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# Combining vehicle routing and bin packing problem for vehicle routing planning: A case study of a chemical factory

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## ABSTRACT

In the logistics distribution process, effective transportation management is required to ensure quality and timely delivery. In addition, transportation must be more economical and faster. The case study company is a chemical plant, an industrial company that produces products for hygiene and cleaning. The delivery manager plans the transportation routes based only on her experience because no decision-making aids are available. In addition, the manager considers the shipping order from first to last when arranging the products on the transportation vehicles. The goods for the final delivery location are placed at the back and bottom of the delivery truck. This cannot guarantee that the transportation routes set by the manager are suitable. Therefore, this study aims to plan delivery routes, arrange items in trucks, and reduce transportation costs for a case study of a chemical factory by using vehicle route problems and container filling problems. Then, the program is developed in Python using the Saving Algorithm, the 3D First Fit Decreasing Algorithm, and the 3D Best Fit Algorithm. The results show that the program method can reduce the use of transportation vehicles from 19 to 14, which is 26.32%; reduce the total distance from 5,499.8 kilometers to 3,406.92 kilometers, which is 38.05%; reduce the wages of transportation vehicles from 36,666 to 24,993 baht, which is 31.84%; can increase the average total weight per vehicle from 961.22 to 1,319.71 kilograms, which is 37.30%; and increase the average space utilization per vehicle from 37.93% to 51.47%, which is 13.54%. This method can reduce costs and increase efficiency for the company. Finally, the developed program also supports inexperienced operations managers in making decisions when planning transportation routes and loading goods, Thereby saving working time.

*Keywords:* Vehicle routing problem, Bin packing problem, Saving algorithm, 3D first fit algorithm, 3D best fit algorithm

## INTRODUCTION

In the logistics distribution process, effective delivery management is required to ensure high-quality and timely delivery. In recent decades, operations research and mathematical programming techniques have been developed to optimize the delivery of goods and services in distribution systems [1]. The optimization challenge posed by many transportation issues requires customized algorithms to be easily solved by computer analytics [2].

The case study company is a Chemical Factory, an industrial company that produces hygiene and cleaning products. The warehouse delivers 200-300 orders per day. For this reason, the company needs many vehicles every day. The company rents trucks from third-party service providers and charges a daily fixed fee per vehicle. However, the manager will consider the transportation route as follows: (1) Bangkok and the surrounding areas are divided into districts. (2) Provincial areas are separated by zip code. The distance and appropriateness will be considered as well. The manager will take the order of shipping from first to last into consideration while arranging products onto transport vehicles. The final delivery location's goods will be put at the back and bottom of the delivery truck. Since all order information is completed by 4.30 p.m., the manager begins routing daily at 4:30 p.m. and finishes at around 6:00 p.m. Please note that the employee gets off work at 5:30 p.m. The delivery manager arranges the transportation routes based only on her experience because there are no decision-making tools accessible. This cannot guarantee that the





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transportation routes the manager decided are the most suitable and use the fewest vehicles. Thus, transportation costs can be decreased by planning effective routes for transportation.

The vehicle routing problem, one of the most studied topics in operational research, arises from the fact that the distribution of products is influenced by a variety of factors, including those arising from the needs of transportation companies, customers, and the external environment [3]. The Bin Packing Problem (BPP) is about arranging a set of products that all have a positive length and packing the products into as few bins as possible. Furthermore, the total length of the products in a bin must not exceed the allocated capacity of the bin [4].

This study deals with the problem of vehicle routing in combination with the problem of storage space occupancy. The combination of these two problems could help the company reduce costs more successfully. Accordingly, this study aims to plan delivery routes, arrange items in trucks, and reduce transportation costs for a case study of a chemical plant by using a VRP and storage space problem program. Thanks to a route-planning program, the company will be able to work more effortlessly. It also allows the company to maintain and grow its market share and have a direct impact on customer satisfaction. Sustainability and environmental aspects can also be affected.

The remainder of this article is organized as follows: A literature review on VRP and bin packing is given in Section 2. The problem statement and assumptions are described in Section 3. Then, we investigate the solution methods in Section 4. Section 5 shows the results and discussion. Finally, Section 6 draws a conclusion and gives recommendations for future work.

