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Abstract

Purpose – The purpose of this paper is to generate line plan in emergencies for railway networks to complete the passenger transportation.

Design/methodology/approach – The authors first build a mathematical model, focusing on the frequency setting and stops setting. Then, considering the OD passenger flow data, the authors first propose the method to solve the train frequency setting problem of different types. Genetic algorithm is designed to solve the stops setting problem. The approach is tested with the data from Beijing-Shanghai high-speed railway and its neighbour existing railway.

Findings – The authors find that the model is suitable to generate line plan in emergencies for railway networks and the algorithm has good calculating performance.

Originality/value – The new algorithms to generate line plan proposed in this paper can be embedded in the decision support system for railway operators.

Keywords Emergencies, Line planning, Railway networks

Paper type Research paper

Introduction

Train planning plays a critical role in operating and managing railroad systems. The planning problem faced by every railway operator consists of several consecutive stages, ranging from strategic decisions concerning, e.g. the acquisition of rolling stock, to operational traffic control. Strategic problems are largely driven by estimates for the long-term demand and constrained by the capacity of the lines. Line planning is the tactical step of the whole planning process as shown in Figure 1, which follows the basic step-demand estimation and capacity calculation. And line planning problem can be divided into three steps, train pathing, train frequency setting and train stops setting.

High speed railway is developing very fast today, which has already improved the topology structure of the railway network. Thus, a modern railway network is being

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built, including the newly built high speed railway and previously built railway. Accordingly, there are two types of rails, high speed rail and normal speed rail, and there are links between them at some important railway intersections, providing the possibility to allow the trains to transfer from one kind of rail to another. In addition, it provides more space to permit the railway managers to route the trains more freely.

Moreover, natural disasters affect railways with characteristics of universality, frequency and variety in recent years. Furthermore, railway accidents occur occasionally, which reduce the capacity of the railway line and degrade the safety and efficiency of the passenger and freight transportation. Objective research into the line planning problem in these emergencies is therefore required.

In this paper, we focus on the line planning problem on the railway network. In Section 1, we take a review of the research publications on the problem. In Section 2, we build the model to generate the line plans under condition of disasters. We propose the method to solve the model built in Section 3. A computing case is presented to analyse the model correctness and the effectiveness of the algorithms in Section 4. In the last section, we draw the conclusion.

1. Related works

A line refers to a cyclic schedule of a set of trains on a particular route and direction of travel. City traffic (metro) lines are typically planned for a day duration and long-distance passenger traffic lines are planned for anywhere between a day to a week. Line planning is considered a strategic railway operation because of the longer planning phase. There is much research work online planning problem. Guihaire and Hao (2008) presented a global review of the crucial strategic and tactical steps of transit planning: the design and scheduling of the network. They separated the papers about line planning into four groups according to different approaches.

The first group uses the mathematical approaches. Murray (2003) studied two variations of line planning problem. In the first part, the relocation of stops stations in an existing network is considered with the objective of minimizing the number of stops. The second part deals with the optimal location of stops to create or extend the network. Given a fixed number of additional stops to locate, the objective is to maximize the extra service access provided to non-covered areas. An integer linear programming model is developed for line planning to satisfy customer demands. A relaxation approach using branch and bound heuristic is also proposed (Bussieck, 1998). Lindner (2000) proposed a cost optimal model for line planning using branch and bound method. Carey and Lockwood (1995) presented a strategic model and algorithm using branch and bound for pathing an additional train in an existing schedule.

The second group exploits the heuristic approaches. Patz (1925) was probably the first to tackle the transit network design problem using heuristics. He put forward an iterative procedure to generate a lines network using penalties. Initially, the network contained a line for each origin – destination pair. Sonntag (1977) presented a heuristic procedure originally created for line planning problem of railway systems.

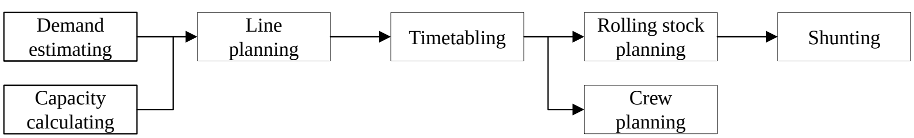

Figure 1.
Steps of the whole planning process of railway transportation

Mandl (1979) tackled the line plan starting with an empty routes network. He proposed a heuristic algorithm to define a transit network given a constant frequency on all bus lines. Jovanovic and Harker (1991) reported heuristic and meta-heuristic approaches to scheduling of railway traffic. Ghoseiri and Morshedsolouk (2006) also proposed a heuristic approach to solve the train scheduling problem, utilizing colony system. Michaelis and Schöbel (2009) integrated line planning, timetabling and vehicle scheduling and designed a customer-oriented heuristic approach.

