Generation Mechanism of Train Operation Conflicts in High Speed Railway

Tao Wang[1], Kang Huang[1*], Xiaoli Song[2], Zhenyi Wang[2]

1Signal and Communication Research institute, China Academy of Railway Sciences Co., Beijing 100081, China
[2]Beijing Hua-Tie Information Technology Development Co., Beijing 100081, China
(*correspondence author)

Abstract

As an important basis for the study of detection and mitigation of train operation conflicts, the analysis on generation mechanism of train operation conflicts in high speed railway has important practical significance on realizing intelligent high-speed railway dispatching command. With train operation late as the necessary conditions for train operation conflicts, the analysis sorts out the main reasons for affecting train operation conflicts from such four aspects as equipment facilities, human behaviour, external environment, and organization management and obtains 17 factors in the end. The interpretative structural modelling (ISM) is adopted to construct the adjacency matrix between the factors and calculate the reachability matrix and finally get a hierarchical and directed graph of the causes of conflicts through the hierarchy of factors. The results show that equipment facilities, transport organizations and dispatchers' professional quality are the main reasons for train operation conflicts; natural environment, equipment operating environment, unexpected passenger flow and the psychological quality, educational level, years of service, etc. of dispatchers are the indirect causes of train operation conflicts; and working environment, the management of equipment and dispatchers and its mechanism are the deep-seated reasons for the train operation conflicts.

Keywords: high-speed railway, interpretative structural modelling (ISM), operation conflicts, train operation late

Received: 27 April 2020

To cite this article:
Tao Wang, Kang Huang, Xiaoli Song, Feng Chen, "Structured Analysis on Generation Mechanism of Train Operation Conflicts in High Speed Railway", in *Electrotehnica , Electronica, Automatica* (*EEA*), 2020, vol. 68, no. 3, pp. 41-46, ISSN 1582-5175. https://doi.org/10.46904/eea.20.68.3.1108005

1. Introduction

Train operation conflicts refer to due to the interference of a large number of uncertainties in the whole process of train operation, a train cannot run in full accordance with the train operation plan, resulting in the train-related technical equipment or related operation organization process don't meet the operational requirements of the train, including the conflicts between train operation and resource utilization, uncoordinated transport organizations and the competition on resources by different train operations [1].

The handling of train operation conflicts is the most complex and important task in dispatchers' daily work. The essence of scheduling issue is to resolve the potential train conflicts because if the train operation conflicts are not resolved in a timely and reasonable way, they will develop into train collision and cause casualties or direct economic loss [2], [3]. Therefore, conflict management has been a key area of railway traffic scheduling research [4].

The research on the management of high-speed railway train operation conflicts mainly involves the analysis of generation mechanism, detection, resolution and others of conflicts [4]-[8], in which the analysis of generation mechanism of conflicts belongs to the basic work of conflict management of train operation, and the analysis of the causes and mechanism of train conflicts may help to improve the effectiveness of conflict detection and resolution.

According to the analysis on the type of train conflicts and their causes, Törnquist, Fay et al. unanimously believe that the train operation conflicts are caused by resource competition, and the train operation conflicts are the most important and the most direct reason for train running late [9]-[12].

According to the train operation interference process and the redundant time utilization process, Wen et al. study the mechanism of the train running conflicts of high-speed railway and establish the recursion process of train running status on high-speed railway under the combination of random disturbance and redundant time [13].

Based on the analysis of the formation mechanism of soft conflicts and its influence, Tang et al. proposes to solve the soft conflicts of train operation diagram by using the integrated simulation of traction power supply and train groups [14]. These researches present a more detailed description of the causes of train operation conflicts. The research results are also instructive in dealing with train conflicts. However, most of the studies are based on single or multiple independent factors instead of the whole system.

In fact, train conflicts often have multiple causes, and these causal factors influence each other.

Therefore, from the whole system, the author will find the main causes of train operation conflicts by combing the causes of train operation conflicts, and then use the Interpretive Structural Model (ISM) method to analyse the train operation conflicts, find out the direct causes, indirect reasons and root-seated reasons which cause the train operation conflicts, in order to provide scientific reference for the conflict management of the high-speed railway trains.

