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Vehicles scheduling of hazardous materials transportation considering safety and customer satisfaction

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ABSTRACT

Rationally arranging hazardous materials (hazmat) transport lines is of great significance to prevent, reduce accidents and improve transportation efficiency. Considering the transportation safety, customer satisfaction and transportation cost, a multi-objective vehicle scheduling discrete optimization model with soft time window constraints, which is no dependence on risk parameters, was created in this paper. A 0-1 integer programming model with 3 goals can be constructed to describe describe the problem. A multi-objective processing method was utilized to translate the problem into a single objective problem. A hybrid genetic algorithm was worked out to solve the model. Finally, a numerical example was given to verify the model and algorithm. The results indicate that the convergence can be quickly and effectively realized, and that the efficiency and stability of the algorithm was verified. This model can be applied to provide a decision scheme for hazmat transportation enterprises to transport dangerous goods, when it is difficult to obtain a large number of statistics, and difficult to guarantee the reliability of the model parameters.

Keywords: vehicle scheduling, multiple objectives, hazmat transportation, genetic algorithm.

INTRODUCTION

Accidents in transporting hazardous materials happened frequently in recent years, has brought severe challenges to social environment, safeties of lives and property of the people. For example, an explosion accident of cargos with black powder was occurred on Henan section in Lianyungang-Huoerguosi expressway in May 2010. 3 people were killed, 3 injured and more than one thousand houses were damaged in the accident. And a leakage accident of liquid ammonia in tank trucks happened in April 2011, caused 4 deaths, more than 200 people to evacuate their home, and more than 3000 square meters farmland pollution. Hazmat transport planning has received more attention from numerous operations research and management science researchers [1].

Different from the general vehicle scheduling problem that modeling taking the cost as the guidance, current researches mostly emphasize the risk parameters to be measured during the transportation, including minimizing expected risk [2,3], maximal risk [4], mean-variance of risk [4]. In such problems, how to identify potential risks and its consequences is essential to the problem [5-7]. But these literatures all belong to single objective optimization problems, ignoring the traditional cost factors. There are also some literatures overall considering transportation cost and the risk of transportation to establish the optimization model [8,9]. Vehicle scheduling optimization that based on risk analysis is an effective way to reduce and control the risk of the transport of dangerous goods. But all of these models contain a common feature, that is, the model application is highly dependent on the risk parameters, including: the probability of accidents, and the punishment cost after the accident. In many cases, the statistical data of the risk parameters is of severe shortage. And it is also hard to guarantee the accuracy and reliability of such parameters. At this time, the availability of risk-analysis-based optimization model of the hazmat transportation vehicles scheduling is restricted. A multi-objective vehicle scheduling discrete optimization model which is no dependence on risk parameters was proposed created in literature [10]. But the model created in literature [10] was based on the Hard Time Window constraints. Relaxing this assumption will make the research more realistic. In addition, in the management of modern enterprise, improving customer satisfaction, and ensuring service level are of great significance to promote the enterprise competitive ability. Therefore, a multi-objective optimization model of hazardous materials transportation undepend on risk parameters with soft time window constraints was created in this paper, considering security, customer satisfaction, and logistics transportation cost. And a hybrid genetic algorithm was designed to solve the proposed model.

EXPERIMENTAL SECTION

Model description and hypothesis

The hazmat transprortaion nerwork contains one distribution center, some demand points, densely populated areas(such as school, residential area, and military administrative zone, etc.), and restricted areas. The delivery of customer demands has soft time window constraints. If demands delivered within the allowed time range, then the customer demands are regarded as completely satisfied. If there is a delay or advance delivery, then the customer satisfaction decline. When the delay or advance beyond a certain level, the customer satisfaction declines to zero. Vehicles travel through restricted areas need to seek help from government and formulate passing programs, and generate additional costs. The fewer total number of densely populated areas that vehicles have passed, the higher safety. However the pursuit of the best security may lead the transportation lines too long, increasing the transportation costs. So the comprehensive balance should be considered between satisfaction, safety and transportation costs. The primary problem to solve in this paper is to make rational disposition of travel routes, in order to realize the lowest cost, best security, and highest customer satisfaction of hazmat transportation.

