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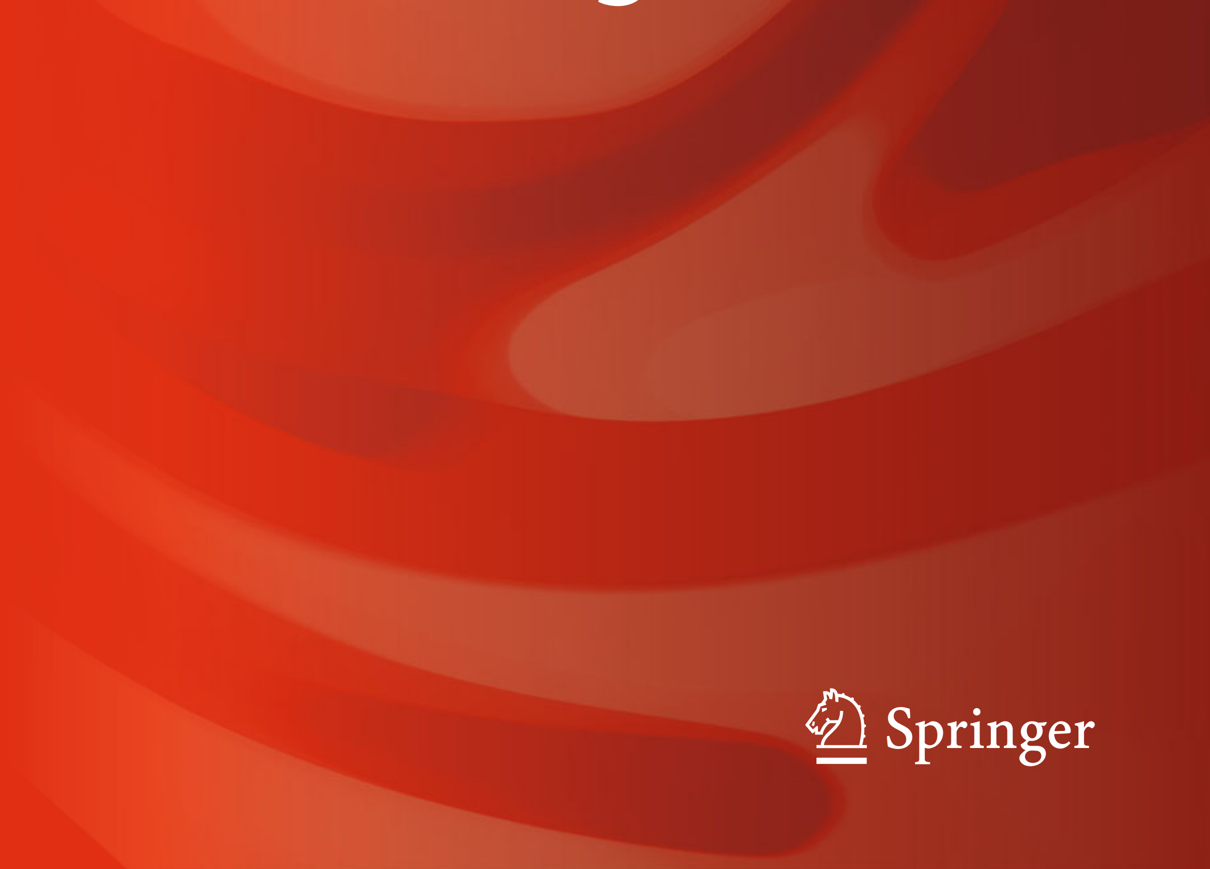
Train Operation in Emergencies



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Preface

Railway transportation, as an important public transport form, has its constant aim, which is to transport passengers and freights safely, rapidly, reliably, punctually, and economically. With the increase in the mileage of the Chinese railway network, the requirement of *higher, faster, and more* for railway transportation is proposed. However, natural disasters affecting railway are characterized in recent years by universality, frequency, and variety. Moreover, there are occasional railway accidents railway safety public incidents, which declined the capacity of the railway line and reduced the safety and efficiency of the passenger and freight transportation. Therefore, research on an objective basis to study the train operating problem in emergencies is required.

On the other hand, with the increase of available mileage in railway (especially high-speed railway), the topology structure of the railway network is changing profoundly. A new railway network is forming gradually, which provides conditions for organizing the train operating work based on the network and makes the train operating work more complicated. It is urgent to study the train operating problem based on the railway network.

Based on this background, this book focuses on the theories and methods for train operation organization in emergencies, using the top-down system analysis method.

The research work includes railway transport organization mode in emergencies, railway service network reconstruction, capacity calculation in emergencies, generation of train paths, train repathing and train re-scheduling problem. The railway transportation mode in emergencies is the most macro, the most fundamental issue, which proposes the most basic constraints for train operation organization. It is a strategic level problem.

And the train service network is the intuitive representation of the line plan, deciding the origin station, destination station, train path, stops plan, service frequency, and other factors, which is a tactical level problem.

Capacity calculation is the basis of train repathing problem, which is also studied in this book.

At the operational level, the train timetable on the dispatching sections is the key issue, determining the inbound and outbound time of the trains at stations.

The solution of strategic level problem is the constraint of the tactical level problem, and the solution of the tactical level problem is the constraint of the operational level problem. Conversely, the solution of the operational level problem can be fed back to the tactical level problem, which can be helpful for the decision-makers of the tactical level problem. In addition, the solution of the tactical level problem can be fed back to the strategic level problem, which can generate some decision-supporting information for the strategic level problem.

The authors and their team are involved in the research work of train operation organization for many years. They have undertaken and completed *China National Key Research and Development Project* (Grant: 2016YFB1200105). The authors developed a series of computer management systems and obtained the software copyright of train operation regulation system for high-speed railway network. The research work of these projects and the results of the work provide materials for this book.

Here the authors want to express thanks to Vice Professor Xu Jie and Li Wang for their valuable advice in writing this book.

When writing this book, the authors searched for various publications. We tried to keep a style of clear definition, with lucid brain, so as to make all kinds of readers have a clear understanding of the transportation organization and train operation in emergencies. Due to the author's knowledge level and the depth and breadth of the study, the views, methods, and theories mentioned in the book certainly have some deficiencies. Do not hesitate connecting with the authors to provide your priceless advice.

Beijing, China Limin Jia
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Contents

Content Summary

This monograph focuses on the train operation theories and methods in emergencies, on the background that the railway accident rate is slightly elevated. It reflects the authors' pioneering research work in the field of railway transportation organization, which is a comprehensive introduction to theories of train operation on the railway network in emergencies.

This book is structured into seven chapters. Chapter 1 introduces the background, significance, necessity, contents of the research work and defines the key concepts involved in this book.

Chapter 2 discusses the train operation in emergencies. It focuses on the analysis of the connotation and structure of railway transportation organization in emergencies. And it presents the methods and strategies for train operation in emergencies.

Chapter 3 studies the transportation mode in emergencies.

Chapter 4 discusses the theories and methods for railway carrying capacity calculation in emergencies.

Chapter 5 discusses the problem of line planning in emergencies for railway network.

Chapter 6 studies repathing passenger train problem in emergencies.

Chapter 7 researches train re-scheduling problem in emergencies.

This book is rigorously structured and combines the theories and production reality tightly. It is suitable for the faculty who works or studies in the field of railway transportation organization. It is also appropriate for graduate students and researchers in the field of related research.

Chapter 1
Introduction

Abstract This chapter is the introduction on train operation problem during emergencies. It first defines the train operation problem. Then it introduces some typical dispatching systems in the world and discusses the possible future railway operation dispatching mode. Then, we give a demonstration of the significance and necessity to study this problem. A review on the related publications is proposed in the second part of it. At last the structure of this book is presented.

1.1 Introduction on Train Operation Problem in Emergencies

1.1.1 Statement of the Problem

Railway transportation is the most important transportation pattern, while it had remained undeveloped for a long period. The contradiction between the transportation capacity and requirement is very sharp.

There are mainly two kinds of measures to solve this problem. One is to strengthen railway infrastructure construction, expand the rail network, and enhance the transport capacity of the railway system. The second one is to utilize the advanced technology and management methods and improve the production efficiency of railway transport, which is expected to maximize the transportation capacity of the existing networks.

At present, the development trends of railway transportation in China are to expand the high-speed railway construction scale, the gradual separation of passenger and freight transport, and other aspects of automation and intelligent management. With the high-speed railway mileage increasing, a new railway network scale is being developed. Since the Tenth Five-Year Plan of the national economy and social development (2000–2005) was carried out, railway construction has been accelerated. In January, 2004, the State Council promulgated the "Long-term Railway Network Plan", which is a clear blueprint for high-speed railway network construction. By 2020, China will build 12,500 km high-speed railways and

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4000 km intercity passenger lines, forming the high-speed railway network, which will connect all the influential cities—including top 30 largest cities (four municipalities, 18 provincial capital cities, and eight coastal cities).

In long-term Railway Network Adjustment Plan issued by the central government on October 31, 2008, the goal of 2020 national railway operation mileages was strengthened to 120,000 km, among which the high-speed railway mileage was changed from 12,000 to 16,000 km. Moreover, the electrification rate is adjusted from 50 to 60%. In addition, the passenger transportation and freight transportation are separated on the busy main railway lines. The reasonable layout, clear structure, perfect function, smooth convergence railway network will be built. Transport capacity will be able to meet the needs of national economic and social development and the quality of main technical equipment will reach the international advanced level. The modern railway network scale continues to be enlarged, which provides the hardware basis for the railway transport capacity strengthening. Chinese railway network is becoming more and more complicated and train operation organization has become extremely complex.

In addition, at present, the production organization mode of railway is a three-level management one, which includes railway company, railway bureaus, and stations levels. Train operation dispatching work is focused on the dispatching sections. The dispatching mode in view of the whole network is not studied systematically, which is not harmonious with the complicated train operation dispatching work.

On the other hand, China has a vast territory and railway natural disasters are widespread, frequent, and multiple (Xu 1997). Emergencies have great effect on the transportation safety and efficiency. The railway accident and railway public security incidents occasionally occur. These events brought serious challenges to the railway transportation organization. In emergency conditions, it will cause the entire railway transportation disorder on the railway line network if the capacity decreases or even interrupts the situation. Current computer-aided decision system existing is not able to give a satisfactory solution. However, if the dispatcher gives the solution subjectively, the quality of the dispatching plan cannot be guaranteed.

So, it is seriously important to study the train dispatching work on the new railway network in emergencies. Although there is much automatic dispatching system, none of them can finish the dispatching work on the whole railway network. The goal of this book is to look into the train dispatching problem on the railway network in emergencies.

1.1.2 Systems on Railway Train Operation Dispatching

At present, the train dispatching systems can be categorized into three groups. The train dispatching system used in Japan is a typical one of the first group. The train dispatching system for high-speed railway is separated from the train dispatching system for normal speed railway. The train dispatching systems in France and

Spanish belong to the second group. The novel train dispatching system is derived from the existing train dispatching system, and combined with the existing train dispatching system. Train dispatching system in German is the third type, which builds several local centers for the train dispatching system.

Train dispatching system for Japanese Shinkansen is a separated one. The train dispatching system is designed and constructed according to the characteristics of the high-speed railway. It takes the dependence of high risk and operation safety for the train dispatching system and sings high importance for the safety. And it considers the high on schedule rate as a most important goal and constructs the comprehensive dispatching system that integrates many functions.

In Spanish, train dispatching system for high-speed railway is not constructed perfectly. The idea to develop the high-speed railway dispatching system is constrained by the operation rule of the existing train dispatching system. The system only includes passenger organization, train operation organization, and the dispatching work of the locomotives and vehicles. The structure of the system is simple and the function of the system is not so powerful, which is not compatible with the high operation speed of the high-speed trains.

High-speed railways are connected with the normal speed railways in German. A general center and seven subcenters are settled in the railway transportation system. Passenger transportation and freight transportation are both managed by a three-level management system, which is dispatching center-sub-dispatching center and station attendant. All of the centers are connected by the communication system to exchange the data. In each dispatching center, there are two subcenters, which are transportation commanding center and the operation control center. The dispatching system has the function of transportation commanding, automatic conflicts solving, automatic dispatching, and information service.

In China, train dispatching systems are all separated, for the normal speed railway, for the intercity railway and for the high-speed railway.

1.1.3 Future Railway Operation Dispatching Mode

The future mode of train dispatching on the railway network has the following several possible forms.

(1) The railway centralized dispatching mode

The dispatch work of high-speed railway, the normal speed, and the intercity railway are gathered together in the same department. All of the dispatchers from all levels will only obey the commands of a relative dispatching console in a single dispatching system. They do not attend the making decisions work of dispatching commands, only receive the commands from the dispatching center and transfer them. This mode is much suitable for the train dispatching work in emergencies for it is not necessary to transfer the dispatching power when emergencies occur.

(2) The mode that the high-speed railway dispatching system is independent

In this mode, the high-speed railway dispatching system is independent from the existing normal speed dispatching system. The system should monitor the daily production site and remotely control the equipment. The special dispatching consoles give the dispatching commands to the stations and trains. High-speed trains must run on the high-speed railway and they are forbidden to transfer to the normal speed railway. Transportation work of high-speed railway and that of normal speed railway are completely independent. It is obvious that the merit of this mode is that the dispatching work is simplified and the dedicated lines are used for the dedicated trains. Its shortage is also clear that the dispatching power cannot be unified when emergencies occur, which does not allow trains to share the rails.

(3) Mode that combines the centralized dispatching mode and the high-speed railway independent mode

In this mode, dispatching systems of high-speed railway, normal speed railway, and the intercity railway are all independent. In the normal condition, the dispatching systems are used for the relative railways, respectively. When emergencies occur, the dispatching power is unified to a dispatching center, which dispatches all kinds of trains to operate on the whole railway network, including all kinds of railways.

We can see that the possibility of using the second mode is relatively small because of its obvious shortage. The first and the third mode requires the dispatchers to do the dispatching work from the view of the railway network, meaning that we should organize the transportation work for the existing normal speed railway, high-speed railway and intercity railway. It is necessary to study the train operation problem based on complex railway network, especially in emergencies.

1.1.4 Significance and Necessity of This Research

Currently research on train re-scheduling problem focuses on the train dispatching on a single railway section. The researchers have not paid much attention to train operation research on a railway network, especially in emergencies. It has the following significance to study the train operation under in emergencies.

(1) The research can enrich the train operation theories on the railway network, explore the essence of train operation organization scheme in emergencies, and fulfill the blank of the research field of train operation organization in emergencies. Theories on train operation in emergencies should be a part of train operation theory system, which can present supporting information for the railway transportation organizers.
(2) The study can improve the railway transportation efficiency. It is clear that the transportation organization plan determines the transportation efficiency. Solid theoretical basis can provide theoretical and method support for transportation

plan design. And it can improve the transportation quality, improve transport efficiency in emergencies, which is expected to solve the problem that emergencies can lead to railway transportation disorder at the condition of lack of relative theoretical support.

(3) Train operation in emergencies problem must be solved. Natural disasters affecting railway are characterized by universality, frequency, and variety in China. Moreover, there are occasional railway accidents railway safety public incidents, which declined the capacity of the railway line and reduce the safety and efficiency of the passenger and freight transportation. So, it requires research on an objective basis to study the train operation problem in emergencies.
(4) It is infeasible to cancel the passenger trains when the emergency reduces the railway capacity even break the rail. If the passenger trains (already on the way) are canceled, the trip of the passengers is suspended, which will bring serious social influence. Therefore, the dispatchers and the researchers must solve this kind of problem. It is the requirement of the society.
(5) It can enrich the function of the automatic train dispatching system. Currently, the automatic train dispatching system works in the normal condition and provides supporting information for the dispatchers. In emergencies, dispatching commands are generated by the dispatchers with their experience. The results of this research can be embedded into the dispatching system, adding functions for the train operation in emergencies. It can help to realize the computer-aided decision-making system of railway operation dispatching command in emergencies. It is no doubt that the research has a strong practical significance to the railway transportation dispatching work.

1.2 Related Works Review and Analysis

1.2.1 Related Works on This Problem

This book is concerned about the train repathing and train re-scheduling problems. So, we list the related works about the two problems.

(1) Research work on train repathing

Research work on train path focuses on support for service plan design. That is to say, the researchers try to decide the train paths through studying the transfer facility, travel distance, and travel cost. Cui (1997) studied the train passenger path generating problem, presenting a method to search for multiple paths. Chen et al. (2001) studied the optimization of passenger train paths under the premise of a given railway passenger station layout and train timetable, proposing a 0-1 programming model. Wang et al. (2006) hired the genetic algorithm to generate k-shortest paths based on the analysis of the traditional method to generate the train shortest paths. Wang and Peng (2007) developed the computer system to realize the visualization of passenger train paths through the integration of electronic map technology. Lv et al. (2007) presented a method to generate the train paths with the constraint of the train number, considering the difference between the path information in the TRS and the real passenger path.

The research publications on freight trains path are numerous and the methods in them can give us much enlightenment. We can categorize the methods in the publications into mathematical programming methods, heuristic algorithm, neighborhood search method, etc.

A. Mathematical programming methods

Wang and Feng (1996) first defined the car flow paths set and presented the application method in the car flow management system. Li and Gu (1997) designed a directed searching method to find the shortest path between every two railway stations and the computing example proved the efficiency of the algorithm. Sun and Zhang (1999) defined the overpass network model of railway and gave calculating steps of DBFS algorithm, which was based on Dijkstra algorithm. Zhou (2002) designed an algorithm to search for the shortest path from a station to another station, which was based on the two-fork tree theory. Shi (1996) built a multi-objective model to solve the car flow path problem, and he and Shi (1999) carried out two improvements on the GP-STEM algorithm. Shi et al. (1997) described the relationship between the car flow path and the train formation plan and proposed a method to optimize comprehensively the car flow path and the train formation plan. Meng et al. (2008) designed a regularized PCG algorithm for the multipath assignment model for the development of railway transportation enterprises. Jin et al. (2005) analyzed the effect of rapidity, equilibrium degree, maximization, and other factors on the parallel flow path selection and constructed an optimization model for train path. Bierlaire and Frejinger (2008) presented a method to analyze the difference between the real data and the model for train path selection.

We can see from the current research literature that the mathematical programming methods to solve the train path problem are widely used. It is because that this kind of problem is easy to be described as a linear programming problem or a nonlinear programming problem with a not very large scale.

When the traffic path problem is combined with the formation plan problem, it becomes a complex large-scale combinatorial optimization problem, which is extremely difficult to solve. The researchers often design heuristic method to solve this kind of problem.

B. Heuristic search method

Heuristic search is a method to evaluate the position of the solution and get the best solution until the solution reaches the destination. It can avoid much useless search work and improve the efficiency, gaining the relative excellent solution in a short period of time.

Lin and Zhu (1996) built the mathematical programming model for the car flow path optimization and the formation plan problem and designed a simulated annealing algorithm to solve the model. Lin et al. (1996) also gave a heuristic algorithm to solve the train pathing problem, considering the manual deciding rules. Wang et al. (2007) proposed a hybrid genetic algorithm based on stochastic simulation. Su and Chen (2008) built a 0-1 model and designed a heuristic algorithm based on damping coefficient concept. Liu et al. (2007) presented a heuristic algorithm, A* algorithm to solve the train pathing problem. Nong et al. (2010) designed a Tabu search method to solve the train pathing problem, considering the problem as a TSP one. Wang and Ji (1999) narrowed the railway network and presented a heuristic algorithm, taking the distance and transferring satisfactory into consideration. Zachariadis and Kiranoudis (2010) built a train path model, taking the minimum cost as the optimization objective and designed a heuristic clustering algorithm.

Although some heuristic algorithms such as genetic algorithm have higher computational efficiency, the termination condition is quite difficult to obtain. In addition, we are not clear whether we have the optimal solution.

