Research on Furniture Distribution and Installation Vehicle Scheduling Considering Multiple Service Modes

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Abstract. With the transformation of e-commerce into the furniture industry and the transformation of consumption patterns, the large-scale, non-standard and fragile characteristics of furniture products poses a huge challenge to product delivery. Furniture products often have installation properties, and professional installation services are required while completing the distribution service. In this paper, based on the actual operation scenarios of furniture product distribution and installation, considering the three service modes of distribution only, installation only ,distribution and installation separation, with the goal of minimizing the total cost, by constructing a vehicle scheduling model with soft time windows and considering multi-demand service order constraints, and designing a particle swarm-genetic algorithm, the simulation results show that the proposed vehicle scheduling model can effectively solve the high cost of furniture distribution and installation.

Keywords: Multiple demand, Service order, Vehicle scheduling problem, Hybrid genetic algorithm.

1. Introduction

In the end-of-sale distribution and installation operation of furniture logistics, due to the dispersion of users, complicated business processes, and diversified product categories, it is difficult to form a standardized operation, which makes the distribution and installation a target of consumer complaints. Simple furniture products consumers can often assemble by themselves, but most complex furniture requires professional installation masters. For furniture products that need to be installed, consumers often want to provide installation services as soon as they receive the goods. At present, the market adopts separate distribution and installation (distribution and installation separation) and distribution and installation of the same vehicle (distribution and installation simultaneously) services. However, the latter is costly and the distribution and installation cannot be effectively integrated, and it is often arranged separately. Therefore, this paper only considers the three service modes of distribution only, installation only and distribution and installation separation to formulate the vehicle scheduling plan.

2. Literature Review

Multi-demand vehicle scheduling problems can be divided into multiple requirements that can be serviced by the same vehicle and not by the same vehicle. For the former, relevant scholars have done a lot of research, such as the vehicle path problem considering the delivery demand [1, 2], the nursing staff scheduling problem in the family health care logistics [3]; the multi-service demand cannot be provided by the same vehicle. The vehicle scheduling problem can be divided into no-service order constraints and vehicle scheduling problems with service order constraints. For the problem of no service order constraint, it can be transformed into multiple independent single-demand vehicle scheduling problems, but less research on vehicle scheduling problems with service sequence. KC Kim [4] and Pang Haijun [5] studied the distribution and installation of complex products involved in the electronics industry, and established a mixed integer programming model with the smallest total travel time, when solving the problem, first calculate the route of the distribution vehicle, and then plan the path of installation vehicle on this basis. since the path of installation vehicle is based on the planning of the distribution vehicle, it cannot guarantee that the optimal solution is the overall optimal solution of the original problem, and it is easy to fall into the local optimal solution. In view of this, Li Zhenping [6] Further, the operation route of the distribution vehicle and the installed vehicle is simultaneously encoded, decoded, crossed, and mutated, and a joint optimization genetic algorithm

that directly searches for the overall optimal solution of the problem is designed. Compared with the two-stage genetic algorithm, the objective function value is reduced by 10%-25% on average. More importantly, this paper extends the classic single-demand vehicle routing problem to multiple requirements, and establishes multiple requirements with time window constraints. The mathematical model of the vehicle routing problem and the effective algorithm for solving the model are designed to provide a basis for decision-making. In view of the problem that the local search ability of genetic algorithm is not strong, Li Zhenping[7] divides the population into elite layer and common layer, and mixes the particle swarm algorithm to search the elite layer locally. The elite layer can use the excellent searched in the population. Individual information guides a further high-quality search process, while the common layer ensures population diversity. It can be seen from the simulation results that the results obtained by the hybrid genetic algorithm are better than those in the literature [6]. For this type of problem, Bae H[8] extended the problem from a single distribution center to a multi-distribution center, constructed a mixed integer programming model and developed a heuristic genetic algorithm to identify approximate optimal solutions. Mankowska D[9] started with a problem of interdependent problems in family health care, built a mixed integer programming model, and solved it with heuristic algorithms, further enriching the research scope of multi-demand vehicle routing problems.

At present, there are few studies on vehicle scheduling problems with multiple demand and demand priority constraints, and most of them focus on the distribution and installation of electronic products and home health care services, but for the moment, the service methods considered are relatively simple, There are still gaps in the actual situation, however, the research idea points out the direction for the vehicle scheduing of the furniture distribution and installation in this paper. It can further comprehensively analyze various service modes and construct a realistic dispatching vehicle scheduling model.

