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Efficient Route Planning for Flour Distribution: A Heuristic Approach

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ABSTRACT

This company operates in the Food and Beverage sector, selling Martabak, an Indonesian snack. The company needs to deliver flour to 25 branches spread across Bandung, Indonesia, every day, with varying demand capacities at each branch. Each day, the total amount of flour to be delivered is 377 boxes. Currently, the company has 12 distribution routes with a total distance of 271,16 km, with each route covering only two stores. However, these routes are too many and vehicle capacities need to be optimized, resulting in a high total travelled distance. The aim of this research is to optimize the delivery routes to reduce the total travelled distance and number of routes. To address this issue, known as the Vehicle Routing Problem (VRP), heuristic methods were employed, specifically the nearest neighbour method for initial route construction and Intra-Route (1-0) Insertion for improvement. Implementing these heuristic methods resulted in a final total of 6 distribution routes with a total distance of 160,90 km. This method successfully reduced the total travelled distance by 110,26 km and reduced the number of routes by 6. In conclusion, the application of heuristic methods in solving the VRP for this company proved to be effective in reducing both the total travelled distance and the number of routes, thereby enhancing the operational efficiency of the delivery process.
Keywords: Distribution Route, Heuristics, Intra-Route, Nearest Neighbour, Vehicle Routing Problem

ABSTRAK

Perusahaan ini bergerak di bidang *Food and Beverage* yang menjual Martabak, makanan ringan dari Indonesia. Perusahaan ini harus mengirim tepung ke 25 cabang yang tersebar di kota Bandung, Indonesia setiap harinya, di mana kapasitas permintaan dari setiap cabang berbeda-beda. Setiap harinya total tepung yang harus dikirim adalah 377 *box*. Kondisi saat ini, perusahaan memiliki 12 rute distribusi dengan total jarak 271,16 km, di mana setiap rutenya hanya mencakup 2 toko. Namun, rute tersebut terlalu banyak dan kapasitas kendaraan tidak dimanfaatkan dengan maksimum, serta total jarak tempuh masih tinggi. Tujuan dari penelitian ini ada mengoptimalakan rute pengiriman untuk mengurangi jarak tempuh dan jumlah rute. Untuk mengatasi masalah ini, yang dikenal sebagai *Vehicle Routing Problem* (VRP), digunakanlah metode heuristik, yaitu nearest *neighbour* untuk konstruksi rute awal dan *Intra-Route* (1-0) *Insertion* untuk melakukan perbaikan. Hasil implementasi metode heuristik ini menghasilkan jumlah rute akhir sebanyak 6 rute distribusi dengan total jarak tempuh 160,97 km. Metode ini berhasil mengurangi total jarak tempuh sebesar 110,26 km dan mereduksi 6 rute. Kesimpulannya, penerapan metode heuristik dalam menyelesaikan VRP pada perusahaan ini terbukti efektif dalam mengurangi total jarak tempuh dan jumlah rute, sehingga meningkatkan efisiensi operasional pengiriman.
Kata Kunci: Heuristik, Intra-Route, Nearest Neighbour, Rute Distribusi, Vehicle Routing Problem

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1. Introduction

Effective logistics is a crucial element of supply chain management, and companies must manage it effectively to achieve profitability [1, 2]. The distribution process, which ensures that customers receive their products, is a key part of logistics [3]. However, this area has many challenges, including the Vehicle Routing Problem (VRP). The VRP is a complex optimization problem that involves finding the most efficient delivery routes, considering several factors such as distance, time, number of vehicles and vehicle capacity[4]. Overcoming these challenges can significantly improve distribution efficiency and overall operational effectiveness. This is supported by research from [5], which solved the VRP for chicken distribution and was able to reduce the travelled distance by 37%, and research from [6], which showed a 27% reduction in distance for fashion bags distribution.

