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Determining Ice Block Distribution Routes for Fishermen in Bone Regency Using the Nearest Neighbors Algorithm Vehicle Routing Problem

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ABSTRACT

Indonesia has the potential to produce quality marine fish, one of which is in Bone Regency. There are 10 sub-districts that have coastal areas with a total of 63 villages, which are divided into 3,301 business units that also develop from this sector. This has led to a surge in demand for ice blocks. The purpose of this research is to determine the route that must be travelled by the Ice transport truck. This research determines the optimal route for block ice distribution in Bone Regency by considering demand data, distance travelled, fleet capacity, and operational constraints such as ice durability and planning horizon. The results showed that block ice distribution scheduling in Bone Regency needs to be optimised by reducing route duplication, adding fleets during high season, and utilising advanced optimisation methods such as Genetic Algorithm (GA) and big data to predict demand patterns. The use of AI-based fleet management systems and integration of multi-location distribution networks will increase efficiency, reduce costs, and fulfil demand on time

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INTRODUCTION

The development of marine and fisheries potential in Bone Regency for fishing, marine and brackish water aquaculture covers 10 sub-districts with coastal areas comprising 63 villages and a coastline stretching 138 km (bone.go.id). This is inseparable from the readiness of the fishing fleet in Bone Regency to face these challenges, with a total of 3,301 fishing vessels, consisting of motorized vessels ≤ 5 GT, including non-motorized boats and outboard motors, totaling 1,620 units, vessels > 5 – 10 GT totaling 155 units, and vessels sized > 10 GT totaling 175 units (source: Bone Regency Marine and Fisheries Service).

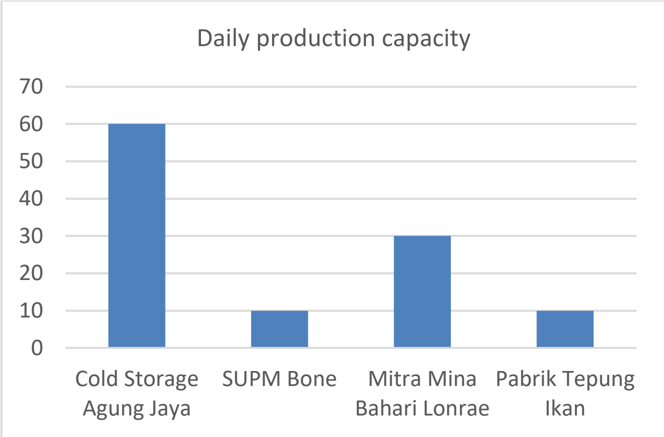

Figure 1. Total Block Ice Production Per Ton

Per day in Bone Regency from the Bone Regency Marine and Fisheries Service 2022. Supported by 9 ice block production machines from 4 ice block factories in Bone Regency, with a production capacity of around 6,060 ice blocks/day, some of which can be seen in Graph 1. The total daily ice block production in Bone Regency is 226 KUB and 1 Joint Business Group Communication Forum (FKKUB), and there is 1 fishing cooperative, namely the Mitra Mina Bahari Cooperative, which oversees all fishermen in Bone Regency. This is directly proportional to the marine and fisheries production in Bone District during the period 2013-2015, as shown in Table 2, which details the annual production of fishermen in Bone District as follows:

Table 1. Annual Production of Fishermen in Bone Regency

Commodity	**2013**	**2014**	**2015**
Cakalang	3.194,30	1.855,20	2.746,90
Tuna	3.194,30	4.740,40	1.932,70
Tongkol	-	-	3.020,30
Layang	4.112,90	6.223,50	15.064,50

Source: Bone Regency Marine and Fisheries Service

The significant increase in fishermen's production is directly proportional to the increase in demand for ice blocks in the area, resulting in a surge in demand. This is positive from an economic perspective but will become a problem if it is not supported by adequate facilities. However, this problem can be minimized by optimizing the use of facilities, which means optimizing the distribution and transportation facilities so that they can distribute demand under the existing conditions and become a managerial decision to consider adding or reducing the fleet. As done by (Arvianto et al., 2018), a simulation study was conducted focusing on the VRP (Vehicle Routing Problem) variant, which includes homogeneous fleet size and mix, multiple trips, multiple products with compartments, split delivery, multiple time windows, and probabilistic demand.

