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Research Article

A Hybrid Simulated Annealing Heuristic for Multistage Heterogeneous Fleet Scheduling with Fleet Sizing Decisions

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This paper deals with multistage heterogeneous fleet scheduling with fleet sizing decisions (MHFS-FSD). This MHFS-FSD attempts to integrate vehicles allocation and fleet sizing decisions considering the vehicle routing of multiple vehicle types. The problem is formulated as mixed integer programming model. The matrix formulation denoting vehicle allocation scheme is explored according to the characteristic of this problem. Generating vehicle allocation scheme with greedy heuristic procedure (VA-GHP) as initial solution of problem is presented. The USP-IVA method to update the initial solution generated by VA-GHP approach is developed. And then, incorporating VA-GHP and USP-IVA into simulated annealing algorithm, a novel heuristic called HSAH-GHP&IVA is proposed. Finally, some experiments are designed to test the proposed heuristic and the results show that the heuristic can generate reasonably good solutions in short CPU times.

1. Introduction

Freight transport companies frequently face the problem of managing a fleet of vehicles which circulate on networks, being dispatched loaded or repositioned empty between various freight terminals of the network. There is recognition of the importance of managing fleets in trucking industry, railroad industry, and shipping industry.

Prior research has most commonly focused on a homogeneous fleet of vehicles. But due to the large amount of loads and complex transport routing conditions, many conflicts will arise between homogeneous fleet of vehicles and heterogeneity transport demands when freight transport schemes are carried out. Instead of homogeneous fleet with substitution of single vehicle types for different types of transport demands, setting up heterogeneous fleets of vehicles is an effective strategy to enhance the efficiency of vehicle utilisation.

In addition, the fleet size decisions are significant to improve the freight carry capacity of fleet. The insufficient vehicles and oversize vehicles can be ineffective in supporting fleet management.

The study on heterogeneous fleet of various vehicle types with fleet sizing decisions is regarded as a promising perspective for the improvement of freight transport scheduling systems. The combinatorial nature of the problem causes the model formulated to be very hard to solve. Therefore, the research focuses on the development of powerful methods that are able to obtain solutions in reasonable time.

In this paper, we focus on scheduling a heterogeneous fleet of various vehicles over time to serve a set of loads with fleet sizing decisions considering the vehicle routing of multiple vehicle types. We name this type of problem as multistage heterogeneous fleet scheduling with fleet sizing decisions (MHFS-FSD). The objective is to maximise total profits over the entire planning horizon. We develop a mixed integer programming model and present a novel hybrid simulated annealing heuristic called HSAH-GHP&IVA.

The remainder of this paper is organised as follows. Section 2 of this paper discusses related earlier research efforts. Section 3 is devoted to the mathematical description of the MHFS-FSD. In Section 4, we describe the mathematical formulation. Section 5 explains the approach of generating vehicle allocation scheme with greedy heuristic procedure (VA-GHP) as initial solution of problem. We develop the updating solution procedure by improving vehicle allocation (USP-IVA) in Section 6. And then the hybrid simulated annealing heuristic called HSAH-GHP&IVA is proposed in Section 7. The computational experiments are described in Section 8, and the effectiveness of the proposed method is shown from the computational results. The last section concludes with a summary of current work and extensions.

2. Literature Review

2.1. State of the Article. In this section, we review the relevant literature about fleet scheduling problems. Literature review indicates that fleet scheduling problems can be divided into four groups, that is, vehicle routing problem, vehicle assignment, transportation network optimisation, and fleet management.

In recent years, many researches on vehicle routing problem have been carried out. The inventory routing problems with pickups and deliveries (IRP-PD) is studied by Archetti et al. [1] with a branch-and-cut method. Ciancio et al. [2] transformed the Mixed Capacitated General Routing Problem with Time Windows (MCGRPTW) into an equivalent node routing problem over a directed graph and solved the equivalent problem by using a branch-price-and-cut algorithm. A new combinatorial algorithm named OVRP_GELS based on gravitational emulation local search algorithm was obtained to solve the open vehicle routing problem (OVRP) by Hosseinabadi et al. [3] The Pickup and Delivery Traveling Salesman Problem with Multiple Stacks was researched by Sampaio and Urrutia [4]. They provided a new integer programming formulation with a polyhedral representation and a branch-and-cut algorithm for solving the proposed formulation. A two-phase approach to deal with the vehicle routing problems with backhauls and time windows is introduced by Reil et al. [5] They proposed Tabu search and first a multistart evolutionary strategy to minimise the total travel distance. Archetti et al. [6] designed and implemented a multistart heuristic which produces solutions with small errors when compared with optimal solutions obtained by solving an integer programming formulation with a commercial solver. Andelmin and Bartolini [7] presented an exact algorithm for solving the green vehicle routing problem and modeled the G-VRP as a set partitioning problem.

The proper configuration of the vehicle assignment is the crucial point of the research on the optimisation of fleet resource allocation. Choi et al. [8] proposed a Dantzig-Wolfe decomposition approach for the vehicle assignment problem with demand uncertainty in a hybrid hub-and-spoke network. Spliet et al. [9] developed a branch-price-and-cut algorithm to arrange the time windows for time window assignment vehicle routing problems with the objective of minimising the expected transportation costs. Lin et al. [10] addressed dynamic vehicle allocation problem. Taking the waiting cost of transportation operation as the objective function of the problem, a Markov decision model is constructed and applied to the automated material handling system in semiconductor manufacturing. João et al. [11] presented a flight scheduling and fleet assignment optimisation model that may assist public authorities to establish the level of service requirements for subsidized air transport networks. Sargut et al. [12] introduced a multiobjective integrated crew rostering and vehicle assignment problem and developed a new multiobjective Tabu search algorithm. Li and Xuan [13] provided a greedy algorithm for solving the vehicle assignment with time window restraints.

The optimisation of transportation network plays a vital role in improving fleet income and reducing various costs. The urban rail transit systems are optimised by Ozturk and Patrick [14]. They extended the setting to several stations and developed a heuristic method, two mixed integer models, and a constraint after proposing an approximation algorithm and a pseudopolynomial dynamic programming algorithm between two sites. Zhang and Zhang [15] explored the dynamic shortest path from a single source to a destination in a given traffic network. To optimise the journey time for the traveler, a novel dynamic shortest path algorithm based on hybridizing genetic and ant colony algorithms was developed. A feasible flow-based iterative algorithm named THTMTP-A is presented to deal with the two-level hierarchical time minimisation transportation problem by Xie et al. [16]. Suhng and Lee [17] developed a new Link-Based Single Tree Building Algorithm in order to reduce the slow execution speed problem of the multitree building algorithm for shortest path searching in an Urban Road Transportation Network and proved its usefulness by comparing the proposed one with other algorithms. The suitability of three different global optimisation methods which included the branch and reduce method, the branch and cut method, and the combination of global and local search strategies for specifically the exact optimum solution of the nonlinear transportation problem is studied by Klansek and Psunder [18].

The fleet management is one of the most important as it is a major fixed investment for starting any business. Hashemi and Sattarvand [19] studied the different management systems of the open pit mining equipment including nondispatching, dispatching, and blending solutions for the Sungun copper mine. A dispatching simulation model with the objective function of minimising truck waiting times had been developed. Zhu et al. [20] focused on solving the scheduled service network design problem for freight rail transportation and proposed a heuristic solution methodology integrating slope scaling, a dynamic block-generation mechanism, long-term-memory-based perturbation strategies, and ellipsoidal search. Li et al. [21, 22], respectively, developed an alternating solution strategy for the stochastic dynamic fleet scheduling problem with variable period and presented a piecewise method by updating preset control parameters for dynamic working vehicle scheduling problem. Tierney et al. [23] studied a central problem in the liner shipping industry called the liner shipping fleet repositioning problem and introduced a simulated annealing algorithm for above problem. Hugo et al. [24] designed an approximate dynamic programming algorithm for large-scale fleet management.

2.2. Contributions. Overall, the objectives of this research are twofold. The first objective is to develop a mathematical model of MHFS-FSD. In the proposed model, the matrix formulation denoting vehicle allocation scheme is explored according to the characteristic of this problem. The second objective is to propose an efficient methodology for solving the model. Specifically, the contributions of this paper are as follows.

(1) We develop the mixed integer programming model (MIP). This model discusses the integration of vehicles allocation and fleet sizing decisions considering the vehicle routing of multiple vehicle types. Particular vehicle type is assigned to some particular transport routing according to the classification of vehicles. The matching of vehicle type and transport route is given. According to the characteristic of this problem, the matrix formulation denoting vehicle allocation scheme is provided.

(2) According to the specific structure of the mixed integer programming model, the approach of generating vehicle allocation scheme with greedy heuristic procedure (VA-GHP) as initial solution of problem is presented. On the basis of the initial solution generated by VA-GHP approach, the USP-IVA method to update the initial solution is developed, and then incorporating VA-GHP and USP-IVA into simulated annealing algorithm, a novel heuristic called HSAH-GHP&IVA is proposed.

(3) To evaluate the performance of the heuristics proposed, we generated randomly three sets of problem instances with different size of freight terminal and time periods, considering different number of vehicles types. Three sets of experiments are oriented to evaluate the performances of the hybrid simulated annealing heuristic. The results show that the proposed heuristic is able to obtain reasonably good solutions in short CPU times.

3. Problem Description and Analysis

This section describes the problem of scheduling a heterogeneous fleet of various vehicles over time to serve a set of loads with fleet sizing decisions. We make a brief overview of some foundational concepts and analysis of the problem.

3.1. Problem Description. The freight transportation scheduling frequently aims to obtain appropriate capacity of transportation systems, discover the potential of fleets of vehicles which circulate on networks, and improve transportation efficiency by arranging daily transportation production reasonably, organising vehicles flow adjustment scientifically, and making plans for loading and unloading operations in their destination terminal of the networks efficiently.

This paper discusses the integration of vehicles allocation and fleet sizing decisions considering the vehicle routing of multiple vehicle types. Let $G(N, E)$ represent the freight transport network, where N is a set of freight terminal and E represents the set of the movement of vehicles between a pair of freight terminal. We assume that time is divided into a set of discrete time periods $H = \{h \mid h = 1, ..., K\}$ where K is the length of the planning horizon and h is the time period. All transitions require multiperiod travel times. Let t_{ij} be the travel time from i to $j, i, j \in N$. The travel time between any pair of terminals is different length of time period and integer multiple of one time period. The operators of transportation systems manage a heterogeneous fleet of various vehicles. We define the set of classification of vehicles as $W = \{1, \cdots, P\}$. Particular vehicle type is assigned to some particular vehicle routing according to the classification of vehicles. The matching of vehicle type and vehicle routing is given. The use of operation vehicles will generate fixed expenses such as vehicle leasing and daily maintenance. It is crucial to decide the size of various vehicle types reasonably.

To maximise total profits over a given horizon, the problem is to optimise the fleet sizing and make the vehicle utilisation decision in view of the profit derived from moving a load from terminal i to terminal j denoted as α_{ij}^{w}, the cost of moving an empty vehicle from terminal i to terminal j denoted as β_{ij}^{w}, the fixed costs of owning or leasing a type of vehicles denoted as γ^{w}, and vehicle routing of vehicle types denoted as π^{w}. Figure 1 displays a snapshot of dynamic space-time network for fleet scheduling with multiperiod travel times.

3.2. Understanding Vehicle Allocation between Pairs of Terminals. A fleet of vehicles must be assigned to loads that have the effect of moving the vehicle from one terminal to the next. The operator of the fleet must either assign each vehicle to a requested loaded movement or move it empty to another terminal to pick up a requested loaded movement, or to hold it in the same terminal until the next time period. So the allocation problem of loaded vehicle and empty vehicle arises.

Serving loads results in the relocation of vehicles. Demands request a vehicle to be available in a specific terminal on a specific time period to carry the load to a given destination terminal. Each load must be served by a vehicle. Loaded movement will generate revenue. So the loaded vehicle assignment is the basis of the vehicle allocation.

The load for movements between various terminals is often imbalanced, and this implies the need for redistribution of empty vehicles over the transport network from terminals at which they have become idle to terminals at which they can be reused. It is important to manage empty vehicle flows in transport network. The loads create requirements for empty vehicle. The arrivals of loaded vehicle flow create the supplies of empties available for repositioning.