## MATERIALS AND METHODS

*Literature reviews*

1. Vehicle routing problem

In the last sixty years, vehicle routing problems (VRP) have been studied extensively and in rapid succession [5]. The Vehicle Routing Problem as a mathematical programming model was developed by [6]. The Vehicle Routing Problem is an extension of the Traveling Salesman Problem (TSP). The VRP is both an NP-hard problem and a combinatorial optimization problem. The number of studies in this field is increasing rapidly, which leads to extending the VRP to several variants to make it a real-world problem. Researchers have tried to develop precise approaches, heuristics, and metaheuristics to solve the problem [7].

Many researchers and industry practitioners have developed vehicle routing for managing logistics operations and have modeled these logistics challenges. An improved metaheuristic moth-flame algorithm is used for electric vehicle routing. Battery capacity and visits to charging stations are taken into account [8]. A supply chain design strategy for organ transplants and a mathematical model were proposed by [9]. The described mathematical model aims to establish a link between the different implementations of the chain to ensure that people's irregular demands are met and the overall cost is minimized. A novel version of VRPD extends the traditional truck-drone delivery problem to a two-echelon network, taking into account a number of real-world constraints, such as consumer deadlines and drone energy capacity [10]. Routing problems with multiple vehicles have a maximum capacity constraint and no time constraint. They found that the TABU search proved to be better than other algorithms in terms of meeting the objective of cost minimization [11]. After reviewing various research papers, it can be concluded that although metaheuristics can be successfully used in VRP, there are still many areas that need further research [12]. One possibility is to develop algorithms that can be better adapted to changes in the operational environment. This has also been demonstrated in various studies conducted on specific VRP models that exist in different real-life situations.

2. Bin packing problem

The Bin Packing Problem (BPP) has been extensively studied by both computer scientists and operations researchers. It is well known that the bin packing problem is NP-hard and can be solved using a variety of techniques that have been proposed by many researchers. The First Fit Decreasing and the Best Fit algorithms were the two primary heuristic algorithms for bin packing used by the system. They were preferred over other heuristic algorithms because they run faster and provide results that are significantly closer to the optimal solution than those of most other heuristic algorithms.

References [13] aim to pack all items to be delivered onto the pallets, reflecting a three-dimensional bin-packing problem of the size of a single bin. They proposed a 3D BPP model that needs to be applied to load all pallets of corresponding customers into each vehicle, with a different objective function: maximizing volume utilization. The problem of packing variable-size containers with time windows is introduced and studied [14], a real problem in the logistics industry. The objective is to choose the most favorable containers to pack each item when there are a number of items with different quantities and time windows and several types of containers with different sizes and costs. A novel problem arises when setting up a last-mile parcel delivery service in a city and considering different transportation companies (TC) [15]. They show how this problem can be represented as a brand new packing problem, the Generalized Bin Packing Problem with Bin-Dependent Item Profits (GBPPI), where



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the TCs are the bins and the items are the parcels to be delivered. The space-saving heuristic for determining the optimal match between the next item to be loaded and the loading position is practical [16]. The subproblem of the vehicle routing problem is solved by the variable neighborhood search (VNS) algorithm, while the subproblem of the bin packing problem is solved by the stochastic gradient homology (SSH) algorithms.

Regarding research gaps, there are many studies that combine these two problems [17-19]. In this study, the sparse algorithm is used to calculate the routing. Then the 3D best fit algorithm and the 3D first fit decreasing algorithm are run to arrange the items.

*Problem description and assumptions*

To support decision making in the planning of transportation routes and the loading of goods for inexperienced operators and to save working time. In this study, a program is also developed in Python using the Saving Algorithm to solve transportation route problems and the 3D First Fit Decreasing Algorithm and 3D Best Fit Algorithm to solve product packaging problems. While the 3D First Fit and 3D Best Fit algorithms are not guaranteed to provide the optimal solution, their simplicity and efficiency make them a practical choice for many real-world applications.

