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Vehicle scheduling based on plant growth simulation algorithm and distribution staff behavior

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ABSTRACT

Considering the distribution staff's satisfaction and fuzzy characteristics of customers' time window, the paper makes fuzzy description and measurement of staff satisfaction from such three aspects as salary and welfare, working strength and harmonious cooperation. Taking the minimum total logistics distribution cost and maximum distribution staff satisfaction as the objective functions, the study constructs the logistics distribution vehicle scheduling model considering the staff satisfaction and fuzzy time window. The plant growth algorithm is designed to solve the logistics distribution vehicle scheduling model. The simulation results show that the proposed the model succeeds in improving the customer satisfaction and the distribution efficiency, and that the optimization algorithm is feasible and effective.

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1. Introduction

In logistics distribution, it is of critical importance for logistics distribution enterprises to provide timely and satisfactory service to customers. The service quality hinges on the psychology and behavior of distribution personnel who are in direct contact with customers. Such personnel normally work in high-intensity environments for long hours and often handle multiple tasks at the same time. This is particularly true for logistics distribution staff. Besides delivering goods to the designated places, they have to guarantee that the goods are intact and fresh. Whether they can provide timely and satisfactory distribution service to customers largely depends on their satisfaction with job. In light of this, designers of logistics distribution vehicle scheduling plans must take the job satisfaction of distribution staff into account.

At present, scholars at home and abroad often put emphasis on quantitative factors like cost and time during the modelling and structural research of vehicle scheduling problem, aiming to minimize the distribution cost of the distribution center under certain constraints (volume, service time or distance), such as shortest route [1, 2, 3], minimum distribution cost [4, 5] and minimum number of vehicles [6]. Erdogan S. (2012) et al. proposed the concept of green vehicle scheduling [7]. Probing into a number of vehicle scheduling problems, Victor (2013) and Tas (2014) put forward several algorithms to solve the corresponding problems [8,9]. Li Juan and Yu Guoyin (2015) established the vehicle scheduling model with the goal of achieving the optimal comprehensive cost, which consists of fixed cost of vehicles, fuel cost and driver pay [10]. Sun Qiongling (2010) and Zhao Rui (2015) introduced customer satisfaction index into logistics distribution vehicle scheduling [11, 12]. Targeted at vehicle failure problem in logistics distribution, Cao Qingkui and Shao Songjuan (2016) constructed the emergency vehicle scheduling model in consideration of the distribution subject awareness [13]. Trancossi M (2016) et al. designed an innovative off-road hybrid vehicle [14].

The research on job satisfaction started early and yielded fruitful results in foreign countries. For instance, Locke (1970) classified the influencing factors of job satisfaction [15] nearly half a century ago. In recent years, foreign scholars have conducted in-depth studies on job satisfaction. Brian N. Rutherford (2014) et al. examined gender influence on job satisfaction and developed customized measures to promote the job satisfaction of the ever-increasing proportion of female employees [16]. Jarrod M. Haar (2014) et al. studied how employees in seven different cultural regions strike a balance between work and life, such as Malaysia, China and New Zealand, to name but a few [17]. Yam B. (2014) et al. suggested that information technology and communication skill are two driving factors of job satisfaction [18]. Scholars also explored the job satisfaction in different professions, like teachers and agents [19, 20]. As above, the research on job satisfaction has become more and more detailed. With the aid of new technologies and new theories, an increasing number of scholars have pursued how the interaction of various factors and different professions affect job satisfaction.

With the rapid development of logistics industry in recent years, the standards on logistics service have become more stringent. In distribution activities, the psychology and behavior of distribution staff exert a great impact on the quality of distribution service, which in turn determines the enterprise reputation. Against this backdrop, it is better aligned with the actual situation to develop an optimization model for logistics distribution vehicle scheduling in the following steps: combine the research on the basic theory and behavioral pattern of logistics distribution, establish the optimization model for logistics distribution vehicle scheduling based on the job satisfaction of distribution staff, conduct optimization processing based on multiple objective functions in the model, merge the functions into a single objective function by linear weighting, and apply plant growth simulation algorithm to the solution of the problem. Following these steps, this paper presents a logistics distribution vehicle scheduling model based on distribution staff satisfaction in consideration of the actual behavior characteristics of distribution staff, and in light of the reasonable and valid distribution mode. The proposed model facilities logistics enterprises to improve their capability and performance of logistics distribution in an ever-increasingly competitive market.

2. Mathematical model for vehicle scheduling

2.1 Problem description

From the perspective of distribution staff satisfaction, this paper summarizes the objectives of vehicle scheduling problem based on staff satisfaction, aiming to achieve the following traditional objectives:

- Minimum vehicle transportation cost;
- Maximum staff satisfaction;
- Lowest satisfaction value of customer satisfaction.

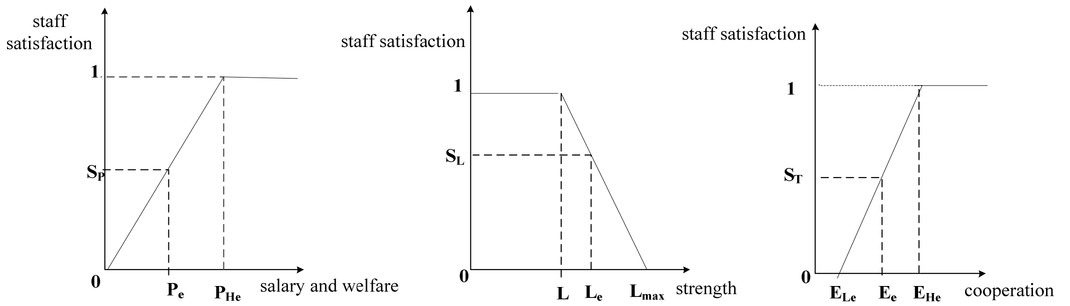
In this paper, the minimum requirement of customer satisfaction is set as θ.