Vehicle allocation has significant effects on the vehicle distribution or utilisation decision and then effects on capacity and efficiency of transport network.

3.3. Understanding Heterogeneous Fleet of Vehicles. Due to the huge transport networks, the large amount of loads, and complex transport route conditions, many conflicts will arise between homogeneous fleet of vehicles and heterogeneity

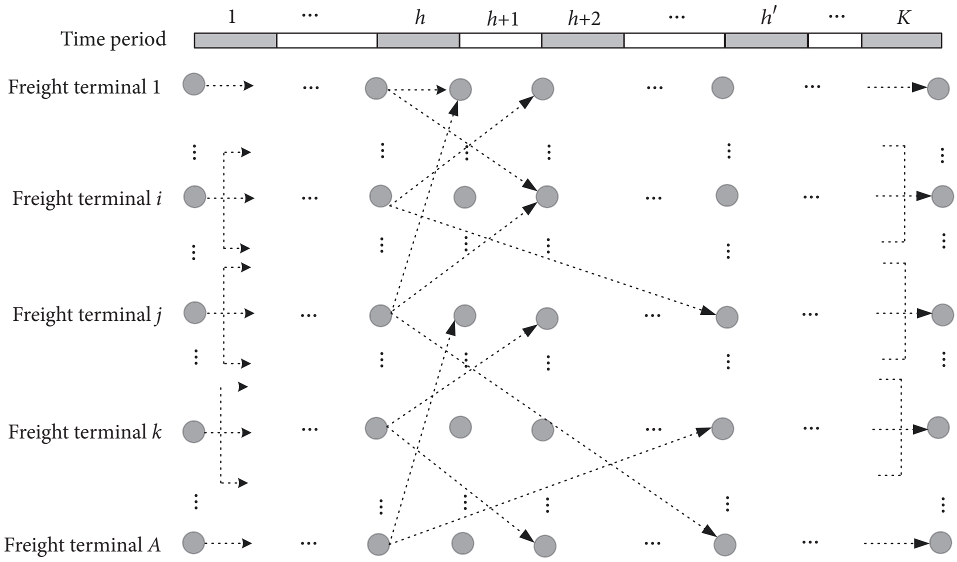


Figure 1: Dynamic space-time network for fleet scheduling with multiperiod travel times.

transport demands when freight transport schemes are carried out. A homogeneous fleet with single vehicle type means inefficiency in satisfying the diverse transport demand. When the operators manage a homogeneous fleet, the vehicle shortage and idleness may occur synchronously. The worsening trend of vehicle utilisation is also possible to appear so that transport efficiency is reduced and transport cost is enhanced. Instead of homogeneous fleet with substitution of single vehicle types for different types of transport demands, setting up heterogeneous fleets of vehicles is an effective strategy to eliminate the above unreasonable phenomena, optimise the vehicle allocation, and enhance the efficiency of vehicle utilisation.

Meanwhile, the fleet size decisions are significant to improve the freight carry capacity of fleet. The insufficient vehicles seriously affect the implementation of transport work. If the number of available vehicles is not enough to meet transport demand, the penalty cost for unmet demand will generate. On the other hand, the oversized supply of fleet far more than the transport demand causes a large number of vehicles to be idle.

3.4. Understanding Vehicle Routing for Particular Vehicle Types. Many works have assumed a homogeneous fleet of vehicles. But most problems in practice have multiple vehicle types with limited substitution. In this paper, we extend the methodology to handle heterogeneous fleets of vehicles with different vehicle types for different transport routing.

The two stage freight transport network is comprised of freight supply location as origin terminal and freight demand location as destination terminal. In practical considerations, the route from any supply location to demand location cannot always be used to carry freight due to limited vehicle types, transport routing condition, transport routing external environment, and so on. The specific reasons can be diverse as follows:

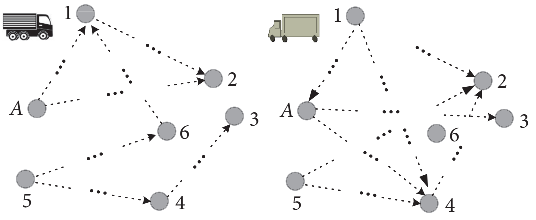


Figure 2: The vehicle routing of multiple vehicle types.

(1) Some transport routes cannot be used by some specific vehicle type due to carry capacity of the road.

(2) Some specific vehicle types are not allowed to travel on certain transport routes due to physical condition of the road versus maintenance condition of vehicles.

(3) Due to inexistence of supply location and demand location for freight exchange, some transport routes disappear.

An illustration of the vehicle routing of multiple vehicle types is shown in Figure 2.

Because some specific vehicle types are only allowed to travel on certain transport routes, we use π as the matching matrix such that $\pi_{ij}^{w} = 1$ if w types of vehicle can be assigned to movement from terminal i to j, and $\pi_{ij}^{w} = 0$ otherwise. We present the notation for more clearly expressing the matching matrix here.

N is the set of freight terminal in the freight transport network. Define $N = \{1, \cdots, A\}$ where A is the number of freight terminal.

W is the set of vehicle types in the heterogeneous fleet. Define $W = \{1, \cdots, P\}$ where P is the total number of available vehicles of various types.

T is the matrix of travel time of vehicles set between a pair of freight terminal. We have

$$T=\begin{bmatrix} 0 & \cdots & t_{1j} & \cdots & t_{1A} \\ \vdots & & \vdots & & \vdots \\ t_{i1} & \cdots & t_{ij} & \cdots & t_{iA} \\ \vdots & & \vdots & & \vdots \\ t_{A1} & \cdots & t_{Aj} & \cdots & 0 \end{bmatrix}, \quad \forall i,\ j \in N \tag{1}$$

π is the matrix of vehicle routing for certain vehicle type. The matrix can be expressed by $\pi = \{\pi^{w} \mid w = 1, \cdots, P\}$. The parameter π^{w} is used to represent practical situations where vehicle type w can be allowed to transport load on certain routes. Correspondingly, we denote that

$$\pi^{w}=\begin{bmatrix} \pi_{11}^{w} & \cdots & \pi_{1j}^{w} & \cdots & \pi_{1A}^{w} \\ \vdots & & \vdots & & \vdots \\ \pi_{i1}^{w} & \cdots & \pi_{ij}^{w} & \cdots & \pi_{iA}^{w} \\ \vdots & & \vdots & & \vdots \\ \pi_{A1}^{w} & \cdots & \pi_{Aj}^{w} & \cdots & \pi_{AA}^{w} \end{bmatrix} \tag{2}$$

$$\pi_{ij}^{w} = \begin{cases} 0, & \text{if vehicle type } w \text{ can move from terminal } i \text{ to } j \\ 1, & \text{otherwise} \end{cases} \qquad \forall i,\ j \in N,\ w \in W.$$

4. Mathematical Formulation

In this section, we define the notation and formulate multistage heterogeneous fleet scheduling with fleet sizing decisions (MHFS-FSD) as a mixed integer programming model. In the following we describe the model parameters and variables used to model the MHFS-FSD.

4.1. Model Parameters. The parameters are needed to describe the problem.

t_{ij} is the travel time moving from origin i to destination j and is the integer multiple of the scheduling time period.

π_{ij}^{w} is the parameter for representing whether or not vehicle type w can be allowed to carry freight along transport routing (i, j). The value of π_{ij}^{w} is 1 if the w types of vehicle can carry freight from the terminal i to the terminal j; otherwise, the value is 0, $\forall w \in W$, and $\forall i,\ j \in N$.

q_{ij}^{h} is the set of loads with origin i and destination j having h as a feasible departure, $\forall h \in H, \forall i,\ j \in N$.

α_{ij} is the profits generated by a unit load being dispatched from terminal i to terminal j, $\forall w \in W, \forall i,\ j \in N$.

β_{ij}^{w} is the cost of w type vehicle being repositioned empty from terminal i to terminal j, $\forall w \in W, \forall i,\ j \in N$.

γ^{w} is the purchase or lease cost for the w type of vehicle, $\forall w \in W$.

λ^{w} is the loading capacity of w type vehicle $\forall w \in W$. That is to say, it is the amount of loads which can be serviced by one w type vehicle.

z_{it}^{w} is the number of available vehicle of w type at terminal i in time period t, $\forall w \in W, \forall i \in N$.

4.2. Model Variables. The decision variables of the mathematical model are

$x_{ij}^{h,w}$ is the number of w type of loaded vehicles from terminal i to terminal j at time period h, $\forall i,\ j \in N, h \in H$.

$y_{ij}^{h,w}$ is the number of w type of empty vehicles from terminal i to terminal j at time period h, $\forall i,\ j \in N,\ h \in H$.

z^{w} is the number for available vehicle of w type.

4.3. Mathematical Models. The mathematical models for multistage heterogeneous fleet scheduling with fleet sizing decisions (MHFS-FSD) are given by

$$\max \quad F(x,y,z) = \sum_{w\in W}\left(\sum_{h=1}^{K}\sum_{i\in N}\sum_{j\in N}\left(\alpha_{ij}\cdot\min\left\{q_{ij}^{h}, \sum_{w\in W}\lambda^{w}x_{ij}^{h,w}\right\} - \beta_{ij}^{w}x_{ij}^{h,w} - \beta_{ij}^{w}y_{ij}^{h,w}\right) - \gamma^{w}z^{w}\right) \tag{3}$$

$$s.t. \quad \sum_{j\in N}\left(x_{ij}^{h,w} + y_{ij}^{h,w}\right)\pi_{ij}^{w} = z_{i}^{h,w}, \quad \forall i \in N,\ \forall h \in H,\ \forall w \in W \tag{4}$$

$$\sum_{w\in W}\lambda^{w}x_{ij}^{h,w} \le q_{ij}^{h}, \quad \forall i, j \in N,\ \forall h \in H \tag{5}$$

$$\sum_{i\in N}\left(x_{ij}^{(h-t_{ij}),w} + y_{ij}^{(h-t_{ij}),w}\right)\pi_{ij}^{w} = z_{j}^{h,w}, \quad \forall j \in N,\ \forall h \in H,\ \forall w \in W \tag{6}$$

$$\sum_{i\in N} z_{i}^{h,w} = z^{w}, \quad \forall h \in H \tag{7}$$

$$x_{ij}^{h,w} \ge 0,\ y_{ij}^{h,w} \ge 0,\ z^{w} \ge 0,\ \text{integer}, \quad \forall i,\ j \in N,\ \forall h \in H,\ \forall w \in W \tag{8}$$

The MHFS-FSD model belongs to a mixed integer programming model (MIP). The objective function (3) aims to maximise the total profit generated by the fleet scheduling scheme during the whole planning horizon. Constraint (4) denotes the number of dispatching loaded vehicles and empty vehicles are determined by supplies of vehicles in time period. Constraint (5) ensures that the number of loaded vehicle cannot exceed available requirements of all loads in each terminal at each time period. Constraint (6) denotes updating equation for total supply of vehicle of various types. Constraint (7) shows having flow conservation of vehicle in each type. Finally, constraint (8) defines the range of decision variables constraints.

As an NP problem, using traditional method for solving MHFS-FSD model is difficult and inefficient. A novel heuristic method is considered to solve this problem.

5. Generating Initial Solution with VA-GHP

According to the characteristic of this problem, the matrix formulation denoting vehicle allocation scheme is provided. And then the approach of generating vehicle allocation scheme with greedy heuristic procedure as initial solution of problem is presented.

5.1. Matrix Formulation of Vehicle Allocation. The solution of MHFS-FSD model represents the vehicle allocation scheme. The solution is expressed as two stage structure. The first term in the solution is matrix formulation of loaded vehicle dispatching scheme. The second term is the matrix formulation of empty vehicle reposition scheme.