1. The savings algorithm

Since 1964, the savings algorithm has been proposed as an approach to increasing computational speed. In addition, numerous extensions of the basic VRP have been investigated using improvements to the sparsity algorithm [20]. The sparsity algorithm of Clarke and Wright (CW) is the most commonly used heuristic for solving the Capacitated Vehicle Routing Problem (CVRP). These extensions take into account constraints such as route length and vehicle capacity. The classical savings algorithm first calculates the cost savings value for each pair of customers as follows:

$$S_{i,j} = D_{1,i} + D_{j,1} - D_{i,j} \tag{1}$$

where $D_{1,i}$ is the traveling distance between depot 1 and customer $i$.

$D_{j,1}$ is the traveling distance between customer $j$ and depot 1.

$D_{i,j}$ is the traveling distance between customer $i$ and customer $j$.

All savings values $S_{i,j}$ are sorted in descending order. Starting with the top entry in the list. Then any two customers, $i$ and $j$, in any value from the list are combined to form the cost savings link, provided that the total demand is less than or equal to the capacity of the vehicle. The process is repeated to process the next value in the list until no feasible connection is possible. Ultimately, the vehicle routes are created by adding customers, $i$ and $j$ to the connection. However, if a customer is unassigned, it is assigned a route that starts at the depot, goes to the unassigned customer, and ends back at the depot [21].

2. 3D best fit algorithm

Decide on a packing direction, each bin has three directions in which to pack, a width direction (or x), a height direction (or y) and a depth direction (or z). Pack one bin at a time. First, we select a pivot point, which is a point in a specific 3D bin that will be attempted to be packed; it is represented by an (x, y, z) coordinate. The lower left corner of the item will be placed at the pivot. The lower left corner of the item will be placed at the pivot. If the item cannot be packed at the pivot position, then it is rotated until it can be packed at the pivot point or until we have tried all 6 possible rotation types. After trying to pack the remaining items, we proceed to pack another item and add the unpacked item to a list of items that will be packed if the item cannot be packed at the pivot point even after rotation. In an empty bin, (0,0,0) is always the initial pivot point [22, 23].

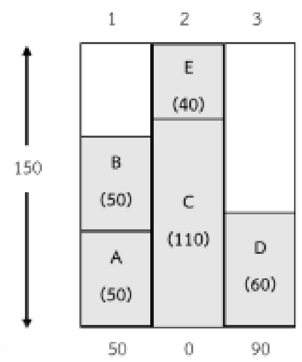


**Figure 1** Best-fit Algorithm.

3. 3D first fit decreasing

To pack an object, you must first decide the packing direction. The longest side of the container corresponds to the packing direction. Then rotate each item so that the longest side of that item is the side that corresponds to the packing direction, i.e., if we pack by width, then the longest side of the item should be the width of the item. For example, if the packing direction is by width and the current height of the item is longer than its width, then you should rotate the item. If the article does not fit into the container after the rotation (s) have been carried out (i.e., one or more dimensions of the article exceed the corresponding dimension of the container), then we rotate the article until the second longest side of this article is the side that corresponds to the packing direction. If the item does not fit into the container after the rotation(s), we rotate the item until the third longest side of this item is the side that corresponds to the packing direction. Next, we sort the items in decreasing order by width, height, or depth, depending on the packing direction [22, 23].



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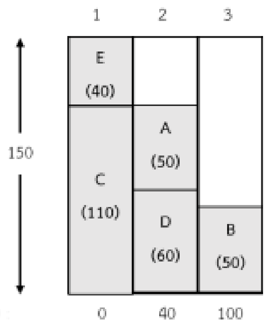


**Figure 2** First-fit Decreasing Algorithm.

*Solution methods*

1. Program

In the program development, the Python code from Github with the username ishelo is used for the route planning of vehicles. The savings algorithm is used to calculate the routing.

On the other hand, the Python code from a Github account with the username Shiu Ruei-Chang is used. We use the package py3dbp, which implements the 3D best-fit algorithm and the 3D first-fit decreasing algorithm for the bin packing problem.

2. Conditions

The delivery vehicles are a pickup truck with a cabin and 4 wheels that can transport heavy water. The payload is 2,700 kilograms. The size of the container is used as a standard for the installation of fixed cabinets. For a pickup with a single-cab cabin, the proportions inside the container are 2.37 meters long, 1.73 meters wide, and 1.25 meters high.