This includes using a fleet of electric vehicles to mobilize these products using the Electric Vehicle Routing Problem (EVRP) approach to achieve the best decision, which is a development of the traditional Vehicle Routing Problem (VRP), specifically in finding the shortest route for electric vehicles. The objective function is to find the best travel route that minimizes mileage. Each route serves a set of customer points that start and end at a specific depot. Battery capacity and charging stations are used as constraints (Pamungkas et al., 2023).

In determining vehicle routes to mobilize ice blocks to fishermen located at several points, as in determining distribution routes, it is necessary to obtain a good route for port distribution. The method used by researchers in determining vehicle routes is called the Vehicle Routing Problem (VRP), which is an effort to find feasible routes (Hutasoit et al., 2014). The role of vehicle route determination So far, although many researchers have spent a lot of time studying VRP in optimizing vehicle driving routes in cold chain logistics, most still use only one VRP echelon as the main focus, from the complex multi-distribution layer in real-life scenarios to do so has not received much attention. For example, the milk supply chain flow can even contain nine stages from cow to consumer associated with a single milk processing facility (Wang & Wen, 2020).

VRP can be simply defined as determining the route with the minimum delivery cost, with goods from the depot to several different customers with different demands ((Paolo Toth & Daniele Vigo et al., 2006; Prabowo et al., 2023). The main objective of VRP is to minimize distribution costs by minimizing vehicle mileage, vehicle travel time, or the number of vehicles used, while still meeting all existing constraints. The VRP problem is classified as a polynomial and non-deterministic NP-hard problem. A problem is said to be polynomial or non-deterministic if there is no definite algorithm for solving it; in other words, the algorithm for the solution can be modified to suit the problem at hand (Cook, 2003; Kurniani & Nurhidayat, 2022).

LITERATURE REVIEW

Various studies have stated that VRP is very important in determining routes, such as delivering ice crystals using three different methods, namely Simulated Annealing Algorithm, Tabu Search, and Nearest Neighbor (Wicaksono et al., 2020). However, when organizations plan routes with minimum costs, they can minimize the number of vehicles used for long-distance travel, and customers may stop at central facilities such as toll gates, warehouses, fuel filling stations, etc. (Poonthalir & Nadarajan, 2019). In real-world cases during peak season demand, companies are unable to meet demand. This is due to suboptimal scheduling and insufficient fleet facilities, so improvements are needed during peak periods without violating constraints. Therefore, the problem that the researchers want to raise in this paper is the route that must be taken by ice block transport trucks by choosing the fastest route so that ice blocks can be delivered in less than 3 hours and every ice block request can be fulfilled. The method used in this study is Nearest Neighbors in the Vehicle Routing Problem with Multiple Trips, Time Windows and Split Delivery (VRPMTSD), which focuses on time endurance and product quality.

METHODS

This study was conducted at an ice block production company in Bone Regency with the aim of determining the optimal distribution route for vehicles transporting ice blocks to several fishing centers in the region. The data used included the demand for ice blocks from each customer, the distance between the depot and customers obtained through Google Maps due to limited company data, the maximum transport capacity of vehicles of 120 ice blocks, and the average vehicle speed of 30 km/hour considering the condition of the fleet, which consisted of old trucks. In addition, loading and unloading times were also taken into account in the planning. This case study has several characteristics, including the use of a single depot as the starting and ending point for vehicles, the possibility of visiting customers more than once during the planning horizon (split delivery), vehicle capacity limitations, and a tour completion duration limited to a 4-hour planning horizon and 3 hours of ice durability. The average unloading process requires 10 seconds per ice block, so all these factors form the basis for determining an efficient distribution route. Based on the development of the VRPMTSD model, the following parameters are required:

Table 2. Parameters and Variables

Code	Desciption
N	Depot node, N = (0, 1, 2, …., n)
K	Set of vehicles, K = (0, 1, 2, ..k)
M	Set of indices that usually includes all nodes that must be served
i, j, p	Node index
wk	Maximum capacity of vehicle k to i
d_i	Demand at node I transported by k
c_{ij}	Distribution cost from i to j
x_{ijk}	[0,1] decision whether node j is visited