Without loss of generality, the following assumptions are formed:1) Each customer demand for hazardous materials does not exceed the maximum capacity of vehicle. 2) Only consider one vehicle type, and the capacity of vehicle is known.3) The demands must be satisfied, and each customer only be served by one vehicle..

Notations

Notations we adopted in proposed model are given as follows:
Parameters:

$G=(N,A)$: hazmat transportaion network;

N : The set of nodes, including the set of customer points I and distribution center θ, $N=\{\theta\}\cup I$;

I : The set of customer points, $I=\{1,2,\ldots,|I|\}$;

θ : The distribution center;

A : The edge set in transportation network;

K : The set of vehicles, $k=1,2,\ldots,|K|$;

CAP : The loading weight limit of the vehicle;

f : The fixed cost of dispatch a vehicle;

$[a_i,b_i]$: The soft time windows of customer i, and a_i denotes the earliest allowable delivery time at customer i, b_i denotes the latest allowable delivery time at customer i ;

q_i : The demands of customer i ;

t_i : The time that vehicle arrives at the customer i ;

μ_i : Customer satisfaction at customer i. The value of μ_i depends on t_i. The relationship between μ_i and t_i can be expressed as triangular trapezoidal fuzzy function:

$$\mu_i(t_i)=\begin{cases}0, & t_i < a_i - \Delta\tau_i \\ e^{-(a_i-t_i)}, & a_i-\Delta\tau_i \le t_i \le a_i \\ 1, & a_i \le t_i \le b_i \\ e^{-(t_i-b_i)}, & b_i \le t_i \le b_i+\Delta\tau_i \\ 0, & t_i > b_i+\Delta\tau_i \end{cases} \quad (1)$$

In the above formula, $\Delta\tau_i$ denotes the parameter of the delay time or advance time at customer i when satisfaction decline to 0.

$d_{i,j}$: The distance between nodes i and nodes j ;

c_{ijk} : The unit transportation cost with vehicle k from nodes i to nodes j ;

$t_{i,j}$: The required transportation time from nodes i to nodes j ;

$P_{(i,j)}$: The set of restricted areas that vehicles travel through from nodes i to nodes j , $(i,j)\in A$;

$G^l_{(i,j)}$: The cost genetated by passing restricted area l from nodes i to nodes j ;

$V_{(i,j)}$: The set of densely populated areas t from nodes i to nodes j , $(i,j)\in A$;

∇ : A constant larger than the maximum customer satisfaction.

Decision variable:

x_{ijk} : Binary variable indicating whether vehicle k is selected into the path from nodes i to nodes j ;

p^l_{ijk} : Binary variable that equals 1 if vehicle k travel through restricted area l between nodes i and nodes j , and 0 otherwise;

v^l_{ijk} : Binary variable that equals 1 if vehicle k travel through densely populated area l between nodes i and nodes j , and 0 otherwise.

Model formulation

*MP*1

$$Z_1=\min\sum_{i\in I}\sum_{j\in I}\sum_{k\in K}d_{ij}\cdot c_{ijk}\cdot x_{ijk}+\sum_{j\in I}\sum_{k\in K}f\cdot x_{ojk}+\sum_{i\in N}\sum_{j\in N}\sum_{k\in K}\sum_{l=1}^{|P_{(i,j)}|}G^l_{(i,j)}\cdot p^l_{ijk}\cdot x_{ijk} \quad (2)$$

$$Z_2=\min\sum_{i\in N}\sum_{j\in N}\sum_{k\in K}\sum_{l=1}^{|V_{(i,j)}|}v^l_{ijk}\cdot x_{ijk} \quad (3)$$

$$\mathrm{Z}_3=\min\nabla-\sum_{\iota\in \mathrm{I}}\mu_\iota(t_\iota) \quad (4)$$

