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Vehicle Assignment For Chemicals Transportation

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RESEARCH ARTICLE

Vehicle Assignment for Chemicals Transportation

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Abstract

Vehicle assignment is a significant challenge faced by chemical logistics companies. The chemical industry typically outsources the delivery of chemicals to professional logistics companies to meet customers' complex and demanding needs. In this regard, this research explores the case study of a logistics company that selects its delivery modes and formulates its vehicle assignment plans based on its personnel's experience rather than any formal system and plans its vehicle routes on the day before the delivery. This study seeks to improve the efficiency and immediacy of logistics companies' vehicle assignments, understand vehicle route planning, maximize space utilization, and minimize transportation costs.

This paper presents both a mathematical programming model and a heuristic algorithm. The algorithm development process comprises four steps: constructing the initial condition, improving transportation cost, reducing customers, and splitting vehicles. The case study company's transportation costs and vehicle distribution results indicate that the proposed heuristic algorithm can effectively save transportation costs and the time cost involved in delivery route planning.

Keywords: Container loading problem, Vehicle assignment problem, Mathematical programming, Heuristic algorithm

1. Introduction

Vehicle assignment is one of the critical factors that allow companies to gain a competitive advantage in the logistics market. Improving the efficiency of logistics and distribution can increase the overall operational efficiency of society and increase the productivity and competitiveness of enterprises. Several enterprises pay significant attention to logistics management and actively invest in logistics management and integrated logistics services. In actual operations, a more detailed understanding of the characteristics of logistics goods is necessary to improve work efficiency and transport safety.

Chemicals can include explosives, gases, flammable liquids and solids, oxidizing substances, poisonous and infectious substances, corrosive substances, and radioactive materials. In Taiwan, different authorities currently manage chemicals based on their intended use. For example, the Environmental Protection Administration agency regulates industrial chemicals based on the Toxic Chemical Substances Control Act.

Taiwan's demand for chemicals is diverse, requiring different shipping conditions. Customers often need a variety of chemicals and require suppliers to provide multiple small deliveries due to the storage limitations of chemicals. In this era of rising oil prices, transportation costs are expected to increase significantly, along with the personnel costs for drivers. Thus, logistics managers must reduce the number of vehicles to reduce costs, increase transport safety, and improve competitiveness.

The conditions required for delivering general chemicals vary, with different chemicals requiring

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different devices to be installed on trucks for their transport. A traditional logistics manager plans delivery routes and assigns vehicles based on personal experience. However, due to the variety in goods, distribution volumes, restrictions, and delivery locations, logistics managers may not complete their ideal route planning within a short time based on their personal experience alone.

Considering the actual nature of chemical logistics operations, it is necessary to develop an efficient planning distribution route and vehicle assignment method. Thus, this study seeks to improve the efficiency and immediacy of logistics companies' vehicle assignments, understand vehicle route planning, maximize space utilization, and minimize transportation costs. The remainder of this paper is organized as follows: Section 2 provides the literature review. Section 3 describes the current situation of the case study company. Section 4 introduces a mathematical programming model and a heuristic algorithm, while Section 5 presents the results. Finally, Section 6 discusses the concluding remarks.

2. Literature review

Transportation costs are mainly affected by vehicle routes and the filling rate of a container. Well-planned vehicle routes and highly loaded containers can significantly reduce transportation costs. Therefore, the following literature review explores both the vehicle routing problem (VRP) and the container loading problem.

The VRP is a combinatorial optimization and integer programming problem that asks, "What is the optimal set of routes for a fleet of vehicles to traverse to deliver goods to a given set of customers?" The mathematical programming model is independent of the solution efficiency, but the solution algorithm matters. It is suitable for using an exact solution method to solve a mathematical model with small instances, while it is not ideal for solving a mathematical model associated with an NP-hard problem with large instances. Thus, literature on the VRP has been almost exclusively concerned with heuristics.

Heuristic algorithms can be broadly classified into two main classes: classical heuristics, mainly developed between 1960 and 1990, and meta-heuristics, developed in recent decades [17]. In general, classical heuristics are of four types: (1) tour building heuristics, (ii) tour improvement heuristics, (iii) two-phase methods, and (iv) incomplete optimization methods. Among tour building heuristics, the Clarke and Wright method [7] has often been mentioned in prior literature. Several modifications have been made to the Clarke and Wright method. [8,34] independently introduced modified savings, Sij-hCij, wherein h is a scalar parameter. The emphasis on the cost of travel between two nodes can be modified by varying h. Tour improvement heuristics are based on [19,20] studies regarding the traveling salesman problem. [5] modified this heuristic for the VRP. Two-phase methods include the methods introduced by [6,13]. An example of a heuristic based on incomplete optimization is the tree-search method, as reported in [6] work.

In recent decades, several researchers have applied tabu searches to the VRP. [10,27–29,31,33] all obtained very satisfactory results.

Since the capacitated VRP (CVRP) has been popular since the introduction of the VRP, as indicated by the section dedicated to this topic in [32] work, we did not discuss this topic any further in this study. As references for our research on VRP, we referred to the CVRP studies of [15,21,23,31]; and [1]. In the last decade, a new variant of the CVRP that minimizes the sum of the arrival times at customers' locations was introduced [16,25,26].

