tarzı sonuçta kararların kalitesine tesir edecektir. (Üre ve Avşaroğlu, 2007, s. 87).

Kişinin duygularını düzenleme yeteneği, etkili yöneticiler için çok önemli bir özelliktir. Duygusal kontrolden yoksun olan ve duygusal seçimlerinin çalışanları üzerindeki etkisini tahmin edemeyen yöneticiler, güven telkin etmede zorluk yaşayacaklardır. İlginç bir şekilde, yöneticiler olumsuz bir duygusal durumdayken daha sistemli kararlar alma eğilimindedirler. Bunun tersine, olumlu duygular hisseden yöneticilerin yaratıcılığı teşvik eden kararlar alma olasılıkları daha yüksektir (Goleman, 2011, s. 15).

İş dünyasında karar almanın temeli olarak duyguları kullanmak, bir kuruluş içindeki çalışanlar arasında iş tatminini ve genel memnuniyeti artıran seçimlerin uygulanmasına olanak tanır. Ayrıca bu yaklaşım, operasyonel verimliliği artıran yenilikçi çözümlerin ve etkin problem çözme tekniklerinin üretilmesini kolaylaştırmaktadır. Yaratıcılığı geliştirmek için duyguların etkisinden yararlanma becerisine sahip olan, kendi duygusal durumlarını doğru bir şekilde tanımlayan ve mantıksal akıl yürütmenin yanı sıra duygusal zekayı da kullanan yöneticiler, sağlam kararlar alma ve uygun eylemleri gerçekleştirme konusunda donanımlıdırlar (Caruso ve Salovey, 2007, s. 39).

Bir organizasyon içerisinde alınan kararların kalitesi, organizasyon ikliminin bir parçası olan duygusal ortamdan etkilenir. Sosyal etkileşim duyguların ortaya çıkmasında rol oynayarak karar almayı daha da etkiler. Kararların değerlendirilmesine ve uygulanmasına hem iç hem de dış faktörler katkıda bulunmaktadır. Dış değişkenleri yönetmek zorluklar yaratsa da karar kalitesini ve karar verme sürecini geliştirmek için duygu ve mantık da dahil olmak üzere insan değişkenlerini tanımlamak ve yönetmek çok önemlidir. Duygular, karar vermede bağlamsal bir arka plan olarak kabul edilir ve karar verme sürecindeki kontrol açısından büyük önem taşımaktadır.

Literatür, duygusal zekanın yönetim uygulamaları üzerindeki etkisinin önemli olduğunu doğrulamaktadır (Ashkanasy ve Daus 2002). Sonuç olarak, yüksek düzeyde duygusal zekaya sahip yöneticilerin örgütsel karar almada rekabet üstünlüğüne katkıda bulunduğuna ve yönetsel prosedürleri geliştirdiğine inanılmaktadır (Fernandez, 2007). Araştırmalar, kişilerarası beceriler, kişisel beceriler, genel eğilim, stres yönetimi ve karar verme tarzı dahil olmak üzere duygusal zekanın çeşitli boyutları arasında dikkate değer bir korelasyon olduğunu doğrulamaktadır (Yılmaz ve Altınok 2010).

Goleman' a (Goleman, 2011, s. 15) göre duygusal zekâ becerilerinin bir yönetim felsefesi olarak benimsenmesi, yönetici yetiştirme programlarının düzenlenmesine yol açmıştır. Günümüzde yöneticilerinin duygusal zekasını ön planda tutan organizasyonlar, emsallerine göre daha hassas kararlar alabilmektedir.

Yöntem

Araştırma Modeli

Araştırma, havacılık işletmelerinde görev yapan yöneticiler özelinde akılcı ve sezgisel karar verme yeteneği ile duygusal zekâ arasındaki ilişkileri incelemektedir. Araştırma, nicel araştırma yöntemlerine dayalı olarak yapısal eşitlik modeline göre gerçekleştirilmiş. Araştırma tanımlayıcı bir araştırma modeli olan ilişkisel tarama modelinde tasarlanmıştır. Yapılan araştırma için İstanbul Topkapı Üniversitesi Bilimsel Araştırma ve Yayın Etiği Komisyonundan etik kurul onayı alınmıştır. (sayı: E-49846378-302.14.1-2400007962. Tarih:18.05.2024)

Çalışma Grubu

Araştırmada çalışma grubu olarak havacılık işletmelerinde görev yapan 191 yönetici oluşturmaktadır.

Veri Toplama Aracı

Verilerin toplanmasında anket yöntemi kullanılmıştır. Araştırmada veri toplama aracı olarak akılcı ve sezgisel karar verme ölçeği ile birlikte duygusal zekâ değerlendirme ölçeği kullanılmıştır. Akılcı ve sezgisel karar verme ölçeği, 1995 yılında Scott ve Bruce tarafından geliştirilmiş, Türkçeye çevirisi 2002 yılında Arzu Taşdelen tarafından gerçekleştirilmiştir. Ölçek 16 maddeden oluşmaktadır. Duygusal Zekâ Değerlendirme Ölçeği, duygusal zekâ düzeyini ölçmek amacıyla 1999 yılında Nick Hall tarafından geliştirilmiş, Türkçeye uyarlaması ise Ergin (2000: 1-100) tarafından yapılmış ve ardından Türkiye'deki birçok araştırmada kullanılmıştır. Toplamda 30 maddeden oluşan ölçek, Duygusal Farkındalık, Kendi Duygularını Yönetme, Motivasyon, Empati ve Diğerlerinin Duygularını Yönetme olmak üzere beş alt boyuttan meydana gelmektedir (Ergin, 2000).

Verilerin İstatistiksel Analizi

İnceleme kapsamında elde edilen bilgiler, IBM SPSS Statistics for Windows, Version 22.0 (SPSS INC., Chicago, IL, USA) ve AMOS istatistik yazılımı kullanılarak analiz edilmiştir. Katılımcıların tanımlayıcı karakterlerini belirlemek için frekans ve yüzde analizlerinden, ölçeğin özelliklerini incelemek amacıyla ise ortalama ve standart sapma istatistiklerinden yararlanılmıştır. Araştırma değişkenlerinin normal dağılıma uyup uymadığını değerlendirmek için çarpıklık (Skewness) ve basıklık (Kurtosis) verileri incelenmiştir. Mevcut literatürde, değişkenlerin çarpıklık ve basıklık ölçütlerinin +1.5 ile −1.5 (Tabachnick ve Fidell, 2013) veya +2.0 ile −2.0 (George ve Mallery, 2010) belirtilen aralıklarda olmasının normal dağılımın bir göstergesi olarak kabul edildiği ifade edilmektedir. Bu kriterlere göre değişkenlerin normal dağılım gösterdiği tespit edilmiştir. Bilgilerin analizinde parametrik tekniklerden yararlanılmıştır. Katılımcıların ölçek seviyelerini oluşturan boyutlar arasındaki bağlantılar, Pearson korelasyon analizi ve yapısal eşitlik modellemesiyle değerlendirilmiştir.

Bulgular

Yöneticilerin ayırt edici özelliklerine ilişkin bulgular aşağıda sunulmuştur.

Tablo 1

Yöneticilerin Belirleyici Özelliklere Göre Dağılımı

Gruplar	Frekans(n)	Yüzde (%)
Cinsiyet		
Kadın	82	42,9
Erkek	109	57,1
Eğitim Durumu		
Lisans	162	84,8
Lisans Üstü	29	15,2
Kıdem		
5 Yıl ve Altı	114	59,7
6-10 Yıl	42	22,0
11 Yıl +	35	18,3
	Ort	**Ss**
Yaş	33,790	5,586

Yöneticiler cinsiyete göre 82'si (%42,9) kadın, 109'u (%57,1) erkek; eğitim durumuna göre 162'si (%84,8) lisans, 29'u (%15,2) lisans üstü; kıdeme göre 114'ü (%59,7) 5 yıl ve altı, 42'si (%22,0) 6-10 yıl, 35'i (%18,3) 11 yıl + olarak dağılmaktadır. Yöneticilerin "yaş" ortalaması 33,790±5,586 (Min=27; Maks=55) olarak saptanmıştır.

Tablo 2

Akılcı ve Sezgisel Karar Verme Yeteneği, Duygusal Zekâ Puan Ortalamaları

	N	Ort	Ss	Min.	Maks.	Alpha
Duygusal Farkındalık	191	4,160	0,486	3,500	5,000	0,869
Kendi Duygularını Yönetme	191	3,661	0,755	1,500	5,000	0,847
Öz Motivasyon	191	3,865	0,422	3,120	4,880	0,873
Empati	191	3,818	0,453	3,000	4,830	0,852
Diğerlerinin Duygularını Yönetme	191	4,016	0,512	3,170	5,000	0,849
Akılcı Karar Verme	191	4,109	0,460	3,290	5,000	0,836
Sezgisel Karar Verme	191	3,575	0,374	2,670	4,330	0,826

Yöneticilerin "duygusal farkındalık" ortalaması yüksek 4,160±0,486 (Min=3.5; Maks=5), "kendi duygularını yönetme" ortalaması yüksek 3,661±0,755 (Min=1.5; Maks=5), "öz motivasyon" ortalaması yüksek 3,865±0,422 (Min=3.12; Maks=4.88), "empati" ortalaması yüksek 3,818±0,453 (Min=3; Maks=4.83), "diğerlerinin duygularını yönetme" ortalaması yüksek 4,016±0,512 (Min=3.17; Maks=5), "akılcı karar verme" ortalaması yüksek 4,109±0,460 (Min=3.29; Maks=5), "sezgisel karar verme" ortalaması yüksek 3,575±0,374 (Min=2.67; Maks=4.33) olarak saptanmıştır.

Tablo 3

Akılcı ve Sezgisel Karar Verme Yeteneği ve Duygusal Zekâ Puanları Arasında Korelasyon Analizi

		Akılcı Karar Verme	Sezgisel Karar Verme
Duygusal Farkındalık	r	0,228**	0,430**
	p	0,001	0,000
Kendi Duygularını Yönetme	r	0,370**	0,549**
	p	0,000	0,000
Öz Motivasyon	r	0,611**	0,460**
	p	0,000	0,000
Empati	r	0,663**	0,390**
	p	0,000	0,000
Diğerlerinin Duygularını Yönetme	r	0,606**	0,553**
	p	0,000	0,000

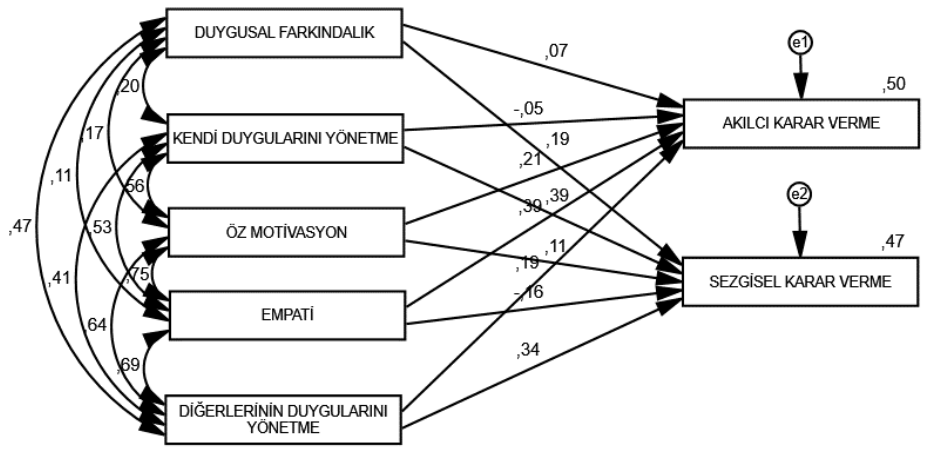
*<0,05; **<0,01; Pearson Korelasyon Analizi

Akılcı karar verme, sezgisel karar verme, duygusal farkındalık, kendi duygularını yönetme, öz motivasyon, empati, diğerlerinin duygularını yönetme, puanları arasında korelasyon analizleri incelendiğinde; duygusal farkındalık ile akılcı karar verme arasında r=0.228 pozitif çok zayıf (p=0,001<0.05), duygusal farkındalık ile sezgisel karar verme arasında r=0.43 pozitif zayıf (p=0,000<0.05), kendi duygularını yönetme ile akılcı karar verme arasında r=0.37 pozitif zayıf (p=0,000<0.05), kendi duygularını yönetme ile sezgisel karar verme arasında r=0.549 pozitif orta (p=0,000<0.05), öz motivasyon ile akılcı karar verme arasında r=0.611 pozitif orta (p=0,000<0.05), öz motivasyon ile sezgisel karar verme arasında r=0.46 pozitif zayıf (p=0,000<0.05), empati ile akılcı karar verme arasında r=0.663 pozitif orta (p=0,000<0.05), empati ile sezgisel karar verme arasında r=0.39 pozitif zayıf (p=0,000<0.05), diğerlerinin duygularını yönetme ile akılcı karar verme arasında r=0.606 pozitif orta (p=0,000<0.05), diğerlerinin duygularını yönetme ile sezgisel karar verme arasında r=0.553 pozitif orta (p=0,000<0.05) düzeyde korelasyon bulunmuştur. Öteki değişkenler arasındaki korelasyon bağlantıları istatistiksel olarak anlamlı bulunmamıştır (p>0.05).

Akılcı ve sezgisel karar verme yeteneği ile duygusal zekâ arasındaki ilişkilere yönelik teorik model yapısal eşitlik yol analizi ile test edilmiştir.

Figür 1

Yol Analizi



Yol analizine dair uyum düzeyine ilişkin kriterler aşağıda sunulmaktadır.