Company X, engaged in the Food and beverage industry, sells Martabak, one of Indonesia's traditional desserts. This company has 25 stores spread across the Bandung City area. The company sends grain flour daily from its main office to these 25 stores. This daily task has become a challenge because the company lacks optimal delivery routes. Currently, deliveries are made based on the intuition of the truck drivers and vehicle capacity, resulting in longer travel times and distances. This inefficiency leads to increased costs and sometimes delays in deliveries to the stores. To solve this problem, heuristic approaches are employed to address the VRP. The nearest neighbour algorithm is used for constructing initial routes, followed by Intra-Route (1-0) Insertion methods for improvement to obtain better results in terms of travelled distance. This study aims to demonstrate how these heuristic methods can significantly enhance the efficiency of flour distribution for Company X, reducing travel distances while ensuring timely supply to all stores.

2. Methodology

2.1. Vehicle Routing Problem (VRP)

Since the late 1950s, researchers have been conducting studies to solve VRP, which involves the distribution of products from a depot or warehouse to customers [4]. The VRP is a challenging problem to solve because considering various attributes involves [7]. For example, the position of customers, the number of vehicles, vehicle capacity, demand, time windows, and multiple depots. VRP can be addressed by applying several methods, as illustrated in Figure 1.

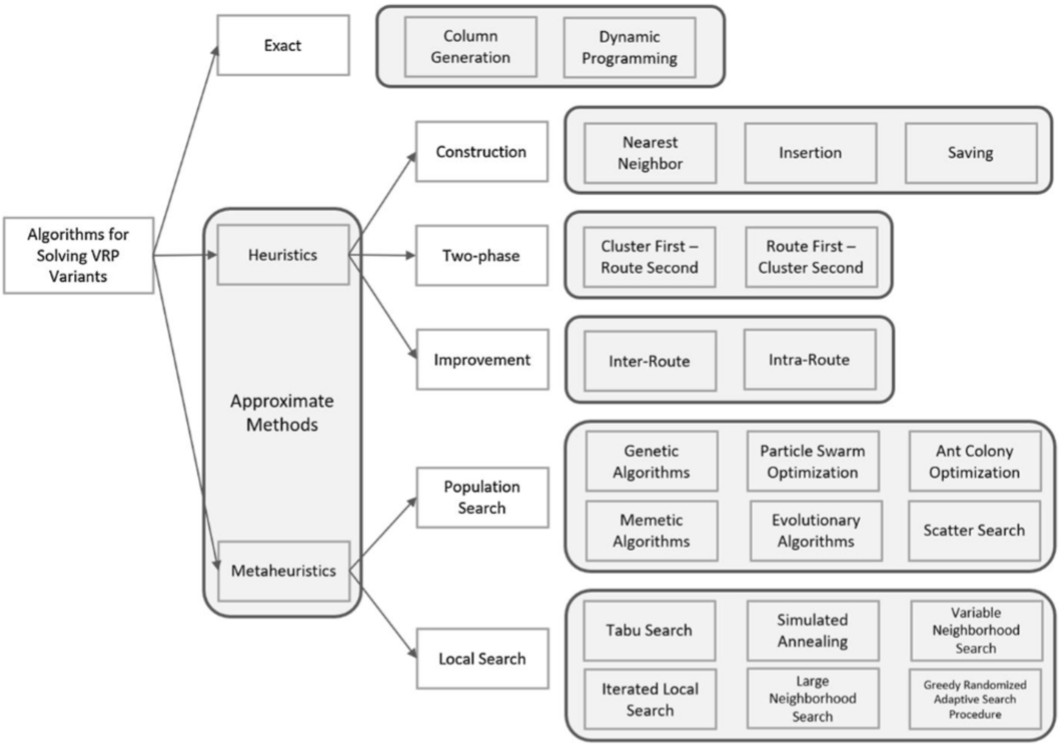

Figure 1. Classification Methods to Solve VRP (Source: [8, 9])

Exact methods can solve the VRP optimally, but they struggle to accommodate complex real-life systems [10]. Additionally, it is tough for exact methods to obtain better results for VRP cases compared to heuristics methods [11]. Heuristics can solve the VRP, especially when the complexity increases due to constraints. Construction heuristics develop routes from scratch while carefully considering the constraints[11]. Moreover, the same author also states that although constructive heuristics can quickly find routes, there is often a discrepancy between the results and the optimal routes. This is why many researchers attempt to combine several methods to achieve optimal results in solving VRP. Many researchers have been trying to determine the best optimal routes. For example, research by Konstantakopoulos [12] used metaheuristics to solve multi-objectives, research by Blocho [13] combined heuristics and metaheuristics, and research by Pasha and Armanda [14, 15] combined exact methods and metaheuristics to solve VRP. Typically, combining methods yields better results, as shown in the previously mentioned research. Heuristic approaches that utilize local search or constructive strategies have also been shown to provide good results.