Fuzzy function of staff satisfaction

We set $a_{e1}, a_{e2}, \cdots$as the states of satisfaction of staff member e in the enterprise described in n indexes, and the satisfaction $Y_e$of staff member e in the enterprise is:

$$Y_e = \sum_{l=1}^{n} \lambda_{el} f(a_{el}) \tag{1}$$

where $f(a)$is the satisfaction function of staff and λ_{el} is the weight coefficient [21]. If $a \geq 0$, then $f(a) \geq 0$; if $a < 0$, then $f(a) < 0$;$0 < \lambda_{el} < 1$ and $\sum_{l=1}^{n} \lambda_{el} = 1$. The distribution staff satisfaction is valued in the range between 0 and 1: 0 represents that the staff are completely dissatisfied and 1 represents that staffs are completely satisfied.



(a) Fuzzy description of distribution staff satisfaction of welfare and salary

(b) Fuzzy description of distribution staff satisfaction of work strength

(c) Fuzzy description of distribution staff satisfaction of cooperation

Fig. 1 Fuzzy description of distribution staff satisfaction

It can be seen from relevant references on logistics enterprise staff satisfaction that factors influencing staff satisfaction, namely salary and welfare, working strength and harmonious cooperation, are what the staff concern the most and the key influencing factors of enterprise distribution staff satisfaction [22-27]. Hence, we conduct fuzzy description of staff satisfaction with these 3 indexes (Fig. 1).

Fuzzy description of logistics distribution staff satisfaction

Definition: logistics distribution staff satisfaction is valued in the range between 0 and 1. 0 represents that the staff are completely dissatisfied and 1 represents that staffs are completely satisfied.

Fig. 1 shows the fuzzy description of staff satisfaction with salary and welfare, working strength and harmonious cooperation. Fig. 1(a) shows the fuzzy description of distribution staff salary and welfare satisfaction. The fuzzy membership function of logistics distribution staff satisfaction described by the salary and welfare P_e can be expressed as:

$$S_P(P_e) = \begin{cases} P_e/P_{He}, \ P_e \in (0, P_{He}) \\ 1, \ P_e \in [P_{He}, +\infty] \end{cases} \tag{2}$$

Fig. 1(b) shows the fuzzy description of distribution staff working strength satisfaction. The fuzzy membership function of logistics distribution staff satisfaction described by the working strength L_e can be expressed as:

$$\mathrm{S}_L(L_e) = \begin{cases} 1, \quad L_e \in [0, L] \\ (L_{max} - L_e)/(L_{max} - L), L_e \in (L, L_{max}) \\ 0, \quad L_e \in [L_{max}, +\infty] \end{cases} \tag{3}$$

Fig. 1(c) shows the fuzzy description of distribution staff harmonious cooperation satisfaction. The fuzzy membership function of logistics distribution staff satisfaction described by the harmonious cooperation E_e can be expressed as:

$$\mathrm{S}_E(E_e) = \begin{cases} 1, \quad E_e \in [0, E_{Le}] \\ (E_e - E_{Le})/(E_{He} - E_{Le}), E_e \in (E_{Le}, E_{He}) \\ 0, \quad E_e \in [E_{He}, +\infty] \end{cases} \tag{4}$$

Determination of element weight in staff satisfaction fuzzy description

The staff satisfaction function Y_e is fuzzily described by salary and welfare P, working strength L and harmonious cooperation E, which is:

$$Y_e = \sum_{e=1}^{N} \sum_{l=1}^{n} \lambda_{el} f(a_{el}) = \sum_{e=1}^{N} \lambda_p \cdot \mathrm{S}_P(P_e) + \sum_{e=1}^{N} \lambda_L \cdot \mathrm{S}_L(L_e) + \sum_{e=1}^{N} \lambda_E \cdot \mathrm{S}_E(E_e) \tag{5}$$

In staff satisfaction function Y_e, λ describes the different degrees of emphasis on each index among the distribution staff. In other words, λ balances the three elements required for the fuzzy description of staff satisfaction.

As mentioned above, the optimization scheduling model based on distribution staff satisfaction is required to achieve the maximum distribution staff satisfaction.

$$\max Y_e = \max \sum_{e=1}^{N}\sum_{l=1}^{n}\lambda_{el} f(a_{el}) = \max\left[\sum_{e=1}^{N}\lambda_p \cdot \mathrm{S}_P(P_e) + \sum_{e=1}^{N}\lambda_L \cdot \mathrm{S}_L(L_e) + \sum_{e=1}^{N}\lambda_E \cdot \mathrm{S}_E(E_e)\right] \tag{6}$$

Fuzzy description of customer satisfaction

First, distribution punctuality is adopted to fuzzily describe customer satisfaction. The time period $[Tz_i, Tw_i]$ represents the service time period accepted by customers; the time period $[Tz_i, Tw_i]$ represents the service time period that satisfies customers the most.