$$\sum_{i\in N}\sum_{k\in K}x_{ijk}=1,\ \forall j\in I \quad (5)$$

$$\sum_{j\in I}q_j\cdot\sum_{i\in I}x_{ijk}\le CAP,\ \forall k\in K \quad (6)$$

$$\sum_{j\in N}x_{ijk}-\sum_{j\in N}x_{jik}=0,\ \forall i\in N,\ \forall k\in K \quad (7)$$

$$t_i=t_j+t_{ij}\cdot x_{ijk},\ \forall i\in I,\ \forall k\in K \quad (8)$$

$$x_{ijk}=\{0,1\},\ \forall i,j\in N,\ \forall k\in K \quad (9)$$

$$p^l_{ijk}=\{0,1\},\ \forall i,j\in N,\ \forall k\in K,\ \forall l\in P_{(i,j)} \quad (10)$$

$$v^l_{ijk}=\{0,1\},\ \forall i,j\in N,\ \forall k\in K,\ \forall l\in V_{(i,j)} \quad (11)$$

The objective function (2) is to minimize the total distribution cost. In the formulation (2), the first term denotes the shipment and delivery cost, the second term denotes the total fixed costs of dispatch vehicles, the third term denotes the additional costs generated by vehicles travel through restricted areas. Expression (3) denote the minimum total amounts of densely populated areas which vehicles travel through, which means the lowest risk. The objective function (4) denotes the highest customer satisfaction. Constraints (5) enforce that each customer is assigned to only one vehicle. Constraint (6) states that the loaded weight of items is constrained by the limits of the truck. Constraint (7) states that vehicle must start from distribution center, and return to the starting point after the task is accomplished. Expression (8) denotes the time that vehicle arrives at the customer i. The (9)-(11) are binary constraints.

RESULTS AND DISCUSSION

Multi-target processing

The model *MP*1 established above is a multi-objective 0-1 integer programming model of hazmat transport vehicles scheduling. The vehicle routing problem (VRP) included in *MP*1 is a proved NP-hard problem. In order to solve this problem, the multi-objective problem should be converted to single objective problem. This paper adopts the following methods to transform the objective functions:

To realize uniform dimension, expression (12) is introduced here. $Z_i^{\min}$ and $Z_i^{\max}$ respectively represent the minimum value and maximum value of objection value i.

$$Z_i^{'} = \frac{Z_i - Z_i^{\min}}{Z_i^{\max} - Z_i^{\min}}, \quad i = 1, 2, 3 \tag{12}$$

The optimization of multiple objectives can be converted into that of single objective by weighting method. The weight of the three goals respectively denoted as ω_1, ω_2, ω_3. let:

$$\omega_1 + \omega_2 + \omega_3 = 1 \;\; 0 \le \omega_i \le 1, i = 1, 2, 3 \tag{13}$$

The comprehensive target value can be expressed as:

$$Z = \min \sum_i \omega_i \cdot z_i^{'}, \quad i = 1, 2, 3 \tag{14}$$

The model can be transformed into *MP*2：

$$Z = \min \sum_i \omega_i \cdot Z_i^{'}, \quad i = 1, 2, 3 \tag{15}$$

S.t. (5)-(13)

The hybrid genetic algorithm

The model *MP*2 is a 0-1 integer programming model, refers to the NP-hard problem, and it is difficult to solve. Genetic algorithm has a good convergence and robustness, becomes very mature to solve this kind of problem. Applying genetic algorithm to solve nonlinear 0-1 integer programming model can effectively reduce the possibility of sinking into local optima, and have a larger probability to get the best solution. Compared with the basic genetic algorithm, a multi-population mutation method is desired to solve multi-objective optimization problem. The method effectively avoids the internal competition between individuals. The concrete steps are shown as follows.

(1)Coding

Using the integer coding, and the customer service order is determined by chromosome codes. The vehicles are allocated by vehicle capacity. The length of each chromosome is $|I|$. Each gene in a chromosome is randomly generated in $[1, |I|]$.

