Design of A Freight Transport System for Highway Rest Areas

Hao Wen¹, Yufeng Liu², Sichao Lu³, Su Fei³,⁴*
¹Shanxi Transportation Research Institute Group Co., Ltd., Taiyuan, Shanxi, 030006, China
²Shanxi Transportation Holdings Group CO.,Ltd., Taiyuan, Shanxi, 030006, China
³China Transport Informatics National Engineering Laboratory Co., Ltd., Beijing, 100028, China
⁴China Transport Telecommunications & Information Center, Beijing, 100011, China
*Corresponding author’s e-mail: SUFEI@CTTIC.CN

Abstract. The rest area is an important place for travelers to have a rest. Therefore, it should be replenished with a variety of goods in time. This article introduces a freight transport system for highway rest areas, including conceptual framework, a mathematical model and its algorithm. The model has two objective functions which aim to minimize transport time as well as maximizing the priority value of highway rest areas. To solve this multi-objective optimization problem, a discrete firefly algorithm which was proposed to solve the multi-temperature joint distribution is extended. To validate the performance of the algorithm, simulation experiments are carried out and the experimental results show that the discrete firefly algorithm is effective for the problem.

1. Introduction
The highway rest area provides travelers and drivers a safe facility to have a rest. Therefore, basic supplies should be replenished timely. In the highway system, rest areas are far from each other and some items should be transported under cold environment. For decision makers in the logistics organization, reasonable load plans and routes of vehicles can reduce fuel cost as well as enhancing customer satisfaction. To cope with this problem, this article proposes a freight transport system for highway rest areas. Furthermore, a mathematical model and its corresponding algorithm which are key features of the system are developed and explained.

The rest of the paper is organized as follows: overview of the freight transport system is introduced in the next section, mathematical model of the freight transport problem for highway rest areas is proposed in Section III. The corresponding algorithm to the model is given in Section IV. Experiments are carried out in Section V. The conclusion is given in the last section.

2. Overview of the freight transport system for highway rest areas
In the freight transport system for highway rest areas, servers are built on a cloud platform. Through Hadoop and Spark, big data can be processed. Demand for goods can be predicted with Tensorflow, which is a popular open-source software for deep learning. Data visualization can be constructed conveniently via tools such as ECharts and Highcharts. The system has a variety of models such as the open vehicle route problem (OVRP) and the Multi-temperature joint distribution (MTJD) in the business intelligence module. Each model corresponds to a type of business model. When the inventory of rest
area drops below a threshold, the system can automatically generate load plans and vehicle routes for available refrigerated trailers.

Figure 1. Illustration of the freight transport system for highway rest areas

In the solution for perishable food cold chain management which was proposed by Lu and Wang [1], artificial intelligence techniques are used as a key enabling technique and a firefly algorithm based approach is introduced to solve the general perishable food loading problem. In this article, using a firefly algorithm to optimize the transport route is explained in detail.

3. Mathematical model of the freight transport problem for highway rest areas

The freight transport problem for highway rest areas can be regarded as a variant of the MTJD, which has two types that are dividing refrigerated compartment into several parts and use of standardized cold insulated equipment in regular vehicles. This article focuses on the first type of the MTJD.

With rapid growth of logistics in recent years, the MTJD has been increasingly studied. For example, Wang et al. [2] constructed two models of MTJD and developed an ant colony algorithm to solve them. Lu and Wang [3] proposed a clustered MTJD model and designed a discrete firefly algorithm as a solution approach.

In some cases, a few rest areas should be served with high priority due to emergencies or serious shortage of certain items. Furthermore, demands of rest areas might not be determined precisely. Therefore, based on former studies, this section proposes a new model to depict this scenario.