2. Type of train operation conflicts and their causes

2.1. Type of train operation conflicts

According to different criteria and methods of classification, there are different types of train operation conflicts.

Referring to the main body and temporal and spatial characteristics of the conflicts, the train operation conflicts can be divided into the conflicts between trains and trains, the conflicts between train operation and equipment utilization, and the conflicts between train operation and operation organization.

Among them, the conflicts between trains and trains include interval time conflicts and range conflicts of stations.

The conflicts between train operation and equipment utilization include the conflict between arrival and starting line utilization, conflicts between operation and maintenance, conflicts between EMU connection duration.

The conflicts between train operation and operation organization include the time conflicts between train operation and passenger transfer, time conflicts of cross-line train entering into the high-speed line and others.

2.2. Causes of train operation conflicts

Based on the statistics of late train data [15], [16], there are four major causes of train operation conflicts: equipment facilities, human behaviour, external environment and organization and management.

Equipment failure, performance degradation and others are important reasons for late train, including EMU, communication signals, lines, power supply systems, rescue equipment and other factors.

Although they will not cause the inevitable traffic accidents, they will disturb the normal traffic order and easily cause the train conflicts.

Human behaviour refers to the dispatching command, mainly including improper command of decision-makers or operators' errors, which is easily influenced by such factors as professional qualification, educational level, psychological factors, working years and so on.

The external environment is divided into two aspects: natural environment and man-made environment.

Natural environment includes typhoon, thunderstorms, hail and other inclement weather; floods, earthquakes and other natural disasters; line damages resulting from debris flow, landslides, collapse and other factors.

The artificial environment includes the working environment of the dispatchers, the operating environment of the equipment and the factors such as the unexpected traffic flow.

Organization management include management mechanism, transportation organization, equipment management, personnel management and other factors. Among them, transportation organization focuses on the defects of dispatching command technology. At present, it is the difficulties and focuses of the handling of train conflicts [17].

Through further analysis and research, the above four categories can be refined into 15 impact factors, and the membership of each factor is shown in Table 1.

Table 1. Classification of factors of train operation conflicts

Type	Factors
Equipment facilities	EMU (S_1), communication signal system (S_2), line (S_3), power supply system (S_4) and rescue equipment (S_5)
Human behaviour	Educational level (S_6), psychological factors (S_7), working years (S_8) and professional qualification (S_9)
External environment	Natural environment (S_{10}), working environment (S_{11}), equipment operation environment (S_{12}) and unexpected traffic flow (S_{13})
Organization management	Management mechanism (S_{14}), transportation organization (S_{15}), equipment management (S_{16}) and personnel management (S_{17})

15 factors are interrelated and interacted with each other, and their directed connections are shown in Figure 1.

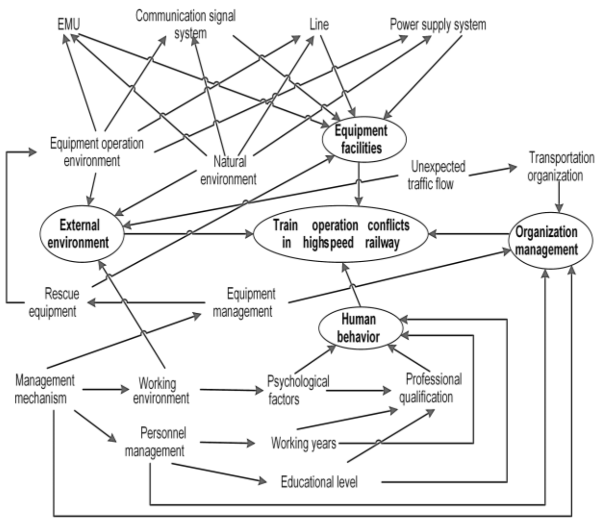


Figure 1. Relationship between causes of train operation conflicts

3. ISM method and steps

Proposed by Professor John n. Warfield in 1973 to analyse complex socio-economic systems [18], ISM method is characterized by decomposing the complex system into several subsystem elements under the principle of associative matrix in graph theory, and finally obtaining an intuitive and well-structured multi-layer hierarchical model.

