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A two-layer optimization model for high-speed railway line planning*

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Abstract: Line planning is the first important strategic element in the railway operation planning process, which will directly affect the successive planning to determine the efficiency of the whole railway system. A two-layer optimization model is proposed within a simulation framework to deal with the high-speed railway (HSR) line planning problem. In the model, the top layer aims at achieving an optimal stop-schedule set with the service frequencies, and is formulated as a nonlinear program, solved by genetic algorithm. The objective of top layer is to minimize the total operation cost and unserved passenger volume. Given a specific stop-schedule, the bottom layer focuses on weighted passenger flow assignment, formulated as a mixed integer program with the objective of maximizing the served passenger volume and minimizing the total travel time for all passengers. The case study on Taiwan HSR shows that the proposed two-layer model is better than the existing techniques. In addition, this model is also illustrated with the Beijing-Shanghai HSR in China. The result shows that the two-layer optimization model can reduce computation complexity and that an optimal set of stop-schedules can always be generated with less calculation time.

Key words: Line plan, Stop-schedule, Passenger assignment, High-speed railway (HSR)
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1 Introduction

Generally, line planning is a procedure of allocating trains with specific travel demands of many origins and destinations to appropriate lines or line sections. As the basis of successive decisions, such as rolling stock planning and timetable planning, line planning is a classical optimization problem in order to obtain stop-schedules and service frequencies.

Today, China is extensively developing the infrastructure of a high-speed railway. The target is to cover its major economic areas with a high-speed railway (HSR) network, with four horizontal and four vertical lines in the next several years. The network scale is much larger than any existing ones in the world. Considering the high train speed and high train frequency of this railway, the impact of capacity loss would be more serious than on existing lines (in this paper, the existing non-high-speed railway line is called existing line for short). On the other hand, high-speed lines are more passenger-oriented than existing lines (Mo *et al*., 2011), where serving different types of passengers, such as regional, interregional, and intercity, is extraordinarily important. Thus, line planning, as the basis of more detailed planning problems, such as the construction of timetables, rolling stock planning, and crew scheduling, is of great theoretical and practical significance for safe and efficient operation of China's HSR network.

The literature describes the line planning problem in two ways. One is to find train routes and service frequencies in the railway network. Most papers focus on balancing the train route and passenger line assignment to reduce the passenger transfer times

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(Baaj and Mahmassani, 1991; Bussieck, 1998; Nielsen, 2000; Chakroborty and Wivedi, 2002; Poon *et al*., 2004; Pfetsch and Borndorfer, 2005; Cepeda *et al*., 2006; Goossens *et al*., 2006; Guan *et al*., 2006; Borndŏrfer *et al*., 2007; Hamdouch and Lawphongpanich, 2008; Schmŏcker *et al*., 2008; Laporte *et al*., 2010; Schmŏcker *et al*., 2011). The objective is to find a set of routes that maximizes the number of direct travelers from a service perspective or minimizes the operational costs from the railway company perspective. The other is to optimize halting stations with a given route between an origin and a destination stations (Goossens *et al*., 2004b; Deng *et al*., 2009), and the objective is to reduce total travel time. Chang *et al*. (2000) developed a multi-objective programming model for the optimal allocation of passenger train services on an intercity high-speed rail line without branches. For a given travel demand and a specified operating capacity, the model is solved by a fuzzy mathematical programming approach to determine the best train service plan, including the train stop-schedule plan, service frequency, and fleet size. However, this may be feasible for short rail lines with few stations, but is not adaptable to long rail lines with dozens of stations. Complex computation is also a significant problem in this model.

Many different algorithms for line planning have been put forward. The integer programming (Goossens *et al.*, 2004a; Guan *et al*., 2006; Borndŏrfer *et al*., 2007), such as branch and bound, and other traditional optimization methods, are usually used for train route optimization and passenger assignment. In recent years, some computational intelligence methods, like genetic algorithm (GA) and particle swarm optimization algorithm, have also been used to solve the large-scale combinatorial optimization problems. Chakroborty and Wivedi (2002) proposed a GA-based evolutionary optimization technique to develop the optimal transit route networks. They developed an initial route set generation procedure with a pre-specified number of routes and gave a measure of goodness of a route set according to the travel time and the passenger demand satisfaction. However, the technique neither involves the service frequency of different routes, nor refers to the influence of different stop-schedules on the passenger assignment. Game theory is also used in line planning. Laporte *et al*. (2010) proposed a game theoretic framework for the problem of designing an incapacitated railway transit network in the presence of link failures and a competing mode. It is assumed that when a link fails, another path or another transportation mode will be provided to transport passengers between the endpoints of the affected link. The goal is to build a network that optimizes a certain utility function when failures occur. The problem is posed as a non-cooperative two-player zero-sum game with perfect information. Schŏebel and Schwarze (2006) presented a game theoretic model for line planning with line players. Each player aims to minimize its own delay, which depends on the traffic load along its edges. Equilibrium exists to minimize the sum of delays of the transportation system. Deng (2007) and Shi *et al.* (2007) proposed a bi-level model through balancing the profit of the railway corporation and demand of passengers, combining passenger train operation plan with a passenger transfer plan and considering the flow assignment on the railway passenger transfer network.