Code	Desciption
x_{ipk}	after i by vehicle k
x_{ijk}	Binary variable that is 1 if vehicle k goes from node i to node p, and 0 otherwise.
x_{0jk}	Binary variable that is 1 if vehicle k moves from node p to node
q_{ijk}	j, and 0 otherwise.
Si	Binary variable that is 1 if vehicle k goes from the depot (node 0) to
$[a_i, b_i]$	node j, and 0 otherwise.
T_{ik}	Variable that indicates the amount of goods or demand fulfilled by vehicle k when it moves from node iii (e.g., depot or previous customer) to node j (next customer).
T_{ki}	Transport volume of the depot or node i
s_i	Earliest start and latest finish at a node (time windows)
t_{ij}	Service start time at node i with vehicle k
L	Service start time at node k with vehicle i

Next, using a mathematical model, we present Mixed-Integer Programming (MIP) formulations for VRPMT, SDVRP, and VRPTW. Where VRPTW involves two types of variables: for each arc (i, j) A and each vehicle k K, there is a binary arc flow variable x_ijk that is equal to 1 if the arc (i, j) is used by vehicle k, and 0 otherwise; for each node i∈V and vehicle k∈K, there is a Time variable T_ik that determines the start of service time at point i when served by vehicle k (Paolo Toth & Daniele Vigo et al., 2006).

a. *Objective fucion*

$$\mathbf{Min} \sum_{i=0} \sum_{j=0} \sum_{v=1} c_{ij} x_{ijk}$$

b. *Constraint*

(1) $$\sum_{k \in K} \sum_{j \in N} x_{ijk} \geq 1 \qquad \forall\, i \in C$$

(2) $$\sum_{i \in N} x_{ipk} - \sum_{j \in N} x_{pjk} = 0 \qquad p = 0,,,.,n; v = 1,.,m$$

(3) $$\sum_{j \in N} x_{0jk} = 1 \qquad \forall \mathrm{k}$$

(4) $$\sum_{i \in S} \sum_{j \in S} x_{ijk} \leq |S\notin -K_1 \qquad 1 \ldots \ldots m; S\ \forall i \in V - \{0\}$$

(5) $$\sum_{j=V} q_{ijk} \geq d_i \qquad \forall \mathrm{i} \in \mathrm{M}, \forall \mathrm{k} \in K$$

(6) $\sum_{i \in N} x_{i,n+1,k} = 1 \qquad \forall\, k \in K$

(7) $t_{i,n+1} \leq L_i^k \leq L \qquad \forall\, i\, \in P\; k\, \in K \setminus$

(8) $x_{ijk}\left(T_{ik} + s_i + t_{ij} - T_{jk}\right) \leq 0 \qquad \forall\, k \in K,\ (i,j) \in N$

(9) $a_i \leq T_{ik} \leq b_i \qquad \forall\, k \in K,\ i \in N$

(10) $x_{ijk} \geq 0\ \ and\ x_{ijk} \in \{0,1\} \qquad \forall\, k \in K,\ (i,j) \in N$

Constraint discussion (0) Minimize the distance traveled. (1) Each request is served separately. (2) Vehicle route k starts and ends at the depot location. (3) The equation avoids the existence of subtours from the solution. (4) and (5) State that nodes with demand greater than or equal to the maximum vehicle capacity will be visited more than once; otherwise, they will be visited once (SI max {wk}). (6)-(10) Are time window constraints. Except for constraint (7), which is the maximum ride time of the vehicle for the liquid ice limit.

RESULTS AND DISCUSSION

Before starting the data processing, the first step is to collect relevant and necessary data. This data includes customer demand for ice blocks, vehicle parameters to be used in distribution, and other objective parameters such as operational costs, vehicle capacity, and delivery time. This data will form the basis for further analysis of distribution patterns and research results related to the optimization of ice block distribution. During the data collection stage, Google Maps was used to estimate the distance between Agung Jaya cold storage locations (depots) and the docks or fishing centers scattered throughout Bone Regency, which are the main customers. Google Maps provides distance and route information that can help design effective distribution routes. In addition to distance, information related to travel time and road conditions are also important considerations in this process.