(1) The Matrix Formulation of Loaded Vehicle Dispatching Scheme. The first section of the solution is used to represent the loaded vehicle dispatching scheme of carrying freight from the origin terminal to the destination terminal. This section is formulated as the matrix form which has A rows and A columns. Each component in row and row intersection of the matrix indicates the number of w type loaded vehicles from origin terminal to destination terminal. The allocation scheme of loaded vehicle is written as the following formula:

$$x^w = \begin{bmatrix} x_{11}^w & \cdots & x_{1j}^w & \cdots & x_{1A}^w \\ \vdots & & \vdots & & \vdots \\ x_{i1}^w & \cdots & x_{ij}^w & \cdots & x_{iA}^w \\ \vdots & & \vdots & & \vdots \\ x_{A1}^w & \cdots & x_{Aj}^w & \cdots & x_{AA}^w \end{bmatrix}, \quad w \in W. \tag{9}$$

(2) The Matrix Formulation of Empty Vehicle Reposition Scheme. The second section of the solution is used to denote the empty vehicle reposition scheme of vehicle moving empty from the origin terminal to the destination terminal. This section is also formulated as the matrix form which has A rows and A columns. Each component in row and row intersection of the matrix expresses the number of w type empty vehicles from origin terminal to destination terminal. The allocation scheme of loaded vehicle is expressed as the following formula:

$$y^w = \begin{bmatrix} y_{11}^w & \cdots & y_{1j}^w & \cdots & y_{1A}^w \\ \vdots & & \vdots & & \vdots \\ y_{i1}^w & \cdots & y_{ij}^w & \cdots & y_{iA}^w \\ \vdots & & \vdots & & \vdots \\ y_{A1}^w & \cdots & y_{Aj}^w & \cdots & y_{AA}^w \end{bmatrix}, \quad w \in W \tag{10}$$

5.2. Greedy Heuristic Procedure to Generate Vehicle Allocation Scheme. According to the fundamental principles of prioritising to consider the vehicle types with large load capacity and transport routing with large carry capacity, the greedy heuristic procedure is presented to generate vehicle allocation scheme. We name this approach as vehicle allocation with greedy heuristic procedure (VA-GHP). An overview of the framework of VA-GHP is explained as follows.

Stage 1 (set of vehicle types selection sequence). According to the vehicle distribution $z_i^{h,w}$ in terminal i at h time period, the set of vehicle types selection sequence W_i^h is obtained with ranking the vehicle types in descending order by loading capacity λ^w. We denote δ as serial number of the vehicle type in this set and $\widehat{\delta}$ as the total quantity of available vehicle types. Thus, W_i^h has the form of

$$W_i^h = \left\{ w_i^h(\delta) \mid w_i^h(\delta) = w,\ w \in W,\ \delta = 1, \cdots, \widehat{\delta} \right\} \tag{11}$$

Stage 2 (set of fleet size selection sequence). Let Z_i^h be the set of fleet size selection sequence. According to the set of vehicle types selection sequence W_i^h, we can express Z_i^h as

$$Z_i^h = \left\{ z_i^h(\delta) \mid z_i^h(\delta) = z_i^{h,w},\ w \in W_i^h,\ \delta = 1, \cdots, \widehat{\delta} \right\} \tag{12}$$

Stage 3 (set of transport routing selection sequence). We randomly choose the terminal i from the set of freight terminal and compute the revenue $\alpha_{ij} q_{ij}^h$ created by loaded vehicle dispatched from origin i to any available destination j. We rank the transport routing in order of the revenue from high to low and the set of transport routing selection sequence S_i^h can be given. We use ξ to denote the serial number of transport routing in this set and the total number of transport routing is represented as $\widehat{\xi}_i^h$. Here S_i^h is written as

$$S_i^h = \left\{ s_i^h(\xi) \mid s_i^h(\xi) = (i, j),\ j \in N,\ \xi = 1, \cdots, \widehat{\xi}_i^h \right\} \tag{13}$$

The set of transport routing in terminal i at h time period is described in Figure 3.

Stage 4 (loaded vehicles dispatching scheme).

Step 4.1 (loaded vehicles dispatching scheme of transport routing). The transport routing $s_i^h(\xi)$ is selected in arranged order from the set of transport routing selection sequence

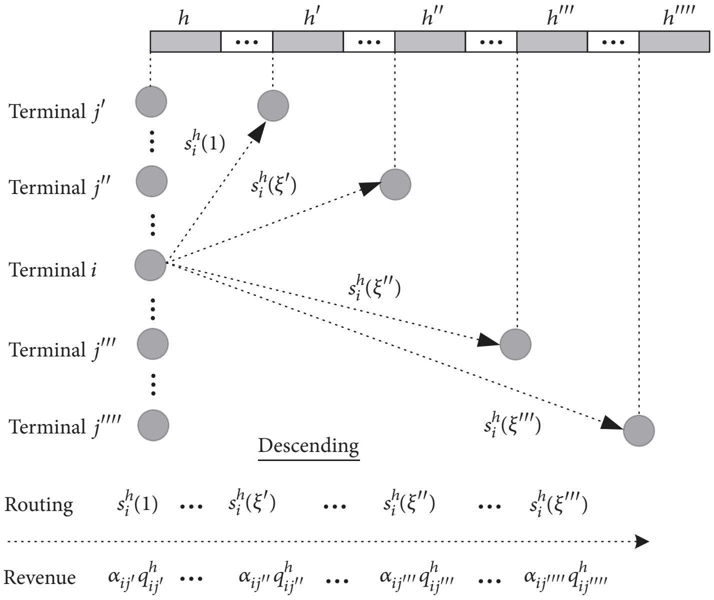


FIGURE 3: A diagram of the set of transport routing selection sequence.

S_i^h. According to the vehicle routing matrix π^w for certain vehicle type, the available vehicle types $w_i^h(\delta)$ allowed to travel on the transport routing $s_i^h(\xi)$ are chosen from the vehicle type selection sequence W_i^h. And the fleet size $z_i^h(\delta)$ of corresponding vehicle types is determined from fleet size selection sequence Z_i^h. We use the formula (14) to compute loaded vehicles dispatching scheme:

$$x_i^{h,\delta}(\xi) = \min\left\{\left\lceil \frac{q_i^h(\xi)}{\lambda^\delta} \right\rceil, z_i^h(\delta)\right\} \tag{14}$$

Step 4.2 (adjusting available loads number and available fleet size for transport routing). (1) If there are $\lceil q_i^h(\xi)/\lambda^\delta \rceil \geq z_i^h(\delta)$, then $x_i^{h,\delta}(\xi) = z_i^h(\delta)$. Besides, let $q_i^h(\xi) = q_i^h(\xi) - \lambda^\delta z_i^h(\delta)$ and $z_i^h(\delta) = 0$; turn to *Step* 4.3.

(2) If there are $\lceil q_i^h(\xi)/\lambda^\delta \rceil \leq z_i^h(\delta)$, then $x_i^{h,\delta}(\xi) = \lceil q_i^h(\xi)/\lambda^\delta \rceil$. Besides, let $q_i^h(\xi) = 0$ and $z_i^h(\delta) = z_i^h(\delta) - \lceil q_i^h(\xi)/\lambda^\delta \rceil$; turn to *Step* 4.4.

Step 4.3 (updating three selection sequence sets).

(1) Updating the Set of Transport Routing Selection Sequence. According to available updated loads number $q_i^h(\xi)$, the revenue of transport routing with an origin terminal i is recalculated. The set of transport routing selection sequence $\overline{S}_i^h$ is updated with ranking the transport routing in descending order of the revenue $\alpha_{ij}q_i^h(\xi)$. The new set $\overline{S}_i^h$ is expressed as follows:

$$\overline{S}_i^h = \left\{\overline{s}_i^h\left(\overline{\xi}\right) \mid \overline{s}_i^h\left(\overline{\xi}\right) = \left(i, \overline{j}\right), \overline{j} \in N, \overline{\xi} = 1, \cdots, \widehat{\xi}_i^h\right\} \tag{15}$$

(2) Updating the Set of Vehicle Types Selection Sequence. Removing the vehicle types $w_i^h(\delta)$ that have been used up from vehicle selection sequence set W_i^h, the new set of vehicle type selection sequence $\overline{W}_i^h$ can be given by

$$\begin{aligned}\overline{W}_i^h &= W_i^h - w_i^h(\delta)\\ &= \left\{\overline{w}_i^h\left(\overline{\delta}\right) \mid \overline{w}_i^h\left(\overline{\delta}\right) = w_i^h(\delta), \overline{\delta} = \delta + 1, \cdots, \widehat{\delta}\right\}\end{aligned} \tag{16}$$

(3) Updating the Set of Fleet Size Selection Sequence. Removing the fleet size $z_i^h(\delta)$ of the vehicle types $w_i^h(\delta)$ from fleet size selection sequence set Z_i^h, the new set of fleet size selection sequence $\overline{Z}_i^h$ can be given by

$$\begin{aligned}\overline{Z}_i^h &= Z_i^h - z_i^h(\delta)\\ &= \left\{\overline{z}_i^h\left(\overline{\delta}\right) \mid \overline{z}_i^h\left(\overline{\delta}\right) = z_i^h(\delta), \delta = \delta + 1, \cdots, \widehat{\delta}\right\}\end{aligned} \tag{17}$$

Step 4.4 (updating two selection sequence sets).

(1) Updating the Set of Transport Routing Selection Sequence. The new set of transport routing selection sequence $\overline{S}_i^h$ is given with removing the transport routing $s_i^h(\xi)$ from transport routing selection sequence S_i^h. The new set $\overline{S}_i^h$ is expressed as follows:

$$\begin{aligned}\overline{S}_i^h &= S_i^h - s_i^h(\xi)\\ &= \left\{\overline{s}_i^h\left(\overline{\xi}\right) \mid \overline{s}_i^h\left(\overline{\xi}\right) = s_i^h(\xi), \overline{\xi} = \xi + 1, \cdots, \widehat{\xi}_i^h\right\}\end{aligned} \tag{18}$$

(2) Updating the Set of Fleet Sizing Selection Sequence. The new set of fleet size selection sequence $\overline{Z}_i^h$ is obtained by updating the corresponding fleet size $z_i^h(\delta)$ of vehicle type $w_i^h(\delta)$ in the

fleet size selection sequence set Z_i^h. The new set $\overline{Z}_i^h$ is denoted as

$$\overline{Z}_i^h = \left\{ \overline{z}_i^h \left(\overline{\delta}\right) \mid \overline{z}_i^h (\delta) = z_i^h (\delta) - \left\lceil \frac{q_i^h (\xi)}{\lambda^\delta} \right\rceil, \right. \\ \left. \overline{z}_i^h (\delta+1) = z_i^h (\delta+1), \overline{\delta} = \delta, \cdots, \widehat{\delta} \right\} \qquad (19)$$

Stage 5 (empty vehicle reposition scheme). We can obtain the loaded vehicles dispatching scheme $x_{ij}^{(h+1-t_{ij}),w}$ by the procedure described in Stage 4. Substituting them into equation $\sum_{i\in N} x_{ij}^{(h+1-t_{ij}),w} \pi_{ij}^w = \tilde{z}_j^{h+1,w}$, the vehicles distribution $\tilde{z}_j^{h+1,w}$ can be obtained at terminal j at time period $h+1$. And, according to the load number q_{ij}^{h+1} at time period $h+1$, empty vehicle reposition scheme $y_{ij}^{h,w}$ can be obtained.

Step 5.1 (calculating the number of loads waiting to be arranged). The number of loads waiting to be arranged at each freight terminal $\tilde{q}_j^{h+1}$ is computed by the following formula:

$$\tilde{q}_j^{h+1} = \sum_{k\in N} q_{jk}^{h+1} - \sum_{w\in W} \lambda^w \tilde{z}_j^{h+1,w} \qquad (20)$$

Step 5.2 (set of freight terminal selected sequence with lack of empty vehicle). For the freight terminal where the number of load waiting to be arranged $\tilde{q}_j^{h+1}$ is nonpositive, it means that there are empty vehicles enough not to continue to call the empty vehicles. Following the abovementioned principles, the freight terminals with lack of empty vehicle are ranked in descending order of the revenues $\sum_{k\in N} \alpha_{jk} \tilde{q}_{jk}^{h+1}$. The set of freight terminal selected sequence with lack of empty vehicle $\tilde{J}^{h+1}$ is formed. We denote σ as the serial number of freight terminal with lack of empty vehicle in this set $\tilde{J}^{h+1}$ and $\widehat{\sigma}$ as the total quantity of freight terminal with lack of empty vehicle. So the new set $\tilde{J}^{h+1}$ can be expressed in the form by

$$\tilde{J}^{h+1} = \{ j(\sigma) \mid j(\sigma) = j, j \in N, \sigma = 1 \cdots, \widehat{\sigma} \} \qquad (21)$$

Step 5.3 (set of empty vehicles shortage amount selected sequence). We count the shortage amount of freight terminal with lack of empty vehicle in the set $\tilde{J}^{h+1}$. Further, the set of empty vehicles shortage amount selected sequence $\widetilde{Q}_j^{h+1}$ is obtained and is denoted as $\widetilde{Q}_j^{h+1} = \{\tilde{q}_j^{h+1}, j \in \tilde{J}\}$.

