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Large neighborhood search for route and fleet optimization in frozen food distribution

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ABSTRACT

This study develops an optimization model to enhance the distribution efficiency of a frozen food distributor. The company faces operational inefficiencies due to excessive fleet capacity and conventional route assignment methods, which increase travel distances and overall distribution costs. To address these challenges, an extended Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) model is proposed, which integrates heterogeneous fleet characteristics and prioritizes customer service constraints. The model is solved using the Large Neighborhood Search (LNS) metaheuristic to determine optimal routing and fleet allocation strategies. The optimized model achieves a 15.95% reduction in total travel distance and a 21.84% decrease in total distribution costs compared with the company's current operations. The findings confirm the effectiveness of the LNS-based CVRPTW approach in improving logistics performance and provide practical insights for companies seeking to minimize distribution costs through strategic route planning and fleet management.

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1. INTRODUCTION

Efficiency in the distribution process is a cornerstone of modern supply chain management, directly impacting operational costs, resource utilization, and customer satisfaction [1], [2]. In the pursuit of a competitive advantage, companies continually seek methods to optimize their logistics operations, particularly in the realm of vehicle routing, also known as the Vehicle Routing Problem (VRP) [3]. The VRP constitutes a class of optimization problems aimed at determining a set of optimal routes for a vehicle fleet. This challenge remains central to both academic research and industrial practice [4].

The state of the art in VRP research is extensive, with foundational models like the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) providing a basis for numerous modern variants that address complex, real-world scenarios [5]. The field is rapidly evolving to tackle emerging challenges such as sustainability through green VRPs [6], the integration of autonomous vehicles like drones, and dynamic routing in response to real-time disruptions [7]–[9]. While these models are powerful, a core hypothesis of this study is that their standard formulations are often insufficient to address unique business rules. A critical research gap exists where many models do not explicitly integrate strategic constraints such as the presence of priority customers who require differentiated service levels, a topic of growing importance in today's customer-centric, last-mile logistics environment [10]–[12]. In this study, the priority customer mechanism is modeled as a hard scheduling constraint rather than a soft penalty, ensuring that priority customers are always served earlier regardless of distance or route geometry. The development of powerful heuristics and metaheuristics to find high-quality solutions for these complex VRP instances has therefore been a major focus of contemporary research [13].

This study specifically addresses the challenges faced by a frozen food distributor. The company utilizes a diverse (*heterogeneous*) fleet and implements a strategic policy to prioritize service for certain customers, a factor that introduces additional complexity into route determination. The significance of this research lies in its effort to bridge the gap between existing VRP theory and actual business practice through the development of a tailored model for the Heterogeneous Fleet VRP [14], [15]. This study also contributes a practical Excel-based VBA optimization tool that makes advanced routing methods accessible to SMEs. In addition, the model provides a clear managerial insight by showing that the fleet can be reduced from four to three vehicles, resulting in measurable cost savings.

The primary objective of this research is to design and develop an extension of the classic CVRPTW model, originally built by Solomon [16], by modifying its formulation to accommodate the priority customer constraint. Priority customers are modeled using a hybrid mechanism that combines strict ordering constraints, and modified time-window logic. To achieve this, the Large Neighbourhood Search (LNS) algorithm is employed, with the model's implementation and solution process carried out using Visual Basic for Applications (VBA) within Microsoft Excel [17]. LNS and its adaptive variants remain state-of-the-art metaheuristics, frequently implemented to solve complex VRPs due to their flexibility and effectiveness in exploring vast solution spaces [18]–[20].The algorithm's efficacy relies on a 'destroy and repair' mechanism, where the strategic choice of removal and insertion operators is critical to its success, with ongoing research continuously proposing more sophisticated operator designs [21]. This methodology has proven robust in a wide range of logistics applications, affirming its suitability for this study [22]. As its main conclusion, the study validates the model's efficacy by revealing a pathway to major operational improvements. The results show a significant optimization of the vehicle fleet, leading to a marked reduction in the total distance traveled and a considerable decrease in overall distribution expenditures [23].

2. MODEL DEVELOPMENT

This section describes the characteristics of the system, notations and assumptions, the mathematical model, and the proposed solution procedure.

2.1. System Description

The system analyzed in this study represents the distribution process of a frozen food distributor operating in the Solo Raya region, Indonesia. The company serves a diverse range of customers, including supermarkets, minimarkets, and hotels. Distribution activities are carried out using a heterogeneous fleet of four vehicles, consisting of two light trucks (each with a capacity of 300 boxes) and two light commercial vans (each with a capacity of 120 boxes). Every vehicle is operated by a two-person crew comprising one driver and one assistant.

Daily operations are conducted between 08:00 and 16:30, with a maximum working duration of eight hours per crew, including a 30-minute break. The service time at each customer location consists of a variable unloading component—approximately 30 seconds per box—and a fixed administrative component ranging from five to fifteen minutes, depending on the customer category. A key operational constraint is the company's strategic policy to prioritize early deliveries to customers classified as Local Modern Trade (LMT) supermarkets to maintain high service levels and strengthen customer satisfaction.

2.2. Notations and Assumptions

The following notations are used in this model.

Decision variables:

X_{ijk} : Vehicle k traveling from node i to node j

Y_k : The type of vehicle k employed

Sets:

V : Set of customers
K : Set of vehicles
A : Set of arcs (i, j)
P : Set of priority customers
N : Set of non-priority customers

Parameters:

d_{ij} : Distance between the customer $i$and customer j.
q_i : Demand/service quantity at the customer i.
S_i : Service time at the customer i.
F_k : Fixed operational cost of the vehicle k.
c_k : Variable transportation cost per kilometer for the vehicle k.
Q_k : Maximum capacity of the vehicle k.
W_k : Maximum allowable working time of the vehicle k.
T^* : Priority service cut-off time; Priority status (1 = priority customer, 0 otherwise).
P_v

The following assumptions were adopted in developing the model:

1. The travel distance and travel time for each vehicle are obtained from Google Maps data and are assumed to accurately represent real-world traffic conditions.
2. The service time at each customer location comprises two components: unloading time and administrative time.
3. The total working duration for all distribution activities is assumed to remain constant across each operational day.

2.1 Mathematical Model

This study proposes an extended CVRPTW model that integrates heterogeneous fleet characteristics, time window constraints, and a priority customer logic. Unlike simply assigning an early TW, our model forces priority customers to be served earlier via an arrival-time ordering constraint, ensuring they appear earlier in the route even if travel time or geography indicates otherwise. The model is developed based on an empirical case study at a frozen food distribution company in Indonesia. Its formulation is adapted and expanded from the foundational CVRPTW framework originally proposed by Solomon [16].