Figure 2. Distribution Route Map shows a visualization of the distribution route with red icons representing the locations of block ice cold storage, while green icons indicate distribution nodes or points consisting of docks or fishing centers. This map serves as a reference for analyzing the most efficient route for block ice delivery, taking into account customer locations and the geographical conditions of the Bone Regency.

After collecting distance data and other parameters, an analysis is conducted to determine the optimal distribution route that can minimize operational costs and meet customer needs in a timely manner. Optimization methods such as Vehicle Routing Problem (VRP) or algorithm-based approaches can be used to solve this distribution problem. With this approach, it is hoped that the distribution of ice blocks from the depot to customers can be carried out efficiently, so that fishermen's needs for ice blocks to maintain the freshness of their fish catches can be met properly.

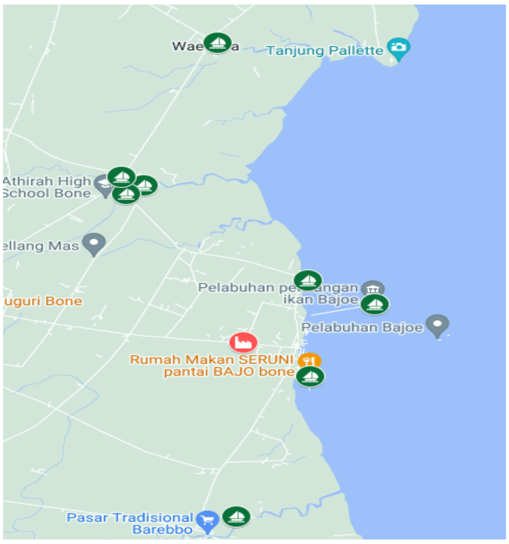

Figure 2. Distribution Route Map

The final result of this analysis will be recommendations for a distribution system that is not only cost-efficient, but also ensures the sustainability of distribution services to customers in Bone Regency. The data obtained is then used to compile a distance matrix between nodes with routes from the depot to the fishing center and from the fishing center to other points. This can be seen in Table 4. Distance Matrix for Each Node.

Table 3. Distance Matrix for Each Node

Matrix DIitance									
Node	**O**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
O	0	3	2.5	6.5	6.4	6.9	10.4	1.8	6.1
A	3	0	2.2	6.1	5.8	6.3	8.8	3	7.6
B	2.5	2.2	0	3.7	3.6	4.2	7.7	2.5	7.1
C	6.5	6.1	3.7	0	0.7	3.1	4.8	8.3	12.1
D	6.4	5.8	3.6	0.7	0	1.1	4.1	8.2	12.7
E	6.9	6.3	4.2	3.1	1.1	0	3.1	9.2	13.7
F	10.4	8.8	7.7	4.8	4.1	3.1	0	12.3	16.6
G	1.8	3	2.5	8.3	8.2	9.2	12.3	0	5.4
H	6.1	7.6	7.1	12.1	12.7	13.7	16.6	5.4	0

Next, the demand and time windows for each customer location are presented. Based on the observations, deliveries are designed to be carried out between 3:00 p.m. and 7:00 p.m. This time frame was chosen considering weather conditions, where deliveries in the afternoon can reduce the risk of ice blocks melting due to higher temperatures during the day. In addition, this time also takes into account the tides so that the ice blocks do not have to wait too long in the fishermen's boats, allowing them to be used immediately after the distribution process is complete.

In determining the unloading time at each customer location, the main parameter used is the number of requests compared to the delivery capacity. If the demand is greater than the capacity, the unloading time is calculated based on the selected delivery capacity. Conversely, if the demand is less than or equal to the capacity, the unloading time is calculated based on the actual demand at that location. The unloading time value is obtained by multiplying the number of units distributed by a fixed value of 1060\frac{10}{60}6010, which represents the unloading time in hours.

Furthermore, the average speed of the distribution vehicle is assumed to be 30 km/hour, with a maximum capacity of 120 ice blocks per vehicle. With these parameters, distribution calculations are performed to optimize deliveries to each customer location within a specified time frame. Complete information regarding total demand and time windows for each customer can be found in Table 4, which contains details on the demand volume for each location, delivery capacity, and estimated delivery times to ensure distribution efficiency and timeliness.

