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OPTIMIZATION OF MERCHANDISE DELIVERY LOGISTICS: CASE STUDIES AT BEJAIA PORT

The object of the study is the logistics of goods delivery by ports. This study presents a methodology designed to improve the efficiency of goods delivery logistics at the Bejaia port (Algeria). It prioritizes the optimization of empty container allocation to the ZEP zone, taking into account the geographical accessibility of the Tixter area, aiming to reduce the high costs linked with goods transportation. At the core of this strategy lies the use of simulation techniques to optimize truck fleets, ensuring maximum utilization rates and effective management of delivery operations by the Bejaia Mediterranean Terminal (BMT) for its clients. Addressing this challenge, the study offers an exhaustive analysis, integrating truck assignment models and accessibility assessments of logistic zones. The results highlight the paramount significance of optimal resource allocation and synchronized client coordination for achieving streamlined goods delivery. It becomes apparent that employing these methodologies can yield substantial productivity improvements, emphasizing their pivotal role in strengthening the port's logistical infrastructure.

Via rigorous analysis and insights derived from data, this study elucidates avenues towards achieving operational excellence within the logistical infrastructure of the port. By harnessing innovative strategies to confront persistent challenges, such as optimizing truck fleets and strategically allocating resources, the research anticipates a profound transformation in the efficiency and cost-effectiveness of goods delivery operations. Ultimately, the integration of these methodologies holds the potential to propel the port of Bejaia towards enduring success and a competitive edge in the ever-evolving landscape of global trade. Through extensive efforts, this strategy can be extended to other national and international ports operating under similar conditions, as it provides valuable information and methodologies to optimize logistics and transportation operations.

Keywords: *goods delivery, goods delivery logistics, port logistics, transport problem, accessibility matrix.*

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1. Introduction

In the current global economic context, optimizing the logistics of goods delivery represents a significant challenge for ports worldwide, which serve as vital hubs of international trade [1–5], as in the case of our study. Let's focus on the port of Bejaia, located in Algeria. This port plays a fundamental role in the region's economy, not only by boosting foreign trade but also by fostering local economic development.

In response to the escalating significance of meeting delivery deadlines, reducing costs, and elevating customer satisfaction, the port of Bejaia is strategically focusing on enhancing the quality of its infrastructure and services provided to goods transporters. This strategic initiative aims to expand the capacity of the container terminal while concurrently pursuing the alignment of port infrastructure rationalization with both customer satisfaction metrics and economic profitability targets [6]. Within this overarching framework, the port has introduced Extra-Port Zones, encompassing designated areas such as Ighil Ouberouak and Tixter, aimed at augmenting the holistic efficiency of its logistical operations.

Bejaia Mediterranean Terminal (BMT) stands as a specialized entity entrusted with the management and operation of the container terminal within the port of Bejaia. The primary imperative confronting BMT within this operational milieu is the imperative to minimize delivery expenses and strategically optimize the placement of logistic zones.

The aim of this research is to optimize the truck allocation problem within the BMT Company to improve delivery times, reduce costs, and enhance customer satisfaction by employing truck allocation models and logistic zone accessibility analyses, potentially identifying effective solutions. Additionally, let's utilize the method of geographic accessibility for a potential analysis to determine if the choice of logistic zone location is optimal or not. As a solution, through this research work, let's aim to develop effective solutions to enhance the management of transportation and logistics operations, which should have a positive impact on the overall performance of the company.

2. Materials and Methods

2.1. Assignment problem. The optimization of resource allocation in the transportation sector, known as the assignment problem, aims to minimize costs or maximize profits associated with task assignments [7–9]. A variety of methodologies have been proposed to address this challenge effectively [10]. Among them, the Hungarian Assignment Method (HAM) stands out as a widely employed approach for minimizing total costs or distances in assignment problems [11–14]. Moreover, a novel strategy known as the Greedy Hybrid Algorithm has emerged, which combines elements of the Balas-Hammer and Hungarian methods. This hybrid approach offers optimal solutions to transportation and assignment problems, outperforming other heuristic methods in certain scenarios [15].