Assuming there are 10 customers, the corresponding chromosome is shown in Figure 1. The distribution order of customer points is 10-8-2-3-1-3-4-7-6-9. In algorithm implementation process, vehicles are dispatched according to the vehicle capacity. Assuming the vehicle arrives at the 10-8-2, if continue to serve customer 3 will exceed the surplus capacity of the vehicle, then activate a new car.

10—8—2—3—1—4—5—7—6—9

←Chromosome→

Fig.1 Schematic diagram of coding

(2) Population initialization and the evaluation of objective functions
Assume $popsize$ is the size of chromosome, randomly generate initial populations. The objective value can be calculated by the expression (15) is a minimum value. Therefore, the fitness function is defined as $f_l = {1}/{Z_l}$, Z_l is the objective value of the chromosome l .

(3) Crossover and mutation
In order to prevent the error code in crossover and mutation process, Selecting the order crossover and partially matched crossover method, reverse mutation.

The order crossover and partially matched crossover: Firstly, randomly choose 2 chromosome P_1 , P_2 from the parent population. And randomly generate 2 integers between $[1,|I|]$, defined as bh_1 , bh_2 ($bh_1 < bh_2$). So the chromesome can be divided to the 3 sections: $[1,bh_1]$, $[bh_1+1,bh_2]$, and $[bh_2+1,end]$. Then, exchange the second section between P_1 , P_2. Afterwards, seek whether the same gene exists in section $[1,bh_1]$ of. If existence, replaced it with the corresponding gene in P_2. Then replace the same gene in section $[bh_2+1,end]$ by analogy. Lastly, repeat the above operation for chromesome P_2.

Reverse mutation: In the first place, randomly selected a chromosome P_3 from the parent population. Then, randomly generate an integer bh_3 between. And the chromesome can be divided to 2 sections: $[1,bh_3]$, $[bh_3+1, end]$. Finally, exchange the positon of the original gene and the last gene, to complete the reverse mutation operation.

(4) Selection
The selection in operated based on roulette mechanism.

(5) Stopping criteria
If the maximum number of iterations is reached, then stop and exit.

Computational results
A numerical example was given based on the background of literature [10]. There are some custmer ponts within the service area of a oil distribution center. Rational disposition of travel routes should be made in order to realize the lowest cost, best security, and highest customer satisfaction of hazmat transportation. The loading weight limit of each truck is 20 tons. The fixed cost of opening a new car is 800 yuan. There are 24 customers. And the parameter values such as position, demands, time windows, restricted areas and densely populated between any two nodes a are available from the literature [10].

The other parameters value involved in this article are set up as follows: $popsize = 100$, $p_c = 0.9$, $p_m = 0.05$, $\omega_1 = 0.3$, $\omega_2 = 0.3$, $\omega_3 = 0.4$, $\nabla = 1$, and the maximum number of iterations $\max gen = 1000$. The algorithm was coded in matlab2010ra tested on an Intel Pentium 1.60GHz processor with 2.0 GBs RAM under Windows 7. The relevant results of the oil distribution problem are provided as follows: The total time of program running is 77.21 seconds, the total cost is 38141.05 Yuan, the total number of densely populated areas that vehicles travel through is 52. 11 vehicles are needed to complete the distribution task. The far most distribution task starting from the distribution center to customer 14, then to serve customer 1 and customer 8, finally return to the distribution center. The expended time is 27.03 hours. The value of the customer satisfaction goal is 0.1436, the average customer satisfaction is more than 0.99 (Table 2).