Limitation of the packaging volume: The total volume of all packaged products must not exceed the volume of the pickup. The program defines tolerances for the filling volume in order to avoid filling incidents with insufficient product or product packaging.

Since the packaged products are chemical products that cannot be rotated vertically as indicated, we also do not indicate that they can be rotated in the direction of the y-axis. Also, after packing, arrange bulky items according to the delivery order.

## RESULTS AND DISCUSSION

The shipping information for each of the 54 locations will be considered once the routing and packaging planning program is completed. The results are as follows:

*1. Vehicle route planning by the delivery manager*

In this case, the delivery manager will use his expertise to plan the vehicle route. Table 1 shows that the lowest total load per vehicle is 106.80 kilograms, and the highest is 2,735 kilograms. The lowest total distance per vehicle is 77.80 kilograms, and the highest is 946 kilometers. The lowest utilization per vehicle is 14.12 percent, the highest is 78.26 percent, and the average is 37.93 percent.

**Table 1** Vehicle Route Planning by the delivery manager.

| No. Vehicle | Route | Weight (Kg) | Total Distance (Km) | Cost (Baht) | Area utilization rate (%) |
|---|---|---|---|---|---|
| 1 | 0>14>53>16>29>41>28>27>7>30>0 | 608 | 300 | 1,950 | 30.58 |
| 2 | 0>3>0 | 316.17 | 200 | 1,650 | 34.09 |
| 3 | 0>51>26>4>20>42>39>21>10>13>49 >22>12>0 | 1,350.09 | 374 | 2,172 | 60.32 |
| 4 | 0>6>47>0 | 1,060 | 166 | 1,548 | 28.72 |
| 5 | 0>5>0 | 1,000 | 319 | 2,007 | 26.93 |
| 6 | 0>44>0 | 2,700 | 196 | 1,638 | 61.72 |
| 7 | 0>33>0 | 181.2 | 241 | 1,773 | 17.70 |
| 8 | 0>50>54>24>0 | 173.6 | 77.8 | 1,500 | 15.03 |
| 9 | 0>52>23>0 | 2,735 | 152 | 1,506 | 78.26 |
| 10 | 0>40>37>15>31>35>0 | 909.5 | 318 | 2,004 | 61.95 |
| 11 | 0>11>25>32>0 | 167 | 348 | 2,094 | 14.12 |
| 12 | 0>46>0 | 1,200 | 324 | 2,022 | 26.93 |
| 13 | 0>45>48>0 | 1,550 | 218 | 1,704 | 40.77 |
| 14 | 0>2>0 | 202.3 | 230 | 1,740 | 35.41 |
| 15 | 0>8>0 | 1,200 | 946 | 3,888 | 35.84 |
| 16 | 0>36>38>19>0 | 106.8 | 278 | 1,884 | 17.73 |
| 17 | 0>17>43>9>18>0 | 1,200.5 | 248 | 1,794 | 64.78 |
| 18 | 0>34>1>0 | 403 | 240 | 1,770 | 42.82 |
| 19 | 0>46>0 | 1,200 | 324 | 2,022 | 26.93 |



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*2. Vehicle route planning by program*

In this case, the program takes both the VDP and the bin packing problems into account when planning the vehicle routes. The results of the transport route planning show that the lowest total load per vehicle is 423 kilograms and the highest is 2,700 kilograms. The lowest total distance per vehicle is 128.79 kilometers, and the highest is 794.26 kilometers. The lowest land utilization rate per vehicle is 38.77 percent, and the highest is 68.70 percent, with an average of 51.47 percent, as shown in Table 2.