Furthermore, there have been advancements in tackling dynamic assignment problems. Rather than relying solely on distance measures, this approach integrates concepts from optimal transport theory, dynamics, and agents' capacities. This integrated approach demonstrates significant cost reductions as the network size increases [16]. These innovative methodologies collectively contribute to enhancing the efficiency of solving assignment problems within transportation contexts, thereby providing more accurate and economically viable solutions.

2.2. Geographic accessibility. Historically, humans have always favored the shortest routes for their travel, which has directly benefited the transport sector as an economic activity due to the reduction of distance between points of origin and destinations [17, 18]. Geographic accessibility is a fundamental concept in several fields, such as healthcare, transportation, urban planning, and the environment. Numerous studies have been conducted to evaluate and understand the impact of accessibility on various aspects of human life and economic activities [19, 20].

The geographic accessibility of a location is determined by the sum of the shortest distances that separate it from other locations. These distances are contained in a matrix known as the geographic accessibility matrix. The lower the value of this sum, the more accessible the location [21]. The various definitions of geographic accessibility can be based on distance, travel time, or transportation networks. Among the methods used to assess geographic accessibility are gravity models, cost-distance analysis, and network analysis.

Our study specifically focuses on distance-based geographic accessibility [22].

Improving geographic accessibility in transportation requires a comprehensive analysis of various factors, such as travel scenarios, transportation network connectivity, and infrastructure planning. It is critical to realistically estimate travel speeds, inclusively engage stakeholders, and validate approaches to enhance access to vital services and destinations, particularly in healthcare [23, 24].

Additionally, it is important to emphasize the need to consider the asymmetry between outbound and return routes, as this can significantly influence the connectivity of transportation networks. This asymmetry plays a crucial role in optimizing public transport routes and in urban development planning [25]. Finally, geographic accessibility not only ensures connectivity but also impacts regional cohesion and spillover effects, particularly in urban areas where the level of benefits varies depending on location and infrastructure improvements [26].

2.3. Presentation of the BMT Company. Situated within the bustling city of Bejaia, at the core of the Kabylie region lies the Algerian port of Bejaia. This port serves as a vital hub for both international trade and hydrocarbon-related operations. Renowned as the second busiest port in Algeria in terms of commercial endeavors, it owes much of its success to its strategic geographical positioning. Acting as a pivotal connection point between the eastern and central regions of the country, it facilitates maritime access for the surrounding hinterland. Its influence extends far beyond the coastal boundaries, catering to a substantial and expansive hinterland [27], as depicted in Fig. 1.

The Bejaia port boasts exceptional nautical accessibility and is equipped with facilities tailored to accommodate diverse types of maritime traffic. It encompasses multiple terminals, among which is the Container Terminal, under the management of Bejaia Mediterranean Terminal (BMT) since 2005.

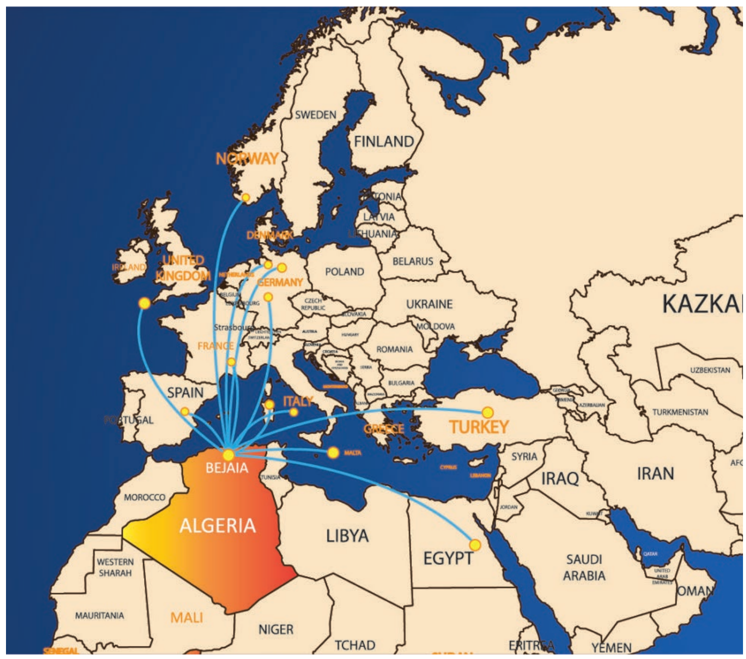

Fig. 1. Geographical location of the Port of Bejaia (BMT, 2023)