The proposed model consists of the following indices, parameters, and decision variables:

- \( V \): indexed on \( v=1,2,...,m \), denotes the set of refrigerated trailers.
- \( A \): indexed on \( i=1,2,...,n \), denotes the set of highway rest areas. (where \( i=0 \) denotes the starting point)
- \( T \): indexed on \( z=1,2,...,s \), denotes the set of freight types.
- \( d^z_i \): demand for \( z \) types of freight of rest area \( i \), it is considered as a triangular fuzzy number \( \tilde{d}^z_i = (\tilde{d}_{il}^z, \tilde{d}_{im}^z, \tilde{d}_{ir}^z) \).
- \( p_i \): priority of rest area \( i \). 0,1,2 denote normal, slightly urgent and urgent respectively.
- \( c^z_v \): capacity of trailer \( v \) for \( z \) types of freight.
- \( t_{ij} \): travel time between rest area \( i \) and \( j \).
- \( t_i \): the moment when a trailer arrives at rest area \( i \). (where \( t_0 \) represents the time when trailers depart from the starting point).
- \( u_i \): unloading time at rest area \( i \).
- \( M \): a large positive number.

- If vehicle \( v \) travels from rest area \( i \) to rest area \( j \) (\( i \neq j \)), then \( x_{ij}^v = 1 \); otherwise \( x_{ij}^v = 0 \).
- If rest area \( i \) is served by trailer \( v \), then \( y^v_i = 1 \); otherwise \( y^v_i = 0 \).

The mathematical formulation for the proposed model is given as follows:

\[
\min I = \sum_{j=1}^{n} \sum_{l=1}^{m} t_{lj} x_{ij}^v + \sum_{j=1}^{n} \sum_{v=1}^{m} u_i y^v_i
\]
The objective function (1) and the objective function (2) aim to minimize the total transport time and maximize the shipment priority respectively. Equation (3) and equation (4) ensure that all rest areas are visited only once. Equation (5) and equation (6) indicate that each route starts and ends at the same point. Equation (7) states that each rest area is visited by only one refrigerated trailer. Equation (8) states that each trailer starts its services from the starting point. Equation (9) and Equation (10) are used to represent the relationship between $x_{ij}^v$ and $y_{ij}$. Equation (11) guarantees that flow conservation is satisfied. Equation (12) and Equation (13) guarantees the consistency of time variables. Equation (14) indicates that the demand of each rest area can be satisfied. Equations (15)-(17) give range constraints on the decision variables.

Given that $d_{ij}^v$ is a triangular fuzzy number, it should be defuzzified before further step. There exist numerous methods regarding to fuzzification and defuzzification. References [4] and [5] uses the $k$-preference integration representation [6] for fuzzifying parameters in knapsack problems. In this article, it is used to defuzzify the demands of highway rest areas. Hence, the $k$-preference integration representation of $d_{ij}^v=(d_{ij}^{p\alpha}, d_{ij}^{p\beta}, d_{ij}^{p\gamma})$ can be defined as:

$$P_i(d_{ij}^v) = \frac{1}{3} [k^2 d_{ij}^{p\alpha} + 2d_{ij}^{p\beta} + (1-k^2)d_{ij}^{p\gamma}]$$

(18)

Based on Eq. (18), Eq. (14) becomes:

$$\frac{1}{3} \sum_{i=1}^{n} y_{ij}^v [k^2 d_{ij}^{p\alpha} + 2d_{ij}^{p\beta} + (1-k^2)d_{ij}^{p\gamma}] \leq c_{ij}^v, \quad \forall v \in A, \forall z \in T$$

(19)

The value of $k^2 \in [0,1]$ can be determined subjectively.