Neighborhood search approaches are introduced in the third group of publications. An aggregated metaheuristic approach to the transit network design problem is considered by Zhao and Ubaka (2004) and Zhao and Zeng (2006) with the objective of minimizing the number of transfers and optimizing route directness while maximizing service coverage. The concept of keynote is defined to elaborate neighbourhoods in the context of met heuristics solution methods. An integrated simulated annealing, Tabu and Greedy search algorithm is proposed by Zhao and Zeng (2006) while basic greedy search and fast hill climb search are implemented by Zhao and Ubaka (2004). These algorithms were tested on benchmark instances and on data from Miami Dade County, Florida.

The fourth group uses evolutionary algorithms. Xiong and Schneider (1993) presented an innovative method to select supplementary routes for an existing network. Their method is based on an improvement on the ordinary genetic algorithm (GA), called the cumulative GA. Chakroborty and Dwivedi (2002) also proposed a GA based on this method. An initial set of routes are determined heuristically, then a process which consists of an evaluation and modification procedure is repeated to obtain the optimal solution.

The references provide us many approaches to solving the line planning problem under conditions of disasters and give us much important inspiration on building the model and designing the algorithm.

2. Modelling for line planning in emergencies

Much research work has been done on the transportation organization pattern of the high speed train. There are two patterns under the normal condition:

(1) The high speed trains run only on the high speed railway lines. They cannot transfer from high speed rail to the normal speed rail and the normal speed trains cannot transfer from normal speed rail to high speed rail.

(2) The high speed train can switch from high speed rail to normal speed rail and run jointly with the normal speed train, but the normal speed trains cannot transfer from normal speed rail to high speed rail.

Emergencies may break the high speed railway and affect the train operation seriously. Therefore, it is necessary to allow the trains to switch to normal speed railway under such situation. In addition, the links between the high speed railway and the normal speed railway become essential.

2.1 Basics of the model

The sets and variables are listed below:

W the number of the stations in the railway network.

M the number of the segments in the railway network.

S	node (station) set.
E	edge (segment) set.
O	a subset that covers all the stations that can play the role of starting station.
D	a subset that covers all the stations that can play the role of terminal station.
$q^{u,v}$	OD flow between station u and station v.
B	the number of the train grades.
k	the grade of the trains determined by running speed.
$q_k^{u,v}$	the number of passengers transported from station u to station v by k type of train.
$l_k^{u,v}$	the number of the k type trains from station u to station v.
A_k^c	the seating capacity of the k type train.
σ^i	the capacity of station i.
ξ^i	the capacity of segment i.
$\lambda_{k,i}^{u,v}$	a flag variable to denote whether k type of trains pass through station i.
$\eta_{k,i}^{u,v}$	a flag variable to denote whether k type of trains pass through segment i.
$d_k^{u,v}$	the distance of the path that k type trains run from station u to station v.
$\mathrm{T}_{turnover}$	time consumed to finish the valid passenger transpiration.
$t_{k,r}^{u,v}$	time consumed for k type trains running from station u to station v.
$t_{k,d}^{u,v}$	time consumed for k type trains dwelling at stops on the path from station u to station v.
$\varsigma_k^{u,v}$	the number of the k type available rolling-stock from station u to station v.

The railway network is described with $G = (S, E)$. k denotes the grade of the trains separated by the speed.

