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Abstract: Determination of effective and efficient routes and delivery scheduling plays an important role in optimizing the logistic cost of a company. This paper addresses the vehicle routing problem with time window for a proposed distribution system that aims to deliver lubricant products with minimum total distance and minimum number of vehicles. Tabu search algorithm is used to solve the problem. As the result, total travel distance for lubricants delivered in box, drum, and pail is 539.90 km, 543.60 km and 453.30 km, respectively. The minimum number of vehicles needed is 10 trucks. The results reduce 38.70% of the current logistic cost.

Keywords: Vehicle routing problem with time window (VRPTW), Tabu Search, Distribution system, Lubricants

1. Introduction

Transportation is one main activity of a distribution system. It deals with two main issues, i.e., transportation mode selection and transportation routing determination. Transportation is a key competitive element of the organizations as it consumes 10%-20% of the cost of any product[1]. From the supply chain decision view, transportation mode selection is categorized as a strategic or planning decision, while routing determination belongs to operational decision[2]. In many companies, an operational decision such as routing determination is a routine activity that serves as important activity influencing the company's profit. In the long run, this activity determines the company well-being.

A lubricant manufacturing company with a high market share in Indonesia faces a distribution problem. Currently, the company has a distribution network that can be classified as Storage Manufacture with Customer Pick-up (shown in Figure 1). This type of distribution network has a pick-up location or Depot Supply Point (DC) where distributors take the ordered products over there using their personal vehicle[2].

The unfulfilled customer demand occurs on the existing distribution system in the company. It is caused by the late arrival of the lubricant to DC. The unorganized delivery schedule from the current DC causes a long waiting time for circulation, resulting in high storage costs. In addition, the lead time for product delivery to customers is long due to the long stages in the distribution network (warehouse-depot-distributor-customer). The long waiting times for consumers lead to high costs [3]. Weak distribution system will also decrease customer satisfaction[4]. In contrast, customer satisfaction is an essential factor for predicting consumer behavior[5]. Also, it has a positive effect on repeat purchases and word-of-mouth advertisement[6].

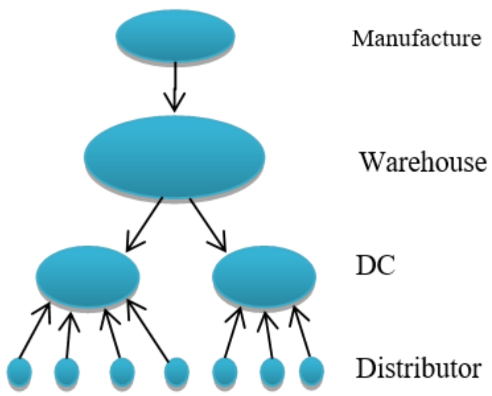

Fig. 1: Existing Distribution System at Lubricant Manufacturing Company.

A company that can optimize its distribution system then the products will be sold competitively and it can compete with other companies. There are three interrelated and mutually influencing decisions in determining the distribution system, namely the selection of facility locations, inventory management, and distribution network selection[7]. A company that integrates these three things in decision making can become a competitive advantage in the market[8].

Changing the distribution system will impact on changes in transportation costs, storage costs and facility costs[2]. This paper proposes a new distribution system where direct shipping is conducted from the company's warehouse to distributors without visiting the in-transit warehouse (DC). Figure 2 shows the proposed distribution system for the company.

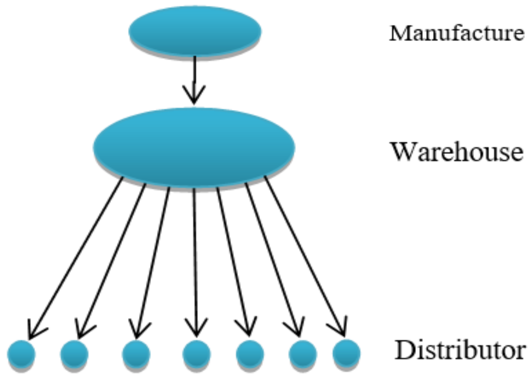

Fig. 2: Proposed Distribution System at Lubricant Manufacturing Company.