Table 4. Total Demand and Time Windows

Node		**Demand**	**TW**		**Unloading**	**Speed**	**Capacity**
Name	**Code**		**ai**	**bi**			
PT Agung jaya	O	0	900	1140	20	30	120
Pelelangan ikan bajoe	A	550	910	1130	20	30	120
Tippulue	B	300	920	980	20	25	120
Dermaga Lapecce	C	150	925	1115	20	30	120
Cumpae	D	35	960	990	5.83	30	120
Awassalo	E	250	980	1120	20	30	120
Waetuo	F	160	960	1125	20	30	120
Pantai Bajo	G	400	990	1115	20	30	120
Pelabuhan Polewali	H	250	1000	1140	20	25	120
PT Agung Jaya	O	0	900	1140	0	30	120

The data processing used in this study was VRPTW with Nearest Neighbor based on the VRPMTSD problem to obtain the fastest route from several existing nodes and to determine the number of vehicles used in the distribution of ice blocks. The results of the first selected node can be seen in Table 5. Iteration 1 for vehicle 1.

Table 5. Iteration 1 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time Unloading	Process Completion Time	Time Windows Constraint	Liquid limit Constraint
A	550	6	910	910	1130	20	930	Yes	Yes
B	300	5	920	920	980	20	940	Yes	Yes
C	150	13	925	925	1115	20	945	Yes	Yes
D	35	12.8	960	960	990	5.83	965.83	Yes	Yes
E	250	13.8	980	980	1120	20	1000	Yes	Yes
F	160	20.8	960	960	1125	20	980	Yes	Yes
G	400	3.6	990	990	1115	20	1010	Yes	Yes
H	250	12.2	1000	1000	1140	20	1020	Yes	Yes

The next step before finding the closest distance from point A (tour) to the other 7 points is to first see whether the request has been fulfilled or not. Since the request has not been fulfilled, the truck fleet must first return to the depot. This situation can be seen in Table 6. Iteration 2 for vehicle 1. Where the truck fleet returns to the depot, namely to point O from point A.

Table 6. Iteration 2 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time Unloadi	Process Completi	Time Window	Liquid limit
O	0	6	900	936	1140	20	956	Yes	Yes

In order to proceed to the next iteration, which can be seen in Table 7, iteration 3 on vehicle 1, the same thing is done to find the closest point, which is selected as node O to D.

Table 7. Iteration 3 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time Unloading	Process Completion Time	Time Windows	Liquid limit
A	430	6	910	962	1130	20	982	Yes	Yes
B	300	5	920	961	980	20	981	Yes	Yes
C	150	13	925	969	1115	20	989	Yes	Yes
D	35	12.8	960	968.8	990	5.83	974.63	Yes	Yes
E	250	13.8	980	980	1120	20	1000	Yes	Yes
F	160	20.8	960	976.8	1125	20	996.8	Yes	Yes
G	400	3.6	990	990	1115	20	1010	Yes	Yes
H	250	12.2	1000	1000	1140	20	1020	Yes	Yes

Based on these results, the same steps were also taken, as can be seen in Table 8. Iteration 4 vehicle 1, where the truck returns to the depot, in Table 9. Iteration 5 on vehicle 1, the closest point from depot O to C is obtained. Table 10. Iteration 6 on vehicle 1, the operation returns to the depot. Table 11 shows that in iteration 7 of vehicle 1, the closest point is obtained from depot O to G. Table 12 shows that in iteration 8 of vehicle 1, the truck returns to the depot.

Table 8. Iteration 4 for vehicle 1

Node	Demand	Travel Time	ai	Start Time	bi	Time	Process Completi	Time Window	Liquid limit
A	430	11.6	910	986.2	1130	20	1006	Yes	Yes
B	300	7.2	920	981.8	980	20	1002	No	Yes
C	150	1.4	925	976.0	1115	20	996.0	Yes	Yes
E	250	2.2	980	980	1120	20	1000	Yes	Yes
F	160	8.2	960	982.8	1125	20	1003	Yes	Yes
G	400	16.4	990	991.0	1115	20	1011	Yes	Yes
H	250	25.4	1000	1000	1140	20	1020	Yes	Yes

Table 9. Iteration 5 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time	Process Completion Time	Time Windows	Liquid limit Constraint
O	0	13	900	1009	1140	20	1029.033	Yes	Yes