C. Other methods

Sun and Jiang (2005) constructed a model to search for the train path, considering the transportation cost as the optimization goal. The essence of this model is to find the shortest path with an iteration strategy. Du et al. (2005) built a multi-objective model to solve the bidirection car flow and empty-loaded car flow path optimization problem. Xie and Xu (2009) proposed a method to optimize the railway network and the storage structure of in the computer system. Hong et al. (2009) designed a two-stage algorithm to solve the train pathing problem. Lee and Chen (2009) studied the train routing and train timetabling problem, with the goal to optimize the usage plan of tracks in stations, hiring the local search method.

(2) Research work on train re-scheduling

There are numerous publications on train re-scheduling problem. The train re-scheduling problem can be divided into two kinds, train re-scheduling on a single-track railway section and train re-scheduling on a double-track railway section.

A. Train re-scheduling on a single-track railway section

Train re-scheduling on a single-track railway section was the first problem drawing attention, and had been a hot research topic for a long period. Szpigel (1973) built a linear programming model to solve the train-scheduling problem, and hired the branch and bound algorithm to solve the problem. D'Ariano et al. (2007) considered re-scheduling problem as a job shop problem. They took the total delay time as the optimizing goal, constructing a job shop model, solved it with branch and bound algorithm.

Sauder and Westerman (1987) also built a train re-scheduling model, taking the total delay time as the optimizing goal and used the exhaustive algorithm to solve the model. Cao (1994) built a model with optional constraints, and solved it with dual linear programming algorithm. Zhao (1999) constructed a model that combined the train re-scheduling problem, the usage plans design problem of the station receiving and sending lines, and the train routing problem. He also utilized the branch and bound algorithm to solve the model, limited the searching depth and avoided that the search space is too large. Cheng (1998) proposed a hybrid simulation method, integrating the modern PERT graph theory and time driving method, to solve the conflicts in train re-scheduling problem. Zhang and Jin (2005) defined the concept of neighbored trains, taking the deviation function as the optimizing object. They hired the genetic algorithm to solve the problem. Caprara et al. (2006) constructed an integer programming model, taking the train operation profits as the optimizing object, using the Lagrange heuristic algorithm to solve the problem.

Cacchiani et al. (2010) also built a train re-scheduling model on a single-track section and solved it with Lagrange heuristic algorithm. Li et al. (2008) built the train re-scheduling model based on the discrete event system theory and solved the problem with the strategy of Travel First. Liu and Kozan (2009) considered the train re-scheduling problem as a job shop problem and designed a feasibility satisfaction method to solve the problem. Zhou and Zhong (2007) solved the constructed train re-scheduling model with an integrated method of branch–bound algorithm and heuristic algorithm. It should be pointed out that the researchers began to pay attention to the uncertainty in train re-scheduling problem. Yang et al. (2009) provided a goal programming model and solved it with the branch and bound algorithm.

The key characteristic of train operation on a single-track railway line is that only one train can occupy a section between two neighbored stations at a same time. The overpass and cross operation must happen on the stations. So we not only pay attention to the trains running at the same direction, but also should pay attention to the trains from different directions.

B. Train re-scheduling on a double-track section

Train re-scheduling problem is also a hot research topic. Araya et al. (1983) built a 0-1 programming model for train re-scheduling problem on a double-track railway section and designed the branch and bound method to solve the problem. Zha et al. (2000) used the Lagrange method to solve the train re-scheduling model, with a linear objective and several nonlinear constraints. Rodriguez (2007) constructed a constraint programming model, taking the total delay time as the optimizing goal and hired the branch and bound algorithm to solve the problem. Törnquist and Persson (2007) proposed a hybrid integer model for train re-scheduling problem, considering the total delay time and delay cost as the optimization goal.

Iida (1983), Cheng and Qin (1992), Schafer and Pferdmenges (1994) respectively designed the expert system for train re-scheduling problem. Zhang et al. (2010) constructed a graph theory model and hired the heuristic algorithm to solve the train re-scheduling problem. The heuristic algorithm is an improved version of the greedy algorithm. Xia et al. (2008) induced train re-scheduling problems as job shop dispatching problem. They presented the train path matrix and the operation order matrix to build a train re-scheduling on a double-track railway section. The ant colony algorithm determines the drawing order of the train running line and the timetable is decided by the max-algebra method. Dong et al. (2005) took the minimal delay rate as the optimizing objective, built a 0-1 programming model to solve the train re-scheduling problem on a double-track railway section. They also hired the Tabu search algorithm to solve the model.

Zhang et al. (1998) constructed an experiment system to simulate the train operation work on the Beijing–Shanghai high-speed railway. Nie et al. (2001) also built an experiment system to study the train operation on Beijing–Shanghai high-speed railway and analyzed the strategy for train re-scheduling on high-speed railway. Li et al. (2006) hired the MAS (Multi-Agent System), described the re-scheduling problem as a process that multi-subjects occupied the tracks and the stations. Chen et al. (2002) built a train re-scheduling model, taking the passenger satisfactory degree as the optimizing objective and used the genetic algorithm to solve the problem. Wang and Du (2004) also hired the genetic algorithm to solve the re-scheduling model on a double-track section. Chung et al. (2009) constructed a hybrid integer programming model, taking the minimum cost of the delay as the optimizing goal.

Zhao and Dang (2009) improved the genetic algorithm by embedding the chaos factor and applied it to train re-scheduling problem. Mu and Dong (2010) hired a three-group particle swarm algorithm to solve the built re-scheduling model on a double-track section. Jia et al. (2006) graded the re-scheduling problem with the large-scale system theory and hired the particle swarm to solve the train re-scheduling model. Cai and Wang (1992) established an expert system for train re-scheduling problem. Zhou and Zhong (2005a, b) took the total train departure interval and the total travel time as the optimizing goal and constructed a model for train re-scheduling problem. They used the branch and bound algorithm. Dorfman and Medaic (2004) built the re-scheduling model on a double-track railway section, taking the total operation time as the optimizing goal. Cheng and Yang (2009) also built a re-scheduling model on a double-track railway section with the total delay time as the optimizing goal and hired the fuzzy Petri technology to solve the problem. Jia and Zhang (1993) tried to generate the re-scheduling plan to recover the train operation work to obey the planned timetable. Zhang et al. (1995) gave a simulation model of train operation with multi-time clock and multi-station interactive program.

Theories and methods for train re-scheduling on a double-track railway section had many same points with that for train re-scheduling on a single-track railway. In general, the method also included mathematical programming, soft computing, and computer simulation. The main difference is that some of the operation rules for train re-scheduling on a double-track railway section are different with that on a single-track section, the constraints of the model are different.

C. Train re-scheduling on unclear kind of railway section

Some of the publications did not point out on what kind of railway section, double-track section, or single-track section, the train re-scheduling problem is studied. We list the publications here. Jovanovic and Harker (1990) studied the heuristic technology and hired the hybrid integer programming model to solve the train re-scheduling problem, which reduced the number of the search points and improved the efficiency of the algorithm. Chiang et al. (1998) designed a local dispatching software package to deal with the operation conflicts, which was also a heuristic method. Li and Zhang (1998) formed the rules database of the expert system, based on the coordination mode of the inner subjects of the system. Chen et al. (2009) utilized the rough set theory to solve the train re-scheduling problem. Qian and Song (2008) also degigned a train re-scheduling model based on the rough set theory and improved the reduction algorithm for the deciding rules of the rough set. Petersen and Taylor (1982) used the simulation method to solve the train re-scheduling problem. Tommii and Satoh (1990) applied artificial intelligence in the solving work of train re-scheduling problem. Liu (2000) established a train re-scheduling model based on the Petri network theory and designed a genetic algorithm for the model. Salim and Cai (1997) solved the overpass station selection problem with the goal to reduce the cost of the stop plan.

Pu et al. (2001) designed the genetic algorithm to solve the train re-scheduling problem. Wang et al. (2006) defined the concept of distance between train timetables and designed the train re-scheduling model based on the penalty function. He also hired the genetic algorithm to solve the problem. Salido et al. (2007) designed a constraint satisfactory model with the goal of minimal total operation time. Abril et al. (2008) constructed a constraint satisfactory model with a super tree structure for train re-scheduling problem. Ghoseiri et al. (2004) built a multi-objective model for train re-scheduling problem. The goals are the minimum total travel time and the minimum energy consumption of the train.

These publications focused on the theories of train re-scheduling. They studied the design of the objectives and the solving methods of the model. When constructing the train re-scheduling model, they did not point out the model was for the single-track railway or the double-track railway, but described the common constraints in a general manner. Even some of the publications did not mention the constraints of the train re-scheduling problem. These publications usually applied the newly existed approach at that time in train re-scheduling problem, which were the supplements of the train re-scheduling theory system.

D. Train re-scheduling on a railway network

There are not many publications on train re-scheduling on a railway network. Chen and Zhou (2010) took the total travel time as the optimizing goal and built a train re-scheduling model on a complex railway network. They used the order optimization theory to solve the problem.

Min et al. (2011) studied the train re-scheduling problem on a double-track railway network. They took the weighted cost of delay time as the optimizing goal and presented a column-generation-based algorithm to solve the model. Castillo et al. (2011) gave a model on a special section, which not only included a single-track subsection, but also a double-track subsection. Peng et al. (2001) established an optimization model for the network timetable, presented a method to decompose the problem. They developed the computer-aided timetabling system.

Ma et al. (2000) proposed a computer-aided system to draw the train timetable on the railway network. Zhou et al. (1998) designed an algorithm named the network hierarchy parallel algorithm of train scheduling.This algorithm first presented the representation of hierarchy nodes of railway network structure and the representation of sequence events of train timetable,and divided the train sequence events into groups according to station and section.He presented a new method to calculate the train timetable which initialized the timetable integrally,graded the train sequence events by train priority, and triggered the algorithm to shift the section events' state according to the state of the station train events on the end point.

Wu et al. (2008) paper proposed a method of composing a train operation plan before transport, which can program traffic capacity overall and can make the transport working in order. By analyzing the requirement of composing a train operation plan, the paper designed a model of the ARTSR and proposed a programmed algorithm based on a method of the fixed train path by the regular characteristic of ARTSR, which could arrange the train schedule on the chosen transport routes. Kong et al. (2008) studied the military transportation security by railway in the condition that there occurred a sudden mass transportation requirement. The listed the rules in securing the military transportation in emergencies. Zhang and Yan (2004) built a discrete event model of train vehicle scheduling problem in emergencies and designed a greedy algorithm to solve the problem. Wang (2008) provided a time event graph simulation model to optimize train timetable from the view of a railway network. He (1995) presented a bi-level programming model for train re-scheduling on a railway network and designed a hybrid fuzzy particle swarm algorithm to solve the model.

1.2.2 Analysis on the Publications

Publications on train path were mainly about the integration problem of train pathing and formation plan optimization. They often took the transportation distance, time, cost, and transportation volume as the optimizing objectives from the view of transportation operation bureaus. The constraints were the capacity of the stations and the railway sections. They often built models to optimize the train path and designed various kinds of algorithms to solve the problem. In addition, publications on the train pathing problem of the passenger trains often took the travel time, cost, and satisfactory degree as the goal to provide the optimal path and transfer plan for the passengers.

Publications usually took the on-schedule rate, total delay time, and the relative cost as the optimizing objectives when resolving the train re-scheduling problem on a double-track railway section. The focus is the train re-scheduling model, including the description of the optimizing goals and constraints and the algorithms.

There are few publications on the comprehensive optimization of train repathing and train re-scheduling problem, especially in emergencies. Moreover, there are several publications on train operation on the railway network, focusing the timetabling problem and the development of the computer-aided timetabling system. So the train operation problem should be paid much attention.

There are still some omissions in the present study as follows.

(1) The scope of the study is limited to a single dispatching section

Current publications mostly focus on the study of train re-scheduling problem on a single railway section, whether it is a single-track railway section or a double-track section. The essence is to redesign the train operation order and inbound and outbound time of the trains at stations. Only a few publications are about the train operation from the view of networked transportation organization.

(2) Lack of study on train operation in emergencies

The present study usually aimed at solving train re-scheduling problem, which was not necessary to change the train operation paths. The assumed emergency was not serious and they could not deal with train re-scheduling problem on a railway network.

(3) The models and the algorithms are rich but not suitable for the problem put forward in this book.

The approaches can be classified into two types: the optimization approaches and the simulation approaches. The optimization approaches included mathematical programming method, heuristic method, soft computing method, expert system method, etc. The models and the algorithms are quite rich, which give us much enlightenment. However, this book focuses on train operation on a railway network, considering the train repathing and train re-scheduling problem comprehensively, especially in emergencies, which will avoid the inadequacy of studying the problems respectively.

1.3 Structure of This Book

This book is constructed with seven chapters, See Fig 1.1. Chapter 1 introduces train operation problem in emergencies and analyzes the related publications in the research field. Chapter 2 focuses on the theories on train operation in emergencies, including railway transportation system in emergencies, macroscopic model of railway transportation, difference between train operation organization and normal

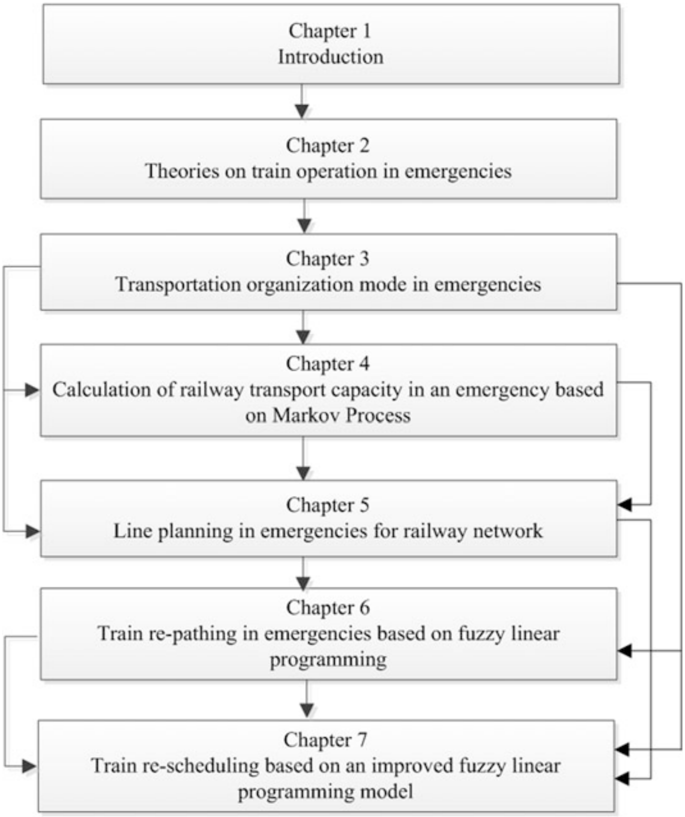

Fig. 1.1 Structure of this book

condition in emergencies, and train operation organization strategy in emergencies. From the third chapter, each chapter studies one subproblem of train operation. Chapter 3 is about the transportation mode, and Chap. 4 discusses the transport capacity of the railway section in emergencies. Chapter 5 focuses line-planning problem in emergencies. Chapter 6 studies train repathing problem in emergencies. Chapter 7 discusses train re-scheduling problem.

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Chapter 2
Theories on Train Operation in Emergencies

Abstract The destination of this chapter is to introduce the theories on train operation in emergencies. It first gives a definition of emergency and classifies the emergencies. Then it analyzes the railway transportation system in emergencies, including the system composition, boundary, function, evolution, and reconstruction of the system. It also presents a macroscopic model of railway transport organization in emergencies, and discusses the difference between train operation organization and normal condition in emergencies. At last it proposes the train operation organization strategies in emergencies.

2.1 Introduction on Emergencies

Emergencies and their effects have drawn researchers' attention from all over the world. The intension and the extension of emergency are the base to study train operation in emergencies. Although the definitions of the emergencies are different today, they all emphasize the expectancy and harmfulness.

A typical definition is given by the European Court of human rights. It says that emergency is a crisis or a dangerous status, which will affect all of the citizens and threat the normal life of the whole society (Qi et al. 2006).

Emergency in the United States is called as critical event. It was defined as a major event under which that in any situation, anywhere in the United States the need for the federal government intervention to provide supplementary assistance, to assist state and local governments to save lives and ensure public health, safety and property or transfer disaster threat (Firenze 2001).

Britain defines emergency as any situation that threatens people's health, life, property, and the environment (Yang and Wei 2010).

According to the Emergency response law of the People's Republic of China, emergency is a natural disaster, an accident disaster, a public health event, or a social security incident, which happens suddenly, and cause or may cause serious social harm, needing to take measures to deal with.

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The generalized contingencies are classified into four categories, as follows:

(1) Natural disasters, including floods and droughts, meteorological disaster, earthquake disaster, geological disaster, marine disasters, biological disasters, and forest and grassland fires;
(2) Accidents and disasters, including industrial and commercial enterprises, such as various types of safety accidents, traffic accidents, public facilities and equipment accidents, environmental pollution and ecological damage events, etc.;
(3) Public health events, mainly including the epidemic situation of infectious diseases, unexplained diseases, food safety and occupational hazards, animal epidemic situation, and other serious impact on public health and life safety;
(4) Social security incidents, including terrorist attacks, economic security incidents, and so on.

According to the nature of all kinds of public emergencies, severity, controllability, and the extent of such factors, the overall plan sudden public events is divided into four levels, namely class I (particularly serious), grade II (Serious), grade III (critical), and IV (general), followed by red, orange, yellow, and blue said.

2.1.1 Definition and Classification of Railway Emergency Events

Above is the definition and classification of the general meaning of the emergency. This book studies the railway train operation organization under the emergency condition, so the definition of the railway emergency event is given first.

In this book, emergency is defined as an event (the railway accident or railway public security event) that occurs suddenly on the railway line or station, affecting the capacity of the railway line or the station, even changing the topology of the railway network, leading to the result that train cannot operate in accordance with the planned path and operational timetable. In the event, needing to repeat the trains and re-schedule the trains to deal with natural disasters to ensure the train arrival established terminal.

There are three classification methods to classify the railway emergencies according to different classification criteria.

(1) According to the formation of railway emergencies, the railway events can be classified into three categories, which are shown as follows.

A. Natural disasters. In this book, natural disaster is a natural event caused by the astronomy, geography, and other factors, which affect the railway transportation equipment, or lead to abnormal fluctuations in the railway passenger flow. It will make the railway could not operate according to the planned timetable (Wang 2012), including meteorological disasters (such as rain, snow, storm, etc.), geological disaster, earthquake disaster.

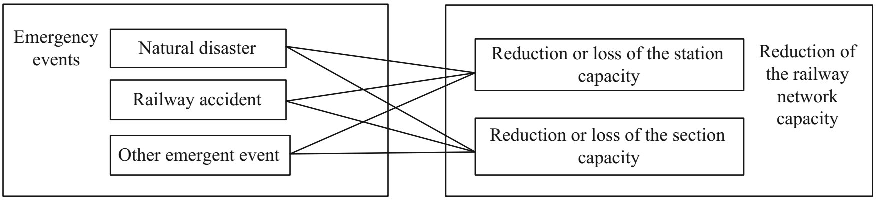


Fig. 2.1 Relation between the emergency and the effects on the railway network

B. Railway accident. According to Railway Traffic Accident Emergency Rescue, Investigation and Handling Regulations, the railway accident refers to the operation accident such as conflict, derailed, fires, explosions, and other effects of the normal railway traffic accidents in the train operation process. It also includes railway accidents occurring in the process of operation and the collision accidents with pedestrians, motor vehicles, non-motor vehicles, livestock, and other obstacles. This book takes this definition as the standard.

From Fig. 2.1, we know unexpected events lead to reduction of railway network capacity: Natural disasters and accidents on the railway; railway public security events all can lead to reduction or even loss of the capacity of station and railway sections. In addition, loss of station capacity causes changes of the railway network topology.

(2) Classification based on the impact on the train operation (Wang 2012)

A. General railway emergency

General railway emergency event is the one that affects the train operation, but the effect can be eliminated by re-scheduling methods. It includes the natural disaster, railway accident, and public security event that has little effect on the railway line, leading to minor fluctuation of passenger flow.

It has the following characteristics.

The duration of the railway line is short, and the capacity loss caused by emergency can be recovered quickly.