Tablo 4

Doğrulayıcı Faktör Analizi İndeks Değerleri

İndeks	Normal Değer*	Kabul Edilebilir Değer**	Değer
χ2/sd	<2	<5	2.91
GFI	>0.95	>0.90	0.98
AGFI	>0.95	>0.90	0.99
CFI	>0.95	>0.90	0.99
RMSEA	<0.05	<0.08	0.07
RMR	<0.05	<0.08	0.01

*, ** Kaynaklar: (Şimşek, 2007; Hooper and Mullen 2008; Schumacker and Lomax, 2010; Waltz, Strcikland and Lenz 2010; Wang and Wang, 2012; Sümer, 2000; Tabachnick ve Fidel, 2007).

Araştırma modeline ilişkin katsayılar aşağıda verilmektedir.

Tablo 5

Yol Analizi Regresyon Katsayıları

Hipotezler			β	Std. β	S.Hata	t	p	R^2
Akılcı karar verme	<---	Duygusal farkındalık	,067	,071	,059	1,136	,256	
Akılcı karar verme	<---	Öz motivasyon	,228	,209	,092	2,490	**,013**	
Akılcı karar verme	<---	Empati	,401	,395	,093	4,325	**p<0,001**	0,500
Akılcı karar verme	<---	Diğerlerinin duygularını yönetme	,168	,186	,078	2,138	**,033**	
Akılcı karar verme	<---	Kendi duygularını yönetme	-,030	-,049	,039	-,760	,447	
Sezgisel karar verme	<---	Kendi duygularını yönetme	,195	,392	,033	5,971	**p<0,001**	
Sezgisel karar verme	<---	Öz motivasyon	,098	,110	,076	1,282	,200	
Sezgisel karar verme	<---	Duygusal farkındalık	,145	,188	,049	2,928	**,003**	0,474
Sezgisel karar verme	<---	Empati	-,131	-,158	,077	−1,686	,092	
Sezgisel karar verme	<---	Diğerlerinin duygularını yönetme	,249	,341	,065	3,807	**p<0,001**	

Duygusal farkındalık ve kendi duygularını yönetmenin akılcı karar verme üzerine etkisi bulunmamaktadır (p>0,05). Öz motivasyon, empati ve diğerlerinin duygularını yönetme akılcı karar verme üzerine pozitif etki yapmaktadır (p<0,05). Akılcı karar verme üzerinde toplam değişimin %50'si duygusal zekâ tarafından açıklanmaktadır.

Öz motivasyon ve empatinin sezgisel karar verme üzerine etkisi bulunmamaktadır (p>0,05). Kendi duygularını kontrol etme, duygusal bilinç ve başkalarının duygularını yönetme, sezgisel karar verme üzerinde olumlu bir etkiye sahiptir (p<0,05). Sezgisel karar verme üzerinde toplam değişimin %47,4'ü duygusal zekâ tarafından açıklanmaktadır.

Sonuç

Akılcı ve sezgisel karar verme yeteneği ile duygusal zekâları arasındaki ilişkinin incelendiği araştırmaya Havacılık işletmelerinde görev yapan 191 yönetici gönüllü olarak katılmışlardır.

Araştırmada, yöneticilerin duygusal zekâ seviyeleri duygusal bilinç, kendi duygularını kontrol etme, öz motivasyon, empati ve başkalarının duygularını yönetme açılarından incelenmiştir. Tüm boyutlarda yöneticiler yüksek düzeyde duygusal zekâ düzeyinde oldukları belirlenmiştir. Yöneticilerin akılcı karar verme ve sezgisel karar verme düzeylerinin de yüksek düzeyde olduğu görülmüştür.

Araştırmada, yöneticilerin akılcı ve sezgisel karar verme becerileri ile duygusal zekâları arasındaki bağlantılar korelasyon analiziyle değerlendirilmiştir. Analiz sonuçlarına göre, tüm boyutlar arasında pozitif yönde anlamlı ilişkiler bulunmuş, en güçlü ilişkinin akılcı karar verme ile empati arasında, en zayıf ilişkinin ise akılcı karar verme ile duygusal farkındalık arasında olduğu tespit edilmiştir.

Araştırmada yöneticilerin duygusal zekâ düzeylerinin akılcı ve sezgisel karar verme düzeyleri üzerindeki etkisi yapısal eşitlik modeli kurularak incelenmiştir. Duygusal farkındalık ve kendi duygularını yönetme düzeyinin yöneticilerin akılcı karar verme düzeylerini etkilemediği, öz motivasyon, empati ve diğerlerinin duygularını yönetme düzeylerinin akılcı karar verme düzeylerini olumlu etkileyerek %50 oranında artırdığı belirlenmiştir.

Sezgisel karar verme üzerinde duygusal zekanın etkilerine bakıldığında ise; öz motivasyon ve empati boyutlarının yöneticilerin sezgisel karar verme düzeylerini etkilemediği, kendi duygularını kontrol etme, duygusal farkındalık ve başkalarının duygularını yönetme seviyelerinin, sezgisel karar verme seviyelerini olumlu yönde etkileyerek %47,4 oranında arttırdığı sonucuna ulaşılmıştır.

Sonuç olarak yöneticilerin duygusal zekâ düzeylerinin gerek sezgisel gerekse akılcı karar verme düzeyleri üzerindeki etkilerinin oldukça önemli olduğu görülmüştür. Bu araştırmanın bazı sınırlılıkları bulunmaktadır. Öncelikle havacılık sektöründe faaliyet gösteren 191 yöneticinin katılımı ile sınırlıdır. Ayrıca, araştırmada kullanılan veri toplama araçları ve analiz yöntemleri ile kısıtlıdır. İleride yapılacak araştırmalarda nicel ve nitel verilerin bir arada toplandığı karma araştırmalar yapılabilir. Böylelikle konuyla ilgili daha detaylı bilgilere ulaşılabilir.

Etik Kurul Onayı	Yapılan araştırma için İstanbul Topkapı Üniversitesi Bilimsel Araştırma ve Yayın Etiği Komisyonundan etik kurul onayı alınmıştır. (sayı: E-49846378-302.14.1-2400007962. Tarih:18.05.2024)
Bilgilendirilmiş Onam	Katılımcılardan bilgilendirilmiş onam alınmıştır.
Hakem Değerlendirmesi	Dış bağımsız.
Çıkar Çatışması	Yazar çıkar çatışması beyan etmemiştir.
Finansal Destek	Yazar finansal destek beyan etmemiştir.

Ethics Committee Approval	Ethics approval was obtained from the Scientific Research and Publication Ethics Committee at İstanbul Topkapı University (dated 18.05.2024, approval number E-49846378-302.14.1-2400007962.)
Informed Consent	Informed consent was obtained from the participants.
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Analysis of Factors Affecting The Service Demands Of Domestic Air Passengers

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Abstract With the increase in urbanization, air transportation has become the most preferred mode of intercity transportation. In addition to the speed and comfort provided by airplanes, economic factors have become important in terms of service demand, especially for domestic airline passengers. This study investigates the economic factors affecting the demand for domestic air passengers in Türkiye. For this purpose, the number of domestic airline passengers was used as the dependent variable, and inflation, exchange rate, and economic growth were used as independent variables. In the analysis of the study, the short- and long-term relationships between the 2007Q1:2023Q4 quarterly time series and the variables was examined by the ARDL (Autoregressive Distributed Lag) bounds test method. The Granger Causality Analysis researched the causality between the number of domestic air passengers and economic factors. When the results of this study were evaluated, it was determined that economic growth and inflation positively affected the service demand of domestic airline passengers. The findings revealed that inflation is more important in affecting the demand for services. In the short-term forecast, all variables affected the demand for services. Because of the Granger Causality analysis, causality was determined only from domestic air passengers to the exchange rate.

Keywords Air Transport · economic growth · exchange rate · inflation · passenger demand · ARDL · Granger Causality

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Analysis of Factors Affecting The Service Demands Of Domestic Air Passengers

In many parts of the world, people want to buy air freight services because it is the fastest way to get from one place to another. Air travel attracts a lot of attention from people today because it offers the opportunity to travel quickly and safely from one point to another. This interest can turn into buying tickets from airlines over time. However, passengers encounter economic and other factors specific to airlines when purchasing tickets. These emerging factors affect citizens living in Türkiye (domestic passengers) differently and citizens living abroad (international passengers) differently. Therefore, the importance of air transport for a country cannot be denied.

Air transportation is an significant means of transportation today because it facilitates the movement of transportation within a country and connects one region to another (Akinyemi, 2019). The airline transportation sector, which enables a person or an item to be quickly and reliably transported from one place to another, has become the most preferred transportation sector by people today. Due to the increasing global mobility in recent years, the air transport sector has developed significantly and accelerated transportation (Öcal, 2021). Both in the world and in Türkiye, air transportation has made rapid progress due to technological developments and continues to do so. Due to the increasing speed and mobility of transportation, the air-transportation sector has started to be preferred by people over other sectors. For this reason, it is important to know in advance the domestic and international travel demands, the service purchases of the passengers, and how they may change over time (Koç and Arslan, 2018). Because of the benefits provided by air transport, there is a continuous increase in the demand for aviation. Factors affecting airline selection, demand, and passengers' purchasing decisions are complex (Efendigil and Eminler, 2017). In this context, the study sought answers to the following questions. How does the exchange rate affect the demand for services by domestic passengers in the long and short term? How does economic growth affect domestic passengers' long- and short-term demand for services? How does inflation affect domestic passengers' long- and short-term demand for services?

Therefore, in this work, the external factors affecting the service demands of domestic passengers in air transport in Türkiyewill be examined with 2007Q1:2023Q4 quarterly data. The purpose of this work is to examine the extent of the link between the variables of the number of domestic passengers using an airline, exchange rate, economic growth, and inflation. Although various studies have been conducted on the factors affecting air transportation demands in the literature, it has been determined that domestic flights are not given much importance, and relatively less importance is given to the Turkish aviation sector. Therefore, this study on the Turkish aviation sector is anticipated to contribute to the literature. In contrast to the studies conducted, the effects on domestic passengers were examined more comprehensively. This study is important as it will contribute to filling the gap in the literature by examining the short- and long-term impacts of inflation, exchange rate, and economic growth on the demand for domestic airline passengers. In particular, this study attempts to determine the impact of the inflationary environment on the aviation sector. In this context, the authors have tried to contribute to the literature by presenting a more original study.

The second part of the work consists of the literature review, the third part consists of the methods and findings, and the last part consists of the results obtained in the analysis.

Literature Review

When the literature is examined, it is seen that the studies examining the economic factors affecting the service demand of domestic passengers are limited. Therefore, this study examines the complex relationship between domestic passenger demand and macroeconomic factors, such as inflation, exchange rate fluctuations, and economic growth. This study expands the existing knowledge in this field by shedding light on the effects of macroeconomic variables on the dynamics of the aviation sector. This approach aims to contribute significantly to the aviation economics literature by providing an innovative perspective. In this context, the reviewed literature is as follows;

In their study, Abed et al. (2001) aimed to conduct an econometric analysis of the factors influencing the demand for international air transport in Saudi Arabia using data between 1971 and 1992. The progressive regression method was used in this study. Because of this study, we determined that the primary determinants of international air travel in Saudi Arabia are population size and total expenditures. Marazzo et al. In their study, et al. (2010) examined the connection between GDP and airline passenger demand in Brazil based on the years 1966 to 2006. In the study, the Johansen cointegration test and Granger causality test were first used. Because of this work, it was revealed that GDP has a strong positive effect on the number of airline passengers, whereas airline passenger growth has a smaller effect on GDP. Chi (2014) examined the short- and long-term effects of the number of passengers, GDP, exchange rate, and 09/11 attacks on international travel demand to and from the US, taking into account quarterly data for the period 1996Q1-2012Q4. In the work in which the ARDL test and Granger causality test were performed, the number of passengers was used as the dependent variable. Because of the study, a strong link was observed between the demand for international air travel and economic growth. The results revealed that the real exchange rate has comparatively little impact on reciprocal air travel flows. Valdes (2015) used data from 2002 to 2008 to examine the factors affecting the air travel demands of middle-income countries. In this study, both static and dynamic panel data models covering 32 countries were used. The total number of passengers, GDP, foreign direct investment, inflation, the real exchange rate, and the jet fuel prices were used as variables in this work. The consequences of this study revealed that the increase in GDP and foreign direct investment has a positive impact on airline demand, and there is a negative relationship between inflation, jet fuel prices, and airline demand. Brida and Bukstein (2016) analyzed the correlation between economic growth and air transport in Italy using data from 1971 to 2012 as a contributor to the factors affecting passenger demand. Cointegration and Granger Causality analysis were used in the study, and as a consequence, a positive relationship was found between the series in the long term as a consequence of the Cointegration test. In addition, the results of the causality analysis revealed the existence of a one-way causality relationship between air transport and GDP. In this work, Suryan (2017) determined the factors affecting the number of airline passengers in Indonesia by using data from 1970 to 2017. In this study, time series regression was applied using GDP, population, and exchange rate variables, and the panel data regression technique was applied using GDP and population variables. Because of the study, it was determined that the exchange rate did not affect the number of passengers, but the population was little affected. It turns out that GDP is an important factor in the number of passengers. Albayrak et al. (2020) analyzed panel data using data between 2004 and 2014 to examine the demand for airline passengers in Türkiye in 47 provinces and 52 airports. Because of this work, it was found that GDP per capita had a statistically important and positive impact on airline passenger demand.