Step 5.4 (set of freight terminal selected sequence for dispatching empty vehicle). The destination terminal j is successively taken out from the set of freight terminal selected sequence with lack of empty vehicle $\tilde{J}^{h+1}$. Then, according to the vehicle routing matrix π^w, the origin terminal i that has a link with destination terminal j is taken out. And, ranking the origin terminal i in ascending order of the distance, the set of freight terminal selected sequence for dispatching empty vehicle $\tilde{I}_j^h$ is formed. We denote θ as the serial number of freight terminal for dispatching empty vehicle in this set $\tilde{I}_j^h$ and $\widehat{\sigma}$ as the total quantity of freight terminal for dispatching empty vehicle. So the new set $\tilde{I}_j^h$ can be expressed in the form by

$$\tilde{I}_j^h = \left\{ i(\theta) \mid \pi_{i(\theta)j}^w = 1,\ i(\theta) \in N, w \in W, j \in \tilde{J}^{h+1}, \theta \right. \\ \left. = 1, \cdots, \widehat{\theta}_j^h \right\} \qquad (22)$$

Step 5.5 (empty vehicle reposition scheme). We choose the destination terminal j from the set of freight terminal selected sequence with lack of empty vehicle $\tilde{J}^{h+1}$ and the origin terminal $i(\theta)$ from the corresponding set of freight terminal selected sequence for dispatching empty vehicle $\tilde{I}_j^h$. In accordance with vehicle distribution $\overline{Z}_{i(\theta)}^h$ at freight terminal for dispatching empty vehicle $i(\theta)$ and loads number $\tilde{q}_j^{h+1}$ at freight terminal with lack of empty vehicle, we make use of the principle of priority arranging large capacity vehicle types to conduct the empty vehicle reposition as the following formula:

$$y_j^{h,\delta}(\theta) = \min \left\{ \left\lceil \frac{\tilde{q}_j^{h+1}}{\lambda^\delta} \right\rceil, \overline{z}_{i(\theta)}^h (\delta) \right\}, \quad i \in \tilde{I}_j^h \qquad (23)$$

(1) If there are $\lceil \tilde{q}_j^{h+1}/\lambda^\delta \rceil \geq \overline{z}_{i(\theta)}^h(\delta)$, then $y_j^{h,\delta}(\theta) = \overline{z}_{i(\theta)}^h(\delta)$. Additionally, let $\tilde{q}_j^{h+1} = \tilde{q}_j^{h+1} - \lambda^\delta \overline{z}_{i(\theta)}^h(\delta)$ and $\overline{z}_{i(\theta)}^h(\delta) = 0$. If there are still some other vehicle types unarranged at freight terminal for dispatching empty vehicle $i(\theta)$, they are furtherly made by using equation (23). Otherwise, succeeding freight terminal $i(\theta)$ should be taken out from the set of freight terminal selected sequence for dispatching empty vehicle $\tilde{I}_j^h$.

(2) If there are $\lceil \tilde{q}_j^{h+1}/\lambda^\delta \rceil \leq \overline{z}_{i(\theta)}^h(\delta)$, then $y_j^{h,\delta}(\theta) = \lceil \tilde{q}_j^{h+1}/\lambda^\delta \rceil$. Besides, let $\tilde{q}_j^{h+1} = 0$ and $\overline{z}_{i(\theta)}^h(\delta) = \overline{z}_{i(\theta)}^h(\delta)$-$\lceil \tilde{q}_j^{h+1}/\lambda^\delta \rceil$. In addition, next destination station j is taken out from set of freight terminal selected sequence with lack of empty vehicle $\tilde{J}^{h+1}$.

Stage 6 (updating the vehicle distributions). We use $\sum_{i\in N}(x_{ij}^{(h+1-t_{ij}),w} + y_{ij}^{(h+1-t_{ij}),w})\pi_{ij}^w = z_j^{h+1,w}$ to count the vehicle distributions $Z_j^{h+1,w}$ in h period and return to *Stage* 1.

The approach of vehicle allocation with greedy heuristic procedure (VA-GHP) is shown in Figure 4.

6. Updating Solution Procedure by Improving Vehicle Allocation

In this section, we develop a method to update the initial solution generated by VA-GHP approach mentioned above. We name this method as updating solution procedure by improving vehicle allocation at local terminal. This method is abbreviated as USP-IVA in order to facilitate problem statement. Specially, the USP-IVA is composed of two subprocedures. The first is called updating solution by improving loaded vehicle dispatching scheme at single terminal and is abbreviated as US-ILVD. The second is denoted as updating solution by improving empty vehicle reposition scheme at

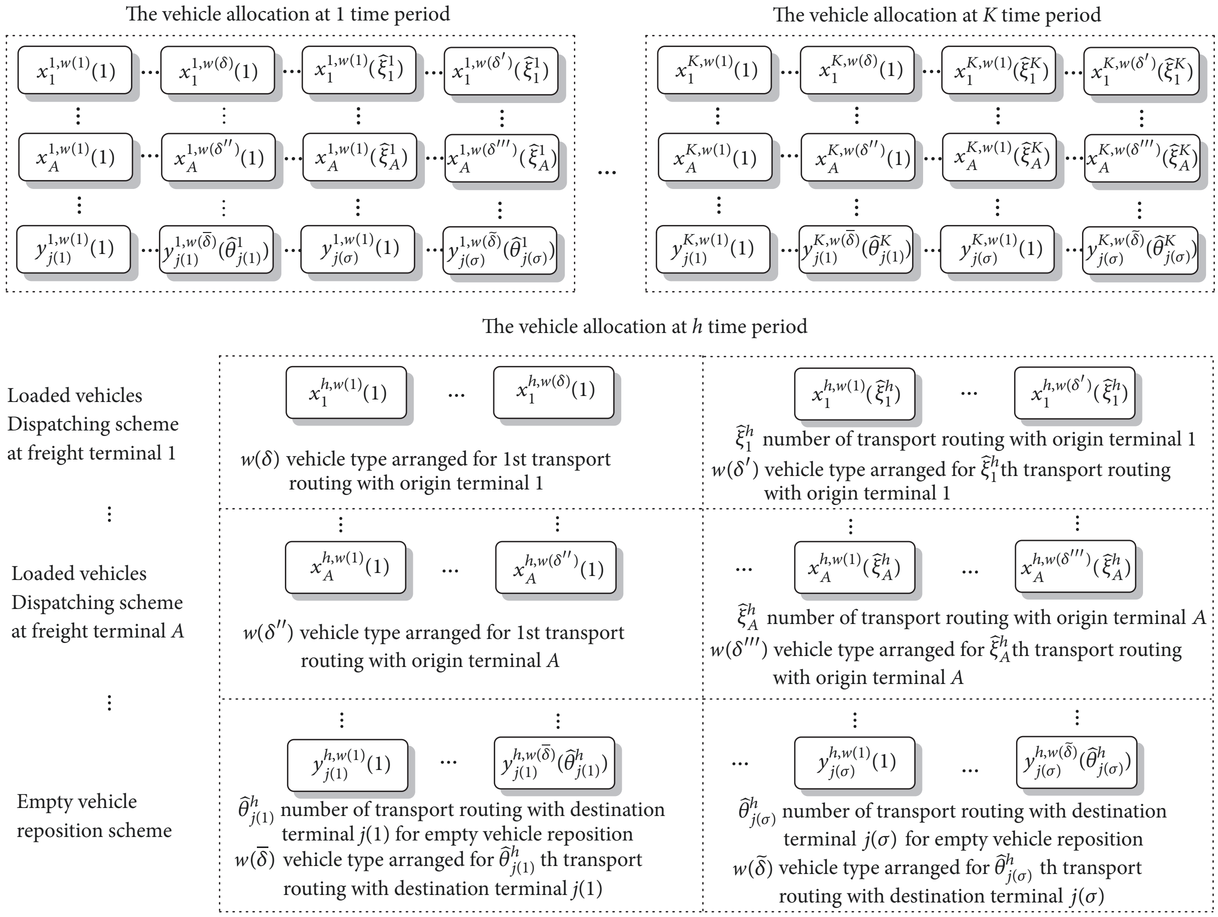


Figure 4: Loaded vehicles dispatching and empty vehicle reposition scheme with greedy heuristic procedure.

single terminal and is abbreviated as US-IEVR. An overview of the framework of US-ILVD and US-IEVR is explained in Sections 6.1 and 6.2.

6.1. Updating Solution by Improving Loaded Vehicle Dispatching Scheme at Single Terminal. It is not suitable to generate vehicle allocation scheme by the principle of priority arrangement for large load capacity vehicle types with VA-GHP approach for all freight terminals. In consideration of these disadvantages, we develop the solution improvement procedure called US-ILVD based on the initial solution. The concrete procedure of US-ILVD is as follows.

Stage 1 (selecting the time period and freight terminal). The time period and freight terminal are selected randomly from the initial vehicle allocation scheme generated by VA-GHP and denoted as $\{i^\circ, h^\circ \mid i^\circ \in N, h^\circ \in H\}$.

Stage 2 (updating loaded vehicle dispatching scheme of specific freight terminal and time period). *Step 2.1* (adjusting the set of vehicle types selection sequence). According to the vehicle distribution $z_{i^\circ}^{h^\circ,w}$ in terminal i° at h° time period, the new set of vehicle types selection sequence $\widehat{W}_{i^\circ}^{h^\circ}$ is obtained with ranking the vehicle types in random order. We denote δ as serial number of the vehicle type in this new set and $\widehat{\delta}$ as the total quantity of available vehicle types. Thus, $\widehat{W}_{i^\circ}^{h^\circ}$ can be recorded as

$$\widehat{W}_{i^\circ}^{h^\circ} = \left\{\widehat{w}_{i^\circ}^{h^\circ}(\delta) \mid \widehat{w}_{i^\circ}^{h^\circ}(\delta) = w, w \in W, \delta = 1, \cdots, \widehat{\delta}\right\} \quad (24)$$

Step 2.2 (adjusting loaded vehicles dispatching scheme of transport routing). The transport routing $s_{i^\circ}^{h^\circ}(\xi)$ is successively chosen from the set of transport routing selection sequence $S_{i^\circ}^{h^\circ}$ in order of the revenue from high to low. According to the vehicle routing matrix π^w, the available vehicle types $\widehat{w}_{i^\circ}^{h^\circ}(\delta)$ allowed to travel on the transport routing $s_{i^\circ}^{h^\circ}(\xi)$ is chosen from the new vehicle type selection sequence $\widehat{W}_{i^\circ}^{h^\circ}$. And the fleet size $\widehat{z}_{i^\circ}^{h^\circ}(\delta)$ of corresponding vehicle types is obtained from fleet size selection sequence $\widehat{Z}_{i^\circ}^{h^\circ}$. We use the formula (25) to ensure loaded vehicles dispatching scheme:

$$x_{i^\circ}^{h^\circ,\delta}(\xi) = \min\left\{\left\lceil \frac{q_{i^\circ}^{h^\circ}(\xi)}{\lambda^{\delta}} \right\rceil, \widehat{z}_{i^\circ}^{h^\circ}(\delta)\right\} \quad (25)$$

Step 2.3 (adjusting available loads number and available fleet size for transport routing). (1) If there are $\lceil q_{i^\circ}^{h^\circ}(\xi)/\lambda^{\delta}\rceil \geq$

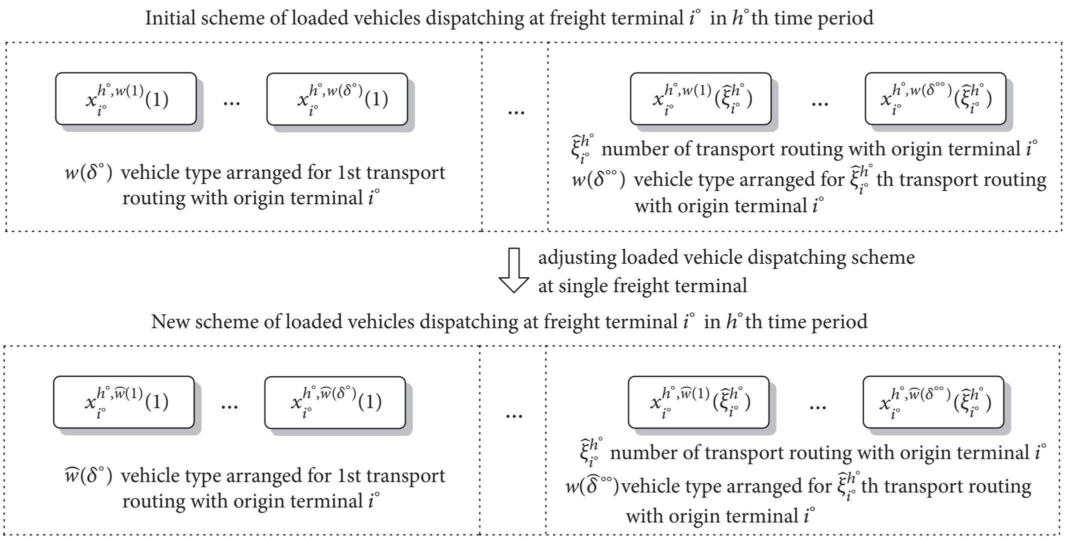


Figure 5: Updating solutions by improving loaded vehicle dispatching scheme at single freight terminal.