The single container loading problem refers to loading a set of boxes into a container. The objective of this problem is to maximize the total volume of the loaded boxes. [2] presented 12 conditions to consider when solving practical problems [4] provided a survey of the container loading problem.

Many heuristic algorithms have been developed to address the single container loading problem, also known as the three-dimensional box packing problem. Some of these methods use the Tabu Search [3,24]; Genetic algorithm [9], combinatorial optimization techniques [18], greedy search [14] and other heuristics suggested by [12,22].

According to previous literature, an enhanced route plan and efficient truck loading can significantly reduce transportation costs. In general, our research described here differs from a vehicle routing problem in that the case study company outsources all its shipping processes to a transporting company. Consequently, the company only needs to assign chemicals to the vehicle provided by the freight company and does not have to plan the vehicle's route. Thus, the main focus of our research is assigning chemicals to trucks. Additionally, truck loading can be reduced to a two-dimensional container loading problem since chemicals cannot be stacked. Our real world problem includes the characteristics of a two-dimensional container loading problem and vehicle assignment problem; it can be formulated as a nonlinear integer programming. This scenario has not been explored in the literature to the best of my knowledge. As mentioned above, it is not suitable to use an exact solution method to solve a nonlinear integer programming with large instances; hence, we developed a heuristic algorithm to solve the vehicle assignment problem in chemicals transportation.

3. Case study company and distribution status

The case study company manufactures high purity electronic chemicals for semiconductor and TFT-LCD processes and provides original equipment manufacturer (OEM) services. The case study company uses competitive bidding to find a transport company to deliver chemicals. Eligibility for participating in the competitive bidding must have more than 25 regular pressure tank trucks. The carrying capacity of each truck should be more than 30 kL. Additionally, each truck must obtain a valid qualified license certificate, i.e., a tank certificate, complying with the "normal pressure liquid tank inspection and management measures" regulations. The contract term was 365 days from the date of commencement, or the execution rate of the contract amount was more than 95%. From the eligibility criteria above, we know that delivery service providers need a sufficient number of vehicles and drivers.

The distribution process of the case study company can be described as follows. The company stores a certain amount of chemicals in functional warehouses. A transport company picks up these chemicals at functional warehouses when orders are received. Next, the transport company delivers the chemicals to chain stores, regional dealer warehouses, or other manufacturers. Finally, the chemicals are sold to customers or redistributed to retailers. The case study company has signed a contract with a transport company for the distribution. The number of vehicles required per day is manually calculated by the case study company.

The transport company assigns customer orders to different types of vehicles for distribution based on the case study company's notifications. The transport company can arrange three types of trucks for transport chemicals, including trucks with a gross weight of 35 tons or a size of 20 pallets, a gross weight of 26 tons or a size of 12 pallets, and a gross weight of 17 tons or a size of 12 pallets, respectively. Figure 1 shows a truck with a gross weight of 35 tons and a size of 20 pallets.

The shipping cost per truck refers to the charges for a single trip. However, several situations may result in higher transportation costs. First, the minimum cargo for calculating the transportation cost is seven tonnages. The number of chemicals to be transported may not be sufficient for seven tonnages. The transport company will charge it for seven tonnages.


Fig. 1. A truck with a gross weight of 35 tons and a size of 20 pallets.

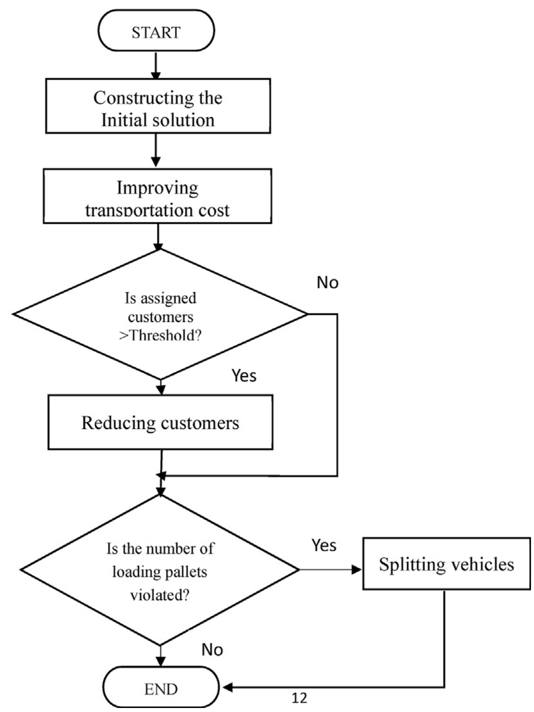

Fig. 2. The computational flow of the vehicle assignment algorithm.

Moreover, due to safety and package factors, non-stackable chemicals may lead to unused truck space, i.e., the loading space per truck will be underutilized. Next, each customer is charged an extra $200 after a truck visits more than four customers. Last, the transportation cost per ton is calculated based on a truck's highest per-ton transport costs. For example, a truck is assigned to a customer for 448 dollars per ton and another for 512 dollars per ton. The price per ton of transportation is calculated at 512 dollars.

Logistics managers assign trucks and plan the appropriate distribution route based on three types of trucks to meet customers' weight and pallets requirements. However, different customers have different distribution and capacity requirements, which increases the complexity of logistics planning. Hence, it is crucial to improve the efficiency of truck assignment and route planning.