Table 1
Literature Summary

Writer	Country	Purpose	Data Set	Method	Result
Fernandes and Pacheco (2010)	Brazil	The study examined the causal relation between economic growth and air passenger	1996-2006	Granger Causality Analysis	A one-way causality relation was found between GDP and passenger demand.
Baikgaki and Daw (2013)	South Africa	Examining the factors that determine demand for domestic airlines	1971-2012	Multiple Regression Model	The increase in GDP, population, consumption, and oil prices positively impacted airline demand.
Brida et al. (2014)	Mexico	Examining the connection between air transport and GDP	1995-2013	Co-integration and Granger Causality test	In the long term, it has been determined that there is a nonlinear relationship between GDP and the number of air passengers. In addition, a two-way causality relationship was obtained from the Granger causality findings.
Hu et al. (2015)	29 provinces in China	Examining the relationship between domestic passenger demand and growth.	2006Q1-2012Q3	Granger Causality Test	A bidirectional causal relationship was found between economic growth and air travel demand.
Sofany (2016)	Ethiopia	To analyze the connection between inflation, domestic passenger demand and the number of domestic passengers, GDP and population,.	2000-2014	ARDL: Abdominal magnetic resonance imaging	Because of the analysis, a positive relationship was found between airline demand and the variables.
Kiracı (2017)	Türkiye	Investigating the relationship between economic growth and airline demands	1960-2015	Toda-Yamamoto causality and Hatami-J asymmetric causality analysis	It has been revealed a important causal relation between airline demand and economic growth.
Eren, Eryer, and Eryer (2020)	Türkiye	Examining the relationship between passenger demand and GDP	1980-2018	Johansen Co-integration and Granger Causality Test	Although there is a long-term positive relation between GDP and demand for the number of airline passengers, a one-way causality relation between GDP and demand for the number of airline passengers.
Ali et al. (2023)	BRIC Countries	To examine the relation between air passenger and economic growth	1993-2019	Panel Data Analysis	Because of the analysis, a one-way relationship was found between air transportation and economic growth, and a one-way relationship was found between air passengers and air transportation.
Eryer (2024)	Five fragile countries	To examine the relationship between economic growth and air passenger transport	2005-2021	time series, cross-sectional, and panel data analyses	In the said period, it was concluded that the number of airline passengers in the Fragile Five countries impacted the increasing economic growth.
Uçar, Ülger, and Atamer (2024)	BRICS-T Countries	Examining the possible effects of air transport on economic growth	1993-2021	Least Squares Method	This shows that the amount of cargo transported by air in BRICS-T countries has a positive impact on economic growth, whereas the number of passengers transported by air has a negative effect.

Methods and Data

In this study, exogenous factors affecting the service demands of domestic passengers in Türkiye were examined for the period 2007-2023. This analysis analyzes the relationship between economic growth, the exchange rate, and inflation of domestic passengers using the airline inTürkiye. The Eviews program was used in the study and the ARDL (Autoregressive Distributed Lag Bound Test) method was selected from the econometric methods. In this context, long-term and short-term coefficient estimations, F bounds tests, autocorrelation LM tests, variable variance tests, and CUSUM and CUSUM Q tests were performed on the variables. In addition, whether there was a connection between the variables was assessed using the Granger Causality test.

ARDL (Autoregressive Distributed Lag Bound Test) is a test used to reveal the existence of cointegration between variables and reveals that there is a stationary combination of at least two series that are observed to be non-stationary at their level. In short, it allows us to analyze short- and long-term causal relationships. The advantage of this model over other models is that a series whose co-integration relationship is investigated does not need to be quite static. In other words, the ARDL bounds testing approach allows the creation of the desired model and the realization of stable levels at I(0) and I(1) (Işık, 2015). ARDL is more productive than other cointegration tests and provides better performance for smaller sample sizes (Akinyemi, 2019).

The equation used in this study is the one in which the effect on the number of domestic passengers is examined. Inflation, economic growth, and exchange rate variables, which are determined as independent variables on the number of domestic passengers as dependent variables, are examined, and the relationship between them is revealed. The equation created for the analysis is as follows;

$$\begin{aligned}\Delta passenger = \alpha_0 + \beta_0 + \sum_{i=1}^{m} \beta_{1i} \Delta passenger_{t-1} + \sum_{i=1}^{m} \beta_{2i} \Delta \ln inflation_{t-1} \\ + \sum_{i=0}^{m} \beta_{3i} \Delta \ln foreignexchange_{t-1} + \sum_{i=1}^{m} \beta_{4i} \Delta growth_{t=1} + \mu_t\end{aligned} \tag{1}$$

The quarterly data for the period 2007-2023 were used in the work. The reason this study started in 2007 is that the effects of the economic crisis experienced during that period were not intended to be reflected in the data. The sample group of the study comprises the number of passengers received from the State Airports Authority (DHMI), the economic growth and inflation rates acquired from the Turkish Statistical Institute (TurkStat), and the exchange rate from the Central Bank of the Republic of Türkiye (CBRT). The data received were used in an inflation-adjusted manner.

Table 2

Data Definition and Sources

Variable	*Definition*	*Source*
Passenger	Number of Domestic Passengers	DHMI Statistics
Inflation	Inflation	Turkish Statistical Institute
Foreign currency	Dollar-Based Exchange Rate	CBRT
Growth	Economic Growth	Turkish Statistical Institute

According to the table above, from the variables; The passenger variable refers to the number of domestic passengers, the inflation variable refers to the inflation rate, the foreign exchange variable refers to the exchange rate, and finally, the Growth variable refers to the economic growth rates. The data were taken from the databases of the State Airports Authority, Turkish Statistical Institute, and Central Bank of the Republic of Türkiye.

When the literature is examined, Marazzo (2010), Fernandes and Pacheco (2010), Kiracı (2017), and Eren et al. (2020) examined the impact of the economic growth variable on passenger demand, Chi (2014) and Suryan (2017) examined the impact of the exchange rate variable on passenger demand, and Valdes (2015) examined the impact of the inflation variable on passenger demand.

Analysis and Data

In this section, the combinations of ADF (Augmented Dickey-Fuller) unit root test consequences applied to variables as trending, non-trending, and constant are given. The ADF unit root test is used serially to determine what difference the time series is stationary after if it is not stationary at the level value, eliminating spurious regression. As a consequence of the fact that some variables in the model were not stationary, the first differences of the non-stationary data were taken, and the result of the ADF unit root test performed at the first difference level was given. Then, the F boundary test, Autocorrelation LM test, Variable variance test, Ramsey Reset test, CUSUM, and CUSUM Q test tests were performed on the variables. The results are given below.

In the first stage of the unit root test, the ADF unit root test was applied to the variables in the model. The consequences are presented in Table 3. The ADF unit root test was performed using three alternative models: trending, non-trending, and constant. At this stage, the difference between the variables is not considered.

Table 3

ADF Unit Root Test Results

Variable	*Intersection point*	*Trend and intersection points*	*Nobody*
Passenger	-3.941644*	-3.979853**	-0.681168
Inflation	-0.393041	-1966260	-0.886984
Foreign currency	3218661	-0.147791	6008238
Growth	-3.923943*	-3.911714**	-2.741497*

Note: *, **, and *** indicate importance at 1%, 5%, and 10%, respectively.

It is necessary to ensure that the series is stationary because of the appearance of a spurious regression problem in non-stationary series. At this stage, it was determined that passenger and economic growth variables are stationary at the 1% importance level, whereas inflation and exchange variables are not stationary. For this reason, the stationarity of the variables was tested by considering the first-degree difference. The test results are given in Table 4.

Table 4

Variable	*Intersection point*	*Trend and intersection points*	*Nobody*
Passenger	-36.48765*	-36.16351*	-36.79617*
Inflation	-6.954679*	-7.046716*	-6.886338*
Foreign currency	-6.484408*	-7.336469*	-5.132810*
Growth	-9.909559*	-9.832011*	-9.987957*

Note: *, **, and *** indicate importance at 1%, 5%, and 10%, respectively.

From the data used in this study, the variables of number of passengers and economic growth remain constant at this level, while inflation and foreign exchange variables remain constant at the 1st difference. This shows that the ARDL model can be applied to examine cointegration relationships (Akkaya, 2018). After Unit Root Tests, the ARDL model was established by selecting the Automatic Selection option. The Akaike criterion was selected for the model, the lag length was determined as 4, and the most appropriate lag length was ARDL (4,2,0,4).

The autocorrelation LM test results are presented in Table 5. Considering the results obtained, it can be seen that there is no autocorrelation problem in the forecasted model.

Table 5

Autocorrelation LM Test

F Statistics	*9.350*	*Probability*	*0.8795*

Table 6 shows the results of the Variable Variance Test. Considering the results obtained, it is seen that there is no variance problem in the estimated model.

Table 6

Breusch-Pagan Godfrey Variable Test of Variance

F Statistics	*1.291*	*Probability*	*0.2475*

Table 7 shows the Ramsey Reset Test results. In light of the results obtained, no errors were observed in the model setup.

Table 7

Ramsey Reset Test

	Value	*Df*	*Probability*
T-statistic	*0.213*	*47*	*0.8320*
F-statistic	*0.054*	*–1,47*	*0.8320*
Probability Ratio	*0.060*	*1*	*0.8050*

The probability values in Table 7 revealed that the probability values of the T and F tests were statistically important at the 10% level. These results support the decision that the exponential variables in the model have no effect on the dependent variable and that it is appropriate to construct the model in linear form.

Table 8 presents the diagnostic statistics of the model, and the R-squared statistical value is 0.93. The fact that the model has this value proves that the linear span power is quite high. The probe (F-statistic) value is less than 0.05. Therefore, the model as a whole turns out to be meaningful. The Durbin-Watson probability value was calculated as 1.92, which is close to 2. This shows that the model does not have an autocorrelation problem.

Table 8

Diagnostic Statistics of the Model

R-squared	*0,931*	*Corrected R-squared*	*0.896*
Sum of Error Squares	*3307*	*Schwarz Criterion*	*1.337*
F-statistic	*26639*	*Hannan-Quinn Criterion*	*0.883*
Probability (F-statistic)	*0.000*	*Durbin-Watson Statistic*	*1.926*

The “k” in Table 9 refers to the number of independent variables. When we look at the F statistical value, which is 9.350, it is seen that it is above both the lower limit and the upper limit at the 1%, 5%, and 10% significance levels. These results support the entity of a co-integration association and reveal the entity of a long-term relationship in the predicted model.

Table 9

F Boundary Test Results

F-statistic	*k*	*Meaningful*	*I(0)*	*I(1)*
9350	*4*	*%1*	*2.57*	*3.68*
		%5	*3.06*	*4.27*

F-statistic	k	Meaningful	I(0)	I(1)
		%10	4.18	5.56

Because the model has a co-integration relationship, short- and long-term relationships can be predicted.

In this section, the long-term forecast results of the ARDL model are given in Table 10. Variable passengers (number of domestic passengers) are the dependent variables, while inflation, foreign exchange, and growth are the independent variables.

Table 10

Long-Term Relationshi Prediction Results

Variable	Coefficient	Std. Error	T-Statistic	Probability
Inflation	0.106	0.060	7.768	0.083***
Foreign currency	−0.063	0.048	−1.131	0.195
Growth	0.011	0.004	2.360	0.020**

Note: *, **, and *** indicate importance at 1%, 5%, and 10%, respectively.

According to the long-term forecasts presented in Table 10, economic growth is statistically significant, with a positive and critical value of 5%. In other words, an economic growth of 1% increases 0.01% in domestic passenger demand. On the other hand, it was noticed that the inflation variable was significant at a critical value of 10%. Based on this information, an inflation increase of 1% can be said to increase domestic passenger demand by 0.10%. There is no important relationship between currency variables. In other words, the currency variable has no impact on passenger demand in the long term. The exchange rate increase does not affect passenger demand in the long term. In this regard, passenger demand does not react to the exchange rate variable in the long term. In other words, the floating exchange rate does not have any impact on passenger demand.

After the long-term coefficient estimation, the short-term coefficient estimation was performed by adding the error term to the model. The results are given in Table 11.

Table 11

Short-Term Relationship Prediction Results

Variable	Coefficient	Std. Error	T-Statistic	Probability
Inflation	−0.460	0.153	−2.993	0.004*
Foreign currency	1.479	0.585	2.529	0.014**
Growth	−0.022	0.008	−2.672	0.010**
CointEq(-1)	−2.564	0.360	−7.116	0.000
C	0.682	0.101	6.716	0.000

Note: *, **, and *** indicate importance at 1%, 5%, and 10%, respectively.

According to the error correction regression model, ContEq(-1) is negative and significant at 2.564. In the short term, a important relationship was found between domestic passenger demand, which is the dependent variable, and inflation, foreign exchange, and economic growth, which are the independent variables. A 1% increase in inflation will reduce passenger demand by 0.46%, whereas a 1% increase in the currency variable will increase passenger demand by 1.47%. At the same time, it turns out that a 1% increase in economic growth will reduce passenger demand by 0.02%. Contrary to expectations, the exchange rate increase did not adversely affect passenger demand but followed a positive course. In this context, it was evident that the passengers were not very sensitive to the increase in foreign currency. Although inflation

negatively affects passenger demand in the short term, it has been shown that the purchasing power of passengers increases as revenues increase, with its positive effect in the long term.

CUSUM and Q tests were performed to examine the continuity of the variable coefficients used in the model.