For analyses on complex systems' factors, safety and risk, ISM has good adaptability [19], specifically with four steps:

Step 1 Generate adjacency matrix A. It's assumed that there are n factors affecting the evaluation objectives in the system, defining its components as $S = \{S_1, S_2, \dots, S_n\}$, based on which adjacency matrix A is established. Factor a_{ij} in A is described as the direct relationship between any two elements, then

$$A = \{a_{ij}\}_{n\times n},\ a_{ij} = \begin{cases} 1, S_i \text{ is related to } S_j \\ 0, S_i \text{ is unrelated to } S_j \end{cases} \qquad (1)$$

Step 2 Calculate reachability matrix *R*. The adjacency matrix *A* and unit matrix *I* are used as the exponentiation of $A + I$ until to the following formula established.

$$A + I \neq (A + I)^2 \neq \cdots (A + I)^r = (A + I)^{r+1} = R \qquad (2)$$

where: the exponentiation follows Boolean operation rules ad matrix $R = (A + I)^r$ is reachability matrix. Factor s_{ij} in *R* reflects whether there are reachable paths between system elements, including the direct as well as indirect relationship between the various elements of the system.

Step 3 Division of hierarchical relation. Based on reachability matrix R, reachable set $M(S_i)$ and antecedent set $N(S_i)$ can be obtained under the following conditions of factor set L_i.

$$M(S_i) \cap N(S_i) = M(S_i) \qquad (3)$$

According to the definition of reachable set and antecedent set, first, confirm the highest level of factors in directed graph of L_i; then, delete the rows and columns corresponding to the elements in L_i from the original reachability matrix R and find the new top-level elements from the remaining reachable matrix; finally, find out the most advanced elements set at all levels.

Step 4 Draw a hierarchical directed graph. According to the level distribution results, the elements are placed from top to bottom, and the relationship is expressed with a directed line segment, thus obtaining the hierarchical directed graph of the system.

In comparison with the two-to-two relational structure between system elements, the hierarchical directed graph obtained by ISM method are more intuitive. For revealing the system structure, especially, it plays a very important role in analysing the hierarchical relationship of system elements and the influence of elements on system functions.

4. ISM analysis of train operation conflicts

4.1. Establish adjacency matrix

Using ISM method to analyse the causes of train operation conflict shown in Table 1 (*supra*), the following adjacency matrix can be obtained according to Figure 1 (*supra*):

$$A = \begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
1&1&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0\\
0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&1&1\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&1&0&1&0&0&0&0&0&0&0&0&0
\end{bmatrix}$$

4.2. Calculate reachability matrix

With exponentiation, when $r = 3$, and $A + I \neq (A + I)^2 \neq (A + I)^3 \neq (A + I)^4$, reachability matrix $R = (A + I)^3$

$$R = \begin{bmatrix}
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&1&1&1&0&0&0&0&0&0&1&0&0&0&0&0\\
0&0&0&0&0&1&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&1&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&1&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
1&1&1&1&0&0&0&0&0&1&0&0&0&0&0&0&0\\
0&0&0&0&0&0&1&0&1&0&1&0&0&0&0&0&0\\
1&1&1&1&0&0&0&0&0&0&0&1&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&1&0&1&0&0\\
1&1&1&1&1&1&1&1&1&0&1&1&0&1&0&1&1\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0\\
1&1&1&1&1&0&0&0&0&0&0&1&0&0&0&1&0\\
0&0&0&0&0&1&0&1&1&0&0&0&0&0&0&0&1
\end{bmatrix}$$

4.3. Division of hierarchical relation

Find out reachability set $M(S_i)$ and antecedent set $N(S_i)$ from reachability matrix *R* and obtain their intersection L_i, the calculating results of the first level are shown in Table 2.