4. Mathematical programming model and heuristic algorithm

4.1. Mathematical programming model

To simplify the analysis, we developed our model based on the following assumptions:

(1) The requirements of all customers are known.
(2) Trucks are assigned to customers to provide daily services.
(3) The available capacity per day (i.e., fleet size) is known.
(4) The daily load per truck cannot exceed its capacity.
(5) Different types of trucks are available.
(6) Multiple trips per truck are allowed if the travel time is not violated.
(7) Customers' delivery can be managed using multiple trucks.
(8) Only one service date can be assigned to each customer.

Next, we presented a nonlinear integer programming model and relevant notations as follows:

$$\text{Minimize } Z = \sum_{k=1}^{m} \mathrm{YCOST_k} * \mathrm{YLOAD_k} + \sum_{k=1}^{m} \mathrm{C_{extra}} * \mathrm{YEXPOINT_k}$$

Subject to

$$\mathrm{YLOAD_k} = \sum_{i=1}^{n} \sum_{j=1}^{n_i} \mathrm{q_{ij}} * \mathrm{X_{ijk}} \quad (k = 1, 2, \ldots, m) \tag{1}$$

$$\mathrm{X_{ijk}} = \begin{cases} 1, & \text{customer i's j}^{\text{th}} \text{ product is delivered by the k}^{\text{th}} \text{ truck,} \\ 0, & \text{otherwise} \end{cases}$$

$$\mathrm{YCOST_k} \geq \mathrm{Cost_i} * \mathrm{X_{ijk}} \quad (\mathrm{j} = 1, \ldots, \mathrm{n}_i; \mathrm{i} = 1, 2, \ldots, \mathrm{n}; \mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{2}$$

$$\mathrm{Mt} - \mathrm{YLOAD_k} \leq \mathrm{My} \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{3}$$

$$\mathrm{YLOAD_k} - \mathrm{Mt} \leq \mathrm{My} \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{4}$$

$$\mathrm{Mt} - \mathrm{YLOAD_k} \leq \mathrm{M}(1 - \mathrm{y}) \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{5}$$

$$\mathrm{YPOINT_k} = \sum_{i=1}^{n} \mathrm{X_{i1k}} \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{6}$$

$$-\mathrm{YEXPOINT_k} + \mathrm{YPOINT_k} - \mathrm{Threshold} \leq \mathrm{Myy} \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{7}$$

$$\mathrm{YEXPOINT_k} - \mathrm{YPOINT_k} + \mathrm{Threshold} \leq \mathrm{Myy} \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{8}$$

$$\mathrm{YPOINT_k} - \mathrm{Threshold} \leq \mathrm{M}(1 - \mathrm{yy}) \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{9}$$

$$\mathrm{YLOAD_k} \leq \mathrm{Q_k} \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{10}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n_i} s_{ij} * \mathrm{X_{ijk}} \leq \mathrm{P_k} \quad (\mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{11}$$

$$\sum_{j=1}^{n_i} \mathrm{X_{ijk}} = 0 \quad (\mathrm{k} = 1, 5; \mathrm{i} \in \mathrm{N_s}) \tag{12}$$

$$-n_i + \sum_{j=1}^{n_i} \mathrm{X_{ijk}} \leq \mathrm{Myyy} \quad (\mathrm{i} = 1, 2, \ldots, \mathrm{n}; \mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{13}$$

$$\sum_{j=1}^{n_i} X_{ijk} \leq \mathrm{M}(1 - \mathrm{yyy}) \quad (\mathrm{i} = 1, 2, \ldots, \mathrm{n}; \mathrm{k} = 1, 2, \ldots, \mathrm{m}) \tag{14}$$

$$\sum_{k=1}^{m} \mathrm{X_{ijk}} = 1 \quad (\mathrm{j} = 1, 2, \ldots, n_i; \mathrm{i} = 1, 2, \ldots, \mathrm{n}) \tag{15}$$

$$\mathrm{X_{ijk}}, \in \{0, 1\} \ \forall i, j, k; \ y, \mathrm{yy}, \ \mathrm{yyy} \in \{0, 1\}; \ \mathrm{YPOINT_k}, \mathrm{YEXPOINT_k}, \mathrm{YCOST_k} \geq 0 \text{ integer}, \forall \ \mathrm{k}; \mathrm{YLOAD_k} \geq 0 \tag{16}$$

Decision variables:

$\mathrm{YLOAD_k}$: weight of the cargo loaded by the k^{th} truck.

$\mathrm{YPOINT_k}$: total number of customers visited by the k^{th} truck (≥0, integer).

$\mathrm{YEXPOINT_k}$: number of customers visited more than four customers by the k^{th} truck (≥0, integer).

$YCOST_k$: cost per ton of cargo loaded by the k^{th} truck ($\geq$0, Integer).

y: a binary variable used in logical constraints.

yy: a binary variable used in conditional constraints.

yyy: a binary variable used in logical constraints.

Parameters and sets:

M: a sufficiently large positive number,

q_{ij}: weight of customer i's jth product,

s_{ij}: required number of pallets for customer i's jth product,

m: number of trucks,

n: number of customers,

n_i: number of customer i's products.

C_{extra}: extra cost for each customer after a truck has visited four customers.

$Cost_i$: delivery cost per tonnage for customer i.