Second, $U_T(T_i)$ is used to express the fuzzy satisfaction of customers and the fuzzy membership function of logistics distribution satisfaction of customer i as described by the distribution punctuality T_i. The parameter can be expressed as:

$$U_T(T_i) = \begin{cases} 0 & 0 \le T_i \le Tz_i \\ (T_i - Tz_i)/(TZ_i - Tz_i) & Tz_i < T_i < TZ_i \\ 1 & TZ_i \le T_i \le TW_i \\ (TW_i - T_i)/(Tw_i - TW_i) & TW_i \le T_i \le Tw_i \\ 0 & T_i > Tw_i \end{cases} \tag{7}$$

In this research, logistics distribution must firstly fulfil the goal of the minimum requirement of customer satisfaction. In light of the fuzzy satisfaction of customers, the goal is expressed as $min\ U_T(T_i) = \theta$.

2.2 Parameter variable and correlation analysis

Parameter variable

We use $i = 0$ to represent the distribution center and $i = 1,2,\cdots,m$ to represent the m customers. The relevant parameters and variables are defined as follows. m: the m customers of distribution, denoted as $1,2,3,\cdots,i,\cdots,j,\cdots,m$; N : the N staff members, denoted as $1,2,3,\cdots,e,\cdots,N$; n: the n staff satisfaction indexes, denoted as $1,2,3,\cdots,l,\cdots,n$; K: the K distribution vehicles, denoted as $1,2,\cdots,k$; q_i: the distribution quantity demanded by customer i; v_i: the measurement of distribution goods of customer i; Q_k: the maximum loading capacity of the k_{th} distribution vehicle; V_k: the maximum loading volume of the k_{th}distribution vehicle; FC_k: the fixed cost of the k_{th} distribution vehicle, i.e. the marginal cost incurred by the addition of a new vehicle; DC_k: the unit distance cost of the k_{th}distribution vehicle;t_i: the time when the distribution vehicle reaches customer i; t_{ij}: the transportation time, i.e. period of time for the distribution vehicle to move from customer i to customer j; t_i': the service (unloading) time of the distribution vehicle at customer i, hereinafter referred to as the service (unloading) time; v: the average running speed of the distribution vehicle; d_{ij}: the distance between customer i and er j; L: the driving distance reaching the compensation point; L_{max}: the maximum running distance of the distribution vehicle in a single distribution activity; δ: the compensation cost coefficient of distribution vehicle beyond the additional compensation point;k_1: the basic salary of distribution staff per unit time during normal working hours; k_2: the pay per unit time during overtime; t_0: the normal working hours of staff members; t: the actual working time of distribution staff members, including transportation time t_{ij} and service (unloading) time t_i'; t_s: the time for the distribution vehicle to depart from the distribution center; t_b: the time for the distribution vehicle to return to the distribution center.

Establishment of distribution optimization model

Objective functions:

$$\min C=\sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{K}DC_K\cdot d_{ij}\cdot x_{ijk}+FC_k\sum_{k=1}^{K}r_{ik}+P(t)+\delta T(d_{ij}) \tag{8}$$

$$\max Y_e=\max\sum_{e=1}^{N}\sum_{l=1}^{n}\lambda_{el}f(a_{el})=\max[\sum_{e=1}^{N}\lambda_p\cdot \mathrm{S}_P(P_e)+\sum_{e=1}^{N}\lambda_L\cdot \mathrm{S}_L(L_e)+\sum_{e=1}^{N}\lambda_E\cdot\xi] \tag{9}$$

$$\min U_T(T_i)=\theta \tag{10}$$

Constraint conditions:

$$\sum_{i=1}^{m}r_{ik}\cdot q_i\le Q_m \tag{11}$$

$$\sum_{i=1}^{m}r_{ik}\cdot v_i\le V_m \tag{12}$$

$$\sum_{i=1}^{m}\sum_{k=1}^{K}x_{ijk}=1 \tag{13}$$

$$\sum_{j=1}^{m}x_{0jk}=\sum_{i=1}^{m}x_{i0k}=1 \tag{14}$$

$$t_{ij}=d_{ij}/v \tag{15}$$

$$t_j=t_i+t_{ij}+t_i' \tag{16}$$

$$t_s=0 \tag{17}$$

$$t_b=0 \tag{18}$$

$$t=t_{ij}+t_i'=\sum_{i=0}^{m}\sum_{j=0}^{m}d_{ij}\cdot\frac{x_{ijk}}{v}+\sum_{i=1}^{m}r_{ik}\cdot t_i'\le t_{\max} \tag{19}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{m}d_{ij}\cdot x_{ijk}\le L_{\max} \tag{20}$$