The decision variables in the model represent the optimal vehicle routing paths and the selection of vehicle types. The objective function aims to minimize the total distribution cost per planning period. The total distribution cost comprises both fixed and variable components: fixed costs include driver and assistant wages, vehicle taxes, and depreciation, while variable expenses cover fuel consumption and vehicle maintenance.

To determine the optimal values of these decision variables, the LNS metaheuristic is employed due to its proven effectiveness in solving complex combinatorial optimization problems. The algorithm is implemented using VBA in Microsoft Excel. LNS was selected because it provides a strong solution quality for medium-sized VRPTW instances, offers flexible destroy–repair operators compatible with heterogeneous fleet and priority constraints, and can be efficiently implemented in Excel VBA, making it suitable for SMEs. The model development process is structured to align with the research objectives and is guided by the characteristics and constraints identified in the case study system. The general formulation of the model is presented as follows.

$$\min Z = \sum \left(F_k Y_k + \sum_i \sum_j c_k \, d_{ij} X_{ijk} \right) \tag{1}$$

The total transportation cost is composed of two main components: fixed costs and variable costs. The fixed cost component includes driver and assistant wages, vehicle taxes, and depreciation expenses. In contrast, the variable cost component consists of fuel consumption and vehicle maintenance expenses. These cost components collectively form the objective function of the model, which aims to minimize the overall distribution cost. Based on these cost definitions, the model is subject to the following constraints:

1. This constraint ensures that each customer is visited exactly once by a single vehicle, preventing both unserved customers and duplicate visits, and thereby guaranteeing complete demand fulfillment without routing redundancy

$$\sum_{j \in V} \sum_{k \in K} X_{ijk} = 1, \forall i \in V \tag{2}$$

2. The constraint enforces that each vehicle route starts at the depot, reflecting the operational condition in which all distribution activities originate from a centralized facility.

$$\sum_{i \in V_0} X_{0jk} = 1, \forall k \in K \tag{3}$$

3. The constraint requires that every active vehicle return to the depot after completing its route, ensuring that all routes are closed and operationally feasible within a daily planning horizon.

$$\sum_{i \in V} X_{i0k} - \sum_{j \in V} X_{0jk} = 0, \ \forall k \in K \tag{4}$$

4. The constraint restricts the total customer demand served by a vehicle not to exceed its maximum load capacity, and represents the physical limitations of the vehicles, ensuring that the routing solution is feasible in practice

$$\sum_{i \in V} q_i \sum_{i \in V} X_{ijk} \leq Q_k Y_k \tag{5}$$

5. The constraint ensures that the combined travel time and service time of each vehicle route does not exceed the maximum allowable working time, thereby maintaining compliance with daily operational and labor regulations.

$$\sum_{i \in V} S_i Y_k + \sum_{i,j \in A} d_{ij} X_{ijk} \leq W_k, \forall k \in K \tag{6}$$

6. This constraint defines the binary nature of the routing decision variables, indicating whether a vehicle travels from node $i$to node j, and ensures logical consistency in route selection.

$$X_{ijk} \in \{0,1\} \forall i,j \in V, \forall k \in K \tag{7}$$

7. The constraint links route selection to vehicle activation, ensuring that a vehicle is considered active only if it is assigned to at least one route segment, and enables accurate accounting of fixed fleet-related costs.

$$Y_k \in \{0,1\} \forall k \in K \tag{8}$$

8. Priority customer service time constraint. Both constraints enforce that priority customers are served before a predefined cut-off time, regardless of route geometry or travel distance. This mechanism models priority service as a hard scheduling constraint, ensuring that priority customers are consistently served earlier within each delivery route.

$$t_i \leq T^*, \ \forall i \in P \tag{9a}$$

$$t_i > T^*, \ \forall j \in N \tag{9b}$$

3. RESULTS

3.1. Development of the VBA tool

The first stage involves the development of a VBA-based computational tool designed to support parameter calculation and solution search processes. The tool integrates several key worksheets, including a custom user interface (ribbon), an initial configuration sheet, a location database, a distance–time matrix, a vehicle data sheet, and a solution output sheet. Each component was developed to ensure seamless interaction between data input, computation, and result visualization.

The construction of the VBA tool represents the foundation of the model's solution procedure. It provides a structured environment that mirrors the operational characteristics of the distribution system while enabling automation of route optimization and cost evaluation tasks. Figure 1 to Figure **5** illustrate the structure and interface of the developed VBA tool, demonstrating its functionality and alignment with the modeled system characteristics. Figure 1 explains the initial configuration worksheet, which is used to verify that all initial condition settings are properly defined and aligned with the specified problem constraints and system characteristics.

Index	Parameter	Value	Notes
0. Interface	Language	Indonesian	
	Google Maps API Key	AIzaSyDZ8rLhjshUNhXOGwO_eaJP1Xxloz0aJgc	https://console.cloud.google.com/
1. Location	Number of Depots	1	[1,20]
	Number of Customers	24	[5,200]
2. Distance	Distance Calculation Method	Google Maps	
	Duration Calculation Method	Average vehicle speed	
3. Vehicle	Number of Vehicle Types	2	
4. Solution	Vehicle Return Policy	Yes - only once at the end	
	Time Window Type	Hard	

Figure 1. Initial configuration worksheet

On the location worksheet page, a verification process is conducted to ensure that any changes in the number of customers are correctly reflected in the system. As illustrated, the location worksheet displays a configuration with a total of 24 customers (Figure 2).

ID Location	Name	Address	Latitude (y)	Longtitude (x)	Service Time	Delivery Quantity	Priority Customer (0/1)
0	Depot				0:00	0	0
1	Customer1				0:00	0	0
2	Customer2				0:00	0	0
3	Customer3				0:00	0	0
4	Customer4				0:00	0	0
5	Customer5				0:00	0	0
6	Customer6				0:00	0	0
7	Customer7				0:00	0	0
8	Customer8				0:00	0	0
9	Customer9				0:00	0	0
10	Customer10				0:00	0	0
11	Customer11				0:00	0	0
12	Customer12				0:00	0	0
13	Customer13				0:00	0	0
14	Customer14				0:00	0	0
15	Customer15				0:00	0	0
16	Customer16				0:00	0	0
17	Customer17				0:00	0	0
18	Customer18				0:00	0	0
19	Customer19				0:00	0	0
20	Customer20				0:00	0	0
21	Customer21				0:00	0	0
22	Customer22				0:00	0	0
23	Customer23				0:00	0	0
24	Customer24				0:00	0	0

Figure 2. Location worksheet with 24 customers

On the distance (Figure 3 (a)) and time (Figure 3 (b)) matrix worksheet, a verification is performed to assess whether the distance and time matrices are automatically adjusted when the number of customers is modified.