We take it for granted that the same kind of trains take the same path from a starting station to another. Then we set:

$$\lambda_{k,i}^{u,v} = \begin{cases} 1, & k\text{th type trains pass through station } i, \\ 0, & k\text{th type trains do not pass through station } i. \end{cases} \tag{1}$$

$$\eta_{k,i}^{u,v} = \begin{cases} 1, & k\text{th type trains pass through segment } i, \\ 0, & k\text{th type trains do not pass through segment } i. \end{cases} \tag{2}$$

2.2 Building line plan generating model

(1) Optimizing objective. There are three main objectives for the line plan-generating model. One is the profit of the railway bureau. The other is the profit of the passengers. The detailed objectives are as follows:

(1) *To maximize the profits of the railway bureau.* The profit is related to the tickets revenue, the transport device loss and the cost in the train operations.
(2) *To minimize the cost of the travel for the passengers.* The cost of the passengers includes time and money, which make it a requirement for the passengers that they spend the minimum money and minimum time to complete the travel for the line plan. The problem concerns the ticket price, stops plan, transferring time, line connection and comfort degree on trains.
(3) *To maximize the number of passengers served.* It is related to the coefficient of utilization of the railway capacity.

We take the passenger distribution efficiency as the optimizing objective in the emergencies. When an accident happens, it will decrease the transport capacity and may create gigantic passenger backups. Meanwhile, the safety of the passengers should be guaranteed. Thus, profits of the railway bureau are no longer the optimizing objective. To distribute the passengers as quickly as possible is the goal. Passenger distributing efficiency is defined in equation (3):

$$Q'(u,v) = \frac{\sum_{k=1}^{B} q_k^{u,v} d_k^{u,v}}{\mathrm{T}_{turnover}} \tag{3}$$

$\mathrm{T}_{turnover}$ denotes time consumed to finish the valid passenger transportation, which can be calculated in equation (4):

$$\mathrm{T}_{turnover} = \mathrm{T}_{run} + \mathrm{T}_{stop} = \sum_{u\in O}\sum_{v\in D}\sum_{k=1}^{B} l_k^{u,v} t_{k,r}^{u,v} + \sum_{u\in O}\sum_{v\in D}\sum_{k=1}^{B} l_k^{u,v} t_{k,d}^{u,v} \tag{4}$$

where T_{run} is the time consumed by all the trains to run from their own starting station to terminal station; T_{stop} denotes the time consumed to make a stop at the stations.

(2) Constraints. There are many constraints in the line planning problem, especially in emergencies. We choose the most important constraints carefully as follows:

$$\sum_{k=1,2} q_k^{u,v} = q^{u,v}, \quad u \in O,\ v \in D \tag{5}$$

$$\frac{q_k^{u,v}}{l_k^{u,v}} \le 1.3A_k^c, \quad u \in O,\ v \in D,\ k = 1,2 \tag{6}$$

$$\sum_{u\in O}\sum_{v\in D}\sum_{k=1}^{B} \lambda_{k,i}^{u,v} l_k^{u,v} \le \sigma^i, \quad i = 1,2,\ldots,W \tag{7}$$

$$\sum_{u\in O}\sum_{v\in D}\sum_{k=1}^{B} \eta_{k,i}^{u,v} l_k^{u,v} \le \xi^i, \quad i = 1,2,\ldots,M \tag{8}$$

$$l_k^{u,v} \le \varsigma_k^{u,v}, \quad u \in O,\ v \in D,\ k = 1,2 \tag{9}$$

$$l_k^{u,v} \in N^+, \quad u \in O,\ v \in D,\ k = 1,2 \tag{10}$$

Equation (5) denotes that the number of passengers allocated to each train is equal to the number of passengers forecasted to be transported. Equation (6) ensures that the load ratio of the trains cannot exceed 130 percent. Equation (7) denotes that the station capacity of approaching trains must be bigger than the designed sending task in the line plan. Equation (8) requires that the number of trains passing through a certain segment designed in the line plan must be smaller than its technical capacity. Equation (9) is a transportation resource constraint that requires the train number cannot be bigger than the number of rolling-stock. Equation (10) requires the number of the trains to be a positive integer. N^+ is the set of positive integers.

3. Solving the line plan generating model under condition of accident

We divide the solving process into two steps. The first one is to calculate the train numbers of different types. The second is to determine the stops of the trains.

3.1 Determining the frequency of the different types of trains

(1) Design of the types of trains. The railway network is constructed by the high speed railway and normal speed railway, and the trains are divided into two types, the high speed trains and the normal speed trains.

The high speed trains can transfer from the high speed railway to normal speed railway and the normal speed trains are not allowed to transfer on the high speed rail and the intercity rail, taking the capacity coefficient of utilization into consideration. Moreover, the speed of high speed trains may be affected by the rails that they run on.