2.3.1. The logistics platform. The Port of Bejaia plans to exploit the Extra-Port Zones (EPZ), which aim to provide the port's overall logistics with a support system to enhance performance in terms of time, cost, and service quality. Currently, there are two logistics zones and eight main customers:

– The logistics zone EPZ of Ighil Ouberouak in Bejaia.
– The logistics zone Tixter in the Bordj Bou Arreridj province (B.B.A).
– The eight main customers are distributed across various provinces in the east and center of the country.

Furthermore, the container delivery process at the Port of Bejaia involves the following steps (Fig. 2):

– The transfer of empty containers from (towards) the port to (from) the EPZ zone.
– Transfer of full containers to the logistics zone in Tixter in the Bordj Bou Arreridj province.
– Delivery of full containers to the customers.
– Return of empty containers from the customers to the EPZ zone.

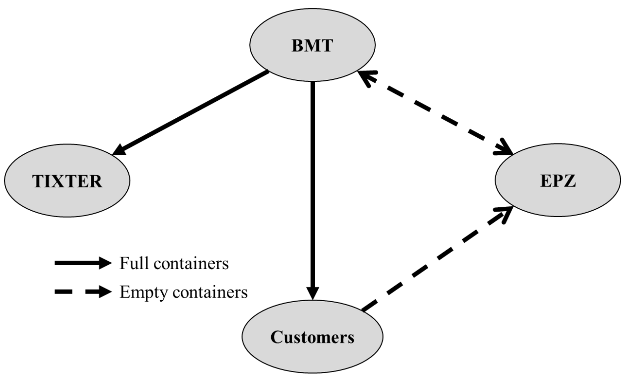

Fig. 2. The delivery process of containers at BMT

2.3.2. The logistics zone of Ighil Ouberouak. The logistics zone, also called as the Extra-Port Zone (EPZ), of Ighil Ouberouak, is located approximately 5 kilometers southeast of the Port of Bejaia. The area of the zone covers a total area of 48560 m^2 and is situated in the municipality of Tala Hamza, Bejaia province, Algeria (Fig. 3).

The EPZ has a spatial capacity of 1040 TEU (Twenty-foot Equivalents Unit) and a commercial capacity of 19000 TEU. It consists of several components, mainly two warehouses measuring 10200 m^2 and 750 m^2, as well as two main entrances, one of which is connects to National Road number 9 (NR_09).

Fig. 3. The ZEP logistics zone at Ighil Ouberouak (Google Maps, 2024)

This article is simulated the assignment problem of repositioning empty containers to the ZEP zone, while taking into account the geographical accessibility of the Tixter zone with the aim of reducing the high costs of goods delivery. Primarily, the simulation aims to optimize the truck fleet and maximize its utilization rate.

3. Results and Discussion

3.1. Modeling the assignment problem. Model construction. BMT's fleet consists of 42 trucks (road trailers) of Man brands, each with a capacity of 36 tones. These trucks are divided into three teams (Morning, Evening and Night) working in rotation for 6 hours each according to the following schedule:
- Shift 1 (Morning): from 06:00 a.m. to 12:00 p.m.;
- Shift 2 (Evening): from 12:00 p.m. to 06:00 p.m.;
- Shift 3 (Night): from 06:00 p.m. to midnight.

3.1.1. The mathematical formulation of constraints. In this part, let's address the mathematical formulation of constraints to optimize the assignment of trucks and delivery of containers. Let's consider the following elements to improve the efficiency of truck assignments and management of container deliveries:
- Ensure that the number of assigned trucks is less than or equal to the fleet's availability.
- Limit each truck's number of rotations to a certain maximum.
- Ensure that for each shift, the number of delivered containers exceeds a specified minimum.

The number of trucks corresponds to the number of containers to be delivered.

3.1.2. First constraint: Truck availability. This constraint ensures that the number of assigned trucks does not exceed the number of available trucks in the fleet. The mathematical model for this constraint is expressed as follows:

$$\sum N_{trucks} \leq N_{available}, \tag{1}$$

where N_{trucks} is the number of assigned trucks; $N_{available}$ is the total number of available trucks in the fleet.