	0	1	2	3	4	5	6	7	8	9	10	11	12
0		7,032	11,819	7,994	12,927	12,457	15,281	7,102	3,945	4,721	16,638	26,585	17,722
1	7,037		3,875	4,657	6,814	4,98	6,73	7,37	3,237	3,417	13,865	23,813	11,97
2	12,212	3,928		4,553	5,237	2,427	4,385	8,405	7,169	7,35	16,057	25,569	10,158
3	8,402	3,955	4,608		5,241	4,771	8,244	4,431	5,837	6,018	17,941	27,889	13,907
4	13,424	6,797	5,149	5,33		4,07	10,187	10,423	10,347	10,528	20,631	30,723	15,312
5	12,871	5,034	2,427	4,776	4,069		5,592	9,063	8,275	8,456	18,099	27,675	12,264
6	13,447	6,84	4,48	8,976	9,272	4,651		11,938	10,291	10,053	19,206	24,424	9,013
7	6,746	5,608	8,404	4,636	9,512	9,042	11,866		6,927	7,108	20,856	30,804	17,528
8	3,945	3,222	7,158	5,473	10,407	9,936	9,797	8,186		0,71	12,56	22,508	13,729
9	4,721	2,558	6,673	5,654	10,587	7,779	9,15	8,366	0,71		12,29	22,238	13,082
10	16,424	13,794	17,069	17,751	20,44	18,431	19,222	20,464	12,731	12,462		10,303	13,216
11	26,379	23,749	25,646	27,706	30,724	27,577	24,497	30,419	22,686	22,416	10,303		15,478
12	17,708	12,058	10,178	14,288	15,256	12,108	9,029	17,503	13,729	13,646	13,216	15,421	
13	11,769	7,251	12,179	11,309	13,568	14,11	11,03	14,022	7,791	7,708	10,21	15,459	5,939
14	9,57	13,387	16,662	15,742	20,676	18,024	18,857	17,748	10,677	11,387	11,412	21,714	23,241
15	19,602	25,074	42,218	38,34	38,901	41,139	47,257	25,191	22,364	23,075	20,781	29,758	33,997
16	34,032	52,877	52,924	49,046	49,606	51,844	57,962	42,907	37,948	38,658	40,105	48,81	67,713
17	27,34	47,584	47,631	43,753	44,313	46,552	52,67	37,614	31,256	31,966	32,912	41,889	62,42
18	21,654	28,182	40,875	36,997	37,557	39,795	45,913	23,848	25,57	26,281	27,227	36,204	55,664
19	13,217	19,746	40,006	18,769	36,688	38,927	26,056	15,411	17,133	17,844	19,617	30,24	29,857
20	18,564	25,093	40,342	36,463	37,024	39,262	45,38	20,758	22,48	23,191	25,021	33,997	55,131
21	17,154	23,682	34,042	22,705	30,724	32,962	29,992	19,348	22,353	23,129	29,373	39,946	35,707
22	14,061	14,222	21,478	12,028	18,16	20,398	19,257	9,083	16,982	17,248	29,922	39,87	36,267
23	14,822	10,503	7,992	6,672	4,236	7,102	12,382	8,13	12,385	12,566	23,474	33,565	18,154
24	11,915	18,443	21,291	17,466	29,114	21,93	24,753	14,109	17,114	17,889	25,52	36,093	31,853

	13	14	15	16	17	18	19	20	21	22	23	24
0	11,783	9,57	19,863	32,732	27,358	21,677	12,935	18,583	17,166	14,033	13,784	11,936
1	7,164	13,662	25,758	52,19	46,817	28,706	19,963	25,611	24,194	14,769	9,606	18,964
2	8,569	17,091	43,093	53,018	47,644	41,062	22,269	40,404	26,5	15,805	8,029	21,27
3	11,137	15,515	38,526	48,451	43,077	36,495	18,458	35,837	22,689	11,831	6,683	17,459
4	13,144	20,538	39,631	49,556	44,182	37,599	37,344	36,941	35,254	17,944	4,236	30,268
5	10,611	18,015	41,925	51,85	46,476	39,893	22,927	39,235	37,548	20,238	7,101	21,928
6	11,014	19,264	47,128	57,053	51,679	45,097	25,802	44,439	30,032	19,337	12,304	24,802
7	12,79	15,234	25,877	43,347	37,973	23,846	15,104	20,751	19,334	9,083	8,143	14,104
8	7,791	10,677	22,774	36,632	31,258	25,577	16,835	22,483	22,342	17,079	12,182	17,112
9	7,144	11,453	23,549	37,408	32,034	26,353	17,611	23,258	23,118	17,26	12,363	17,888
10	10,21	11,412	21,47	38,616	33,242	27,561	19,617	25,598	29,374	29,721	24,461	25,521
11	15,517	21,714	30,074	48,81	41,846	36,165	30,166	33,983	39,922	39,676	33,516	35,066
12	5,939	23,675	34,103	67,255	61,881	55,298	29,993	54,64	52,953	35,643	18,048	30,368
13		18,277	29,393	42,551	37,178	31,497	22,754	28,402	28,39	23,199	16,36	23,16
14	17,842		12,097	28,401	23,027	17,346	9,277	15,258	19,05	25,109	24,43	15,197
15	28,627	11,765		18,71	13,337	9,141	11,449	11,441	21,043	26,251	36,149	17,19
16	45,273	29,747	19,802		6,235	16,773	22,484	22,475	24,834	36,956	46,854	28,225
17	38,581	23,055	14,039	5,971		10,081	15,792	13,43	18,263	31,664	41,562	21,533
18	32,895	17,369	10,03	15,22	9,846		10,106	8,436	13,269	24,908	34,806	15,847
19	24,458	9,277	11,426	20,45	15,076	9,395		6,3	11,263	24,039	33,937	7,41
20	29,805	15,258	11,762	18,804	13,43	8,436	7,016		7,786	24,374	34,272	10,509
21	30,308	19,052	21,76	24,832	19,763	13,269	10,987	7,786		13,797	27,972	5,186
22	21,404	25,13	27,454	37,379	32,005	25,423	17,065	24,765	13,794		12,553	11,484
23	15,986	21,936	36,364	46,289	40,915	34,333	21,626	33,675	31,987	12,393		20,627
24	26,455	15,199	17,907	26,931	21,557	15,876	7,134	10,509	5,186	11,038	20,807	