In this paper, we investigate a two-layer model with a decision support mechanism (DSM) for line planning. Note the three prominent features of this mechanism: realizing interaction with dispatchers, emphasizing passengers' satisfaction, and reducing computation complexity with a two-layer modeling approach.

2 Decision support mechanism (DSM) for line planning

In order to handle operation tasks, there is usually a train line planning system for dispatchers. When a new rail line is constructed, dispatchers usually issue a line plan through this system before timetable planning. The proposed DSM is shown in Fig. 1.

The line planning consists of five components executed in a loop. From the optimization perspective, the line planning problem is decomposed into two layers. The first layer optimizes the stop-schedule and service frequency, and the second layer assigns the passengers to the trains. The detailed descriptions of the components are given below.

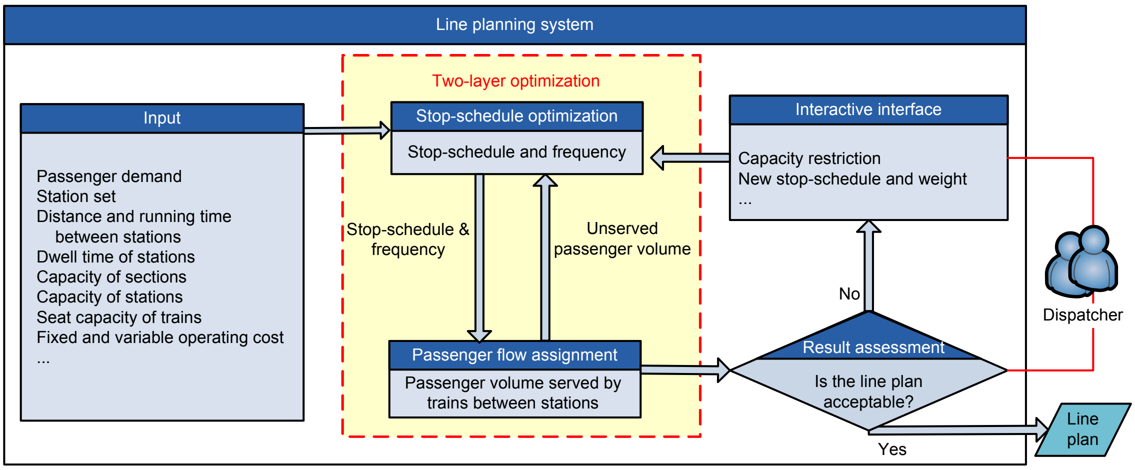

Fig. 1 Architecture of the decision support mechanism

2.1 Stop-schedule optimization

This layer aims at finding the optimal stop-schedule and service frequency. Thereafter, the optimization objective is to minimize the operation cost, the weighted unserved passengers, and used capacities, where the weights correspond to the passengers' priorities. In practice, HSR lines in China usually span several provinces, with dozens of stations. There are two kinds of stations. One is the start or end station of a train trip (such a station is called major station for short); the other is the station that is not used as a start or end of a train trip (such a station is called minor station for short). Four kinds of stop-schedule patterns are usually adopted for the long rail line according to the passengers' traveling habits.

Non-stopping-schedule (NSS): the train taking this schedule runs between two major stations and does not stop at any other stations. Thus, this schedule uses the least travel time to serve the passengers with the highest priority.

Stop at major stations (SMS): the train taking this schedule can stop at intermediate major stations besides the two endpoint stations. This schedule also has a high priority.

Stop at staggered stations (SSS): the train taking this schedule staggeringly stops at minor stations besides intermediate major stations. This schedule can satisfy most of the passenger demands with a middle priority.

Stop at all stations (SAS): the train taking this schedule must stop at all stations between the two endpoint stations. This schedule can satisfy the short path passenger demands with a lower priority.

2.2 Passenger assignment optimization

Given the stop-schedule and service frequency, the passenger assignment decides the number of passengers taking different trains between different origins and destinations. This layer builds two optimization objectives: one is to maximize the product of the number of passengers and their travel length (in this paper, the product is called served passenger volume); the other is to minimize the total travel time.