Threshold: the threshold of number of customers for charged an extra 200 dollars per customer.

Mt: minimum tonnage for calculating the transportation cost.

Q_k: weight capacity of truck k.

P_k:number of allowed loading pallets in truck k.

Ns: set of customers that a large truck is not allowed to visit for delivery.

The objective was to identify an optimal vehicle assignment solution by minimizing the total cost function. The total cost function includes the loading cost per truck and the additional cost of delivering to more than four customers.

The purpose of the conditions mentioned above are as follows:

Constraints (1) determine whether customer i's jth product is delivered by truck k.

Constraints (2) ensure that each vehicle's cargo loaded cost per tonnage is greater than or equal to the customer's delivery cost per tonnage.

Constraints (3), (4), and (5) represent the minimum tonnage constraints. In these logical constraints, y is a binary variable. When $y = 0$, $YLOAD_k = Mt$. When $y = 1$, $YLOAD_k \geq Mt$.

Constraints (6) calculate the total number of customers visited by the kth truck.

Constraints (7) and (8) calculate the proportion of all trucks that were assigned more than four customers. In these conditional constraints, yy is a binary variable. When $yy = 0$, $- YEXPOINTk+YPOINTk- Threshold = 0$. When $yy = 1$, $-M\leq -YEXPOINTk+YPOINTk- Threshold \leq M$.

Constraints (9) require that the total number of customers with fewer than four visits is no more than the number of trucks that can be assigned.

Constraints (10) restrict the loaded weight of truck k to be less than the weight limit of truck k.

Constraints (11) ensure that the required number of pallets of customer i's jth product is less than the maximum number of pallets that can be loaded by truck k.

Constraints (12) restrict customers with special requirements (the special requirement column in Table 2) who cannot use a truck with a maximum load of 18 tonnages for delivery.

Constraints (13) and (14) require that the number of customer i's products in truck k is less than or equal to the number of customer i's products. In these logical constraints, yyy is a binary variable. When $yyy = 0$, the number of customer i's products in truck k is less than or equal to the number of customer i's products. When $yyy = 1$, customer i's products are not assigned to truck k.

Constraints (15) ensure that customer i's jth product is delivered by one truck.

Constraints (16) are nonnegtive constraints.

4.2. Heuristic algorithm

Before introducing our heuristic algorithm, we describe the concept for designing the heuristic algorithm. Our heuristic algorithm is a four-step procedure for solving vehicle assignments that minimize transportation costs. To reduce transportation costs, we must consider all factors that could increase transportation costs.

Scenarios increasing transportation costs are summarized as follows: First, the truck's freight per trip equals the number of tons loaded on a truck multiplied by the cost per ton of transportation. When the loaded weight of each truck is less than seven tons, freight is still calculated at seven tons. Hence, we must reduce the unloaded weight of each truck. Next, the transportation cost per ton is calculated based on a truck's highest per-ton transport costs. For example, a truck is assigned to a customer for 448 dollars per ton and another for 512 dollars per ton. The price per ton of transportation is calculated at 512 dollars. Assigning customers with the same per-ton transport cost into the same truck can avoid increasing the transportation cost. Lastly, when a truck is assigned more than four customers, an extra cost of 200 dollars is charged for each additional customer. Reducing the number of customers in trucks with more than four customers can further cut the transportation cost.

Based on the above concept, we develop a heuristic algorithm including four procedures: constructing the initial solution, reducing transportation cost, reducing customers, and splitting vehicles. Our heuristic algorithm can be described in main procedures as follows:

Step 1: Set the required inputs and generate an initial solution.

Step 2: Improving the transportation cost by reducing the unused loading weight of each truck and reducing the number of assigned trucks.

Step 3: Check the number of assigned customers in a truck. If the number of assigned customers is greater than the Threshold, go to Step 4 else, go to Step 5.

Step 4: Reduce the number of assigned customers in a truck by moving customers to other trucks.

Step 5: Check the number of assigned pallets in a truck. If the number of assigned pallets is violated, go to Step 6 else stop the algorithm.

Step 6: Split the customer's order into different vehicles.

The computational flow of our heuristic algorithm is shown in Figure 2. In the following we describe the algorithm by examining its main procedures separately.

1. Constructing the initial solution

We construct the initial solution based on the same tonnage fare and special requirements.

1 Input the customer number, loading weight, loading pallets, tonnage fare, special requirement, geographical location information, and truck loading capacity.
2 Calculate the total number of customers, n, and the number of products per customer, ni [i].
3 To determine the number of trips required, we summed up the loaded weight and the number of loaded pallets of all customers. If the total loaded weight or the total number of loaded pallets exceeds the available trucks' capacity, a second trip is required.
4 Divide the customers into different groups based on the tonnage fare.
5 Find the head position, tail position, and the total number of groups in the array.
6 Calculate the number of customers who need a large truck (the maximum load tonnage is greater than 7.74, i.e., 1st truck to 6th truck in Table 1).
7 Sort customers who need a large truck in descending order using a bubble sort based on the customers' loaded weight.
8 Assign customers to large trucks (1st truck to 6th) in sequence, identifying customers with special requirements who are not allowed to load a 35-ton truck with a maximum load capacity of 18 tons (i.e. 1st truck and 5th truck in Table 1) during the assignment process. If necessary, assign such customers to the other large trucks (third or fourth truck).
9 If the total number of pallets in a truck cannot accommodate the requirement of all customers, swap the truck to produce a feasible solution. If a customer's loaded weight or the number of loaded pallets still exceeds the truck capacity, it may produce an infeasible solution in this procedure. Then leave this customer for the final splitting vehicles procedure that will split the customer's products into different trucks.
10 Assign the remaining customers to a small truck (7th truck to 16th truck in Table 1). If the small trucks run out of capacity, assign the unassigned customers to two additional large trucks with remaining capacity (5th truck to 6th truck).