$\widehat{z}_{i^\circ}^{h^\circ}(\delta)$, then $x_{i^\circ}^{h^\circ,\delta}(\xi) = \widehat{z}_{i^\circ}^{h^\circ}(\delta)$. Besides, let $q_{i^\circ}^{h^\circ}(\xi) = q_{i^\circ}^{h^\circ}(\xi) - \lambda^{\delta}\widehat{z}_{i^\circ}^{h^\circ}(\delta)$ and $\widehat{z}_{i^\circ}^{h^\circ}(\delta) = 0$; turn to *Step* 2.4.

(2) If there are $\lceil q_{i^\circ}^{h^\circ}(\xi)/\lambda^{\delta}\rceil \leq \widehat{z}_{i^\circ}^{h^\circ}(\delta)$, then $x_{i^\circ}^{h^\circ,\delta}(\xi) = \lceil q_{i^\circ}^{h^\circ}(\xi)/\lambda^{\delta}\rceil$. Besides, let $q_{i^\circ}^{h^\circ}(\xi) = 0$ and $\widehat{z}_{i^\circ}^{h^\circ}(\delta) = \widehat{z}_{i^\circ}^{h^\circ}(\delta)$-$\lceil q_{i^\circ}^{h^\circ}(\xi)/\lambda^{\delta}\rceil$; turn to *Step* 2.5.

Step 2.4 (adjusting three selection sequence sets). We recount the revenue $\alpha_{ij}q_{i^\circ}^{h^\circ}(\xi)$ for each transport routing. The new set of transport routing selection sequence $\overline{S}_{i^\circ}^{h^\circ}$ is updated with ranking the transport routing in descending order of the revenue. Then after removing the vehicle types $\widehat{w}_{i^\circ}^{h^\circ}(\delta)$ used up from vehicle selection sequence set $\widehat{W}_{i^\circ}^{h^\circ}$, the new set of vehicle type selection sequence $\widehat{\widehat{W}}_{i^\circ}^{h^\circ}$ can be given. Further removing the fleet size $\widehat{z}_{i^\circ}^{h^\circ}(\delta)$ of the vehicle types $\widehat{w}_{i^\circ}^{h^\circ}(\delta)$ from fleet size selection sequence set $\widehat{Z}_{i^\circ}^{h^\circ}$, the new set of fleet size selection sequence $\widehat{\widehat{Z}}_{i^\circ}^{h^\circ}$ can be obtained.

Step 2.5 (adjusting two selection sequence sets). The new set of transport routing selection sequence $\overline{S}_{i^\circ}^{h^\circ}$ is given after removing the transport routing $s_{i^\circ}^{h^\circ}(\xi)$ from $S_{i^\circ}^{h^\circ}$. The new set of fleet sizing selection sequence $\widehat{\widehat{Z}}_{i^\circ}^{h^\circ}$ is obtained after updating the corresponding fleet size $\widehat{z}_{i^\circ}^{h^\circ}(\delta)$ of vehicle type $\widehat{w}_{i^\circ}^{h^\circ}(\delta)$ in the set of fleet sizing selection sequence $\widehat{Z}_{i^\circ}^{h^\circ}$.

Stage 3 (determining loaded vehicle dispatching scheme of other freight terminals). We work out the loaded vehicle dispatching scheme at other freight terminals in the h°th time period by the VA-GHP approach. And then the vehicle distributions at each freight terminal in the $(h^\circ + 1)$th time period are updated.

Stage 4 (determining loaded vehicle dispatching and empty vehicle reposition scheme for remaining time periods). The loaded vehicle dispatching and empty vehicle reposition scheme is obtained by VA-GHP approach for remaining time periods after the h°th time period. The updating solution by improving loaded vehicle dispatching scheme at single terminal is shown in Figure 5.

6.2. Updating Solution by Improving Empty Vehicle Reposition Scheme at Single Terminal.

On the basis of the improved solution obtained by US-ILVD, secondary improvement procedure called US-IEVR is further carried out. The concrete procedure of US-IEVR is as follows.

Stage 1 (selecting the time period and freight terminal). The time period h^* is selected randomly from planning horizon. And then the destination freight terminal j^* is chosen randomly from freight terminal selected sequence with lack of empty vehicle $\widetilde{J}^{h^*}$. They are denoted as $\{j^*, h^* \mid j^* \in N, h^* \in H\}$.

Stage 2 (adjusting the set of freight terminal selected sequence for dispatching empty vehicle). According to the vehicle routing matrix π^{w}, the origin terminal i^* that has a link with destination terminal j^* is taken out. And, ranking the origin terminal i^* in ascending order of the distance, the set of freight terminal selected sequence for dispatching empty vehicle $\widetilde{I}_{j^*}^{h^*-1}$ is obtained. We denote $i^*(\theta)$ as the serial number of freight terminal for dispatching empty vehicle in this set $\widetilde{I}_{j^*}^{h^*-1}$.

Stage 3 (adjusting empty vehicles reposition scheme). We choose successively the origin terminal $i^*(\theta)$ from the corresponding set of freight terminal selected sequence for dispatching empty vehicle $\widetilde{I}_{j^*}^{h^*-1}$. In accordance with vehicle

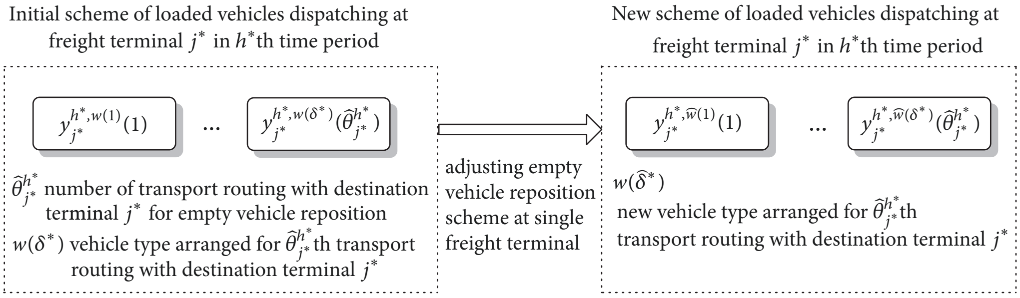


Figure 6: Updating solutions by improving empty vehicle reposition scheme at single freight terminal.

distribution $\widehat{Z}_{i^*(\theta)}^{h^*-1}$ at freight terminal for dispatching empty vehicle $i^*(\theta)$ and loads number $\widetilde{q}_{j^*}^{h^*}$ at freight terminal with lack of empty vehicle j^*, we make use of the principle of randomly arranging vehicle types to generate the empty vehicle reposition scheme as the following formula:

$$y_{j^*}^{h-1,\delta}(\theta) = \min\left\{\left\lceil \frac{\widetilde{q}_{j^*}^{h^*}}{\lambda^{\delta}} \right\rceil, \widehat{z}_{i^*(\theta)}^{h^*-1}(\delta)\right\}, \quad i^* \in \widetilde{I}_{j^*}^{h^*-1} \tag{26}$$

(1) If there are $\lceil \widetilde{q}_j^{h^*}/\lambda^{\delta} \rceil \geq \widehat{z}_{i^*(\theta)}^{h^*-1}(\delta)$, $y_{j^*}^{h-1,\delta}(\theta) = \widehat{z}_{i^*(\theta)}^{h^*-1}(\delta)$. Additionally, let $\widetilde{q}_{j^*}^{h^*} = \widetilde{q}_{j^*}^{h^*} - \lambda^{\delta}\widehat{z}_{i^*(\theta)}^{h^*-1}(\delta)$ and $\widehat{z}_{i^*(\theta)}^{h^*-1}(\delta) = 0$. If there are still some other vehicle types in freight terminal for dispatching empty vehicle $i^*(\theta)$, we generate further the empty vehicle reposition scheme by equation (26). Otherwise, the next freight terminal $i^*(\theta)$ is taken out from the set of freight terminal selected sequence for dispatching empty vehicle $\widetilde{I}_{j^*}^{h^*-1}$.

(2) If there are $\lceil \widetilde{q}_j^{h^*}/\lambda^{\delta} \rceil \leq \widehat{z}_{i^*(\theta)}^{h^*-1}(\delta)$, $y_{j^*}^{h^*-1,\delta}(\theta) = \lceil \widetilde{q}_{j^*}^{h^*}/\lambda^{\delta} \rceil$. Besides, let $\widetilde{q}_{j^*}^{h^*} = 0$ and $\widehat{z}_{i^*(\theta)}^{h^*-1}(\delta) = \widehat{z}_{i^*(\theta)}^{h^*-1}(\delta) - \lceil \widetilde{q}_{j^*}^{h^*}/\lambda^{\delta} \rceil$. And the procedures are stopped.

Stage 4 (determining empty vehicle reposition scheme of other freight terminals). We work out the empty vehicle reposition scheme at other freight terminals in the h^*th time period by the VA-GHP approach. And then the vehicle distributions at each freight terminal in the $(h^* + 1)$th time period are updated.

Stage 5 (determining loaded vehicle dispatching and empty vehicle reposition scheme for remaining time periods). The loaded vehicle dispatching and empty vehicle reposition scheme is obtained by VA-GHP approach for remaining time periods after the h^*th time period. The updating solution by improving empty vehicle reposition scheme at single terminal is shown in Figure 6.

7. Hybrid Simulated Annealing Algorithm Combining VA-GHP&USP-IVA

In this section, we develop a hybrid simulated annealing heuristic to solve MHFS-FSD using the VA-GHP approach and USP-IVA method described previously in Sections 5 and 6. In this proposed algorithm, we use the VA-GHP procedure to generate initial solutions and the USP-IVA procedure to improve the solutions. We incorporate VA-GHP and USP-IVA into simulated annealing algorithm. So the hybrid simulated annealing heuristic is proposed. The detailed steps of hybrid simulated annealing heuristics (HSAH) are as follows.

