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VEHICLE ROUTING PROBLEM WITH PARTLY SIMULTANEOUS PICKUP AND DELIVERY FOR THE CLUSTER OF SMALL AND MEDIUM ENTERPRISES

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Abstract:

The transportation service for the cluster of small and medium enterprises (SMEs) is different with traditional vehicle routing problems. In the cluster of SMEs, parts of enterprises are pickup and delivery spots simultaneously, but some enterprises are partly pickup and delivery simultaneously. It is necessary to optimize this transportation service with an effective mathematics and algorithm to reduce transportation costs for manufacturers. However, traditional mathematics models and algorithms are not suitable to solve the vehicle routing problem partly simultaneous pickup and delivery (VRPPSD) because these items mainly focus on the vehicle routing problem with pickup and delivery simultaneously. In this paper, a mathematics operational model is proposed to analyze the transportation service of the cluster companies and to describe transportation processes. A hybrid algorithm which is composed by tabu search, genetic algorithm and local search is used to optimize the operational model. The crossover and mutation contained by genetic algorithm are used to generate neighborhood solutions for tabu search, and the local search is used to improve optimizing solutions. The data of a cluster of SMEs, investigating from Changzhou city, China, are employed to show the validity of our mathematical model and algorithm. The results indicate that our model and hybrid algorithm is effective to solve VRPPSD. In this paper, the satisfied solutions of VRPPSD are found by hybrid algorithm. At the same time, the results also show that carriers with optimal routs can service customers with more profits (increasing 5.6%). The potential saving of transport cost will increase profits of carriers in SMEs. Sensitivity analyses about adjusting service time and rate of new orders are lunched to analyze how these two factors influence the profits of the VRPPSPD in a dynamic case. A bottleneck that influences the profits is found, and there has a shorter service time which could increase gross profits, but not significantly.

Key words:
cluster, pickup and delivery, tabu search, small and medium enterprises, simultaneous

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1. Introduction

There are numerous clusters of small and medium enterprises (SME) in Yangtze River delta, China. An Industry chain can be formed by a cluster of small and medium enterprises, such as aircondition (Changzhou city), electric cable (Wuxi city), and glasses (Danyang city). The parts of products are come from different SMEs in their cluster. The three part carriers transport parts among different SMEs belonged to the cluster. This kind of transportation has three characteristics: (i) parts of SMEs have multiple-small-batch transportation demand; (ii) parts of enterprises are the pickup and delivery spots simultaneously. The others are the pickup or delivery spot separately; (iii) each small batch needs to be serviced respectively. This kind of vehicle routing problem with partly simultaneous pickup and delivery is defined as vehicle routing problem partly pickup and delivery simultaneously (VRPPSPD) in this paper.

Many researchers studied vehicle routing problem (VRP) with separated pickup and delivery spots (Li et al., 2016; Subramanian et al., 2011). Vehicle routing problem with mixed pickup and delivery problem, considering either pickup or delivery demand in a company, was researched (Avci and Topaloglu, 2015; Nagy et al., 2013; Veenstra et al., 2017; Wassan et al., 2008). The other researchers had focused on vehicle routing problem with simultaneous pickup and delivery (VRPSPD) (Szczepański et al., 2014; Izdebski, 2014; Yu and Lin, 2016). Those researches didn't focus on all characteristics of transportation demands for the cluster of SMEs, but these models inspired our model considering partly simultaneous pickup and delivery spots.

This paper studies a hybrid problem based on characteristics from VRPSPD and VRP. VRPSPD and VRP had some constraints such as vehicle and orders, capacity, travel time, split, time windows, service time, profits et al (Avci and Topaloglu, 2015; Ghilas et al., 2016). In the paper, a transportation problem considering the cluster of SMEs with constraints of time windows and full truckloads is studied. A SME can be serviced more than once if there is more than one batch of demand within a planning horizon. This is different from the general VRPSPD (A customer is serviced one time in each planning horizon in the general VRPSPD). An integer linear programming model for VRPPSPD is proposed in this paper.