The advantages of two-layer decomposition can be interpreted from different angles. From the system perspective, it facilitates the interaction with dispatchers. They are enabled to explicitly control the capacity restrictions, and add some new stops for the stop-schedule. From the problem solving perspective, it effectively reduces the complexity of optimization. Long computation time is usually a curse for line planning problems because of the large number of decision variables, which prevents the application of optimization-based automatic line planning algorithms.

3 Statistical analysis of wind monitoring data

The line planning optimization is decomposed into two layers as mentioned above. Data transference between the layers is shown in Fig. 1. The top layer aims at finding the optimal stop-schedule and its service frequency subject to weighted unserved passenger volume calculated from the bottom layer. GA is adopted to solve the nonlinear stop-schedule optimization model in this layer. Finally, mixed integer linear programming (MILP) is used to model the passenger assignment problem in the bottom layer. We will describe the key parts of the problem as follows. First, the numerical inputs of the line planning model are described.

3.1 Input data

T: The planned operating period, i.e., one day.

S: The station set in the railway network.

E: The section set in the railway network.

l: The train type. There are two kinds of trains running on the HSR in China, high-speed trains and quasi-high-speed trains.

$L_{o,d}$: The distance between stations o and d.

$P_{o,d,l}$: The travel demand of multiple origins and destinations with different train types for the planned operating period T.

$T_{o,d,l}$: The running time of train l between stations o and d.

T_i^{s} : The dwell time of station i.

C_i^{s} : The carrying capacity of station i for the planned operating period T.

C_j^{e} : The carrying capacity of section j for the planned operating period T.

C_l: The seat capacity of train l.

K: Attendance ratio for the trains. If all the passengers always have seats, then $K<1$.

C_i^{d} : If the station i can be used as a start or an end station from which a train trip starts or ends, then $C_i^{\mathrm{d}}=1$; otherwise, $C_i^{\mathrm{d}}=0$.

D: The fixed overhead cost for one train.

F: The variable operating cost for one train running one kilometer.

M: The total service frequency for all stop-schedules of the plan. It is a large integer for the passenger demand.

3.2 Model of the stop-schedule optimization

Note that not all the stations in China can be used as a start or end station from which a train trip starts or ends, and this layer adds many terminal restrictions, which is different from other studies. The objective of this layer is to minimize the total operation cost and unserved passenger volume. Some decision variables are described as follows.

3.2.1 Decision variables

y_j: If train j exists in the line plan, then $y_j=1$; otherwise, $y_j=0$.

$x_{j,i}$: If train j stops at station i in the line plan, then $x_{j,i}=1$; otherwise, $x_{j,i}=0$.

$o_{j,i}$: If the start station of train j is station i, then $o_{j,i}=1$; otherwise, $o_{j,i}=0$.

$d_{j,i}$: If the end station of train j is station i, then $d_{j,i}=1$; otherwise, $d_{j,i}=0$.

$u_{j,o,d}$: The passengers served by train j between stations o and d.

$z_{j,l}$: If the type of train j is l, then $z_{j,l}=1$; otherwise, $z_{j,l}=0$.

$s_{j,i}$: If station i exists in the stop-schedule of train j, then $s_{j,i}=1$; otherwise, $s_{j,i}=0$.

$e_{j,i}$: If section i exists in the stop-schedule of train j, then $e_{j,i}=1$; otherwise, $e_{j,i}=0$.

3.2.2 Objective functions

1. To minimize the total operation cost:

$$C_{\mathrm{cost}}=\min\sum_{j=1}^{M}D\cdot y_j+\sum_{j=1}^{M}\sum_{o=1}^{S-1}\sum_{d=o+1}^{S}y_j\cdot F\cdot L_{o,d}\cdot o_{j,o}\cdot d_{j,d}. \tag{1}$$

2. To minimize the unserved passengers:

$$C_{\mathrm{passenger}}=\min\sum_{l}\sum_{o=1}^{S-1}\sum_{d=o+1}^{S}\Big(P_{o,d,l}-\sum_{j=1}^{M}u_{j,o,d}\cdot z_{j,l}\cdot y_j\Big). \tag{2}$$

3.2.3 Constraints

1. Trains cannot start from a station without original capacity:

$$C_i^d\ge o_{j,i},\ i=1,2,\dots,S-1. \tag{3}$$

2. Trains cannot end a trip at a station without destination capacity:

$$C_i^d\ge d_{j,i},\ i=2,3,\dots,S. \tag{4}$$

3. Trains cannot pass by any station before the start station:

$$\sum_{j=1}^{M}\sum_{i=2}^{S-1}\sum_{i1=0}^{i-1} y_j \cdot o_{j,i} \cdot x_{j,i1} = 0, \tag{5}$$

$$\sum_{j=1}^{M}\sum_{i=2}^{S-1}\sum_{i1=0}^{i-1} y_j \cdot o_{j,i} \cdot s_{j,i1} = 0. \tag{6}$$

