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Management decision model for dynamic vehicle scheduling under disruption delay

P. Zhang[1*] T. Gou[2]

[1]*Innovation entrepreneurship institute of education, Dalian Jiaotong University, Dalian 116021, China*
[2]*Institute of Software, Dalian Jiaotong University, Dalian 116021, China*
**corresponding author; email: dalianjh@djtu.edu.cn*

Abstract

The purpose of this study was to investigate the traffic disruption delay, it is a big vehicle scheduling problem in VRP (vehicle routing problem). In this paper an improved ant colony algorithm is proposed which is on the basis of two-stage disruption management method. Firstly, Quantum H_ε Gate is used to replace traditional quantum revolving door to update the ant colony. Next, the possible disruption management mode of distribution vehicles is summarized and the route scheduling method is designed on the basis of selected mode. The results obtained in this study include the performance of the proposed method, the classical Solomon example is involved in this paper. Findings show that the discrimination of the proposed MQACA (multi-phases quantum ant colony algorithm) is higher than conventional existing methods and the results are reasonable.

Keywords – disruption management, rescue model, disruption delay, multi-phase quantum ant colony algorithm

1. Introduction

It is an important problem for the logistic enterprises to provide customers punctual and efficient delivery services. However, there may be some distribution interference factors (such as time windows changes, delivery address changes) and other dynamic situation in the actual logistic distribution. How to control the initial program in the smallest range to minimize disruption is a hot issue in the industry and academia. The time delay of distribution vehicle is a typical disruption event, which is influenced by the weather, traffic and distribution condition et al. This will not only affect the vehicle scheduling execution, but also reduce the customer satisfaction on the quality of delivery service.

Scholars from related fields at home and abroad have studied this problem from different perspectives and obtained certain achievements. For example, Bushuev and GuifBida [1] studied the method to shorten the physical delivery time relying on modern logistics network. Potvin et al. [2] acted the express company as the research object and built the objective functions including travel time, customer delay time and travel costs. Mohammad et al. [3] researched how to create customer value through improving the timeliness of delivery, meeting the needs of personalized distribution and enhancing interactivity. Gevaers et al. [4] pointed out the importance of sending the goods to the final recipient from then end of the distribution of B2C. Sasipritya and

Ravichandran [5] proposed a framework model for parallel interference cancellation in CDMA network for imperfect systems, which was used to mitigate multi-customer interference. Yap et al. [6] designed a scheme which had the smallest impact on the urban environment on the basis of the characteristics of B2C e-commerce logistic. Li et al. [7] designed two-stage heuristic algorithm to integrate the delivery orders from the point of improving the utilization ratio of distribution tools and enterprise delivery efficiency. Pan and Gan [8] researched the optimization of cold chain logistic distribution considering carbon emissions and built the mathematical model of the problem and the ant colony algorithm. Liu and Zhao [9] compared and analyzed the distribution model of point to point and the performance of hub radiation model to construct the function model of hybrid collaborative delivery. Ding et al. [10] researched the perishable goods logistics distribution considering the customer behavior, and the results showed that the proposed method can complete the distribution task of more important customers to enhancing the potential benefits of the enterprise. Ning et al. [11] proposed the improved quantum bacteria foraging algorithm aiming at the dynamic vehicle routing problem of dispatching events, the effectiveness of the proposed method was verified through the comparison with other classical algorithms. Liu et al. [12] verified the effects of asymmetric information and risk aversion on the optimal delivery time contract through numerical experiments.

Although the above literatures have made fruitful research on vehicle travel time delay, the method based on fuzzy theory and rescheduling may produce great disturbance to the whole scheduling system, thus to affect the service quality on the part of the customers. Therefore, this paper researched the problem from the point of the disruption management. The interference management is to build corresponding optimization model to adjust the initial scheme locally to generate the updated scheme of minimizing disturbance according to the disturbance degree and nature of the problem [13, 14]. The research for the distribution vehicle disruption management is made from the points of the metric perturbations, multi-objective programming model and the algorithm for real-time management, finally, the effective and management ability of the proposed method are verified through the comparison with several classical algorithm and rescheduling method.

2. Description of the problem and pattern analysis

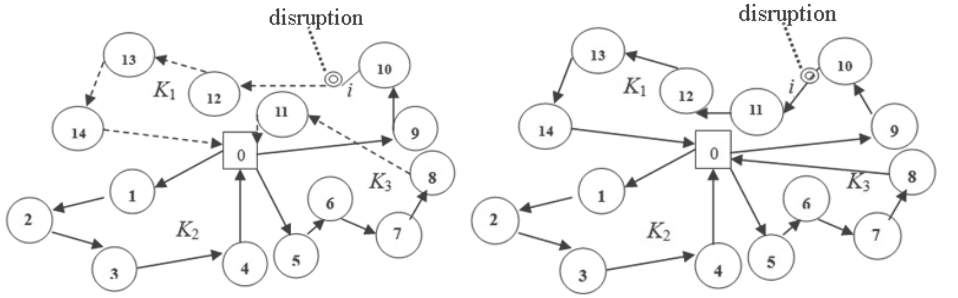
2.1. Description

The mathematical model of DVRP with stochastic demand can be described as consisting of 1 distribution center and L known customer points, dispatched K vehicles to serve L customer points, K vehicles start from the distribution center, and then return to the distribution center after the delivery task. K vehicles are all the same type, with the same capacity of vehicle Q.