This inequality ensures that the number of assigned trucks adheres to the constraint of staff availability.

3.1.3. Second constraint: Delivery limits. The second constraint is based on the delivery limits of each truck during a shift. It is mathematically expressed as follows:

$$\frac{T_{sh}}{T_{ri}} \leq N_r, \tag{2}$$

where T_{sh} is the times of each shift; T_{ri} is the rotation time of each truck per; N_r is the maximum number of rotations authorized for each truck; T_{sh}/T_{ri} is the average of the number of rotations for each truck.

This constraint ensures that the average number of rotations for each truck does not exceed the maximum authorized.

For our assignment, let's limit ourselves to the approach from the EPZ zone, and the time taken by each truck for each rotation is presented in Table 1.

Table 1

Average Time per Shift and Authorized Number of Rotations

EPZ of Ighil Ouberouak	Shift 1	Shift 2	Shift 3
Average Times (min)	24	30	26
T_{sh}/T_{ri}	15 Trucks	12 Trucks	13 Trucks

Respecting this constraint, it is possible to calculate that the optimal use of trucks for the three shifts (Morning, Evening, and Night) is 40, ensuring efficient delivery logistics management.

Additionally, the maximum number of containers to be transported per day is 221 containers. Therefore, the number of rotations per truck is calculated as follows: 221/40=approximately 6 rotations/truck.

According to the random assignment of BMT Company trucks per shift, as shown in Table 2.

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Table 2

Truck assignment by BMT and number of rotations performed

Days	Number of trucks			Assignment by BMT			Total
	morning	evening	night	morning	evening	night	
01/01/2024	0	0	0	0	0	0	0
02/01/2024	16	12	11	50	65	36	151
03/01/2024	12	12	14	20	63	45	128
04/01/2024	16	14	13	80	60	22	162
05/01/2024	4	4	0	4	4	0	8
06/01/2024	11	13	11	45	64	80	189
07/01/2024	12	13	12	39	34	49	122
08/01/2024	14	14	12	24	16	0	40
09/01/2024	10	16	14	26	68	32	126
10/01/2024	15	16	15	59	62	16	137
11/01/2024	13	15	14	23	38	14	75
12/01/2024	3	3	0	0	0	0	0
13/01/2024	15	14	16	48	7	0	55
14/01/2024	15	15	16	54	75	64	193
15/01/2024	16	9	13	28	34	13	75
16/01/2024	13	16	6	50	65	22	137
17/01/2024	15	16	16	34	9	25	68
18/01/2024	14	16	16	6	0	0	6
19/01/2024	0	0	0	0	0	0	0
20/01/2024	15	15	15	55	59	44	158
21/01/2024	16	15	15	0	55	26	81
22/01/2024	17	15	15	54	74	57	185
23/01/2024	17	14	15	55	41	55	151
24/01/2024	16	14	13	64	44	32	140
25/01/2024	18	13	13	65	37	13	115
26/01/2024	0	0	0	0	0	0	0
27/01/2024	13	18	13	55	81	77	213
28/01/2024	13	18	13	44	45	47	136
29/01/2024	13	17	15	35	54	57	146
30/01/2024	13	17	15	30	58	42	130
31/01/2024	13	16	15	30	48	41	119
Total	378	390	356	1077	1260	909	3246

3.2. Analysis of fuel consumption costs. Efficient management of fuel consumption costs is crucial to optimizing container transport operations to the Ighil Ouberouak EPZ logistics zone. In this section, let's analyze the average fuel consumption cost for transporting containers to the EPZ logistics zone of Ighil Ouberouak.

The specific fuel consumption, the distance for transferring empty containers to the EPZ logistics zone, and the cost fuel are as follows:

– The specific fuel consumption (C) of a truck is 29.3 liters for a distance (d) of 100 km.

– The distance from the EPZ logistics zone to the BMT terminal is approximately 5 km.

– The cost of one liter of fuel (Diesel) in 2024 is 29.01 Algerian Dinars (DA).

Furthermore, the average fuel consumption of a 36-ton truck is calculated using the following formula:

$$C_{avg} = \frac{C \cdot d}{100} = 1.465, \quad (3)$$

where C_{avg} is the average fuel consumption in liters per truck.