(a) Distance matrix worksheet

	0	1	2	3	4	5	6	7	8	9	10	11	12
0		00:17:55	00:27:15	00:19:12	00:29:42	00:28:12	00:34:44	00:16:10	00:09:43	00:12:00	00:31:06	00:46:37	00:40:00
1	00:17:03		00:12:56	00:12:11	00:19:05	00:15:44	00:17:48	00:17:25	00:08:43	00:09:27	00:27:05	00:42:36	00:23:42
2	00:27:34	00:12:23		00:10:43	00:10:54	00:05:53	00:10:16	00:19:01	00:21:08	00:21:53	00:34:09	00:45:53	00:19:01
3	00:20:01	00:09:55	00:10:40		00:11:36	00:10:07	00:18:55	00:10:57	00:15:04	00:15:49	00:36:43	00:52:14	00:27:45
4	00:32:06	00:20:25	00:12:05	00:13:24		00:10:08	00:21:08	00:21:13	00:25:48	00:26:33	00:44:57	00:57:59	00:31:07
5	00:28:58	00:15:05	00:05:45	00:10:15	00:08:35		00:11:55	00:20:24	00:23:50	00:24:34	00:39:06	00:51:00	00:24:08
6	00:33:25	00:18:29	00:10:45	00:19:13	00:18:42	00:10:48		00:27:04	00:26:55	00:26:02	00:35:48	00:42:52	00:16:00
7	00:15:54	00:14:08	00:19:09	00:10:45	00:21:36	00:20:06	00:26:38		00:18:00	00:18:45	00:41:20	00:56:50	00:35:28
8	00:09:37	00:08:41	00:19:53	00:14:39	00:25:08	00:23:39	00:26:00	00:19:53		00:02:07	00:22:37	00:38:07	00:30:37
9	00:11:50	00:08:18	00:20:06	00:15:26	00:25:55	00:22:54	00:24:59	00:20:40	00:02:08		00:22:26	00:37:56	00:29:37
10	00:29:21	00:26:57	00:35:52	00:35:30	00:44:06	00:39:55	00:36:10	00:40:44	00:22:36	00:22:28		00:16:32	00:23:35
11	00:45:04	00:42:40	00:46:08	00:51:13	00:56:37	00:49:47	00:43:31	00:56:28	00:38:20	00:38:11	00:16:38		00:27:08
12	00:39:38	00:24:54	00:19:05	00:27:40	00:29:33	00:22:43	00:16:27	00:34:46	00:30:21	00:27:13	00:23:04	00:26:54	
13	00:28:44	00:17:58	00:23:55	00:28:24	00:32:04	00:27:33	00:21:17	00:33:39	00:19:26	00:16:18	00:18:34	00:28:20	00:11:16
14	00:19:41	00:29:59	00:38:54	00:34:48	00:45:18	00:42:57	00:43:34	00:33:36	00:22:06	00:24:13	00:20:26	00:36:58	00:41:44
15	00:35:31	00:49:30	00:45:19	00:40:39	00:38:23	00:43:22	00:54:22	00:42:24	00:41:37	00:43:44	00:34:14	00:49:38	00:57:50
16	00:57:28	01:01:36	00:57:06	00:52:25	00:50:10	00:55:09	01:06:09	00:56:17	01:06:44	01:08:52	01:04:45	01:18:32	01:12:24
17	00:44:54	00:50:26	00:45:56	00:41:16	00:39:00	00:43:59	00:54:59	00:45:07	00:54:10	00:56:17	00:53:49	01:09:13	01:01:14
18	00:36:43	00:48:14	00:42:07	00:37:27	00:35:11	00:40:10	00:51:10	00:39:12	00:46:00	00:48:07	00:45:39	01:01:03	00:57:25
19	00:24:17	00:35:48	00:39:30	00:33:46	00:32:35	00:37:33	00:49:17	00:26:45	00:33:33	00:35:41	00:36:17	00:51:13	00:54:34
20	00:34:02	00:45:33	00:43:03	00:38:23	00:36:07	00:41:06	00:52:06	00:36:30	00:43:18	00:45:25	00:43:56	00:59:20	00:58:21
21	00:29:27	00:40:59	00:45:54	00:38:56	00:38:58	00:43:56	00:54:28	00:31:56	00:38:39	00:40:56	00:47:32	01:05:08	01:02:26
22	00:28:12	00:30:49	00:32:18	00:25:48	00:25:22	00:30:20	00:41:41	00:20:28	00:34:16	00:35:54	00:56:19	01:11:49	00:47:35
23	00:33:39	00:24:15	00:17:58	00:15:05	00:09:59	00:16:48	00:28:14	00:19:17	00:29:24	00:30:09	00:50:50	01:03:51	00:36:59
24	00:21:11	00:32:43	00:38:43	00:30:40	00:34:31	00:39:40	00:46:12	00:23:40	00:30:23	00:32:40	00:41:36	00:59:12	00:56:30