3. Construction and Solution of Furniture Distribution and Installation Vehicle Scheduling Model

3.1 Problem Description.

Furniture distribution and installation vehicle scheduling problem can be described as distributing vehicles and installing vehicles from the same distribution center $J = \{0\}$, providing a series of customers $C = \{1,2,\dots,n\}$ with independent requirements and return to the distribution center upon completion of the service. For the customers who only need delivery and distribution and installation separation, the distribution demand of each customer point q_i is known, the on-board capacity of the distribution vheicle is Q; the distribution service and installation service must be completed by a dedicated vehicle, among the customers who are separated from the distribution and installation,the distribution vehicle is required to arrive at the customer point earlier than the installation vehicle, and the installation vehicle is later than The time interval at which the distribution vheicle arrives cannot exceed the given service level SL. Compared with the traditional vehicle scheduling problem, the problems considered in this paper involve two types of vehicles and three service modes, and the three service modes affect each other,meanwhile ,the distribution and installation links are interlocked.

3.2 Model Hypothesis.

Considering the complexity of the actual furniture logistics end distribution and installation operation scenarios, in order to simplify the problem modeling and solving, this paper makes the following reasonable and necessary assumptions for specific problems.

(1) Both the distribution vheicle and the installation vehicle must start from the same distribution center and return to the distribution center after completing customer service.

(2) The coordinates and demand of the distribution center and customer points are known, and the distance between the two points is calculated by the Euclidean distance; the demand of each customer is less than the vehicle capacity of the distribution vheicle, and the demand cannot be divided.

(3) The driving speed of the distribution vheicle and the installed vehicle is a fixed value. The driving time of the vehicle is proportional to the distance, and special circumstances such as traffic congestion, traffic control, bad weather, and vehicle failure are not considered.

(4) The service time window and service mode of each customer point are known.

(5) The travel time of the vehicle on each route cannot exceed the maximum travel time of the vehicle, and the maximum travel time cannot exceed the time window of the distribution center.

(6) Delivery and installation services can be performed simultaneously.

3.3 Model Building.

Through the description of the problem in Sections 3.1 and the reasonable assumptions made in the actual situation in 3.2, this section first defines the symbols involved in the model and builds the model on this basis.

3.3.1 Symbol Definition.

C: Customer point collection

J: distribution center

C^0: Distribution center and customer point collection

V^D: Distribution vehicle collection

V^A: Installation vehicle collection

C^D: Need distribution service customer point collection

C^A: Need to install service customer point collection

C^{SD}: Only need to distribution customer point collections

C^{SA}: Only need to install customer point collections

C^{DJ}: Need distribution service customer point collection and distribution centers

C^{AJ}: Need to install service customer point collection and distribution centers

C^{prec}: Distribution and installation of separate customer point collections

v_1: Distribution vheicle speed

v_2: Installation vehicle speed

d_{ij}: The distance between the distribution center or customer point i to j

Q_{ij}: Time of distribution vheicle from i to j

R_{ij}: Time of installation vehicle from i to j

P_{di}: Time of the distribution vheicle d reaches point i

A_{ai}: Time of the installation vehicle a arrives at point i

S_{di}: Start service time of the distribution vheicle d reaches point i

Z_{ai}: Start time of the installation vehicle a arrives at point i

E_i^1: Waiting time for the distribution vheicle to arrive earlier than the time window

L_i^1: The penalty time for the distribution vheicle to arrive later than the time window

E_i^2: Waiting time for installing the vehicle before the time window arrives

L_i^2: Penalty time to install the vehicle later than the time window

t_1: Distribution service time at customer i

t_2: Installation service time at customer i

SL: Service Level

C_1: Fixed cost of the distribution vheicle d

C_2: Fixed cost of installing vehicle a

C_3: Variable cost of the distance traveled by the distribution vehicle

C_4: Variable cost of installing vehicle unit travel distance

C_5: Early arrival waiting time per unit time

C_6: Late penalty cost per unit time

T_1: Distribution center maximum service time

T_2: Maximum working time of the vehicle

q_i：The demand of customer i

Q：Maximum capacity of the distribution vheicle

M：Very large real number

3.3.2 Furniture Logistics Distribution Vheicle Scheduling Model.

Through the above analysis, the following mathematical model is constructed.