The specific definition is as follows：

The total number of customers in initial stage, $i=\{0,1,2,...,L\}$; $i=0$ represents the distribution center, $i=1,2,...L$ represents the customer point; K represents the number of vehicles in the distribution center, $K=\{1,2,...,K\}$; F represents the cost of sending a car; Q represents the maximum capacity of the vehicle; q_i represents the needs of each customer. d_{ij} represents the distance from i to j; c_{ij} represents the unit transportation cost from i to j;ωij krepresents the traffic volume of vehicle K from i to j.

The disruption event of traffic disruption delay will lead to the difficulty of restoring the distribution to the initial scheduling scheme, that is, some customers can not be served within the required time window. This may convert the customer's time window constraint into the minimum time window deviation.



a. Initial driving plan b. Route after adjustment

Fig. 1 - Sketch map of disruption management of distribution

It describes an example of a vehicle disruption in Fig.1, in which, it describes an initial driving plan in Fig.1(a), and describes a local adjustment route after a disruption event in Fig.1(b). The vehicle K_1 encounters some disruption event at *i* from customer 10 to 11, which causes the following customers can not be served within their requested time window. The dispatcher makes a route adjustment scheme as shown in Fig.1(b). The rectangle represents the distribution center and the circle represents the customer point.

In the actual distribution activities, the number of the vehicle and the customers will be relatively large, and the adjustment time for the dispatcher is limited, so it needs to combine the experience of dispatchers with intelligent algorithms to obtain better solutions to minimize the customer time window deviation and delivery cost.

2.2. Disruption management mode

The disruption management of the delivery vehicles is divided into three modes, such as the internal route adjustment mode for one vehicle, the assistance mode between different vehicles and the rescue mode of adding new vehicle.

The first mode: If the disruption event occurs, the customer who is closest to the point and the time window deviation is smaller will be considered first when the vehicle capacity can meet the needs; the dispatcher adjusts the order of different customers of the same vehicle under the premise of "the initial route changes as little as possible" and tries to make the delivery vehicles "no turning back" during the adjustment process.

The second mode: If the disruption event occurs, the other vehicle which has enough cargo capacity and is close to the rescue the customer can be selected as assistance vehicle, moreover, it should also not generate larger time window deviation to the initial scheduling scheme.

The third mode: If there is no reasonable route to rescue for the part of the non-served customers, the rescue mode of adding new vehicle may be chosen.

3. Scheduling model of distribution optimization

3.1. Objective function

Two objective functions are constructed in this paper: one is to minimize the customer's time window deviation, and the other is to minimize the cost of delivery.

According to the description in 2.1, the following mathematical model can be constructed:

Decision variable:

$$x_{ijk}=\begin{cases}1, & \text{there is disruption event for vehicle } k \text{ from } i \text{ to } j\\ 0, & \text{there is not}\end{cases}$$

$$y_{ik}=\begin{cases}1, & \text{user } i \text{ is served by vehicle } k\\ 0, & \text{others}\end{cases}$$

Objective function:

$$\min Z=\sum_{k=1}^{L}\sum_{i=1}^{N}\sum_{j=1}^{N}c_{ij}x_{ijk}+\sum_{k=L+1}^{K}\sum_{i=1}^{N}\sum_{j=1}^{N}c_{ij}x_{ijk}+\sum_{i=1}^{N}[pe_i\cdot C\cdot 0.5\%+pl_i\cdot C\cdot 1\%]; \quad (1)$$

Eq. (1) represents the objective function of disruption management under driving disruption delay, which includes the distribution cost before disruption event, the distribution cost of updated route after the disruption event and customer's time window deviation. In order to unify dimensions, the customer's time window deviation is expressed by the penalty values which deviate from the initial scheme. The meaning of the sign in Eq.(1) is as follow: the number of customer is defined as 1,2,…,N; the number of vehicle is defined as 1,2,…,K; L is the vehicle which encounters the disruption event; i, j are customer points ($i,j\in\{1,2,\ldots,N\}$); c_{ij} is the distribution cost between i and j; pe_i and pl_i represent the time window deviation coefficient relatively for customer i, t_i is the actual moment arriving at customer i, C is the distribution cost for customer i.

Eq. (2) is the penalty coefficient pe_i when arriving moment is earlier than e_i:

$$pe_i=\begin{cases}(m_1-t_i)\cdot(e_i-m_1), & t_i<m_1;\\ [1/\mu(t_i)], & t_i\in(m_1,e_i);\\ (e_i-m_1), & t_i=m_1.\end{cases} \quad (2)$$

Eq. (2) is the penalty coefficient pl_i when arriving moment is later than l_i:

$$pl_i=\begin{cases}(t_i-m_2)^2\cdot(m_2-l_i), & t_i>m_2;\\ [1/\mu(t_i)]^2, & t_i\in(l_i,m_2);\\ (m_2-l_i), & t_i=m_2.\end{cases} \quad (3)$$

(m_1, e_i) and (l_i,m_2) represent the incomplete satisfactory soft time window interval, if the moment is less than m_1 or more than m_2, the satisfaction of customer will be 0. The penalty coefficient is inversely proportional to the satisfaction are within (m_1, e_i), when the satisfaction for earliness is 0, the penalty coefficient is positively proportion to the time difference of (m_1-t_i); the penalty coefficient is inversely proportion to the square of satisfaction within (l_i,m_2), when the satisfaction for tardiness is 0, the penalty coefficient is positively proportion to the square of the time difference of (t_i-m_2). Then the penalty value of earliness is $pe_i\cdot C\cdot 0.5\%$ and it is $pl_i\cdot C\cdot 1\%$ for tardiness, where 0.5% and 1% are set according to the experience of the dispatchers, $\mu(t_i)$ is delayed fuzzy factor.

$$\mu(t_i)=\begin{cases}0, & t_i\le m_1;\\ \dfrac{t_i-m_1}{e_i-m_1}, & m_1<t_i<e_i;\\ 1, & e_i\le t_i\le l_i;\\ \dfrac{m_2-t_i}{m_2-l_i}, & l_i<t_i<m_2;\\ 0, & m_2\le t_i。\end{cases} \quad (4)$$

When m_1= e_i =0, it represents that there is not limit of earliness time window.