**Table 2** Vehicle Route Planning by Program.

| No. Vehicle | Route | Weight (Kg) | Total Distance (Km) | Cost (Baht) | Area utilization rate (%) |
|---|---|---|---|---|---|
| 1 | 0>18>0 | 945 | 202.40 | 1,658 | 59.82 |
| 2 | 0>44>0 | 2,700 | 159.83 | 1,530 | 61.72 |
| 3 | 0>46>0 | 2,400 | 268.66 | 1,856 | 53.85 |
| 4 | 0>52>0 | 2,400 | 128.79 | 1,500 | 68.70 |
| 5 | 0>27>2>33>0 | 423 | 208.00 | 1,675 | 53.83 |
| 6 | 0>16>53>29>1>43>9>34>0 | 523 | 207.02 | 1,672 | 54.06 |
| 7 | 0>41>30>35>40>7>32>0 | 582 | 215.38 | 1,697 | 53.40 |
| 8 | 0>5>14>28>0 | 1,165 | 270.33 | 1,862 | 38.77 |
| 9 | 0>45>48>0 | 1,550 | 152.10 | 1,507 | 40.77 |
| 10 | 0>47>17>19>38>37>36>15>31>11>25>0 | 1,415 | 300.38 | 1,952 | 53.94 |
| 11 | 0>3>23>0 | 651 | 166.21 | 1,549 | 43.65 |
| 12 | 0>39>26>42>20>13>21>10>4>12>22>0 | 964 | 159.00 | 1,528 | 43.38 |
| 13 | 0>6>49>51>24>0 | 1,435 | 174.57 | 1,574 | 45.25 |
| 14 | 0>54>8>50>0 | 1,323 | 794.26 | 3,433 | 49.50 |

**Table 3** Comparison results.

| No. | Planning by | | Difference Percentage |
|---|---|---|---|
| | Delivery manager | Program | |
| Number of transport vehicles used | 19 | 14 | 26.32 |
| Average total weight (Kg) | 961.22 | 1,319.71 | 37.30 |
| Total distance (Km) | 5,499.8 | 3,406.92 | 38.05 |
| Shipping cost (Baht) | 36,666 | 24,993 | 31.83 |
| Area utilization rate (%) | 37.93 | 51.47 | 13.54 |

*3. Arrange products by routing*

From a total of 14 vehicle routes, the program has arranged the positions as shown in Figure 3. It can be seen that some trucks will not have the full amount of products or room for additional products. However, if the researchers add more orders to this vehicle, it will exceed the limits of the truck, be overweight or unable to arrange the products, etc.

*4. Comparison results between vehicle route planning by the delivery manager and the program*

Table 3 shows that a total of 19 transport vehicles are used by the delivery manager when planning the transport routes. The total distance of the transport is 5,499.8 kilometers. The average load weight per vehicle is 961.22 kilograms. The total cost of the transport vehicles is 36,666 baht, and the average space utilization is 37.93. In contrast, a total of 14 vehicles are used in the program-controlled planning of the transport routes. The total transport distance is 3,406.92 kilometers. The average payload per vehicle is 1,319.71 kilograms. The total cost of the transport vehicles is 24,993 baht, and the average space utilization is 51.47.

In summary, the results show that the program's route plans are to be preferred. Even if it is not the optimal solution, the program can process the answer in a reasonable time and is easy to use for the users. Moreover, the case study company can accept these results and be satisfied with them. The vehicle routing application will simplify the company's operations [25]. In addition, the combination of vehicle route planning and container packing problems will enable a reduction in the number of vehicles, total distance, and transportation costs. It also increases the average total weight and the space utilization rate. Sustainability is also influenced by fewer vehicles and routes, as carbon dioxide emissions are reduced [24].