Min $Z =$

$$\sum_{d\in V^D} C_1 P_d + \sum_{a\in V^A} C_2 A_a + \sum_{i\in C^0}\sum_{j\in C^0}\sum_{d\in V^D} x_{ijd} C_3 + \sum_{i\in C^0}\sum_{j\in C^0}\sum_{a\in V^A} y_{ija} C_4 +$$

$$\sum_{i\in C^{SD}\cup C^{prec}}\sum_{j\in C^D}\sum_{d\in V^D} x_{ijd}(C_5 E_i^1 + C_6 L_i^1) + \sum_{i\in C^{SA}}\sum_{j\in C^A}\sum_{a\in V^A} y_{ija}(C_5 E_i^2 + C_6 L_i^2) \qquad (1)$$

$$\sum_{j\in C} x_{ijd} - \sum_{j\in C} x_{jid} = 0, i\in J, \forall d\in V^D \qquad (2)$$

$$\sum_{j\in C} y_{ija} - \sum_{j\in C} y_{jia} = 0, i\in J, \forall a\in V^A \qquad (3)$$

$$S_{di} + t_1 + Q_{ij} \le T_1 + M(1 - x_{ijd}), \forall i\in C, j\in J, d\in V^D \qquad (4)$$

$$Z_{ai} + t_2 + R_{ij} \le T_1 + M(1 - y_{ija}), \forall i\in C, j\in J, a\in V^A \qquad (5)$$

$$\sum_{i\in C^0}\sum_{j\in C^0} x_{ijd}Q_{ij} \le T_2, \forall d\in V^D \qquad (6)$$

$$\sum_{i\in C^0}\sum_{j\in C^0} y_{ija} R_{ij} \le T_2, \forall a\in V^A \qquad (7)$$

$$P_{di} = S_{di} = A_{ai} = Z_{ai} = 0, \forall d\in V^D, a\in V^A, i\in J \qquad (8)$$

$$E_i^1 = L_i^1 = E_i^2 = L_i^2 = 0, \forall d\in V^D, a\in V^A, i\in J \qquad (9)$$

$$\sum_{i\in C^0}\sum_{d\in V^D} x_{ijd} = 1, \forall j\in C \qquad (10)$$

$$\sum_{i\in C^0}\sum_{a\in V^A} y_{ija} = 1, \forall j\in C \qquad (11)$$

$$\sum_{j\in C^{DJ}} x_{ijd} = \sum_{j\in C^{DJ}} x_{jid}, \forall i\in C^{DJ}, d\in V^D \qquad (12)$$

$$\sum_{j\in C^{AJ}} y_{ija} = \sum_{j\in C^{AJ}} y_{jia}, \forall i\in C^{AJ}, a\in V^A \qquad (13)$$

$$\sum_{i\in C^D}\sum_{j\in C^{DJ}} x_{ijd}q_i \le Q, \forall d\in V^D \qquad (14)$$

$$S_{di} + t_1 + Q_{ij} \le P_{dj} + M(1 - x_{ijd}), \forall i\in C^{DJ}, j\in C^{DJ}, d\in V^D \qquad (15)$$

$$Z_{ai} + t_2 + R_{ij} \le A_{aj} + M(1 - y_{ija}), \forall i\in C^{AJ}, j\in C^{AJ}, a\in V^A \qquad (16)$$

$$P_{di} \le A_{ai}, \forall d\in V^D, a\in V^A, i\in C^{prec} \qquad (17)$$

$$P_{di} + SL \ge A_{ai}, \forall i\in C^{prec}, d\in V^D, a\in V^A \qquad (18)$$

$$e_i - M(1 - x_{ijd}) \le P_{di} + E_i^1 - L_i^1 \le L_i + M(1 - x_{ijd}), \forall i\in C^D, d\in V^D$$

$$e_i - M(1 - y_{ija}) \le A_{ai} + E_i^2 - L_i^2 \le L_i + M(1 - y_{ija}), \forall i\in C^{SA}\cup C^{sim}, a\in V^A$$

$$S_{di} = max\{e_i, P_{di}\}, \forall i\in C^{SD}, d\in V^D \qquad (21)$$

$$Z_{ai} = max\{e_i, A_{ai}\}, \forall i\in C^{SA}, a\in V^A \qquad (22)$$

$$S_{di} = Z_{ai} = max\{e_i, P_{di}, A_{ai}\}, \forall i\in C^{sim}, a\in V^A, d\in V^D \qquad (23)$$