On the other hand, the cost of fuel (Diesel) for a truck per rotation is calculated as follows:

$$Cost = C_{avg} \cdot fuel\ price\ per\ liter;$$

$$Cost = 1.465 \cdot 29.01 = 42.50\ \text{DA/truck/rotation}.$$

The fuel consumption during January 2024, resulting from BMT Company's random assignment of trucks per shift, is depicted in Fig. 4.

Fig. 4 indicates that BMT's random assignment leads to the highest fuel consumption in the evening shift with 3692 liters, followed by the morning shift with 3156 liters, and then the night shift with the lowest at 2663 liters. It is observed that there is a significant increase in fuel consumption across all three shifts in January 2024. The total average fuel consumption for all three shifts in January 2024 amounts to 9511 liters.

On the other hand, according to the proposed new assignment, let's obtain the following results, as shown in Fig. 5.

Fig. 5 illustrates the fuel consumption for the three shifts (morning, evening, and night). The morning shift recorded the highest fuel consumption at 5300 liters, followed by the evening shift at 2335 liters, and the night shift at 1846 liters. The total average fuel consumption for January 2024 amounts to 9481 liters. This notable decrease in fuel consumption underscores the significant influence of working hours on fuel-related operating costs, underscoring the necessity for optimal truck assignment strategies.

The fuel consumption costs during January 2024, resulting from the random assignment of trucks per shift by BMT company and our assignment, is depicted in Fig. 6.

Fig. 6 presents a comparison of fuel consumption costs in Algerian Dinars (DA), between our proposed assignment and BMT's random assignment, distributed across the three work shifts.