$$x_{ijk}=0\ or\ 1,\ \ i,j=1,2,3,\cdots,m;\ \ k=1,2,3,\cdots,K \tag{21}$$

$$r_{ik}=0\ or\ 1,\ \ i=1,2,3,\cdots,m;\ \ k=1,2,3,\cdots,K \tag{22}$$

Eq. 8 is the minimum total logistics distribution cost, Eq. 9 is the maximum distribution staff satisfaction, and Eq. 10 is the minimum requirement of customer satisfaction of logistics distribution service. Constraint conditions in Eqs. 11 and 12 describe the capacity limitation of distribution vehicle. Specifically, Eq. 11 means the goods should not exceed the maximum loading weight of the vehicle and Eq. 12 means each vehicle is able to hold the goods in the distribution activities. Constraint conditions in Eqs. 13 and 14 depict the running limitations of the distribution vehicle. Specifically, Eq. 13 means each customer point is served only once by one distribution staff member and one distribution vehicle, and Eq. 14 means each staff member and vehicle leaves from the distribution center, and returns to the distribution center after completing the distribution. Constraint conditions in Eqs. 15 to 18 present the time limitations of distribution vehicle. Specifically, Eq. 15 describes the transportation time, i.e. the time for the vehicle to move from one customer to the next customer; Eq. 16 illustrates the arrival time at the next customer, which equals to the sum of the arrival time and the service (unloading) time at the current customer, and the transportation time; Eqs. 17 and 18 represent the time for the vehicle to depart from or return to the distribution center, respectively; both of the two parameters are set as 0. Constraint conditions in Eqs. 19 and 20 show the working limitations of the distribution staff. Specifically, Eq. 19 specifies that the working time of the distribution staff should not exceed the maximum working time during each distribution; Eq. 20 stipulates that the running distance of the distribution vehicle should not exceed the maximum running distance during each distribution. Last but not the least, constraint conditions in Eqs. 21 and 22 determine the value of decision variables.

Analysis of objective functions

In distribution activities, the total cost is composed of distribution cost, salary of distribution staff and compensation cost. The distribution cost is further divided into the fixed cost of logistics distribution vehicle and running cost, which are expressed as:
$C_1 = FC_k \sum_{k=1}^{K} r_{ik}$, $C_2 \sum_{i=1}^{m} \sum_{j=1}^{m} \sum_{k=1}^{K} DC_k \cdot d_{ij} \cdot x_{ijk}$.

It is assumed that the goods in the distribution are common goods of the same quality and the vehicles are moving at a constant speed. Consisting of basic salary and overtime salary, the salary of distribution staff is expressed in piecewise function of working time:

$$C_3 = P(t) = \begin{cases} k_1 t, & t \leq t_0 \\ k_1 t_0 + k_2 (t - t_0), & t > t_0 \end{cases} \tag{23}$$

Compensation cost: Whereas the working strength of distribution staff increases when the driving distance in a single distribution is excessively long, it is necessary to give distribution staff some compensation. In this research, the working strength of distribution staff is quantified based on the running distance of the distribution vehicle in one distribution activity. It is expressed as below.

$$T(d_{ij}) = \max[\sum_{i=1}^{m} \sum_{j=1}^{m} (d_{ij} \cdot x_{ijk} - L), 0] \tag{24}$$

The compensation cost function can be expressed as follow:

$$C_4 = \delta \sum_{k=1}^{K} T(d_{ij}) = \delta \sum_{k=1}^{K} \max[\sum_{i=1}^{m} \sum_{j=1}^{m} (d_{ij} \cdot x_{ijk} - L), 0] \tag{25}$$

Since the distribution staff satisfaction should be determined through quantification of salary and welfare, working strength and harmonious cooperation, the distribution staff satisfaction function can be written as follows if the harmonious cooperation is regarded as a constant:

$$\begin{aligned} \max Y_e &= \max \sum_{e=1}^{N} \sum_{l=1}^{n} \lambda_{el} f(a_{el}) \\ &= \max \left[\sum_{e=1}^{N} \lambda_p \cdot \mathrm{S}_P(P_e) + \sum_{e=1}^{N} \lambda_L \cdot \mathrm{S}_L(L_e) + \sum_{e=1}^{N} \lambda_E \cdot \mathrm{S}_E(E_e) \right] \\ &= \max[\sum_{e=1}^{N} \lambda_p \cdot \mathrm{S}_P(P_e) + \sum_{e=1}^{N} \lambda_L \cdot \mathrm{S}_L(L_e) + \sum_{e=1}^{N} \lambda_E \cdot \xi] \end{aligned} \tag{26}$$

3. Configuration of vehicle scheduling by plant growth simulation algorithm

3.1 Optimized scheduling model based on plant growth simulation algorithm

Inspired by the growth of plants in nature, the plant growth simulation algorithm (PGSA) is a type of optimization algorithm used to simulate the plant growth characteristics.

Taking a certain plant as the object, the length of the main stem is denoted as M, the length of the branch is denoted as m, the number of growing points on the main stem is denoted as K, which can be expressed as $S_M = (S_{M1}, S_{M2}, \cdots, S_{Mk})$, the auxin concentration of growing points is denoted as $P_M = (P_{M1}, SP_{M2}, \cdots, P_{Mk})$, the number of growing points on the branch is denoted as q, which can be expressed as $S_m = (S_{m1}, S_{m2}, \cdots, S_{mq})$, the auxin concentration at growing points is denoted as $P_m = (P_{m1}, SP_{m2}, \cdots, P_{mq})$. The auxin concentration at each growing point on the main stem and branch of this plant can be calculated according to the following formulas:

$$P_{Mi} = \frac{f(x_0) - f(S_{mi})}{\sum_{i=1}^{K}\big(f(x_0) - f(S_{mi})\big) + \sum_{i=1}^{q}(f(x_0) - f(S_{mi}))} \tag{27}$$

$$P_{Mj} = \frac{f(x_0) - f(S_{ml})}{\sum_{j=1}^{K}\big(f(x_0) - f(S_{mj})\big) + \sum_{j=1}^{q}(f(x_0) - f(S_{mj}))} \tag{28}$$

$$\sum_{i=1}^{K}\sum_{j=1}^{q}\left(P_{Mi} + P_{Mj}\right) = 1 \tag{29}$$

3.2 Design and implementation of algorithm flow

The X is used to represent the bounded closure on the R^n and the $f(x)$ is used to represent the objective function. Thus, the flow and implementation of the PGSA are shown in Fig. 2.