4. Trains cannot pass by any station after the end station:

$$\sum_{j=1}^{M}\sum_{i=1}^{S-1}\sum_{i1=i+1}^{S} y_j \cdot d_{j,i} \cdot x_{j,i1} = 0, \tag{7}$$

$$\sum_{j=1}^{M}\sum_{i=1}^{S-1}\sum_{i1=i+1}^{S} y_j \cdot d_{j,i} \cdot s_{j,i1} = 0. \tag{8}$$

5. There is only one start station for each train:

$$\sum_{j=1}^{M}\sum_{i=1}^{S} y_i \cdot o_{j,i} = 1. \tag{9}$$

6. There is only one end station for each train:

$$\sum_{j=1}^{M}\sum_{i=1}^{S} y_i \cdot d_{j,i} = 1. \tag{10}$$

7. The train must dwell at its start station:

$$o_{j,i} \le x_{j,i}. \tag{11}$$

8. The train must dwell at its end station:

$$d_{j,i} \le x_{j,i}. \tag{12}$$

9. The train must pass by the stations that it has dwelt at:

$$s_{j,i} \ge x_{j,i}. \tag{13}$$

10. Station capacity restrictions:

$$C_i^{\mathrm{s}} \ge \sum_{j=0}^{M} y_j \cdot s_{j,i}. \tag{14}$$

11. Section capacity restrictions:

$$C_i^{\mathrm{e}} \ge \sum_{j=0}^{M} y_j \cdot e_{j,i}. \tag{15}$$

The stop-schedule optimization is a multi-objective, discrete, nonlinear program. It is very difficult to obtain a solution through traditional optimization techniques. Thus, GA is used to solve the difficult problem.

3.2.4 Coding and initialization

The solution in this layer means a description of all stop-schedules and their service frequencies. The stop-schedules are represented as a two-dimensional matrix $\boldsymbol{X}$; each row of the matrix means a schedule and the columns represent the stations. The element value of the matrix is 1 or 0. If a train, based on the stop-schedule j, stops at station i, then $X_{j,i}=1$; otherwise, $X_{j,i}=0$. The service frequencies are represented as a string, each element of which corresponds to the appropriate stop-schedule. The element value of the service frequency string is an integer, and 0 means that no train will take the stop-schedule in the line plan. Fig. 2 shows a typical solution. There are N stations and M stop-schedules with U service frequency strings. Thus, the chromosome size is M and the population size is U.

As proposed in DSM for line planning section, four kinds of stop-schedule patterns are usually used in the railway line. Thus, the solution matrix is initialized as all the possible stop-schedules. The service frequency is created randomly subject to an upper bound. Note that if a service frequency with the stop-schedule goes beyond the capacity of some sections or stations, the initialization of this string should repeat at once.

Since the service frequency, designed as a string, participates in the crossover and mutation process with the fixed stop-schedule matrix, and the solution coding covering all the possible stop-schedules can meet lots of the terminal restrictions, the complexity of the algorithm is effectively reduced.

3.2.5 Crossover operator

The purpose of crossover is to exchange different features of good strings with the hope of obtaining better strings (Eiben and Smith, 2003). In the present scenario, features of strings are service frequencies. First, we select two different parent strings and determine the starting position s and end position e for crossover randomly; then exchange the string fragments between s and e to form two new service

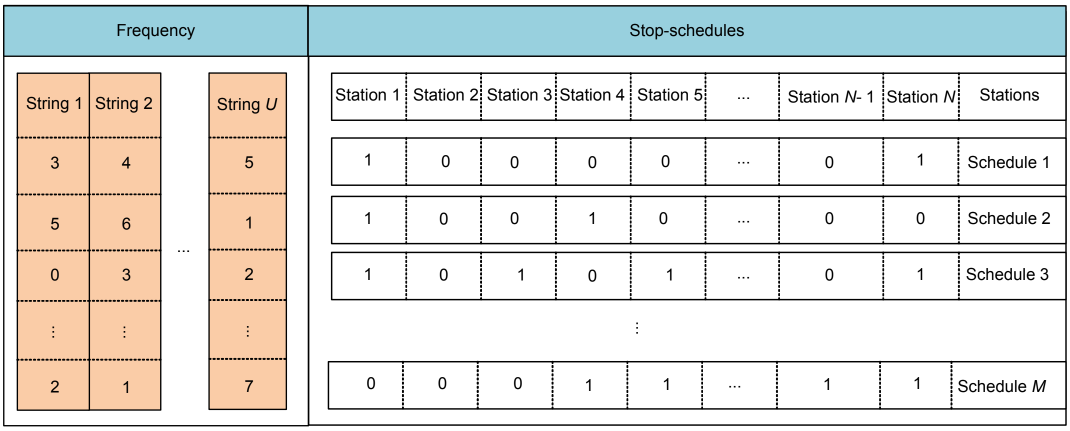

Fig. 2 Representation of stop-schedules

frequency strings. Repeat the procedure until U new service frequency strings are created. Note that this procedure also needs to verify the capacity constraints.