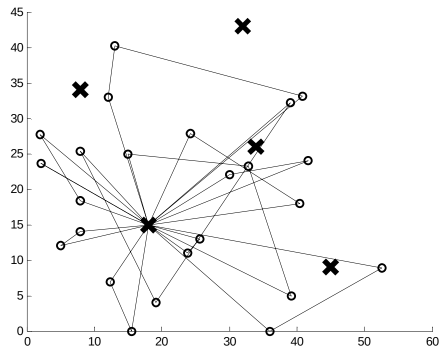

Fig.2 hazmat transportation routes

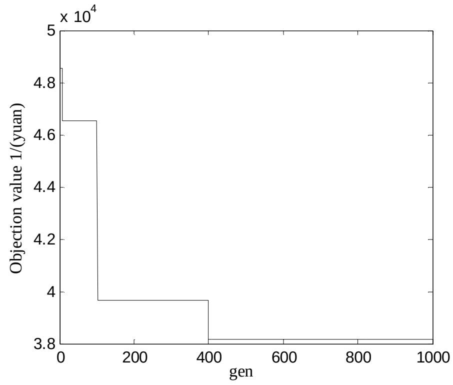

Fig.3 Convergence of objective function value 1

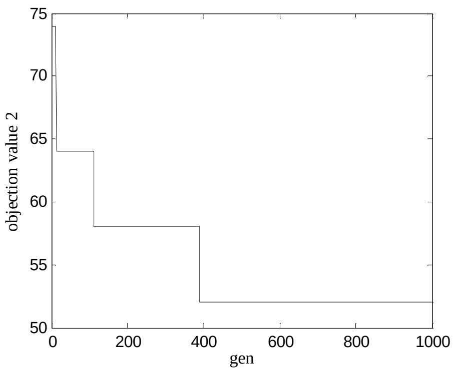

Fig.4 Convergence of objective function value 2

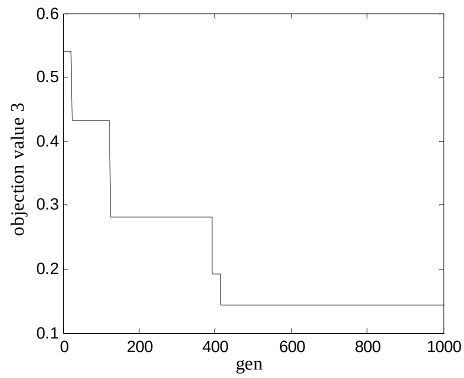

Fig.5 Convergence of objective function value 3

We can find that a satisfactory solution can be got in a short time from Fig.3- Fig.5. The algorithm has a good convergence. In addition, different sizes of test examples show that (Table 1), even for large scale problems, the calculate time can also be controlled in a relatively short period of time.

Table 1 The algorithm running time with different scales

number	Demand points	Time
1	10	31.13
2	20	52.44
3	24	77.21
4	30	81.56
5	50	103.29
6	80	159.34
7	100	211.23

Table 2 Transportation Vehicle Routing

Vehicle number	Concrete transportation line	Arrival time	Vehicle number	Concrete transportation line	Arrival time
1	0-13-4-0	0-2.37-12.01-16.59	**7**	0-17-24-0	0-4.94-14.44-17.02
2	0-10-19-12-0	0-2.17-15.04-23.22-26.65	**8**	0-16-15-0	0-4.59-9.90-12.08
3	0-22-11-9-0	0-1.79-8.15-11.97-14.63	**9**	0-2-23-0	0-3.01-15.52-20.87
4	0-21-7-0	0-3.43-8.68-11.41	**10**	0-18-0	0-6.47-12.95
5	0-14-1-8-0	0-4.84-14.12-21.26-27.03	**11**	0-6-0	0-1.32-2.64
6	0-5-3-20-0	0-2.83-9.29-13.61-16.52			

CONCLUSION

The safety, economy and customer satisfaction of the hazmat transportation were both considered in this paper, and a multi-objective vehicle scheduling model with soft time window constraints was built. Applying this model can avoid the obstacle that parameter difficult to obtain in risk-analysis-based models. And the model has a good applicability and operability. According to the proposed model, a hybrid genetic algorithm was designed to solve the problem.

This paper assumes that the demands of any customer are not exceeding the maximum capacity of the vehicle. Although this hypothesis conforms to the reality in many cases, but relax it will make the research more convenient. In addition, the assumption with deterministic demands can be relaxed too. The hazmat vehicle scheduling problem under the environment of uncertainty of Demand (random, fuzzy, and so on) should be further studied.

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