The model takes real conditions of clusters into consideration and maximizes the profits of carriers, because each carrier aims to pursue maximal his own profit. A case study, coming from a cluster of SMEs in Changzhou city, is adopted to show the validity of the proposed model. The paper is organized as follows. In Section 2, the problem and mathematical model is introduced. A hybrid algorithm which is composed by genetic algorithm, tabu search and local search is developed in Section 3. In Section 4, an experiment framework is designed to assess the performance of the algorithm. Finally, conclusions and discuss some future research directions is presented in Section 5.

2. Mathematical formulation

In this paper, an operational model for VRPPSPD is based on Subramanian et al (2010) that proposed general VRPSPD model. This model is proposed based on new characteristic of problem proposed in this paper. The model can be defined as following: let $G = (V, A)$ be a complete direction graph where $V= \{0, \dots , i\}$, 0 represents the depot and other elements represent all orders' pickup spot and delivery spot. We define orders' set as K which contains all orders. In practice, an order's pickup and delivery spot may be the same as anther order but order's time window is different because a SME contains more than an order. In order to avoid confusion, each order is defined as an individual element in K with pickup spot (k_p), delivery spot (k_d) and time window (t_k) where $k_p \in V'$ and $k_d \in V'$. $A = \{(i, j)| i, j \in V, i \neq j \}$, each edge has non-negative cost c_{ij} and $i \in V' = V - \{0\}$. Each vehicle is represented by w which is an element contained by W. A general mathematical model of pickup and delivery problem can be modified to solve VRPPSPD by adopting these definitions.

To formulate the problem VRPPSPD with profits and time windows, the following parameters are used:

price_k	The *price* of order of *k*.
$\Re$	The set of all routs.
$[ET_k, LT_k]$	The time window of order of *k*.
x_{ijw}	The arc (i, j) traveled by vehicle *w*.
t_k	The time of vehicle arriving order's (k) pickup spot.

The mathematical model following:

$$\max \text{Profits} = \sum_{k \in K} price_k - \sum_{i \in V} \sum_{j \in V} \sum_{w \in W} c_{ij} x_{ijw} \quad (1)$$

$$\text{s.t.} \sum_{j \in V} \sum_{w \in W} x_{jk_p w} = 1 \quad \forall k \in K \quad (2)$$

$$\sum_{w \in W} x_{k_p k_d w} = 1 \quad \forall k \in K \quad (3)$$

$$\sum_{j \in V'} x_{0jw} = \sum_{j \in V'} x_{j0w} = 1 \quad \forall w \in W \quad (4)$$

$$\sum_{\{i,j\} \in S} x_{ijw} \le |S| - 1 \quad \forall S \in \Re, w \in W \quad (5)$$

$$ET_k < t_k < LT_k \quad \forall k \in K \quad (6)$$

$$x_{ijw} \in \{0,1\} \quad \forall \{i,j\} \in A, w \in W \quad (7)$$

The objective function (1) represents the gross profits of the carrier and is equal to all income from the completion of all current orders minus the total transportation costs. The first part of function (1) is number of orders multiplied by price and the second part is routing cost. Constraint (2) indicates that each order's pickup spot must be travelled once. Constraint (3) indicates that each order should be serviced once. Constraint (4) indicates that all vehicles must start from the depot initially and return to the depot finally. Constraint (5) guarantees that a subcircuit does not occur. Constraint (6) ensures that the service time of the orders obey time windows. Constraints (7) are known as decision variables.

3. Solution approach

The hybrid algorithm consists of a tabu search (TS) and operators provided by a genetic algorithm. Tabu search was introduced by Glover (1986) firstly. Tabu search was used to optimize the VRP in former works (Li et al., 2012; Cordeau and Maischberger, 2012). The optimal results were gotten by tabu search for simultaneous pickup and delivery problem (Avci and Topaloglu, 2016; Liu et al., 2013; Zhang et al., 2014). The GA consists of adaptive methods inspired by the natural evolution of biological organisms. An initial population of individuals (chromosomes) evolves through generations until satisfactory criteria of quality, a maximum number of iterations or time limits are reached. New individuals (children) are generated from individuals forming the current generation (parents) by means of genetic operators (crossover and mutation) (Cattaruzza et al., 2014). The efficiency of genetic algorithm to solve VRP has been proved by many examples (Lewczuk 2015; Boonkleaw et al., 2010; Izdebski et al., 2017). A hybrid algorithm which is composed by genetic algorithm and tabu search is used to find the optimal result of our model, because the model of our paper (VRPPSPD) is similar with the simultaneous pickup and delivery problem. In this paper, pseudo-code of hybrid tabu search is as following:

Algorithm 1 – Pseudo-code of hybrid TS

1: Initialize all of the variables and parameters. Set *k*=1, and go to the next step.
2: Initial solution *x* is produced randomly.
3: **While** (*k*<Maxstep) **do**
4 Candidate solution *Csolution* is generated by neighborhood operators to *x*.
5: *Csolution* is evaluated by an evaluation function.
6: The best-candidate solution is selected to assign *x*.
7: Update tabu list.
8: **End**
9: **Termination:** output best solution.

3.1. Neighborhood operators

In this section, three neighborhood operators were used to improve efficiency of searching. The features of genetic algorithm were inserted in tabu search. The crossover, mutation and local search process are implemented to improve quality of solution (Szczepański et al., 2014; Izdebski et al., 2017). All neighborhood solutions are considered as chromosomes in this paper.

By means of the crossover process, the generations share information among each other. The crossover operator is applied to the parent chromosome obtained from the selection operation. We used one-point crossover method which is randomly chosen position in chromosome and exchange gens of two individuals after that position. In this paper, the detail about crossover operation, please refer to Eroglu and Kilic (2017).

The mutation operator is used as a diversification strategy that usually prevents the convergence to a local optimum in genetic algorithm. In the hybrid algorithm, the chromosomes that will be mutated are randomly selected from the population according to a mutation rate. In the mutation process, the value of a randomly selected gene of the randomly selected chromosome is changed to a new random value. In

this research a single point mutation is adopted in the process (Bräysy and Gendreau, 2005).
Hybrid metaheuristics such as integrating a local search technique with a genetic algorithm and tabu search have recently received additional attention. There are many operators used to solve VRP, such as insert, swap, 2-opt, 2-opt* and the exchange operator (Bräysy and Gendreau, 2005). In this paper, VRPPSPD is a variant of vehicle routing problem. The exchange operator is used to improve chromosomes. In this paper, 2-opt* is considered as local search operator.

3.2. Fitness calculation

After a new generation of vehicle routes is created following the above steps, the optimal scheduling for each vehicle route needs to be found and thus the maximal profit can be calculated by each chromosome. In this paper, the fitness is calculated based on function (1) which is composed by revenue and cost. The costs of routing are calculated by chromosomes and the revenue is also counted by number of orders. In each loop, neighborhood solutions need to be produced by the biggest fitness. The biggest fitness can be saved in each loop because the maximum profits need to be acquired, which can help algorithm to accelerate convergence.

4. Case study

4.1. Dynamic case

This section presents the result of our computational study in which we test the performance of the model and algorithm mentioned above. The data of a cluster of SMEs, investigating from Changzhou city, are employed. The software platform is MATLABR2012b. The specifications of the computer are as follows: 1.9GH AMD A8-4500M CPU and 6GB RAM. In this paper, the dynamic case is calculated with fitting data. Fitting orders data is gotten by computer based on distribution of real data. Table 1 is part of the orders information. To eliminate the effect of randomness, every result is the average of 10 times of calculations. Since carriers work 7 hours per day (30 days per month), the simulation cycle time was set to 7*30*60 (min) to simulate a month works. The results are illustrated in Fig. 1.