3.2.6 Mutation operator

The purpose of the mutation operator is to slightly modify the frequencies. U new chromosomes are created by crossover process, thus there are $2U$ strings to participate in mutation. First, select a gene of a chromosome randomly and then change it to any of its probable service frequency. In the model, the mutation probability is set to 20%, which means 20% of the $2U$ strings will be modified.

3.2.7 Reproduction operator

The purpose of the reproduction operator is to select U good strings for the next generation from the $2U$ strings. First, calculate the total objective value, $f=\lambda_1 C_{\text{cost}}+\lambda_2 C_{\text{passenger}}$, where λ_i (i=1, 2) is the weight of the objective i, so the fitness function is $1/f$; then, select the string with the highest fitness function to form the next generation; finally, select the residuary $U-1$ strings using the Roulette Wheel selection (Goldberg, 1989). The fitness function is performed considering the operation cost, weighted unserved passengers, and used capacity, and the weight λ_i shows the impact of different objectives in the final decision. Although it is a simple way to deal with the multi-objectives by taking the sum of the weighted objectives as the final objective, it works in the model, which is validated by the case in Section 4. The principle for selection of λ_i is reflecting the optimization purpose, and the trial and error method or the Delphi method can be used in the selection of λ_i.

3.2.8 Termination

As proposed in the paper, DSM is designed to facilitate the interaction with dispatchers and effectively utilize the precious experience. Hence, there are some conditions for the dispatchers to terminate the generational process.

1. A solution is found with lower operation cost, less unserved passengers, and used capacity.
2. Computation time or fixed number of generations is reached.
3. The highest ranking solution's fitness has reached a plateau such that successive iterations no longer produce better results (Eiben and Smith, 2003).
4. Combination of the above conditions occurs during the iterative process.

3.3 Model of the passenger assignment

Given the stop-schedule set and service frequencies, the passenger assignment optimization is abstracted as an MILP.

3.3.1 Objective functions

1. To maximize the served passenger volume:

$$\max \sum_{j=1}^{M}\sum_{o=1}^{N-1}\sum_{d=o+1}^{N} y_j \cdot u_{j,o,d} \cdot L_{o,d}. \tag{16}$$

2. To minimize the total travel time for all passengers:

$$\min \sum_{j=1}^{M}\sum_{o=1}^{N-1}\sum_{d=o+1}^{N} y_j \cdot u_{j,o,d} \cdot \Big(\sum_{l} T_{o,d,l} \cdot z_{j,l} + \sum_{o1=o+1}^{d-1} x_{j,o1} \cdot T_{o1}^{s}\Big). \tag{17}$$

3.3.2 Constraints

1. Passenger demand restrictions:

$$\sum_{o=1}^{N-1}\sum_{d=o+1}^{N}\Big(\sum_{j=1}^{M} y_j \cdot u_{j,o,d} \cdot z_{j,l} \le P_{o,d,l}\Big),\ l=1,2. \tag{18}$$

2. Train seat capacity restrictions:

$$\sum_{o=1}^{k}\sum_{d=k+1}^{N} y_j \cdot u_{j,o,d} \le \sum_{l} C_l \cdot K \cdot z_{j,l} \cdot y_j, \quad j=1,2,\ldots,M,\ k=1,2,\ldots,N-1. \tag{19}$$

The whole composite algorithm procedure of the two-layer model is shown in Fig. 3. Note that weighted passenger assignment, performed in the fitness function calculation, is integrated in the stop-schedule optimization.