Fluctuation of passenger flow is slight: the growth of the passenger can be undertaken by the trains in the original plan. According to reference (Wang 2006), train seat utilization rate is generally taken as 0.7–0.8 to improve the comfortable degree of the passengers in the daily transportation work. The rate even reached to be 1.19 in the case of large fluctuations in the holidays. In the case of general railway emergency, the focus of passengers has shifted to reach to the destination as soon as possible, rather than the demand for travel comfort. Therefore, the seat utilization rate can be appropriately increased.

Line capacity loss is sight: disturbs occurred on a section and the trains cannot run as planned. However, most of the trains can reach their destinations after re-scheduling work without serious delays.

In this case, the original plan can accommodate the growth of the passenger flow caused by the emergency. It is not necessary to add more trains. Due to the events of short duration, line capacity loss is small. There is no need to adjust the path and the running of the train number. We can only adjust the train operation plan on a time dimension and can finish the transportation job within a reasonable period.

B. Serious incidents

Railway serious incidents refer to the emergent events whose influence on railway transportation cannot be eliminated through the adjustment of train diagram, including the large loss of local line capacity, larger passenger flow fluctuation and (or) continuous natural disasters which last for a long time, the railway traffic accidents and (or) public security events. They have the following characteristics.

The duration is long: the influence lasts for a long period and the capacity loss caused by an emergency cannot be recovered quickly.

Fluctuation of passenger flow is larger: Although the fluctuation of passenger is larger, the trains in the plan can accommodate the growth of the passengers.

Line capacity loss is large: Disturbs on the railway cause the rate limiting on most of the railway sections, or even some of the sections are unavailable which causes the change of the topology of the railway network. Then the trains cannot run according to the planned timetable and we cannot complete the transportation task.

In this kind of case, the trains designed in the original plan can accommodate the growth of the passengers. However, influence of the incidents lasts for a long period, the capacity loss is large, and we cannot complete the transportation work only by adjusting the transportation plan on the time dimension. The measure to reduce the number of trains on the original path should be taken, such as detour, train reconnection.

C. Pernicious railway incidents

Pernicious railway incidents are the events that are must dealt with the adjust on the strategy of train operation, and even the cross-industry cooperation, including the large range of line capacity loss, large passenger flow fluctuations, and (or) the natural disasters which last for a long period of time, rail transport accidents, and (or) public safety incidents. The characteristics are as follows.

The duration is long: the influence lasts for a quite long period and the capacity loss caused by emergency can be recovered after a long period of time.

Fluctuation of passenger flow is larger: the fluctuation of passenger is seriously large and the trains in the plan cannot accommodate the growth of the passengers.

Line capacity loss is extremely large: disturbs on the railway cause strict rate limiting on most of the railway sections for a long period of time, or even most of the sections are unavailable which causes a large change of the topology in the railway network.

In this kind of case, the contradiction between traffic requirements and transport capacity is significant. Train re-scheduling and adjustment on the train paths cannot deal with the serious condition. Related companies must cooperate and change the train operation strategy, and re-establish the train operation plan to release the contradiction between traffic requirements and transport capacity.

In general, railway bureaus have contingency plans to deal with the natural disasters and incidents, which cause the decrease of the capacity. However, emergency plan is only to respond to emergencies, in order to ensure quickly and effectively carry out emergency rescue operations, reduce accidental loss, and formulate the plan or scheme. It offers few rules related to the disposal of train operation organization to support the train operation in emergencies on the railway network.

Under emergency conditions, train operation organization, which belongs to the category of operational plan adjustment, is the research works focus of this book. That is, the work focuses on train operation organization in the condition of network capacity loss.

2.1.2 Characteristics of Railway Emergency Events

According to the analysis above, the characteristics of railway emergency events are as follows (Wang 2012).

(1) Variety of remote causes

Due to different types of railway emergencies, the formation incentive of the railway emergency events is also different.

The first category is a natural disaster caused by natural phenomena, such as heavy rain, blizzard, high wind, earthquake, debris flow, etc., which may cause the train speed limit or interruption. Second, the status of all kinds of fixed equipment and mobile equipment in the railway transportation system directly affects the efficiency and safety of the trains. In addition, some man-made factors, such as the efficiency of dispatchers and drivers curb personnel and road pedestrian, vehicle walking path, and other factors, will influence the normal operation of the railway transportation system.

(2) The sudden nature of the event itself

In recent years, with the development of computer technology, aviation technology, geology, and other disciplines, people realize the forecast on the temperature, humidity climatic conditions for a period and region. But the most devastating natural disasters (such as debris flow, landslide, earthquake, etc.) cannot be forecasted because that the natural disaster has significant uncertainty. In addition, due to the running state of the equipment, different cycles and the difference of the technical level, the state of mind and the work efficiency of the railway staff, and the railway accidents caused by machinery, equipment, and human factors have not existing rules to follow.

(3) Diversity of the objects affected

Depending on the different causes and grades of unexpected events, the affected people will involve the ones from different industries and fields. First, the influenced scope of emergency events is very different. It may affect the passengers from one or more lines. In addition, when emergency events cause huge harm and need rescuing, it will affect the local garrison, police forces, health care, and other government departments.

(4) Consequences of the emergency events

Railway emergency events will generally cause a greater influence on society. It may cause a considerable area of the train delay and affect the travel of a great amount of passengers. Even it may harm the passenger's life and property, causing serious damage on railway infrastructure, and greatly reduces the confidence on the safety of railway transportation.

(5) Urgency of event handling

For delays caused by emergencies, dispatchers should adjust train diagram in time, reduce the delay spreading, and restore the operation as far as possible.

If the emergency causes serious disruptions, which lead to the break of the rail, railway operation departments shall immediately organize repair work, adjusting the train paths. They should seek assistance from the local government if it is necessary. They can establish emergency rescue agencies at the scene start the corresponding contingency plans, reduce the effects of the accident. In a word, regardless of what type and level of emergencies, we should take timely corresponding measures to effectively prevent and control the situation, to reduce the harm and loss caused by emergency events.

(6) Resonance between the events

Different types of emergencies often influence each other and exist at the same time in the real operating environment. For example, a wide range of rainfall may lead to the result that the trains run at a limited speed. At the same time, the rain may evoke a landslide or debris flow that may cause the interruption of railway lines. In addition, if is accompanied by thunder and lightning, it can also cause failure of the railway signal system and bring inconvenience to dispatcher's work. The common effect of many kinds of emergencies greatly increases the complexity of train operation work.

(7) Expansion of the impact scale

The essence of railway transportation is to complete the cargo and passenger transportation process by occupying the rail lines and station resources. When the incident causes an abnormal occupancy of a rail line or a station, it is bound to lead to train delays. Especially under the condition of line break off, it needs to relocate the trains on the other rail lines to reduce the loss and make full use of network resources. Therefore, a single emergency in a specific section may cause changes of train operation plan in a network of a region.

(8) Uncertainty of associated attributes

The attributes such as occurring time, influence scope, and duration of an emergency are difficult to predict and described by precise numbers. The status of trains also takes on a fuzzy and fuzziness and random show. These characteristics have increased difficulty of train operation in emergencies.

(9) Difference of traffic organizing content

According to the different extents of the impact of emergency events on the railway transportation system, the measures to deal with the emergency have much difference. When the impact of emergency events is relatively small, we can only adjust train operation plan, which will be able to absorb the interference caused by emergencies. Thus, we can complete the transportation task within the prescribed period of time. When the impact of emergency events is large, train operation plan adjustment time cannot cope with the status. Then we need to adjust the train operation plan both at the space dimension and the time dimension, namely to optimize the train number, stops setting strategy, train path and timetable, which involves two aspects, service plan and train timetable. In addition, in harsh emergency conditions, it often needs to set up an emergency organization and organize emergency rescue. It is urgent to distribute the passengers as soon as possible. It is more difficult compared with the first two kinds of circumstances.

2.2 Railway Transport System in Emergencies

2.2.1 System Type of Railway Transportation System

System exists in different forms. Depending on the system-generated reasons and the properties, systems can be classified into various types. According to the origin of the system, they can be divided into natural and artificial systems. According to the size and structure, systems can be divided into simple systems and large-scale systems. According to the time characteristics, systems can be divided into static system and dynamic system. According to the relationship between the systems and the external environment, they can be divided into open system and closed system.

Yan (2004) pointed out that the railway organization scheme of train operation system is an open artificial system in his doctoral thesis. Naturally, the railway transport system in emergencies is also an opening of the artificial system. We must constantly change and optimize the railway transportation system to make the system adapt to the social environment, which requires railway transportation system to have sufficient flexibility and adjustability.

The railway transportation system is a multi-objective system. The total target of railway transportation system is to achieve social benefits and economic benefits. But the specific target is varied and it is very difficult to meet all of the requirements, such as efficient, fast, economy, comfort, safety, and environmental protection, because that there is a very strong *trade-off* or *trade-off phenomenon* (Wang 2008). That is, at the same time of a function is optimized, there must be one or several other functions experience the loss of profits. For instance, there is an obvious "trade-off phenomenon" between the direct train rate and railway transportation cost.

Such multi-objective conflict phenomenon exists in the railway transportation system, especially in emergency conditions. So we adjust various goals to obtain the overall optimal effect of the railway transport system. Especially in the emergency, this kind of adjustment is particularly important.

2.2.2 System Composition

The structure of the system is the interaction of the elements and the way or the order of each other in the system. It is the specific link between the various elements of the role of form, which is the internal basis to maintain the integrity of the system.

Railway transportation system components include equipment and staff. The equipment is divided into fixed and mobile devices. And fixed equipment includes railway lines and stations, and mobile devices include trains and EMU. Staff includes production and management personnel.

Relations between trains and railway line, stations are the most important relations in railway transportation system. The key work in railway transportation is to arrange the relation between trains and the railway lines, and the relation between trains and the stations. The plan is in the form of transportation mode, train service plan, operation diagram, EMU plan, etc.

Railway transportation system can be divided into staff, stations, rail lines, and equipment. There are complex relations between the staff, stations, rail lines, and the equipment of different types of railways. The internal structure of the railway system is very complicated.

The railway transportation system is a large-scale system. Chinese railway transportation system includes not only the general speed railway, but also intercity railway, high-speed railway line, equipment, and staff, which is a system involving many factors. In emergencies, various types of elements, namely line, equipment, and personnel, must cooperate and the relationship between these elements becomes more and more complex. The structure of the railway transportation system becomes very complicated. Moreover, in emergencies, the railway transport system elements are with strong random state property changes, which make the structure of the railway transportation system uncertain. So we can conclude that the railway transportation system in emergencies is a typical large-scale system.

The mathematical description of railway system is $S_{\text{trans}} = (S_{\text{station}}, R_{\text{rail}}, T_{\text{train}}, F_{\text{faculty}}, R)$, in which S_{trans} is the railway transportation system, S_{station} is the set of stations, R_{rail} is the set of railway lines, T_{train} is the set of trains, F_{faculty} is the set of staff, and R is the set of relations between all of the elements.

2.2.3 Boundary of the System

If the railway transportation system is regarded as the analysis object, passenger demand, the natural environmental conditions constitute the environment of the system. The boundary of the system is a set of status nodes that can start and end the action. For the railway transport organization system, system boundary is the set of OD nodes. That is to say, the nodes are the stations where the passenger flow and freight flow are generated and disappeared.

Emergency conditions may result in the invalidation of the railway transportation system in the station, so the boundary of the railway transportation system under emergency conditions is different from the one under normal conditions. Under emergency conditions, the boundary of the railway transportation system can be smaller than the boundary of the railway transportation system under normal conditions. The mathematical description is as follows.

Under normal conditions, the boundary of the railway transportation system is $S_e = S_{\text{station}}$. But under emergency conditions, the boundary of the railway transportation system is $S_e^A = S_{\text{station}}^A$. And there is $S_e^A \subseteq S_e$. S_e^A is the station set of railway stations in emergencies.

2.2.4 Function and Behavior of the System

The railway transportation system, whether under normal conditions or under emergency conditions, plays the role of realizing the displacement of passengers and cargo. The function of the railway transportation system is determined by the relationship between the stations, sections, trains, and faculty. Under normal conditions, the function of the railway transport system is visible, which is controlled by a variety of transportation plans. In emergency conditions, changes occur in the external environment of the system, which leads to the change of the relationship between the different parts of the transportation system. The function is affected, which means that it cannot complete the scheduled transport plan. At this time, it needs to re-adjust the transportation plan to recover the function of the railway transportation system. Its mathematical description is as follows:

The railway transportation system, $S_{\text{trans}} = (S_{\text{station}}, R_{\text{rail}}, T_{\text{train}}, F_{\text{faculty}}, R)$, $\forall R^0$, S_{trans}, has the function of F^0 in E^0 environment. The emergency forces the relationships between different parts of the system to change, then $R^0 \rightarrow R'$. Thus $F^0 \rightarrow F'$. The task is to search for A which can cause the change $R' \rightarrow R''$. The function F' of system $S_{\mathrm{trans}} = (S_{\mathrm{station}}, R_{\mathrm{rail}}, T_{\mathrm{train}}, R'')$ is expected to approach to F^0 as much as possible. That is to say, the emergency changes the function of the railway transportation system, and then we must find a plan to make the system remain the function as much as possible through changing the relationship between the parts of different parts of the railway transportation system.

The work of this book is to find the plan to repath the trains and re-schedule the trains. Its essence is to design the relationship between train, track, and stations in railway transportation system. The destination is to remain the function of the railway system. Train path assignment is the embodiment of the spatial relationship between train and railway line, but the train re-scheduling plan is the embodiment of the temporal and spatial relationship between train and railway line.

2.2.5 Evolution and Reconstruction of the System

For any system, the evolution of the system is a basic attribute, and it is an irresistible trend. The state of the system, structure, behavior, and function change with the passage of time, which is called the system evolution.

The relationship between the stations, trains, sections, and faculties is the key relationship in the railway transportation system. With the continuous expansion of the scale of the railway network, new entrants in the railway system, such as the stations, equipment, lines, and the staff, form extremely complex temporal relationships with the existing equipment, lines, and the staff. In fact, the structure is changed in the railway transportation system.

In addition, the change in the environment can also force the structure of the railway transportation system change, through altering the relationship between the elements of the railway transportation system. While the reconstruction is to change the inner structure of a system as a prerequisite to keep the function of the system, reconstruction can be divided into two types: the active reconstruction and the passive reconstruction. Active reconstruction is an active adjustment on the system structure to stable the system structure and perfect the system function. Passive reconstruction is an adjustment caused by the emergency effect on the system to remain the system function.

Under normal conditions, dispatching work on different sections of the railway line is relatively independent. Staff, equipment, and stations on different lines have little relationship, except that with a cross-line organization mode, there is a certain relationship. The coupling degree is weak.

In the event of an emergency, the status of line is affected, forcing the railway staff to redesign the organization scheme, making the time–space relationship between trains, lines, and station change. These relations include not only the relationship between existing trains, railway lines, and stations, but also the relationship between the high-speed line, the stations, and the existing trains. All these changes mean the structure of the railway transportation system has been changed. Its essence is the reconstruction of the railway transportation system.

So we can conclude that transportation organization in emergencies is a process adjusting the inner time–space relationship between the trains and stations (sections), which is also a process to restrict the system. Detailed embodied form is the relocation of the trains on the railway lines and the re-scheduled timetable for the trains.

2.3 Macroscopic Model of Railway Transport Organization in Emergencies

Generally, we decide to activate the appropriate levels of emergency plans due to the severity and the extent of emergency. The emergency plan is a macroscopical plan to deal with the emergency and its effect, which present some constraints for the design of the detailed operation plan.

So, we first discuss the general principles and methods for the emergency disposition, and then establish macro-general suitable model for railway transportation organization in emergencies.

2.3.1 General Principles and Methods of Emergency Handling in Emergencies

(1) General principle

First of all, the country establishes a management system for emergency handling of unified leadership, comprehensive coordination, and classification management.

The State Council under the leadership of the premier will research, decide, and deploy serious emergencies. According to the actual need, the country establishes the national emergency command agency, which is responsible for emergency handling. When it is necessary, the State Council may send a working group to guide the work.

Local people's governments shall set up relevant emergency handling departments, which include the leader of the government, the local Chinese People Liberation Army, and the Chinese People's Armed Police Force. The emergency handling department will lead the emergency handling work and coordinate with the related departments of Local Government and the departments of a lower level government to carry out emergency response.

The competent departments of the people's government at a higher level shall, within their respective functions and duties, guide, assist the people's governments at lower levels and their relevant departments to do a good job in dealing with emergencies.

(2) Emergency handling

After the occurrence of unexpected events, the government should organize all the related departments and dispatch the rescue teams and social power to deal with the emergency according to its attributes, characteristics, and serious degree. It should take emergency measures due to the relative laws, regulations and rules.

A. Disposition of natural disasters or public health events

The government should take the following measures to deal with natural disasters and accident disasters.

a. It should organize the team to rescue and treat the injured persons and evacuate and properly set the threatened personnel, take other rescue measures;
b. It should control the dangerous sources, indicate the danger area, block the dangerous places, designate warning area, and implement the traffic control and other control measures;
c. It should immediately repair the damaged traffic, communications, water supply, drainage, power supply, gas supply, heating, and other public facilities, provide shelter and basic necessities of life, and implement the medical and health measures and other security measures;
d. It should prohibit or restrict the use of equipment, facilities, close or limit the use of the relevant premises, suspend personnel intensive activities or production activities which may cause damage, and take other protective measures;
e. It should enable the financial reserves and the reserved emergency relief supplies. And the other relief supplies should be provided when it is necessary;
f. It should secure an adequate supply of necessity for life, such as food, water, and fuel;
g. It should punish the acts to disrupt the market order, such as store up goods too much, drive up prices, counterfeit goods, and stabilize the market price, maintain the market order.

B. Handling of social security incidents

After the occurrence of social events, the government should organize all the related departments and dispatch the rescue teams and social power to deal with the emergency according to its attributes, characteristics, and serious degree. It should take emergency measures due to the relative laws, regulations, and rules.

a. It should force the use of instruments to fight against each other or the parties involved in the conflict of violence, and properly resolve disputes in the field to control the development of the situation;
b. It should control the buildings, vehicles, equipment, facilities, and supply of fuels, gas, electricity, water, and water in a specific area;
c. It should blockade the relevant premises, roads, and make clear the identity of the site personnel documents, and restrict the activities of the public places;
d. It should take other necessary measures required by the law and administrative regulations.

When the serious social incident happens, the public security organs should promptly dispatch police power. It should restore normal social order as soon as possible in accordance with the law and take appropriate coercive measures;

When the emergent event happens and seriously affect the normal operation of the national economy, the State Council or the relevant competent departments authorized by the State Council may take safeguard, control, and other necessary emergency measures to guarantee the people's basic living needs and minimize the impact of unexpected events.

The government can requisition emergency rescue equipment, facilities, venues, vehicles, and other materials from enterprises and individuals when necessary. It can request other local governments to provide manpower, material resources, and financial and technical support. It has the authority to require the enterprises to produce the life necessaries and production necessaries and require public services departments, such as hospitals to provide the corresponding services.

The government should release the emergency information timely.

The residents' committee by the emergency site should obey the command from the superior government and organize the relative people to save themselves or save each other and stable the social order.

2.3.2 Macroscopic Model of Railway Transport Organization in Emergencies

The designed macro-model for transportation in emergencies includes three parts of different levels. The three levels are strategic level, the tactical level, and the operational level. In this model, the strategic level corresponds the emergency plan, which will give macro-constraints for the transportation organization model. In this level, the main work is to decide the train operation mode. In the tactical level, the model takes the transportation mode as the constraints, which determines passenger evacuation plan, vehicle usage plan, the train operation section plan, train repathing, etc. The micro-level is the operational level, which corresponds with train timetabling, re-scheduling, EMU usage plan design, etc.

The model is designed in accordance with the principle of top-down order. It has a distinct gradation, which combines the emergency plan, the handling measure, the dispatching command, the transportation mode, the service plan, and the timetable. It is a comprehensive model including all the aspects of transportation in an emergency. The structure is shown in Fig. 2.2.