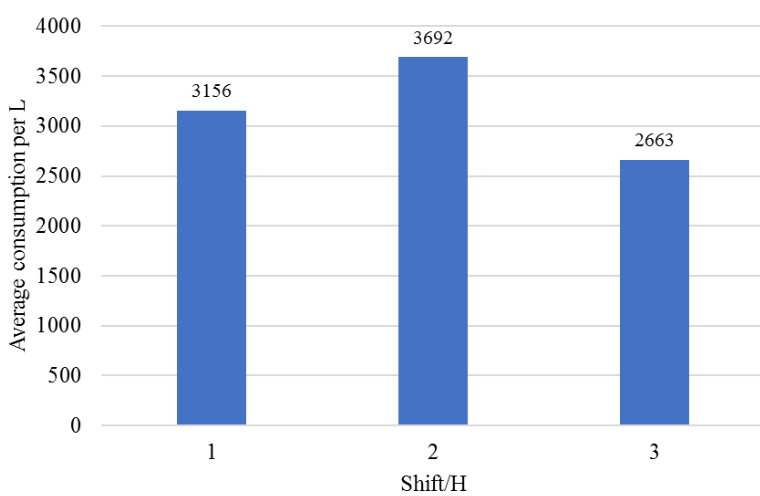

Fig. 4. Fuel consumption for the month of January 2024 per Shift

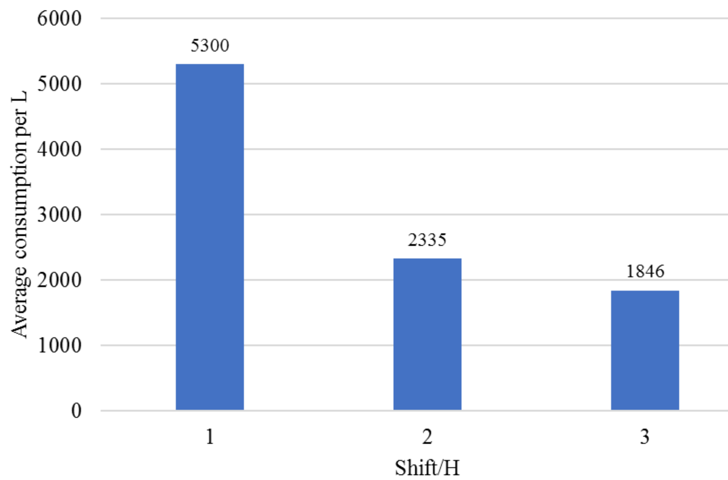

Fig. 5. Fuel consumption for the month of January 2024 per shift

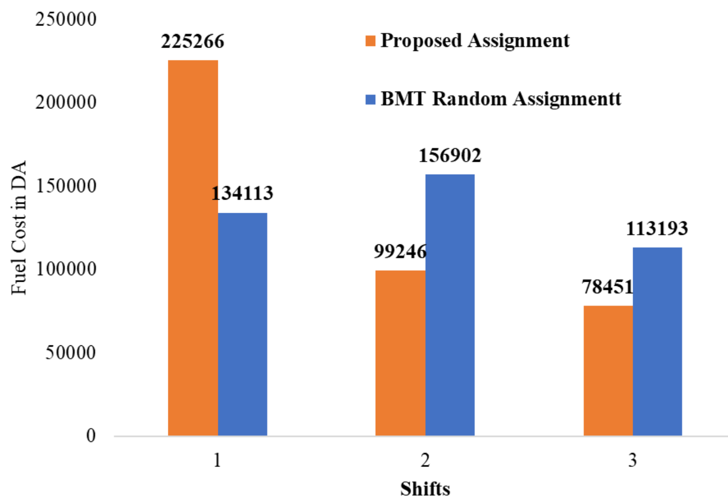

Fig. 6. Comparison of fuel Consumption costs

In the first shift, the random assignment is significantly more economical, with costs 134113 DA compared to 225266 DA for the proposed assignment. However, for the second and third shifts, the proposed assignment becomes more advantageous: the costs decrease to 99246 DA and 78451 DA respectively, compared to 156902 DA and 113193 DA for the random assignment. Summing these figures, the total cost for the random assignment reaches 404208 DA while that for the proposed assignment is 402963 DA. These results indicate that the proposed assignment is overall less costly than BMT's random assignment.

3.3. Location analysis by geographic accessibility. Generally, the creation of the Extra-Port logistics zone at Tixter aims to bring containers closer to customers in the highlands such as Bordj Bou Arreridj (B.B.A), Setif, Mila, Constantine (Cons), Batna, M'Sila, Bouira, and Algiers (Fig. 7). In this part, let's check whether the location of the Tixter zone is optimal. To verify this, the current location of the logistics zone is optimal; it is possible to apply the method of geographic accessibility. This method assesses the accessibility of location based on various criteria, such as the distance between zones and the transportation time.

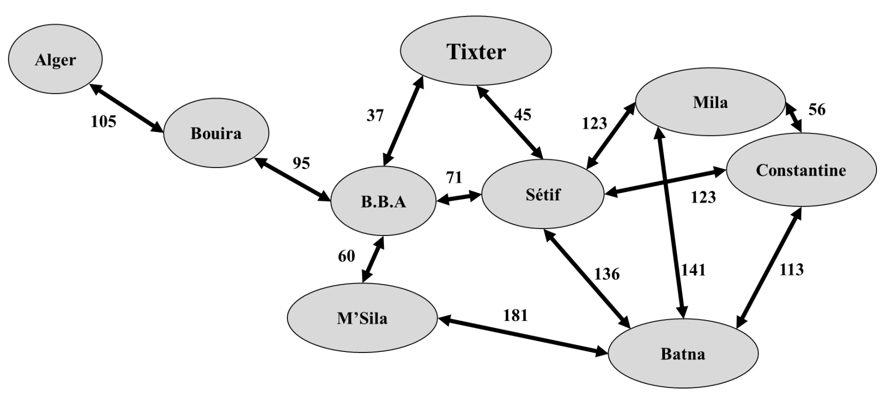

Fig. 7. Delivery to customers for other regions

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A zone is considered to be the most accessible when the sum of all the distances separating it from other zones is the lowest, according to the following formulation used to calculate the geographic accessibility matrix [28]:

$$A(G)_i = \sum_{j=i}^{n} d_{ij}, \quad (4)$$

where $A(G)_i$ is the geographic accessibility of a zone i; d_{ij} is the short distance between zones i and j; n is the total number of zones.

Table 3 shows the geographic accessibility matrix from Fig. 6. This matrix highlights the short distances between different zones, which is important for logistics and container transport planning. Each value in the table represents the distance in kilometers between two zones.