	13	14	15	16	17	18	19	20	21	22	23	24
0	00:28:44	00:19:23	00:35:49	00:54:48	00:44:05	00:35:33	00:23:03	00:33:50	00:28:42	00:27:46	00:30:59	00:20:47
1	00:17:45	00:29:02	00:49:17	01:03:38	00:52:51	00:48:30	00:36:00	00:46:47	00:41:39	00:32:27	00:26:07	00:33:44
2	00:21:49	00:38:34	00:47:44	00:57:39	00:46:52	00:42:59	00:40:01	00:42:51	00:45:41	00:34:03	00:17:56	00:37:45
3	00:26:32	00:33:43	00:42:04	00:51:59	00:41:13	00:37:19	00:32:28	00:37:11	00:38:08	00:25:59	00:15:07	00:30:12
4	00:32:37	00:45:48	00:41:16	00:51:11	00:40:25	00:36:31	00:35:04	00:36:23	00:39:01	00:26:41	00:11:02	00:36:50
5	00:26:46	00:41:27	00:45:25	00:55:20	00:44:34	00:40:41	00:41:25	00:40:32	00:43:10	00:30:51	00:16:13	00:39:09
6	00:21:01	00:42:56	00:55:33	01:05:28	00:54:41	00:50:48	00:48:05	00:50:40	00:53:44	00:42:06	00:26:20	00:45:49
7	00:30:45	00:32:09	00:43:08	00:55:22	00:44:36	00:38:23	00:25:53	00:36:41	00:31:33	00:20:14	00:18:58	00:23:37
8	00:19:21	00:21:12	00:41:27	01:03:53	00:53:10	00:44:38	00:32:08	00:42:56	00:38:10	00:34:26	00:29:01	00:30:14
9	00:18:20	00:23:25	00:43:40	01:06:06	00:55:23	00:46:51	00:34:21	00:45:08	00:40:22	00:35:12	00:29:48	00:32:27
10	00:18:37	00:20:25	00:36:15	01:04:59	00:54:16	00:45:44	00:35:39	00:45:31	00:47:27	00:54:31	00:49:52	00:41:48
11	00:28:14	00:37:04	00:50:13	01:17:11	01:08:14	00:59:42	00:52:16	00:59:12	01:04:04	01:10:14	01:03:39	00:58:06
12	00:10:54	00:42:00	00:59:03	01:11:30	01:00:43	00:56:50	00:53:52	00:56:42	00:59:20	00:47:00	00:36:35	00:53:30
13		00:31:45	00:49:39	01:15:34	01:04:51	00:56:19	00:43:49	00:54:36	00:50:51	00:49:11	00:39:06	00:42:55
14	00:31:06		00:20:14	00:47:53	00:37:11	00:28:38	00:17:00	00:26:52	00:29:46	00:40:54	00:48:26	00:24:07
15	00:48:28	00:19:25		00:33:58	00:23:16	00:18:01	00:20:23	00:23:03	00:33:25	00:34:03	00:45:03	00:27:46
16	01:17:07	00:50:30	00:35:57		00:14:53	00:32:02	00:37:56	00:40:36	00:44:57	00:45:49	00:56:50	00:45:19
17	01:04:33	00:37:56	00:25:07	00:12:51		00:19:28	00:25:22	00:26:59	00:33:38	00:34:40	00:45:40	00:32:44
18	00:56:22	00:29:45	00:19:58	00:30:07	00:19:25		00:17:11	00:17:34	00:24:13	00:30:51	00:41:51	00:24:34
19	00:43:56	00:17:42	00:19:34	00:34:04	00:23:21	00:14:49		00:13:07	00:17:46	00:28:14	00:39:14	00:12:08
20	00:53:41	00:26:52	00:23:07	00:37:16	00:26:33	00:17:05	00:14:30		00:15:00	00:31:47	00:42:47	00:20:30
21	00:51:48	00:29:51	00:34:46	00:42:08	00:34:07	00:23:54	00:17:31	00:15:04		00:27:28	00:45:37	00:11:23
22	00:47:25	00:40:50	00:35:32	00:45:27	00:34:41	00:30:48	00:28:30	00:30:39	00:27:47		00:26:37	00:22:51
23	00:38:30	00:47:21	00:46:15	00:56:10	00:45:23	00:41:30	00:40:31	00:41:22	00:44:00	00:25:46		00:38:15
24	00:45:52	00:23:55	00:28:50	00:43:20	00:32:38	00:24:05	00:11:35	00:20:32	00:11:36	00:21:43	00:39:13	

(b) Time matrix worksheet

Figure 3. Distance (a) and Time (b) data matrices

Figure 4 presents the fleet worksheet after the model has been executed. The resulting fleet worksheet corresponds to the number of vehicles specified in the initial configuration, indicating that the fleet setup has been generated correctly.

Starting from	Vehicle Type	Capacity	Fixed Cost per Trip	Variable Cost per Unit Distance	Working Time Limit	Number of Vehicles
Depot	LT HINO	300	Rp 241.734	Rp 1.203	8:00	2
	GM	120	Rp 236.865	Rp 1.247	8:00	2

Figure 4. Vehicle worksheet

The next stage involves generating the solution worksheet by applying the LNS algorithm, in which the resulting solutions correspond to the available fleet size. The appearance of the solution worksheet, illustrated using examples with 4 vehicles, is shown in Figure 5.

Total Cost:	Rp 1.230.289						
Vehicle:	V1 (LT HINO)	Stops:	13	Cost :	Rp 390.042		
Stop Count	Location Name	Distance Traveled	Driving Time	Arrival Time	Departure Time	Work Time	Load
0	Depot	0,00	0:00		08:00	0:00	87
1	sami luwes	6,64	0:17	08:17	08:46	0:46	59
2	Kkm grosir	20,30	0:46	09:15	09:22	1:22	54
3	Bares frozen	32,40	1:06	09:42	09:53	1:53	43
4	london	51,11	1:40	10:27	10:37	2:37	42
5	Master Frozen	57,35	1:55	10:52	10:58	2:58	40
6	Pondok ibnu abas klaten	67,43	2:14	11:18	11:24	3:24	38
7	Monique Klaten	77,53	2:31	11:41	11:46	3:46	37
8	Arfathar	83,83	2:44	11:59	12:10	4:10	25
9	Keenan	91,62	2:59	12:25	12:31	4:31	23
10	Toko bima	96,81	3:11	12:43	12:57	4:57	4
11	Shafa	107,85	3:33	13:19	13:26	5:26	1
12	ryu mart	116,93	3:53	13:46	13:57	5:57	0
13	Depot	123,28	4:08	14:12		6:12	0
14							
15							
16							
17							
18							
19							
20							

Vehicle:	V2 (LT HINO)	Stops:	0	Cost :	Rp 241.734		
Stop Count	Location Name	Distance Traveled	Driving Time	Arrival Time	Departure Time	Work Time	Load
0	Depot	0,00	0:00		08:00	0:00	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Vehicle:	V3 (GM)	Stops:	13	Cost :	Rp 361.647		
Stop Count	Location Name	Distance Traveled	Driving Time	Arrival Time	Departure Time	Work Time	Load
0	Depot	0,00	0:00		08:00	0:00	109
1	LUWES MOJOSONGO	11,43	0:26	08:26	08:43	0:43	105
2	aneka frozen food	18,60	0:47	09:04	09:12	1:12	99
3	toko amida	19,31	0:49	09:14	09:20	1:20	98
4	waroeng LA	31,60	1:12	09:42	09:48	1:48	97
5	toko tiga putra	41,90	1:28	10:04	10:10	2:10	96
6	warung sayur kita 2	57,41	1:57	10:38	10:44	2:44	94
7	toko alfara	63,25	2:08	10:55	11:01	3:01	93
8	PERBEKUAN FROZEN UNS	72,43	2:25	11:18	11:24	3:24	91
9	ulala frozen	77,08	2:36	11:35	12:07	4:07	37
10	toko haifa	81,15	2:44	12:15	12:22	4:22	34
11	Nur arief 2	85,38	2:55	12:33	12:43	4:43	33
12	SRIKANDI FROZEN	92,05	3:10	12:58	13:20	5:20	0
13	Depot	100,07	3:30	13:39		5:39	0
14							
15							
16							
17							
18							
19							
20							

Vehicle:	V4 (GM)	Stops:	0	Cost :	Rp 236.865		
Stop Count	Location Name	Distance Traveled	Driving Time	Arrival Time	Departure Time	Work Time	Load
0		0,00	0:00		08:00	0:00	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Figure 5. Solution worksheet for 4 vehicles

3.2. Model Execution through Replications

Following the development of the VBA-based tool, the model was executed through a series of replications to determine the optimal routing and fleet allocation solutions. The replications were conducted over a specified period corresponding to the week with the highest customer demand within a given month. This approach was adopted to ensure that the model was tested under the most operationally demanding conditions.