Different types and levels of emergencies occur frequently in railway transportation system and trains are affected by varying degrees of interference. Railway managers and dispatchers take different measures to deal with a different degree of disturbance. So, managers and dispatchers should follow such treatment flowsheet in emergencies as shown in Figs. 2.3 and 2.4.

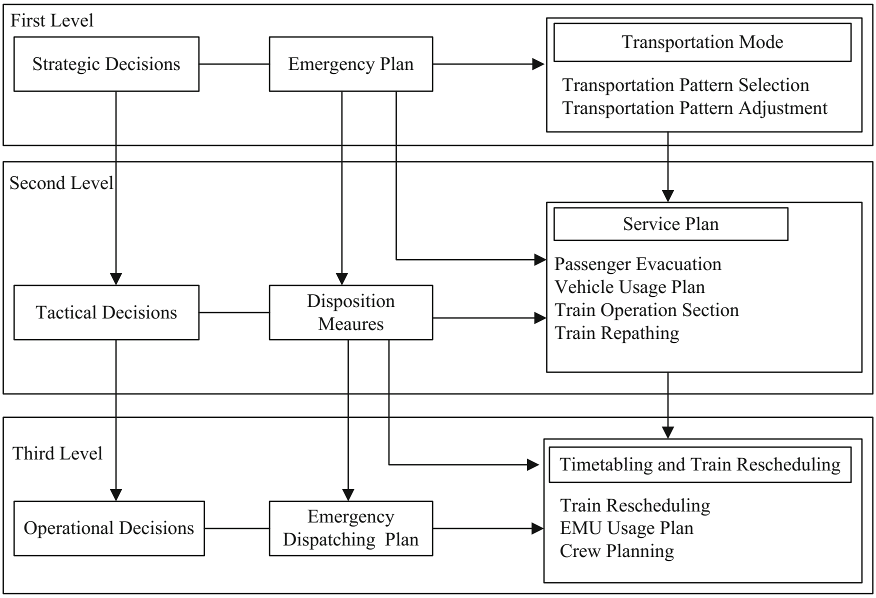
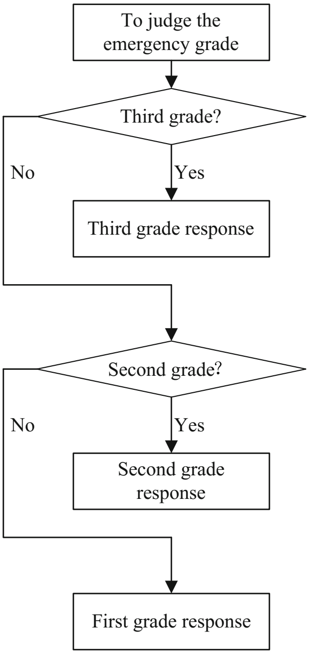


Fig. 2.2 Structure of macroscopic model of railway transport organization in emergencies

Fig. 2.3 Treatment flowsheet for transportation organization in emergencies



(1) The third-grade responding process. If the effect of the emergency is slight, disturbance on trains is also slight and the capacity of the railway line is not affected seriously. In this occasion, we only need to re-schedule the trains to complete the transportation task. The problem is a typical train re-scheduling problem, optimizing the summary total delay time of all the trains, the on schedule rate, and the passenger satisfactory degree. The affected trains are from a single railway section. The problem involves only the operational level in the macro-model for transportation and has no relationship with other levels. We can optimize the train timetable with the iteration and rolling optimizing method.

(2) The second-grade responding process. When the third-grade responding process cannot deal with the emergency and its effect, the managers will activate the second responding process. In this occasion, the emergency is more serious and brings more effect on train operation. Natural disasters or the incidents reduce the capacity of the railway lines, even lead to rail line interruption. Thus, not all of the trains can run on its planned path. We must find a new path for the trains that the path has been interrupted or redesign the running paths for all of the trains related. In this case, we take remaining the trains in the service plan as the optimization goal, and consider the cost of the trains, total delay time, the passenger satisfactory degree, social benefits, etc.

(3) The first-grade responding process. When the effect of emergency is serious and the normal transportation plan will take a long time to recover, the second-grade responding is ineffective. The emergency plan should be first activated to evacuate the passengers. Then we redesign a series of technical files, including the service plan, timetable, and vehicle usage plan. In this case, we should design the plans from the top level, strategic level, to the bottom level, the operational level.

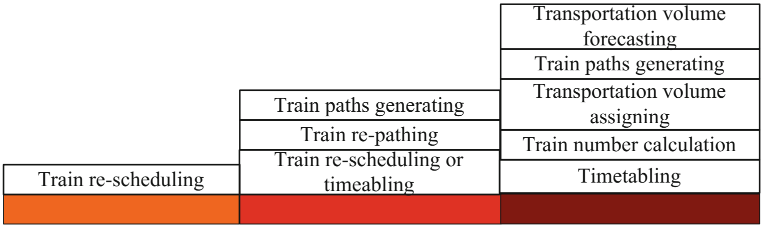


Fig. 2.4 Train operation organization in different grade emergencies

2.4 Difference Between Train Operation Organization and Normal Condition in Emergencies

The essence of railway transportation is to harmonize different parts of the railway transportation system, optimize the system inner structure, and improve the transportation system function. Transportation in emergencies is to optimize the disturbed structure by the emergencies and to recover its function in normal conditions. Today in China, the relationships in the railway system include the relationship between the normal-speed trains, high-speed trains, and the existing normal railway lines, the high-speed railway lines. The difference between train operation organization in emergencies and that in normal conditions is as follows.

2.4.1 Different Goals of Transport Organization

Railway transportation organization includes transportation mode selection, service plan design, and timetabling. The optimization goals are different at different organization levels.

(1) Transportation mode level

In normal conditions, when deciding the transport organization mode, we mainly consider passenger-attracting scope, the safety of transportation service, speed, punctuality, traffic, and railway operating costs. The transportation organization mode selection of the pursuit of the goal has obvious diversity.

In the international, France railway system takes the mode that high-speed train can run on the normal-speed railway line, extending TGV operating mileage. The optimization goal of transportation mode selection is to expand the accessible range of high-speed passenger trains and to reduce the number of transfer passengers.

Germany and Japan railway system focuses on the efficiency of passenger organization when designing the transportation mode, trying to create more direct transportation conditions and reduce the number of passengers needing to transfer (He 1995).

In China, as early as 1996, Professor Hu (1996) pointed out that there should be two kinds of transportation modes on the Beijing–Shanghai high-speed railway. One is the *all high-speed trains run on high-speed railway*, and the other is that high-speed trains and medium trains together run on high-speed trains.

He put forward the transport organization mode of “full speed and rapid transit”, which is based on the safety, speed, punctuality, and comfort degree of passenger transport, namely the goal of transportation mode selection is due to safety, speed, punctuality, and comfort degree.

Peng et al. (2004) considered the utilization of high-speed railway capacity when they studied the transportation organization mode selection problem. Chang argued (2008) that we should consider average passenger travel time, average passenger travel fares, passenger comfort degree, passenger travel convenience degree, income of railway bureaus, rail line reconstruction cost, and vehicle costs when choosing the transportation organization mode.

In emergencies, we should take the transportation task into account. We should transport the passengers and freights as soon as possible when the emergency occurs, reducing the effect of the emergencies and the social cost. For example, Guangzhou Railway Bureau issued an emergency dispatching command in accordance with the requirements of the Railway General Corporation to deal with overlay of snow disaster and large passenger flow in the winter of 2008. The dispatch command required the trains dwelt in Guangzhou station and on the southern part of the Beijing–Guangzhou Railway to change the path to the Beijing–Jiulong, Shanghai–Kunming, Sanshui–Maoming, and Jiaozuo–Liuzhou railways. With the development of the railway network, there may be more chances to change the train path; then, in the transportation mode, high-speed trains only on high-speed railway are bound to be changed.

(2) Service plan level

In normal conditions, there are two main optimizing goals when the service plan is designed. One is the profits of the railway bureaus, that is to say, to control the operating costs in the condition that the ticket fare cannot float. The other is that the satisfactory degree, waiting time, transferring time, and total traveling time are often taken as the optimizing goals from the passenger's point of view. And some of the publications combine the goals to construct the optimization model, hiring bi-level model or multi-objective programming model.

Wang and Yang (2007) divided the operation cost into two kinds, the fixed cost and the variable cost. They built a model to generate the service plan, which took the railway cost, seat waste rate, and the total passenger waiting time as the optimizing goals. Shi et al. (2007) presented a bi-level programming model, taking the railway bureau profits as the upper level model-optimizing goal and the passenger profits as the lower level model. Chang et al. (2000) proposed a multi-objective model for service planning of Taiwan high-speed railway. They took the operation cost and the total traveling time as the optimizing goal.

In emergencies, trains may change the paths to avoid the affected railway sections. The goal is to reach the destination station as soon as possible. The emergency usually causes the capacity loss and leads to train delay on a large scale. Then the social service function will be questioned. So the most important objective is to complete the transportation in emergencies to improve the social benefits. The goal of the service plan level (tactical level) is to relocate the trains on the affected railway network and complete the transportation task as soon as possible.

(3) Timetable level

In the normal conditions, the objective is to reduce the total dwelling time, train delay rate, and total delay time, and to improve the satisfactory degree. Wang et al. (2007) designed the total dwelling time as the optimizing goal, taking the timetabling problem as the cycle event-scheduling problem.

In emergencies, the goal of train operation adjustment is different from that of train operation in normal conditions. In emergencies, the target is to improve the punctuality rate and reduce the total delay time. In addition, the re-scheduled timetable is expected to have the recovering capability when it is affected.

2.4.2 Different Orders of Operation Plan

Under normal conditions, train operation organization scheme design follows the top-down design sequence. The order is transportation organization pattern choice—service plan design—timetabling—EMU utilization plan design and crew planning. In emergencies, the division of the hierarchy of the train operation organization is the same as that of the transportation organization under normal conditions. But the order of the problem is changed. In emergencies, the train operation organization is the first to consider whether the operation plan can be adjusted to achieve the established plan. When adjusting the operation plan fails, we consider changing the existing operating plan, even transportation mode to complete the transportation task. Therefore, in emergencies the breakthrough point of the train operation organization is different from that in normal conditions.

2.5 Train Operation Organization Strategy in Emergencies

2.5.1 Connotation of Train Operation Organization in Emergencies

The essence of train re-scheduling in emergencies is to redesign the time–space relationship between trains and railway lines in the condition that the external environment is changed. The specific embodiment is the train repathing plan and the train re-scheduling plan. The problem can be divided into three levels, see Fig. 2.5.

The first level is the coordination problem on the railway network, which is the highest level. The destination is to relocate the trains on the train paths felicitously and coordinate the number of trains on the road.

The capacity of the railway is reduced when the emergency affects the railway line, which cannot undertake the planned transport task. So it is necessary to search for a number of train paths to share the transport task. First, we search for the paths and form the feasible path set and provide it for the decision makers. The path set is the basis to relocate the trains on the available paths. Then we coordinate the capacity utilization coefficient of all the railway sections due to the train number on the sections and the capacity. The coordinate result is the relocation plan of the related trains. Obviously, the prerequisite is that there exist available paths and the capacities are not zero.

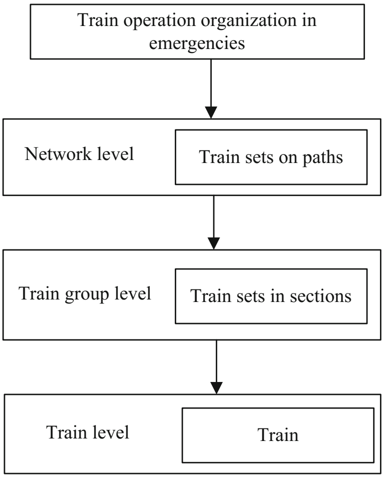


Fig. 2.5 Hierarchical structure of train operation organization problem in emergencies

We should relocate the different grades and type of trains on different paths to gain the most satisfying operation results, considering the equipment and other resources on the railway lines. The traditional method is to designate temporarily the paths for the trains, which are usually a subjective decision. The designation plan is often not very appropriate.

The second level is the one that coordinates the train groups. The trains on different paths were grouped into different groups according to the grades. Each group of trains is given a same weight in order to coordinate the operation order of different groups of trains. That is to say, the priorities of the trains in a same group are the same, while the trains in different groups have not the same priorities.

The group classification is linked to the grades and the priorities of the trains. In China, there are various kinds of trains on the railway network. If we divide the trains according to the transport objects, the trains can be divided into two kinds: the passenger trains and freight trains. If the trains are divided according to the operation speed, passenger trains can be divided as high-speed trains, express trains, fast trains, normal-speed trains, low speed trains, and temporary trains. Freight trains can be classified into five groups, the parcel express special trains, five scheduled trains, fast goods trains, coal direct trains, and oil direct trains.

In this book, we classify the trains into seven groups, which have different priorities in the train dispatching work.

(a) High-speed trains (Started with G)
(b) Intercity trains (Started with C) and EMU (Started with D)
(c) Passenger direct trains (Started with Z)
(d) Express trains (Started with T)
(e) Fast trains (Started with K)
(f) Normal-speed trains
(g) Other trains

This book divides the trains to be re-scheduled into seven groups and coordinates the relationship between group and group setting the priority of them. According to the basic classification of train group, we re-schedule the trains from the highest level to lowest level due to the group classification, which is called automatic coordination.

On the railway transport production site, the dispatchers are allowed to reset the re-scheduling priority of the trains, which is called manual coordination. The reason is that the priority of the trains may be changed in emergencies. For example, the relief supplies train must be adjusted as the train with the highest priority.

The third level is the train level. In this level, the priority of each train in a group is determined, which also includes the automatic coordination and the manual coordination. Automatic coordination in this level can adjust the priorities of each train according to the actual situation. For instance, if a train is delayed for a fairly long period of time, the priority is reduced. Manual coordination may move a train from one group to another group, or, set the priority of the trains manually. Currently, research on the train re-scheduling focuses on re-scheduling trains on a single section and seldom on the train re-scheduling trains on a railway network. We must consider fully the coordination of the trains on different paths and the mutual influence relation when studying train re-scheduling on a railway network, especially in emergencies.

So the connotation of train operation in emergencies is as follows. In emergencies, on the basis of calculating the capacity of the affected railway sections, it generates the available paths set and re-schedules the trains, including trains relocation plan design, the dwelling time design, and the inbound time and outbound time at stations of the trains.

2.5.2 Basic View of Train Operation Organization in Emergencies

Thus, there are two main sub-problems in train operation, train repathing (trains relocating), and train re-scheduling.

(1) Basic view on train repathing

Due to the general rules of train operation, the higher level trains will be set in the train timetable; first, the lower level trains and the trains delayed for a long period of time. In this book, the higher level trains and the important trains that must be guaranteed are arranged on the better paths, reducing the total delay time as little as possible. The basic view in train repathing is that the higher level trains occupy the better paths and relocate the trains on the paths according to the priority.

(2) Basic view on train re-scheduling

According to the general train operation rule, we guarantee the high-level trains' punctuality and reduce the total delay time. The newly located trains on the paths may conflict with the original planned trains on the path. We can discuss the situation on two cases.

A. The newly relocated trains on the path have the same, or a lower priority, compared to the originally located trains. Thus, we keep the train running tracks of the originally located trains to obey the rule of guaranteeing the punctuality trains. Then the newly relocated trains are inserted into the train diagram to decide the inbound and outbound time at stations.
B. The newly located trains have a higher priority than the originally planned trains. In this case, there are two tactics. The first one is to do the work as presented in the preceding paragraph. The second is to order all of the trains, including the originally located trains and the newly located trains according to their level and priority. Then we re-schedule them due to the order. The essence of this method is to reorder and re-schedule all the related trains.

2.5.3 Basic Method of Train Operation Organization in Emergencies

The review on the related works tells us that the approaches to solve the train operation problem can be classified into two types: One is the mathematical programming method and the other is the intelligent optimization method. Train paths generation problem is a mathematical programming problem, which can be solved with the mathematical optimization method. The train repathing problem is a complex combinatorial optimization problem, which can be solved through constructing a mathematical model. And train scheduling problem is a large-scale combinatorial optimization problem, whose complexity is much greater than that of train repathing. Constraints in train re-scheduling work are very complex and many of them cannot be described by the mathematical formulae. As a result, the problem cannot be solved with the traditional model and algorithm. The intelligent algorithm can give the problem a feasible solution in the condition of a certain cost (generally refers to time and space). Although the approach based on the intelligent algorithm cannot get the optimal solution, it can gain the satisfactory solution and meet the requirements of timeliness, which was proved effective. Therefore, we hire the mathematical optimization method to solve the train repathing problem and the intelligent optimization method to solve the train re-scheduling problem. So we combine mathematical optimization method and intelligent optimization method to solve the train operation problem in emergencies.

2.5.4 Principles and Measures of Train Operation Organization in Emergencies

We should obey the principles and measures when repathing the trains in emergencies.

(1) Principles and measures for repathing the trains.

A. Higher level trains should be located on the better paths.
B. Higher level trains can transfer from higher level railways to lower level railways.
C. Lower level trains cannot transfer from lower level railways to higher level railways, especially high-speed railway.
D. To reduce the transfer between different level railways as much as possible.
E. To meet the stops requirements of high-level trains.

(2) Principles and measures for re-scheduling the trains

A. Higher level trains have the priority to occupy the railway stations and sections.
B. Punctual trains have the priority to occupy the railway stations and sections when the trains belong to a same group.
C. All the trains depart the stations as early as possible.
D. If a train has a special requirement, it can be arranged with priority.
E. Trains can overtake each other if they belong to a same group.
F. Higher level trains can overtake lower level trains.
G. Lower level trains cannot overtake high-level trains.

(3) Concrete measures for train operation in emergencies

A. To relocate the affected trains on the newly found paths.
B. To accelerate the delayed trains and change the inbound time of the trains at stations.
C. To speed up the technical operation at the stations and change the outbound time of the trains.
D. To organize the higher level trains to overtake lower level trains with the crossover link rails.
E. To organize the trains to run a negative direction.
F. To change the usage plan of the receiving and departing lines.
G. To change the routes of EMUs and extend or shorten the running section of EMUs.
H. To change the connection time.

Measure A is an essential one for train operation in emergencies, which will affect the originally located trains on the paths. The implementation process is complex. Measure B and C are the easiest to realize. Measure D and E are difficult to implement. Measure D requires the crossover link rail and the related signaling equipment, or there is the artificial signaling condition. Measure E is the most dangerous one because the conflicting routes must be checked and considered. Measure F has the same complexity and security with Measure E. Measure G and Measure H have the same complexity and security with Measure A.

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Chapter 3
Transport Organization Mode in Emergencies

Abstract This chapter focuses on the transport organization mode in emergencies. First, it introduces the various modes of train operation. Then it discusses the transportation mode selection problem, including the necessity and feasibility of redesign the transport organization mode. Then, it presents a model of transport organization mode selection in emergencies.

3.1 Transportation Organization Modes

Transportation organization mode is to determine what kind of trains run on what kind of railway lines and how to organize the train operation. The transportation mode on the existing normal-speed railway is that the freight trains and passenger trains of different grades all run on it. The possible transportation modes of the newly built railway are all-high-speed mode, high-speed train transferring to normal-speed railway, passenger trains and freight trains both run on the high-speed railway and middle speed railway transferring to the high high-speed railway (He 1995).

3.1.1 Different Transportation Organization Modes of High-Speed Railway of Several Representative Countries and Regions

High-speed railway is developing fast in recent years and has become the developing direction in many countries. Because of the different national conditions, the transportation organization modes vary widely. In France, Japan, Spain, only the high-speed trains can run on the high-speed railways, while in Germany and Italy, freight trains and passenger trains are both allowed to run on the high-speed railway.

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(1) Transportation mode of Shinkansen of Japan

Shinkansen of Japan includes Tokaido Shinkansen, Sanyo Shinkansen, Tohoku Shinkansen, Joetsu Shinkansen and Hokuriku Shinkansen, which are self-forming high-speed railway system, respectively. All-high-speed train is the transportation of Shinkansen. It is also called *All-high-speed and Transfer* mode. Each train runs on a high-speed railway and does not transfer from one ling to another. Non-through passengers must transfer in the system.