Figure 1

CUSUM Test

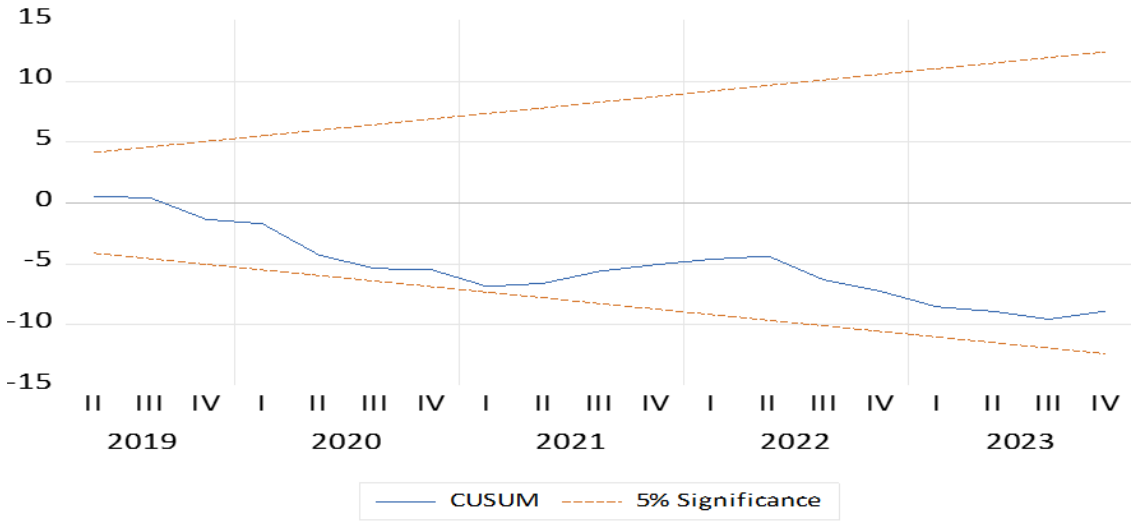

Figure 1 The ratio of error term totals to standard deviation remains below the critical value limit of 5% during the CUSUM test estimation period. This notation reveals that the coefficients are stable.

The structural fracture occurred in the CUSUM Q test. The pandemic crisis between 2019 and 2021 greatly affected the aviation industry. Because of these restrictions, the number of passengers using the airline has sharply decreased. Therefore, there was a break in the analysis due to the data for that period. To eliminate the existence of structural breakage, a dummy variable was added to the model for the 2019:Q1-2021:Q1 periods, which cover the pandemic period. After adding the dummy variable, the CUSUM Q test was performed again, and the results are presented in Figure 2.

Figure 2

CUSUM Q Test

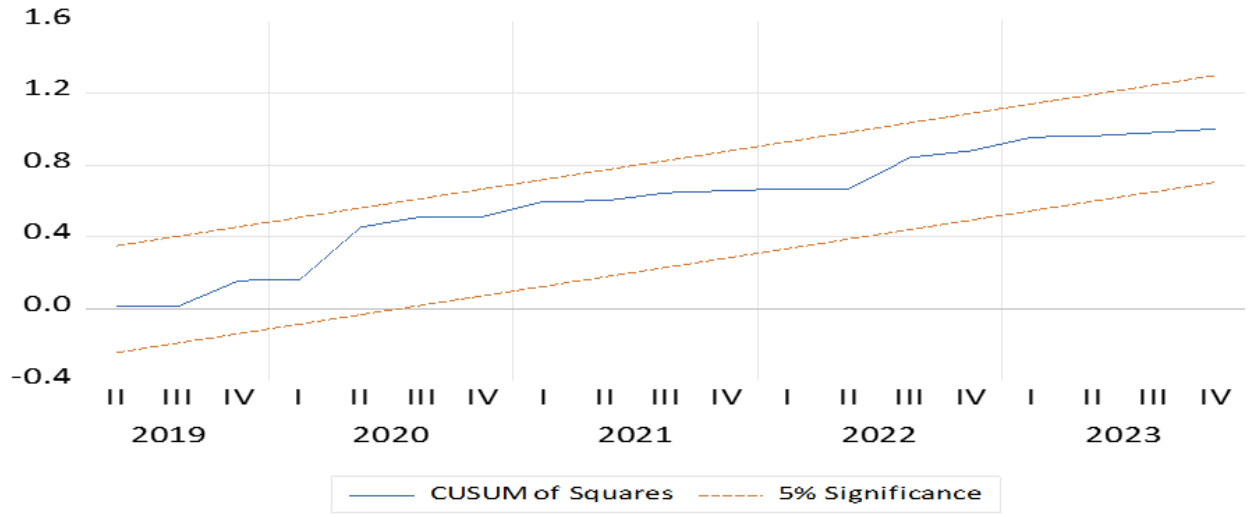

Figure 2 shows that the variance of the total squares of the error terms in the estimation period of the CUSUM Q test with the dummy variable is within the critical value limits of 5%. This notation reveals that the coefficients are stable.

Because of the tests, the existence of a co-integration correlation between the variables was determined, and therefore the Granger causality test was applied. The results of the Granger Causality test are presented in Table 12.

Table 12

Granger Causality Test Results

	F Statistics Probability	*Probability*
Enf-Passenger	*0.716*	*0.638*
Passenger-Enf	*0.827*	*0.554*
Dvz-Passenger	*0.416*	*0.864*
Passenger-Dvz	*3.916*	*0.002**
Growth-Passenger	*1.593*	*0.169*
Passenger Growth	*0.878*	*0.518*

Note: *, **, and *** indicate importance at 1%, 5%, and 10%, respectively.

According to Table 4.10, the relationship between inflation and domestic passenger demand is not due to Granger. Likewise, the cause of inflation is not domestic passenger demand. In this context, there is no bidirectional causality between inflation and domestic passenger demand. Although the relationship between foreign currency and domestic passenger demand shows that there is no Granger reason, the relationship between foreign currency and domestic passenger demand reveals that this is the Granger reason. In other words, a one-sided causal relationship between the exchange rate and domestic passenger demand. The increasing number of passengers increases the company's sales revenues, and it is thought that this situation is reflected in the company as foreign currency.

Conclusions and Discussions

In this study, using the 2007Q1:2023Q4 quarter data, the exogenous factors affecting passenger purchasing demands in air passenger transportation in Türkiye were examined. This study investigates the scope of the relationship between the number of domestic passengers using the airline, exchange rate, economic growth, and inflation variables. The effects of the determined external factors on the number of passengers were examined using the ARDL model. Granger causality tests were then performed to observe causality between variables. The analysis started with the ADF unit root test to determine the stationarity levels of the variables, and after the stationarity of the variables was tested, the F boundary test, Autocorrelation LM test, Variable variance test, Ramsey Reset test, and CUSUM and CUSUM Q test tests were performed. After the variables passed the tests, the long-term and short-term coefficients between the variables were examined. Finally, the causality relationship between each other was investigated using Granger causality analysis.

When the result of the analysis was examined, the entity of a long-term relationship in the model was accepted. Accordingly, the findings indicate that economic growth is statistically significant at a positive and critical value of 5%. In other words, a 1% rise in economic growth results in a 0.01% rise in domestic passenger demand. On the other hand, the inflation variable was significant at a critical value of 10%. In this way, an inflation increase of 1% can be said to increase domestic passenger demand by 0.10%. There is no important relationship between currency variables. In other words, the currency variable has no impact on passenger demand in the long run. In the short run, a important relationship was found between the dependent variable and the independent variables, inflation, foreign exchange, and economic growth. A 1%

increase in inflation will reduce passenger demand by 0.46%, whereas a 1% rise in the currency variable will rise passenger demand by 1.47%. At the same time, it turns out that a 1% increase in economic growth will reduce passenger demand by 0.02%. Because of the Granger Causality analysis, inflation and domestic passenger demand are not Granger causes of each other. It turns out that the reason for Granger is the relationship between foreign Exchange and domestic passenger demand.. When we look at the economic growth variable, there is no causality relationship between economic growth and domestic passenger demand.

The findings show that inflation, which is one of the factors affecting the purchasing demands of airline passengers, has a positive impact on domestic passenger demand in the long term and a negative impact on it in the short term. It has been shown that this situation reduces the purchasing power of passengers in the short term, and in the long term, it decreases as revenues increase. At the same time, economic growth and exchange rates affect domestic passenger demand. As a consequence of the analysis, it has been determined that inflation affects domestic passenger demand more than economic growth in both the long and short term, while foreign exchange affects it more than the other two variables only in the short term. However, this effect did not reduce passenger demand. This revealed that the passenger was not very sensitive to foreign currency.

As a consequence of the literature review, inflation, economic growth, and the exchange rate, which are among the independent variables considered in terms of whether they affect passenger demand, were also examined in different studies. In this context, Hu et al. (2015) observed a long-run relationship between passenger demand and economic growth, while Chi (2014) observed a strong link between economic growth and demand for international air travel, but found that the exchange rate had relatively little effect on the demand for air travel. In his study, Öcal (2021) found that the exchange rate and economic growth have a positive impact on air transport. Valdes (2015), however, revealed the existence of a negative link between inflation, which he used as an independent variable, and passenger demand. In addition to these studies, the findings of this study are relatively similar. In this study, the effects of inflation, exchange rate, and economic growth affect the long- and short-term purchasing demands of domestic passengers. This result is also supported by other studies.

Based on this article, which examines the external factors affecting the purchasing demands of airline passengers in Türkiye, a study on internal factors can be conducted in other articles on this subject. In addition, a different perspective can be provided by changing the variables and analysis method on the same subject, and a contribution can be made to the Turkish aviation industry in line with the analysis. In addition, the study used data from all years, but no seasonal distinction was made. In this context, researchers may be advised to analyze changes in domestic or external demand in summer and winter by making seasonal adjustments.

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Strategic Assessment of eVTOLs for Sustainable Urban Air Mobility Using the CRITIC-Based EDAS Method

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Abstract The selection of electric vertical takeoff and landing (eVTOL) aircraft is a strategic decision that directly shape the economic sustainability of urban air mobility (UAM) systems due to high investment costs and its impact on operational efficiency. In, this study aims to provide an objective framework for evaluating and selecting suitable eVTOL aircraft, which is an important step in establishing sustainable urban air mobility. In the study, the CRITIC-based EDAS method was used in an integrated manner to determine the importance of the evaluation criteria of eVTOL aircraft and to rank the models. The criteria of pax number, range, speed, alt meter, empty weight, payload, and maximum take-off weight identified from the literature have provided a unique perspective for evaluating eVTOLs regarding sustainability and efficiency. The results revealed that there were significant differences in the performances of the eVTOL aircraft in the context of the determined criteria. This demonstrates the critical importance of strategic decision-making frameworks in sustainable urban air mobility planning. It is expected that this research will provide strategic guidance for manufacturers and urban planners by developing a systematic approach to eVTOL evaluation.

Keywords Urban Air Mobility · Strategic Decisions · eVTOL · CRITIC · EDAS

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Strategic Assessment of eVTOLs for Sustainable Urban Air Mobility Using the CRITIC-Based EDAS Method

The global population is becoming increasingly concentrated in urban areas. Currently, approximately 57% of the world's population lives in urban areas, and this proportion is increasing daily (World Bank, 2025). It is anticipated that this trend will rise to 66% by 2050 (United Nations, 2014). However, there will be a substantial increase in the number of individual journeys. At present, approximately 64% of all journeys are made in urban areas. It is projected that urban travel will triple by 2050 (Swadesir & Bil, 2019). As urban populations grow, existing transport systems face traffic problems such as traffic congestion, pollution, accidents and infrastructure failure (Audenhove et al., 2014). These problems cause mobility disruptions, especially in developing economies. The goal of any city is to have a flexible transport system without frequent and severe disruptions (Mageto et al., 2024). Specifically, mounting challenges related to escalating traffic congestion, environmental concerns, and the imperative for efficient transportation systems have exerted substantial pressure on contemporary urban transport infrastructures.

Traditional roads and public transportation systems are no longer sufficient for urban mobility. Cities have been trying to overcome this problem for many years. Today, urban air mobility is seen as a practical and effective solution to combat urban traffic problems (Zhang et al., 2024). The first aircraft used in urban air mobility was the helicopter. However, these efforts have not reached the desired levels due to problems such as fatal accidents with helicopters, noise restrictions and financial difficulties (Vascik et al., 2018). Unlike conventional fixed-wing aircraft and helicopters, eVTOL aircraft have the ability to take off and land vertically with exceptional efficiency in confined spaces (Brown & Harris, 2020; Zhang et al., 2024). To solve the traffic problems of megacities, eVTOL aircraft are considered more suitable than helicopters in the UAM system.

eVTOL aircraft are suitable for operation in densely populated areas because they can take off and land in confined spaces like helicopters. Unlike airports, passengers can reach take-off and landing points faster thanks to vertiport positioned in various parts of cities (Ackerman et al., 2022; Bridgelall, 2023). These innovative aircraft outperform helicopters in areas such as operating costs, noise pollution, sustainability, and energy efficiency (Garrow et al., 2025; Swadesir & Bil, 2019; Vascik et al., 2018). With the ability to hover and maneuver in confined spaces and the potential for autonomous flight, these aircraft could serve as air taxis, emergency response units, and logistics platforms while reducing noise pollution and carbon emissions (Exactitude Consultancy, 2024).

The global eVTOL aircraft market reached USD 13.16 billion in 2023, and the market continues to develop rapidly. This rate is estimated to increase to approximately $38 billion by 2032, with a CAGR of roughly 12% (Zion Market Research, 2024). According to a different study, this market will reach approximately $24 billion by 2030 (Exactitude Consultancy, 2024). It will continue to develop in parallel with the countries' demands for sustainable transportation solutions. eVTOL aircraft generally run on electricity and promise a sustainable future by reducing dependence on land transportation (Grand View Research, 2024).

The eVTOL industry includes various designs and manufacturers such as Joby Aviation, Lilium, and Archer Aviation. These companies are bringing a new dimension to urban transport with eVTOLs (Ugwueze et al., 2023). With their low carbon emissions, quiet operation, and flexible use, these aircraft are expected to be one of the building blocks of future urban air mobility (Kiesewetter et al., 2023; Liu et al., 2024).However, selecting a sustainable eVTOL for urban air mobility is a complex decision problem. This situation arises from the diversity in the design, operational capabilities, and urban requirements of the eVTOL aircraft.