2. Improving transportation costs

Transportation costs can be lowered by reducing the number of assigned trucks or the unloaded weight of each truck. The steps involved in reducing costs are summarized below:

```
1 for k ← 1 to m
    if (loading weight of truck [k] ≤ Mt) then truckload_lt_Mt [k] = 1

2 for ka ← 1 to m
    for kb ← 1 to m
      if (truckload_lt_Mt [ka] = 1) and (truckload_lt_Mt [kb] = 1)
        if (truck tonnage fare [ka] = truck tonnage fare [kb])
```

Table 1. Vehicle dimensions and maximum load capacity.

Truck number in the program	Gross weight (tonnage)	Bare weight (tonnage)	Maximum load (tonnage)	Loading pallets
1, 5	35	17	18	20
2, 6	35	17.7	17.3	20
3	26	12.65	13.35	12
4	26	13.7	12.3	14
7, 12	17	9.26	7.74	12
8, 13	17	9.6	7.4	12
9, 14	17	9.91	7.09	12
10, 15	17	9.91	7.09	12
11, 16	17	9.52	7.48	12

```
        if (unloaded weight of truck [kb]>loaded
        weight of truck [ka]) and (remaining unloaded
pallets of truck [kb]>loaded pallets of truck [ka])
  merge the cargo of the assigned customers of
truck ka with that of truck kb
  update information for truck kb and delete the
information of truck ka

3 sum up loaded weight = loaded weight of truck
  [ka]+ loaded weight of truck[kb]

  sum up loaded pallets = loaded pallets of truck
[ka]+ loaded pallets of truck [kb]
  for kd ← 1 to 6
  if (assigned customers [kd] = 0)
    if (loaded weight of truck [kd]> sum up loaded
    weight) and (loaded pallets of truck [kd]> sum
    up loaded pallets)
    if (no customer needs a special requirement)
    and (kd≠1 and kd≠5)
    merge the customers of trucks ka and kb
    with those of truck kd, delete the information of
    trucks ka and kb, and update the information of
    truck kd

4 if (truckload_lt_Mt [ka] = 1) and (truckload_lt_Mt
  [kb] = 1)

    if (unloaded weight of truck [kb]>loaded weight
    of truck [ka])   and (remaining unloaded pallets
    of truck [kb]>loaded pallets of truck [ka])
    if (the transportation cost after merging ka with
    kb < the original transportation cost without
    merging)
    merge the cargo of the assigned customers of
    truck ka with that of truck kb
    update information for truck kb and delete the
    information of truck ka

5 for ka ← 1 to m
      for kb ← 1 to m
       if (truckload_lt_Mt [ka] = 1) and (truckload_
        lt_Mt [kb] = 1)
      if (truck tonnage fare [ka]≠ truck tonnage
        fare [kb])
      sum up loaded weight = loaded weight of
       truck [ka]+ loaded weight of truck [kb]
      sum up loaded pallets = loaded pallets of
       truck [ka]+ loaded pallets of truck [kb]
       for kd ← 1 to 6
      if (assigned customers [kd] = 0)
       if (loaded weight of truck [kd]> sum up
       loaded weight) and (loaded pallets of truck
       [kd]> sum up loaded pallets)
          if (no customer needs a special require-
          ment) and (kd≠1 and kd≠5)
         if (the transportation cost after merging ka,
        kb with kd < the original transportation cost
        without merging)
        merge the customers of trucks ka and kb
      with those of truck kd, delete the information of
      trucks ka and kb, and update the information
      of truck kd

6 for kc ← 1 to m

   if (truckload_lt_Mt [kb] = 1)
    if (truck tonnage fare [kb] = truck tonnage fare
     [ka] = truck tonnage fare [kc])
     if ((loaded weight of truck [kb] can be split into
      truck ka and truck kc).
      if (the transportation cost after splitting kb into
       ka and kc < the original transportation cost
       without splitting)
     split the customers of trucks kb into truck ka
     and truck kc, delete the information of truck kb,
     and update the information of truck ka and kc

7 for kc ← 1 to m

   if (truckload_lt_Mt [kb] = 1)
    if (truck tonnage fare [kb]≠ truck tonnage fare
    [ka]) and (truck tonnage fare [kb] ≠ truck
    tonnage fare [kc]) and (truck tonnage fare
    [ka] = truck tonnage fare [kc])
     if (loaded weight of truck [kb] can be split into
      truck ka and truck kc)
      if (the transportation cost after splitting kb into
       ka and kc < the original transportation cost
       without splitting).
      split the customers of trucks kb into truck ka
       and truck kc, delete the information of truck
       kb, and update the information of truck ka
       and kc

8 for kc ← 1 to m

   if (truckload_lt_Mt [kb] = 1)
    if (truck tonnage fare [kb]≠ truck tonnage fare
     [ka]) and (truck tonnage fare [kb] ≠ truck
     tonnage fare [kc]) and (truck tonnage fare
     [ka] ≠ truck tonnage fare [kc])
     if (loaded weight of truck [kb] can be split into
      truck ka and truck kc)
       if (the transportation cost after splitting kb
        into ka and kc < the original transportation
        cost without splitting)
      split the customers of trucks kb into truck ka
        and truck kc, delete the information of truck
```

kb, and update the information of truck ka and kc.