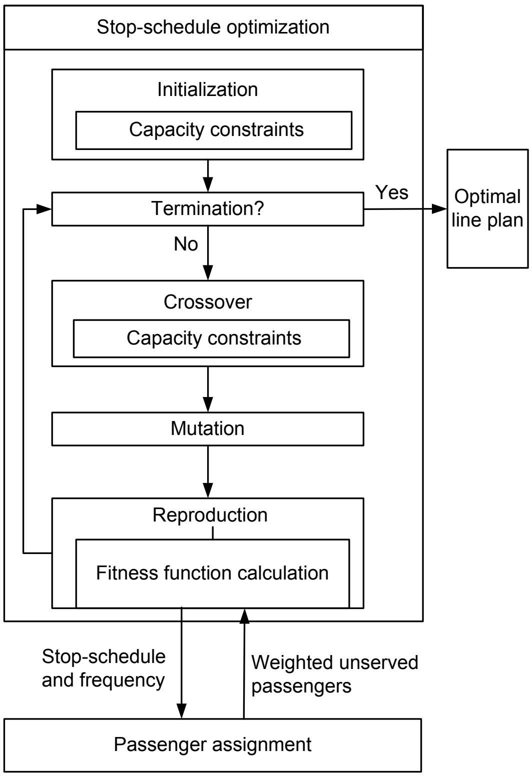

Fig. 3 Composite algorithm procedure of the two-layer model

4 Case studies

In this section, we complete two cases studies. The first one is simulated on the Taiwan HSR, aiming to compare the two-layer model proposed in this paper and the model in (Chang *et al.*, 2000). The other case is illustrated with the Beijing-Shanghai HSR line with 20 stations, which proves the two-layer model in practical situations with a long rail line.

4.1 Taiwan HSR

The Taiwan HSR system is a 340-km intercity passenger service line without branches along the western corridor of the island. It connects two major cities, Taipei and Kaohsiung, with seven intermediate stations and three terminal stations. For more details of the Taiwan HSR system, we can refer to (Chang *et al.*, 2000).

First, we obtain all the four kinds of stop-schedules according to the top-layer optimization rules. There are three stop-schedules of NSS, one stop-schedule of SMS, 14 stop-schedules of SSS, and three stop-schedules of SAS. Thus, the chromosome size is 21 and the population size is set to 50. Fig. 4 shows that the solution converges at 18277.2 after 40 iterations. The detail line plan is shown in Fig. 5. All the passengers have been served in the plan, and the total service frequency is 11. There is one train departing from station 4, which is different from the result of (Chang *et al.*, 2000). That is because all trains must take the first station as the start in (Chang *et al.*, 2000). Also, the computation time is 67 s, which is less than the model in (Chang *et al.*, 2000). All the models are achieved on a Java platform and the passenger assignment programming is solved by IBM ILOG CPLEX 12.2.

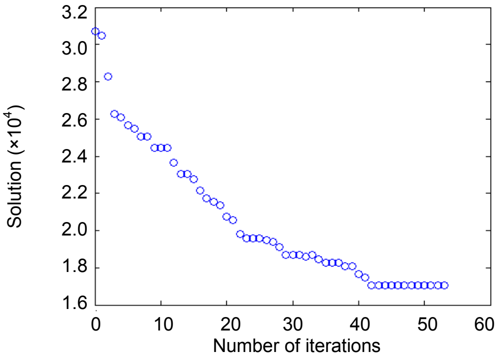

Fig. 4 Iteration procedure of the solution of the Taiwan High-Speed Railway (HSR)

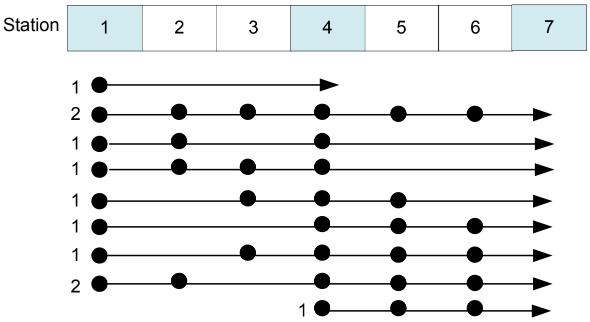

Fig. 5 Optimal line plan of the Taiwan High-Speed Railway (HSR)
Stations 1, 4, and 7 are the major stations which can be used as a start or an end station. Lines with points (stops) and arrows denote different stop-schedules with the figures on the left of the lines meaning the service frequencies of the stop-schedules

4.2 Beijing-Shanghai HSR

This model is also simulated on the Beijing-Shanghai HSR. As the north-south aorta of China, the Beijing-Shanghai HSR connects Beijing (the capital of China) and Shanghai (the biggest economic centre of China) and goes through the Yangtze River Delta region (the most developed area in China). Fig. 6 shows three kinds of rail lines in the network, HSR, intercity line, and existing line. There are three close lines (the Shanghai-Nanjing intercity HSR, the Beijing-Tianjin intercity HSR, and the existing Beijing-Shanghai line), almost parallel to the Beijing-Shanghai HSR. As Fig. 6 shows, there are 20 stations on the Beijing-Shanghai HSR with five terminal stations: Beijing, Tianjin, Jinan, Nanjing, and Shanghai. The lengths of the 19 sections starting from Beijing to Shanghai are 59.3, 62.8, 87.9, 103.8, 92.3, 58.6, 70.3, 92.2, 65.3, 67.0, 88.2, 116.0, 32.0, 59.0, 65.3, 61.0, 57.4, 26.8, 31.4, and 43.6 km, respectively. The average running speed is 300 km/h, average dwell time of station is 2 min, train seat capacity is 1200, and the attendance ratio for the trains is set to 1. Daily passenger travel demand of multiple origins and destinations is shown in Table 1 (Wang, 2006). The number of passengers with high priority is 52% with the reference of NSS and SMS, the number of passenger with middle priority is 28% with the reference of SMS and SSS, and the number of passenger with low priority is 20% with the reference of SSS and SAS. We only consider the direction from Beijing to Shanghai without loss of generality, since all of the lines are double-track.