7.1. Acceptance Measure of Solutions. (1) Acceptance Measure for US-ILVD. Let $\psi^* = \{(X^h, Y^h, Z^h) \mid h = 1, \cdots, K\}$ denote the solution accepted currently and $\psi_{US-ILVD}^{(i^{\circ},h^{\circ})} = \{\psi^* \longrightarrow \widehat{X}_{i^{\circ}}^{h^{\circ}}\}$ express the new solution obtained by US-ILVD of single terminal (i°, h°). We let $F_{US-ILVD}^{+(i^{\circ},h^{\circ})}$ be the incremental cost as follows:

$$F_{US-ILVD}^{+(i^{\circ},h^{\circ})} = F\left(\psi_{US-ILVD}^{(i^{\circ},h^{\circ})}\right) - F\left(\psi^*\right) \tag{27}$$

The acceptance measure of new solution $\psi_{US-ILVD}^{(i^{\circ},h^{\circ})}$ is written as follows:

$$P\left(\psi_{US-ILVD}^{(i^{\circ},h^{\circ})}\right) = \begin{cases} 1, & \text{if } F_{\text{US-ILVD}}^{+(i^{\circ},h^{\circ})} \leq 0. \\ \exp\left(-\dfrac{F_{US-ILVD}^{+(i^{\circ},h^{\circ})}}{t}\right), & \text{if } F_{\text{US-ILVD}}^{+(i^{\circ},h^{\circ})} > 0. \end{cases} \tag{28}$$

where $P(\psi_{US-ILVD}^{(i^{\circ},h^{\circ})})$ denotes the acceptance probability of new solution $\psi_{US-ILVD}^{(i^{\circ},h^{\circ})}$.

(2) Acceptance Measure for US-IEVR. Let $\psi^* = \{(X^h, Y^h, Z^h) \mid h = 1, \cdots, K\}$ denote the solution accepted currently and $\psi_{US-IEVR}^{(j^*,h^*)} = \{\psi^* \longrightarrow \widehat{Y}_{j^*}^{h^*}\}$ express the solution obtained by US-IEVR of single terminal (j^*, h^*). Let us define $F_{US-IEVR}^{+(j^*,h^*)}$ as the incremental cost. We have that

$$F_{US-IEVR}^{+(j^*,h^*)} = F\left(\psi_{US-IEVR}^{(j^*,h^*)}\right) - F\left(\psi^*\right) \tag{29}$$

We can form the acceptance measure of new solution $\psi_{US-IEVR}^{(j^*,h^*)}$ as follows:

$$P\left(\psi_{US-IEVR}^{(j^*,h^*)}\right) = \begin{cases} 1, & \text{if } F_{US-IEVR}^{+(j^*,h^*)} \leq 0. \\ \exp\left(-\dfrac{F_{US-IEVR}^{+(j^*,h^*)}}{t}\right) & \text{if } F_{US-IEVR}^{+(j^*,h^*)} > 0. \end{cases} \quad (30)$$

where $P(\psi_{US-IEVR}^{(j^*,h^*)})$ is the acceptance probability of new solution $\psi_{US-IEVR}^{(j^*,h^*)}$.

7.2. Control Parameters of the Heuristics.

(1) Initial Temperature Parameter t_0. In order to return a high quality final solution at the end of the algorithm iteration, we must give a large enough value to t_0. But the exorbitant initial temperature can cause the sharp growth of CPU run time so that makes the algorithm lose its feasibility. So we let $t_0 = 2 \times F(\psi^*)$, where $F(\psi^*)$ is the objective function value obtained by taking the vehicles allocation scheme $\psi = \{(X^1, Y^1, Z^1), \ldots, (X^K, Y^K, Z^K)\}$ into objective function of MHFS-FSD model.

(2) Termination Criterion. Here we give a very small positive number t_f as the termination temperature of hybrid simulated annealing heuristics. During the iterative procedure of the algorithm, the temperature control parameter t is gradually reduced. When the temperature control parameter t is less than t_f, the algorithm will be terminated.

(3) Attenuation Function of Temperature Control Parameter. In order to avoid overlong running times in each iteration, the decrement of temperature control parameter t should take a small value. Here we have the attenuation function of temperature control parameter as follows:

$$t_{k+1} = \alpha \cdot t_k, \quad k = 0, 1, \ldots, \quad 0 < \alpha < 1 \quad (31)$$

where t_k and t_{k+1} are, respectively, the temperature control parameter in kth iteration and $(k+1)$th iteration, α is the attenuation coefficient, and we assume α to be 0.9.

(4) Solution Transformation Times. The acceptance probability of new solution will reduce with the decrease of the temperature control parameter t_k. Consequently, solution transformation times L_k should gradually increase when temperature control parameter t_k drops; that is, $t_k \downarrow \Longrightarrow L_k \uparrow$. Here we have the dynamic solution transformation times based on algorithm iterative procedure:

$$L_{k+1} = \beta \cdot L_k, \quad k = 0, 1, \ldots, \quad \beta > 1 \quad (32)$$

where L_k and L_{k+1} are, respectively, the solution transformation times in kth iteration and $(k+1)$th iteration and β is the increasing rate. We assume β to be 1.1 and L_0 to be a number between 50~100.

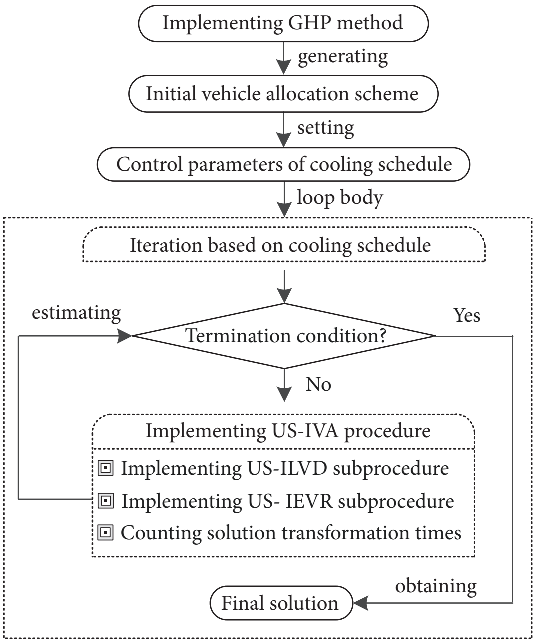


FIGURE 7: Flow diagram of hybrid simulated annealing heuristics.

7.3. Heuristic Procedure. For illustration purpose, the hybrid simulated annealing heuristic combining greedy heuristic procedure for initial solution and improving vehicle allocation for updating solution is abbreviated as HSAH-GHP&IMA. Figure 7 depicts a flowchart of the hybrid simulated annealing heuristics. The heuristic procedure can be described as follows.

Stage 1 (initial scheduling scheme generated by GHP). Let $\psi = \{(X^1, Y^1, Z^1), \ldots, (X^K, Y^K, Z^K)\}$ denote the vehicle allocation scheme of whole planning horizon obtained by VA-GHP. And then the objective function value $F(\psi)$ can be obtained by taking it into the objective function of MHFS-FSD model. Besides, we let $\psi^* = \psi$.

Stage 2 (setting control parameters). We set the initial temperature t_0, termination temperature t_f, attenuation coefficient of temperature control parameter α, initial solution transformation times L_0, and increasing rate of solution transformation times β. And then let $t = t_0$, $L = L_0$; turn to *Step* 2.

Stage 3 (iteration based on cooling schedule).

Step 1 (measuring termination condition). In case $t > t_f$, the algorithm procedure turns to *Step* 2. Otherwise, move to *Step* 4.

Step 2 (implementing US-IVA procedure). Let $i = 1$.

Step 2.1 (implementing US-ILVD subprocedure). After choosing randomly the adjustment freight terminal and time period (i°, h°), we use US-ILVD procedure to improve solution ψ^* so that the new solution $\psi_{US-ILVD}^{(i^\circ,h^\circ)}$ is obtained. The

$F^{+(i^{\circ},h^{\circ})}_{US-ILVD}$ value is calculated by equation (27). If $F^{+(i^{\circ},h^{\circ})}_{US-ILVD} \leq 0$, we accept the new solution and let $\psi^{*} = \psi^{(i^{\circ},h^{\circ})}_{US-ILVD}$. If a random number $\mathfrak{R}$ between 0 and 1 is generated and $\exp(-F^{+(i^{\circ},h^{\circ})}_{US-ILVD}/t) \geq \mathfrak{R}$, we accept the new solution and let $\psi^{*} = \psi^{(i^{\circ},h^{\circ})}_{US-ILVD}$. Otherwise, we reject to accept the new solution and ψ^{*} remain unchanged. The procedure goes to *Step* 2.2.

Step 2.2 (implementing US- IEVR subprocedure). After choosing randomly the adjustment freight terminal and time period (j^{*}, h^{*}), we use US-IEVR procedure to improve solution ψ^{*} so that the new solution $\psi^{(j^{*},h^{*})}_{US-IEVR}$ is obtained. The $F^{+(j^{*},h^{*})}_{US-IEVR}$ value is calculated by equation (29). If $F^{+(j^{*},h^{*})}_{US-IEVR} \leq 0$, we accept the new solution and let $\psi^{*} = \psi^{(j^{*},h^{*})}_{US-IEVR}$. If a random number $\mathfrak{R}$ between 0 and 1 is generated and $\exp(-F^{+(j^{*},h^{*})}_{US-IEVR}/t) \geq \mathfrak{R}$, we accept the new solution and let $\psi^{*} = \psi^{(j^{*},h^{*})}_{US-IEVR}$. Otherwise, we reject to accept the new solution and ψ^{*} remain unchanged. The procedure goes to *Step* 2.3.

Step 2.3 (counting solution transformation times). Let $i = i + 1$. If there is $i \leq L$, turn to *Step* 2.1; else go to *Step* 2.4.

Step 2.4 (adjusting temperature and solution transformation times). Let $t = t \times \alpha$ and $L = L \times \beta$, and go to *Step* 1.

Stage 4 (obtaining final solution). When the termination criterion is met, the final solution ψ^{*} can be obtained.

8. Numerical Experiments

In this section, we try to evaluate the quality of the hybrid simulated annealing algorithm combining VA-GHP&USP-IVA proposed in previous section to solve the MHFS-FSD in terms of traditional measure such as objective function and execution time. The scenarios for MHFS-FSD are described in Section 8.1 and three sets of experiments are devised to test the effectiveness of the hybrid simulated annealing algorithm proposed. Section 8.2 reports the numerical results.

8.1. Scenario Settings of the Experiments. To design the experiments scheme, the scenarios settings need to be firstly set up. This section describes the data used in the numerical testing of the models. We generated the dataset based on the freight enterprise in Henan Province, China. However, the data have some inconsistencies caused by multiple types of the vehicles, differences in financial accounting system of various corporations, and so on. Therefore the data has to be cleaned.

Here we chose a certain range from 40 RMB to 60 RMB per load as the revenue of loaded movement between various freight terminals. The loading capacity of various type vehicles is allowed the certain range from 20 units to 30 units per vehicle. The cost of empty reposition is allowed the certain range from 200 RMB to 300 RMB per vehicle. We use the cost range from 2000 RMB to 3000 RMB per vehicles as purchase or lease cost of various vehicles.

To evaluate the performance of the heuristics proposed, we generate randomly three sets of problem instances with different size of freight terminal and time periods, considering different number of vehicles types. Three sets of experiments are oriented to compare the performances of the hybrid simulated annealing algorithm with the CPLEX solver and VA-GHP approach.

In the first set of contrast experiment, there are the heterogeneous fleet with three types of vehicles and five time periods. The number of the freight terminal is from 5 to 10. In the second set of contrast experiment, there are the heterogeneous fleet with five types of vehicles and ten time periods. The number of the freight terminal is from 11 to 20. In the third set of contrast experiment, there are the heterogeneous fleet with ten types of vehicles and thirty time periods. The number of the freight terminal is from 21 to 50.

The test work has been done using a computer with Intel i5-5200CPU (2.2 GHz). The hybrid simulated annealing algorithm combining VA-GHP&USP-IVA has been coded in Microsoft Visual C++.

8.2. Performance Evaluation. In this section the computational experiments are performed using three methods to solve the MHFS-FSD model: HSAH program, GHP approach, and CPLEX solver. And we use two measures to evaluate the performance. The first one is the OPT, which is the value of the objective function obtained by the CPLEX solver, GHP approach, and HSAH program. OPT as one of the major criteria in assessing the performance of the HSAH, GHP, and CPLEX represents the profit generated by revenues for dispatching loaded vehicles, repositioning empty vehicles, and ownership costs for owning vehicle in planning horizon. The second measure of performance is the CUP time to run CPLEX solver, the GHP approach, and HSAH program for MHFS-FSD model. We aim at quantifying the benefits of the proposed method in two aspects: (1) the efficiency of the proposed method executed with no time limit imposed and (2) the efficiency of the proposed method executed with time limit imposed.