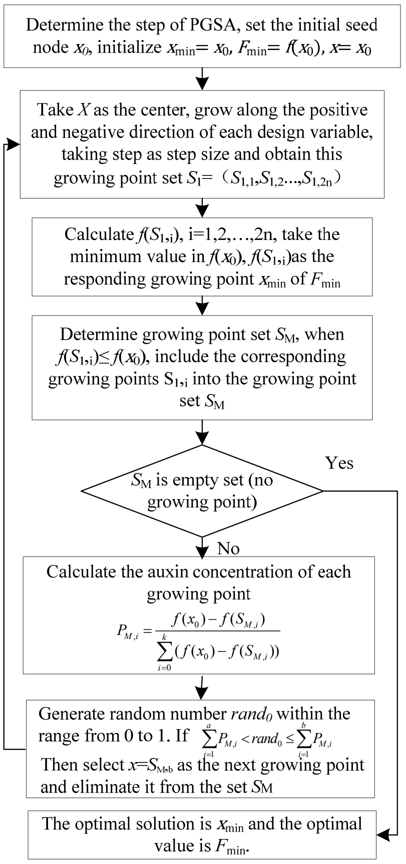


Fig. 2 The flow and implementation of the PGSA

4. Simulation analysis based on the PGSA

4.1 Data collection

In light of the lack of standard testing dataset for the research on vehicle scheduling problem, this paper designs a concrete algorithm instance. The objective of initial scheduling plan is to minimize logistics distribution cost and maximize customer satisfaction. The demand information parameters and time window constrains for 22 customer points are selected randomly by a computer. Table 1 and Table 2 list the coordinates of the customer points and the demand information.

Table 1 Customer point coordinates and demand information

Number	Customer location		Quantity /piece	Service (unloading) t_i'/min	Time window
	X coordinate	Y coordinate			
0	26	33	—	—	—
1	32	19	21	25	[7:00-8:00]
2	18	35	23	30	[9:00-11:45]
3	34	54	30	40	[7:00-9:00]
4	42	51	19	20	[8:00-10:45]
5	24	28	13	16	[7:00-11:45]
6	17	26	17	20	[7:00-8:45]
7	37	11	21	26	[13:00-18:00]
8	54	20	13	18	[14:00-16:45]
9	30	27	11	14	[12:00-18:00]
10	48	35	29	38	[7:00-8:45]
11	51	48	19	38	[14:00-16:45]
12	25	19	9	10	[9:00-11:45]
13	26	26	25	35	[7:00-8:45]
14	11	24	15	20	[7:00-8:45]
15	36	23	11	16	[15:00-17:45]
16	30	36	13	15	[13:00-17:00]
17	54	18	23	30	[17:00-18:00]
18	48	40	21	24	[14:00-17:45]
19	18	54	12	18	[8:00-18:00]
20	42	29	15	22	[9:00-18:00]
21	24	41	21	25	[7:00-15:45]
22	53	42	24	30	[13:00-18:00]

Table 2 Distance between each customer point and the distribution center

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
0	0	18	30	15	29	9	16	28	35	8	27	32	20	8	18	15	8	35	25	28	19	10	30
1	18	0	25	40	40	18	19	12	30	14	29	40	9	13	25	8	20	29	28	40	16	28	37
2	30	25	0	32	30	13	11	32	45	20	36	40	23	17	15	23	25	40	34	23	29	11	40
3	15	40	32	0	9	28	35	48	43	30	26	22	39	32	40	39	24	45	28	20	30	18	27
4	29	40	30	9	0	34	40	45	39	30	23	12	38	34	48	30	22	39	20	26	28	29	18
5	9	18	13	28	34	0	10	26	40	12	30	40	19	8	18	23	20	43	30	38	35	32	43
6	16	19	11	35	40	10	0	35	56	23	45	57	34	15	19	34	28	48	42	47	46	42	45
7	28	12	32	48	45	26	35	0	23	25	35	48	25	35	48	22	36	38	47	69	34	68	48
8	35	30	45	43	39	40	56	23	0	34	35	55	35	43	64	25	38	7	34	57	34	40	44
9	8	14	20	30	30	12	23	25	34	0	23	34	12	7	23	10	19	34	45	39	23	35	35
10	27	29	36	26	23	30	45	35	35	23	0	24	34	35	46	38	33	37	14	58	24	57	27
11	32	40	40	22	12	40	57	48	55	34	24	0	47	57	89	33	43	40	12	35	24	30	12
12	20	9	23	39	38	19	34	25	35	12	34	47	0	12	16	22	34	41	56	43	20	22	38
13	8	13	17	32	34	8	15	35	43	7	35	57	12	0	23	34	23	44	34	54	23	41	39
14	18	25	15	40	48	18	19	48	64	23	46	89	16	23	0	29	34	54	56	78	66	43	76
15	15	8	23	39	30	23	34	22	25	10	38	33	22	34	29	0	34	34	35	56	24	35	40
16	8	20	25	24	22	20	28	36	38	19	33	43	34	23	34	34	0	40	35	34	32	16	38
17	35	29	40	45	39	43	48	38	7	34	37	40	41	44	54	34	40	0	34	98	34	56	47
18	25	28	34	28	20	30	42	47	34	45	14	12	56	34	56	35	35	34	0	45	32	38	15
19	28	40	23	20	26	38	47	69	57	39	58	35	43	54	78	56	34	98	45	0	47	32	56
20	19	16	29	30	28	35	46	34	34	23	24	24	20	23	66	24	32	34	32	47	0	32	34
21	10	28	11	18	29	32	42	68	40	35	57	30	22	41	43	35	16	56	38	32	32	0	45
22	30	37	40	27	18	43	45	48	44	35	27	12	38	39	76	40	38	47	15	56	34	45	0