3. Reducing customers

When a truck is assigned more than four customers, an extra cost of 200 dollars is charged for each additional customer. The detailed steps for reducing the number of customers in trucks with more than four customers are as follows:

1 for i ← 1 to m

if assigned customers [i] > 4

2 for k ← 1 to m

if assigned customers [k] <4

3 for j ← 1 to ni

if (remaining unloaded pallets of truck [k] ≥ pallets of customer [j]) and (unloaded weight of truck [k] ≥ weight of customer [j]) then

4 original cost = cost of truck[i] + cost of truck [j]

new cost = cost of truck after removing customer m [i]+ cost of truck after inserting customer m [j]

5 if (new cost < the original cost), move customer m from truck i to truck j and update the loaded weight, loaded pallets and the number of assigned customers of truck i and truck j

6 if assigned customers[i] > 4 go to step 2

else go to step 1.

4. Splitting vehicles

It is critical that all orders from the same customer must be assigned to the same truck. In some cases, the loaded weight of all orders from the same customer does not exceed the truck's loaded weight, but the number of loaded pallets for all orders is greater than the number of loaded pallets for the truck. Therefore, the customer's order must be split with another truck in this situation. The detailed steps of this procedure are described as follows:

1 for i ← 1 to m

2 if (assigned pallets of truck[i] > allowed pallets of truck[i])

then overloaded pallets of truck [i] = assigned pallets of truck [i]- allowed pallets of truck [i]

3 for j ← 1 to ni

if (order pallets [j] ≥ overloaded pallets of truck [i])

order pallets [j] = overloaded pallets of truck [i]

4 for k ← 1 to m

if (tonnage fare of truck [k] = tonnage fare of truck [i]) then

if (loaded weight of truck [k] ≤ Mt) and ((remaining unloaded pallets of truck [k] ≥overloaded pallets of truck [i]) and (unloaded weight of truck [k] ≥ unloaded weight of truck [i])) then go to step 8

5 if (tonnage fare of truck[k] = tonnage fare of truck[i]) then

if ((remaining unloaded pallets of truck [k] ≥overloaded pallets of truck [i]) and (unloaded weight of truck [k] ≥ unloaded weight of truck [i])) then go to step 8

6 if (loaded weight of truck[k] ≤ Mt) and ((remaining unloaded pallets of truck[k] ≥ overloaded pallets of truck[i]) and (unloaded weight of truck[k] ≥ unloaded weight of truck [i])) then go to step 8

7 if ((remaining unloaded pallets of truck[k] ≥overloaded pallets of truck[i]) and (unloaded weight of truck[k] ≥ unloaded weight of truck[i])) then go to step 8

8 Move order pallets [j] from truck i to truck k. Update the loading weight and loading pallets of truck i and truck k.

5. Results and discussion

5.1. Actual data of the case study company

The available trucks are of three types based on their gross weight, i.e., 35 tons, 26 tons, 17 tons, respectively. To facilitate the interpretation and verification of the vehicle assignment results, we present data regarding the truck number, maximum load, and loading pallets in Table 1.

In the leftmost column of Table 1, there are seven rows with two truck numbers, except the rows with truck numbers 3 and 4. We utilized two truck numbers in each row to indicate that the same truck must run the second trip for programming convenience.

Based on the actual data of the case company, this study utilized the orders received in August 2018 from Northern Taiwan as an example. We included data for 12 days, i.e., 8/1, 8/2, 8/3, 8/6, 8/14, 8/15, 8/17, 8/23, 8/24, 8/27, 8/29, and 8/30, in the empirical analysis. Due to space limitations, Table 2 only summarizes orders made by the case study company on 3rd August 2018.

Table 2. Case study company's orders on 3rd August.

Customer number	Loading weight (kg)	Loading pallets	Tonnage fare	Special requirement	Geographical location
1	1620.00	2	448		1
1	1980.00	3	448		1
2	920.00	1	448		1
3	49.68	0	384		
3	4020.00	5	384		
4	2207.74	6	384	1	
4	1800.00	2	384	1	
4	4500.00	5	384	1	
5	691.20	1	384		
6	1360.00	2	384	1	
6	920.00	1	384	1	
6	1680.00	2	384	1	
6	1080.00	1	384	1	
7	1360.00	2	448		2
7	2760.00	3	448		2
7	920.00	1	448		2
8	87.36	1	448		2
8	81.00	1	448		2
8	480.00	1	448		2
9	2.24	0	448	1	2
9	0.70	0	448	1	2
10	1080.00	1	448		2
11	4600.00	5	448		2
12	105.00	1	448	1	2
12	147.00	0	448	1	2
13	21.60	0	448		2
13	15.20	0	448	1	2
14	460.00	2	448		2
15	800.00	1	448		2
16	2760.00	3	587		
16	8280.00	9	587		
17	908.00	1	587		
18	5520.00	6	587		
19	106.40	0	908		
20	1840.00	2	1056		
20	1840.00	2	1056		
21	1080.00	1	1056		
21	1080.00	1	1056		
22	608.00	1	1056		
23	802.40	1	1056		
24	2760.00	3	1056		
24	1080.00	1	1056		
24	4200.00	3	1056		
25	510.00	1	1056		
25	170.00	0	1056		
25	1080.00	1	1056		
25	840.00	1	1056		
26	1840.00	2	1056		
27	2300.00	3	1056		
27	5980.00	7	1056		