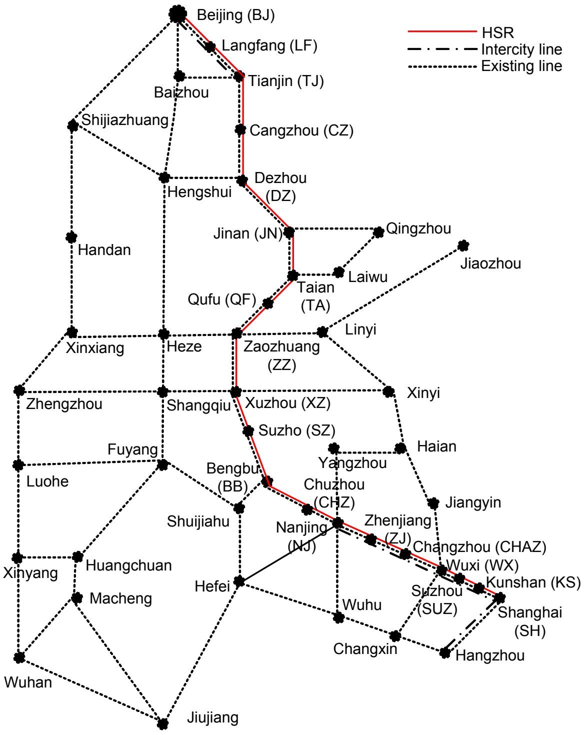

Fig. 6 Railway network around the Beijing-Shanghai High-Speed Railway (HSR)

First, we obtain all the four kinds of stop-schedules set according to the top-layer optimization rules. There are six stop-schedules of NSS, 19 stop-schedules of SMS, 38 stop-schedules of SSS, and four stop-schedules of SAS. Thus, the chromosome size is 67 and the population size is set to 150. Fig. 7 shows that the solution converges at 42 714.398 after 103 iterations. The detail line plan is shown in Fig. 8. All the passengers have been served in the plan. The sum of service frequencies is 133, and the computation time is 316 s.

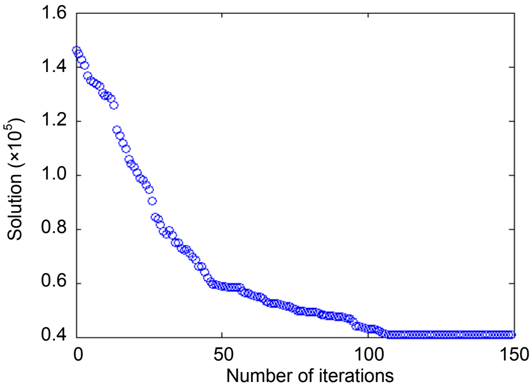

Fig. 7 Iteration procedure of the solution of the Beijing-Shanghai High-Speed Railway (HSR)

Table 1 Passenger travel demand for the Beijing-Shanghai High-Speed Railway (HSR)

Station	Number of passengers																		
	LF	TJ	CZ	DZ	JN	TA	QF	ZZ	XZ	SZ	BB	CHZ	NJ	ZJ	CHAZ	WX	SUZ	KS	SH
BJ	135	792	297	213	741	306	429	99	438	81	132	63	783	84	120	114	105	99	1263
LF		141	93	60	66	0	0	0	30	0	0	0	84	0	0	0	0	0	87
TJ			225	246	366	105	222	57	360	45	168	39	219	48	51	54	42	45	297
CZ				42	75	18	18	12	36	9	21	6	72	12	21	21	18	15	87
DZ					147	54	66	45	42	24	33	0	78	21	27	27	24	24	96
JN						207	210	192	171	30	51	21	339	54	72	75	69	75	390
TA							51	48	123	15	21	0	90	18	27	27	27	24	96
QF								36	42	12	18	6	111	30	39	39	36	42	138
ZZ									72	15	57	6	48	51	36	36	45	81	102
XZ										75	147	105	297	87	108	147	147	258	357
SZ											99	132	141	45	51	51	30	48	183
BB												108	162	114	120	123	126	120	396
CHZ													72	30	39	84	96	60	240
NJ														102	111	114	171	108	1281
ZJ															120	114	168	150	183
CHAZ																81	300	120	255
WX																	450	261	429
SUZ																		288	435
KS																			315