The results of these replications are summarized in Table 1 to Table 3, which present the daily run summaries and the corresponding costs incurred by each fleet. In the summary of the simulation results over a six-day replication period, the cost incurred by each vehicle is reported; a zero cost indicates that the vehicle was not utilized. The summarized results include the total travel distance along with the number of iterations (Table 1). Based on these results, the total distance traveled by all fleets using the optimized model amounts to 2,271.02 km.

Table 1. Summary of distance traveled for all replications

Day	Distance Traveled Vehicle 1 (km)	Distance Traveled Vehicle 2 (km)	Distance Traveled Vehicle 3 (km)	Distance Traveled Vehicle 4 (km)	Total Distance Traveled (km)
1	131.19	169.55	114.41	0	415.15
2	202.56	151.02	165.48	0	519.06
3	124.06	0	100.81	0	224.87
4	179.56	163.77	35.51	0	378.84
5	180.98	129.05	115.47	0	425.50
6	194.34	113.26	0	0	307.60
		TOTAL			2,271.02

Meanwhile, the comparison of the total distance traveled per day between the actual system and the modified model is presented in the Figure 6.

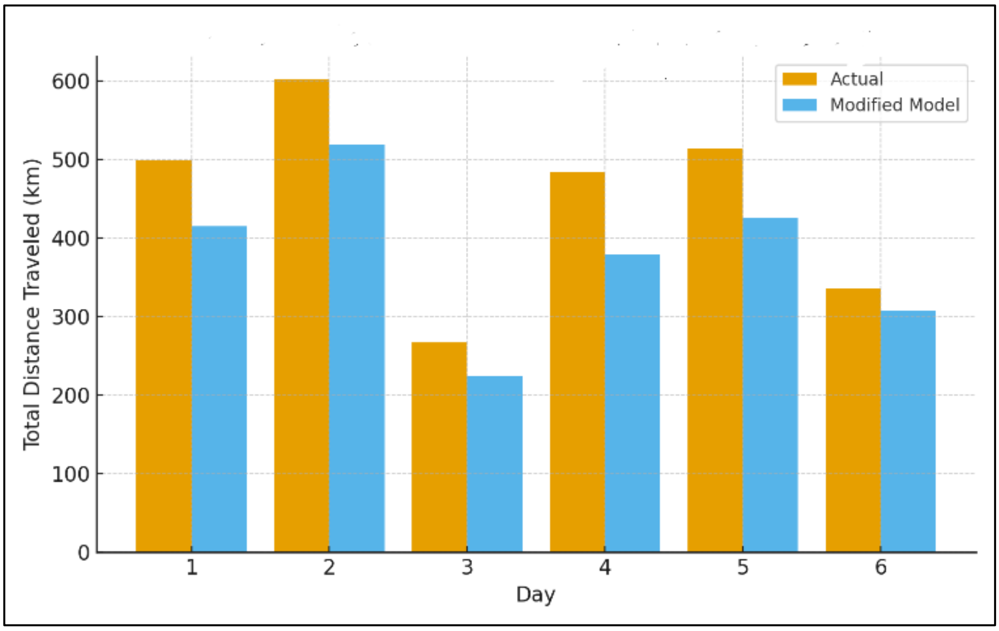


Figure 6. Total distance traveled per day: Actual vs. modified model

The second set of results includes the fleet travel time summary, in which Fleet 4 was not utilized in any replication, resulting in a working time of zero (Table 2). Based on these results, a comparison of the number of fleets used per day between the actual system and the modified model can be made, as shown in the Figure 7.

Table 2. Summary of travel time for all replications

Day	Travel Time Vehicle 1 (H:Mn)	Travel Time Vehicle 2 (H:Mn)	Travel Time Vehicle 3 (H:Mn)	Travel Time Vehicle 4 (H:Mn)
1	6:03	6:27	6:56	0:00
2	7:53	7:45	7:57	0:00
3	6:13	0:00	5:40	0:00
4	7:21	6:33	2:51	0:00
5	7:36	6:44	7:09	0:00
6	7:45	6:51	0:00	0:00

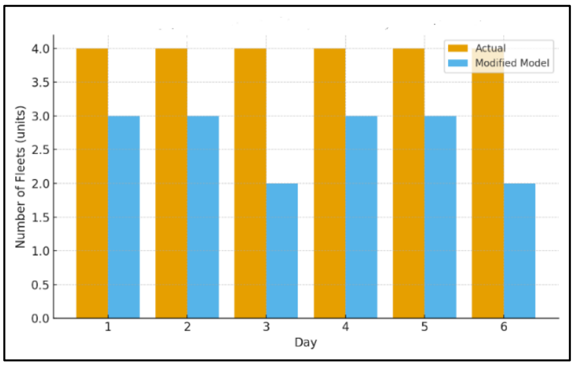


Figure 7. Number of fleets used per day: Actual vs. modified model

Based on the total cost across all replications, the total distribution cost amounts to IDR 8,498,627. Furthermore, Fleet 4 was not utilized; therefore, its total cost reflects only the fixed cost of IDR 236,865 (Table 3). Meanwhile, Figure 8 illustrates a comparison of the total daily distribution cost between the actual system and the modified model.

Table 3. Summary of total cost for all replications

Day	Cost Vehicle 1 (Rp)	Cost Vehicle 2 (Rp)	Cost Vehicle 3 (Rp)	Cost Vehicle 4 (Rp)	Total Cost (Rp)
1	399,554	445,698	379,528	236,865	1,461,645
2	485,415	423,411	443,224	236,865	1,588,915
3	390,981	241,734	362,570	236,865	1,232,150
4	457,747	438,747	281,151	236,865	1,414,510
5	459,458	396,975	380,861	236,865	1,474,159
6	475,527	377,991	236,865	236,865	1,327,248
TOTAL					8,498,627