$$E_i^1 = max\{e_i - P_{di}, 0\}, \forall i\in C^D, d\in V^D \qquad (24)$$

$$L_i^1 = max\{P_{di} - l_i, 0\}, \forall i\in C^D, d\in V^D \qquad (25)$$

$$E_i^2 = max\{e_i - A_{ai}, 0\}, \forall i\in C^{SA}\cup C^{sim}, a\in V^A \qquad (26)$$

$$L_i^2 = max\{A_{ai} - l_i, 0\}, \forall i\in C^{SA}\cup C^{sim}, a\in V^A \qquad (27)$$

$$x_{ijd} = \{0,1\}, i,j\in C^{DJ}, d\in V^D \qquad (28)$$

$$y_{ija} = \{0,1\}, i,j\in C^{AJ}, a\in V^A \qquad (29)$$

$$P_d = \{0,1\}, d\in V^D \qquad (30)$$

$$A_a = \{0,1\}, a\in V^A \qquad (31)$$

Formula (1) is the objective function, which means minimizing the sum of the costs; the constraints (2) and (3) respectively indicate that the distribution and installation vehicles depart from the distribution center and return to it; constraints (4),(5) means that the distribution and installation vehicles need to return before the distribution center stops service; the constraints (6) and (7) indicate that the distribution vheicle and the installation vehicle work time must not exceed the maximum working time allowed by the vehicle; constraints (8), (9) indicates the constraints on the relevant time of the distribution center; the constraints (10) and (11) respectively indicate that the customer who needs to deliver the service or install the service can only be served once by the corresponding professional vehicle; the constraints (12), (13) respectively indicates the balance of the flow of the

distribution vhe icle and the installed vehicle; the constraint condition (14) Indicates the constraint on the vehicle's capacity of the distribution vheicle, that is, the sum of all customer demand on the route cannot exceed the maximum capacity of the vehicle.; constraints (15) (16) respectively indicate the sequential time-order relationship constraint of the distribution vheicle and installation vehicel; the constraint condition (17) indicates that the distribution vheicle arrives earlier than the installation vehicle in the distribution and installation separation service mode; the constraint condition (18) indicates service level constraints; the constraints (19), (20) respectively represent the time window constraints of the customer point for the distribution vheicle and the installation vehicle; the constraint condition (21), (22), (23) respectively indicate the relationship between the arrival time and the start service time of the distribution vheicle or the installation vehicle only for the delivery customer, only the installation customer and the distribution and installation separation customer; constraints (24), (25), (26) and (27) respectively indicate the early arrival waiting time and the late penalty time of the distribution vheicle and the installation vehicle; the constraint conditions (28), (29), (30), and (31) are value constraint constraints.

3.4 Model Solving.

The vehicle scheduling problem has been proved to be NP-hard. In solving this problem, the exact algorithm is often not efficient and practical, and the heuristic algorithm is widely used in solving such problems. This paper refers to the two-stage genetic algorithm proposed in [5] and [6], the first stage to solve the route of the distribution vheicle and the time to reach the customer point, the second stage solves the vehicle routing problem with hard time windows based on the output of the first stage. On this basis, in order to avoid the defect that genetic algorithm is easy to fall into the local optimal solution, the particle swarm optimization algorithm is introduced and solved by MATLAB.

4. Case Verification and Result Analysis

J Company is a professional furniture logistics service provider. This article selects the order data of J Company in Beijing area for instance verification, and eliminates the order of delivery and installation simultaneously. There were 72 orders on the day, of which only 22 were delivered, only 13 were installed, and 37 were delivered and installed separated. The basic data information is shown in Table 1. Requirement Type 1.2.3 indicates delivery only, install only and distribution and installation separation.

Table 1 Customer and distribution center basic data

Numbering	longitude	latitude	Type of demand	Demand	Time Window
0	116.348583	39.697340			9:00-22:00
1	116.218810	39.761456	3	0.75	17:00-21:00
2	116.116387	39.962089	2	3.35	9:00-13:00
……	……	……	……	……	……
72	116.259319	39.886487	1	0.77	17:00-21:00

According to the actual situation, the model related parameters are shown in Table 2.