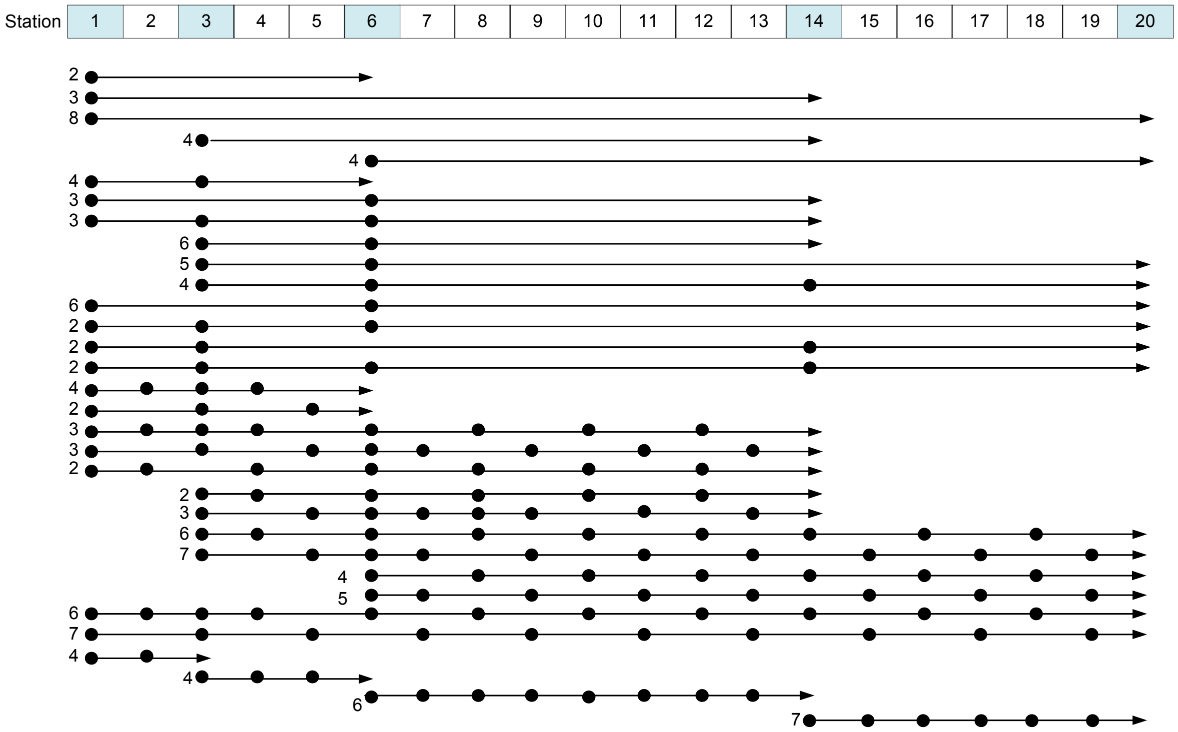

Fig. 8 Optimal line plan of the Beijing-Shanghai High-Speed Railway (HSR)
Stations 1, 3, 6, 14, and 20 are the major stations which can be used as a start or an end station. Lines with points (stops) and arrows denote different stop-schedules with the figures on the left of the lines meaning the service frequencies of the stop-schedules

5 Conclusions and future work

This paper deals with a DSM for dispatchers to use line planning in China. The main contributions include: (1) Passenger assignment is incorporated into the stop-schedule optimization with a two-layer optimization model; (2) GA with innovative solution coding is used to solve the nonlinear stop-schedule optimization model to reduce the computation complexity; (3) Weighted passengers are incorporated into the passenger assignment to optimize stop-schedules for different failure modes of the railway network; (4) Dispatchers are effectively involved into the line planning so that their valuable experience can be leveraged, while most research work on line planning focuses on the optimization model itself. The proposed mechanism, methods, and models are simulated on the Taiwan HSR and Beijing-Shanghai HSR. The proposed DSM shows good performance in the sense that different stop-schedules are created to match the railway station set.

There remain some interesting topics to explore concerning the proposed model. First, travel demand tends to change in spatial and temporal distribution in different situations. How to forecast the passenger demand is an issue. Second, the rolling stock rebalancing is yet to be considered together with the line planning. Finally, integrated optimization of line planning and timetable scheduling is our ultimate goal for safe and efficient operation of China's HSR.

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