Table 3

The geographic accessibility matrix

Wilaya	Tixter	Mila	Constn	Batna	Setif	B.B.A	M'Sila	Bouira	Algiers	$A(G)_i$
Tixter	0	190	230	251	106	165	210	141	246	1539
Mila	190	0	59	145	135	202	264	295	399	1689
Cons	230	59	0	113	128	195	257	289	392	1663
Batna	251	145	113	0	134	195	181	290	394	1703
Setif	106	135	128	134	0	72	132	166	304	1177
B.B.A	165	202	145	195	72	0	70	96	199	1144
M'Sila	210	264	257	181	132	70	0	141	245	1500
Bouira	141	295	289	290	166	96	141	0	105	1523
Algiers	246	399	392	394	304	199	245	105	0	2284
$A(G)_j$	1539	1689	1663	1703	1177	1144	1500	1523	2284	–

Following the analysis of the geographic accessibility matrix, it is that Tixter is the area with the best accessibility, while Algiers is the least accessible. This observation highlights the critical importance of geographic accessibility in logistics planning, while also suggesting potential strategies to optimize transportation and distribution flows.

3.4. Discussion. The research findings are of paramount importance for optimizing logistics and transportation operations in ports. Implementing truck allocation models and fuel consumption optimization strategies has enabled us to reduce operating costs, enhance efficiency, and improve overall service quality in ports. Applying these methodologies can assist logistics managers in making informed decisions regarding truck assignments and fuel management, leading to more sustainable and cost-effective operations. Thus, following the methodologies applied and the results obtained in this research, this strategy can be generalized to national and international ports, provided that local context and specific conditions are taken into account. However, for ports in different countries, the proposed models can be adapted to their unique operational environments, considering factors such as local fuel prices, labor costs, and infrastructure capacities. It should also be noted that to effectively utilize the results of this research, certain conditions must be met, namely:

– *Data Availability*: Accurate and comprehensive data on fuel consumption, truck movements, and operational schedules are crucial for implementing the proposed models.

– *Technological Infrastructure*: Adequate technological infrastructure, including GPS tracking systems and fuel monitoring tools, is necessary to collect and analyze the required data.

– *Management Support*: Strong support from port management and relevant stakeholders is crucial for the successful implementation of the proposed strategies.

To confirm the results obtained, subsequent case studies must be conducted in various geographical and operational contexts to validate the applicability and effectiveness of the proposed models. Simultaneously, explore the scalability of the models to adapt to different sizes of ports and varying levels of operational complexity.

4. Conclusions

This paper explores optimizing merchandise delivery logistics at Bejaia Port, addressing the substantial challenges posed by transportation and logistics within maritime ports.

Through this study, it is possible to observe that the choice of the Tixter logistic zone is the most accessible. Consequently, the average fuel consumption decreased in our assignment compared to the random assignment by BMT. Furthermore, it is possible to notice that delivery tariffs are beneficial for BMT given their growth. To address this, we have proposed a contribution study aimed at reducing this cost by utilizing truck assignment models and improving the accessibility of logistic zones.

Moving forward, the development of the transportation and logistics function has become an economic necessity, particularly with the rise in freight traffic. Port logistics encompasses all operations necessary for the movement of goods imported by sea, which remains the most important and sought-after mode of transportation for transporting goods from production to sales locations, focusing on the delivery of goods, their modes, strategies, and the import-export process.

However, we have identified some shortcomings within this company where recommendations have been proposed to establish an optimal transportation plan based on the assignment model and adherence to deadlines at minimal cost. Among other things, given the information provided and valuable methodologies employed to optimize logistics and transportation operations, this strategy can be extended to other national and international ports operating under similar conditions.

Finally, the method proposed for calculating fuel consumption and goods delivery is limited in its temporal scope. In the future, it is possible to apply this method quarterly and consider goods delivery by wilayas for a more comprehensive analysis.

According to this study, electrostatic separation is effective in concentrating phosphate ore originating from a subarid region, while removing a large proportion of dolomite and a small amount of silica. The various models of electrostatic separators used produced similar results with slight variations.

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Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm they did not use artificial intelligence technologies when creating the presented work.

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