Japan railway system kept trying to present better transferring advantage for the passengers. The railway system used the scribing management after privatization. Shinkansen and the neighboring existing normal-speed railway are operated by a same company, which enlarges the attracting range and gains many social and economic benefits. Paths of the high-speed trains extend to the normal-speed railway and reduce the transfer times of the passengers.

High-speed trains on Shinkansen are the force scattered EMUs. The new main line has the advantages of high density, large passenger transport capacity, good security, good service facilities, convenient transfer, convenient passenger travel, and so on. At the same time, in order to meet the different needs of long-distance passengers and the passengers along the line, the Shinkansen used a different stops plan, which has attracted a large number of passenger flows.

(2) Transportation mode of French railway system

French high-speed railway-TGV has three forms of the transportation mode. One is that the high-speed railway is dedicated for the passenger train. The second mode is to combine the passenger train and the freight train. The third is to improve the number of trains and reduce the transfer times. The new passenger dedicated use refers to allow only TGV high-speed train to run a new high-speed rail, which is the so-called “pure speed.” Highest speed (the southeast line of 270 km/h) was improved to 300 km/h (the Atlantic line), and even to 350 km/h (the Mediterranean line). At the same time, in the case without interrupting operation, they allow the trains originally running in the passenger dedicated line to transfer to the normal-speed railway line, and to run at the speed of at least 160 km/h. France adopted the “high-speed trains transfer to normal-speed line” method, extending the TGV high-speed train operation distance, expanding its scope of access. It reduced transfer times of the passengers.

On the whole, the mode of French high-speed rail can be attributed to the *full speed-off-line* mode. High-speed rail line is only for high-speed trains. While only the high-speed trains are allowed to run on the high-speed railway and they are permitted to extend the path to the normal-speed railway. So they can make full use of the existing infrastructure and minimize construction difficulties and cost. It is convenient for the trains to enter big cities, such as Paris and Lyon.

From the overall point of view of the system, France high-speed railway company took the following organizational measures in order to obtain the best economic benefits.

A. They set maintenance time according to the operational requirements. High-speed trains operate during the daytime, and the maintenance time is set for the night, which is at least 1.5 h.
B. They make full use of the characteristics of TGV high-speed trains that can be two-way operation. According to the time requirement to turn back they try to connect a timetable of a direction to another timetable of a counter direction.
C. They make full use of the characteristics of TGV high-speed trains that can be linked. They join two trains at the peak hour of a day or a week to carry more passengers.

French railway operation department set the relative train number due to the passenger flow volume. The mode meets the requirements of the transportation market and improves the reliability of the railway system, leading to the result that the attendance rate is high. The number of the stops is reduced and the total travel time of the trains is controlled. However, the intervals between trains are not constant. The passengers must prepare a timetable in hand.

(3) Transportation mode of German railway system

German high-speed rail network is formed by the transformation of the existing railway line (the highest speed is 200 km/h) and the newly built high-speed line (maximum speed 250–300 km/h). German high-speed railway construction expresses special emphasis on expanding freight transport capacity, enhancing the quality of transport, and eliminating the bottleneck of the railway section. As a result, they use the mode of passenger train and freight train both operating on high-speed railway. High-speed railway is expected to be very busy.

German ICE EMU uses the periodic transportation mode, in which the intervals between the trains are constant.

Every 1 h an ICU high-speed train is sent in many big cities of Germany. The periodic timetable is very easy to remember and convenient for the passengers. For the railway operation department, the required train number is not large. The regular operation makes the operating personnel work in order. Thereby, reducing the irregular operation process. In addition, optimization of maintenance procedures to reduce the trains to run back. And constant departure interval of train makes it easy for other transportation vehicle to link up with.

The disadvantage of this mode of transport is the train speed must be compatible with the train timetable. The result is that the average train speed is reduced. The passenger trains and freight trains cannot run on the same railway line because of the short intervals between trains.

To provide more convenience for the passenger transferring, the trains are designed to stop at a same platform. This mode requires the operation reliability and punctuality of the whole railway network. In addition, they also apply the method to exchange the train operation line to reduce the transferring frequency. Although the high-speed railway system has a good mechanism to make it easy to transfer at the stations, it still tries to provide the through conditions. For example, some of the ICE and IC series trains may run at the normal-speed railway.

Moreover, German railway system operates the short distance trains to meet the requirements of the passengers and to improve the flexibility of the service. An EMU train can operate as a whole on the busy railway line. And it also can be divided into two parts. Each part can run as a smaller size train, which can be used on the free railway line. This mode can meet the transportation requirements and save the railway capacity. It also can compete with the cars transportation.

(4) Transportation mode of Italian and Spanish railway system

IN Italy, freight trains and the passenger trains both operate on the high-speed railway. The main train type is medium coach. Some of the high-speed trains only run on the high-speed railway, while other not only run on the high-speed railway, but also on the normal-speed railway, to reach the big cities that are not along with the high-speed railway. Additionally, the normal-speed train can run on the high-speed railway, such as the IC and EC trains, and some of the trains that deliver fresh and perishable goods also have the right to run on the high-speed railway. Normal freight trains cannot transfer to the high-speed railway. Madrid-Seville high-speed railway of Spain is designed to meet the requirements of high-speed trains and medium speed trains to run together on a same railway line.

(5) Transportation mode of Taiwan railway system

Taiwan railway system takes the *All-high-speed and transfer* mode. Taiwan high-speed railway is built with the Japanese Shinkansen as a reference. The highest speed is 300 km/h, using the power scattered EMUs. The railway service level is improved greatly through optimizing the transportation mode. Taiwan high-speed railway to implement leapfrog stop strategy, attracting more passengers along the high-speed railway line. Starting from Taipei, we can arrive in Kaohsiung by the high-speed train in 80 min.

(6) Current transportation mode of mainland China system

A. Transportation modes of the railway with the highest speed above 300 km/h

There are six transportation modes for the railway with the highest speed above 300 km/h.

a. Only the self-line trains with the highest speed above 300 km/h can run on the high-speed railway and there is no transfer operation. The trains needing to cross the railways all run on the normal-speed railways.
b. Only the self-line trains with the highest speed above 300 km/h can run on the high-speed railway and there is a transfer operation. The trains needing to cross the railways all run on the normal-speed railways.
c. The self-line trains with the highest speed above 300 km/h and the trains needing to cross the railways can run on the high-speed railway. Other trains needing to cross the railways all run on the normal-speed railways.
d. The self-line trains with the highest speed above 300 km/h and the trains needing to cross the railways can run on the high-speed railway with the speed above 300 km/h.

e. The self-line trains with the highest speed above 300 km/h and the trains needing to cross the railways can run on the high-speed railway with a speed between 200 and 300 km/h.
f. The self-line trains and the crossing trains can run together on the high-speed railway. Self-line trains must run at the speed above 300 km/h. The crossing trains can run at the speed above 300 km/h if it is possible and other crossing trains run at the speed between 200 and 250 km/h.

Among the six modes above, the former four modes are the *All-high-speed modes*. Mode e and mode f are the modes that allow different speed trains to run on high-speed railway. The former four modes are more suitable for the high-speed railway than the last two in China.

B. Transportation modes of the railway with the highest speed above 300 km/h

Intercity passenger dedicated line is designed to attract intercity passenger flow, mainly to transport the high density, highly flexible passenger flow, which is a strong competitor of urban road traffic. The characteristics of its operations are: Most of the traffic is concentrated in the day. The passengers do not have to wait when they arrive at the station.

Therefore, the mode of transport organization only allows the self-line intercity trains. This mode does not consider the link with the normal-speed railway and the form is quite simple. The trains can be divided into two groups. One is the direct train, only stopping at the central cities. The other is the train, stopping at each station. A few trains can transfer on the high-speed railway; both the transferring condition is very strict. The transportation modes of the trains with the highest speed of 200 and 250 km/h are as follows.

a. Only the self-line trains are allowed to run on the high-speed line. There is no transferring operation. The crossover trains all run on the normal-speed railway line. In this mode, the trains with the highest speed of 200 and 250 km/h are allowed to run on the high-speed railway. The speed of a direct train is no less than 250 km/h and the speed of other trains are no less than 200 km/h.
b. At the joint station, the cross train can transfer on the high-speed railway.

3.1.2 Analysis of Different Kinds of Transportation Modes

The modes of railway transportation of the representative countries are summarized as follows.

A. Only the high-speed trains can run on the high-speed railway and the high-speed train cannot run on the other kind of railways. This mode is called *All-high-speed and transfer* mode.
B. Only high-speed trains are allowed to run on the high-speed railway. And the high-speed trains can run on the normal-speed railway. This mode is called *All-high-speed and turn to normal-speed railway* mode.

C. Both passenger trains and freight trains have the right to run on the high-speed railway, which is called the *hybrid transportation* mode.

All-high-speed and transfer mode: In this mode, all the high-speed trains must run on the high-speed railway. Other trains cannot run on the high-speed railway. The direct passenger number is large and the passengers who need to cross the railway lines must transfer from a train to another at a certain station. This mode is suitable for the self-forming passenger dedicated railway lines. The advantage of this mode is that the train speed is high (the speed can reach to 200–300 km/h), the interval between trains are short, the operation work is simple and the transportation capacity is large. However, passengers who need to cross the railways must transfer one or more times, the travel time is prolonged. So some of the passengers may choose other transportation modes and increase traffic pressure in the city. So transfer problem is the key problem of this railway transportation mode.

All-high-speed and turn to normal-speed railway mode: This mode allows the high-speed train not only run on the high-speed railway, but also on the normal-speed railway. This mode is suitable for the high-speed railway that is linked with the normal-speed railway. The advantage is that the speed of the trains on the high-speed railway are similar. The capacity of the railway is large. The fact that the railway can run on the normal-speed railway can extend the accessibility of high-speed trains and expand the service area of high-speed line. It can raise the utilization of high-speed railway line and reduce the transfer number to solve the problem of passenger crossing the railways. The shortage of it is that it needs much EMUs to support the transportation mode and the railways must have the same format.

Hybrid transportation mode: This mode is suitable for the high-speed railway that was transformed from the normal-speed railway, even from the low speed railway. The advantage is that the investment is small. But the speed difference between the trains is large and the railway capacity cannot be fully utilized. The operation work is more complicated than other transportation mode and the highest speed of the trains is limited to 160–200 km/h, prolonging the travel time of the passengers.

3.2 Transport Organization Modes in Emergencies

3.2.1 *The Necessity of Adjusting Transportation Organization Mode in Emergencies*

When natural disasters and emergent events happen, the capacity of the railway will be reduced, even the railway line can be broken. The planned transportation mode may not support the situation, so we need to study how to change or redesign the transportation mode in emergencies. Otherwise, the train cannot operate as planned and the railway transportation system will collapse. So it is very necessary to study the transportation mode redesign problem to distribute the delayed trains and recover the transportation order.

3.2.2 The Feasibility of Adjusting the Transportation Organization Mode in Emergencies

(1) Matching feasibility of Train and railway line

The high-speed railway with the design highest speed of 200–250 km/h uses the ballasted tracks. Then the normal-speed trains, the normal-speed locomotives can transfer to this kind of high-speed railway. They can run at the speed of their limited speeds.

The high-speed trains with the speed of 200 km/h can run on the high-speed railway with the design highest speed of 300 km/h or the railway with the slab tracks. Other level of trains can run on the high-speed railway if they change the freight bogie to assure they are not harmful to the rail tracks. In the same manner, the high-speed trains can run on the normal-speed railway if the car wheels are not damaged.

(2) Feasibility of Train operation control

The rules of the CTC system are as follows:

A. The train over speed protection system conforming to the CTCS specification should be able to meet the requirements of the whole process control of a set of vehicle equipment.
B. System onboard equipment is downward compatible.
C. System level conversion can be completed automatically.
D. System ground, vehicle configuration, such as the condition, in the system fault conditions should be allowed to downgrade the use.
E. System level conversion does not affect the normal operation of the train.
F. System at all levels should have a clear representation.

Specific requirements are:

A. CTCS level conversion happens in the railway section (which should not happen at the home signal), and provides the corresponding sound and light warning signals to the driver. The driver presses the confirming button, lift the warning signal. When automatic conversion fails, the driver completes the conversion manually according to the respective warning information about the ATP onboard equipment and LKJ.
B. CTCS level conversion should be set up with a fixed information responder that has the function of forecast and implement. Each operation direction needs to be set separately the responder. The implementation responder can be used with the interval fixed responder.
C. In the conversion between the levels, the control of the car should be ensured to get a reliable and smooth transition. The power to control the train is based on ATP vehicle equipment.

D. If it has been the starting point for braking, the braking action should be maintained. Then the driver can complete the automatic conversion.

To sum up, we can realize the conversion between CTCs at all levels of the system to a certain extent when the trains running in the railway sections, to ensure that the trains can run on different railways in emergencies.

3.2.3 The Model of Transportation Organization Mode Selection in Emergencies

Railway transport organization mode is designed to determine the space relationship between different types of train, between the train and the network. Elements of the system are mainly railway network and EMUs, then the relationship between the network and EMUs is the logical relationship between the internal elements of the system relationship.

In emergencies, the target of the transportation organization is to quickly evacuate the passengers. The objective function of the model of the railway transport organization problem is to maximize the passenger evacuation speed.

$$\mathrm{TOP} = \{\mathrm{top}_1, \mathrm{top}_2, \ldots, \mathrm{top}_n\} \tag{3.1}$$

(1) Objective of transportation mode selection model

A. Macroscopic transportation organization mode

The transportation mode can be described as

$$\mathrm{TOP} = \mathrm{HD} \times \mathrm{NU} \tag{3.2}$$

where

$$\mathrm{HD} = \{\mathrm{hd}_1, \mathrm{hd}_2\} \tag{3.3}$$

hd_1 represents that the high-speed train can transfer to normal-speed railway;
hd_2 represents that the high-speed train cannot transfer to normal-speed railway.

$$\mathrm{NU} = \{\mathrm{nu}_1, \mathrm{nu}_2\} \tag{3.4}$$

nu_1 represents that the normal-speed train can transfer to high-speed railway;
nu_2 represents that the normal-speed train cannot transfer to high-speed railway.

B. Medium transportation organization mode

a. If divide the classified the high-speed trains and the normal-speed trains, then

$$\mathrm{TOP} = \prod_{i=1}^{M} \mathrm{HT}^{i} \times \prod_{j=1}^{N} \mathrm{NT}^{j} \tag{3.5}$$

The number of the transportation mode is 2^{M+N}, $n = 2^{M+N}$where M is the number of the high-speed train types, N is the number of the normal-speed train types.

$$\mathrm{HT}^{i} = \{\mathrm{ht}_1^{i}, \mathrm{ht}_2^{i}\} \tag{3.6}$$

$$\mathrm{NT}^{i} = \{\mathrm{nt}_1^{i}, \mathrm{nt}_2^{i}\} \tag{3.7}$$

ht_1^{i} represents that the ith type high-speed train can transfer to normal-speed railway;
ht_2^{i} represents that the ith type high-speed train cannot transfer to normal-speed railway;
nt_1^{i} represents that the ith normal-speed train can transfer to high-speed railway;
nt_2^{i} represents that the ith normal-speed train cannot transfer to high-speed railway.

C. Another approach is not to distinguish the high-speed trains and normal-speed trains. The trains will be divided into M types, and then, we use the relationship between the train and the lines to express a variety of transport organization modes.

$$\mathrm{TOP} = \bigcup \mathrm{TRAIN} \times L, \tag{3.7}$$

where

$$\mathrm{TRAIN} = \{\mathrm{train}_1, \mathrm{train}_2, \ldots, \mathrm{train}_M\} \tag{3.8}$$

$$L = \{l_1, l_2, l_3\} \tag{3.9}$$

l_1 represents that trains can only run on the high-speed railway;
l_2 represents that trains can only run on the normal-speed railway;
l_3 represents that trains can run both on the normal-speed railway and the high-speed railway.

Then, the number of the transportation modes is $3M$, $n = 3M$.

The objective of transportation selection model is

$$\text{top} = \text{optimal}\{\text{top}_1, \text{top}_2, \ldots, \text{top}_n\} \tag{3.10}$$

That is

$$\min T_{\text{waiting}} = \sum n_i^{\text{original}} t_i + \sum n_i^{\text{transfer}} t_i^{\text{transfer}} \tag{3.11}$$

(2) Constraints of the transportation mode selection model

A. The existing railway structure. Whether there are links between the high-speed railway and the normal-speed railway

$$N^{\text{intersect}} = HN \cap NN \neq \varnothing, \tag{3.12}$$

where $\text{HV} = \{\text{hv}_1, \text{hv}_2, \ldots, \text{hv}_N\}$ represents the set stations nodes on the high-speed railway,$\text{NV} = \{\text{nv}_1, \text{nv}_2, \ldots, \text{nv}_N\}$ represents the set stations nodes on the normal-speed railway.

$$\text{HV}^{\text{disabled}} \subset \overline{N^{\text{intersect}}} \tag{3.13}$$

B. The constraints from the disabled stations and sections

Disabled stations nodes cannot play the role of a crossing station node. The set of the disabled station nodes is the proper subset of the joint stations of high-speed railway and the normal-speed railway.

Reference

He, B. (1995). The transport organization patter for Beijing-Shanghai high-speed railway. *China Railway Science, 16*(3), 13–23. (in Chinese).

Chapter 4
Calculation of Railway Transport Capacity in an Emergency Based on Markov Process

Abstract This chapter proposes a method to calculate the railway transport capacity in an emergency to support the dispatching work of control centers. The effect of an emergency on section transport capacity is analyzed and the basic method to calculate the transport capacity is presented. The results show that the situation-changing process in emergencies is actually a Markov process. The calculation rule is presented based on division of the time segment during which the emergency lasts. The algorithm is designed to calculate the transport capacity of each time segment. The pessimistic strategy and the fuzzy strategy are proposed to determine the computing value of the transport capacity of each time segment, to satisfy the calculating requirements in different occasions. Our study shows that the method is reasonable and practical and the method can be embedded in the train dispatching system to support the operation work in an emergency.

4.1 Introduction

The section capability of a railway is the maximal number of trains that can go through the section in a period of time (a day or an hour), with certain kinds of locomotives and cars, and with a certain kind of organization rule. From the definition, the section capability is related to the equipment, such as locomotives and cars and the organization plan. In reality, the locomotives and cars are relatively stable. So the section capability is mainly determined by the organization rule and plan. The organization rules cover a series of organization constraints and leading principles, such as the minimum running time through the sections, the minimum intervals between trains and the maximal speed that the section can support. The most significant factor that affects the transport capacity is the maximal speed in the section.

There are three major methods to calculate the section capacity. An analytical method is designed to model the railway environment by means of mathematical formulae or algebraic expressions (Zhao 2001; Hu 1991; Abril et al. 2008). A simulation method simulates the trains' dynamic behavior of a system by moving

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it from state to state in accordance with well-defined rules to get the capacity (Yang and Yang 2002; Chang 2009). An optimization method is more strategic for solving the railway transport capacity problem and provides much better solutions than purely analytical formulae (Steven 2009; Oliveira and Smith 2000). In this chapter, an analytical method is proposed, which is different from the methods in reference 1–3 in that it uses the Markov process to describe the dynamic changes of segment capacity.

4.2 The Effect of an Emergency on Section Capacity

The transportation organization pattern, the ratio between different types of trains and similar information is all uncertain. While we cannot calculate the actual capacity, we can calculate the transport capacity of the parallel train graph.

An emergency compels the control center to adjust the speed constraint according to the degree of the emergency, which leads to the reduction of the section capacity.

The most popular formula to calculate the transport capacity is:

$$N = \frac{1440 \times 60 - (T_\mathrm{s} + T_\mathrm{w})}{I}, \tag{4.1}$$

where N is the capacity, T_s is the skylight time which is reserved to do the maintenance work (s), T_w is the extra wasted time (s) and I is the interval between two neighbor trains. So the calculation of I as shown below is the key point.

$$I = \frac{L_\mathrm{t} + L_\mathrm{s} + L_\mathrm{p} + L_\mathrm{b}}{v} \times 3.6 + T_\mathrm{a} \tag{4.2}$$

where L_t is the length of the train (m), L_s is the length of time segment that former train occupies (m), L_p is the length to assure the following train no to enter the section the preceding train occupies (m), L_b is the braking distance (m), v is the average speed of all the trains (km/h), and T_a is the additional time reserved for drivers to recognize the signals. Different braking distances correspond with different speed constraints.