(2) Calculating the numbers of trains of different types. There is a widespread rule to design the number of the trains on the segments. That is to calculate the number of the trains according to the number of the passengers. The equation to calculate the number of the trains is as follows:

$$l_k^{u,v} \geq \frac{q_k^{u,v}}{(1+\alpha)A_k^c} \tag{11}$$

In emergencies, a certain degree of overload is allowed on the train to transport the passengers as quickly as possible. α is the overload ratio. We set the overload ratio to be 0.3 according to the Chinese railway passenger transportation policy. Then the equation is innovated to be:

$$l_k^{u,v} \geq \frac{q_k^{u,v}}{1.3A_k^c} \tag{12}$$

Generally, the train number must be an integer, so the k type train number is:

$$l_k^{u,v} = INT\left(\frac{q_k^{u,v}}{1.3A_k^c}\right) + 1 \tag{13}$$

where INT is a bracket function.

3.2 Designing the stops of the trains

It is very hard to select the stops of a train since the stops selection is influenced by numerous factors. We use a GA to solve it, with 0 representing that a train does not stop at a station and 1 denoting that the train stops at a station. The searching space is very large and there are many decision variables. The heuristic algorithm is therefore suitable for solving this problem. The steps of the algorithm are as follows:

(1) design the code of the problem;
(2) initialize the population $X(0) = (x_1, x_2, \ldots, x_L)$;
(3) calculate the value of adaptive function $F(x_L)$ of each chromosome in population $X(t)$;
(4) create the middle generation $X(t)$;
(5) create the new generation $X(t+1)$ based on the middle generation $X(t)$; and
(6) set $t = t + 1$; if the exiting condition does not exist, go step (4).

The algorithm designed for the train stops setting problem is as follows.

(1) Coding of the problem. Coding is to express the feasible solution as a characteristic string, which can describe the characteristics of the problem. And the codes are required to be easy to deal with. The train stops can be coded as a string and there is a 0 or 1 at each bit. 0 denotes that the train will not stop at a certain station and 1 denotes that it will. When the strings of all the trains are linked, a chromosome is formed.

In this paper, the code of k type trains stops is designed as a one-dimensional array x_{L_k}. The length L_k is:

$$L = m_k^{u,v} \tag{14}$$

$m_k^{u,v}$ denotes the number of the stops when k type trains run from station u to station v.

Then the population size of the chromosome is:

$$pop\_size = \sum_{u \in O} \sum_{v \in D} \sum_{k=1}^{B} l_k^{u,v} m_k^{u,v} \tag{15}$$

The code of a chromosome is constructed as shown in Figure 2.

(2) Initialization of the population. Initialization of the population is to construct the original population as the initial solution to the problem. To create the population of the initial solution is to generate *pop_size* chromosome, which is shown in Figure 2. And it is a constraint to meet the station capacity requirement. So it is necessary to judge whether the capacity constraint is satisfied during the process of generating the initial solution.

(3) Evaluation of the population. It is essential to evaluate the population to judge the quality of the population. The index is the value of the adaptive function. The adaptive function value is the symbol of the adaptability of the chromosome. The bigger the function value is, the more opportunities to survive the chromosome will have. The adaptive function and the objective function are closely related to each other. The objective function can be seen as the mutation of the adaptive function. Generally speaking, the adaptive function can be used as the objective function when the objective function is non-negative or the problem is to maximize the objective function value. When the goal is to minimize the objective function value, the objective function

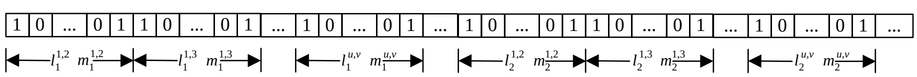

Figure 2.
Coding representation

can be designed as the difference between a large enough number and the adaptive function. In this paper, passenger distributing speed is taken as the objective function and it is non-negative. It is a maximal optimizing problem, so the adaptive function is designed to be equal to the objective function.