With the current distribution network, the company has no distribution route since their distributors are the ones who pick-up the lubricants using their vehicle. It means the company spends relatively less on transportation costs currently. However, using vehicle in large quantities produces high emissions that will increase greenhouse gas concentration[9].

On the other side, under the new distribution system, the company is the one who responsible for delivering their products to their customers. The proposed distribution scheme causes additional product delivery locations in the form of increasing product delivery distances. Therefore, this study also proposes a Vehicle Routing Problem (VRP) model to determine the distribution route for shipping lubricant products to their distributors with minimum travel cost. With its impact reducing transportation cost, VRP can be considered as a tool to reduce environmental degradation[10].

VRP model has been applied to many practical distribution problems, including transportation planning, supply chain management in logistics networks, production management, and so on[11]. Aspects of combined fleet composition, routing, and road-based transportation also could be determined[12]. VRP is a well-known combinatorial optimization problem arising in transportation logistics, usually scheduled in a restricted environment. In the management of transport, there is a requirement to provide goods and/or services from the supply point to various points spread geographically with significant economic implications. VRP has the objective to obtain the minimum-cost route that serves a set of customers with known demands. Each customer is assigned to exactly one vehicle-route and the total delivery of any route must not exceed the vehicle capacity[7].

In this company's problem, each customer (here is the distributor) must be visited within a given time interval. This setting sets as an additional constraint to be fulfilled. Therefore, the problem is categorized as Vehicle Routing Problem with Time Windows (VRPTW). VRPTW is an extension of VRP, which involves the added time windows on each consumer. For VRPTW, in addition to their vehicle capacity constraint, there are additional obstacles that require the vehicle to serve the consumers in a certain time frame. Vehicles must arrive before opening time, but the consumer can not be served until the time the windows open. Distribution is not served when the time windows are closed[13]. The objective of VRPTW is to find such assignments and routing of vehicles under the given constraints so that the cost is minimized. The route must be designed so that each point is visited only one time by exactly one vehicle in a certain time interval (time windows).

VRPTW is an NP-hard problem for a fixed number of vehicles[14]. As an NP-hard problem, metaheuristic approaches are usually employed to solve large VRPTW instances in a reasonable amount of computation time[15,16]. Various metaheuristics methods provide excellent results for the VRPTW. These methods are easy to implement and proven efficient in finding optimal solutions for different applications[17,18]. A performance comparison study for VRPTW was carried out using the tabu search, genetic algorithm, and simulated annealing[19]. A more recent metaheuristic utilization was using elephant herd optimization[20].

Tabu Search (TS), a local search algorithm, is one constructive heuristic to solve VRPTW[21]. TS is widely used because its efficient characteristics and its ability to prevent solutions from being trapped in the local optima. In TS, the search for better solution on the neighbors who previously visited, which is called the tabu list, is forbidden be selected again to avoid repetition. Tabu list serves as short-term memory, in which the components that go into the list will be kept updated on each iteration. TS is used for the vehicle routing problems with time windows and split deliveries in a reasonable time[22]. TS apparently benefited from using long-term memory and diversification strategy for VRPTW problem[23]. Tabu search algorithm is also used for solving the open vehicle routing problems with soft time windows and customer satisfaction[24]. So that, this study uses TS algorithm as the solution method to solve the lubricant delivery problem.

The purpose of this study is to demonstrate the magnitude of cost savings that can be achieved by replacing the existing distribution system with the one with no DC. For this purpose, after developing the mathematical model that covers the problem setting and boundaries, the model is solved for a real problem with 18 distributors and 1 warehouse. The distribution system is used to distribute three different lubricant products that haul with different vehicles but have the same capacity.

This paper is organized as follows: Section 1 presents the problem background, aim and boundaries of the study. Section 2 presents a mathematical model, data gathering and data processing. Section 3 discusses the result and sensitivity analysis of the model. Section 4 is a conclusion.