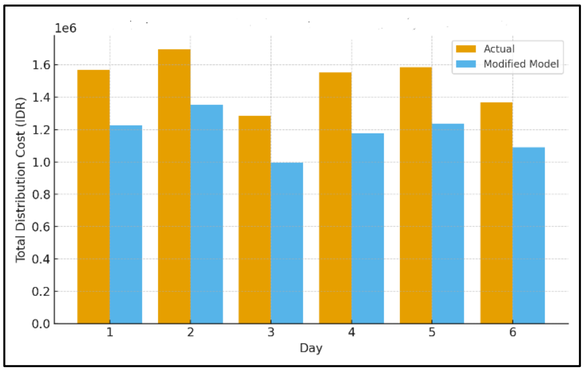


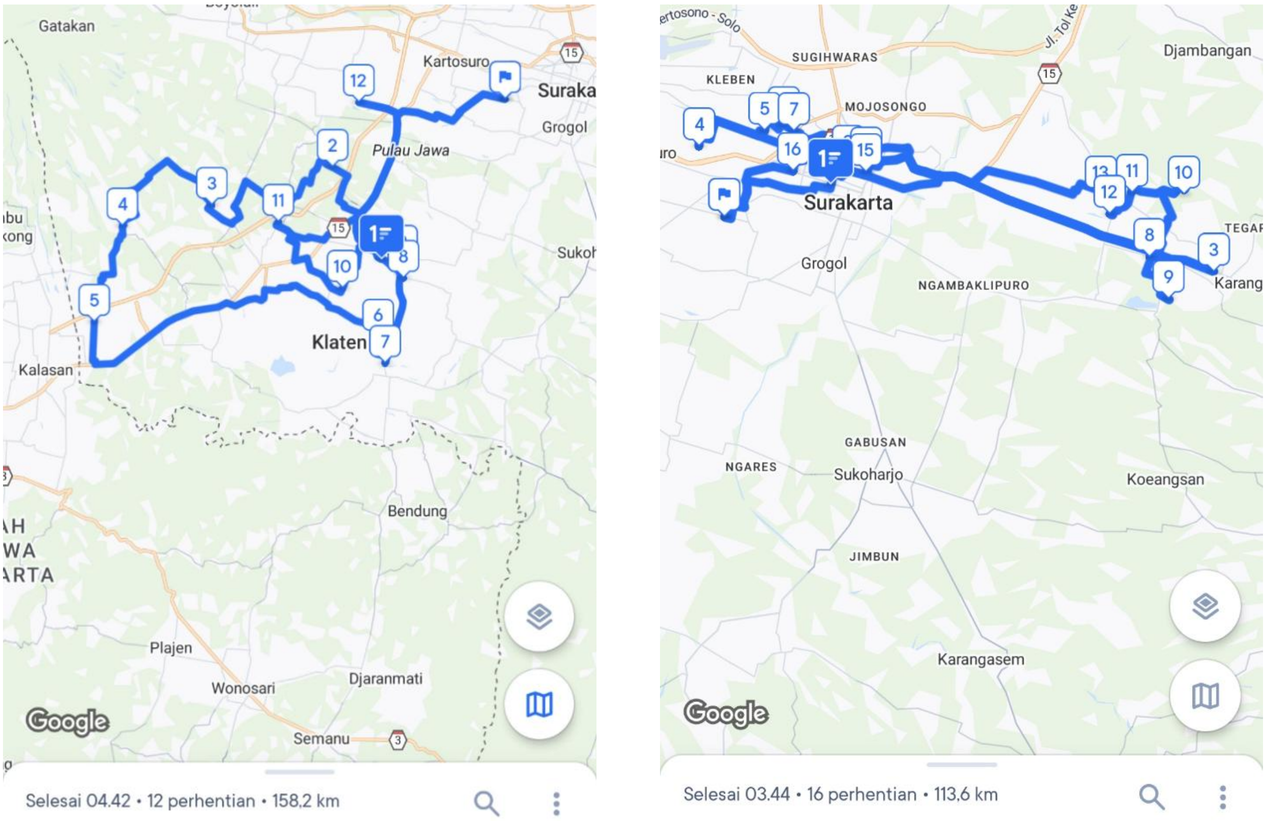
Figure 8. Total distribution cost per day: Actual vs. modified model.

3.3. Model validation

The third stage validates the model outputs to ensure that all constraints are satisfied and that the total travel distance generated by the VBA model aligns with actual distances obtained from Google Maps. This validation step confirms the accuracy and reliability of the model implementation.

The validation process was conducted to assess the realism and feasibility of the routes generated by the developed model. The results from the model runs indicate that all routing solutions are feasible and comply with the applied operational constraints. Specifically, the working time for each active vehicle adheres to the eight-hour daily limit and remains within the operational window of 08:00–16:30. Additionally, vehicle load levels do not exceed the respective maximum capacities. For the first day of operation, the model dispatched Fleets 1, 2, and 3, while Fleet 4 remained unused.

Route validation was further performed by comparing the total distances generated by the VBA model with the corresponding distances obtained from Google Maps (Figure 9). This comparison confirms that the distances computed by the model closely align with real-world conditions, demonstrating high consistency between simulated and actual route data. Table 4 presents a detailed comparison between the actual distances and the model-generated distances for each vehicle used on the first day of delivery. The close correspondence between the two validates the model's accuracy and applicability for real distribution operations.



(a) Actual route (b) Route generated by the proposed model

Figure 9. Actual route on the first day for Fleet 3 (GM Blind Van 1).

Table 4. Validation of actual and model-generated route distances

No.	Vehicle Type	Calculated Distance (km)		Validated Distance (km)	
		Actual	Modified Model	Actual	Modified Model
1	Hino LT 1	221,4	131,19	225,8	128,8
2	Hino LT 2	59,4	169,55	57,6	171,2
3	GM *Blind Van* 1	151,5	114,41	158,2	113,6
4	GM *Blind Van* 2	65,1	0	64	0

3.4. Sensitivity analysis

The final stage performs sensitivity analysis on the vehicle load capacity parameter to assess the model's responsiveness to parameter changes. The analysis examines scenarios with capacity variations of ±5% and ±10% to evaluate the stability and scalability of the proposed model.

In this study, a sensitivity analysis was conducted to evaluate the model's responsiveness to changes in vehicle load capacity. The analysis examined variations of −10%, −5%, +5%, and +10% in the load capacity parameter during the third day of the delivery period. Under the baseline scenario, the total distribution cost was IDR 995,285 (derived from IDR 1,232,150 after subtracting the fixed cost of the fourth vehicle), with a total travel distance of 224.87 km. The results of the sensitivity analysis are summarized in Table 5 and Table 6.