Since this study is based on a decision problem, the use of MCDM methods has been considered appropriate. MCDM methods, which are among the contemporary decision-making approaches, allow optimal choices among different alternatives according to a large number of criteria and are also used in evaluating and ranking these alternatives. The study used the CRITIC (Criteria Importance Through Intercriteria Correlation) method to evaluate the criteria and the EDAS method to determine the most suitable eVTOL aircraft. First, the weights of the criteria were determined by the CRITIC method. Then, the obtained weightings were used as the input of the EDAS method and the ranking of 10 eVTOL aircraft for UAM was made. In practice, the CRITIC method is preferred because the criterion weights can be found directly from the quantitative data without consulting any decision maker. EDAS is preferred because it uses two distance measures such as Positive Distance from Average (PDA) and Negative Distance from Average (NDA). Thus, by considering the average solution when selecting the best alternative, the eVTOL aircraft with the highest and lowest suitability levels in terms of UAM can be ranked by comparing them to the eVTOL with the average suitability level.

Many criteria impact the successful integration of eVTOL aircraft into urban air mobility systems. The study identified seven criteria for evaluating eVTOLs: Number of passengers, range, speed, altitude, empty weight, payload and MTOW. These criteria will facilitate a deeper understanding and more effective evaluation of the role of eVTOL aircraft in the UAM ecosystem. To determine the most suitable aircraft for UAM, eVTOL aircraft from the top ten original eVTOL aircraft manufacturers were identified.

The findings of this study provide valuable insights to various stakeholders such as policy makers seeking solutions to urban air mobility problems, manufacturers who are rapidly developing eVTOL prototypes, and urban planners. In addition, the absence of studies identifying eVTOL selection criteria in the literature highlights the originality of this research and its contribution.

This study contributes to the literature on air transport management and urban planning by offering an objective framework for evaluating and selecting suitable eVTOL aircraft, a crucial step in establishing a sustainable urban air mobility system. As eVTOL technology continues to evolve rapidly, the proposed framework provides both theoretical and methodological guidance for future research, supporting the development of sustainable mobility solutions. By addressing the key challenges in eVTOL adoption, this study aims to inspire further academic inquiry and practical advancements in the field.

The remaining sections of the article proceed as follows: A literature review on eVTOL selection is presented in Section 2. In the third section, the introduced methodology of the study is explained, while in the fourth section, it is applied and the results are discussed. The last section contains the results of the study.

Literature Background

A review of studies on eVTOL aircraft reveals that topics such as environmental impacts (Velaz-Acera et al., 2025), charging efficiency (Phung et al., 2024; Qasem et al., 2024), design studies (Kim et al., 2025; Zhou et al., 2025), potential cities for implementing (Spühler et al., 2025), determination of vertiport location (Jiang et al., 2025), evaluation of use in cargo transportation (Farazi & Zou, 2024), market segmentation (Garrow et al., 2025), enhancing human comfort (Bhalla et al., 2025), certification requirements (Cardoso et al., 2022), navigation systems (Wei et al., 2024) and air taxi (Boddupalli et al., 2024) are addressed. Given that eVTOL technology is a relatively new and rapidly developing field, it is observed that the majority of research focuses on fundamental design and engineering challenges. No studies on eVTOL aircraft selection have been found. It can be seen that most studies in the literature focus on conventional aircraft selection. When these studies are analyzed, it is clear that the methods and criteria used for conventional aircraft

selection can also be used effectively in the evaluation of eVTOL aircraft. Due to the nature of these studies, a methodological analysis shows that they are predominantly based on multi-criteria decision-making methods.

Methods used for aircraft selection in air transport include EDAS (Bağcı & Kartal, 2024), CRITIC (Kaur et al., 2023), Analytic Hierarchy Process (AHP) (Dožić & Kalić, 2014; Kiracı & Akan, 2020) , Fuzzy AHP (Akyurt & Kabadayı, 2020; Dožić et al., 2018),Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Kocakaya et al., 2021), Fuzzy TOPSIS (Güntut & Gökdalay, 2023), Even Swaps (Dožić & Kalić, 2015a), Hypothetical Equivalents and Inequivalents model (See et al., 2004), Fuzzy Set Theory (Yeh & Chang, 2009), ELECTRE (Sun et al., 2011), Fuzzy logic (Dožić & Kalić, 2015a), Linear Physical Programming (Ilgın, 2019), Interval Type-2 fuzzy sets (Kiracı & Akan, 2020), VIKOR (Ardil, 2020; Tanrıverdi et al., 2022), SWARA (Bağcı & Kartal, 2024) and COPRAS (Bağcı & Kartal, 2024).

As demonstrated in the extant literature, different selection criteria are used in the studies conducted on aircraft selection. Considering the traditional aircraft selection criteria, these can also be used to evaluate eVTOL aircraft. The prominent criteria include speed (Kiracı & Akan, 2020), range (Ardil, 2023; Dožić et al., 2018), seat capacity (Bağcı & Kartal, 2024; Ilgın, 2019), luggage capacity (Ardil, 2023; Dožić & Kalić, 2014, 2015b; Ilgın, 2019), cargo capacity (Bağcı & Kartal, 2024), maximum takeoff weight (Bağcı & Kartal, 2024; Dožić & Kalić, 2014) untechnical performance (Bruno et al., 2015). In this context, evaluating eVTOL aircraft using traditional selection criteria allows us to develop a comprehensive understanding of the next generation of air transportation and produce appropriate solutions for sustainable urban air mobility.

Methodology

CRITIC

In multi-criteria decision-making methods, there are many subjective and objective weighting methods for determining the importance of criteria (Alkan, 2024). As the weighting of criteria in subjective weighting methods is influenced by the subjective judgments of the analysts, there is some debate in the literature about the reliability of these studies (Sahoo & Goswami, 2023). There are objective evaluation methods as well as subjective approaches in determining the criterion weights. In this study, the CRITIC method, which is an objective evaluation method, was used to determine the importance level of the criteria. The CRITIC method is an objective weighting method that considers the interrelationship, direction, and intensity of input and output factors without making personal judgments (Çaloğlu Büyükselçuk & Tozan, 2022). The steps of the method are as follows;

Stage 1: Organizing the decision matrix;

At the beginning of the weighting stage, the decision makers form a decision matrix by combining ‘n’ criteria and ‘m’ alternatives. y_{ij} is the performance value of alternative i under criterion j.

$$Y = [y_{ij}] = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{1}$$

Stage 2: Normalization of the decision matrix;

In the second stage of the application, the criteria values to be included in the analysis are converted into a common unit by performing the normalization process using the formulas below.

$$r_{ij} = \frac{y_{ij} - y_j^{\min}}{y_j^{\max} - y_j^{\min}} \tag{2}$$

$y_j^{\min}$ = Minimum value of criterion j

$y_j^{\max}$ = Maximum value of criterion j

Stage 3: Organizing the correlation coefficient matrix;

To determine the direction and strength of the relationship between the criteria, the correlation coefficient of the relevant criteria is calculated using the following equation.

$$\rho_{jk} = \frac{\sum_{i=1}^{m}(r_{ij} - \overline{r}_j)(r_{ik} - \overline{r}_k)}{\sqrt{\sum_{i=1}^{m}(r_{ij} - \overline{r}_j)^2 \sum_{i=1}^{m}(r_{ik} - \overline{r}_k)^2}} \tag{3}$$

Stage 4: Calculation of the total amount of information;

At this stage, the value of (C_j), which represents the total amount of information contained in each criterion, is calculated using the formula below. The normalized decision matrix's standard deviation is used in the calculation process.

$$C_j = \sigma_j \sum_{k=1}^{n}(1 - \rho_{jk}) \tag{4}$$

In the above equation, it is assumed that the criteria with a low correlation coefficient and a high standard deviation value contain the most information, and therefore their importance level is quite high.

Stage 5: Calculation of criterion weights;

In the final stage of the analysis, the following equation calculates the weighting of the criteria included in the analysis according to their importance levels.

$$w_j = C_j / \sum_{k=1}^{n} C_k \tag{5}$$

EDAS

The EDAS (Evaluation Based on Distance from Average Solution) method was developed by Keshavarz Ghorabaee and colleagues in 2015. The authors compared the EDAS method with other multi-criteria decision making (MCDM) methods such as VIKOR, TOPSIS, SAW and COPRAS and tested the validity of the method (Keshavarz Ghorabaee et al., 2015). When the content of the method is examined, it is seen that the preference of the alternatives depends on two different indicators. These are positive distance to the average solution and negative distance to the average solution (Fan et al., 2019). In the evaluation phase, it is preferred that the positive distance is maximum and the negative distance is minimum for the optimal solution. The method is guiding in determining the best alternative (Yalçın & Karakaş, 2019).

The steps of the EDAS method are listed as follows (Keshavarz Ghorabaee et al., 2015, 2017; Keshavarz-Ghorabaee et al., 2018; Kiracı & Bakır, 2019)

Stage 1: Building the decision matrix;

In the first step, the decision matrix (X) showing the criteria and alternatives of the decision problem is formed. In the decision matrix shown in equation (6), yi represents the performance of alternative i according to criterion j.

$$Y = [Y_{ij}]_{nxm} = \begin{bmatrix} Y_{11} & Y_{12} & \dots & Y_{1m} \\ Y_{21} & Y_{22} & \dots & Y_{2m} \\ \dots & \dots & \dots & \dots \\ Y_{n1} & Y_{n2} & \dots & Y_{nm} \end{bmatrix} \tag{6}$$

Stage 2: Organization of the mean matrix;

The second stage of the method calculates the mean solution for all criteria using Equation (7).

$$AV_j = \frac{\sum_{i=1}^{n} Y_{ij}}{n} \tag{7}$$

Stage 3: Calculation of negative and positive distances from the mean

The positive distance from the Average (PDA) and Negative Distance from the Average (NDA) matrices are generated for each criterion. In calculating these values, the benefit and cost analyses of the relevant evaluation criteria are considered. If the requirements are maximization (benefit) oriented, equations (10) and (11) are used; if they are minimization (cost) oriented, equations (12) and (13) are used.

$$= \left[NDA_{ij}\right]_{nxm} \tag{8}$$

$$PDA = \left[PDA_{ij}\right]_{nxm} \tag{9}$$

$$NDA_{ij} = \frac{max\left(0, \left(AV_j - Y_{ij}\right)\right)}{AV_j}, j \in \text{benefit criterion} \tag{10}$$

$$PDA_{ij} = \frac{max\left(0, \left(Y_{ij} - AV_j\right)\right)}{AV_j}, j \in \text{benefit criterion} \tag{11}$$

$$NDA_{ij} = \frac{max\left(0, \left(Y_{ij} - AV_j\right)\right)}{AV_j}, j \in \text{cost criterion} \tag{12}$$

$$PDA_{ij} = \frac{max\left(0, \left(AV_j - Y_{ij}\right)\right)}{AV_j}, j \in \text{cost criterion} \tag{13}$$

In the above equations, the cost criterion represents the minimum desired criterion, while the benefit criterion represents the maximum desired criterion.

Stage 4: Calculation of the weighted totals for each criterion;

At this analysis stage, the weighted total negative distances (SNi) and the weighted total positive distances (SPi) are calculated using the following equations. In the calculation stage, the weight coefficients (Wj) expressing the importance levels of the relevant criteria are multiplied by the distance matrix (NDA).

$$SN_i = \sum_{j=1}^{m} W_j \times NDA_{ij} \tag{14}$$

$$SP_i = \sum_{j=1}^{m} W_j \times PDA_{ij} \tag{15}$$

The increase in the (SPi) value while the (SNi) value decreases shows that the alternatives have reached the desired level. In other words, the optimality of the options varies according to the increases and decreases in the (SNi) and (SPi) values.

Stage 5: Normalization of total weighted values for each criterion;

At this stage, the normalization process is applied to the weighted total negative distances (SNi) and the weighted total positive distances (SPi) through the equations below.

$$NSN_i = 1 - \frac{SN_i}{\max_i(SN_i)} \tag{16}$$

$$NSP_i = \frac{SP_i}{\max_i(SP_i)} \tag{17}$$

Stage 6: Calculation of the evaluation score for each alternative;

In the final stage of the analysis, the evaluation score (AS) for each alternative was calculated using the following equation, and the alternative with the highest score was determined as optimal.