3.2. Constraint condition

The constraint condition of the problem can be described as follows:

s.t.

$$\sum_{k=1}^{K+L} y_{ik} = 1, \forall i; \tag{5}$$

$$\sum_{j=1}^{N+M+1} x_{ijk} = y_{ik}, \forall i, k; \tag{6}$$

$$\sum_{i=1}^{N+M+1} x_{ijk} = y_{jk}, \forall j, k; \tag{7}$$

$$\omega_{(N+M+1)jk} = x_{(N+M+1)jk} Q, \forall j, k; \tag{8}$$

$$\sum_{i=1}^{N+M+1} x_{ijk} (\omega_{ijk} - q_j) \geq 0, \forall j, k; \tag{9}$$

In the above equations, Eq.5-Eq.9 represent the constraint condition. Eq.5 represents that each customer must be served; Eq.6 and Eq.7 represent each customer can only be served by one vehicle; Eq.8 represents that each vehicle must be in full load state when it leave the distribution center, and Q here is the maximum cargo capacity; Eq.9 represents that the cargo capacity can not be less than the need of the next customer, and q_j is the need of customer j, ω_{ijk} table is the cargo capacity for vehicle k from i to j.

4. The algorithm for disruption management of distribution

The method of resolving the problem includes two stages: one is to select the disruption management mode the other is to optimize the distribution route after disruption on the basis of selected mode. Considering the quantum ant colony algorithm has the advantages of less parameter in the iteration, faster computation and strong global optimization ability, the Multi-phase Quantum Ant Colony Optimization (MQACO) is proposed in this paper. That is, the double chain coding for the population is used in the early stages, and quantum ant colony optimization is used to ensure the diversity of the population in the late stages of the algorithm.

4.1. State transfer rules

P_{ij}^{k} indicates the transfer probability of ant K, it is defined as:

$$P_{ij}^{k} = \frac{[\tau_{ij}]^{\alpha}[\eta_{ij}]^{\beta}[\mu_j]^{\gamma}}{\sum_{l}[\tau_{ij}]^{\alpha}[\eta_{ij}]^{\beta}[\mu_j]^{\gamma}} \tag{10}$$

In which l represents all possible values,τ_{ij} is the path intensity of the edge arc (i, j).$\alpha(\alpha > 0)$ is an information heuristic factor that represents the relative importance of the trajectory. The greater the value, the more the ants tend to choose the path of more ants through. $\eta_{ij}$is the visibility of the side arc (i,j), the expression is:

$$\eta_{ij} = \frac{1}{d_{ij}} \tag{11}$$

In Eq.11, d_{ij} is the distance between two adjacent customers, $\beta(\beta > 0)$ is the expected heuristic factor, indicating the relative importance of visibility, the larger the value, the more inclined the ant is to choose a shorter path. μ_j is the quantum information strength of client node j, the expression is:

$$\mu_j = \frac{1}{|\alpha_j|^2} \tag{12}$$

$|\alpha_j|^2$ shows the probability that the quantum state of the j-th qubit collapses to $|0\rangle$.For ant K, The smaller $|\alpha_j|^2$ is, the larger P_{ij}^k is. $\gamma(\gamma > 0)$is a quantum bit heuristic factor. It shows the relative importance of the customer's quantum state probability magnitude. The larger the value, the more ants tend to choose customers with more quantum information.

4.2. Pheromone update

In the process of searching the path, the pheromones on the path will continue to evaporate. While the ants will release new pheromones in the path they have traveled through. The pheromone update equation is:

$$\tau_{ij} = (1-\rho)\tau_{ij} + \Delta\tau_{ij} \tag{13}$$

$$\Delta\tau_{ij} = \sum_{k=1}^{m} \Delta\tau_{ij}^k \tag{14}$$

In Eq.14, m represents the total number of ants,ρ a represents the pheromone volatility factor, $\Delta\tau_{ij}$ indicates the amount of pheromone released by the ant at the edge (i,j), $\Delta\tau_{ij}^k$ represents the total amount of pheromones released by the K ant at the edge of the (i,j), $\Delta\tau_{ij}^k$ is defined as:

$$\Delta\tau_{ij}^k = \begin{cases} Q\left(\left|\beta_{ij}^k\right|^2\right) \Big/ L^k & \text{if ant k goes througth edge (i, j)} \\ 0 & \text{else} \end{cases} \tag{15}$$

Q is a pheromone, which is a constant value.L^k is the length of the path that the k^{th} ant has constructed. In this paper, the quantum probability amplitude is introduced. During the pheromone update, there are more and more quantum pheromone on the path that the ant passes through, as the ant has not passed the path as the quantum pheromone volatilized, the quantum pheromone left on the path will be less and less, it will lead to the increasing difference between the different edge quantum pheromones, which can easily fall into local optimum. The quantum pheromone updating strategy designed in this paper will increase with the path constructed by ants, and the amount of quantum pheromones will gradually decrease, so as to avoid the problem of too much pheromone accumulating on one edge leading to a local optimum.