Table 2 includes six columns, namely customer number, loading weight, loading pallets, tonnage fare, special requirement, and geographical location. In Table 2, we can see 50 orders from 27 customers. That is, we need to assign trucks to 27 distribution points. The load weight column lists the weight of each order, while the loading pallet column describes the required number of pallets for each order, and the tonnage fare column corresponds to the customers' location for each ton freight. The special requirement column represents who cannot use a 35-ton truck with a maximum load capacity of 18 tons (i.e., 1st truck and 5th truck in Table 1) if one is denoted in this column. The rightmost column represents the geographical location, wherein one represents Taipei city, and two stands for Hsinchu city.

The case study company is located between Taipei and Hsinchu. We do not assign customers from Taipei and Hsinchu to the same truck since they are located in opposite geographical directions.

5.2. Manual assignment in the case study company

Customers are often required to inform the company of their delivery requirements one day or a few days before the order service day. To avoid vehicle assignment complexity, increased delivery costs and delivery delays, the case study company does not accept orders that require delivery on the same day they are placed; such orders are known as "instant orders." Manual vehicle assignments are usually done a day before the customer's order service date. However, manual vehicle assignment has the following disadvantages:

(1) To simplify its operational process, the case study company typically appoints only one employee to deal with vehicle assignment problems. Due to the limitations of human memory, same-day delivery orders during busy periods can place significant pressure on the sole logistics personnel. This individual may not be able to grasp the locations of the entire vehicle fleet and order service status (arrival, departure, loading, unloading, etc.), which may cause assigned vehicles to travel along farther routes, thus increasing service costs.

(2) When there are a large number of orders, the case study company usually assigns more than one person to solve vehicle assignment problems. In theory, cooperation and division of labor can improve the efficiency of logistic operations. However, in reality, time pressure can easily affect logistics personnel, leading to reduced operational efficiency.

(3) The logistics personnel process customer orders based on the company's established rules of thumb. However, there are no specific guidelines regarding when to send out a vehicle. If a vehicle is sent out too early, it may result in wasted vehicle resources. Additionally, if a dispatch is made close to the order requirement time, the delivery may be delayed and not completed within the service time.

(4) If the same-day orders are allowed, and deliveries must be completed on the same day, labor and time costs will increase due to the need to reschedule planned routes. Furthermore, with a sudden increase in the number of orders, logistics personnel may not be able to select the most appropriate routes in the given timeframe.

In small-scale vehicle assignment problems, assignments based on the personnel's experience are feasible. However, as a company experiences growth, its orders will increase, and manual assignment (following the rule of thumb) may not be sufficient to meet order requirements accurately. Additionally, customers may cancel their orders before delivery due to various factors, or vehicles themselves may not start the task due to unexpected events. Manual operations cannot clearly judge how to assign vehicles effectively. Hence, it was necessary to develop a heuristic algorithm that could effectively execute the vehicle assignment operation and consider the various unexpected situations.

5.3. Empirical analysis results

Table 3 summarizes the costs and execution times between manual vehicle assignment and the proposed heuristic algorithm. The comparison results showed that the cost of the proposed algorithm was

Table 3. Summary of the costs and execution times between manual assignment and the proposed algorithm.

Date	Manual assignment ($)	Proposed algorithm ($)	% Cost savings	Manual (minutes)	Proposed algorithm (seconds)
8/1	52685.13	46990.17	10.81	28	0.01
8/2	43810.02	34382.44	21.52	14	0.02
8/3	63696.19	56620.12	11.11	23	0.08
8/6	55100.64	54137.84	1.75	19	0.02
8/14	53606.50	50259.74	6.24	15	0.03
8/15	47652.80	46032.53	3.40	20	0.03
8/17	76519.97	74296.60	2.91	18	0.01
8/23	26339.88	24045.00	8.71	20	0.02
8/24	71377.24	69999.10	1.93	17	0.03
8/27	58054.24	56459.61	2.77	14	0.03
8/29	50716.31	49674.17	2.05	19	0.05
8/30	33756.84	29776.28	11.7	24	0.03

Table 4. Summary of vehicle assignment results using the current manual method and the proposed heuristic algorithm.