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \tag{18}$$

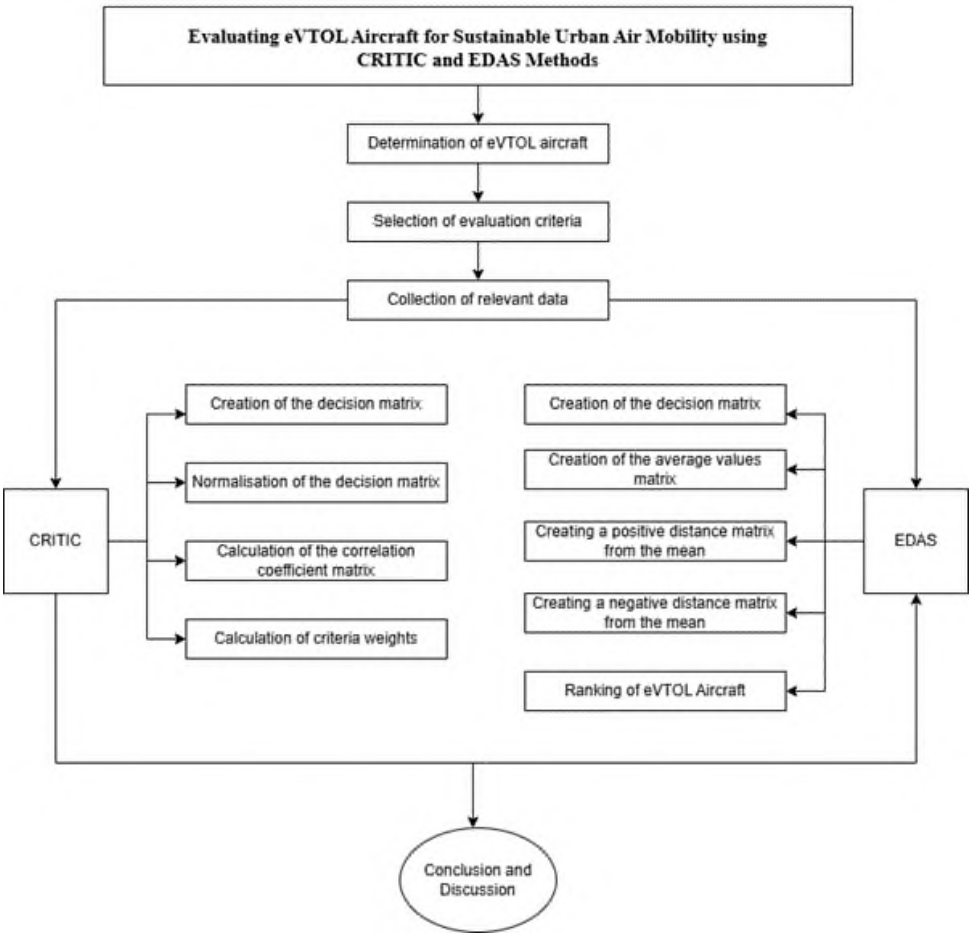
Application and Findings

In this study, eVTOL vehicles were ranked according to a defined set of criteria for sustainable urban air mobility. The Criterion Importance Through Intercriteria Correlation (CRITIC) method was used to determine the weights of the criteria used in the ranking. Using these weights, the EDAS method was applied, and 10 different eVTOLs were ranked for sustainable urban air mobility.

There is no study in the literature that uses the CRITIC-based EDAS method to compare eVTOLs in urban air mobility; therefore, this study is the first to contribute to the literature based on the relevant characteristics.

Figure 1

Research workflow



In this study, where the use of integrated MCDM methods is considered appropriate, the UAM applications offered by the top ten original eVTOL aircraft manufacturers were sampled as an alternative. Table 1 shows that eVTOL aircraft developed by the top ten eVTOL manufacturers are widely considered to have advanced powertrain technologies combined with contemporary design concepts. These include various eVTOLs designed with different philosophies such as bladeless multi-copters, hybrids, lift + cruise, tilt rotor, tilt rotor + wing configurations and thrust vectoring concepts (Imanov, 2024). Most of the proposed characteristics can

be considered when selecting UAM aircraft appropriate to the geographical characteristics of the country concerned.

Table 1

eVTOL models evaluated in the study.

	Manufacturer	eVTOL
1	Airbus	City Airbus
2	Archer	Midnight
3	Beta Tech	ALIA-250
4	EHang Intel. Tech	EHang216
5	Jaunt Air Mobility	Jaunt journey
6	Joby Aviation	S4
7	Lilium	Lilium jet
8	Vertical Airspace	VA-X4
9	Volocopter	VoloCity
10	Wisk aero	Cora Gen 5

In this study, 7 different criteria were identified to evaluate eVTOLs. These criteria were selected based on the relevance of eVTOLs to UAM, the effectiveness of these vehicles and those that are frequently used as selection parameters in the academic literature. This will facilitate a deeper understanding and more effective evaluation of the role of VTOLs within the UAM ecosystem.

Table 2

eVTOL aircraft evaluation criteria

Kod	Criteria	Reference	Objective
C1	Pax Number	(Rakas et al., 2021)	Max
C2	Range (km)	(M. Liu et al., 2024)	Max
C3	Speed (km/h)	(Hascaryo & Merret, 2020)	Max
C4	Alt Meter	(Mou et al., 2021; Wang, 2024)	Max
C5	Empty Weight (kg)	(Anderson et al., 2024)	Max
C6	Payload (kg)	(Xu et al., 2024)	Max
C7	MTOW (kg)	(Alves et al., 2022)	Max

In the study, the CRITIC method was primarily used to calculate the weights of the eVTOL evaluation criteria. The criteria and technical information regarding the eVTOL aircraft are given in the table below. Relevant data are compiled from open sources.

Table 3
Technical data for the eVTOL aircraft

	Pax Number	Range (km)	Speed (km/h)	Alt Meter	Empty Weight (kg)	Payload (kg)	MTOW (kg)
City Airbus	4,00	80,00	120,00	3.100,00	1.950,00	250,00	2.200,00
Midnight	5,00	80,00	240,00	610,00	1.050,00	450,00	1.500,00
ALIA-250	4,00	463,00	270,00	2.438,00	2.540,00	635,00	3.175,00
EHang216	2,00	35,00	130,00	3.000,00	360,00	260,00	620,00
Jaunt Journey	5,00	129,00	282,00	1.829,00	1.633,00	453,00	2.722,00
S4	5,00	290,00	322,00	3.350,00	1.950,00	453,00	2.404,00
Lilium jet	7,00	300,00	300,00	3.048,00	1.800,00	700,00	2.500,00
VA-X4	4,00	161,00	241,00	3.000,00	2.750,00	450,00	3.200,00
VoloCity	2,00	65,00	110,00	1.981,00	700,00	200,00	900,00
Cora	2,00	100,00	180,00	900,00	1.088,00	180,00	1.268,00

Kaynak: (Imanov, 2024; Vertical Flight Society, 2024)

Application of the CRITIC method

In the initial phase of the study, the CRITIC method, an objective weighting technique, was used to determine the weights of the criteria. In multi-criteria decision making (MCDM), there are several studies where the weights of the criteria are determined based on expert opinion (Chen, 2016a, 2016b; Tanrıverdi et al., 2022; Tsaur et al., 2002). However, such studies have found that the opinions, perspectives and biases of experts, as well as their practical or theoretical experience, are influential in decision-making processes. Moreover, subjective evaluation and weighting methods inherently reflect the value judgements of experts and the uncertainties associated with those judgements (Trinkūnienė et al., 2017). For this reason, the CRITIC method, which determines the criteria weights through objective measures, is deemed the most fitting approach for this study. In this part of the study, the weighting process required to solve the problem was carried out using the CRITIC method. This approach minimized the uncertainties and challenges associated with the subjective weighting methods.

The first stage of the CRITIC method begins with the construction of the decision matrix. As shown in Table 4, the decision matrix, constructed using Equation (1), consists of 10 eVTOL vehicles (alternatives) and 7 criteria (indicators). On the other hand, the analysis of the criteria shows that all of them focus on benefits, meaning they aim to reach their maximum levels.

Table 4
Decision matrix

	Max.	Max.	Max.	Max.	Max.	Max.	Max.
	C1	C2	C3	C4	C5	C6	C7
City Airbus	4,00	80,00	120,00	3.100,00	1.950,00	250,00	2.200,00
Midnight	5,00	80,00	240,00	610,00	1.050,00	450,00	1.500,00
ALIA-250	4,00	463,00	270,00	2.438,00	2.540,00	635,00	3.175,00
EHang216	2,00	35,00	130,00	3.000,00	360,00	260,00	620,00
Jaunt Journey	5,00	129,00	282,00	1.829,00	1.633,00	453,00	2.722,00
S4	5,00	290,00	322,00	3.350,00	1.950,00	453,00	2.404,00
Lilium jet	7,00	300,00	300,00	3.048,00	1.800,00	700,00	2.500,00
VA-X4	4,00	161,00	241,00	3.000,00	2.750,00	450,00	3.200,00

	Max.	Max.	Max.	Max.	Max.	Max.	Max.
	C1	C2	C3	C4	C5	C6	C7
VoloCity	2,00	65,00	110,00	1.981,00	700,00	200,00	900,00
Cora	2,00	100,00	180,00	900,00	1.088,00	180,00	1.268,00

In the second stage of the CRITIC method, the decision matrix undergoes a normalization process. This process is performed using Equation (2), where the maximum values for each criterion are identified, followed by applying the equation using alternative values. The resulting normalized decision matrix is presented in Table 5.

Table 5

Normalized decision matrix

	C1	C2	C3	C4	C5	C6	C7
City Airbus	0,40	0,11	0,05	0,91	0,67	0,13	0,61
Midnight	0,60	0,11	0,61	0,00	0,29	0,52	0,34
ALIA-250	0,40	1,00	0,75	0,67	0,91	0,88	0,99
EHang216	0,00	0,00	0,09	0,87	0,00	0,15	0,00
Jaunt Journey	0,60	0,22	0,81	0,44	0,53	0,53	0,81
S4	0,60	0,60	1,00	1,00	0,67	0,53	0,69
Lilium jet	1,00	0,62	0,90	0,89	0,60	1,00	0,73
VA-X4	0,40	0,29	0,62	0,87	1,00	0,52	1,00
VoloCity	0,00	0,07	0,00	0,50	0,14	0,04	0,11
Cora	0,00	0,15	0,33	0,11	0,30	0,00	0,25
σ_j	0,33	0,32	0,37	0,35	0,32	0,34	0,36

As shown in Table 5, not only was the normalization process performed, but the standard deviation values (σ_j) used in the calculation of the (c_j)values were also determined. Following the normalization process on the criteria, a correlation analysis was conducted to reveal the relationship and strength between the criteria. The results of the correlation analysis are shown in Table 6.

Table 6

Correlation Coefficients Between Criteria

	C1	C2	C3	C4	C5	C6	C7
C1	1,00	0,50	0,78	0,22	0,50	0,83	0,63
C2	0,50	1,00	0,70	0,33	0,68	0,80	0,70
C3	0,78	0,70	1,00	0,11	0,56	0,83	0,69
C4	0,22	0,33	0,11	1,00	0,41	0,25	0,36
C5	0,50	0,68	0,56	0,41	1,00	0,60	0,96
C6	0,83	0,80	0,83	0,25	0,60	1,00	0,72
C7	0,63	0,70	0,69	0,36	0,96	0,72	1,00

Following the calculation of the correlation coefficients between the criteria, the subsequent step was to calculate the information content and determine the weights of the criteria. In this process, the information content (c_j) of each criterion was calculated using Equation (4), with the standard deviation values from Table 5 being used to determine it. Finally, the value of each criterion (c_j) was divided by the sum of all criterion values (c_j) to calculate the criterion weights, as shown in Equation (5). The information content (c_j) and the criterion weights (w_j) for each criterion are presented in Table 7.

Table 7
Criterion Weights for the eVTOL Evaluation

	C1	C2	C3	C4	C5	C6	C7
c_j	0,83	0,74	0,86	1,53	0,74	0,68	0,69
w_j	0,136625	0,121378	0,142065	0,251755	0,122015	0,111544	0,114618

Application of the EDAS Method

This study constitutes an evaluation of the most suitable eVTOL for use in urban air mobility transportation. The CRITIC method was used to determine the criterion weights, followed by the EDAS method to rank the alternatives (eVTOLs). The initial step in the EDAS method involves the construction of the decision matrix using Equation (6). This matrix is derived by averaging the values in each column of the decision matrix, as illustrated in Table 8.

Table 8
Decision matrix

	Mak.	Min.	Mak.	Mak.	Mak.	Mak.	Mak.
	C1	C2	C3	C4	C5	C6	C7
City Airbus	4	80	120	3100	1950	250	2200
Midnight	5	80	240	610	1050	450	1500
ALIA-250	4	463	270	2438	2540	635	3175
EHang216	2	35	130	3000	360	260	620
Jaunt Journey	5	129	282	1829	1633	453	2722
S4	5	290	322	3350	1950	453	2404
Lilium jet	7	300	300	3.048	1.800	700	2.500
VA-X4	4	161	241	3.000	2.750	450	3.200
VoloCity	2	65	110	1.981	700	200	900
Cora	2	100	180	900	1.088	180	1. 268
AV_J	4	170	220	2326	1582	403	2049

As an example of the calculation of (AV_J) values presented in Table 8, the C1 criterion value for 10 eVTOL vehicles is calculated as follows:

$$AV_{C1} = \frac{4+5+4+2+5+5+7+4+2+2}{10} = 4$$

After the construction of the decision matrix, the positive and negative distances from the mean matrices are created. These matrices are generated using Equations (8) and (9), which consider the benefit and cost characteristics of the criteria. As is well known, in decision problems involving benefit-based criteria, the matrices are constructed based on the benefit characteristic using Equations (10-13). The positive and negative distance-from-average matrices are presented in Tables 9 and 10, respectively.

Table 9
Positive Distance from the Average Matrix

	C1	C2	C3	C4	C5	C6	C7
City Airbus	0,0000	0,0000	0,0000	0,3330	0,2325	0,0000	0,0737
Midnight	0,2500	0,0000	0,0934	0,0000	0,0000	0,1163	0,0000
ALIA-250	0,0000	1,7187	0,2301	0,0483	0,6055	0,5753	0,5496
EHang216	0,0000	0,0000	0,0000	0,2900	0,0000	0,0000	0,0000

	C1	C2	C3	C4	C5	C6	C7
Jaunt Journey	0,2500	0,0000	0,2847	0,0000	0,0322	0,1238	0,3285
S4	0,2500	0,7029	0,4670	0,4405	0,2325	0,1238	0,1733
Lilium jet	0,7500	0,7616	0,3667	0,3106	0,1377	0,7365	0,2202
VA-X4	0,0000	0,0000	0,0979	0,2900	0,7382	0,1163	0,5618
VoloCity	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Cora	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

As demonstrated in Table9, the creation of the (PDA_{ij}) matrix is achieved through the implementation of Equation (11), which is predicated on the benefit characteristics of the criteria. To illustrate this, consider the City Airbus scenario:

$$PDA_{CityAirbusC1} = \frac{max\big(0,\,(X_{ij} - AV_j)\big)}{AV_j} = \frac{max(0,\,(4-4))}{4} = \frac{max(0,\,-4)}{4} = 0{,}0000$$

Table 10

Negative Distance from the Average Matrix

Dönem	C1	C2	C3	C4	C5	C6	C7
City Airbus	0,000	0,530	0,453	0,000	0,000	0,380	0,000
Midnight	0,000	0,530	0,000	0,738	0,336	0,000	0,268
ALIA-250	0,000	0,000	0,000	0,000	0,000	0,000	0,000
EHang216	0,500	0,794	0,408	0,000	0,772	0,355	0,697
Jaunt Journey	0,000	0,243	0,000	0,214	0,000	0,000	0,000
S4	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Lilium jet	0,000	0,000	0,000	0,000	0,000	0,000	0,000
VA-X4	0,000	0,055	0,000	0,000	0,000	0,000	0,000
VoloCity	0,500	0,618	0,499	0,148	0,558	0,504	0,561
Cora	0,500	0,413	0,180	0,613	0,312	0,553	0,381

As demonstrated in Table 10, the generation of the (NDA_{ij}) matrix for the benefit criteria employs Equation (10). The negative distance from the average matrix is constructed following steps similar to those applied in the positive distance from the average matrix.