4.2 Parameter setting of the model and the algorithm

Model parameters

In this research, the number of distribution vehicles is set as 4, and the nominal load, average driving speed d, per kilometer driving cost, and the maximize driving distance in a single distribution of each vehicle are set as 2,000 kg, 30km/h, 2.5 yuan, and 200km, respectively. Any distribution activity beyond the maximum distance will incur compensation cost. The salary of distribution staff in working hours is 15 yuan/h and the overtime salary is 30 yuan/h. The details of the parameter setting are shown in Table 3.

Table 3 Parameter setting of the model

Parameter	Meaning	Value
FC_k	The fixed cost of the distribution vehicle	150
DC_K	The unit distance cost of the distribution vehicle	2.5
v	The average driving speed of the distribution vehicle	30
L	The driving distance reaching the compensation point	120
L_{max}	The maximum distance in a single distribution activity	200
δ	The compensation cost coefficient of the distribution vehicle	100
k_1	The basic salary per unit time of distribution staff during normal working hours	15
k_2	The pay per unit time during the overtime	30
t_0	The normal working hours of staff members	6
t_{max}	The maximum working hours of distribution staff	10
θ	The minimum requirement of customer satisfaction	0.75
ξ	The harmonious cooperation of distribution staff	0.8

Algorithm parameters

This paper adopts the PGSA to solve this model. The main parameter settings of the algorithm are: population size is 30, crossover probability is 0.8, mutation probability is 0.05, number of generation is 100, and step is 1.

4.3 Optimization of the model

One deputy general manager, two scheduling managers, five distribution staff members and two experts are invited to weigh the importance of salary P_e, working strength L_e and harmonious coopetition E_e. Each person determines the weight of λ_p, λ_L and λ_E, and the final results are: the weight of salary is 0.51, the weight of working strength is 0.27 and the weight of harmonious coopetition is 0.22.

Without considering staff satisfaction, the logistics distribution activity aims to minimize the total distribution cost and meet the minimum requirement of customer satisfaction in the same distribution activity. Irrespective of customer satisfaction, we can obtain the following distribution plan (Table 4) by solving the original scheduling problem.

In this plan, the total distribution cost is 2,878 yuan and the total distribution distance is 443km. The average satisfaction of all customers is 77.32 % and the average satisfaction of distribution staff is 58.63 %. The distribution route and vehicle scheduling results are shown in Fig. 3 and Table 5.

Table 4 Vehicle scheduling plan without considering distribution staff satisfaction

Vehicle k	Optimal route
1	0-2-19-3-21-0
2	0-13-5-6-14-12-7-1-9-0
3	0-15-17-8-10-20-0
4	0-16-4-11-22-18-0

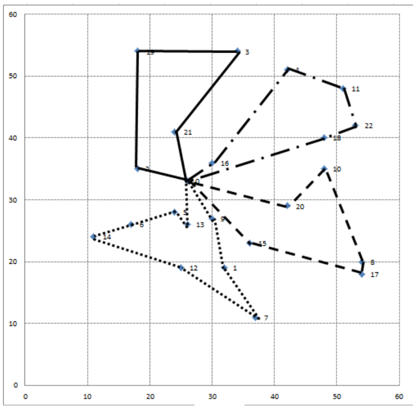


Fig. 3 Distribution vehicle scheduling route without considering distribution staff satisfaction

Table 5 Vehicle scheduling results without considering distribution staff satisfaction

Distribution route	Fixed cost /yuan	Transportation cost / yuan	Labor cost during normal working time/yuan	Labor cost during overtime/ yuan	Total cost / yuan	Average customer satisfaction, (%)	Distribution staff satisfaction, (%)
Route1	150	252.5	78.75	0	481.25	77.16	58.2
Route2	150	302.5	90	24	666.5	80.63	53.41
Route3	150	317.5	90	9	1266.5	76.4	48.73
Route4	150	235	78.75	0	463.5	75.1	74.18

Considering distribution staff satisfaction, this paper adopts Matlab7.1 coding to realize the algorithm based on the proposed vehicle scheduling optimization model and plant growth simulation algorithm. The solution is carried out on a laptop of Intel(R) Core(TM) i3-380M CPU 2.53 GHz and 4 GB memory. The average time consumption is 13.5 s and 4 distribution routes are obtained. The optimal scheduling plan of distribution vehicle in this instance is shown in Table 6.