Table 2. Reachability set and antecedent set of the first level

i	Reachability set $M(S_i)$	Antecedent set $N(S_i)$	Intersection L_i
1	1	1, 5, 10, 12, 14, 16	1
2	2	2, 5, 10, 12, 14, 16	2
3	3	3, 5, 10, 12, 14, 16	3
4	4	4, 5, 10, 12, 14, 16	4
5	1, 2, 3, 4, 5, 12	5, 14, 16	5
6	6, 9	6, 14, 17	6
7	7, 9	7, 11, 14	7
8	8, 9	8, 14, 17	8
9	9	6, 7, 8, 9, 11, 14,17	9
10	1, 2, 3, 4, 10	10	10
11	7, 9, 11	11, 14	11
12	1, 2, 3, 4, 12	5, 12, 14, 16	12
13	13, 15	13	13
14	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 14, 16, 17	14	14
15	15	13, 15	15
16	1, 2, 3, 4, 5, 12, 16	14, 16	16
17	6, 8, 9, 17	14, 17	17

As shown in Table 2, factors of $L_i = M(S_i) \cap N(S_i)$ include S_1, S_2, S_3, S_4, S_9 and S_{15}, indicating these factors are the top level of system, factors of the first level are indicated $L_1 = \{1,2,3,4,9,15\}$. Similarly, $L_2 = \{6,7,8,10,12,13\}, L_3 = \{5,11,17\}$, $L_4 = \{16\}$ and $L_5 = \{14\}$ can be obtained.

4.4. Draw a hierarchical directed graph

According to the result of hierarchical relationship division, some levels are integrated to obtain a hierarchical directed graph of the causes for train operation conflicts in high-speed railway, as shown in Figure 2.

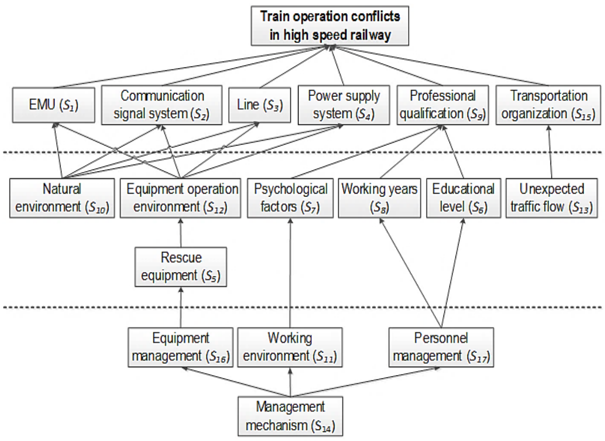


Figure 2. Hierarchical directed graph caused by train operation conflicts

4.5. Analysis of ISM

As shown in Figure 2, the cause system of high-speed railway train operation conflicts is a complex system with multi-hierarchy structure, and the causes are divided into 3 levels:

(1) Direct factors in the top level include 6 factors such as EMU (S_1), communication signal system (S_2), line (S_3), power supply system (S_4), business quality (S_9), and transportation organization (S_{15}) and other factors, which can be interpreted as bad state of hardware, the unsafe behaviours of people, and the defects of scheduling command software, indicating the multi-pronged approach should be adopted to prevent train operation conflicts. EMU, communication signal system, line, power supply system and other hardware are basic conditions of train operation and their operation directly affects the service quality of high-speed railway. Owing to the particularity of the railway's own rail transport, it is easy to cause train conflicts, and economic loss and social impact should not be ignored. People are the main body of dispatching command, transportation organization is the soft tool of scheduling command, and any mistake may cause the occurrence of train conflicts.

(2) The indirect influence factors of the intermediate layer include 7 factors, such as natural environment (S_{10}), equipment operating environment (S_{12}), rescue equipment (S_5), psychological factors (S_7), working years (S_8), education level (S_6), and unexpected passenger flow (S_{13}), which can be included into train operation environment and people's adverse characteristics. Obviously, in order to ensure the normal use of the hardware system, It's necessary to improve the natural disaster early warning capacity while maintaining the operational environment of the equipment and good state of rescue equipment; in order to reduce errors of dispatching personnel, it's necessary to improve physical quality, technical level and work experience of people in all aspects; in order to ensure normal transportation organization, it's necessary to monitor real-time traffic, forecast the future passenger flow, complete early warning of unexpected traffic flow and formulate corresponding emergency treatment measures.