After creating the positive and negative distance-from-average matrices, the weighted total negative (SN_i) and positive (SP_i) distance values were calculated using Equations (14) and (15). Given the implementation of the CRITIC-EDAS integrated method in this study, the criterion weights obtained through the CRITIC method were utilized in the weighting process conducted via Equations (14-15). After the calculation of the total weighted distances, the normalization step was performed. The normalization was applied to the (SN_i) and (SP_i) values using Equations (16-17), resulting in the (NSN_i) and (NSP_i) values.

In the final stage of the EDAS method, the evaluation scores reflecting the performance of the alternatives are calculated using Equation (18). In this process, half of the sum of the (NSN_i) and (NSP_i) values is determined as the evaluation score (AS_i) for the relevant alternative. The alternative with the highest (AS_i) value is designated as optimal, according to the criterion. The calculation results of the stages of the EDAS method performed using Equations (14-18) and the rankings of the relevant alternatives are presented in Table 11.

Table 11
eVTOL ranking

	SP_i	SN_i	NSP_i	NSN_i	AS_i	**Sıralama**
City Airbus	0,12066	0,17112	0,26547	0,61270	0,439084	6
Midnight	0,06040	0,32182	0,13290	0,27162	0,202260	7
ALIA-250	0,45451	0,00000	1,00000	1,00000	1,000000	1
EHang216	0,07301	0,43645	0,16063	0,01218	0,086402	8
Jaunt Journey	0,13000	0,08319	0,28601	0,81171	0,548860	5
S4	0,35875	0,00000	0,78932	1,00000	0,894658	3
Lilium jet	0,44941	0,00000	0,98878	1,00000	0,994391	2
VA-X4	0,25436	0,00663	0,55965	0,98500	0,772322	4
VoloCity	0,00000	0,44004	0,00000	0,00406	0,002032	9
Cora	0,00000	0,44184	0,00000	0,00000	0,000000	10

Table 11 presents a quantitative comparison of 10 eVTOL aircraft for sustainable UAM. The most compatible eVTOL aircraft were determined to be ALLIA-250 and Lilium Jet. These two models achieved superior scores in all normalized parameters. The strong performance of these aircraft in critical criteria such as range, payload and maximum take-off weight demonstrates their adaptability to urban environments. These aircraft will be followed by the S4 and VA-X4 eVTOL models. The results obtained suggest that these models are also suitable for urban air mobility.

Conclusion

This study presents the evaluation of eVTOL models through the superior performance criteria of eVTOL aircraft over conventional aircraft for sustainable urban air mobility. In this context, the study provides valuable strategic insights into the evaluation of eVTOL aircraft. The research shows that there are performance differences between the eVTOL aircraft models. This confirms that the strategic decision-making processes play a critical role in a sustainable UAM system.

This study employed a combined CRITIC-EDAS methodology to objectively assess and rank eVTOL aircraft models. By leveraging the CRITIC method, we established the relative importance of evaluation criteria, minimizing subjective bias often inherent in decision-making processes. Subsequently, the EDAS technique facilitated the ranking of eVTOL models based on these weighted criteria. To ensure a robust and transparent evaluation, we focused on readily available, open-access data related to key performance indicators. These indicators, derived from existing literature, specifically included passenger capacity, range, speed, altitude capability, empty weight, payload, and maximum take-off weight. This selection aimed to provide a comprehensive assessment of eVTOLs, particularly concerning their sustainability and operational efficiency.

According to the results of the CRITIC method analysis, the three most important criteria are the alt meter, speed, and pax number. Other criteria received similar values. Studies have shown that the alt meter criterion is an important factor in terms of safety, operational performance and regulatory compliance for eVTOL aircraft (MOU et al., 2021; Wang, 2024). Altitude measurement systems enable the successful integration of eVTOLs into the airspace ecosystem (Sánchez et al., 2021). The speed criterion directly impacts the safety level, performance, energy efficiency, and compliance with the regulatory standards of eVTOL aircraft. In this respect, eVTOL aircraft that can balance speed and other factors will be a more suitable option for urban air mobility (Al-Rubaye et al., 2023; Xiang et al., 2024). Another criterion in which eVTOL aircraft differ is the pax number criterion. eVTOL aircraft with different passenger capacities are designed to meet different UAM needs. While smaller models are suitable for short-haul flights with low demand, larger models can be

effective on longer routes with high demand (Hader et al., 2020). According to the results of the analyses, the importance of the range, empty weight, payload and maximum take-off weight criteria evaluated in the research were close to each other.

The criterion importance weights determined by the CRITIC method were used as input to the EDAS method to compare and rank eVTOL aircraft. There are over 400 eVTOL aircraft in production for urban air mobility. This study tested the compatibility of selected aircraft from the top ten eVTOL manufacturers. These aircraft were analyzed using the EDAS method to measure their compatibility with sustainability. The findings show significant differences in the performance of the eVTOL models. According to the evaluations, the eVTOL aircraft named ALIA-250 is the most suitable aircraft and showed the highest performance according to all criteria. The closest model to this model is the Lilium Jet. It has demonstrated superior performance, particularly in terms of range, speed and number of passengers. In this context, both the ALLIA-250 and the Lilium Jet model can be considered as the most technically and operationally suitable eVTOL aircraft for urban air mobility. On the other hand, it is understood that other eVTOL models that received lower values according to the analysis results need to be improved in terms of design and operation. This situation indicates the need for continuous innovation and strategic differentiation of eVTOL aircraft for a sustainable UAM system.

The findings of this study provide valuable insights to various stakeholders such as policy makers seeking solutions to urban air mobility problems, manufacturers who are rapidly developing eVTOL prototypes, and urban planners. In addition, the fact that there is no study in the literature that identifies eVTOL selection criteria is extremely important in terms of bringing the originality of this study and selection criteria into the literature.

This study also has some limitations. In this study, the evaluation of eVTOL aircraft was only carried out according to specific criteria. eVTOL manufacturers are continuously making improvements to increase the efficiency of these aircraft. Depending on these developments, new criteria may be defined. Different criteria and methods may be preferred in future studies. This study presents an original methodology by applying the CRITIC-based EDAS method for eVTOL evaluation for the first time in the literature. The findings in this study can be compared using different MCDM methods. This study evaluated selected aircraft from the top ten eVTOL manufacturers. In different research, other aircraft can be evaluated using the model presented in this study.

As a result, it is expected that eVTOL aircraft will be widely used for a sustainable future. The key issue will produce and selecting suitable eVTOL aircraft for establishing a sustainable urban air mobility system. In this respect, the study contributes to the literature by providing an objective framework that can be used in the evaluation of these aircraft in today's rapidly developing eVTOL technology. It is expected to provide theoretical and methodological inspiration for future studies.

Finally, this study makes a valuable contribution to the literature on air transport management and urban planning by providing an objective framework for the selection of these aircraft during the rapid development of eVTOL technology. This framework will provide a theoretical and methodological basis for future studies.

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Word Cloud Analysis of Special Issues in Maritime Transportation Journals

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Abstract Due to the dynamic structure of maritime transportation, research in this field must proceed in parallel with current sectoral developments. In this sense, the regular issues of maritime transportation-themed academic journals undoubtedly contribute to sectoral development. However, unlike regular issues, journal special issues, which direct the research focus of the scientific community with thematic calls that reflect sectoral development, undertake a valuable function in order to produce rapid scientific solutions to the sectoral needs. Therefore, an examination of the articles brought together in special issues can be used to follow the emerging themes in the relevant field. To conduct word cloud analysis on special topics in maritime transportation-related journals, 353 articles in 73 special issues of 17 journals published between 2013-2023 were compiled. By interpreting the word clouds obtained from the titles and keywords of relevant publications, the themes that came to the fore were identified. Findings show that words related to environmental sustainability, China's Belt and Road Initiative, risk management and network design are the prominent themes. Besides demonstrating the trends in maritime transportation research, this article also proposes a method to conduct a word cloud-based preliminary analysis, aiding researchers in detecting current themes to direct their academic focus.

Keywords Maritime Transportation · Special Issues · Word Cloud

Author Note The study has been developed by expanding the paper titled "Emerging Areas in Maritime Transportation Research: Word Cloud Analysis on Journal Special Issues," which was presented at the 1st International Maritime and Logistics Congress.

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Word Cloud Analysis of Special Issues in Maritime Transportation Journals

As a result of being a dynamic industry, maritime transportation is constantly evolving under the influence of socio-cultural, economic, regulatory and technological changes (Cerit, 2000). The dynamic features of the industry drive its actors to remain in the competition through persistent research and development efforts, adaptation strategies and collaboration in the name of solving industry-wide problems. Besides its dynamic features, the industry is also viewed as a complex one, as it encompasses a vast number of actors consisting of shipping companies, agents, brokers, port operators, freight forwarders and other related stakeholders (Akpinar & Caylan, 2021). Furthermore, the industry has a global nature, which also adds to its dynamism and complexity (Almklov & Lamvik, 2018). As a result, reaching the common goals set by the industry becomes much more difficult and necessitates a coordinated effort among the stakeholders.

Due to both its dynamism and complexity, the academic research regarding maritime transport is bound to feed from different disciplines. Thus, studies from various disciplines, such as geography, economy, engineering, politics, operations research and law, play a crucial part in revealing the challenges and opportunities for the industry and guide industry leaders, policy makers and related stakeholders collaboratively. To perform accordingly, the academic research field of maritime transportation, including a substantial number of journals, acts as a medium to create the change for industrial development.

Research in the field of maritime transportation began to be published in academic journals under the theme of transportation in the middle of the 20th century. "Defense Transportation Journal" and "Transportation Journal", initially published in 1945 and 1961 (Farris, 1997), can be viewed as pioneering journals that involve scientific publications on maritime transport. In the following era, journals specifically defining maritime transport as their major field started to be published and the research in this field gained depth. First published in 1973, the journal titled "Maritime Studies and Management (currently known as Maritime Policy & Management) is valued greatly because it is one of the earliest and well-established journals, specifically focused on maritime transportation (Taylor & Francis Online, 2023).

Today, the research field in question is scientifically fueled from many branches, since both maritime transport-oriented journals and journals with broader scopes regularly include academic studies on maritime transport exist. In addition to the regular issues of these journals, the special issues they publish also represent scientific knowledge. Different from regular issues, special issues involve publications that are in harmony with the themes determined by the editors of the journal (or the guest editors) (Knöchelmann et al., 2022). The "call for papers" written by the editors in the publication of the relevant issues determine the framework of the theme in question as well as guide the researchers by justifying and demonstrating the lack of research about this theme in the relevant field. This guidance helps to solidify the bond between scientific research and application areas, in addition to directing a collective scientific effort toward questions that need answers. As this mechanism of scientific publication conforms with the dynamic nature of the maritime industry, there has been a substantial increase in the quantity of special issues, which allows researchers to better reflect and react to the recent rapid changes taking place within the industry.

By evaluating the articles published in special issues in an integrated manner, researchers can reach an understanding of the changes in trending topics within the time frame that is included in the analysis. In this context, the titles, texts (as a whole or partly) and keywords of the mentioned publications can be considered as input data, and the emerging concepts in these publications can be determined by different methods. Word cloud analysis is one of these methods that is based on visualization and has the advantage of its ease of application.

In this paper, the purpose is to conduct a word cloud analysis on special issues in maritime transportation-related journals, with an effort to reveal emerging areas within the literature and demonstrate how these publications establish the dynamic and evolving nature of the maritime industry. The analyzed data from 73 special issues, encompassing 353 articles published between 2013 and 2023 across 17 academic journals, was used. The titles and the keywords of these articles were used as input data and the separate word clouds were generated on each input type in detail.

The application of word cloud analysis on special issues of maritime transportation journals helps researchers to visually analyze the trending topics in the investigated period. Since it is one of the challenges for maritime researchers to stay up to date and direct their academic efforts to benefit the solution of current industrial challenges, such preliminary analysis can be used as a means to find the right research question. Moreover, said analysis can help researchers to become familiar with the themes discussed within the scope of emerging research agendas. Through these advantages, researchers can increase the chance of their upcoming scientific work being published. Therefore, the value of this paper lies not only in demonstrating emerging areas in maritime transportation research but also in proposing a method for researchers to conduct a word cloud-based preliminary analysis, aiding them in detecting current themes to direct their academic focus.

A detailed briefing about the method will be given and the findings will be interpreted accordingly in the following parts of the study.