Table 6 Vehicle scheduling plan considering distribution staff satisfaction

Vehicle *k*	Optimal route
1	0-6-14-2-19-21-16-0
2	0-3-4-11-22-18-0
3	0-10-8-17-20-0
4	0-5-13-12-1-7-15-9-0

For this plan, the optimized route and the scheduling results are shown in Fig. 4 and Table 7, respectively. We can see that the total distribution distance of this logistics activity is 429km and the distribution cost is 3,126.05 yuan. The average satisfaction of all customers is 83.5 % and the average satisfaction of distribution staff is 91.93 %.

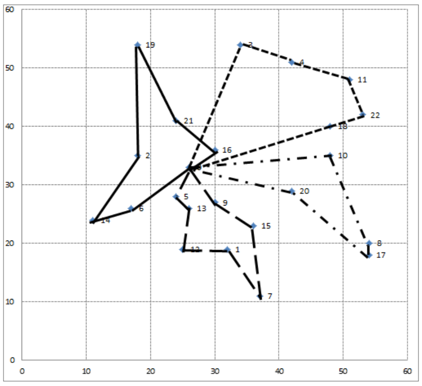


Fig. 4 Logistics distribution vehicle scheduling route considering distribution staff satisfaction

Table 7 Vehicle scheduling results considering distribution staff satisfaction

Distribution	Fixed cost	Distribution cost (yuan)	Labor cost during normal working time/yuan	Labor cost during over-time/ yuan	Total cost /yuan	Average customer satisfaction (%)	Distribution staff satisfaction (%)
Route1	150	322.5	90	12.9	1475.4	82	92.6
Route2	150	220	82.05	0	452.05	89	91.1
Route3	150	305	88.05	0	743.05	85	93.8
Route4	150	225	80.55	0	455.55	78	90.2

4.4 Contrastive analysis of results

According to the contrastive analysis of the optimization results and the vehicle scheduling results without considering distribution staff satisfaction, we have the following findings:

- Compared with the scheduling plan without considering distribution staff satisfaction, the customer satisfaction in the proposed distribution plan has improved significantly, which is less than 20 %;
- The optimized distribution plan has improved the distribution efficiency significantly as it costs less time to complete the same logistics distribution activity and lower maximum time consumption of a single scheduling route than the original distribution plan;
- The logistics cost of the optimized scheduling plan is 8.6 % higher than that of the original plan.

It can be inferred from the previous analysis that the distributions staff satisfaction increases at the expense of the distribution cost. With the improvement of distribution staff satisfaction, however, the time consumption of the same distribution activity in the proposed plan is significantly less than that in the original plan. The tremendous improvement of the distribution efficiency and customer satisfaction would contribute to customer retaining and reduction of customer loss. Moreover, the improvement of distribution staff satisfaction also boosts the working enthusiasm and the sense of ownership of the staff members and reduces staff turnover rate. The results are conducive to the long-term development of enterprises.

5. Conclusion

For the purpose of establishing the logistics distribution vehicle scheduling model based on distribution staff satisfaction and time window, this paper makes fuzzy description of the variables of distribution staff satisfaction, e.g. salary and welfare, working strength and harmonious cooperation, and takes them as the constraints. Then, the author sets up the plant growth simulation algorithm model of the distribution vehicle scheduling, and obtains the scheduling optimization plan and scheduling results through simulation analysis. The new scheduling plan manages to improve the satisfaction degree and distribution efficiency at the expense of higher distribution cost. The subsequent research will deal with the uncertainties in the actual situation, such as bad weather, road blockage, vehicle failure, changes of customers' time window, etc.

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References

[1] Jiang, D., Yang, X., Du, W., Zhou, X. (1999). A study on the genetic algorithm for vehicle routing problem, *Systems Engineering – Theory & Practice*, Vol. 19, No. 6, 40-45, doi: 10.3321/j.issn:1000-6788.1999.06.007.

[2] Lang, M.X., Hu, S.J. (2002). Study on the optimization of physical distribution routing problem by using hybrid genetic algorithm, *Chinese Journal of Management Science*, Vol. 10, No. 5, 51-56, doi: 10.3321/j.issn:1003-207X.2002.05.011.

[3] Berger, J., Barkaoui, M. (2004). A parallel hybrid genetic algorithm for the vehicle routing problem with time windows, *Computers & Operations Research*, Vol. 31, No. 12, 2037-2053, doi: 10.1016/S0305-0548(03)00163-1.

[4] Gong, Y.C., Guo, X.F., You, X.L., Zhao, Y. (2004). Solving the vehicle routing and scheduling problems by genetic algorithms, *Mathematics in Practice and Theory*, Vol. 34, No. 6, 93-97, doi: 10.3969/j.issn.1000-0984.2004.06.017.

[5] Hwang, H.-S. (2002). An improved model for vehicle routing problem with time constraint based on genetic algorithm, *Computers & Industrial Engineering*, Vol. 42, No. 2-4, 361-369, doi: 10.1016/S0360-8352(02)00033-5.

[6] Renaud, J., Boctor, F.F. (2002). A sweep-based algorithm for the fleet size and mix vehicle routing problem, *European Journal of Operational Research*, Vol. 140, No. 3, 618-628, doi: 10.1016/S0377-2217(01)00237-5.

[7] Erdoğan, S., Miller-Hooks, E. (2012). A green vehicle routing problem, *Transportation Research Part E: Logistics & Transportation Review*, Vol. 48, No. 1, 100-114, doi: 10.1016/j.tre.2011.08.001.

[8] Pillac, V., Gendreau, M., Guéret, C., Medaglia, A.L. (2013). A review of dynamic vehicle routing problems, *European Journal of Operational Research*, Vol. 225, No. 1, 1-11, doi: 10.1016/j.ejor.2012.08.015.