Table 10. Iteration 6 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time Unloading	Process Completion Time	Time Windows Constraint	Liquid limit Constraint
A	430	6	910	1035.033	1130	20	1055.0	Yes	Yes
B	300	5	920	1034.033	980	20	1054.0	No	Yes
C	65	13	925	1042.033	1115	10.83	1052.9	Yes	Yes
E	250	13.8	980	1042.833	1120	20	1062.8	Yes	Yes
F	160	20.8	960	1049.833	1125	20	1069.8	Yes	Yes
G	400	3.6	990	1032.633	1115	20	1052.6	Yes	Yes
H	250	12.2	1000	1041.233	1140	20	1061.2	Yes	Yes

Table 11. Iteration 7 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time Unloading	Process Completion Time	Time Windows Constraint	Liquid limit Constraint
O	0	3.6	900	1056	1140	20	1076	Yes	Yes

Table 12. Iteration 8 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time Unloading	Process Completion Time	Time Windows Constraint	Liquid limit Constraint
A	430	6	910	1082.233	1130	20	1102.2	Yes	Yes
B	300	5	920	1081.233	980	20	1101.2	No	Yes
C	65	13	925	1089.233	1115	10.83	1100.1	Yes	Yes
E	250	13.8	980	1090.033	1120	20	1110.0	Yes	Yes
F	160	20.8	960	1097.033	1125	20	1117.0	Yes	Yes
G	280	3.6	990	1079.833	1115	20	1099.8	Yes	Yes
H	250	12.2	1000	1088.433	1140	20	1108.4	Yes	Yes

Table 13 shows the results of the 9th iteration for vehicle 1, where the closest point to node O that can be served is node G. After serving that node, vehicle 1 returns to the depot according to the plan in Table 14, which is the result of the 10th iteration. In this iteration, the vehicle completes the delivery route by returning to the depot after serving all nodes that are still possible within the time constraints. However, Table 15 shows the results of the 11th iteration, where vehicle 1 can no longer serve several nodes (B, C, E, F, and G) because the time window constraints have been exceeded, as indicated by the No status. This is also influenced by the warehouse operating hours, which indicate that delivery to these nodes is no longer feasible. Under these conditions, an additional vehicle, vehicle 2, is needed to continue distribution to the unfulfilled nodes. The addition of this vehicle aims to ensure that all customer requests are fulfilled without violating the specified time window constraints. This strategy is important to maintain operational efficiency and ensure that distribution services remain in line with customer needs and existing time constraints.

Table 13. Iteration 9 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time Unloading	Process Completion Time	Time Windows	Liquid limit
O	0	3.6	900	1103.433	1140	20	1123.4	Yes	Yes

Table 14. Iteration 10 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time Unloading	Process Completion Time	Time Windows	Liquid limit
A	430	6	910	1129.433	1130	20	1149.4	Yes	Yes
B	300	5	920	1128.433	980	20	1148.4	No	Yes
C	65	13	925	1136.433	1115	10.83	1147.3	No	Yes
E	250	13.8	980	1137.233	1120	20	1157.2	No	Yes
F	160	20.8	960	1144.233	1125	20	1164.2	No	Yes
G	160	3.6	990	1127.033	1115	20	1147.0	No	Yes
H	250	12.2	1000	1135.633	1140	20	1155.6	Yes	Yes

Table 15. Iteration 11 for vehicle 1

Node	Demand	Travel Time	ai	Start Time (Wi)	bi	Time Unloading	Process Completion Time	Time Windows	Liquid limit
O	0	13	900	1160	1140	20	1180	No	Yes

Based on the results of determining the first route of vehicle 1 obtained using the nearest neighbor algorithm, it is depot O (PT Agung Jaya) →node A (Bajoe fish auction) →depot O →node D (Cumpae) →node C (Lapecce pier) →depot O →node G (Bajo beach) → Depot O → Node G → Node O. The distance of this route is 26.4 kilometers. With 900 minutes, from 3:00 p.m. to 1123.43 minutes, in 18.72 hours, the total time is 223.43 minutes or 3.72 hours. For more details, refer to Table 12. Distribution route results for each vehicle. In real-world high-season demand scenarios, the company is unable to meet demand. This is due to suboptimal scheduling and insufficient fleet capacity. Therefore, improvements are made during peak periods without violating constraints.