Background Of The Study

Scientometrics is a field of study concerned with the quantitative analysis of the textual features and content characteristics of scientific literature as well as its communication (Mingers & Leydesdorff, 2015). It has been widely used by scholars with various aims such as identifying the emerging themes within a literature, revealing the collaboration networks of authors, and measuring authors', journals' and institutions' productivity (Brindha and Murugesapandian, 2016). Since the field focuses on the scientific literature from a production perspective, it helps clarify the research direction in any field under investigation and improves scientific quality. The indicators on the quality of scientific journals (e.g. rankings and impact factors) (Argento and van Halden, 2022) and the indicators on the performance of researchers (e.g. h and g indexes) (Linton et al. 2012) are becoming more important day by day, since the expectations of academic institutions from their researchers are shaped by performance criteria based on these concepts (Khoklov, 2020). Therefore, the researchers are looking for ways to publish their articles in the most highly ranked journals so that their citation scores would increase and meet their institutions' expectations.

The research field of maritime transportation is not different. Although there are many journals now that are specifically focused on the maritime industry, the ones with high journal rankings are quite limited. Moreover, the acceptance rates of the said journals are lower than the average. It is possible to make this inference when it is seen that the acceptance rate of the journal "Maritime Policy & Management" (as an exemplary journal in the research field) is 19%, and in Herbert (2020) calculation on 2300 journals covering different disciplines, the average acceptance rate is 32%. From this point of view, it would be a correct strategy for researchers to determine their research topics in line with the calls of the journal editors in order to publish in high-quality journals. Therefore, in addition to the special issue calls of these journals, the contents of the articles accepted in these issues are very useful in guiding researchers. This is because these special issues not only reveal current academic issues in the maritime sector but also reveal the journals' priorities, with justifications.

In summary, it is to the advantage of researchers in the relevant field to follow special issues in order to stay up-to-date and to be familiar with research topics that will increase the possibility of publication in target journals. While it is possible for researchers to stay up to date by carefully following (through subscription) the journals in question, it would also be beneficial to follow the journals more systematically with certain tools and thus identify the emerging areas in the relevant field. Considering the quantity of scientific publications being too large for scientists' capacity to easily comprehend (Larsen & von Irs, 2010), the use of such tools has become a necessity to track what is new and what needs more scientific attention.

Therefore, different methods have been proposed depending on variables such as the size of the data to be handled and the scope of the analysis. The number of publications using these tools to identify current themes in different scientific fields is increasing in parallel with the increase in need. Text mining tools, as they offer one of the ways to detect emerging themes, are gaining popularity with their capacity of handling large sample sizes (Thakur & Kumar, 2021). It is possible to see that the amount of text mining-based research is increasing in the maritime transportation literature as well. As an example, the study of Bai et al. (2021) examined 3199 academic studies in the field of maritime transportation using the latent Dirichlet allocation method. The authors found that "port management", "container operations" and "liner shipping" are the major areas of focus in the examined literature. Shin et al. (2018) also used the latent dirichlet allocation method, but the authors focused on academic articles addressing the sustainability aspect of maritime transportation. In this study conducted in a narrower area, 155 articles were discussed and the themes that emerged in the study were reported as "green port", "environmental regulations" and "carbon emissions". The study of An (2024) focused on the use of big data in maritime transportation and identified the prominent themes in this specific field. In this study, the authors determined the themes using keyword co-occurrence and clustering techniques.

Applying the methods mentioned above will help to obtain much more robust results in determining the themes of the relevant literature, but these methods require a certain level of mastery of text mining tools. Therefore, it may also be preferable to use word cloud analysis (in relatively smaller samples), which is a module within various qualitative research softwares such as MAXQDA, AtlasTi and NVivo. In particular, the fact that it does not require specialized technical skills or knowledge of computational methods as text mining tools would require, creates an advantage in choosing the method. In the remainder of this study, detailed information on the use of this analysis is presented as a recommendation to researchers in the relevant field.

Method

Word clouds provide a quick summary of the most frequently used terms in a text, presenting them visually for enhanced accessibility compared to a conventional table listing words and their frequencies (Kuckartz & Rädiker, 2019; 57). Thanks to these features, it has been considered as a useful analysis method to visualize trends in various fields of study. Abazi-Bexheti et al. (2020)'s analysis on computer science research, Kalmukov (2021)'s analysis on the papers of a particular conference and Alam et al. (2023)'s analysis on halal hotel literature in the Scopus database are examples adopting a similar approach since they are also in the pursuit of comprehending how word clouds can be used in revealing emerging trends.

The first step of the analysis was to determine the special issues published between 2013 and 2023, which have their complete focus on maritime transportation or involve articles within this field of study. For this purpose, the list of journals focusing on this research field was reached by searching the web of science master journal list with the keyword "maritime transportation".

Afterwards, the core collection selection was determined as SSCI and the search was narrowed. Later, the websites of the 37 listed journals were accessed and the special issues published within the specified period were examined. If the special issue had purely been based on maritime transport, all articles in that issue were gathered for analysis. As for the special issues concentrating on broader subjects, only the articles focusing on maritime transport were chosen. Throughout the data collection process, which was conducted with this approach, 73 special issues were identified in 17 academic journals. In total, 353 articles solely focusing on maritime transport were identified from these issues. Table 1 shows the distribution of articles in the selected journals.

The titles and keywords of these articles were compiled into two separate text files. To put it differently, a total of two separate text documents were included, one of which compiled all the titles and the other compiled all the keywords. The files were then uploaded to the MAXQDA 2020 software for word cloud analysis. Before the generation of word clouds, a list that consists of words that need to be omitted, such as pronouns, prepositions and conjunctions, was prepared and inserted as a “stop list”. In the final step, separate visuals of word clouds for each of the input data mentioned above were generated.

Word cloud analysis was carried out in two different ways. While both word clouds were examined integrated in the first analysis, a comparative analysis was carried out in 5-year periods in the second analysis. The first analysis helps visualize the themes that come to the fore in the 10-year period, whereas the second analysis provides the opportunity to determine whether there is any change in the 5-year periods. Therefore, the findings of both applications were compiled under relevant headings ("Overall Assessment of Article Titles and Keywords" for the first analysis and "Comparative Assessment of Article Titles and Keywords" for the second analysis).

Table 1

List of Journals and Number of Selected Articles

List of Journals	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Accident Analysis & Prevention	0	0	0	0	0	0	0	0	7	0	0
European Journal of Operations Research	0	10	0	0	0	0	0	0	0	0	0
International Journal of Logistics Research and Applications	0	0	6	0	0	0	0	3	0	0	0
International Journal of Shipping and Transport Logistics	17	18	10	15	12	11	12	6	0	3	0
Journal of Transport Geography	5	2	0	0	0	4	0	0	0	7	0
Mairitme Policy and Management	7	11	6	0	0	0	0	0	0	8	0
Marine Policy	0	0	0	0	0	0	0	0	0	2	0
Maritime Economics and Logistics	0	0	5	0	0	0	0	5	7	18	0
Physical Distribution&Logistics Management	0	0	0	0	0	0	0	0	1	0	0
Research in Transport Business and Management	0	0	0	0	0	0	0	0	0	13	6
Transport Policy	0	0	0	0	0	0	0	0	7	11	3
Transport Reviews	0	0	0	0	0	4	1	0	0	0	0
Transport Science	0	2	8	0	0	0	0	0	0	0	0
Transportation Research Part A.Policy and Practice	0	0	0	0	0	8	0	3	0	0	0
Transportation Research Part B Methodological	0	0	0	6	0	0	0	0	0	0	
Transportation Research Part D. Transport and Environment	0	8	0	1	0	0	0	0	18	0	9

List of Journals	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Transportation Research Part E. Logistics and Transportation	9	0	6	0	0	3	5	0	0	4	0
Total Number of Papers	38	51	41	22	12	30	18	17	40	66	18

Findings

Overall Assessment of the Article Titles and Keywords

Word cloud findings based on article titles can be seen in Figure 1. As can be clearly seen, the words "port", "shipping" and "container" were the most frequently used words in the titles of the articles, with frequencies above 50. Although it is not that surprising to see these words, considering the significance of these terms in maritime transport, the visual still helps us comprehend that a vast portion of the articles are focused mainly on ports and elements of container transportation (including container terminals) among other subfields of maritime transportation. Focusing on words that have between 15 and 30 repetitions and are visualized in the second order size, it is possible to identify the concepts that have been highlighted in maritime transportation in the last decade. For instance, the word "network", repeated 23 times, is mostly used in studies focusing on network designs for liner shipping companies, and this indicates an extensively studied theme. Equivalently, it can be observed that the words related to the sustainability of maritime transportation such as "carbon", "emission", "co2", "fuel", "environmental" are recurrently used in the titles. In line with this finding, it can be inferred that the environmental dimension of sustainability is studied more frequently than its social and economic dimensions. In conclusion, looking at the words that have 10-15 repetitions and are visualized in third order size, it is possible to see the words "belt", "road" and "Chinese". As can be inferred, these words are about the project that China calls the Belt and Road Initiative, which is closely interrelated to maritime transportation. Hence, it is possible to determine that the relevant project has been subject to an academic interest.

Figure 1

Word Cloud based on Article Titles

Findings related to the word cloud based on articles' keywords can be found in Figure 2. The words with more than 50 repetitions in the keyword-based analysis are also the words "port", "shipping" ands "container", which coincide with the analysis based on titles. Similarly, it is possible to see the words "network", "environmental", "carbon" and "emission" among the words with 15-30 repetitions, as in the previous analysis output. In this analysis, it can be seen that the word "risk" is among the frequently repeated words. If we are to analyze the usage areas of the word in depth, it can be observed that it is used within concepts such as "risk analysis", "risk assessment" and "risk management". Another word that can be highlighted in the word cloud is "programming". Similarly, after an in-depth examination, it can be concluded that it is a keyword with a sheer number of repetitions due to the frequent use of the linear programming method in the relevant research field.

Figure 2

Word Cloud based on Keywords

Comparative Assessment of Article Titles and Keywords

As already mentioned in the method section, word cloud analysis also allows researchers to track changes in trending topics between periods by dividing the documents and generating separate word clouds. In this analysis, publications for the period 2013-2017 and publications for 2018-2024 were divided into two groups to observe the difference between them. The analysis outputs of both periods, based on the article titles, are shown in Figure 3 and Figure 4. While the words with the highest frequency in both figures are generic concepts such as "maritime", "port" and "container", as the frequency values decrease, it becomes possible to follow the periodic changes of the prominent concepts. When we go beyond generic words in the word cloud of 2013-2017, it is seen that concepts related to environmental sustainability, which are gaining importance in the sector, such as "green", "compliance" and "emission", are at the forefront. When looking at the word cloud for the years 2018-2023, it is seen that there is no decrease in importance due to the existence of these concepts. However, during this period, the diversity of concepts increased and, unlike the previous 5-year period, the words "Covid", "autonomous" and "belt" and "road" reflecting China's Belt and Road Initiative project emerged. In this regard, it is possible to see that studies covering the Covid-19 pandemic in the context of its impact on maritime transportation, examining the impact of autonomous technologies on maritime transportation and port management, and dealing with China's Belt and Road Initiative from different dimensions constitute the themes of the special issue calls of the period.

Figure 3
Word Cloud based on Article Titles between 2013 and 2017

Figure 4
Word Cloud based on Article Titles between 2018 and 2023

The analysis outputs performed on keywords with the same periodic separation can be seen in Figure 5 and Figure 6. Although there is not much difference from the analysis of titles, this analysis broadens the scope as method-based trends can also be observed due to the fact that research methods are frequently included in keyword lists. For instance, while both word clouds have the word "programming" as a result of the continuity in popularity of linear programming, words in "data envelopment analysis" show increased frequencies in the latter word cloud.

Figure 5

Word Cloud based on Keywords between 2013 and 2017

Figure 6

Word Cloud based on Keywords between 2018 and 2023

Discussion And Conclusion

It is highly expected that academic journals will swiftly adapt to evolving trends within their scope and offer proactive agendas for discussion. Special issues are usually employed as an instrument to address these rapid changes, providing a more flexible approach that is beneficial for academia and society as a whole. There has been a noteworthy increase both in the quantity of publications and the number of special issues by means of maritime transportation-related journals, which allows them to better reflect and respond to the rapid changes occurring within the industry in the last decade. With the aim of conducting a word cloud analysis of the mentioned special issues in maritime transportation-related journals, the findings demonstrated emerging areas within the field of study between the years 2013 and 2023. Both the world clouds of keywords and article titles indicate that port and container transportation research stands out as the most prominent part of the maritime transportation literature. Concepts related to environmental sustainability, China's Belt and Road Initiative project, risk management and network design have also been frequently studied and addressed in the examined pieces of literature. These findings are quite parallel to the findings of Bai et al. (2021) with only one exception which is "Belt and Road Initiative". This shows

that the relevant subject is not studied intensively enough to constitute a single theme in the corpus of maritime transport literature, but its importance is rather reflected through special issues. Among the special issues examined, 5 of them compiled research directly related to China's initiative in question. It is possible to determine that there are overlapping points with the findings of Shin et al. (2018) as well, since the authors also found out that sustainability issues in the literature are mostly studied on the basis of "carbon reduction". In other words, it is possible to state that environmental sustainability is at the forefront of sustainability issues and that its social aspect has not been sufficiently studied to become an emerging theme.

The findings of this paper can be interpreted as proposals for further research, as the analysis visually represents the trending topics in the field. Thus, the main practical contribution made by this study is for the sake of the researchers in the field since the word clouds reflect the journal editors' guidance for the academia in the name of developing the existing studies.

This study not only reveals the emerging trends in the field but also helps comprehend how word cloud analysis can serve as a guide to the researchers in their pursuit of research areas to drill. Further studies can adapt this tool in various ways and with different aims. For instance, narrowing down the scope of the research (i.e. focusing solely on port research) or the scope of the data (i.e. focusing solely on a specific journal) can also offer practical ways, since such an approach would require less time in the generation of word clouds and allow rapid identification of the related themes.

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