(1) Measure of Performance with No CPU Time Limit Imposed. In this section, we focus on the numerical studies on the performance of GHP approach, HSAH program and CPLEX solver executed with no CPU time limit imposed. We compare the performance of these three methods in two aspects: solution quality and computational efficiency. In Tables 1–3 we present the results obtained by solving randomly generated MHFS-FSD problems. We compare the solutions obtained by solving the MHFS-FSD problems using GHP approach, HSAH program, and CPLEX solver.

CPLEX solver is executed with no time limit imposed. The parameters used for the HSAH are as follows. The initial temperature is set by $t_0 = 2 \times F(\psi^{*})$, where $F(\psi^{*})$ is the objective function value obtained by taking the initial solution solved with VA-IGP into objective function of MHFS-FSD model. The termination temperature is set to 1. The attenuation coefficient of temperature control parameter is assumed to be 0.9. The initial solution transformation

Table 1: Performance for CPLEX, GHP, and HSAH applied to small size problem with no time limit imposed.

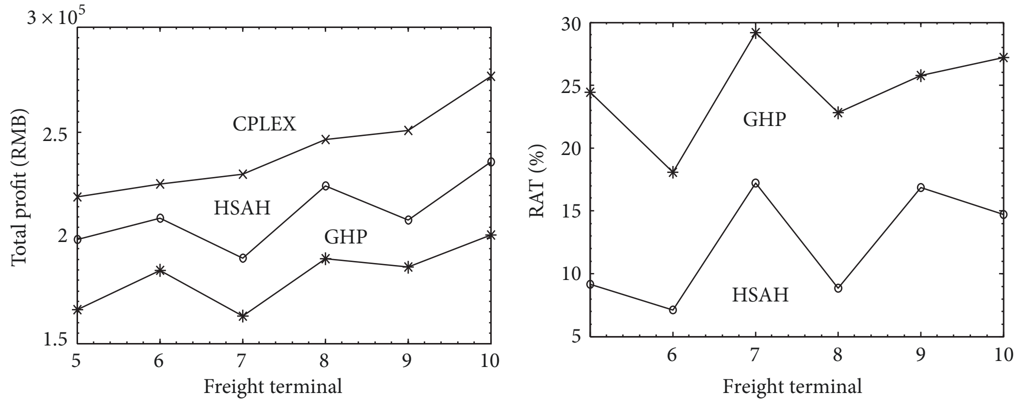
Problem size (freight terminal × vehicle types × time period)	CPLEX		GHP				HSAH			
	OS (RMB)	CPU time (second)	OFV (RMB)	CPU time (second)	RAT (%)	GAP (second)	OFV (RMB)	CPU time (second)	RAT (%)	GAP (second)
5 × 3 × 5	219586	214.5	165894	13.6	24.45	200.9	199473	33.6	9.16	180.9
6 × 3 × 5	225465	235.7	184759	15.7	18.05	220.0	209484	37.5	7.09	198.2
7 × 3 × 5	230187	356.2	163028	13.9	29.18	342.3	190583	36.6	17.21	319.6
8 × 3 × 5	246586	248.3	190324	21.6	22.82	226.7	224756	45.6	8.85	202.7
9 × 3 × 5	250829	321.2	186206	25.8	25.76	295.4	208573	50.4	16.85	270.8
10 × 3 × 5	276585	314.5	201478	23.1	27.16	291.4	235859	55.6	14.72	258.9

Table 2: Performance for CPLEX, GHP, and HSAH applied to medium size problem with no time limit imposed.

Problem size (freight terminal × vehicle types × time period)	CPLEX		GHP				HSAH			
	OS (RMB)	CPU time (second)	OFV (RMB)	CPU time (second)	RAT (%)	GAP (second)	OFV (RMB)	CPU time (second)	RAT (%)	GAP (second)
11 × 5 × 10	727865	389.5	512034	89.7	29.65	299.8	708543	196.7	2.65	192.8
12 × 5 × 10	767289	397.2	536401	91.4	30.09	305.8	741478	183.4	3.36	213.8
13 × 5 × 10	876537	405.7	641963	103.4	26.76	302.3	835317	209.9	4.70	195.8
14 × 5 × 10	782685	412.3	541069	113.5	30.87	298.8	729294	220.3	6.82	192.0
15 × 5 × 10	813858	434.2	571648	73.8	29.76	360.4	787625	177.8	3.22	256.4
16 × 5 × 10	882385	451.8	642917	112.5	27.13	339.3	837674	229.6	5.07	222.2
17 × 5 × 10	926048	446.9	702541	100.9	24.14	346.0	892573	214.2	3.61	232.7
18 × 5 × 10	949874	467.1	731529	85.2	22.99	381.9	932074	192.1	1.87	275.0
19 × 5 × 10	998375	482.6	768359	78.4	23.04	404.2	948927	187.4	4.95	295.2
20 × 5 × 10	1010948	513.7	763542	104.3	24.47	409.4	978375	210.6	3.22	303.1

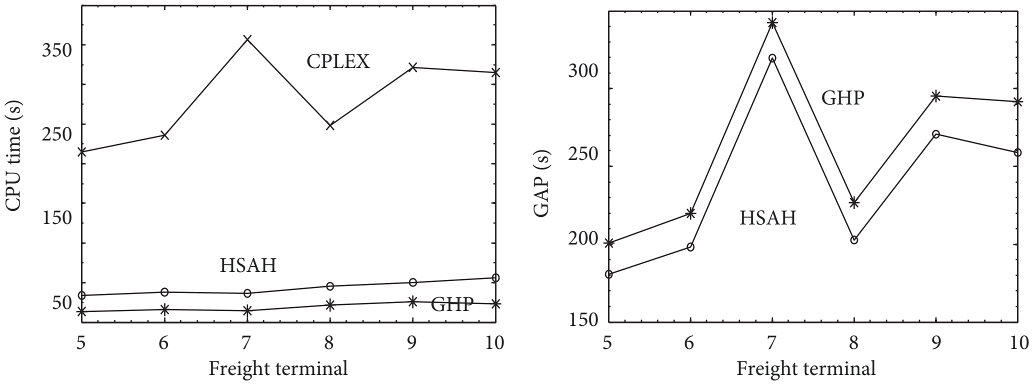
Table 3: Performance for CPLEX, GHP, and HSAH applied to large size problem with no time limit imposed.

Problem size (freight terminal × vehicle types × time period)	CPLEX		GHP				HSAH			
	OS (RMB)	CPU time (second)	OFV (RMB)	CPU time (second)	RAT (%)	GAP (second)	OFV (RMB)	CPU time (second)	RAT (%)	GAP (second)
21 × 10 × 30	3641457	1046.6	3162419	351.7	13.16	694.9	3592236	631.5	1.35	415.1
22 × 10 × 30	3960247	1153.7	3375864	363.2	14.76	790.5	3890437	654.2	1.76	499.5
23 × 10 × 30	4093746	1241.3	3392618	389.1	17.13	852.2	3962476	691.0	3.21	550.3
24 × 10 × 30	4172590	1306.9	3521607	412.5	15.60	894.4	4063582	719.6	2.61	587.3
25 × 10 × 30	4395799	1388.1	3862453	434.7	12.13	953.4	4298741	767.9	2.21	620.2
26 × 10 × 30	4673825	1449.7	3971641	443.8	15.02	1005.9	4495476	779.0	3.82	670.7
27 × 10 × 30	4691793	1533.8	4071358	503.4	13.22	1030.4	4586179	839.1	2.25	694.7
28 × 10 × 30	4762133	1592.4	4193062	536.7	11.95	1055.7	4703167	864.2	1.24	728.2
29 × 10 × 30	4792619	1640.3	4083017	576.3	14.81	1064.0	4698731	899.6	1.96	740.7
30 × 10 × 30	4821617	1731.6	4262843	598.6	11.59	1133.0	4803164	904.3	0.38	827.3
31 × 10 × 30	4865329	1796.1	4228019	602.6	13.10	1193.5	4829316	932.5	0.74	863.6
32 × 10 × 30	4887691	1874.2	4353762	647.9	10.92	1226.3	4796317	966.7	1.87	907.5
33 × 10 × 30	4963720	1924.0	4464907	712.4	10.05	1211.6	4850691	1043.2	2.28	880.8
34 × 10 × 30	5120379	1989.6	4526143	726.8	11.61	1262.8	5006479	1132.5	2.22	857.1
35 × 10 × 30	5436826	2046.5	4593011	779.3	15.52	1267.2	5267984	1164.6	3.11	881.9
36 × 10 × 30	5761844	2165.3	4612938	852.4	19.94	1312.9	5706914	1254.2	0.95	911.1
37 × 10 × 30	5839764	2221.2	4685714	837.0	19.76	1384.2	5784639	1275.6	0.94	945.6
38 × 10 × 30	6032875	2302.2	4703519	954.3	22.04	1347.9	5859217	1324.8	2.88	977.4
39 × 10 × 30	6361448	2399.5	4794808	989.4	24.63	1410.1	6263941	1396.1	1.53	1003.4
40 × 10 × 30	6673280	2556.4	4862714	1032.6	27.13	1523.8	6612476	1443.2	0.91	1113.2
41 × 10 × 30	6805218	2826.5	5182913	1058.1	23.84	1768.4	6569031	1504.1	3.47	1322.4
42 × 10 × 30	6961760	2973.3	5403917	1129.8	22.38	1843.5	6795213	1575.4	2.39	1397.9
43 × 10 × 30	7134752	3205.6	5632051	1186.7	21.06	2018.9	6948217	1614.5	2.61	1591.1
44 × 10 × 30	7446389	3360.5	5789830	1056.3	22.25	2304.2	7164206	1653.2	3.79	1707.3
45 × 10 × 30	7623796	3586.6	5913517	1219.4	22.43	2367.2	7501286	1741.8	1.61	1844.8
46 × 10 × 30	7853219	3888.2	6242683	1234.7	20.51	2653.5	7632689	1813.6	2.81	2074.6
47 × 10 × 30	7905256	4169.6	6590263	1196.4	16.63	2973.2	7693618	1856.8	2.68	2312.8
48 × 10 × 30	8134962	4275.3	6832657	1324.7	16.01	2950.6	8047603	1943.6	1.07	2331.7
49 × 10 × 30	8416732	4453.6	7207149	1717.2	14.37	2736.4	8267798	2066.2	1.77	2387.4
50 × 10 × 30	8601795	4679.1	7421678	1536.8	13.72	3142.3	8396419	2164.7	2.39	2514.4



(a) Objective function value

(b) Deviation rate



(c) CPU running time

(d) CPU time gap

Figure 8: Results of comparison for small size problem.

frequency is allowed 80. The increasing rate of the solution transformation frequency is assumed to be 1.1.