2. Methodology

This study used optimization methods to solve the VRPTW. The method is started with developing a mathematical model that represents the real problem. The model is run on the data available using Tabu Search Algorithm (TS) to obtain a distribution route that is able to provide more optimal mileage, number of trips, and number of fleets. The results are analyzed and translated with the high-end language to make them sensible. The sensitivity analysis of the model is used to show the cost savings that can be achieved from changing the distribution network and comparing the distribution routes from the initial solution results with the results of software processing.

2.1 Mathematical Modelling

The mathematical model that represents VRPTW in this study is presented by Equations (1) – (10). The model is formulated as integer programming. The objective function for the model is shown by Equation (1), which is to minimize travel distance for distributing products to all distributor locations. Equations (2) – (10) are the constraints of the model that restricts each solution to fulfill.

Indices:
i, j, h = spot/location of warehouse and customers, *i, j, h* = 0, 1, 2, …, *n*, …, *N* with *n* = 0 represents the warehouse and 1 to *N* are the distributors.

Decision variables
$x_{ijk} \in \{0, 1\}$, x_{ijk} = 1 if vehicle *k* travels from *i* to *j*, and 0 if not.

The objective function:

$$\min \sum_{i=0}^{N} \sum_{j=0, j\neq i}^{N} \sum_{k=1}^{K} d_{ij}\, x_{ijk} \tag{1}$$

The constraints:

$$\sum_{i=0, i\neq j}^{N} \sum_{k=1}^{K} x_{ijk} = 1 \quad for\ \forall\ j \tag{2}$$

$$\sum_{j=0, j\neq i}^{N} \sum_{k=1}^{K} x_{ijk} = 1 \quad for\ \forall\ i \tag{3}$$

$$\sum_{j=1}^{N} x_{0jk} \leq 1 \quad for\ \forall\ k \tag{4}$$

$$\sum_{j=1}^{N} x_{j0k} \leq 1 \quad for\ \forall\ k \tag{5}$$

$$\sum_{j=1}^{N} x_{0jk} = \sum_{j=1}^{N} x_{j0k} \quad for\ \forall\ k \tag{6}$$

$$\sum_{i=1, i\neq h}^{N} x_{ihk} - \sum_{j=0, j\neq h}^{N} x_{hjk} = 0 \quad for\ \forall\ h, k \tag{7}$$

$$\sum_{i=0}^{N} q_i \left(\sum_{j=0, j\neq i}^{N} x_{ijk} \right) \leq Q_k \quad for\ \forall\ k \tag{8}$$

$$\sum_{i=0}^{N} \sum_{j=0, j\neq i}^{N} x_{ijk}\,(t_{ij} + s_i) \leq w_k \tag{9}$$

$$x_{ijk} \begin{cases} 1, & \text{if } k \text{ departs from } i \text{ to } j \\ 0, & \text{otherwise} \end{cases} \tag{10}$$

Equations (2) and (3) state that all customers must be assigned to at most 1 vehicle. Equation (4) states that all vehicles should start their travel by distributing the products from the same starting point (the depot). Equation (5) dictates all distributing vehicles should end their travel at the same ending point (the depot). Equations (4-6) ensure that all vehicles use a closed-loop route that starts and finishes at the depot. Equation (7) is a constraint that ensures all vehicles that enter one particular node must come out from that node. Equation (8) ensures that the vehicles that carry the lubricant products will not violate their loading capacity. Equation (9) is a time window constraint to ensure that the time required by the vehicle to serve all points on all routes does not exceed the depot's working hours. Equation (10) is non-negativity constraint in the form of binary (0, 1).

2.2 Data Gathering

2.2.1 Depot and Distributors Location

The company in this study has one warehouse located in Jakarta. This warehouse operates from 08:00 to 17:00. The company has to serve its 14 distributors in Jakarta and 4 distributors at Bandung. Figure 3 shows an aerial view of the company and its 18 distributors' locations.

Using Google Maps, distance data among the company and its 18 distributors are estimated. With 0 referring to the company's warehouse, each distributor is assigned an index of 1 to 18. Table 1 shows distance data between 2 serve points in kilometer.