Table 1. Part of the orders information

SMEs	Service time/min	*ET* /min	*LT* /min	Pickup spot/km	Delivery spot/km	Price/*yuan*	Number of orders
1	11	127	185	2.5，1.4	2.4，2.76	20	1
2	25	171	235	0.8，0.3	-0.407，2.5	30	1
3	14	202	267	0.62，1.8	2.5，1.4	25	2
4	6	296	359	0.62，1.8	2.5，1.4	25	3
5	12	320	385	0.668，0.3	0.8，0.3	15	1
6	18	492	746	0.8，0.3	0.668，0.3	15	4

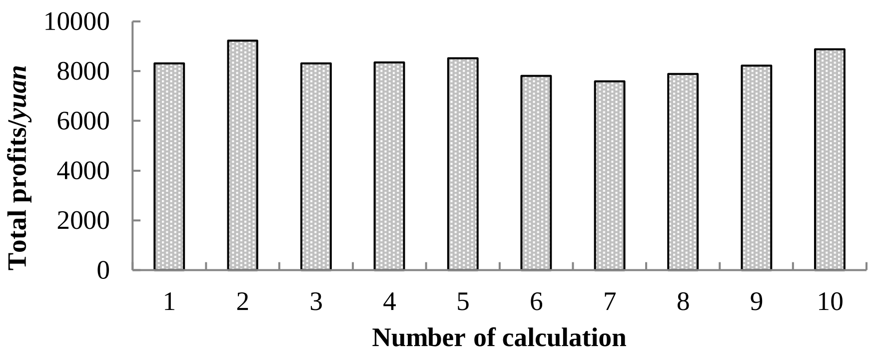

Fig. 1. Gross Profits

Figure 1 shows that the gross profits maintains at more than 8000 *yuan*. The average profits of ten times of calculation are 8310 *yuan*, and average number of orders is 437. The calculation results indicate that the model and algorithm is effective to solve VRPPSPD with profits and time windows because profits are improved by 5.6% based on investigation.

4.2. Sensitivity analysis

To better reflect the different factors that influence the profits of the VRPPSPD in a dynamic case, this section adjusts the service time and the order frequency to analyze what extent the parameter deviation can influence on the carrier's profits.

4.2.1. Sensitivity analysis

The service time (t) follows a normal distribution, with a mean of 10 min for every order. The mean of service time can be adjusted to be 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, and 30 min. The calculated results of the simulation are shown in Fig. 2.

Fig. 2 indicates that the decreasing trend of gross profits does not change when the service time increases. This finding reflects that there is no influence on the increasing trend of gross profits when the service time increases. Number of orders has the same decreasing trend with profits when the service time increases. However, gross profits don't notably decrease when the service time increases. To a certain extent, a shorter service time increases gross profits, but not significantly.

4.2.2. Rate of new orders adjustment

As fitted in Section 4.1, orders have a mean interval time of 50 min and a mean service time of 10 min. The mean time between orders (T) is adjusted to 40, 45, 50, 55, and 60 min. The calculation results are displayed in Fig. 3.