(4) Selection. Selection is to select an outstanding chromosome from a generation and pass its excellent gene to the next generation. The roulette method is often adopted in programming. The roulette method is a proportion strategy. Its main idea is to select the chromosome according to the adaptive function value. The four steps of roulette are as follows:

(1) Calculate the adaptive value $eval(c_h)$ of every chromosome c_h:

$$eval(c_h) = f(x); \quad h = 1, 2, \ldots, pop\_size \tag{16}$$

(2) Calculate the summary of the adaptive value of all the chromosomes:

$$F = \sum_{1 \leq h \leq pop\_size} eval(c_h) \tag{17}$$

(3) Calculate the selecting probability p_h of chromosome c_h:

$$p_h = \frac{eval(c_h)}{F}; \quad k = 1, 2, \ldots, pop\_size \tag{18}$$

(4) Calculate the accumulated probability r_k of every chromosome c_h:

$$r_h = \sum_{1 \leq j \leq h} p_j; \quad h = 1, 2, \ldots, pop\_size \tag{19}$$

Then a plate is formed and it is cycled for *pop_size* times. Every time one chromosome is selected to create the new generation:

- generate a pseudo-random number $z \in [0, 1]$; and
- if $z \leq r_1$, then select the first chromosome c_1, otherwise, to select the hth chromosome c_h to meet the requirement $r_{h-1} \leq z \leq r_h$.

(5) Crossover. The crossover operation includes one-point crossover, multi-point crossover, part – crossover and, etc. In this paper the one-point crossover is hired. The operation steps are as follows:

(1) select a single point as the starting point randomly from two father chromosomes; and
(2) exchange values at the same places from the starting point till the end of the chromosomes, generating two different chromosomes.

(6) Mutation. The task of the mutating is to change the value of a specified bit. In this paper, mutating is to negate on the bit. That is to say, to change 1 into 0 and 0 to 1. It has two steps. The first step is to select a place to determine the bit to execute mutation operation. The second is to execute the negating operation. Then the new generation is created after steps (2)-(6).

(7) Judge if the loop can be cancelled. If yes, then exit, or else go step (2).

4. Simulation example

4.1 Assumption of the case

We suppose that a serious accident happens at the segment on the high speed rail between Xuzhou and Bengbu. The task is to design a line plan for the next day. The passenger OD flows between the stations in this accident are calculated and forecasted based on the historical data and the negative effects of the accident at that time. The OD flows data are listed in Table I. The numbers of rolling-stock available for the paths in the accident are shown in Table II(a). The emergency will last for three days and it requires the running speed to be reduced to 40 km/h in section between Xuzhou and Bengbu. Other sections are not affected by the emergency. The window time is set to be 240 min in the emergency for the workers to overhaul the railway equipment to assure safety. Under normal condition, the interval time between the departure times of two trains must be longer than 6 min on the normal rail in Chinese railway system. The maximum speed is 160 km/h. And the interval time on the high speed rail must be longer than 5 min. The maximum speed is 350 km/h. According to the method that we proposed (Meng *et al.*, 2012), we calculated the sections capacities and got the stations capacities with the help of the dispatchers from Shanghai Railway Bureau. The capacities are shown in Table II(b) and (c). In this case, number of train grades $B = 2$.

4.2 Available paths

The railway lines around are shown in Figure 3. Paths found for the trains are as follows:

- Xuzhou (high speed rail) – Bengbu (normal speed rail) – Nanjing;
- Xuzhou (normal speed rail) – Bengbu (normal speed rail) – Nanjing;
- Xuzhou (high speed rail) – Bengbu-Huinan-Hefei (high speed rail) – Nanjing;
- Xuzhou (high speed rail) – Bengbu-Huinan-Hefei (normal speed rail) – Nanjing;
- Xuzhou (normal speed rail) – Bengbu-Huinan-Hefei (high speed rail) – Nanjing;
- Xuzhou (high speed rail) – Bengbu-Huinan-Hefei (high speed rail) – Nanjing;
- Xuzhou-Shangqiu-Fuyang-Huainan-Hefei (high speed rail) – Nanjing;
- Xuzhou-Shangqiu-Fuyang-Huainan-Hefei (normal speed rail) – Nanjing; and
- Xuzhou-Xinyi-Yangzhou-Nanjing.