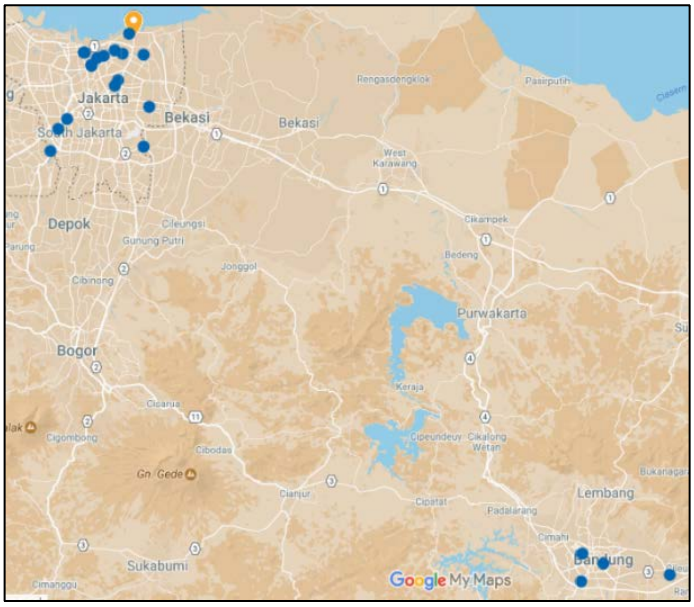

Fig. 3: Aerial view that shows the company and its distributors' locations

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Table 1. Distance Data Between Serve Points (Kilometer)

Loc	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	0	40	11	3	13	12	3	18	14	11	14	153	158	165	30	33	13	151	11
1	40	0	29	30	22	24	29	26	16	25	15	160	166	172	23	4	21	158	37
2	11	29	0	5	5	11	10	25	5	10	5	152	161	172	31	25	5	150	12
3	3	30	5	0	9	10	7	19	8	11	8	157	163	171	23	30	10	156	7
4	15	22	5	9	0	12	11	28	4	14	4	159	165	172	30	16	0	155	22
5	10	24	11	10	12	0	13	11	8	3	8	147	153	161	17	21	12	146	11
6	3	29	10	7	11	13	0	22	14	11	14	151	157	165	25	28	11	150	8
7	25	26	25	19	28	11	22	0	20	13	22	139	145	154	10	20	27	137	11
8	16	16	5	8	4	8	14	20	0	9	0,5	163	169	176	25	14	4	153	13
9	9	25	10	11	14	3	11	13	9	0	8	147	153	160	17	16	13	145	11
10	16	15	5	8	4	8	14	22	0	8	0	163	169	176	26	14	5	162	15
11	153	160	152	157	159	147	151	139	163	147	163	0	6	26	139	152	161	7	147
12	158	166	215	163	165	153	157	145	169	153	169	6	0	11	141	154	167	6	149
13	165	172	172	171	172	161	165	154	176	160	176	26	11	0	149	162	175	12	158
14	32	23	31	23	30	17	25	10	25	17	26	139	141	149	0	20	32	137	29
15	31	4	25	30	16	21	28	20	14	16	14	152	154	162	20	0	17	148	29
16	15	21	5	10	0	12	11	27	4	13	5	161	167	175	32	17	0	156	21
17	151	158	150	156	155	146	150	137	153	145	162	7	6	12	137	148	156	0	146
18	7	37	12	7	22	11	8	11	13	11	15	147	149	158	29	29	21	146	0

2.2.2 Travel Time

Travel time data is collected from actual observation within 08:00 to 17:00 time window. Table 2 shown travel time data between two serve points in minutes. Service time is the loading and unloading time required. The value is calculated using Equation (11).

$$s_i = \left(0.4\ x\ q_i\right) + 15 \qquad (11)$$

2.2.3 Vehicles

Vehicles used in this study have one size as follow: 6,000 mm length, 2,400 mm width, and 2,200 mm height. The vehicles have 6 tires and maximum capacity 8 ton. The products are packaged in box, drum, and pail. The using full load approach, each vehicle is able to carry 350 boxes, 30 drums, and 100 pails.