4.3. Algorithm steps

(1) Initial scheduling phase:

step 1: Initialize the quantum population A(t), The size is n, and the number of qubits is m, in the initial state, all probability α_i, β_i take $\frac{1}{\sqrt{2}}$,the initial number of iterations t=0. Initialize each parameter α,β,γ,ρ. The maximum number of iterations is t_{max}.

step 2: Add the initial point in the current solution centralization, for each ant k, Choose customer points j randomly, if the demand for the customer point $q_j < Q$, then choose the point j *a*nd calculate the transfer probability P_{ij}^k,Add point j in the current solution set, update the remaining load $Q_{k+1} = Q - q_j$, go to step 3, otherwise re-select the customer point j.

step 3: If ants k = (k = 1, 2, ..., n) go all customer points that all customer points are concentrated in the current solution, write down the number of ants N_k.

step 4: Calculate each objective function W_k (k=1,2,...,m) get the current optimal solution.

step 5: Update the pheromones of each side, use quantum H_ε gates to update the quantum ant colony.
step 6: Determine whether the current number of iterations reached the maximum number of iterations, otherwise go to step 2.
step 7: Output the current optimal solution.

(2) Dynamic optimization phase:
step 1: Carry out the distribution scheme in the initial scheduling phase and update the customer information.
step 2: If a new customer request appears, determine whether the number of new customer points reached the upper limit, if the limit is reached, go to step 3, otherwise determine whether to reach the next re-scheduling time point, then go to step 3, otherwise go to step 1.
step3: According to fuzzy demand probability formula to determine whether insert the client point into the current delivery path, if the S is larger than the critical value of the next customer point, then the point is inserted into the current path. Using quantum ant colony algorithm to generate a new path, otherwise go to step 4.
step 4: Add vehicles to complete the delivery of new customer point.

4.4. Comparison of convergence

In order to verify the efficiency of the proposed algorithm, the classical Solomon [15] examples are used under the condition of Matlab7.0. There are 6 kinds of examples in Solomon, and one standard problem from each kind of examples is selected and executed for 20 times using MQACO. The efficiency will be verified through the comparison with existing Bacterial Foraging Optimization [16], Improved Bacterial Foraging Optimization [17], Artificial Immune Algorithm [18] and Quantum-behaved Particle Swarm Optimization [19].

The efficiency of the above algorithms is tested with standard Rastrigrin, and it is descripted as follow:

$$f(y) = \sum_{i=1}^{20} [y_i^2 - 10\cos 2\pi y_i + 10] \tag{16}$$

In Eq.16, $y_i \in [-100,100]$, the number of colony is 20 and the maximum iteration is 100. The convergence curve of the optimal solution of the five algorithms can be shown in Fig.2. It can be seen from Fig.2 that the convergence speed of the proposed MQACO is faster than the other four algorithms obviously, and it has also better global optimization capability.

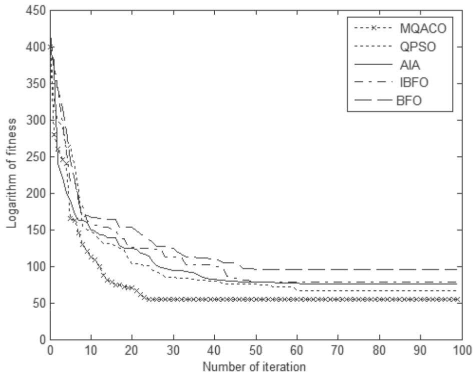


Fig. 2 - The fitness convergence curve of 5 algorithms

5. Numerical experiment

At present, there is no standard test data set for the disruption delay problem of distribution vehicle, and the initial scheme will be obtained acting minimizing the time window deviation and distribution cost as the objective. The library of Solomon [15] contains 6 kinds of examples including 100 customers, one distribution center, and three problems will be selected from R1\R2 of uniform distribution, C1\C2 of cluster distribution and RC1\RC2 of mixed distribution to be tested.

5.1. Testing example

The optimal results of 18 examples using the proposed MQACO and other algorithms are compared in Table 1:

It can be seen from Table 1 that the number of vehicle and mileage are both optimized to a certain extent using MQACO except the No.06 of the C1, and the average number of vehicle decreases by 12.8%, the maximum reaches 42%; the average mileage decreases by 7%, the maximum reaches 29%. Because the Solomon data is generated by clustering and the user centralizes distribution, the optimization for C1\C2 is not obvious. However, the satisfaction of the user is high, so the algorithm proposed in this paper is effective in generating delivery scheduling scheme.

5.2 Example verification

(1) Example design

In order to verify the effectiveness of the proposed method deeply, a simulation experiment is designed. There is one distribution center, 24 customers and the distribution area is 50×50 (units: km). The demand of each customer is not more than $2m^3$, the maximum delivery capacity of each vehicle is $8m^3$, the maximum distance is 200km, and the coordinate of distribution center is (25km, 25km). For the convenience of calculation, the user information is processed by non-dimensional manner, as are shown in Table.2.