Specific statistics on the percentage of heuristic methods applied to solving VRP in companies in Indonesia are not widely documented. However, companies in Indonesia have been implementing heuristic algorithms in software for calculation convenience. Globally, it is common practice to integrate heuristics algorithms into Enterprise Resource Planning (ERP) systems used by companies [16]. Another example by Oppen [17] proposed a Tabu Search method to tackle the livestock collection issue within Norway's meat industry. They approached the problem as a vehicle routing problem, incorporating inventory constraints to maintain consistent production at slaughterhouses. Additionally, they accounted for various animal welfare constraints. In this study, the VRP is solved using heuristic methods: initially, the Nearest Neighbour algorithm is employed for route construction, followed by the Inter-Route application for further improvement. This combination aims to achieve optimal results.

The initial stage involves identifying the variables used in this study. The variables used in this research include; (1) Dependent variable: Distance travelled and (2) Independent variables: Distance, number of vehicles and vehicle capacity.

The following are the steps for determining the distribution route for flour distribution:

1. Step 1: Saving Matrix Methodology. The Saving Matrix method is utilized to minimize distance, time or cost while adhering to system constraints such as the number of vehicles and their capacities [18]. The process of calculating the saving matrix involves the following steps:

- Identify the distance matrix: This step involves determining the distance between two points, such as from the Depot to Store one or from Store 1 to Store 2, depending on the number of depots and stores in the scenario. In this study, distances are determined using straight-line measurements between points, as calculated via Google My Maps.

- Identifying the saving matrix: The savings value indicates the benefits of allocating a pair of stores on the same route rather than separately. These values aim to prioritize which store pairs to group together to reduce travel distance. In this step, the saving distance is calculated based on the distance matrix using the formula:

$$S(x,y) = J(D, x) + J(D, y) - J(x, y) \quad (1)$$

Where: $S(x, y)$ is defined as Saving matrix; $J(D, x)$ is defined as Distance from depot to point x; $J(D, y)$ is defined as Distance from depot to point y; $J(x, y)$ is defined as Distance from point x to point y

- Allocate Vehicles and Routes: In this step, vehicles and routes are allocated, starting with the pairs of points that offer the highest savings. By iteratively combining routes in descending order of savings, the method ensures that the most efficient pairings are made first, effectively reducing the total number of routes required.

- Sequence Customers Within Routes: The result from step 3 only groups destinations without determining specific routes. To generate the routes, algorithms such as the Nearest Neighbour are applied to sequence the customers within each route. This algorithm iteratively selects the closest unvisited store, creating an efficient route that minimizes travel distance while adhering to vehicle capacity constraints and route length.

2. Step 2: The Nearest Neighbour Algorithm. The nearest neighbour algorithm is an essential part of construction routes and is used as a nonparametric alternative, meaning it does not assume a specific parametric form for the underlying distribution of the data [19]. Instead of relying on predefined models with fixed parameters, these methods are more flexible and make fewer assumptions about the data. In this context, the nearest neighbour algorithm utilizes results from grouping stores based on a saving matrix. The implementation of the nearest neighbour algorithm is often employed to solve the VRP to find efficient routes. In VRP, the goal of implementing the nearest neighbour algorithm is to find the shortest possible route. The algorithm starts at an arbitrary location and repeatedly visits the nearest unvisited location until all have been visited [20].