(3) The indirect influence factors of underlying layer include 4 factors such as management system (S_{14}), equipment management (S_{16}), personnel management (S_{17}) and the working environment (S_{11}), among which the first 3 factors belong to the organization management, with certain subordinate relations, while the last one belongs to external environment, indicating that strengthening the management mechanism construction, reinforcing the management of equipment and scheduling and improving working conditions are conducive to the protection of train running on time.

5. Conclusions

(1) The direct causes of train operation conflicts can be summed up as the hardware system, software system and human factor system, in which the hardware system includes EMU, communication system, signal, lines, power supply system and other factors; the software system mainly refers to the transport organizations' dispatching command technology; human factor system mainly refers to professional quality of dispatching command personnel.

(2) In terms of the hardware system, the natural environment, equipment operating environment, rescue equipment, equipment management and its system are the influencing factors. Therefore, the equipment should be inspected and maintained regularly during the train operation to ensure the reliable use of the equipment. At the same time, it is necessary to strengthen the early warning of the natural environment and improve the reliability of the equipment operation.

(3) In terms of software system, advanced transportation organization technology for unexpected passenger flow is helpful to reduce interference on train operation and improve train punctuality rate.

(4) In terms of human factor system, the professional quality of dispatchers is influenced by such factors as psychological factors, educational level, working years, working environment and the management and system of dispatching personnel. Improving the comprehensive quality of dispatching personnel and providing a good working environment are helpful to reduce the faults of dispatching personnel and improve the reliability of train operation.

6. References

[1] WEN, C., PENG, Q.Y., CHEN, Y.H., "Pandect on the operation conflict management of high-speed train", *China Safety Science Journal*, 2010, vol. 20, no. 10, pp. 8-12.

[2] LI, Y.F., LING, X.D., WU, X.Y., "Research on conflict in scheduling problem", *Ordnance Industry Automation*, 2007, vol. 26, no. 6, pp. 41-43.

[3] ANDERSSON, E., "An economic evaluation of the Swedish prioritisation rule for conflict resolution in train traffic management", *Procedia - Social and Behavioural Sciences*, 2014, vol. 111, pp. 634-644.

[4] ŞAHIN, İ., "Railway traffic control and train scheduling based on inter-train conflict management", *Transportation Research Part B: Methodological*, 1999, vol. 33, no. 7, pp. 511-534.

[5] OH, S.M., HONG, S.H., CHOI, I.C., "Railway conflict detection and resolution in the Korean railway system", Seventh International Conference on Computers in Railways IX, Southampton UK, 2004, pp. 675-684.

[6] ZHUANG, H., FENG, L., WEN, C., TANG, Q., "High-speed railway train timetable conflict prediction based on fuzzy temporal knowledge reasoning", *Engineering*, 2016, vol. 2, no. 3, pp. 366-373.

[7] D'ARIANO, A., PRANZO, M., HANSEN, I.A., "Conflict resolution and train speed coordination for solving real-time timetable perturbations", *IEEE Transactions on Intelligent Transportation Systems*, 2007, vol. 8, no. 2, pp. 208-222.

[8] SHI, F., LI, X.H., QIN, J., DENG, L.B., "The earliest conflict optimal method for train operation adjustment on single track railway", *China Railway Science*, 2005, vol. 26, no. 1, pp. 106-113.

[9] TÖRNQUIST, J., "Computer-based decision support for railway traffic scheduling and dispatching: A review of models and algorithms", 5th Workshop on Algorithmic Methods and Models for Optimization of Railways (ATMOS'05), Palma de Mallorca, Spain, 2005.

[10] FAY, A., "A fuzzy knowledge-based system for railway traffic control", *Engineering Applications of Artificial Intelligence*, 2000, vol. 13, no. 6, pp. 719-729.