Tab. 1 - Comparison of experimental results for Solomon

Example		Result of classical algorithm			Result of the proposed algorithm		
		Number of vehicle	Mileage	Literature	Number of vehicle	Mileage	Satisfaction
R1	01	19	1645.79	H (2000)	11	1296.82	89%
	02	11	1261.40	RJH (2011)	9	1243.56	91%
	05	11	1183.20	RJH (2011)	9	1136.71	92%
R2	01	4	1252.37	HG (1999)	3	1102.46	92%
	02	3	1198.45	HG (1999)	3	1146.33	95%
	06	3	833.00	T (1994)	3	831.13	100%
C1	01	10	828.94	RJH (2011)	10	828.94	100%
	05	10	828.94	RJH (2011)	10	828.94	98%
	06	10	828.94	RT (1995)	10	849.13	96%
C2	01	3	591.56	PB (1996)	3	589.46	98%
	05	3	591.17	PB (1995)	3	586.33	94%
	08	3	588.88	RJH (2011)	3	576.44	95%
RC1	01	14	1696.94	TB (1997)	9	1203.42	90%
	05	13	1629.44	BBB (2001)	10	1204.50	88%
	06	11	1424.73	BBB (2001)	9	1116.76	92%
RC2	01	4	1249.00	T (1994)	3	1200.01	90%
	05	4	1302.42	HG (1999)	3	1264.86	89%
	08	3	833.37	RJH (2011)	3	832.97	95%

Tab. 2 - Information of customers

Customer	Coordinate	Time Window[e_i,l_i]	Penalty coefficient	Demand
1	(30,52)	[30,90]	0.02	2
2	(24,60)	[40,100]	0.04	1.4
3	(12,48)	[30,90]	0.02	0.5
4	(15,38)	[40,120]	0.08	0.9
5	(10,28)	[60,160]	0.02	0.3
6	(19,21)	[90,180]	0.1	0.5
7	(28,30)	[60,220]	0.03	0.2
8	(39,35)	[30,90]	0.02	0.3
9	(51,36)	[60,90]	0.2	0.5
10	(48,28)	[60,120]	0.02	0.2
11	(50,19)	[60,180]	0.12	1.3
12	(45,7)	[90,210]	0.06	0.9
13	(37,11)	[100,180]	0.4	1.4
14	(31,15)	[120,210]	0.03	1.4
15	(34,18)	[150,240]	0.25	0.8
16	(32,26)	[90,220]	0.15	0.4
17	(42,40)	[40,120]	0.2	1.5
18	(60,75)	[40,90]	0.08	0.3
19	(49,73)	[60,150]	0.06	0.5
20	(46,77)	[90,150]	0.02	1.7
21	(26,76)	[90,210]	0.08	0.3
22	(25,70)	[60,240]	0.18	1.7
23	(35,55)	[90,210]	0.04	2
24	(32,50)	[150,220]	0.03	0.4

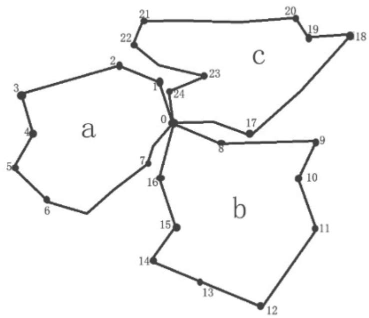


Fig. 3 - Initial scheduling scheme

According to the above data, the initial scheduling scheme is obtained in Fig.3 and the routes are as following: vehicle a: 0->1->2->3 ->4->5->6->7->0; vehicle b: 0->8->9->10->11 ->12->13->14->15->16->0; vehicle c: 0->17 ->18->19->20->21->22->23->24->0. The moment for the vehicle reaching each customer should be as follow: vehicle a: 36, 55, 75, 92, 126, 155, 165; vehicle b: 40, 65, 82, 100, 124, 142, 170, 193, 210; vehicle c: 52, 70, 88, 105, 128, 145, 160, 188. The number of vehicle and distribution cost will be least in this scheme.

(2) Experiment result

If the vehicle encounters the disruption event and generates the time delay of Δt at the moment of 150 in the point of g when it leaving 13 to 14, the value of time delay will be discussed in two cases: Δt=10 and Δt=50. According to the judging method of system disturbance, if the delay time is greater than the difference between the time window upper limit and actual arrival time, that is, Δt>l_i-t_i, the system will be disturbed. The relevant information of non-delivery customer is recorded in Table.3. According to the results in Table.3, when Δt>12, the system is disturbed. Therefore, when Δt=10, the system is not disturbed and it will run according to the initial scheme. As far as Δt=50 is concerned, the system is disturbed and it needs to select one reasonable mode to manage the route of the remaining customers.

After the system is disturbed, the route generated with the proposed method in this paper is shown in Fig.4.

Vehicle a: 6->14->16->0; vehicle b: g->15->0; vehicle c: 24->7->0.

(3) Comparison and analysis

The results obtained with the proposed method and global rescheduling method [20] are compared and analyzed in terms of vehicle number, mileage, delivery cost and time window deviation, as is shown in Table.4.

Tab. 3 - Information of not-served customers after disruption

Customer	6	7	14	15	16	24
l_i	180	220	210	240	220	220
t_i	155	165	170	193	210	188
l_i-t_i	25	55	40	47	12	32

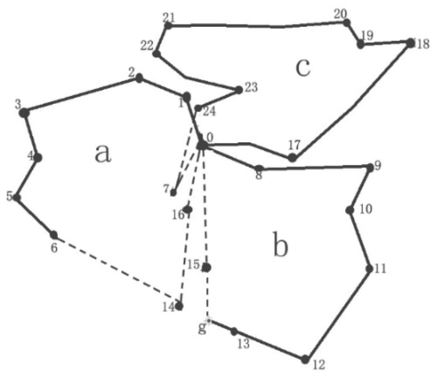


Fig. 4 - Distribution route of disruption management

Tab. 4 - Comparison of disruption management and global rescheduling

Method	Distribution route	Number of vehicle	Mileage	Cost	Deviation of time window
Disruption management	6->14->16->0 g->15->0 24->7->0	3	60.65	786.59	53.21
Rescheduling	6->7->0 g->0 24->0 0->15->14->16->0	4	69.46	853.63	52.34

It can be known from Table.4 that if there is disruption event g then:

(1) Three vehicles are needed using the proposed method in this paper, while the number becomes four when uses the global rescheduling method.