Table 16. Distribution route results for each vehicle

Vehicle	Route	Distance (km)	Time (Minutes)
1	O-A-O-D-C-O-G-O-G-O	26.8	223.43
2	O-A-O-C-E-O-G-O-G-A-O	33.9	249.3
3	O-A-O-A-E-O-H-O	34.4	213.57
4	O-B-O-B-O-H-O-H-O	34.4	232.35
5	O-B-F-O-E-O-E-O	48.2	246.83
6	O-F-O	20.8	117.47

From the results in Table 16, which explains the distribution route for each vehicle, it can be concluded that the first route visiting nodes O-A-O-D-C-O-G-O-G-O covers a distance of 26.48 km with a travel time of 223.43 minutes. Second, the route with nodes O-A-O-C-E-O-G-O-G-A-O has a distance of 33.9 km and a travel time of 249.3 minutes for vehicle 2. Third, the calculation results for route O-A-O-A-E-O-H-O yielded a distance of 34.4 km and a travel time of 213.57 minutes for vehicle 3.

Fourth, for vehicle 4, the result was obtained with the route O-B-O-B-O-H-O-H-O, producing a distance of 34.4 km in a travel time of 232.35 minutes. Fifth, for vehicle 5, the route with nodes O-B-F-O-E-O-E-O resulted in a distance of 48.2 km in 246.83 minutes. Finally, for vehicle 6, the route O-F-O resulted in a distance of 20.8 km in 117.47 minutes.

In this study, to facilitate understanding of the route determination results, the researcher used the Python programming language to visualize the routes in graph form. This visualization provides a more intuitive picture of each vehicle's distribution route, complete with information on distance traveled, travel time, and the relationship between the nodes passed. By utilizing Python, each route is clearly visualized with nodes representing the depot and destination locations, as well as connecting lines that illustrate the vehicle's travel flow.

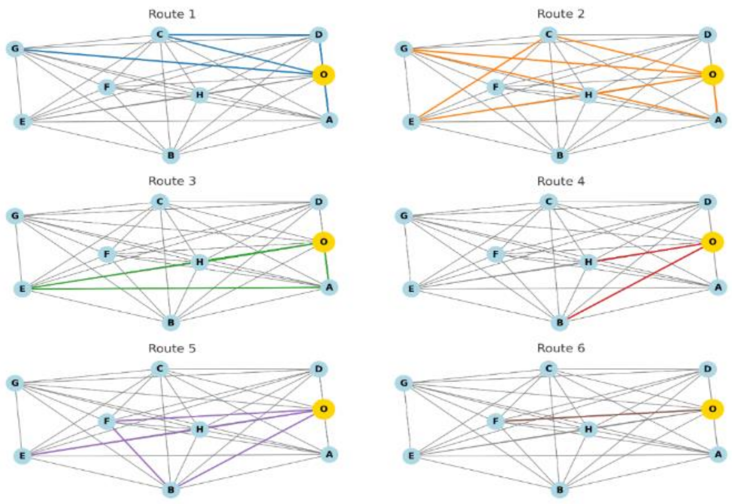

Figure 3. Selected Fleet Route

CONCLUSION AND RECOMMENDATION

This study shows that even though the distribution schedule has been well designed, there are still opportunities to improve efficiency by reducing duplicate visits to certain nodes and adding to the fleet, especially during high demand seasons. With schedule optimization, additional fleet investment, and special planning during high season, companies can improve distribution efficiency, reduce operating costs, and provide more timely service. This research can be used as a reference by management in determining ice block distribution routes in the Bone Regency area.

FURTHER STUDY

In the future, further research using other optimization methods such as Tabu Search, LINGO, or Farthest Insertion is recommended to compare more optimal results. In addition, advanced algorithm-based approaches such as Genetic Algorithm, Simulated Annealing, and Ant Colony Optimization, as well as the application of big data and machine learning, can enrich demand forecasting and dynamic scheduling. Computer simulations and AI-based fleet management systems also have the potential to improve responsiveness to actual conditions and optimize multi-location distribution networks as a whole.

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