2.2.4 Transportation Cost

Equation (12) is the formula to calculate transportation cost *TC*.

$$TC = \text{Rp. } 855{,}00 \text{ x delivered products (KL) x total distance (Km)} \qquad (12)$$

Table 2. Travel Time Data Between Serve Points (Minutes)

Loc	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	0	69	19	6	22	21	6	32	23	19	23	204	211	220	52	57	22	201	18
1	69	0	50	52	37	40	50	44	28	43	26	213	221	229	39	7	35	211	64
2	19	50	0	9	9	18	17	43	9	17	8	203	215	229	53	42	9	200	20
3	6	52	9	0	15	16	12	32	14	19	13	209	217	228	40	51	17	208	13
4	22	37	9	15	0	21	19	47	7	23	7	212	220	229	52	28	0,2	207	37
5	21	40	18	16	21	0	22	19	14	5	13	196	204	215	28	35	21	195	19
6	6	50	17	12	19	22	0	38	23	18	23	201	209	220	43	47	19	200	14
7	32	44	43	32	47	19	38	0	34	22	37	185	193	205	17	35	46	183	20
8	23	28	9	14	7	14	23	34	0	16	1	217	225	235	43	25	6	204	22
9	19	43	17	19	23	5	18	22	16	0	13	196	204	213	29	27	22	193	18
10	23	26	8	13	7	13	23	37	1	13	0	217	225	235	45	25	8	216	26
11	204	213	203	209	212	196	201	185	217	196	217	0	11	45	185	203	215	9	196
12	211	221	215	217	220	204	209	193	225	204	225	11	0	19	188	205	223	8	199
13	220	229	229	228	229	215	220	205	235	213	235	45	19	0	199	216	233	15	211
14	52	39	53	40	52	28	43	17	43	29	45	185	188	199	0	35	54	183	49
15	57	7	42	51	28	35	47	35	25	27	25	203	205	216	35	0	30	197	50
16	22	35	9	17	0	21	19	46	6	22	8	215	223	233	54	30	0	208	37
17	201	211	200	208	207	195	200	183	204	193	216	9	8	15	183	197	208	0	195
18	18	64	20	13	37	19	14	20	22	18	26	196	199	211	49	50	37	195	0

2.2.5 Demand

Demand data is differentiated by the type of packaging. Split delivery will be used for several demands that exceed the vehicle capacity. The demand of each distributor is shown in Table 3.

Table 3. Distributor's Demand

Location	Distributor code	Demands		
		Box (Pcs)	Drum (Pcs)	Pail (Pcs)
1	KEP	64	1	0
2	PP	94	2	10
3	WGU	106	17	3
4	SNR	80	3	32
5	WDU	350	12	8
6	DBP	120	20	30
7	RUJ	70	0	0
8	KPG	45	7	33
9	SJS	166	14	10
10	DWS	20	15	8
11	LK	188	2	15
12	LRI	81	6	14
13	MA	14	7	10
14	LKR	0	15	8
15	PNJ	130	8	14
16	SNU	0	18	1
17	SKI	66	13	20
18	SLL	256	4	0
Total		1850	163	216

2.3 Data Processing

Steps to find the shortest route from the company's warehouse to the distributor's using TS is shown in Figure 4. Input data for the tabu search algorithm includes mathematical models, distance matrix data, service time matrices, distributor demands, delivery fleet capacity, time windows, and control parameters. The coding program is developed uses Netbeans IDE 8.2 software.

The initial step of TS algorithm is to input the initial solution. The solution is done manually using the creative approach proposed by (25). The initial total delivery solution obtained with the box packaging is 863 km, the drum is 904 km, and the pail are 491 km. The minimum number of vehicles used for the initial solution is 10 trucks.