4.3 The Transport Capacity Calculating Strategy in an Emergency

The degree of an emergency changes randomly during a period of time. Accordingly, the maximal speed will be changed by the control center. So, the section transport capacity also changes with the change of the degree of the emergency. We prove that the changing process is a typical Markov process.

We divide the time section into N time segments, as shown in Fig. 4.1. The maximal speeds in each time segment are possibly different, which leads to the different capacity.

Set

$$\{\Delta t_i = t_i - t_{i-1}, \quad i = 1, 2, \ldots, N\} \tag{4.3}$$

Then

$$c_{\mathrm{T}} = \sum_{i=1}^{N} a_i, \tag{4.4}$$

where a_i is the actual section transport capacity of the time segment i.

Although the lengths of every time segment are not the same because the length is determined by the actual situation of the emergency, we assume that they are the same in this chapter. We will study the relation between the time segment length and the emergency in the future.

4.4 Calculating Algorithm

Suppose that there are M constraint speeds in an emergency in a railway. Relatively, there are M transport capacity values (marked as $c_1, c_2, \ldots, c_M$ and $c_1 < c_2 < \cdots < c_M$) that form the transport capacity value set $\boldsymbol{C}$.

The constraint speed situation-changing matrix is

$$P = \begin{pmatrix} p_{1,1} & p_{1,2} & \cdots & p_{1,M} \\ p_{2,1} & p_{2,2} & \cdots & p_{2,M} \\ \vdots & \ddots & & \vdots \\ p_{M,1} & p_{M,2} & & p_{M,M} \end{pmatrix}. \tag{4.5}$$

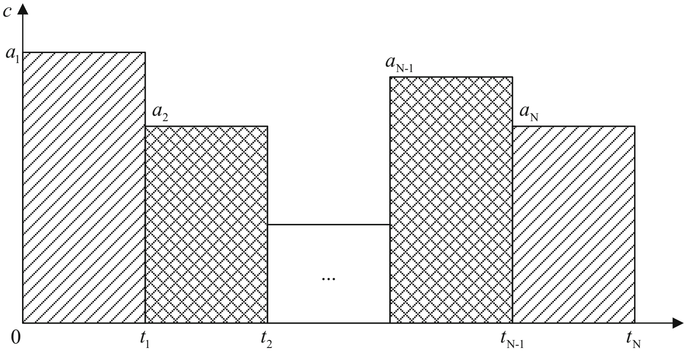

Fig. 4.1 Changing process of section in an emergency

The period of time that the emergency lasts, T, is divided into N time segments. Each time segment corresponds with a constraint speed. During T, the emergency situation changes for $N - 1$ times. The transport capacities of each time segments are $a_1, a_2, \ldots, a_N$. Their values are all from set $\boldsymbol{C}$. a_1 is the transport capacity of the first time segment. Set $a_1 = c_i,\ 1 \le i \le M$. Then

$$E(a_2) = p_{i,1}c_1 + p_{\mathrm{i},2}c_2 + \cdots + p_{i,M}c_M = \sum_{j=1}^{M} c_j p_{i,j} \tag{4.6}$$

Set of former time segment of kth time segment as $c_h,\ h = 1, 2, \ldots, M$. That is to say, $a_{k-1} = c_h$, then the equation can be generalized as follows:

$$E(a_k) = p_{h,1}c_1 + p_{h,2}c_2 + \cdots + p_{h,M}c_M = \sum_{j=1}^{M} c_h p_{h,j}, l = 2, 3, \ldots, N. \tag{4.7}$$

The transport capacity values of $N - 1$ time segments except the first one can be calculated with Eq. 4.7, while h is not the same. That is to say, the expected capacity of $i + 1$ time segment is determined by its former situation, the ith situation. It is not related to the former time segments (the $i - 1$ time segments) situation of ith situation. We can see that the process of the situation changing is Markov process.

The value of transport capacity must be a determined value, not an expected value. The control center sets the speed constraint at the beginning of every time segment. So the transport capacity of the time segment is defined. And value of each time segment can be found in set $\boldsymbol{C}$. The capacity of each time segment can be calculated with the equation as follows.

There must be two elements in set $\boldsymbol{C}$, which meet the inequality $c_i \le E(a_k) \le c_{i+1}$ where $E(a_k)$ is the expected value of a_k. Then the actual value of a_k must be either c_i or c_{i+1}. There are also two strategies to determine the value of a_k.

Strategy 1: Pessimistic strategy

Set $a_k = c_i$. That is to say, the pessimistic strategy is to set the transport capacity value to be the smaller one, which probably forces the control center to find more paths for trains, assuring the reliability of the train operating plan.

Strategy 2: Fuzzy strategy

For that capacity has the fuzzy characters in an emergence, the capacity can be calculated based on fuzzy functions. The fuzzy functions tending to c_i and c_{i+1} are designed, respectively. A possible fuzzy membership function tending to a_k is as follows:

$$r_1 = \begin{cases} 0 & E(a_k) = c_{i+1} \\ \frac{c_{i+1} - E(a_k)}{c_{i+1} - c_i} & c_i < E(a_k) < c_{i+1} \\ 1 & E(a_k) = c_i \end{cases}. \tag{4.8}$$

We get

$$r_1 = \frac{c_{i+1} - E(a_k)}{c_{i+1} - c_i}. \tag{4.9}$$

By the same rule, the membership function tending to c_i is

$$r_2 = \frac{E(a_k) - c_i}{c_{i+1} - c_i} \tag{4.10}$$

Then

$$a_k = \begin{cases} c_i & r_1 \geq r_2 \\ c_{i+1} & r_1 < r_2 \end{cases} \tag{4.11}$$

It can be seen that the triangle fuzzy membership function is used to calculate the section transport capacity in the emergency. The essence of this method is a closer-choosing rule. Of course, we can design other functions to replace the triangle function, such as trapezoid function, Gaussian function, Bell function and Sigmoid function.

4.4.1 Brief Summary

We analyze the randomness of the emergency when designing the method. The changing process of an emergency situation is proved to be a Markov process. The pessimistic strategy to determine the actual transport capacity of a time segment can assure the reliability of the operating plan. And the fuzzy strategy can make the calculated results as close to the actual value as possible and the algorithm is easy to realize. The method can be embedded in a train dispatching system to support the operation work in an emergency. We will study the time segment division and the dynamic capacity pattern and probability in the future.

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Chapter 5
Line Planning in Emergencies for Railway Network

Abstract To generate line plan in emergencies for railway networks to complete the passenger transportation, we first build a mathematical model in this chapter, focusing on the frequency setting and stops setting. Then, considering the OD passenger flow data, we 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 the Beijing–Shanghai high-speed railway and its neighbor existing railway. We find that the model is suitable to generate line plan in emergencies for railway networks and the algorithm has good calculating performance. The new method to generate line plan proposed in this chapter can be embedded in the decision support system for railway operators.

5.1 Introduction to Line Planning in Emergencies

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 Fig. 5.1, 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 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.

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Fig. 5.1 Steps of the whole planning process of railway transportation

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 chapter, we focus on the line planning problem on the railway network. In Sect. 5.1 we take a review of the research publications on the problem. In Sect. 5.2, we build the model to generate the line plans under condition of disasters. We propose the method to solve the model built in Sect. 5.3. A computing case is presented to analyze the model correctness and the effectiveness of the algorithms in Sect. 5.4. In the last section, we draw the conclusion.

5.2 Related Works to Transportation Capacity Calculation

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 on the line 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 on 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 a 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 the line planning problem of railway systems. 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 metaheuristic 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), 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 neighborhoods 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 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, called the cumulative GA (Genetic Algorithm). Chakroborty and Dwivedi (2002) also proposed a genetic algorithm 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.

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.

5.3 Modeling for Line Planning in Emergencies

Much research work has been done on the transportation organization mode 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.

5.3.1 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
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

$$\lambda_{k,i}^{u,v} = \begin{cases} 1, & k\text{th type trains pass through station } i, \\ 0, & k\text{th type trains do not pass through station } i. \end{cases} \tag{5.1}$$

$$\eta_{k,i}^{u,v} = \begin{cases} 1, & k\text{th type trains pass through station } i, \\ 0, & k\text{th type trains do not pass through station } i. \end{cases} \tag{5.2}$$

5.3.2 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:

A. 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.
B. 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.
C. 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 Eq. (5.3).

$$Q'(u,v) = \frac{\sum_{k=1}^{B} q_k^{u,v} d_k^{u,v}}{T_{\text{turnover}}} \tag{5.3}$$

T_{turnover} denotes time consumed to finish the valid passenger transportation, which can be calculated in Eq. (5.4).

$$T_{\text{turnover}} = T_{\text{run}} + T_{\text{stop}} = \sum_{u \in O} \sum_{v \in D} \sum_{k=1}^{B} l_k^{u,v} t_{k,r}^{u,v} + \sum_{u \in O} \sum_{v \in D} \sum_{k=1}^{B} l_k^{u,v} t_{k,d}^{u,v} \tag{5.4}$$

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:

$$\sum_{k=1,2} q_k^{u,v} = q^{u,v},\ u \in O, v \in D \tag{5.5}$$

$$\frac{q_k^{u,v}}{l_k^{u,v}} \leq 1.3A_k^c,\ u \in O, v \in D, k = 1,2 \tag{5.6}$$

$$\sum_{u \in O} \sum_{v \in D} \sum_{k=1}^{B} \lambda_{k,i}^{u,v} l_k^{u,v} \leq \sigma^i, \quad i = 1,2,\ldots,W \tag{5.7}$$

$$\sum_{u \in O} \sum_{v \in D} \sum_{k=1}^{B} \eta_{k,i}^{u,v} l_k^{u,v} \leq \xi^i, \quad i = 1,2,\ldots,M \tag{5.8}$$

$$l_k^{u,v} \leq \varsigma_k^{u,v},\ u \in O, v \in D, k = 1,2 \tag{5.9}$$

$$l_k^{u,v} \in N^+,\ u \in O, v \in D, k = 1,2 \tag{5.10}$$

Equation (5.5) denotes that the number of passengers allocated to each train is equal to the number of passengers forecasted to be transported. Equation (5.6) ensures that the load ratio of the trains cannot exceed 130%. Equation (5.7) denotes that the station capacity of approaching trains must be bigger than the designed sending task in the line plan. Equation (5.8) requires that the number of trains passing through a certain segment designed in the line plan must be smaller than its technical capacity. Equation (5.9) is a transportation resource constraint that requires the train number cannot be bigger than the number of rolling stock. Equation (5.10) requires the number of the trains to be a positive integer. N^+ is the set of positive integers.

5.4 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.

5.4.1 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:

$$l_k^{u,v} \geq \frac{q_k^{u,v}}{(1+\alpha)A_k^c} \tag{5.11}$$

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

$$l_k^{u,v} \geq \frac{q_k^{u,v}}{1.3A_k^c} \tag{5.12}$$

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

$$l_k^{u,v} = INT\left(\frac{q_k^{u,v}}{1.3A_k^c}\right) + 1 \tag{5.13}$$

where *INT* is a bracket function.

5.4.2 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 genetic algorithm 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 $X(t)$;
(6) Set $t = t + 1$; If the exiting condition does not exist, go to 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 chapter, the code of k type trains stops is designed as a one-dimensional array x_{L_k}. The length L_k is

$$L = m_k^{u,v} \tag{5.14}$$

$m_k^{u,v}$ 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

$$pop\_size = \sum_{u \in O} \sum_{v \in D} \sum_{k=1}^{B} l_k^{u,v} m_k^{u,v} \tag{5.15}$$

The code of a chromosome is constructed as shown in Fig. 5.2.

(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 Fig. 5.2. 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.

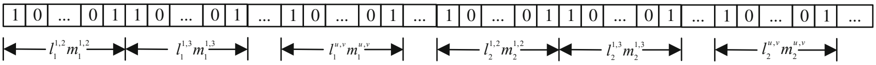

Fig. 5.2 Coding representation

(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 nonnegative or the problem is to maximize the objective function value. When the goal is to minimize the objective function value, the objective function can be designed as the difference between a large number and the adaptive function. In this chapter, passenger distributing speed is taken as the objective function and it is nonnegative. 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:

A. Calculate the adaptive value $eval(c_h)$ of every chromosome c_h;

$$eval(c_h) = f(x); \quad h = 1, 2, \ldots, pop\_size \tag{5.16}$$

B. Calculate the summary of the adaptive value of all the chromosomes;

$$F = \sum_{1 \le h \le pop\_size} eval(c_h) \tag{5.17}$$

C. Calculate the selecting probability p_h of chromosome c_h;

$$p_h = \frac{eval(c_h)}{F}; \quad k = 1, 2, \ldots, pop\_size \tag{5.18}$$

D. Calculate the accumulated probability r_k of every chromosome c_h.

$$r_h = \sum_{1 \le j \le h} p_j; \quad h = 1, 2, \ldots, pop\_size \tag{5.19}$$

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

A. Generate a pseudorandom number $z \in [0, 1]$;
B. 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, etc. In this chapter the one-point crossover is hired. The operation steps are as follows:

A. Select a single point as the starting point randomly from two father chromosomes;
B. 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 chapter, 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 step (2) to step (6).
(7) Judge if the loop can be canceled. If yes, then exit, or else go step (2).

5.5 Simulation Example

5.5.1 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 5.1. The numbers of rolling stock available for the paths in the accident are shown in Table 5.2. The emergency will last for 3 days and it requires the running speed to be reduced to 40 km/h in section between Xuzhou and Bengbu. Other sections are not subject to 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 5.2. In this case, number of train grades $B = 2$.

Table 5.1 Forecasted OD flows of passenger in a day between stations in the accident

	Xuzhou	Shangqiu	Bengbu	Xinyi	Yangzhou	Fuyang	Huainan	Hefei	Nanjing
Xuzhou	–	9644	13,918	4548	246	1205	247	2164	85,808
Shangqiu		–	4329	2164	494	767	2630	2877	4548
Bengbu			–	115	0	98	493	3836	6339
Xinyi				–	493	88	0	130	493
Yangzhou					–	79	90	110	1918
Fuyang						–	5507	4795	1671
Huainan							–	4740	1644
Hefei								–	4329
Nanjing									–

Table 5.2 Basic data of the railway network in the emergency

(a) Number of rolling stocks available for the paths in the accident		
Running segments	Number of rolling stocks	
	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	
Railway segments	Capacity
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

(continued)

Table 5.2 (continued)

Shangqiu	80
Fuyang	165
Huainan	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

5.5.2 *Available Paths*

The railway lines around are shown in Fig. 5.3. 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–Huainan–Hefei (high-speed rail)–Nanjing
- Xuzhou (high-speed rail)–Bengbu–Huainan–Hefei (normal-speed rail)–Nanjing
- Xuzhou (normal-speed rail)–Bengbu–Huainan–Hefei (high-speed rail)–Nanjing
- Xuzhou (high-speed rail)–Bengbu–Huainan–Hefei (high-speed rail)–Nanjing
- Xuzhou–Shangqiu–Fuyang–Huainan–Hefei (high-speed rail)–Nanjing
- Xuzhou–Shangqiu–Fuyang–Huainan–Hefei (normal-speed rail)–Nanjing
- 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:

- Xuzhou–Nanjing
- Xuzhou–Shangqiu
- Xuzhou–Bengbu
- Xuzhou–Xinyi
- Xuzhou–Hefei
- Shangqiu–Nanjing
- Shangqiu–Bengbu

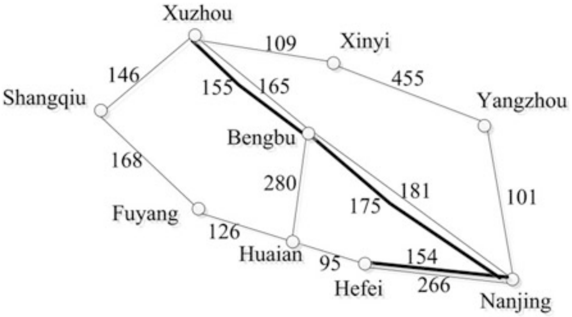

Fig. 5.3 Affected part of the railway network. *Note* The *thicker lines* stand for high-speed railway lines and the *thinner lines* stand for normal-speed railway lines. The *numbers* besides the lines are the lengths of the railway sections (measurement unit: km)

- Bengbu–Hefei
- Fuyang–Hefei
- Hefei–Nanjing
- Shangqiu–Xinyi

The paths between the OD pairs are shown at the left side of Table 5.3.

5.5.3 Frequency Setting and Stops Setting for This Case

In this chapter, a high-speed train contains 16 cars and its seating capacity is 1200. The normal-speed train contains 17 cars and has the seating capacity of 1400. We first get the forecasted OD flows of passenger data between stations, shown in Table 5.1. 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 5.3. We set the crossover probability to be 0.6 and mutation probability to be 0.1. The maximal iteration number is 1000.

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 5.3.

Table 5.3 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	8 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	3 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	2 NSTs stop at Shangqiu
Shangqiu–Xuzhou–Xinyi	0	2	Both have no stops

Note H represents high-speed trains and N represents normal-speed trains in this table. NST represents normal-speed train. HST represents high-speed train

5.5.4 *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 are not so many passengers 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.

50 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, 3 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 5507 and the OD flow between Huainan and Hefei is 4740. 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.

5.6 Brief Summary

In this chapter, 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 genetic algorithm 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 chapter meets the demand of most of the passengers in emergencies.

Future research is directed toward a generation of the model to generate the 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 chapter. 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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Chapter 6
Train Re-Pathing in Emergencies Based on Fuzzy Linear Programming

Abstract Train pathing is a typical problem which is to assign the train trips on the sets of rail segments, such as rail tracks and links. This chapter focuses on the train pathing problem, determining the paths of the train trips in emergencies. We analyze the influencing factors of train pathing, such as *transferring cost*, running cost, and social adverse effect cost. With the overall consideration of the segment and station capability constraints, we build the fuzzy linear programming model to solve the train pathing problem. We design the fuzzy membership function to describe the fuzzy coefficients. Furthermore, contraction–expansion factors are introduced to contract or expand the value ranges of the fuzzy coefficients, coping with the uncertainty of the value range of the fuzzy coefficients. We propose a method based on triangular fuzzy coefficient and transfer the train pathing (fuzzy linear programming model) to a determinate linear model to solve the fuzzy linear programming problem. An emergency is presented which is based on the real data of the Beijing–Shanghai Railway. The model in this chapter was solved and the computation results prove the availability of the model and efficiency of the algorithm.

6.1 Introduction

Nowadays, railway transportation needs to become more and more competitive, so new features are required to improve the planning process. There are two approaches to improve the capacity of the railway infrastructure. One is to enhance the construction of railway infrastructure, such as extending the rail tracks and improving performance of the signaling systems. The other is to utilize the existed infrastructure more efficiently. It is generally believed that the railway operation work can be divided into three levels, strategic level, tactical level, and operational level (Narayanaswami and Rangaraj 2011). The strategic level is about transportation pattern selecting, which is related to the national transportation policy. And the middle one, tactical level, is on the line plan designing, which is also called service plan, determining the trains number, paths and stops, etc.

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And the line plan is divided into several parts, which are the origin and destination stations determining, the trains number calculation, the train pathing, and the stops setting. Among them, train pathing is the most important step to design the whole line plan, which is the basis of stops setting. Generally, the paths of the trains are relatively steady, according to the yearly railway line plan. However, there are occasional railway accidents which reduce the capability of the railway line and make it impossible for the trains to run on the planned paths. It is necessary to find the substitute path for the trains. On the other hand, with the increase of the available rail, the topology structure of the railway network is changing profoundly. A new railway network is forming gradually, which makes it possible that more than one path can be found for the trains and train trips can be allocated on the paths.