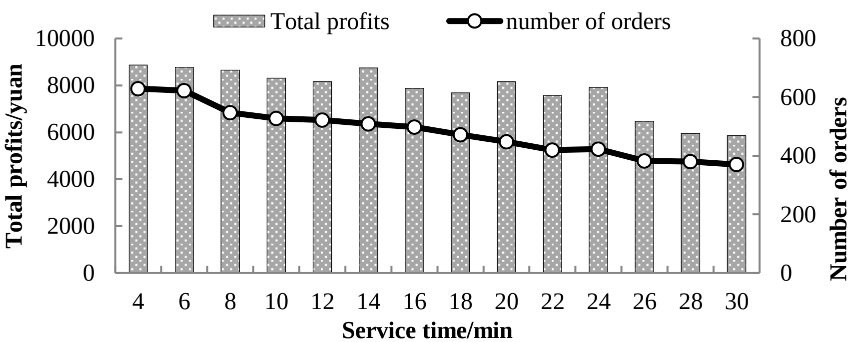

Fig. 2. Gross Profits and number of orders

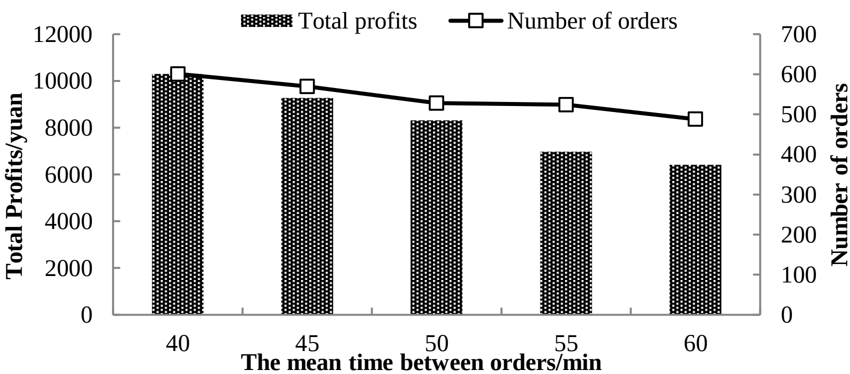

Fig. 3. Gross Profits and number of orders

Fig. 3 shows that profits notably increase when the vehicle accepts 110% of the number of orders. The profits have same downtrends with number of orders when order mean of interval time increase. The profits for T=40 increase notably more than the others, which shows that the order number that the carrier accepts creates a bottleneck that influences the profits.

4.2.3. Simultaneous variation of the service time and the order interval time

The number of orders and the order completion time notably influence gross profits. In this section, these two factors are analyzed simultaneously. The range of the service time is 4, 6, 8, 10, 12, 14, 16, 18, and 20 min; the range of the order interval time is 40, 45, 50, 55, and 60 min. Every case is calculated 5 times, and the results are shown in Fig. 4.

The calculation results notably increase when the order interval time and the service time are reduced, as shown in Figure 4. The increase in gross profits is not significant when only the service time is changed. Gross profits notably change when the order interval time is reduced, which shows that the main factor that influences gross profits is the number of orders accepted. The carrier should increase the number of orders within the range of its ability and use industrial engineering methods to reduce the service time. Yang (2004) studies multivehicle truckload pickup and delivery problems with real-time and sensitivity analysis. Their research focuses on varying the degrees of advanced information and varying the levels of traffic intensity, and they find that adjusting the earliest pickup time is the main factor that affects gross profits. This is similar to our finding in this paper regarding adjustments to the service time. However, adjusting the service time shows an obvious advantage in improving gross profits compared to Yang (2004).

5. Conclusion

In this paper, a new variation vehicle routing problem is presented for the cluster of SMEs, where some enterprises are pickup and delivery spot simultaneously but others not. VRPPSD extends the classical vehicle routing problem with pickup and delivery problem and has applications in practice. A mathematics model is used to formulate the problem and tabu search is adopted to solve it. Although the approximate optimal solution can be found, but the results we can accept.

The partly simultaneous pickup and delivery for cluster of SMEs is a new topic for future research. Thus the current work can serve as the first step for future multiple-depot cases. The second direction is to solve collaborative transportation about the partly simultaneous pickup and delivery for the cluster of SMEs. The exact algorithm will be used in the future to solve VRPPSD because it can get optimal solution.

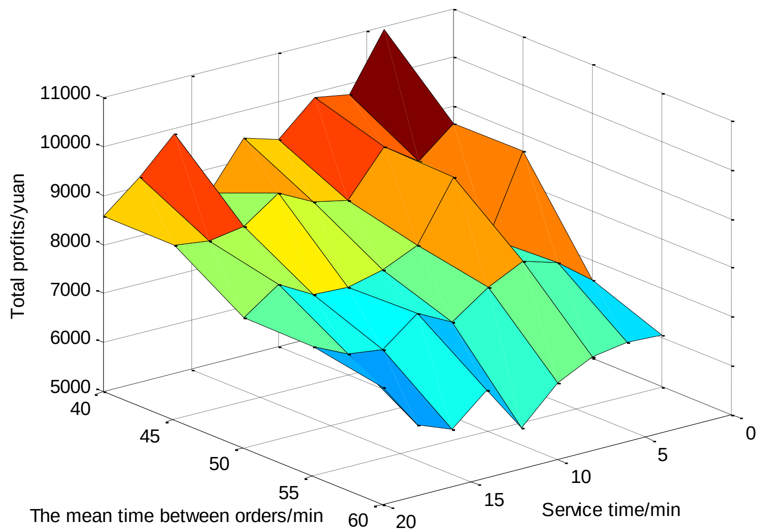

Fig. 4. Result of Sensitive Analysis

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