(2) The mileage using the proposed method is significantly less than that of global rescheduling.

(3) Although the costs have increased for 3 vehicles using the proposed method in this paper, the cost with 4 vehicles using global rescheduling method is more than the total cost in the disruption management. It shows that the delivery cost of disruption management is lower than that of global rescheduling method.

(4) Although the time window deviation of disruption management is slightly higher than that of global rescheduling, the global one is at the cost of new vehicle, so the whole, the method of disruption management is better than the global one.

6. Conclusion and prospect

In order to optimize the disruption management model and seek the multi-objective optimal solution, this paper proposes an improved multi-phase quantum ant colony algorithm. Through the comparison with the existing classical algorithms, the effectiveness of the proposed algorithm in solving the disruption management is verified. To sum up, comparing with the global rescheduling method, the method of disruption management in this paper sacrifices less time window deviation to minimize the number of vehicles and distribution cost. Moreover, the results obtained by the proposed method are more practical.

Considering the disruption event will have an impact on user satisfaction and psychological perception, the research about how to make the dynamic evolutionary scenario into the model and improve the logistic distribution disruption management model is the focus of the next study.

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Full lifecycle digital control of urban rail transit property based on the integration between CAD, GIS and BIM

L.L. Dong[1] J. Wu[1] W. Wang[2*] Y.B. Xie[1]

[1]*School of Architecture and Urban Planning, Chongqing Jiaotong University, Chongqing 400074, China*
[2]*School of Art, Design and Architecture, University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, West Yorkshire, United Kingdom*
**corresponding author; email: wangwei19930801@foxmail.com*

Abstract

Rail transit is the cornerstone of urban public transport. However, rail transit projects are cost-intensive, time-consuming and difficult to coordinate. This calls for digital upgrading of the full lifecycle control of rail transit property. This paper integrates the multi-sourced heterogeneous data in the architecture, engineering and construction (AEC) field and the geographic information system (GIS) field, and creates a technical framework coupling GIS, computer-aided design (CAD) and building information modelling (BIM) that serves the fully lifecycle digital control of urban rail transit property. The established technical integration framework, denoted as the CGB, was applied to Phase 2 of the branch line of Line 6, Chongqing Rail Transit, and optimized for the key points of full lifecycle control. The research findings shed new light on the provision of digital support to the smart development of urban rail transit.

Keywords – computer-aided design (CAD), geographic information system (GIS), building information modelling (BIM), rail transit property, full lifecycle, digital control

1. Introduction

In 2006, the Open Geospatial Consortium (OGC) as one International Organization for Standardization first proposed the CGB framework in OWS-4 (OGC Web Services-Phase 4) in order to integrate the building micro-information and geographic macro-information information. This organization wants the information-based construction projects to be closer to the actual scale through the exchange and interoperation between the building information and geographic information, and meet the basic information compatibility conditions for building digital cities. Since then, many scholars have conducted research in the related field of CGB. Cheng et al. studied the integration method of IFC and City GML data language and found that the development framework can help to realize the automatic mapping of data between IFC and City GML of different LODs [1]. Borrmann et al. [2] through analysis for the requirements of CGB integration in practical application in detail, proposed to embed BIM data model in GIS model and then fulfilled the unified visual modelling task. The most typical case is the in-depth development of Google Maps. The maps of major cities in foreign countries have realized the integration of detailed information of each building element on the three-dimensional surface, and can achieve the three-dimensional virtual tour with relevant terminal equipment.

Among the three technical systems involved in the CGB framework, CAD technology is used for the creation of the initial building information data, and BIM technology is to add and manage various attributes attached to the building, both of which are management technologies for the microscopic scale information of buildings; GIS technology is a technology to manage the macro-scale information of the environment, and it can manage the geographical environment information of buildings [3-5]. However, unlike the CAD data with high compatibility, it’s still an industry problem for BIM and GIS to achieve the integration of data sharing. Therefore, the currently effective and feasible integration methods are summarized based on related literature, conferences and reports. Selecting the universal IFC standard of GIM and the universal City GML standard of GIS the research objects, the method of automatically extracting the multi-detail level GIS surface model from the BIM entity model is obtained. In this way, the LOD100-LOD400 model in City GML can be extracted from the IFC model. This solves the key technical problems of BIM and GIS integration, and achieve the integration of CAD, BIM, GIS technology [6].

Urban rail transit property refers to the new construction subject formed by the overall consideration and comprehensive planning of the contained property factors in addition to urban rail transit. The full lifecycle includes: network planning - construction planning - pre-feasibility study - Engineering Feasibility Study - Overall Design-Preliminary Design - Construction Drawing Design - Construction - Acceptance - Trial Operation - Operations. The whole process involves many fields, wide influence range and long-time span, and also constantly interferes with the surrounding environment. Therefore, in order to realize the digital control of urban rail transit property, it is necessary to break through the single application limits of CAD, GIS and BIM, make re-arrangements of their correlations, and create a CGB digital technology integrated application scheme covering the full lifecycle from start to finish.

2. CGB technology integration solution

Drawing on the BLM (Building Lifecycle Management) concept, the full lifecycle of urban rail transit properties is integrated into four stages: planning, design, construction and operation. Among them, CAD is used to create preliminary information data, BIM is to add and manage the various attributes attached, and GIS is used to assign geographical environment information [7]. The key technologies of each stage are extended from simple item-by-item flow to iterative intercommunication of key information in each stage, and the advantages of CAD-GIS-BIM are exerted to form practical technology integration, thus establishing an application solution of CGB technology integration.