3. Step 3: Intra-Route Improvement heuristics. Intra-route is an improvement heuristic aimed at achieving better routes in terms of distance and time efficiency. This method enhances routes generated by local search algorithms by facilitating the movement of customers within route, thereby aiming to achieve better outcomes [11]. There are several Inter-Route improvement heuristics that can be utilized, such as Intra-Route (1-0) Insertion, Relocate, Exchange, etc. These methods all operate by rearranging the customers by changing their sequence in a route. Each of these methods has its strengths and weaknesses, and the most effective method to solve VRP will depend on the specific characteristics of the problem. Another factor to consider when deciding the methods is the specific requirements of the problem, such as the number of customers, route constraints, and optimization goals. A combination of these methods is often employed to achieve the best results.

Intra-Route (1-0) Insertion is a local search method that moves a customer to a different position within the same route[21]. It compares the initial route with the route resulting from the insertion, and the route with the shorter distance will replace the initial route (First Best Solution), also known as the Best Solution. This local search has been applied to find the solution for the VRP and its variant (see [22] and [23]). In this study, Intra-Route (1-0) Insertion will be employed to improve the result obtained from the nearest neighbour algorithm.

The steps are as follows: (1) Select a customer to be arranged and place it in a different position within the same route; (2) Calculate the total distance of the new route and compare it to the previous route; (3) If the distance is shorter, accept the new route; if not, change the position again and recalculate; and (4) If, after all possible movements, no new route results in a shorter distance than the initial route, retain the initial route.

This process ensures that the most efficient route in terms of distance is selected, optimizing the overall delivery process.

3. Results and Discussion

There are 12 routes for distributing flour packages to 25 stores around Bandung City daily. Each store has a varying demand that must be fulfilled, with a total of 377 flour packages. The company owns three vehicles, each with a capacity of 80 boxes, to meet this demand. Demand information and current routes are shown in Table 1 and Table 2, respectively.

Table 1. Demand Information

Store	Demand	Store	Demand
Store 1	18	Store 14	10
Store 2	16	Store 15	17
Store 3	16	Store 16	14
Store 4	12	Store 17	15
Store 5	11	Store 18	16
Store 6	18	Store 19	13
Store 7	11	Store 20	17
Store 8	22	Store 21	13
Store 9	17	Store 22	15
Store 10	10	Store 23	20
Store 11	17	Store 24	13
Store 12	14	Store 25	18
Store 13	14		

Table 2. Demand Information

Route Number	Route	Boxes Carried	Distance (km)
1	D - ST 17 - ST 15 -D	32	22,07
2	D - ST 8 - ST 7 - D	33	21,62
3	D - ST 14 - ST 10 - D	20	17,15
4	D - ST 2 - ST 19 - D	29	6,5
5	D - ST 25 - ST 9 - D	35	24,16
6	D - ST 21 - ST 16 - D	27	16,45
7	D - ST 5 - ST 12 - D	25	24,04
8	D - ST 13 - ST 20-ST 4 - D	43	32,06
9	D - ST 23 - ST 1 - D	38	10,15
10	D - ST 22 - ST 6 - D	33	31,9
11	D - ST 11 - ST 18 - D	33	27,76
12	D - ST 23- ST 24 - D	29	37,3
Total		377	271,16

*D stands for Depot and ST stand for Store

Based on the initial routes, it is observed that vehicle capacity utilization ranges only between 20 to 40 boxes, despite each vehicle having a capacity of 80 boxes. Consequently, the number of routes expands to 12. The high number of routes, with each route visiting only two stores, increases distance as vehicles frequently return to the depot to pick up additional flour packages. Improvement can still be made to the current routes to achieve more efficient outcomes regarding the number of routes, total distance travelled and vehicle capacity utilization. The following step shows the calculation to obtain better routes for this company. Table 3. presents the distance matrix, which shows the distances between all pairs of stores and the depot.

Table 3. Distance Matrix

	Depot	Store 1	Store 2	…	Store 23	Store 24	Store 25
Depot							
Store 1	2,65						
Store 2	2,69	0,902					
Store 3	15,9	17,7	17,1				
…	…	…	…	…			
Store 24	10,3	10,5	9,62	…	13,4		
Store 25	2,81	5,45	5,38	…	7,1	10,6	

Table 4 shows the saving matrix derived from the distance matrix. The saving matrix helps identify potential distance savings by combining routes, thereby reducing the total travel distance. Table 5 displays the results obtained from applying the saving matrix.