In addition to determine the initial solution, a control parameter incorporated into the program coding needs to be set. In this study, the program was run 50 times for each product type. The program's results are the sequence of time taken along with the distance and total distance travelled. The control parameters for the length of the tabu list is used by 20, the number of neighbors solutions by 50 and the number of iterations of 1000 with a fixed tenure tabu. Furthermore, initial randomization is done to determine the candidates of new solutions by performing the move (exchange) nodes (consumers) are nearby. So, the entire nodes (consumers) have gone through the exchange of each other. The final step is select the best new solution candidates that exist and set it as the optimal solution as seen from the smallest value of the distance travelled by the route.

Before the program is used to run on the real data, it should be verified and validated to ensure that the program gives an appropriate and correct result. The verification process was done to ensure the correctness of logic models and the changing value of a control parameter. Validation was done by comparing the manual calculations and program results using dummy data. The verification and validation process were done after the coding program was completed.

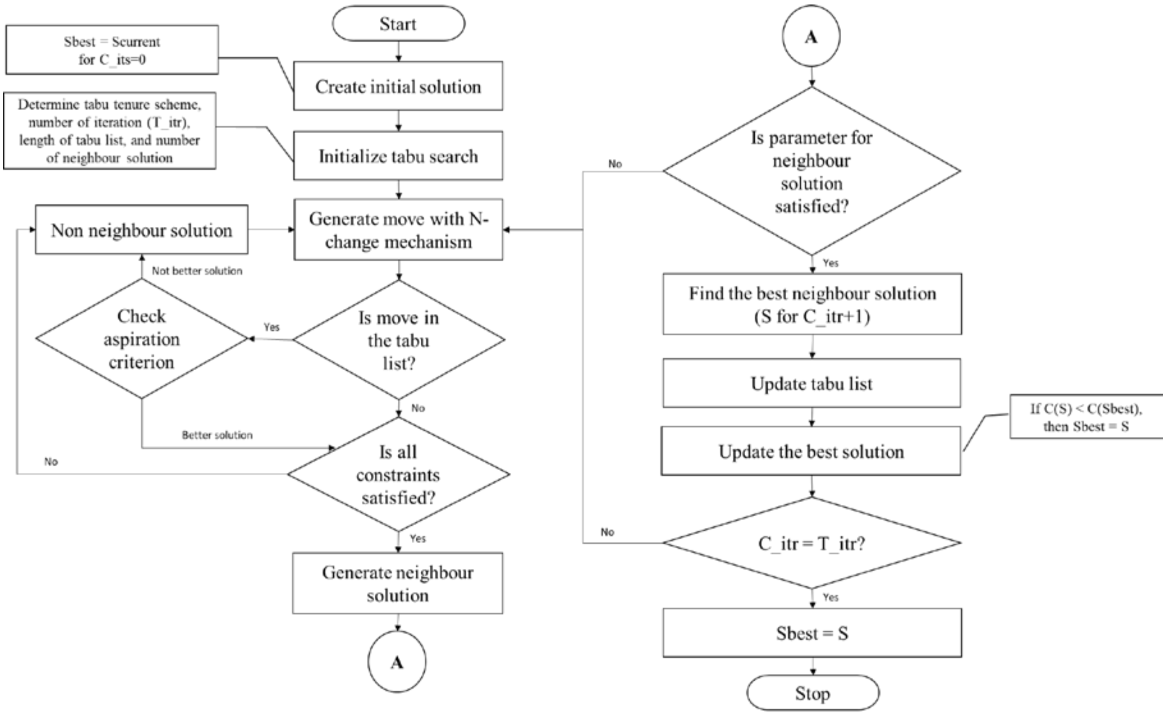

Fig. 4: Tabu Search Algorithm Steps.

3. Result and Discussion

3.1 Route Analysis

The result of running the program, the optimal route for lubricant in boxes, drums, and pails deliveries is 539.90 km, 543.60, and 453.30 km, respectively. The minimum number of vehicles to be used is nine trucks. Tables 5, 6, and 7 show the optimum distribution route for box packaging, drum packaging, and pail packaging, respectively. When compared with the initial solution, the total output delivery within a smaller program and the minimum number of vehicles that are used even less. However, when compared to its current service delivery from the warehouse to the DSP, the distance delivery of a larger program output is about 3 times the distance of the current conditions. This is because changes in the distribution system from the pick-up into direct shipping transport, so the distance will increase beside the point of service was increased from 2 (baseline) to 18 (conditions of the proposal).