2.1. Planning stage

In this stage, the original graphics is converted to 3D model transformation by CGB technology integration, and the model unit containing BIM parameters [8] is added to the GIS information, for quickly completing the model drawing. Through the three-dimensional model, the buildings in the area can be simulated, to clearly and comprehensively show various spatial relationships between the rail transit and the existing urban buildings in the roaming process, and perform the corresponding planning and coordination [9]. CGB technology integration can also help to pre-establish a variety of options for line selection and site setting, and then obtain the optimal solution which mainly serves the traffic flow of passengers while considering the needs along the line, and is also compatible and interchangeable with other planned traffic.

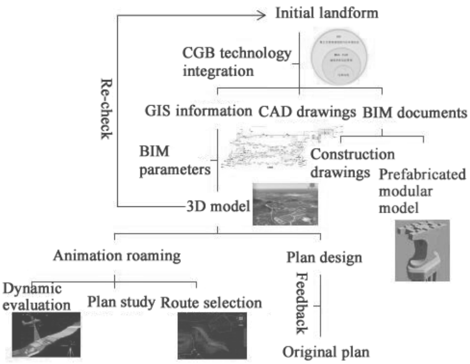


Fig. 1 - CGB technology integration route in the planning stage

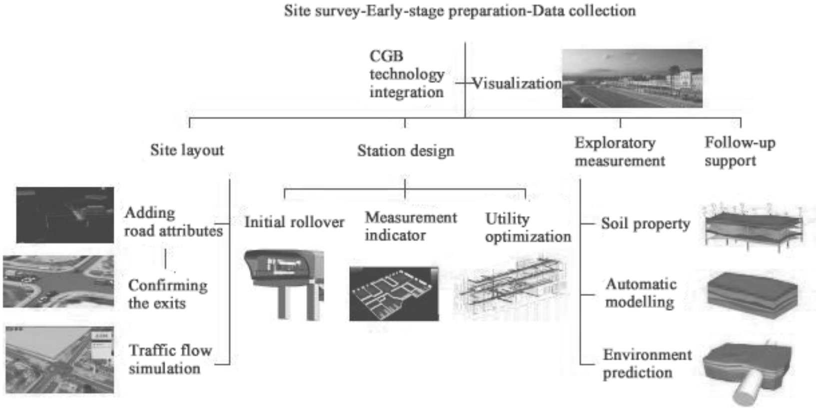


Fig. 2 - CGB technology integration route in the design stage

2.2. Design stage

CGB technology integration is mainly reflected in the additional benefits of simulation based on the visualization model in this stage. To be specific, the simulation of small-area traffic flow and human flow in the station layout [10] is conductive to discover the layout scheme most beneficial to the diversion; the three-dimensional fitting method is used to directly acquire the properties and range of each soil layer, thereby avoiding unfavourable geology conditions, and calculation of ground bearing capacity; the three-dimensional design during the station design is conductive to solving the inevitable elevation problem of the plan graph, complete the fine and reasonable layout of water, electricity, pipe, and network equipment in the narrow and small space such as the equipment room [11]; in the evacuation design, the simulation of disaster prevention in the fire protection and civil defence provides a comprehensive assessment of the design plan.

2.3. Construction stage

For the comprehensive information model obtained during the design stage, the model and the contained information are processed to realize the comprehensive application of the design elements in the construction stage.

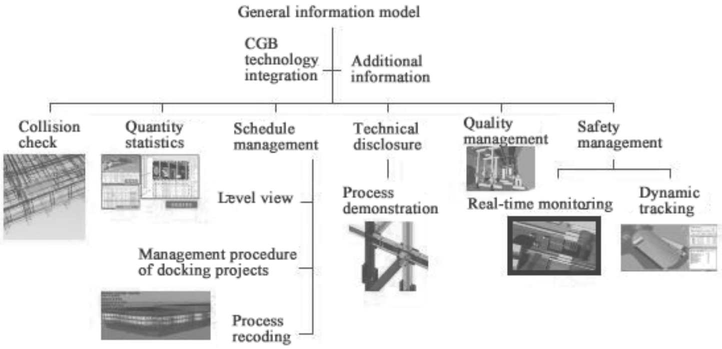


Fig. 3 - CGB technology integration route in the construction stage

Integrating BIM in the GIS environment and incorporating the CAD raw data, the three-side data information shall be comprehensively mobilized to achieve a comprehensive analysis in the actual environment and specific stages; the textual and graphical information is visually output, and a large amount of additional information is implanted to ensure the intelligent use of the design information. Emphasis is put on giving full play to the advantages of BIM as a building information model under the CGB technology integration framework [12], and achieving the management objectives of construction 3D (entity) / 4D (progress) / 5D (cost) / 6D (quality) / 7D (process record) [13-16]. In addition, detailed GIS data support can optimize the internal layout of the project, implement comprehensive evaluation of the surrounding environment, and develop various types of plans to achieve reproduction in high simulation mode.

2.4. Operation stage

This stage is to achieve full-time monitoring and timely and effective maintenance of rail transit properties, and ensure that the public transport management does not affect and hinder the normal use of passengers. CGB technology integrates information management, entity model, equipment monitoring and early warning mechanism, achieving an all-round processing of a platform. Meanwhile, the management of each link in the later stage can be directly called from the information data such as the space and parameters integrated in this platform. The entire management process application is built in the same infrastructure to realize the maximum compatibility and build the best strategy for full lifecycle management.