Table 4. Saving Matrix

	Store 1	Store 2	Store 3	…	Store 23	Store 24	Store 25
Store 1							
Store 2	4,438						
Store 3	0,85	1,49					
Store 4	4,08	4,88	7,28				
…	…	…	…	…			
Store 24	2,45	3,37	15,1	…	1,47		
Store 25	0,01	0,12	4,71	…	0,28	2,51	

Table 5. Saving Matrix Result

Route Number	Route	Boxes Carried
1	ST3 - ST7 - ST9 - ST18 - ST22	75
2	ST 4 - ST 12 - ST 13 - ST 20 - ST 24	70
3	ST 6 - ST 8 - ST 10 - ST 14 - ST 19	73
4	ST 5 - ST 11 - ST 16 - ST 21 - ST 25	73
5	ST 1 - ST 2 - ST 15 - ST 23	71
6	ST 7	15
Total		377

The saving matrix is used to group stores into several routes by considering the number of vehicles and vehicle capacity. Based on the calculation of the saving matrix, new routes can be grouped into 6, whereas previously there were 12 routes or able to reduce up to 50%. The saving matrix only grouping the stores and not showing the routes so the distance still cannot determine yet. To achieve that, a local search algorithm, Nearest Neighbour, is used to obtain the routes based on grouping stores from the saving matrix result. Table 6. shows the new routes after implementing the Nearest Neighbour algorithm.

Table 6. Routes from The Nearest Neighbour Algorithm

Route Number	Route	Boxes Carried	Distance (km)
1	D - ST 9 - ST 18 - ST 7 - ST 22 - ST 3 - D	75	67,71
2	D - ST 12 - ST 24 - ST 20 - ST 5 - ST 13 - D	69	28,57
3	D - ST 8 - ST 10 - ST 14 - ST 4 -ST 6 - D	72	32,52
4	D - ST 16 - ST 21 - ST 25 - ST 11 - ST 19 - D	75	26,93
5	D - ST 1 - ST 2 - ST 23 - ST 15 - D	71	13,952
6	D - ST 17 – D	15	1,56
	Total	377	171,24

The Nearest Neighbour algorithm reduced the distance by 99,92 km, from 271,16 km to 171, 24, a significant reduction of 36,84%. This algorithm did not change the number of routes. It still uses the same result from the saving matrix, only changing the sequence to find the shortest routes. Based on the result in Table 6, the vehicle capacity in 5 of the six routes increased to approximately 70 boxes, closer to the capacity vehicle of 80 boxes. This increase is because each route covers four or five stores per trip. However, Route 6 covers only one store with a capacity of 15 boxes, and the total distance is less than 2 km. The next step is to apply a heuristic algorithm, Intra-Route (1-0) Insertion, to improve the routing obtained from the nearest neighbour algorithm. This algorithm rearranges the store sequence within a route with the main objective of reducing the total distance travelled. An example of calculating Intra-Route (1-0) Insertion can be seen in Table 7, and The Results are presented in Table 8.

Table 7. Example Intra-Route (1-0) Insertion

	Route 4	Distance
Initial Route	D - ST 21 - ST 16 - ST 25 - ST 11 - ST 19 - D	26,12
Rearranging Store 25	D - ST 21 - ST 16 - ST 11 - **ST 25** - ST 19 - D	31,26
	D - ST 21 - ST 16 - ST 11 - ST 19 - **ST 25** - D	26,93
	D - **ST 25** - ST 21 - ST 16 - ST 11 - ST 19 - D	**21,83**
	D - ST 21 - **ST 25** - ST 16 - ST 11 - ST 19 - D	27,26

This is an example of Intra-Route (1-0) Insertion. Initially, the total distance for Rout 4 is 26,93 km, covering flour distributions to 4 stores. By applying the Intra-Route (1-0) Insertion technique, Store 25 is moved to every possible position within Route 4. If the resulting route has a shorter total distance than the original route, the new route replaces the original one. In this example, the position of Store 24 was changed, as shown in Table 7. This adjustment resulted in a new total distance of 21,38 km, compared to the previous 26,93 km.