According to the paths above and the stations characteristics, we design the OD pairs that can be the starting stations and terminal stations, which are as follows:

Table I.
Forecasted OD flows of passenger in a day between stations in the accident

	Xuzhou	Shangqiu	Bengbu	Xinyi	Yangzhou	Fuyang	Huainan	Hefei	Nanjing
Xuzhou	–	9,644	13,918	4,548	246	1,205	247	2,164	85,808
Shangqiu		–	4,329	2,164	494	767	2,630	2,877	4,548
Bengbu			–	115	0	98	493	3,836	6,339
Xinyi				–	493	88	0	130	493
Yangzhou					–	79	90	110	1,918
Fuyang						–	5,507	4,795	1,671
Huainan							–	4,740	1,644
Hefei								–	4,329
Nanjing									–

(a) Number of rolling-stocks available for the paths in the accident		
	Number of rolling-stocks	
Running segments	*H*	*N*
Xuzhou-Shangqiu-Fuyang-Huainan-Hefei-Nanjing	0	10
Xuzhou-Xinyi-Yangzhou-Nanjing	0	10
Xuzhou-Bengbu-Nanjing	60	5
Shangqiu-Xuzhou-Bengbu-Nanjing	0	5
Shangqiu-Xuzhou-Bengbu	0	10
Bengbu-Huainan-Hefei	0	10
Fuyang-Huainan-Hefei	0	10
Hefei-Nanjing (high speed rail)	15	5
Xuzhou-Shangqiu	0	10
Xuzhou-Bengbu (high speed rail)	0	10
Xuzhou-Xinyi	0	12
Xuzhou-Shangqiu-Fuyang-Huainan-Hefei	0	8
Shangqiu-Xuzhou-Xinyi	0	5
(b) Section capacity in the accident		
Railway segments	*Capacity*	
Xuzhou-Xinyi	98	
Xuzhou-Shangqiu	200	
Xuzhou-Bengbu (normal speed rail)	200	
Xuzhou-Bengbu (high speed rail)	50	
Xinyi-Yangzhou	98	
Yanzhou-Nanjing	98	
Shangqiu-Fuyang	98	
Fuyang-Huainan	98	
Huainan-Hefei	98	
Heifei-Nanjing	200	
Bengbu-Huainan	98	
Bengbu-Nanjing (normal speed rail)	200	
Bengbu-Nanjing (high speed rail)	240	
(c) Station capacity in the accident		
Xuzhou (on normal speed railway)	125	
Xuzhou (on high speed railway)	298	
Xinyi	65	
Yangzhou	72	
Nanjing (on normal speed railway)	180	
Nanjing (on high speed railway)	320	
Shangqiu	80	
Fuyang	165	
Huaian	72	
Hefei (on normal speed railway)	125	
Heifei (on high speed railway)	240	
Bengbu (on normal speed railway)	106	
Bengbu (on high speed railway)	160	

Table II.
Basic data of the railway network in the emergency

- Xuzhou-Nanjing;
- Xuzhou-Shangqiu;
- Xuzhou-Bengbu;
- Xuzhou-Xinyi;
- Xuzhou-Hefei;

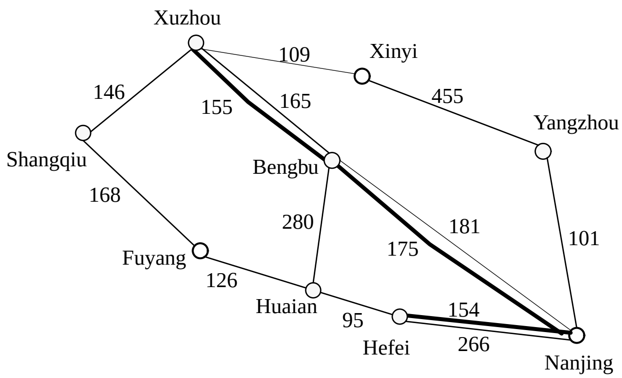

Figure 3. Affected part of the railway network in the emergency in this case

Notes: The thicker lines stand for high-speed railway lines and the thinner lines stand for normal speed railway lines; the numbers besides the lines are the lengths of the railway sections (measurement unit: km)

- Shangqiu-Nanjing;
- Shangqiu-Bengbu;
- Bengbu-Hefei;
- Fuyang-Hefei;
- Hefei-Nanjing; and
- Shangqiu-Xinyi.

The paths between the OD pairs are shown at the left side of Table III.