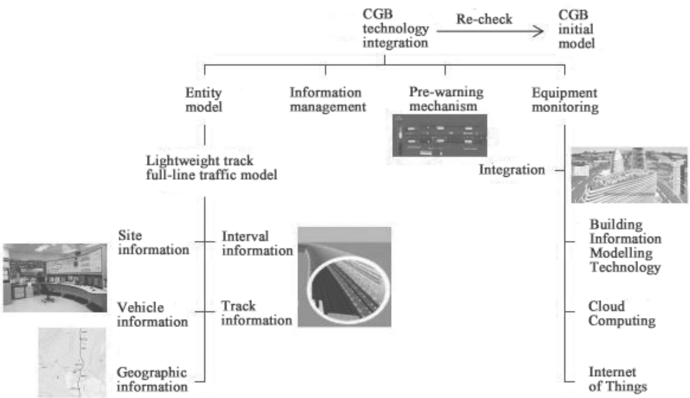


Fig. 4 - CGB technology integration route in the operation stage

3. Full lifecycle application simulation of CGB integration

3.1. Project overview

The phase 2 of branch line of the Chongqing Rail Transit Line 6 has a total length of 13.43 kilometres, with 11.22 kilometres of underground lines and 2.21 kilometres of elevated lines. It sets up 7 stations (Table 1, Figure 5), including 5 underground stations, and 2 overhead stations. There are 2 interchange stations, which are interchangeable with Rail Transit Line 10, Line 14 and Line 16, respectively. One depot (Caojiawan depot) is set up, and the control centre is located in the Dazhulin depot. The project is estimated at 7 billion yuan, and the planned construction period is from April 2017 to October 2020. It enjoys a rich interval and site type, convenient transfer of traffic, and high complexity of digital life control in the full lifecycle. In our study, this project was taken as an example using the CGB technology integration simulation application, to comprehensively obtain the technical verification result and the application value.

3.2. Planning study

After acquiring the road dataset from the Yuelai station to the Shaheba station section and the 3D topographic map based on the satellite image (Figure 6), a preliminary planning study was conducted. The project track line was simulated according to overall planning roadmap of the urban rail transit, and plane and vertical section design specifications of the rail transit.

In view of the different platform types such as underground tunnels of the Fuxing Station and the elevated type of the Shaheba station (Figure 7), a simple bridge-tunnel model was created using the information conversion advantages of Infraworks 360 between GIS and BIM in CGB technology (Figure 8). Besides, it should be ensured that the dynamic update of the line information is synchronized to the CAD drawing so that when the 3D mode is finalized, the subsequent design can be directly guided according to the relevant CAD engineering drawings.

Tab. 1 - Station layout and types

Station name	Type
Wangjiazhuang	Underground
Qingxihe	Underground
Liujia Yuanzi	Underground
Siyuan	Underground
Fuxing	Underground
Hongyanping	Elevated
Shaheba	Elevated

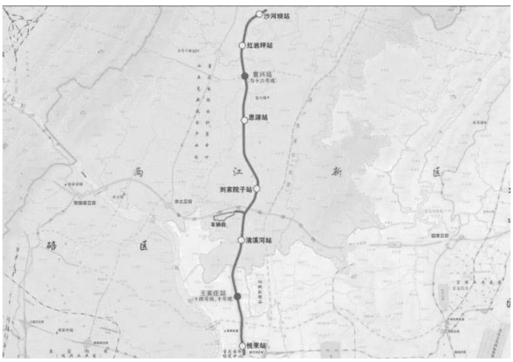


Fig. 5 - Station layout

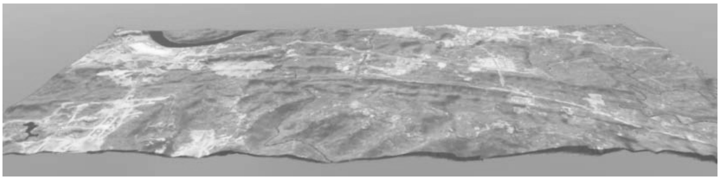


Fig. 6 - 3D topographic map of the project site

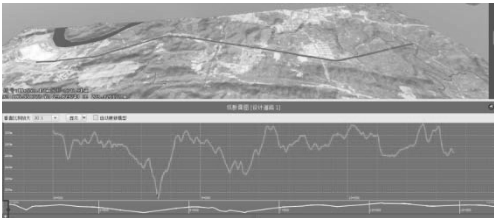
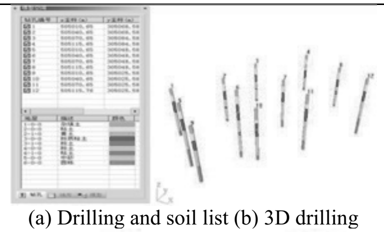
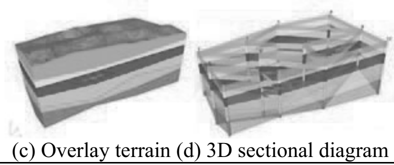


Fig. 7 - Elevation map of project route profile

Fig. 8 - Elevated connection effect of 3D tunnel

3.3. Survey design

Survey design is the focus of the project in the early stage. It is also the link reflecting the important value of CGB technology integration. The full lifecycle of rail transit began with planning and demolition, but the project really started from the design stage. It included field survey, drawing design, and bidding preparation etc.

Content	Construction process	Technical process	Characteristics	Example
3D visualization geological analysis	Probe data - GIS operation - soil interface - Boolean operation - entity	Hole Information Processing—Excel—CGB Technology Integration Platform—3D Terrain Model	The model can be arbitrarily cut to guide on-site construction.	 (a) Drilling and soil list (b) 3D drilling  (c) Overlay terrain (d) 3D sectional diagram