Table 5. Summary of sensitivity analysis for vehicle load capacity (-5% and -10%)

Vehicle Type	Capacity Change (%)	Load Capacity (boxes)	Distance Traveled (km)	Cost per Fleet (IDR)	Total Cost (IDR)
GM Blind Van 1	-5	114	73.48	328,495	
Hino LT 1	-5	285	155.73	429,077	
Hino LT 2	-5	285	0	241,734	999,306
GM Blind Van 1	-10	108	73.51	328,532	
Hino LT 1	-10	270	162.47	437,185	
Hino LT 2	-10	270	0	241,734	1,007,451

Table 6. Summary of sensitivity analysis for vehicle load capacity (+5% and +10%)

Vehicle Type	Capacity Change (%)	Load Capacity (boxes)	Distance Traveled (km)	Cost per Fleet (IDR)	Total Cost (IDR)
GM Blind Van 1	+10	132	52.72	302,607	
Hino LT 1	+10	330	167.63	443,393	
Hino LT 2	+10	330	0	241,734	987,734
GM Blind Van 1	+5	126	84.15	338,098	
Hino LT 1	+5	315	140.37	410,599	
Hino LT 2	+5	315	0	241,734	990,431

The analysis reveals that variations in vehicle load capacity have a substantial influence on both total travel distance and overall distribution cost. An increase in fleet capacity enables the model to generate more efficient routing solutions, thereby reducing total travel distance and, consequently, overall distribution expenditures. In contrast, a reduction in vehicle capacity limits feasible routing combinations and may compel vehicles to travel longer distances to meet all customer demands, which increases variable costs and total distribution expenses. These findings confirm that the model is highly sensitive to changes in vehicle capacity, emphasizing the strategic importance of optimal fleet configuration and capacity planning in enhancing logistics efficiency.

In addition, a sensitivity analysis was conducted to examine how the routing results change when the priority rule is relaxed. Three scenarios were compared: strict priority enforcement, a relaxed priority window, and the absence of priority constraints. The findings show that relaxing the rule increases routing flexibility and reduces both distance and cost, while the strict-priority case yields the highest operational cost due to limited routing freedom.

4. DISCUSSION

The application of the proposed LNS-based CVRPTW model to the case study of a frozen food distributor demonstrates its effectiveness in addressing the company's complex distribution planning challenges. The simulation results for the peak demand period reveal that the required fleet can be optimized from four to three vehicles, indicating that the current capacity is sufficient without additional resources. The optimized configuration results in a significant reduction in total travel distance—from 2,702.1 km to 2,271.02 km over six operational days—leading to notable operational cost savings. Under the optimized policy, the total distribution cost decreases, corresponding to a 21.84% reduction (Table 7). These improvements highlight the model's ability to enhance resource utilization and overall distribution efficiency.

Table 7. Comparative analysis of actual and optimized model results

Day	Total Distance Traveled (km)		Number of Fleets (units)		Total Distribution Cost (IDR)	
	Actual	**Modified Model**	**Actual**	**Modified Model**	**Actual**	**Modified Model**
1	499.5	415.15	4	3	1,567,627	1,224,780
2	602	519.06	4	3	1,696,544	1,352,050
3	267.3	224.87	4	2	1,285,869	995,285
4	484.2	378.84	4	3	1,552,538	1,177,645
5	513.5	425.5	4	3	1,584,815	1,237,294
6	335.6	307.6	4	2	1,367,463	1,090,383
TOTAL	2,702.1	2,271.02	4	3	9,054,856	7,077,437

Compared with existing models in the literature, such as those presented by Adi and Kusniawati [24], Fadjriani, et al. [25], which primarily considers homogeneous fleets, the proposed model provides additional value by simultaneously integrating two key dimensions of real-world distribution systems: heterogeneous fleet composition and priority customer service. While prior CVRPTW formulations offer strong methodological foundations, their simplifying assumptions often restrict their applicability in practice. By relaxing these assumptions, the present model achieves greater realism and applicability for distributors managing mixed fleets and differentiated customer segments. From an implementation perspective, the use of an Excel-based VBA optimization tool aligns with prior work by Erdogan [26], who demonstrated that spreadsheet-based VRP solvers can effectively support real-world decision making for small and medium-sized enterprises. This supports the practical relevance of the proposed model, particularly in environments where access to specialized optimization software is limited.

A further strength of the model lies in its explicit incorporation of the priority customer policy. Instead of assuming uniform service among all customers, the model prioritizes high-value clients, thereby aligning distribution decisions with corporate service-level objectives and customer retention strategies. From a managerial perspective, the developed framework serves as an effective decision-support tool that enables planners to transition from experience-based routing toward data-driven optimization. It provides quantitative evidence for both daily operational planning and long-term strategic decisions, such as fleet sizing, allocation, and investment planning. Moreover, the results emphasize the critical role of accurate data acquisition—particularly for travel time and service parameters—in sustaining optimization performance. The reduction in total distance traveled under the modified model also implies lower fuel use and consequently reduced CO_2 emissions. Because vehicle emissions are strongly correlated with distance, the improved routing contributes directly to a smaller carbon footprint even without calculating exact emission values.

The sensitivity analysis further validates the model's robustness. Variations of −10%, −5%, +5%, and +10% in vehicle load capacity were examined to assess the model's responsiveness to parameter changes. This parameter was selected because of its dual physical and financial significance. The analysis reveals that moderate adjustments in capacity substantially affect total distance and cost outcomes, underscoring the importance of optimal fleet utilization. These findings highlight a key managerial insight: even small improvements in capacity planning can generate measurable efficiency gains, reinforcing the value of continuous fleet assessment in logistics operations.

5. CONCLUSION

Based on the data processing and analysis presented in the preceding sections, several key conclusions can be drawn regarding the developed optimization model and its operational impact. This study successfully developed and implemented an LNS-based model for determining optimal routing and fleet allocation in frozen food distribution. A major contribution of the model lies in its capability to incorporate priority customer service constraints, ensuring that high-priority clients are served earlier within each delivery route. The proposed model provides a systematic framework that minimizes total distribution costs through the simultaneous optimization of fleet configuration and routing decisions. A key contribution of this research is the VBA-based optimization tool, which offers a practical solution for firms without specialized software. The model also delivers a direct managerial insight by identifying that only three vehicles are required, reducing operational costs significantly.

The results indicate that a strategic reduction in the company's fleet size enhances distribution efficiency without compromising service performance. Specifically, the analysis suggests the removal of one Grand Max Blind Van (Fleet 4), which remained unused throughout the VBA-based simulations. Consequently, an optimal fleet configuration consists of three operational units: two Hino Light Trucks and one Grand Max Blind Van.

The application of the model yields substantial improvements in operational performance. The optimized routing configuration reduces the total travel distance from 2,702.1 km under actual operating conditions to 2,271.02 km, representing a 15.95% reduction in distance. Correspondingly, the total distribution cost decreases from IDR 9,054,856 to IDR 7,077,437, resulting in a cost saving of 21.84%. These findings validate the effectiveness of the LNS-based CVRPTW approach in enhancing distribution efficiency and demonstrate its practical applicability for logistics systems that employ heterogeneous fleets and prioritize service requirements.

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