Table 2 Model related parameter settings

parameter	Numerical value	parameter	Numerical value	parameter	Numerical value
v_1	40	C_4	0.455	Q	15
v_2	50	t_1	20	P_{d0}	9
C_1	549.31	t_2	60	A_{a0}	9
C_2	314.61	SL	120	C_5	0.5
C_3	0.91	T_2	720	C_6	1

This paper uses particle swarm-genetic algorithm and solves with MATLAB, the population number is set to 200, the number of iterations is set to 2000, the crossover probability and mutation probability are set to 0.8 and 0.1 respectively, and the learning factor in the particle swarm algorithm is set to 1.8 and 1.7. The inertia factor maximum value is set to 0.93, the inertia factor minimum value is set to 0.8, the variable interval is [-1, 1], the speed interval is [-0.7, 0.7], and the program is run

using Matlab 2018a. The result indicates that seven distribution vheicles and nine installation vehicles are required. The total cost is 7708.8. The distribution vehicle line is shown in Table 3, the installation vehicle driving line is shown in Table 4, the optimized iteration curve is shown in Fig. 1.

Table 3 Optimal delivery path of distribution vehicles

Distribution vehicle	Driving path	Load capacity
1	0-47-16-5-26-50-63-64-1-0	7.91
2	0-19-46-53-9-8-24-48-71-39-0	12.79
3	0-25-38-65-13-41-15-61-3-6-59-72-66-0	13.68
4	0-43-32-34-54-52-45-42-35-7-11-22-44-4-29-10-0	14.79
5	0-69-20-68-0	4.55
6	0-67-62-70-57-36-55-0	9.33
7	0-30-33-28-31-12-58-0	7.58

Table 4 Optimal vehicle delivery path

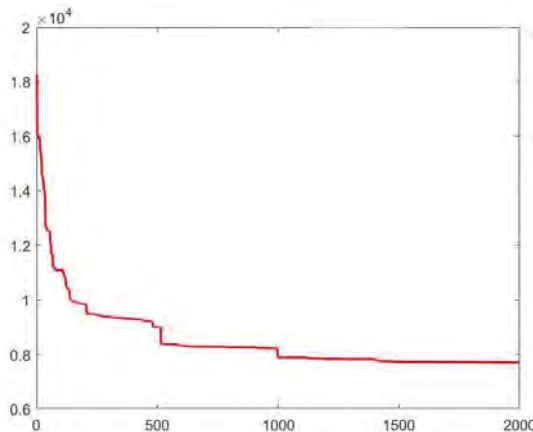| Installation vehicle	Driving path	Installation vehicle	Driving path
1	0-57-12-46-65-0	6	0-21-16-41-48-40-4-0
2	0-55-17-53-61-0	7	0-62- 2-36-25-27-37-39-0
3	0-58-51-11- 1- 0	8	0-33-56-49-38-9-0
4	0-69-20-28-60-42-35-0	9	0-34-31-14-52-13-64-0
5	0-70-54-18-45-5-6-23-59-0		

Fig. 1 Optimized iteration curve

The comparison table between the optimized scheduling results and the actual operating conditions is shown in Table 5.

Table 5 Comparison of optimizat

category	Actual operation	Optimize scheduling results
cost	8713.5	7708.8
Number of distribution vheicles	8	7
Number of installed vehicles	10	9
Full load rate	58.9%	67.3%

Through calculation, the optimized delivery cost is 7708.8, while the actual operating cost is 8713.5, and the cost is reduced by 11.53%, mainly reflected in the number of distribution vehicles and installed vehicles. The number of distribution vheicles is reduced from 8 to 7. The number of vehicles installed has been reduced from 10 to 9 vehicles. At the same time, the reduced use of distribution vehicles has increased the vehicle full load rate from 58.9% to 67.3%. This shows that through the reasonable scheduling of distribution vheicles and installation vehicles.,it can effectively reduce the cost and increase the vehicle full load rate, and this gap will become more apparent as the order size increases.

5. Summary

This paper addresses the complex business scenario of end-of-sale distribution and installation of furniture logistics. Considering only three interplaying service modes: distribution only, installation only, and distribution and installation separation, a vehicle scheduling model with time window and access sequence constraints is constructed, and the particle swarm optimization-genetic algorithm is designed to solve the model. The example verification results show the practicability of the model. At the same time, with the expansion of the order size, the model can effectively reduce the cost and improve the coordination of the distribution and the installation vehicle by changing the service level. At present, related companies are also actively trying to distribute and install simultaneous service methods, that is, the distribution and installation are still provided by different vehicles, but through the scheduling of the distribution and the installation vehicles, both of them provide services to the customers at the same time.,future research can add this service approach based on this paper.

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