4. The discrete firefly algorithm

4.1. Overview of the algorithm

In recent years, the firefly algorithm has been quite popular and thus many variants of it have been developed. In reference [7], the inventor of the standard firefly algorithm extended it to solve multi-objective continuous optimization problems. Lu and Wang [8] proposed a discrete firefly algorithm to solve multi-objective knapsack problems. After observing the characteristics of the model proposed in this article, a new algorithm which blends the approaches in references [3] and [8] is introduced in this section.
4.2. Coding Method and light intensity

In the firefly algorithm, each firefly represents a solution. The set $X_f^f$ is used to represent the $f$-th solution vector, which indicates that the order of rest area $i$ visited by vehicle $v$ is $r_f$. The light intensity of firefly $f$ ($X_f^f$) is denoted by $I_t^f$ and $I_p^f$, which are values of objective function (1) and (2) respectively. Solution $X_f^f$ is said to be superior than solution $X_g^g$ if and only if $I_t^f \geq I_t^g$, $I_p^f \geq I_p^g$ or $I_t^f < I_t^g$, $I_p^f \leq I_p^g$.

4.3. Main Procedure

In the population initialization period, solutions are generated by using a greedy algorithm. For a rest area in any route, find the nearest rest area as the next visiting point with a probability $R_I$. A higher value of $R_I$ indicates a higher diversity of initial solutions. $P=\{X^1, X^2, \ldots, X^N\}$ are generated as the initial pareto set. When a new solution is obtained and no elements in $P$ is superior to it, the new solution is added to the pareto set $P$. Any element in $P$ will be removed if the new obtained solution is superior to it.

After initialization, the pseudocode of the iteration procedure is summarized as follows.

1: for $h=1$ to $H$
2:   for $i=1$ to $|P$
3:     for $j=1$ to $|P$
4:       if $(i \neq j)$
5:         calculate distance $r_{ij}$ between firefly $i$ and firefly $j$
6:         move firefly $i$
7:         add new firefly to $P$ or discard it
8:     end if
9:   end for
10: end for
11: end for

Get the arrival time series $t^i=(t_1^i, \ldots, t_n^i)$. $t_n^i$ denotes the time when rest area $i$ is visited. Reordering the elements of $t^i$ in ascending order to get $\theta^i$. Thus, the distance between any two fireflies $X^i$ and $X^j$ is determined by

$$r_{ij}=\sum_{h=1}^{n}(\theta_{h}^i - \theta_{h}^j)$$

(20)

The formula of how a firefly moves is shown in equation (21). InsertionFunction is detailed explained in reference [3]. $\gamma$ is the light absorption coefficient which affects the performance of the algorithm greatly.

$$X^i=\text{InsertionFunction}(X^i, r_{ij}/\gamma)$$

(21)

When the number of elements in pareto set $P$ exceeds $P_n$, the performance of the algorithm will degrade seriously. Therefore, the crowded-comparison approach in NSGA-II is used to remove solutions. According to reference [9], 50 fireflies could deal with almost all problems.

5. Simulation experiments

5.1. Parameter Settings

In this section, data of 30 highway rest areas in 4 clusters and 2 trailers are randomly generated for the following experiments. All the rest areas have corresponding $(x,y)$ coordinates, where $x \in [-55000, 81000]$ metres and $y \in [-40000, 40000]$ metres. The speed is set to be 1000m/min. Values of other critical parameters are given in table 1.
Table 1. Values of parameters involved in the experiments.

| Item | Descriptions | Values |
|------|--------------|--------|
| $z$  | freight types | 2      |
| $d_{ij}$ | demand for refrigerated freight, $d_{im} \sim U(0,0.3)$, $d_{it}^0 = 0.95d_{im}$, $d_{it}^0 = 1.05d_{im}$ |
| $d_{ij}$ | initial demand for general freight, $d_{im} \sim U(0,0.5)$, $d_{it}^1 = 0.95d_{im}$, $d_{it}^1 = 1.05d_{im}$ |
| $k_0, k_1$ | Parameters in defuzzification | 0.5 |
| $p_i$ | priority of rest area $i$ | $p_i \in \{0,1,2\}$ |
| $c_{1i}$ | capacity of trailer #1 for refrigerated freight | 3 |
| $c_{1i}$ | capacity of trailer #1 for general freight | 5 |
| $c_{2i}$ | capacity of trailer #2 for refrigerated freight | 4 |
| $c_{2i}$ | capacity of trailer #2 for general freight | 6 |
| $u_i$ | unloading time at rest area $i$ | $N(10,1)$ |
| $N$ | initial population size of fireflies | 20 |
| $P_i$ | limit of the population size | 60 |
| $\gamma$ | light absorption coefficient | 50 |
| $I_\tau$ | iteration limit | 1200 |