The result is not only giving the minimum travel distance, but the approach also utilizes minimum number of vehicles. Assuming that the trucks can serve customers maximum 2 times (multi trip), the minimum number of vehicles to deliver three types of products is 9 trucks. Using capacity of 8 tons, truck utilization is 86.08%.

Table 5. Proposed Distribution Route for Lubricant in Box

No	Vehicle route	*Demand* (box)	Time (minutes)	Distance (km)
1	0-3-2-8-10	265	168.92	28.00
2	0-18-7-0	326	214.48	40.30
3	0-5-0	350	196.48	24.20
4	0-9-4-0	246	193.21	37.80
5	0-6-1-15-0	314	259.69	69.50
6	0-13-12-11-17-0	349	539.69	340.10
	Total	1850	1,572.47	539.90

Table 6. Proposed Distribution Route for Lubricant in Drum

No	Vehicle route	*Demand* (box)	Time (minutes)	Distance (km)
1	0-18-9-5-0	30	88.88	36.00
2	0-3-8-2-0	26	71.12	28.00
3	0-15-1-6-0	29	145.69	69.50
4	0-4-16-0	21	68.14	26.10
5	0-10-14-0	30	147.00	70.00
6	0-13-12-11-17-0	28	531.20	340.10
	Total	163	1,052.03	543.60

Table 7. Proposed Distribution Route for Lubricant in Pail

No	Vehicle route	*Demand* (box)	Time (minutes)	Distance (km)
1	0-9-5-14-15-8-0	73	135.32	78.90
2	0-6-4-16-8-10-2-3-0	84	54.28	34.30
3	0-13-12-11-17-0	59	535.02	340.10
	Total	216	963.59	453.30

3.2 Cost Analysis

Logistics cost in this study is the sum of transportation and inventory costs. The transportation cost is calculated using Equation (12). The transportation cost generated by the proposed model is higher than the existing model. This is because transportation cost is variable cost that depends on the distance travelled, so that if there is a significant difference in distance between the current condition and the proposed condition, it will result in a significant cost difference. A comparison of transport costs in the current condition and the condition of the proposal can be seen in Figure 5.

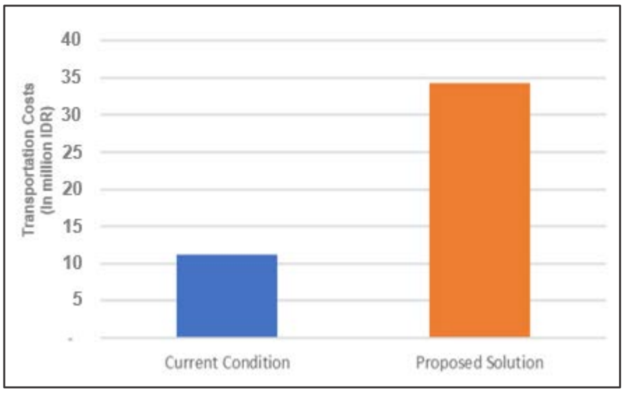

Fig. 5: Transportation Cost Comparison.

Inventory cost in this study includes the cost of stocking storage, material handling costs (material handling), staff salaries (non-operating), routine operational costs (others), and warehouse rental costs (facilities). From the five components, the cost of storage is a component stock of the cost with the greatest value and has the largest contribution to the inventory cost. Therefore, the impact of changes in the distribution system and the reduction in the facility, in this case, the removal of two DSP in Jakarta and Bandung has very significant influence on the reduction of the stock of storage cost.

Figure 6 shows the comparison of the cost of inventory of the current condition and the proposed condition. The logistics costs decrease with the implementation of the proposed distribution system amounted to 38.70%.