[11] MAKKINGA, F., METSELAAR, S., "Automatic conflict detection and decision support for optimal usage of railway infrastructure", Seventh international Conference on Computers in Railways VII, Southampton, UK, 2000, pp. 1057-1064.

[12] MAZZARELLO, M., OTTAVIANI, E., "A traffic management system for real-time traffic optimization in railways", *Transportation Research Part B*, 2007, vol. 41, no. 2, pp. 246-274.

[13] WEN, C., PENG, Q.Y., CHEN, Y.H., "Running conflict mechanism of high-speed railway train", *Journal of Traffic and Transportation Engineering*, 2012, vol. 12, no. 2, pp. 119-126.

[14] TANG, J.J., ZHOU, L.S., RAN, F., CHEN, L.C., "Research on train scheduling for high-speed railway lines based on soft conflict adjustment", *Journal of the China railway Society*, 2012, vol. 34, no. 4, pp. 1-8.

[15] DING, W., LIU, X.H., JIANG, R., "Research on railway passenger train delays based on Bayesian network", *Journal of Lanzhou Jiaotong University*, 2014, vol. 32, no. 6, pp. 115-118.

[16] XU, P., CORMAN, F., PENG, Q., "Analysing railway disruptions and their impact on delayed traffic in Chinese high-speed railway", *IFAC-Papers Online*, 2016, vol. 49, no. 3, pp. 84-89.

[17] MIN, Y.H., PARK, M.J., HONG, S.P., HONG, S.H., "An appraisal of a column-generation-based algorithm for centralized train-conflict resolution on a metropolitan railway network", *Transportation Research Part B: Methodological*, 2011, vol. 45, no. 2, pp. 409-429.

[18] WARFIELD, J.N., "Binary matrices in system modelling", *IEEE Transactions on Systems, Man, and Cybernetics*, 1973, vol. 3, no. 5, pp. 441-449.

[19] WU, X.Y., MA, D.W., QIAO, Y.L., "Interpretative structural model for risk analysis of weapons development based on rough set theory", *Systems Engineering and Electronics*, 2005, vol. 27, no. 9, pp. 1590-1593.

Funding Sources

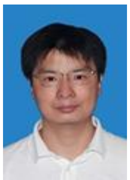
The work is supported by the Project of High-speed Rail Joint Fund "Research on Theory and Method of Intelligent Dispatching of High-speed Railway Based on Cooperative Command (U1834211)".

Authors' Biographies

Tao Wang was born in Beijing(China), on Apr. 13, 1977.
He graduated Beihang University, Beijing, China, in 1999.
He received the PhD degree from China Academy of Railway Sciences, Beijing, China, in 2014.
He is a Senior Researcher at China Academy of Railway Sciences.
His research interests include railway signal and communication, railway traffic modelling and simulation, railway intelligent control and dispatching.
Email: 13910023420@139.com

Kang Huang was born in Zhejiang province(China), on Mar. 22, 1976.
He graduated Beijing Jiaotong University, Beijing, China, in 1998.
He received the PhD degree from China Academy of Railway Sciences, Beijing, China, in 2004.
He is a Senior Researcher at China Academy of Railway Sciences.
His research interests include railway traffic safety and simulation, urban railway system designation and signal traffic control.
Email: rails10008101@hotmail.com

Xiaoli Song was born in Henan province(China), on July 22, 1979.
She received bachelor degree from ZhenZhou University, Henan province, China, in 2003.
She is an engineer at Beijing Huatie Information Technology Co. Ltd.
Her research interests include railway traffic information management and simulation and train data organization.
Email: 13910912725@139.com



Zhenyi Wang was born in Beijing(China), on July 20, 1974.
He received bachelor degree from Beijing Jiaotong University, Beijing, China, in 1996.
He is a senior engineer at Beijing Huatie Information Technology Co. Ltd.
His research interests include railway traffic information standardization, urban railway system designation and train timetable adjustment.
Email: 13701233707@139.com