5.2. Experimental Results

The algorithm is implemented in C#, running 5 times on an Intel Core i5 CPU with 4GB RAM and Windows 10 system. Solution numbers and runtime of the experimental results are briefly shown in table 2.

Table 2. Experimental results.

| Problem instance no. | 1 | 2 | 3 | 4 | 5 |
|----------------------|---|---|---|---|---|
| $|P|$                  | 16| 53| 59| 50| 37|
| Time (seconds)       | 115| 126| 107| 144| 61|

Figure 2. Pareto front of the freight transport model for highway rest areas

To visualize the solutions for further investigation, Figure 2 illustrates the Pareto sets of the simulations. From the figure, it can be clearly seen that the algorithm can effectively optimize the model.
6. Conclusions
In this paper, a freight transport system for highway rest areas is designed. To optimize the routes of refrigerated trailers, we extend the discrete firefly algorithm in reference [3] as the solution approach. Simulation experiments show that the discrete firefly algorithm can optimize the routes of refrigerated trailers effectively.

Confined to time and page limit, this paper does not compare firefly algorithm with other algorithms. In the future, more algorithms could be designed and implemented to make comparisons with each other. Furthermore, how to improve the algorithm performance such as increasing diversity of solutions and reducing runtime requires consideration.

Acknowledgements
This work was financially supported by The National Key Research and Development Program of China(2017YFC0803900).

References
[1] Lu, S.C., Wang, X.F. (2016) Toward an Intelligent Solution for Perishable Food Cold Chain Management. In: IEEE 7th International Conference on Software Engineering and Service Science. Beijing. pp. 852–856.
[2] Wang, S.Y., Sun, H., Mou, J.J., Jin, H. (2016) Optimization and Efficiency of Multi-temperature Joint Distribution of Cold Chain Products: Comparative Study Based on Cold Accumulation Mode and Mechanical Refrigeration Mode. Journal of Highway and Transportation Research and Development, 33: 146–153.
[3] Lu, S.C., Wang, X.F. (2016) Discrete Firefly Algorithm for Clustered Multi-Temperature Joint Distribution with Fuzzy Travel Times. Int. J. Comput. Int. Sys., 11: 195–205.
[4] Changdar, C., Mahapatra, G.S., Pal, R.K. (2015) An improved genetic algorithm based approach to solve constrained knapsack problem in fuzzy environment. Expert Syst. Appl., 42: 2276–2286.
[5] Lu, S.C., Wang, X.F. (2016) Modeling the fuzzy cold storage problem and its solution by a discrete firefly algorithm. J. Intel. Fuzzy Syst., 31:2431–2440.
[6] Chen, S.H., Hsiech, C.H. (1998) A new method of representing generalized fuzzy number. Tamsui Oxford Journal of Management Sciences, 13-14:133-143.
[7] Yang, X.S. (2012) Multiobjective firefly algorithm for continuous optimization. Eng. Comput., 29:1–10.
[8] Lu, S.C., Wang, X.F. (2017) Optimizing a Tri-objective Fuzzy Agricultural Food Load Planning Problem for Point-to-point Short-haul Road Transportation with a Pareto-based Discrete Firefly Algorithm. Chem. Eng. Trans., 57:427–432.
[9] Gandomi, A.H., Yang, X.S., Alavi, A.H. (2011) Mixed variable structural optimization using Firefly Algorithm. Comput. Struct., 89:2325–2336.