Table 8. Intra-Route (1-0) Insertion Results

Route Number	Route	Boxes Carried	Distance (km)
1	D - ST 9 - ST 18 - ST 3 - ST 7 - ST 22 - D	75	67,31
2	D - ST 24 - ST 20 - ST 12 - ST 5 - ST 13 - D	69	27,91
3	D - ST 6 - ST 8 - ST 10 - ST 4 -ST 14 - D	72	30,93
4	D - ST 25 - ST 21 - ST 16 - ST 11 - ST 19 - D	75	21,83
5	D - ST 2 - ST 1 - ST 23 - ST 15 - D	71	11,362
6	D - ST 17 -D	15	1,56
	Total	377	160,90

The results indicate that implementing the Intra-Route (1-0) Insertion method was successful, as it effectively reduced the total travelled distance from 171.24 km to 160.9 km, reducing approximately 10 km. The results also show changes in the store sequence for 5 out of the routes. Route 6 remains unchanged because it consists of only one store, making rearrangement unnecessary. Importantly, the capacity of the boxes carried remained the same, as the intra-route (1-0) Insertion method does not alter the store assigned to each route but only reorders their sequence within the route. Overall, these findings demonstrate the effectiveness of the Intra-Route (1-0) Insertion method in reducing travel distances. By optimizing the sequence of deliveries within each route, significant efficiency gains can be achieved without compromising the load capacity or the number of stores served. This method proves to be a valuable tool for improving logistics and distribution operations.

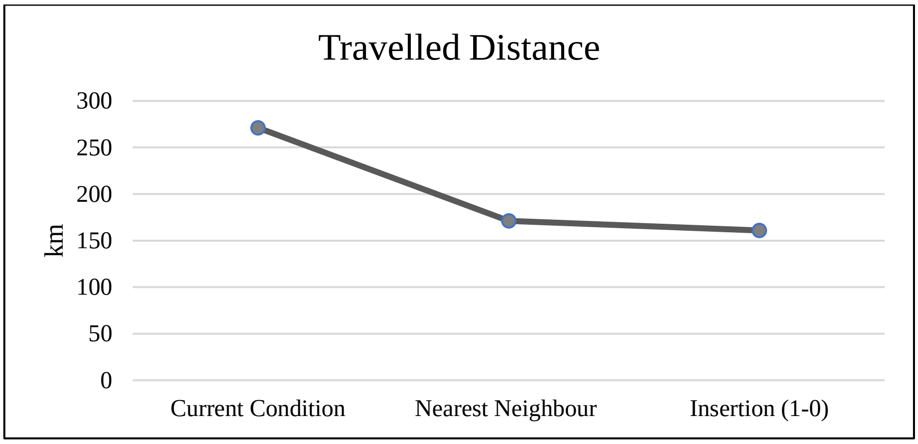

Figure 2. Travelled Distance

The line chart depicts the reduction in travelled distance in this study. At the beginning, or under the current condition, the company travels 271,16 km to distribute flour. Applying the nearest neighbour algorithms reduce the distance to 171.24 km, achieving a reduction approximately 100 km. Following this, the (1-0) insertion method also show positive results by slightly decreasing the travelled distance by an additional 10 km.

4. Conclusion

In this research, heuristics construction and improvement methods were applied to solve VRP for flour distribution. The application of these methods proved to be effective in addressing the problem. The results demonstrated a significant improvement, where the initial travelled distance of 271,16 km with 12 routes was reduced to 160,90 km with only six routes. This indicates a reduction in distance by 40,66%, showcasing the effectiveness of chosen methods in optimizing the routes. Even though, in this study, heuristics showed good results by reducing the distances for flour distribution, this method still has weaknesses, such as the possibility of the result getting trapped in a local optimal solution and heuristics do not guarantee the optimal solution. To overcome the drawbacks, future research could incorporate heuristic improvements such as inter-route methods to find the best routes by assigning stores to different routes. By adopting these strategies, it is possible to achieve even greater reductions in travelled distance, further enhancing the efficiency of the distribution system.

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