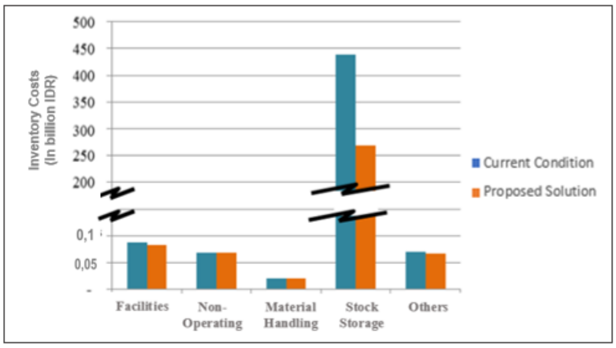

Fig. 6: Inventory Cost Comparison.

3.3 Sensitivity Analysis

Sensitivity analysis is conducted toward two parameters: fleet operating time window and the number of products requested. This study carried sensitivity analysis for time windows by reducing and adding the operational time of 60 minutes and 120 minutes. The addition of this amount of time is based on consideration of the uncertainty in road traffic such as congestion and accidents. The changing fleet operational time/time window affected the total distance shipping fleet due to changes in the number of trips and fleets used. A significant change in mileage is visible when there is a reduction in time. Because the delivery distance from the depot to the Bandung distributor is very far, the reduction of operating time significantly affects the condition of the product delivery. Therefore, the reduction of time of 120 minutes did not produce a feasible solution.

Sensitivity analysis for demand was carried out with the condition of adding and subtracting the number of demands by 10% from the initial demand of each distributor. The change in the number of demands for packaging boxes and drums significantly impacts travel distance. Demand increment increases the number of trips which is more than the number at initial condition. This occurs because of vehicle limitation. In addition to the increase in distance delivery, there will be additional days of service, especially for the packaging box and drum. When the number of demands reduces, changes are on the distance and utility vehicles increment. For packaging boxes, the total distance reduces and the vehicles' utility increases. As for the packaging drums, there is an increase in vehicle utilization and reduction in the number of vehicles used. Initially the number of trucks is 5 trucks. On the condition of the number of demands reduces as much as 10%, the number of vehicles used to serve all distributors is 3 trucks.

4. Conclusion

This study is about replacing the existing distribution system with one that does not use DC in a lubricant company. Due to this new set up, Vehicle Routing Problem with Time Windows (VRPTW) problem is solved with Tabu Search.

This study comes up with several findings as follows: Distribution for lubricant in boxes is using 6 routes: depot-WGU-PP-KPG-DWS-depot, depot-SLL-RUJ-depot, depot-WDU-depot, depot-SJS-SNR-depot, depot-DBP-KEP-PNJ-depot, and depot-MA-LRI-LK-SKI-depot. Distribution for lubricant in drums is through 6 different routes: depot-SLL-SJS-WDU-depot, depot-WGU-KPG-PP-depot, depot-PNJ-KEP-DBP-depot, depot-SNR-SNU-depot, depot DWS-LKR-depot and depot-MA-LRI-LK-SKI-depot. Distribution for lubricant in pails are 3 long routes: depot-SJS-WDU-LKR-PNJ-KPG-depot, depot-DBP-SNR-SNU-KPG-DWS-PP-WGU-depot and depot-MA-LRI-LK-SKI-depot.

The minimum distance for the route is 539.90 km, 543.60 km and 453.30 km for lubricant in boxes, drums, and pails delivery, respectively. The minimum number of trucks to haul the three types of lubricants' products are 10 trucks with a capacity of 8 tons. The total transportation cost of the new distribution scheme is 34,353,322 IDR and the logistics costs that can be saved with the new distribution scheme is 170,041,805, 089 IDR. It is comparable with 38.70% reduction of current logistics costs. This study shows those cost savings can be achieved by replacing the existing distribution system with one that does not use DC.

Nomenclature

k	Number of vehicles, k = 1,2, ..., K
d_{ij}	The distance from the *i* to *j* (km)
q_i	The number of requests at *i*
Q_k	The maximum capacity of vehicle *k*, depending on the type of vehicle
t_{ij}	Travel time from *i* to *j*
s_i	The service time at *i*.

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