The organization of this chapter is as follows. Following this introduction, we first discuss related works on the problem in Sect. 6.2. Then we build the train pathing model based on fuzzy linear programming in Sect. 6.3. In Sect. 6.4, we analyze the fuzzy coefficients in the train pathing model and design a new algorithm to solve the fuzzy linear model. Furthermore, we study the values range of the fuzzy coefficients, designing a method to describe the uncertainty of the fuzzy characters of the coefficients. We prove the availability of the model and the efficiency of the algorithm with a computation case in Sect. 6.5. In Sect. 6.6, we draw a conclusion.

6.2 Related Works

Caprara et al. (2007) and D'Ariano and Pranzo (2009) grouped the major published railway operation as line planning, timetabling, platforming, rolling stock management, shunting, and crew planning. Train pathing is a key step of line planning, which belongs to the tactical level. Train timetables are usually specified after the train pathing (Cordeau et al. 1998). So, it is a must to determine the path plan before timetabling, especially in emergencies.

There are two kinds of approaches to solve the train pathing problem in the limited number of publications, the mathematical approaches and heuristic approaches.

Carey (1994a) presented a mathematical model, algorithms, and strategy for pathing trains of different speeds and stopping patterns for a double track rail line dedicated to trains in one direction. The model included track assignment to trains within stations (choice of platform) and between stations (choice among multiple lines). Station layout was also considered in the model. He applied the model to a small network and found an acceptable solution. He further extended the model from one-way to two-way-tracks (Carey 1994b). Carey and Lockwood (1995) developed a model and algorithm for the TPP for one train line with station stops, and solved instances of 10 trains and 10 links. All the trains on the line travel in the same direction. D'Ariano et al. (2008) hired a branch-and-bound algorithm for sequencing train movements, while a local search algorithm is developed for rerouting optimization purposes. And they analyzed different types of disturbances, including train delays and blocked tracks. The authors of this chapter defined generating paths in emergencies as a *k*-shortest path problem and proposed the method to solve it, innovating *Dijkstra* algorithm (Meng et al. 2010). Fuzzy programming is introduced to solve the train routing and pathing problem recently. And Yang et al. (2011) considered the fuzziness in the railway transportation system, proposed a min–max chance-constrained programming model to solve the freight train routing problem with fuzzy information.

Heuristic is also hired in train pathing problem solving in recent years. Carey and Crawford (2007) developed a heuristic to settle for a plan that brings trains through a rail corridor with multiple lines and multiple stations. They started from algorithms that schedule trains at a single train station, and extend these to handle a series of complex stations linked by multiple one-way lines in each direction, traversed by trains of differing types and speeds. The algorithm was based on a set of rules to resolve the conflicts. Lee and Chen (2009) also presented a heuristic that includes both train pathing and train timetabling, and has the capability to solve real-sized instances. This heuristic allowed the operation time of trains to depend on the assigned track. Blum and Eskandarian (2002) used a delegation model to improve agent collaboration is an effective way to improve the efficiency of an A-Team for railroad flow optimization, including train pathing and railroad routing. Erlebach et al. (2001) studied the method to assign trains to satisfy scheduled routes in a cost-efficient way and proposed approximation algorithms. Törnquist (2007) presented a heuristic approach for railway traffic rescheduling during disturbances and a performance evaluation for various disturbance settings using data for a large part of the Swedish railway network. Dorfman and Medanic (2004) developed a local feedback-based travel advance strategy, using a discrete event model of train advances along the lines of the railway to quickly handle perturbations on the railway network, including train pathing. Caimi et al. (2011) addressed the problem of generating conflict-free train schedules on a microscopic model of the railway infrastructure and developed an alternative model using the sequence of resources that each train path passes, encoded in a resource tree. They showed that the number of maximal conflict cliques is linear in the number of train paths and verified the model with real-world data from the Swiss Federal Railways. Lusby et al. (2013) described a set packing inspired formulation of train routing problem and developed a branch-and-price-based solution approach. They verified the model with the test instance arising in Germany and supplied by the major German railway company, Deutsche Bahn. Pellegrini et al. (2014) proposed a mixed-integer linear programming formulation for tackling this problem, representing the infrastructure with fine granularity. They tackled randomly generated instances representing traffic in the control area named triangular of Gagny, and instances obtained from the real timetable of the control area including the Lille Flandres station (both in France) and found that negative impact of a rough granularity on the delay suffered by trains was remarkable and statistically significant. Li et al. (2013) constructed a train routing model combined with a train scheduling problem, which is a 0–1 mixed-integer nonlinear programming problem. They designed a Tabu search procedure to further improve the route schemes. Train re-pathing problem is similar with the train routing problem in several aspects. So their approach also gave us some enlightenment.

All these related works gave us much enlightenment when we built the train re-pathing model and designed the algorithm to solve it. However, fuzzy characteristics of train re-pathing problem were not considered in these publications, and the rail segments capability is not set to be the restriction when building the model in most of the publications. Therefore, we also focus on the processing of fuzzy coefficients processing in the train re-pathing model.

6.3 Train Re-Pathing Model

The objective is to reduce the total cost as much as possible. The input data include the paths between two stations, the capability of the rail segments affected, and the stations affected and all the trains information needing changing paths.

6.3.1 Basic Assumption

(1) Assumption on crew. We took it for granted that the crew resource is sufficient to cope with the trains flow distribution.
(2) Assumption on rails availability. We took it for granted that all the trains can run on all the types of rails.

6.3.2 Graph-Based Description of Rail Networks

$G = (V, E)$ is a railway network that is constructed of all kinds of rails. V is the set of vertexes in the railway network. E is the set of edges in the railway network. V includes the stations of the existent normal speed railway, the existent intercity railway, and the newly built railway. And E not only includes the rail segments of the different types of railway, but also includes the links between different types of rails.

6.3.3 Available Paths Set Generating

According to the method in our previous research paper (Meng et al. 2009), we can generate the paths set P when an emergency occurs. The calculating steps are as follows.

Step 1: To find the shortest path with *Dijkstra* algorithm between the origin and the destination. Put the shortest path, length of the shortest paths and nodes on the shortest path into the path array *P*, distance array *D,* and node array *M*.
Step 2: To find neighbor nodes of the shortest path in array *P* and put them into another array *N*.
Step 3: To calculate the distance of *n*-shortest path of v_s-v_t-v_j-v_e, which pass through neighbor v_t and put it into array *T*. v_j is a node on *n*-shortest path.
Step 4: To order the lengths values in array *T*. To select the smallest one and put the relative path in array *P*. To add 1 to the number of the shortest paths.
Step 5: If the total capability of the all the shortest paths reaches to the required capability, stop the calculation. Else, go step 2.

Then we can generate a set of shortest paths for the train operation and the sum of capability of all the paths in the path set is enough for train re-pathing work.

6.3.4 Optimization Objectives

The cost can be divided into three parts, the running cost, transferring cost, and social effect punishment cost. The running cost is an inevitable cost, which occurs during the running process.

When distributing the trains on paths, which consist of different kinds of rails, the transferring cost and the social effect punishment cost occur. In this chapter, transferring cost is used to denote the cost occurs when a train transfers from one type of rail line to another type of rail line. *Transferring cost* includes equipment cost, technology operation cost, and abrasion cost (Pu 1999). Among them the equipment costs and abrasion costs are very difficult to calculate accurately. The technology operation cost is related to profit of the railway bureau and the technology operation quantity. The *transferring cost* also depends on the rail grade, train type, and the fact whether a ferry-locomotive is needed, which is very difficult to calculate exactly. But we can set the value range of it.

The social effect punishment cost is related to the passenger satisfaction, which is also difficult to figure out and the value range can be defined.

Transferring cost and social effect punishment cost are more characterized by fuzziness in actual transportation operation, especially in emergencies. The coefficient can be expressed by some fuzzy functions, such as triangular fuzzy function and trapezoidal fuzzy function. All the optimization objectives can be compromised to some extent. As long as the values of the optimization objectives reach into a certain value range, it is considered that the optimization process is successful. We designed the method to cope with the fuzzy character of all the objectives and the algorithm to solve the trains flow distribution problem.

6.3.5 Train Distribution Model

The decision variables and parameters are as follows.

V	the set of all the station nodes in the network considered in this chapter
k	index of train type
M	the number of the train types
p	index of path
P	the set of available p
Q^p	the set of all segments on path p
R^p	the set of all stations on path p
s	index of station
t	index of station
v_s, v_t	station node s and station node t
e_t^s	the segment from station v_s to station v_t
d_t^s	the length from station v_s to station v_t
n_p^k	the number of the k type trains allocated at path p
δ_t^s	the transferring cost coefficient from station v_s to station v_t
ξ_t^s	the running cost coefficient of segment from station v_s to station v_t
λ_p^k	the social cost punishment coefficient if a k type train allocated at path p
D_t^s	the capability of segment e_t^s
B_s	the capability of station s
$N+$	the set of positive integers

6.3.5.1 Formulation of Objectives

The costs are listed and analyzed in Sect. 6.3.4. Here we formulate the costs respectively.

(1) *Transferring cost*

$$Z_T = \sum_{k=1}^{M} \sum_{p \in P} \sum_{e_t^s \in Q^p} \delta_t^s n_p^k \tag{6.1}$$

(2) Running cost

$$Z_R = \sum_{k=1}^{M} \sum_{p \in P} n_p^k \left(\sum_{e_t^s \in Q^p} \xi_t^s d_t^s \right) \tag{6.2}$$

(3) Social effect punishment cost

$$Z_S = \sum_{k=1}^{M} \sum_{p \in P} \lambda_p^k n_p^k \tag{6.3}$$

Then, we normalized the three kinds of cost by adding the coefficients, δ_t^s, ξ_t^k and λ_p^k. Then the total cost of the model is as follows.

$$\min Z_{TT} = Z_T + Z_R + Z_S \tag{6.4}$$

It is equal to

$$\min Z_{TT} = \sum_{k=1}^{M} \sum_{p \in P} \sum_{e_t^s \in Q^p} \delta_t^s n_p^k + \sum_{k=1}^{M} \sum_{p \in P} n_p^k \left(\sum_{e_t^s \in Q^p} \xi_t^s d_t^s \right) + \sum_{k=1}^{M} \sum_{p \in P} \lambda_p^k n_p^k \tag{6.5}$$

6.3.5.2 Constraints of the Model

There are many constraints when assigning all the trains to the available paths. The main constraints to be considered are as follows.

(1) Segments capacity constraints

The number of trains running through segment e_t^s cannot surpass its capability.

$$\sum_{k=1}^{M} \sum_{p \in P} \sum_{e_t^s \in Q^p} n_p^k \le D_t^s \tag{6.6}$$

D_t^s is the capability of segment e_t^s.

(2) Stations capacity constraints

The capability of every station in the railway network is bigger than the number of all the trains inbound and outbound.

$$\sum_{k=1}^{M} \sum_{p \in P} \sum_{v_s \in R^p} n_p^k \le B_s \tag{6.7}$$

(3) Non-negativity constraints

$$n_p^k \in N+ \ \text{or}\ n_p^k = 0 \tag{6.8}$$

We can see that the model is a linear integer programming model.

6.4 Fuzzy Coefficients Processing and Train Re-Pathing Model Solution

There are numerous fuzzy numbers in the model built up in Sect. 6.3.5. Thus, we first present the method to process fuzzy numbers of the model. Then based on the processing, we propose the steps to set the model with optimization software LINGO 11.0.

6.4.1 Fuzzy Coefficients Processing

A fuzzy number is a generalization of a regular, real number in the sense that it does not refer to one single value but rather to a connected set of possible values, where each possible value has its own weight between 0 and 1. This weight is called the membership function. In the engineering computation field, many elements cannot be described with definite numbers, while we can tell how much they belong to a certain range. The degree can be represented by fuzzy numbers. It is a powerful tool to describe this kind of element.

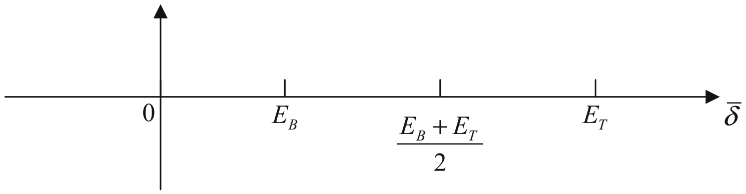
Generally, fuzzy linear programming models can be divided into three groups. The first group of models has fuzzy resources in the constraints of the model. That is to say, the resources of the constraints are fuzzy which should be described with the fuzzy membership functions. The second group of models has the fuzzy coefficients of the objectives. The fuzzy numbers occur in the optimization goal equations. The last group has the characteristics of the above two groups. They both have the fuzzy resources constraints and the fuzzy objective coefficients.

In this chapter, there are several objective coefficients which are uncertain and difficult to obtain and we model the problem as the second group. Transferring cost is a typical fuzzy number and it is very difficult to get. When disturbs occur, the price assessment of transferring cost is with more fuzziness. Fuzzy factors could be defined with fuzzy numbers. Typical fuzzy membership functions are triangular function, trapezoid function, and so on. When the fuzzy degree is out control with the typical definition of the fuzzy factors, we should improve the function to deal with the situation.

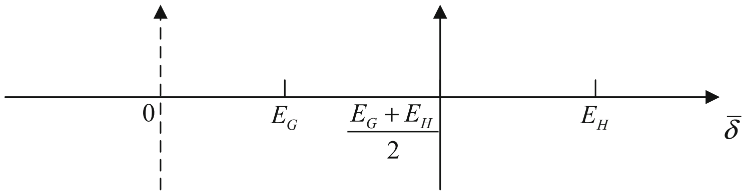
It is clear that the train distribution model is a fuzzy linear integer programming model. The tolerance method is the most typical method. In this section, we introduce the tolerance method and present a new method to solve the fuzzy linear integer programming model. And we propose a method to enlarge the fuzzy coefficients support.

In some occasions, the boundaries of the value range are also difficult to determine, especially in emergencies. So, we design a method, hiring a function $F(x)$ to expand the value range.

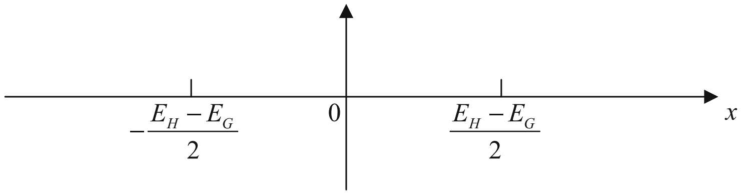
Set E_H to be the optimistic value of δ, and E_G to be the pessimistic value. Then $E_G \leq \delta \leq E_H$, $E_G \geq 0, E_H \geq 0$, $\bar{\delta}$ is the average value of δ, as shown in Fig. 6.1a.



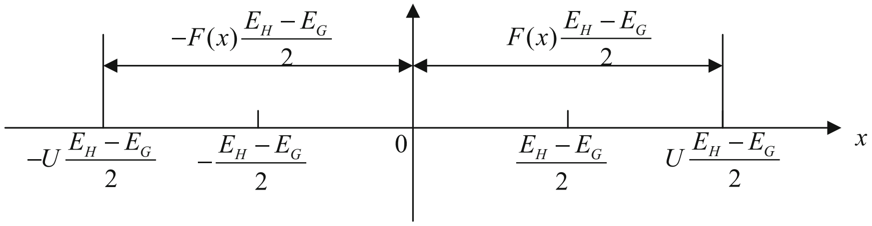
(a) Original range of the fuzzy variables



(b) The longitudinal axis is been moved to the right



(c) Original range of the fuzzy variables after the longitudinal axis is moved



(d) Alterable range of the fuzzy variables

Fig. 6.1 Design of alterable range of the fuzzy variables

Set

$$x = \delta - (E_G + E_H)/2 \tag{6.9}$$

The change is shown in Fig. 6.1b.
Then

$$-(E_H - E_G)/2 \le x \le (E_H - E_G)/2 \tag{6.10}$$

So x is symmetrical by y axis, as shown in Fig. 6.1c.
Then, $F(x)$ is hired to expand the value range of x.

$$-F(x)\frac{E_H - E_G}{2} \le x \le F(x)\frac{E_H - E_G}{2} \tag{6.11}$$

So

$$-F(x)\frac{E_H - E_G}{2} + \frac{E_G + E_H}{2} \le \delta \le F(x)\frac{E_H - E_G}{2} + \frac{E_G + E_H}{2} \tag{6.12}$$

It can be seen in Fig. 6.1d.
That is to say,

$$\begin{aligned} &- F(\delta - (E_G + E_H)/2)\frac{E_H - E_G}{2} + \frac{E_G + E_H}{2} \\ &\quad \le \delta \le F(\delta - (E_G + E_H)/2)\frac{E_H - E_G}{2} + \frac{E_G + E_H}{2} \end{aligned} \tag{6.13}$$

So the fuzzy coefficients value range is as flows after steps above.

$$\left[-F(\delta - (E_G + E_H)/2)\frac{E_H - E_G}{2} + \frac{E_G + E_H}{2}, F(\delta - (E_G + E_H)/2)\frac{E_H - E_G}{2} + \frac{E_G + E_H}{2}\right] \tag{6.14}$$

It can be seen that the expanded value range is related to the original range and the average value of the fuzzy coefficients. This method can deal with the fuzzy coefficients flexibly, making the coefficients close to the real cost as much as possible.

6.4.2 Steps to Solve Train Distribution Model

It is obvious that the programming model is a fuzzy linear programming with fuzzy objective coefficients. Since some coefficients of the objective are fuzzy, we must deal with them first. We design the method to express the coefficients with the pessimistic value, average value, and optimistic value. Since E_H is the optimistic value of δ, and E_G is the pessimistic value of δ, we set E_A to be the average value of δ. We assume that $\delta = w_1 E_H + w_2 E_G + (1 - w_1 - w_2) E_A$, where w_1 and w_2 are the weights of the optimistic value and pessimistic value respectively. We can see that the fuzzy linear programming can be transferred into different deterministic linear programming with different pairs of w_1 and w_2. Then the steps to solve the problem are as follows.

Step 1: Set $w_2 = 0.1$;
Step 2: Set $w_2 = w_2 + 0.1$;
Step 3: Set w_1 to be 0.1, then solve the linear programming with LINGO 11.0;
Step 4: Repeat Step 2 with w_1 increasing 0.1 a time;
Step 5: Record the value of w_1, w_2 and the computing results;
Step 6: Go to Step 2 and repeat the process until $w_2 = 1.5$.
Step 7: Select the satisfying solution for the model.

6.5 Case Study

6.5.1 Case Scenario

It is assumed that there is an emergency at DK856+321 on the Beijing–Shanghai high-speed railway. Then the trains cannot run through the segment of East Xuzhou to Bengbu. And the time required to recover is 4–8 h. The railway network around the emergency place is shown in Fig. 6.2. We will study the trains flow distribution problem on the downgoing direction.

6.5.2 Trains to Be Re-Pathing

Trains arrive at Xuzhou joint from 8 to 12 are as follows.