Table III. Train operation plan for segment Xuzhou-Bengbu

Running segments	H	N	Stop plan
Xuzhou-Shangqiu-Fuyang-Huainan-Hefei-Nanjing	0	3	One NST stops at Fuyang, one NST stops at Hefei, the last has no stops
Xuzhou-Xinyi-Yangzhou-Nanjing	0	3	One NST stops at Yangzhou, one NST stops at Xinyi. The other has no stops
Xuzhou-Bengbu-Nanjing	50	4	Eight HSTs stop at Bengbu
Shangqiu-Xuzhou-Bengbu-Nanjing	0	3	All stop at Xuzhou
Shangqiu-Xuzhou-Bengbu	0	3	All have no stops
Bengbu-Huainan-Hefei	0	2	One stops at Huainan
Fuyang-Huainan-Hefei	0	6	Three NSTs stop at Huainan
Hefei-Nanjing (high speed rail)	9	0	All have no stops
Xuzhou-Shangqiu	0	3	All have no stops
Xuzhou-Bengbu (high speed rail)	0	5	All have no stops
Xuzhou-Xinyi	0	4	All have no stops
Xuzhou-Shangqiu-Fuyang-Huainan-Hefei	0	3	Two NSTs stop at Shangqiu
Shangqiu-Xuzhou-Xinyi	0	2	Both have no stops

Notes: [a]H represents high speed trains and N represents normal speed trains in this table; NST – normal speed train; HST – high speed train

4.3 Frequency setting and stops setting for this case

In this paper, a high speed train contains 16 cars and its seating capacity is 1,200. The normal speed train contains 17 cars and has the seating capacity of 1,400. We first get the forecasted OD flows of passenger data between stations, shown in Table I. According to the methods of the previous section, we calculate the number of the two types of the trains based on the passenger data. The computing results are shown in Table III. We set the crossover probability to be 0.6 and mutation probability to be 0.1. The maximal iteration number is 1,000.

The adaptive function raised value to its peak value 263,100 after 580 iterations. Then we get the stops plan through interpreting the best chromosome. The stop plan is shown at the right side of Table III.

4.4 Analysis of the computing results

According to the computing results, the high speed trains are located for the OD pairs of Xuzhou and Nanjing, Hefei and Nanjing. This is because that high speed rail exists between the two pairs of OD stations. And we can see that there is no normal speed train from Hefei to Nanjing because there is not so many passenger OD from Hefei to Nanjing and the goal is to improve the transportation speed. Other OD pairs all have the normal speed trains to meet the passengers' journey requirements of going out.

Fifty high speed trains will be sent from Xuzhou to Nanjing. The foremost reason is that the OD flow between Xuzhou and Nanjing is great that requires so many trains to transport the passengers. Another reason is that the goal is to improve the transportation efficiency, so the number of high speed trains is 50, which is much bigger than the number of the normal speed trains. Furthermore, we can see that the number is equal to the capacity of the section between Xuzhou and Bengbu. The solution makes extensive use of the section capacity.

On the path Xuzhou-Shangqiu-Fuyang-Huainan-Hefei-Nanjing, three trains are designed to finish the passenger transportation task. Two of them are set to stop at the intermediate stations. On the path Fuyang-Huainan-Hefei, there are six trains allocated, and three of them have a stop at Huainan. This is because that the OD flow between Fuyang and Huainan is 5,507 and the OD flow between Huainan and Hefei is 4,740. These are quite large OD flows. For the same reason, two of three trains designed on the path Xuzhou-Shangqiu-Fuyang-Huainan-Hefei stop at Shangqiu station.

From the analysis above, we can see that the computing results are reasonable which can prove the validity of the model. It demonstrates that we can generate the feasible line plan for a local railway network in emergencies with the model and the algorithm.

5. Conclusion

In this paper, a method is presented for line planning in emergencies for the railway network. We divided line planning into two steps. The first is to calculate the number of different types of trains. The second is to determine the stops of the trains along the railway line.

The above computational results and analysis show that it is practical to use the model presented to describe the line planning problem on the railway networks in emergencies, and the computational results of a two-step solution algorithm are satisfied. It also shows that the method to calculate the train numbers of different types is feasible and efficient. The GA is successfully introduced in train stops setting, which is very easy to understand and realize. The stop plan designed based on the approaches in this paper meets the demand of most of the passengers in emergencies.

Future research is directed toward a generation of the model to line planning for the railway on a more complex network, not only under the situation of emergencies but also under normal conditions. Line planning problem on a larger scale railway network can also be described by the model presented in this paper. For dealing with the more complex line planning problem, extensions of the model with modular and hierarchical could be studied and utilized in the future research work.

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