[9] Taş, D., Jabali, O., van Woensel, T. (2014). A vehicle routing problem with flexible time windows, *Computers & Operations Research*, Vol. 52, Part A, 39-54, doi: 10.1016/j.cor.2014.07.005.

[10] Li, J., Yu, G. (2015). Study on chaotic firefly algorithm for vehicle scheduling problem with minimal comprehensive cost, *Logistics Technology*, No. 4, 180-183, doi: 10.3969/j.issn.1005-152X.2015.04.055.

[11] Sun, Q.-L., Wang, L. (2010). A Study on domestic business enterprises' vehicle scheduling problems based on satisfaction of customers, *Logistics Sci-tech*, Vol. 33, No. 6, 18-21, doi: 10.3969/j.issn.1002-3100.2010.06.007.

[12] Zhao, R., Hu, X., He, H. (2015). E-commerce logistics distribution routing optimization considering customer satisfaction, *Journal of Shanghai Maritime University*, No. 3, 64-70, doi: 10.13340/j.jsmu.2015.03.011.

[13] Cao, Q.-K., Shao, S.-J., Ren, X.-Y. (2016). Study on the rescue vehicle scheduling considering the perception of the distribution subject, *Logistics Sci-tech*, Vol. 39, No. 2, 1-3, doi: 10.3969/j.issn.1002-3100.2016.02.001.

[14] Trancossi, M., Pascoa, J.C., Xisto, C.M. (2016). Design of an innovative off road hybrid vehicle by energy efficiency criteria, *International Journal of Heat and Technology*, Vol. 34, No, 2, 387-395, doi: 10.18280/ijht.34Sp0228.

[15] Locke, E.A. (1970). Job satisfaction and job performance: A theoretical analysis, *Organizational Behavior & Human Performance*, Vol. 5, No. 5, 484-500, doi: 10.1016/0030-5073(70)90036-X.

[16] Rutherford, B.N., Marshall, G.W., Park, J.-K. (2014). The moderating effects of gender and inside versus outside sales role in multifaceted job satisfaction, *Journal of Business Research*, Vol. 67, No. 9, 1850-1856, doi: 10.1016/j.jbusres.2013.12.004.

[17] Haar, J.M., Russo, M., Suñe, A., Ollier-Malaterre, A. (2014). Outcomes of work–life balance on job satisfaction, life satisfaction and mental health: A study across seven cultures, *Journal of Vocational Behavior*, Vol. 85, No. 3, 361-373, doi: 10.1016/j.jvb.2014.08.010.

[18] Limbu, Y.B., Jayachandran, C., Babin, B.J. (2014). Does information and communication technology improve job satisfaction? The moderating role of sales technology orientation, *Industrial Marketing Management*, Vol. 43, No. 7, 1236-1245, doi: 10.1016/j.indmarman.2014.06.013.

[19] Si, H.Y., Wang, Y., Yin, F.F. (2014). Effects of call center representative's psychological capital on work stress and job satisfaction, *Chinese Journal of Ergonomics*, Vol. 20, No. 1, 41-44, doi: 10.13837/j.issn.1006-8309.2014.01.009.

[20] Gagliano, A., Nocera, F., Detommaso, M., Evola, G. (2016). Thermal behavior of an extensive green roof: Numerical simulations and experimental investigations, *International Journal of Heat and Technology*, Vol. 34, No. 2, 226-234, doi: 10.18280/ijht.34S206.

[21] Chen, P. (2001). Staff satisfaction model analysis and application, *Industrial Technology & Economy*, No. 3, 80-81, doi: 10.3969/j.issn.1004-910X.2001.03.036.

[22] Yan, Z.-G. (2007). Management on the job satisfaction of the third-party logistics company, *Journal of Guangdong Communications Polytechnic*, Vol. 6, No. 2, 70-72, doi: 10.3969/j.issn.1671-8496.2007.02.024.

[23] Xu, L. (2012). Study on logistics enterprise human resource management based on employee satisfaction, *Logistics Technology*, Vol. 31, No. 8, 177-179, doi: 10.3969/j.issn.1005-152X.2012.08.061.

[24] Wang, Y. (2013) Empirical study on employee satisfaction of logistics consignor enterprises: The Example of Xi'an, *Logistics Technology*, Vol. 32, No. 5, 348-349, doi: 10.3969/j.issn.1005-152X.2013.05.110.

[25] Sun, L.-H., Huang, F., Yuan, X.-F., Shui, H.-H. (2015). The evaluation research of job satisfaction among logistics employee in we-commerce company, *Chinese Journal of Ergonomics*, Vol. 21, No. 4, 30-35, doi: 10.13837/j.issn.1006-8309.2015.04.0007.

[26] Tan, T.T., Tan, J.T. (2016). Research on the relationship between job stressors and job burnout of employees in logistics enterprises, *Modern Business*, No. 13, 71-74, doi: 10.3969/j.issn.1673-5889.2016.13.035.

[27] Li, T., Wang, C.-F., Wang, W.-B., Su, W.-L. (2005). A Global optimization bionics algorithm for solving integer programming - Plant growth simulation algorithm, *Systems Engineering – Theory & Practice*, Vol. 25, No. 1, 76-85, doi: 10.3321/j.issn:1000-6788.2005.01.012.