Date	Manual	Heuristic
8/1	First truck: 20 Second truck: 7, 8, 9 Third truck: 1, 2 Fourth truck: 3 Fifth truck: 18 Seventh truck: 17, 19 Eighth truck: 10,11, 12, 14,15,16 Eleventh truck: 4, 5,6,13	First truck: 18, 19 Second truck: 20 Third truck: 1, 5, 16 Fourth truck: 3 Fifth truck: 7, 8, 9, 10, 11, 12, 14 Eighth truck: 6, 13, 15 Ninth truck: 2, 4, 17
8/2	First truck: 1 Second truck: 14 Third truck: 12, 13 Fourth truck: 8, 9, 10 Fifth truck: 6, 7, 11 Seventh truck: 2, 3, 4, 5 Eighth truck: 15, 16 Ninth truck: 17, 18	First truck: 1 Second truck: 14, 12 Third truck: 2, 3, 4, 5 Fourth truck: 9, 17, 18 Seventh truck: 13 Eighth truck: 15, 16 Ninth truck: 6, 10 Tenth truck: 11, 7, 8
8/3	First truck: 22, 23, 24,25, 26 Second truck: 19, 20, 21, 27 Third truck: 16 Fourth truck: 3, 5 Seventh truck: 10, 11, 12, 13 Eighth truck: 7, 8, 9 Ninth truck: 1, 2, 4 Tenth truck: 17,18 Eleventh truck: 6, 14, 15	First truck: 16, 17, 18, 13 Second truck: 27, 20, 21, 22, 23 Third truck: 24, 25, 26, 19 Fourth truck: 4, 5 Eighth truck: 1, 2, 3, 12 Ninth truck: 6 Tenth truck: 7, 8, 9, 10 Eleventh truck: 11, 14, 15

consistently lower than that of the manual assignment. The proposed algorithm obtained significant cost savings on 8/1, 8/2, and 8/3. The cost savings ranged between 10.81 and 21.52%. A further analysis of the results on 8/6, 8/14, 8/15, 8/17, 8/23, 8/24, 8/27, 8/29, and 8/30 indicates that the cost of the proposed heuristic algorithm was still lesser than that of the manual assignment. However, the difference in cost savings between manual assignment and the proposed algorithm was insignificant. The average cost savings was about 7.08%.

The proposed heuristic algorithm was programmed using FORTRAN. All computations were performed on a notebook with an Intel Core i5 2.7 GHz processor. Compared to the current manual assignment time of more than 25 min, the proposed algorithm can provide accurate and low-cost vehicle assignments in an average of 0.03 s. This indicates that the proposed heuristic algorithm can reduce meaningless assignments to maximize the case study company's benefits.

Table 4 summarizes the vehicle assignment results obtained using the current manual assignment method as well as those obtained using the proposed heuristic algorithm. Due to space limitations, we only present the assignment results for three days. The results show that the proposed algorithm tends to assign fewer trucks to deliver the chemicals. This indicates that the manual method of vehicle assignment is significantly influenced by the logistics personnel, which means that vehicle assignment efficiency cannot be maintained stably. The current manual assignment method depends on the personal experience of personnel based on available information, related business experience, and the judgment of the responsible personnel.

The heuristic algorithm was based on a systematic analysis of data to summarize and reduce costs. A good heuristic algorithm typically obtains both the optimal solution and the near-optimal solution. Additionally, manual assignments do not allow to conduct cost comparisons as quickly and accurately as computers. Thus, under normal circumstances, the results for vehicle assignment using heuristic algorithms were better than those obtained using manual vehicle assignment.

6. Conclusions

The vehicle assignment problem is of great significance in real-life operations and logistics management for minimizing transportation costs. This study explored the vehicle assignment problem inherent in the logistics of chemicals. The case study company outsources the delivery of chemicals to professional logistics companies to satisfy their customers' complex and demanding needs. Currently, its logistics company presents its vehicle assignment plan on the day before the delivery based on its personnel's experience rather than any formal system. Thus, it is necessary to identify an efficient way of managing chemical distribution operations.

Based on a literature review of both periodic VRPs and container loading problems, this study proposed both a mathematical programming model and a heuristic algorithm to solve the vehicle assignment problem for hazardous chemicals. Although a nonlinear mathematical programming model was formulated in the study, it was not suitable for practical applications since the optimal solution could not be obtained within a reasonable timeframe. Based on the company's real-life chemical distribution situation, we proposed a heuristic algorithm to minimize unused space and maximize space utilization for chemical distributors.

The empirical results showed that transportation costs based on heuristic algorithm planning were always lesser than those based on manual planning. This study found that a heuristic algorithm can effectively save transportation costs and the time involved in route planning. Moreover, the proposed algorithm can help to reduce unused space when transporting non-stackable items and can be extended to explore vehicle assignment in the case of stackable items.

In this study, the manual assignment result, though not reliable, serves as a benchmark from practice for a preliminary evaluation of the proposed heuristic's performance. More tests to further evaluate the accuracy of our proposed algorithms should be made in the future. In addition, the development of a theoretical bound for evaluating the heuristic is non-trivial and can also be a direction for future research.

The purpose of mathematical programming is insight, not numbers [11]. In applications, as every experienced practitioner should know, is to help develop insights into system behavior to guide the development of effective plans and decisions. Hence, we provide some managerial insights for our case study. The proposed heuristic algorithm is practical, serving as fast and feasible solutions to planning problems. The main downside of the heuristic algorithm is that it cannot always obtain an optimal solution to planning problems. As a company continues growth, software automation is required that integrates order information and the proposed algorithm. The primary benefit of automation is that software can execute tasks of three to four people. It can significantly reduce the operating cost. In addition, employees do not relish entrapment in manual legacy procedures.

Conflicts of interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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