In order to facilitate problem analysis, we introduce two analytical indicators. The first denoted as RAT represents the deviation rate from the optimal solution. Let OFV be the objective function value with GHP approach and HSAH program. And let OS be optimal solution obtained with CPLEX solver. The RAT is calculated by

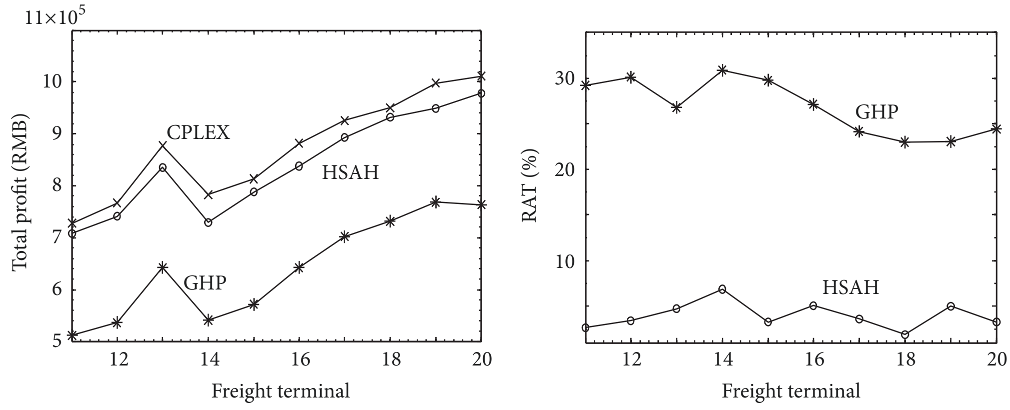
$$\text{RAT} = \frac{(\text{OS} - \text{OFV})}{\text{OS}} \tag{33}$$

The second is the CPU time gap denoted as GAP. It is calculated by the difference between CUP time of running the HSAH program or GHP approach and that of CPLEX solver. The CPU times of running HSAH program, GHP approach, and CPLEX solver are, respectively, denoted as CPUT.HSAH, CPU.GHP, and CPUT.CPLEX. The GAP is calculated by

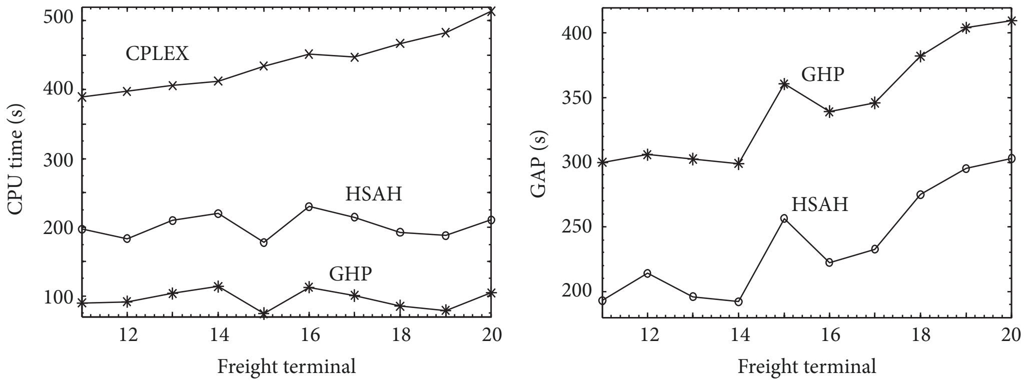
$$\begin{gathered} \text{GAP} = (\text{CPUT.CPLEX} - \text{CPUT.HSAH}) \\ \text{GAP} = (\text{CPUT.CPLEX} - \text{CPUT.GHP}) \end{gathered} \tag{34}$$

The performance of small size problem is shown in Table 1. Here we have 6 test problems. Each problem is, respectively, solved using the proposed GHP approach, HSAH program, and CPLEX solver. For the small size problem, the performance of GHP and HSAH is not very prominent when compared to CPLEX. And the performance of HSAH is better than GHP. The deviations of GHP from the optimal solution are the range from 18% to 30% while the deviations of HSAH from the optimal solution are the range from 7% to 20%. The CPU times to obtain the solutions are the range from 33.6 s to 55.6 s for HSAH, the range from 13.6 s to 23.1 s for GHP, and the range from 214.5 s to 356.2 s for CPLEX. The superiority of GHP and HSAH in computing time can be shown distinctly. The results of comparison are displayed in Figure 8.

The performance of medium size problem is shown in Table 2. Here we have 10 test problems. Each problem is respectively solved using the proposed GHP, HSAH, and CPLEX. For the medium size problem, the GHP and HSAH perform well when compared to CPLEX. The performance of HSAH is prominent than GHP. The deviations from the optimal solution are reduced to a reasonable range from 2% to 7% for HSAH and the deviations from the optimal solution range from 22% to 31% for GHP. One obvious observation is that the increase of CUP time to obtain the solutions using CPLEX begins to appear a trend of acceleration. But the rising step of CPU times to obtain the solutions using GHP and HSAH increases is relatively flat. So the superiority of GHP and HSAH in computation time is very obvious. The performance comparisons are shown in Figure 9.



(a) Objective function value (b) Deviation rate



(c) CPU running time (d) CPU time gap

Figure 9: Results of comparison for medium size problem.

The performance of large size problem is shown in Table 3. Here we have 30 test problems. Each problem is respectively solved using the proposed GHP, HSAH, and CPLEX. For the large size problem, performance of solving the problem using the GHP and HSAH is more excellent than that of CPLEX. The deviations from the optimal solution for HSAH are limited to a very small range within 4% while the deviations from the optimal solution for the GHP are limited to range within 30%. But the CPU times for obtaining the solutions using CPLEX solver increase in a sharp speed due to the high memory requirements. The superiority of GHP and HSAH in computation time is particularly obvious. The performance comparisons are shown in Figure 10.

(2) Measure of Performance with CPU Time Limit Imposed. In the experiment, we test the performance of the HSAH program and CPLEX solver with CPU time limit imposed. Since the performance of GHP approach is obviously inferior to that of HSAS program, GHP approach is no longer tested in the experiment. Here the HSAS program is fully executed. And let CPLEX solver be executed for the same CPU time. Then we compare the objective function value obtained by solving the MHFS-FSD problems using HSAH program and CPLEX solver. The tests are performed mainly in Tables 4–6.

From above three sets of contrast tests, the objective function values obtained by HSAH program are significantly better than those obtained by CPLEX solver with CPU time limit imposed.

In sum, we can conclude that the HSAH is effective to obtain good solutions in relatively low run times for the MHFS-FSD. The results obtained indicate the benefits of using HSAH, helping MHFS-FSD to find better solutions in reasonable short CPU times, which are acceptable for practical applications.

9. Conclusions

The study described in this paper attempts to integrate vehicles allocation and fleet sizing decisions considering the vehicle routing of multiple vehicle types. We name the problem as multistage heterogeneous fleet scheduling with fleet sizing decisions (MHFS-FSD). In this paper, a mixed integer programming model has been developed for MHFS-FSD. As an NP problem, using traditional method for solving MHFS-FSD model is difficult and inefficient. A novel heuristic is considered to solve this problem.

According to the characteristic of this problem, the matrix formulation denoting vehicle allocation scheme is provided. The approach of generating vehicle allocation scheme with greedy heuristic procedure (VA-GHP) as initial solution of problem is presented. On the basis of the initial solution generated by VA-GHP approach, the USP-IVA

Table 4: Results for HSAH and CPLEX applied to small size problem with time limit imposed.

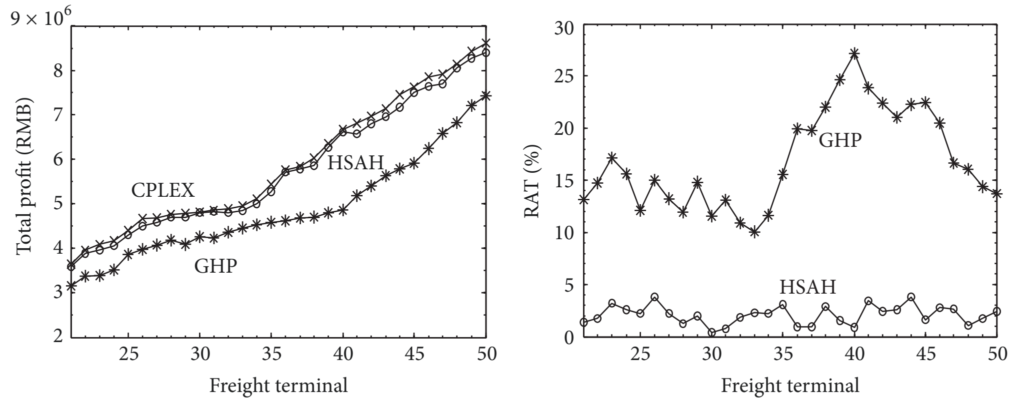
Problem size (freight terminal × vehicle types × time period)	OFV (RMB)		CPU time (second)
	CPLEX	HSAH	
5 × 3 × 5	53817	199473	33.6
6 × 3 × 5	57429	209484	37.5
7 × 3 × 5	61437	190583	36.6
8 × 3 × 5	68413	224756	45.6
9 × 3 × 5	73076	208573	50.4
10 × 3 × 5	78462	235859	55.6

Table 5: Results for HSAH and CPLEX applied to medium size problem with time limit imposed.

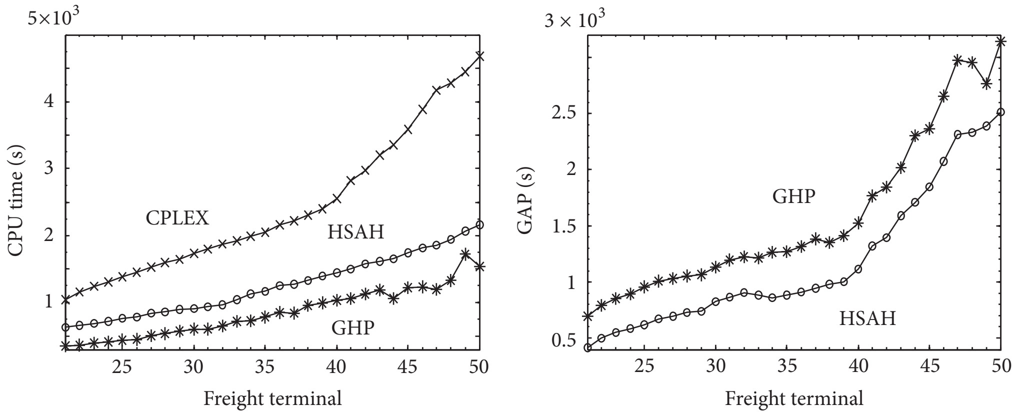
Problem size (freight terminal × vehicle types × time period)	OFV (RMB)		CPU time (second)
	CPLEX	HSAH	
11 × 5 × 10	493276	708543	196.7
12 × 5 × 10	497625	741478	183.4
13 × 5 × 10	513410	835317	209.9
14 × 5 × 10	526683	729294	220.3
15 × 5 × 10	525914	787625	177.8
16 × 5 × 10	543728	837674	229.6
17 × 5 × 10	562807	892573	214.2
18 × 5 × 10	567436	932074	192.1
19 × 5 × 10	573614	948927	187.4
20 × 5 × 10	592460	978375	210.6

Table 6: Results for HSAH and CPLEX applied to large size problem with time limit imposed.

Problem size (freight terminal × vehicle types × time period)	OFV (RMB)		CPU time (second)
	CPLEX	HSAH	
21 × 10 × 30	2561437	3592236	631.5
22 × 10 × 30	2746308	3890437	654.2
23 × 10 × 30	3012561	3962476	691.0
24 × 10 × 30	3348021	4063582	719.6
25 × 10 × 30	3585719	4298741	767.9
26 × 10 × 30	3602476	4495476	779.0
27 × 10 × 30	3680418	4586179	839.1
28 × 10 × 30	3764292	4703167	864.2
29 × 10 × 30	3791068	4698731	899.6
30 × 10 × 30	3822516	4803164	904.3
31 × 10 × 30	3849317	4829316	932.5
32 × 10 × 30	3886203	4796317	966.7
33 × 10 × 30	3965042	4850691	1043.2
34 × 10 × 30	4002837	5006479	1132.5
35 × 10 × 30	4125340	5267984	1164.6
36 × 10 × 30	4196205	5706914	1254.2
37 × 10 × 30	4273568	5784639	1275.6
38 × 10 × 30	4305217	5859217	1324.8
39 × 10 × 30	4362208	6263941	1396.1
40 × 10 × 30	4385426	6612476	1443.2
41 × 10 × 30	4412716	6569031	1504.1
42 × 10 × 30	4472930	6795213	1575.4
43 × 10 × 30	4502814	6948217	1614.5
44 × 10 × 30	4575356	7164206	1653.2
45 × 10 × 30	4598325	7501286	1741.8
46 × 10 × 30	4620819	7632689	1813.6
47 × 10 × 30	4673369	7693618	1856.8
48 × 10 × 30	4702923	8047603	1943.6
49 × 10 × 30	4785527	8267798	2066.2
50 × 10 × 30	4832509	8396419	2164.7



(a) Objective function value (b) Deviation rate



(c) CPU running time (d) CPU time gap

Figure 10: Results of comparison for large size problem.

method to update the initial solution is developed. And then, incorporating VA-GHP and USP-IVA into simulated annealing algorithm, a novel heuristic called HSAH-GHP&IVA is proposed. Finally, we evaluate the performance of the hybrid simulated annealing heuristic in terms of traditional measure such as objective function and execution time. The results show that the proposed heuristic is able to obtain reasonably good solutions in short CPU times.

Future research can focus on new heuristics to solve the MHFS-FSD. Another prospective research will be to extend the model of MHFS-FSD by introducing further realistic aspects and relaxing hard constraints.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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