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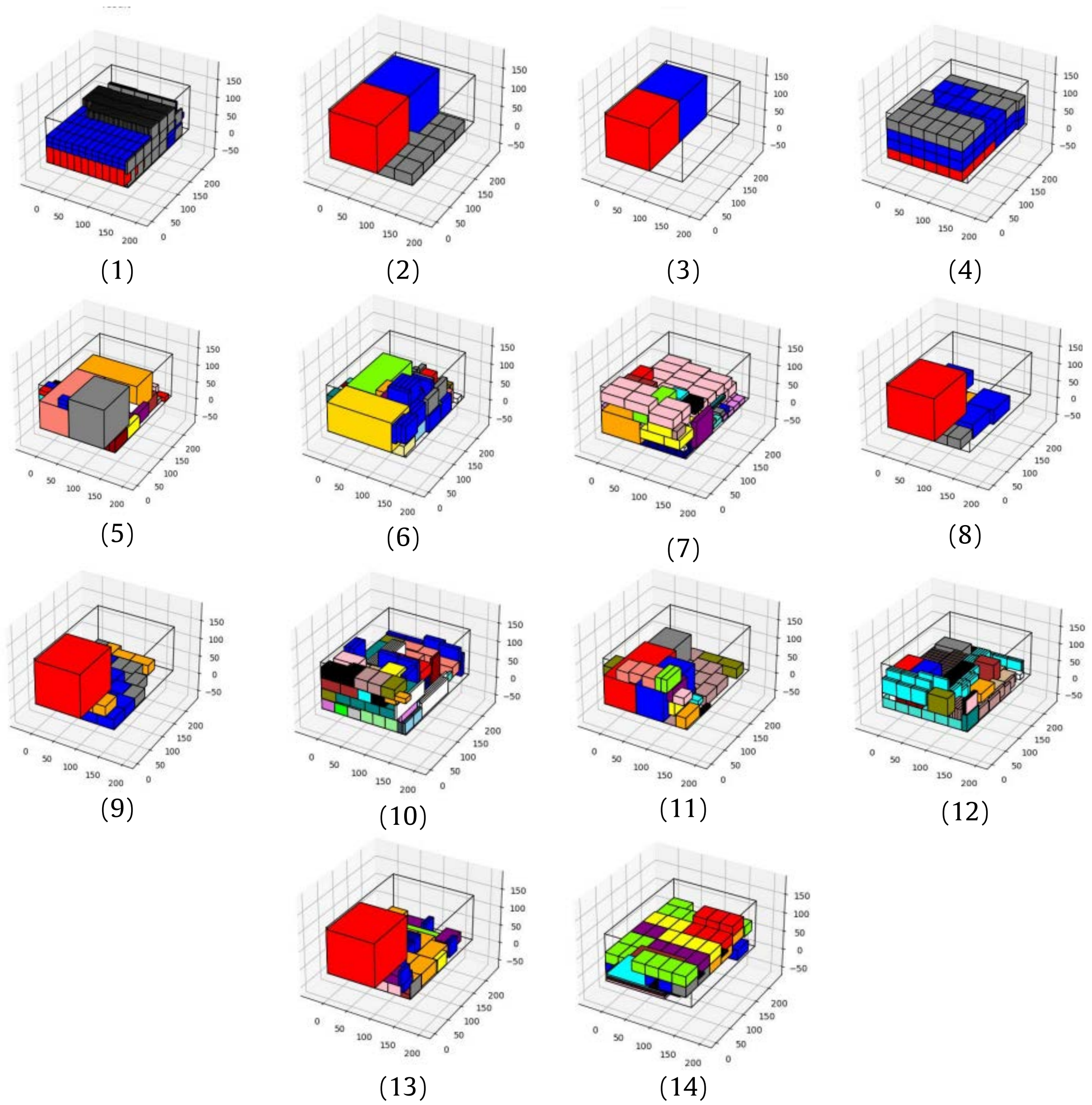


**Figure 3** Items on vehicle number 1-14.

## CONCLUSIONS

This study is about planning delivery routes, arranging items in trucks, and reducing transportation costs for a case study of a chemical plant using VRP and storage space issues. In this study, a program was also developed in Python using the Spar Algorithm to solve traffic routing problems and the 3D first fit decreasing algorithm and 3D best fit algorithm to solve product packaging problems. Python code provided by users via the Github website was used, with weight and volume constraints added to the routing constraints. Furthermore, since the products to be packaged are chemical products that cannot be rotated vertically as specified, we do not specify that they can be rotated in the y-axis direction. Also, after packing, arrange the bulky items according to the delivery sequence.

The results from the execution of the program are compared with the results of the calculation by the delivery manager. It has been found that the vehicle routes provided by the program can help reduce costs and make operations more efficient. As for the results of the data set, even if the program is not optimal, it can process the answer in a reasonable time and is easy for users to operate. Furthermore, the case study company can accept these results and be satisfied with them. So the results may not be the cheapest, but they are appropriate for the company's work.

In the future, other solutions can be used for product packaging, such as genetic algorithms, local search, etc. Additionally, consider line balancing to ensure equality between shippers/drivers in terms of driving hours or similar amounts of distance traveled.

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