(1) The high-speed trains (shorthand: H): G301, G303, G305, G101, G103, G105, G107, G109, G111, G113
(2) Multiple Units (shorthand: M): D88/5
(3) T trains and K trains (shorthand: T&M): K58/5, K518/5, K101/4/1
(4) Normal speed trains (shorthand: N): 1230/27
(5) Low-speed trains (shorthand: L): 10135, 10625, 11301, 23005, 11305
(6) Temporary trains (shorthand: T): None
(7) Other trains (shorthand: O): None

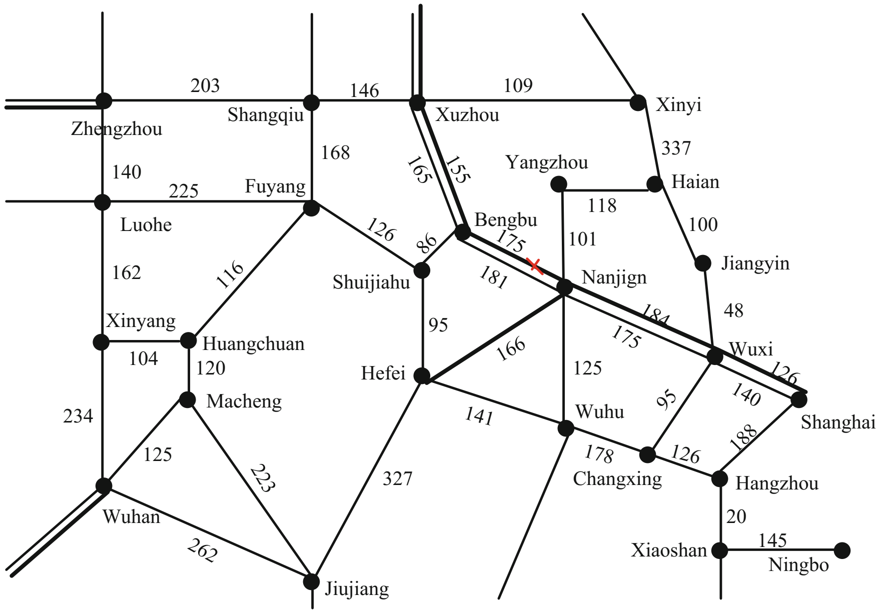


Fig. 6.2 Railway network around the emergency place. *Note* The *broader lines* stand for high-speed rails and the *thin lines* stand for low speed rails

6.5.3 *Available Paths*

According to the method in our previous paper (Meng et al. 2009), we generate the available paths according to the succinct description in Sect. 6.3.3, shown in Table 6.1 and Fig. 6.3.

Table 6.1 Available paths from Xuzhou to Nanjing (by *C*-enough plan)

No.	Available paths	Length (km)
1	1-2-5-6-3	336
2	1-4-5-6-3	346
3	1-4-5-7-8-6-3	502

And lengths of every segments on the paths are shown in Table 6.2

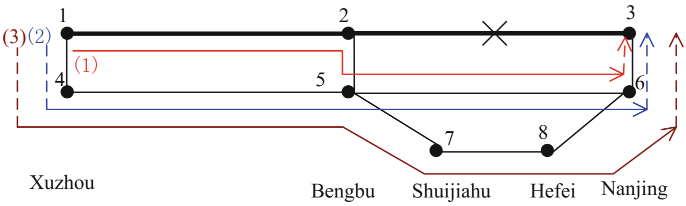


Fig. 6.3 Paths between Xuzhou and Nanjing in an emergency

Table 6.2 Lengths of segments in the paths

Segment No.	Segments	Length (km)
1	1–2	155
2	4–5	165
3	5–6	181
4	5–7	86
5	7–8	95
6	8–6	166

6.5.4 *Distribution Plan*

6.5.4.1 Specification of the Train Distribution Model

We can see that there are three available paths in the partial railway network, which are marked (1), (2) and (3), as shown in Fig. 6.3. Eight stations and six segments are in the network.

Now the goal is to allocate the trains on the three paths in Table 6.1.

We specified the model as follows:

$$\begin{aligned}\min Z = {} & \delta_4^1(n_2^1 + n_3^1) + \delta_5^2(n_1^1) + \delta_3^6(n_1^1 + n_2^1 + n_3^1) \\ & + \xi_2^1 n_1^1 \times 155 \\ & + \xi_5^4(n_2^1 + n_2^2 + n_2^3 + n_2^4 + n_2^5 + n_3^1 + n_3^2 + n_3^3 + n_3^4 + n_3^5) \times 165 \\ & + \xi_6^5(n_1^1 + n_2^1 + n_2^2 + n_2^3 + n_2^4 + n_2^5) \times 181 \\ & + \xi_7^5(n_3^1 + n_3^2 + n_3^3 + n_3^4 + n_3^5) \times 86 \\ & + \xi_8^7(n_3^1 + n_3^2 + n_3^3 + n_3^4 + n_3^5) \times 95 \\ & + \xi_6^8(n_3^1 + n_3^2 + n_3^3 + n_3^4 + n_3^5) \times 166 \\ & + \lambda_1^1(n_1^1) + \lambda_2^1(n_2^1) + \lambda_3^1(n_3^1) \\ & + \lambda_3^2 n_3^2 + \lambda_3^3 n_3^3 + \lambda_3^4 n_3^4 + \lambda_3^5 n_3^5\end{aligned}$$

s.t.

$$\begin{cases} n_1^1 \le C_2^1 \\ n_2^1 + n_3^1 + n_2^2 + n_3^2 + n_2^3 + n_3^3 + n_2^4 + n_3^4 + n_2^5 + n_3^5 \le C_5^4 \\ n_1^1 + n_2^1 + n_2^2 + n_2^3 + n_2^4 + n_2^5 \le C_6^5 \\ n_3^1 + n_3^2 + n_3^3 + n_3^4 + n_3^5 \le C_7^5 \\ n_3^1 + n_3^2 + n_3^3 + n_3^4 + n_3^5 \le C_8^7 \\ n_3^1 + n_3^2 + n_3^3 + n_3^4 + n_3^5 \le C_6^8 \\ n_1^1 \le B^2 \\ n_2^1 + n_3^1 + n_2^2 + n_3^2 + n_2^3 + n_3^3 + n_2^4 + n_3^4 + n_2^5 + n_3^5 \le B^4 \\ n_1^1 + n_2^1 + n_3^1 + n_2^2 + n_3^2 + n_2^3 + n_3^3 + n_2^4 + n_3^4 + n_2^5 + n_3^5 \le B^5 \\ n_1^1 + n_2^1 + n_3^1 + n_2^2 + n_3^2 + n_2^3 + n_3^3 + n_2^4 + n_3^4 + n_2^5 + n_3^5 \le B^6 \\ n_3^1 + n_3^2 + n_3^3 + n_3^4 + n_3^5 \le B^7 \\ n_3^1 + n_3^2 + n_3^3 + n_3^4 + n_3^5 \le B^8 \\ n_1^1 + n_2^1 + n_3^1 = 10 \\ n_1^2 + n_2^2 + n_3^2 = 1 \\ n_1^3 + n_2^3 + n_3^3 = 3 \\ n_1^4 + n_2^4 + n_3^4 = 1 \\ n_1^5 + n_2^5 + n_3^5 = 5 \\ n_p^k = 0\, or\, n_p^k \in N^+, \quad k = 1,2,3,4,5; \;\; p = 1,2,3 \end{cases}$$

δ_4^1, δ_5^2, δ_3^6 are got from the publication (Pu 1999).

λ_3^2, λ_3^3, λ_3^4, λ_3^5 are social effect punishment cost coefficient when the 2th, 3th, 4th, 5th kinds of trains are allocated on path 3. The can be attained by the Delphi method.

We got the train running cost coefficients according to the data listed in two publications (Li and Lu 1997; Qi and Xiong 2008). The coefficients are as follows.

$$\xi_2^1 = \xi_6^8 = 325, \xi_5^4 = \xi_6^5 = \xi_7^5 = \xi_8^7 = 92.4.$$

The capabilities of the related segments and stations are as follows.

$$C_2^1 = 115, C_5^4 = 20, C_6^5 = 20, C_7^5 = 12, C_8^7 = 12, C_6^8 = 62, B_2 = 30, B_4 = 32$$
$$B_5 = 38, B_6 = 30, B_7 = 20, E_G B_8 = 70$$

Set $\delta_4^1 \sim$ (2800, 3000, 3200), $\delta_5^2 \sim$ (2600, 2800, 3000), $\delta_3^6 \sim$ (3000, 3200, 3400), $\lambda_1^1 \sim$ (20,000, 22,000, 24,000), $\lambda_2^1 \sim$ (60,000, 64,000, 68,000), $\lambda_3^1 \sim$ (80,000, 86,000, 92,000), λ_3^2, λ_3^3, λ_3^4, $\lambda_3^5 \sim$ (10,000, 11,000, 12,000).

For example, $\delta_4^1 \sim$ (2800, 3000, 3200) means that the largest value of the fuzzy number δ_4^1 is 3200 and the smallest value is 2800. The average value is 3000. That is to say that $E_H = 3200$ and $E_G = 2800$.

If at this time $w_1 = 0.1$ and $w_2 = 0.5$, $\delta_4^1 = 0.1 * 3200 + 0.5 * 2800 + (1 - 0.1 - 0.5) * 3000 = 2920$. All the other fuzzy coefficients can be calculated out in the same way. The fuzzy linear programming model is turned into a deterministic linear programming model, which can be easily solved with the software LINGO 11.0.

It should be noticed that there is little *transferring cost* at Hefei and Nanjing on path (3), for the segment between Hefei and Nanjing is a high-speed segment. But the transferring operation is in the station, and the cost is very little. So, this *transferring cost* is not taken into consideration in this model.

6.5.4.2 Solutions

(1) Solving the problem in original value range

We compute the results respectively while w_1 is assigned to be 0.1–1.5. The results are shown in Table 6.3.

It can be seen that the fuzzy coefficients are bigger than the average value. It means that the smaller the value of the fuzzy coefficients, the bigger of the objective value is. It is obvious that the relative results are not satisfying. So the results in shadowed part in Table 6.3 are the unreasonable solution.

When w_1 is 0.5, the fuzzy coefficients are equal to their average value. This is the most possible situation of the reality, in which the fuzzy membership is 1. The total cost is 1.2778E06 at this point, which is the highest.

When w_1 is set to be 0.7–1.5, solution of the problem is not changed. That is to say, all the solutions with the membership under 0.8 are the same. However, the objective value changes with the fuzzy coefficients changing. According to the rule that the solution with maximal membership value and the minimum objective value should be selected, the solution is taken as $n_1^1 = 10, n_2^1 = 0, n_2^2 = 1, n_2^3 = 3, n_2^4 = 1$, $n_2^5 = 5$, $n_3^1 = n_3^2 = n_3^3 = n_3^4 = n_3^5 = 0$. The objective value is 1.2659E06.

(2) Solving the problem in variable value range

Set the variable function $F(x) = 2$. So, the value range is twice as large as the original value range. That is to say, the expanding coefficient is 2. We take the calculation of δ_4^1 for instance. Since $F(x) = 2$, $E_G = 2800$ and $E_H = 3200$, the value range of δ_4^1 is

$$\begin{aligned}
&\left[-F(x)\frac{E_H - E_G}{2} + \frac{E_G + E_H}{2}, F(x)\frac{E_H - E_G}{2} + \frac{E_G + E_H}{2}\right] \\
&\quad = \left[-2 \times \frac{3200 - 2800}{2} + \frac{3200 + 2800}{2}, 2 \times \frac{3200 - 2800}{2} + \frac{3200 + 2800}{2}\right] \\
&\quad = [2600, 3400].
\end{aligned}$$

All the other coefficients value range can be obtained by the same means. In fact, we expand the value range by this means based on the original value range, according to Eq. (6.12).

Table 6.3 Computation results of the trains flow distribution model

w_1	$F1$	$F2$	$F3$	$F4$	$F5$	$F6$	$F7$	n_1^1	n_2^1	n_3^1	n_2^2	n_3^2	n_2^3	n_3^3	n_2^4	n_3^4	n_2^5	n_3^5	S_{mf}	Z (10^6)
(a) In original value range																				
0.1	**3080**	**2880**	**3280**	**22,800**	**65,600**	**88,400**	**11,400**	**9**	**1**	**0**	**1**	**0**	**2**	**1**	**1**	**0**	**3**	**2**	**4.20**	**1.3684**
0.2	**3060**	**2860**	**3260**	**22,600**	**65,200**	**87,800**	**11,300**	**9**	**1**	**0**	**1**	**0**	**2**	**1**	**1**	**0**	**4**	**1**	**4.90**	**1.3389**
0.3	**3040**	**2840**	**3240**	**22,400**	**64,800**	**87,200**	**11,200**	**9**	**1**	**0**	**1**	**0**	**2**	**1**	**1**	**0**	**4**	**1**	**5.60**	**1.3361**
0.4	**3020**	**2820**	**3220**	**22200**	**64,400**	**86,600**	**11,100**	**9**	**1**	**0**	**1**	**0**	**3**	**0**	**1**	**0**	**4**	**1**	**6.30**	**1.3068**
0.5	3000	2800	3200	22,000	64,000	86,000	11,000	9	1	0	1	0	3	0	1	0	5	0	7.00	1.2778
0.6	2980	2780	3180	21,800	63,600	85,400	10,900	9	1	0	1	0	3	0	1	0	5	0	6.30	1.2752
0.7	2960	2760	3160	21,600	63,200	84,800	10,800	10	0	0	1	0	3	0	1	0	5	0	5.60	1.2659
0.8	2940	2740	3140	21,400	62,800	84,200	10,700	10	0	0	1	0	3	0	1	0	5	0	4.90	1.2635
0.9	2920	2720	3120	21,200	62,400	83,600	10,600	10	0	0	1	0	3	0	1	0	5	0	4.20	1.2611
1.0	2900	2700	3100	21,000	62,000	83,000	10,500	10	0	0	1	0	3	0	1	0	5	0	3.50	1.2587
1.1	2880	2680	3080	20,800	61,600	82,400	10,400	10	0	0	1	0	3	0	1	0	5	0	2.80	1.2563
1.2	2860	2660	3060	20,600	61,200	81,800	10,300	10	0	0	1	0	3	0	1	0	5	0	2.10	1.2539
1.3	2840	2640	3040	20,400	60,800	81,200	10,200	10	0	0	1	0	3	0	1	0	5	0	1.60	1.2515
1.4	2820	2620	3020	20,200	60,400	80,600	10,100	10	0	0	1	0	3	0	1	0	5	0	0.70	1.2491
1.5	2800	2600	3000	20,000	60,000	80,000	10,000	10	0	0	1	0	3	0	1	0	5	0	0.00	1.2467
(b) In variable value range																				
0.1	**3160**	**2960**	**3360**	**23,600**	**66,400**	**89,200**	**12,200**	**9**	**1**	**0**	**1**	**0**	**2**	**1**	**1**	**0**	**3**	**2**	**4.20**	**1.3804**
0.2	**3120**	**2920**	**3320**	**23,200**	**65,800**	**88,400**	**11,900**	**9**	**1**	**0**	**1**	**0**	**2**	**1**	**1**	**0**	**4**	**1**	**4.90**	**1.3473**
0.3	**3080**	**2880**	**3280**	**22,800**	**65,200**	**87,600**	**11,600**	**9**	**1**	**0**	**1**	**0**	**2**	**1**	**1**	**0**	**4**	**1**	**5.60**	**1.3412**
0.4	**3040**	**2840**	**3240**	**22,400**	**64,600**	**86,800**	**11,300**	**9**	**1**	**0**	**1**	**0**	**3**	**0**	**1**	**0**	**4**	**1**	**6.30**	**1.3094**
0.5	3000	2800	3200	22,000	64,000	86,000	11,000	9	1	0	1	0	3	0	1	0	5	0	7.00	1.2778
0.6	2960	2760	3160	21,600	63,400	85,200	10,700	9	1	0	1	0	3	0	1	0	5	0	6.30	1.2728
0.7	2920	2720	3120	21,200	62,800	84,400	10,400	10	0	0	1	0	3	0	1	0	5	0	5.60	1.2611

(continued)

Table 6.3 (continued)

w_1	$F1$	$F2$	$F3$	$F4$	$F5$	$F6$	$F7$	n_1^1	n_2^1	n_3^1	n_2^2	n_3^2	n_2^3	n_3^3	n_2^4	n_3^4	n_2^5	n_3^5	S_{mf}	Z (10^6)
0.8	2880	2680	3080	20,800	62,200	83,600	10,100	10	0	0	1	0	3	0	1	0	5	0	4.90	1.2563
0.9	2840	2640	3040	20,400	61,600	82,800	9800	10	0	0	1	0	3	0	1	0	5	0	4.20	1.2515
1.0	2800	2600	3000	20,000	61,000	82,000	9500	10	0	0	1	0	3	0	1	0	5	0	3.50	1.2467
1.1	2760	2560	2960	19,600	60,400	81,200	9200	10	0	0	1	0	3	0	1	0	5	0	2.80	1.2419
1.2	2720	2520	2920	19,200	59,800	80,400	8900	10	0	0	1	0	3	0	1	0	5	0	2.10	1.2371
1.3	2680	2480	2880	18,800	59,200	79,600	8600	10	0	0	1	0	3	0	1	0	5	0	1.60	1.2323
1.4	2640	2440	2840	18,400	58,600	78,800	8300	10	0	0	1	0	3	0	1	0	5	0	0.70	1.2275
1.5	2600	2400	2800	18,000	58,000	78,000	8000	10	0	0	1	0	3	0	1	0	5	0	0.00	1.2227

The solutions in bold are the unreasonable solutions

The expanded value ranges are as follows.

$$\begin{aligned}&\delta_4^1 \sim (2600, 3000, 3400), \delta_5^2 \sim (2400, 2800, 3200), \delta_3^6 \sim (2800, 3200, 3600),\\&\lambda_1^1 \sim (18,000, 22,000, 26,000), \lambda_2^1 \sim (58,000, 64,000, 70,000),\\&\lambda_3^1 \sim (78,000, 86,000, 94,000), \lambda_3^2, \lambda_3^3, \lambda_3^4, \lambda_3^5 \sim (8000, 11,000, 14,000).\end{aligned}$$

The computation results are shown in Table 6.3.

From Table 6.3 we can see that the objective value is reduced when the membership values are the same, as shown in Fig. 6.4.

The difference between the objective value calculated with the original value range and that calculated with the variable value range becomes obvious from the point where w_1 is 0.7. And the difference is becoming more and more obvious till the point where w_1 is 1.5. The objective value is 1.2467E06 with the original value range and the objective value is 1.2227E06 with the variable value range. So we can see the object value is optimized when we make the value range variable.

The solution with the variable value range is also $n_1^1 = 10$, $n_2^1 = 0, n_2^2 = 1$, $n_2^3 = 3, n_2^4 = 1$, $n_2^5 = 5$, $n_3^1 = n_3^2 = n_3^3 = n_3^4 = n_3^5 = 0$.

And we can see in Fig. 6.5 that all the trains are allocated on path 1 and path 2. No train is allocated on path 3. It is related to the required capacity which is 40, when searching for the available paths. However, the number of trains needing to be allocated is 20. It is necessary to set the required capacity to be bigger than the number of trains needing to be allocated. For one thing, the accurate number of the trains needing to be allocated is difficult to forecast. For another, it is a must to reserve extra capacity to deal with the uncertain situation of the reality.

The methods presented in this chapter can give the optimized solution, satisfying the fuzzy membership constraint. So, we can deal with the fuzzy character of the trains flow distribution model to approach the reality as possible as we can. We can

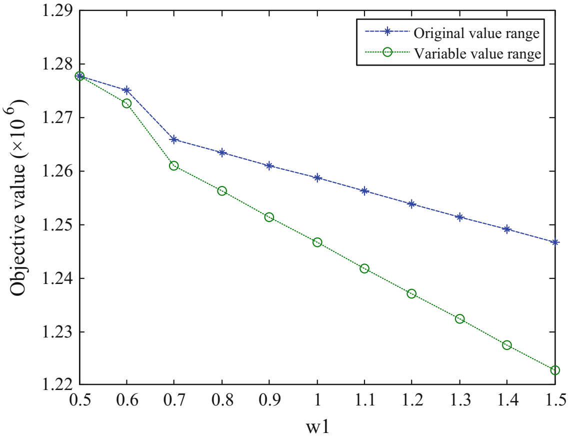


Fig. 6.4 Solution of the train paths distributing model

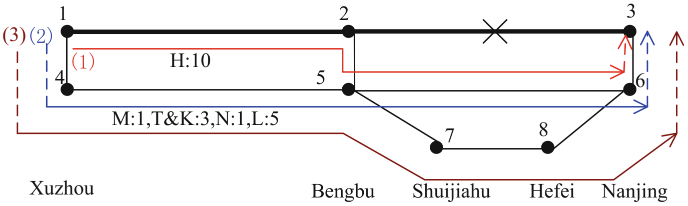


Fig. 6.5 Solution of the train paths distributing model shown on the railway network graph

propose several available solutions, at different fuzzy membership level for the managers to make the decision.

6.6 Brief Summary

This chapter proposes a feasible, effective approach to solve the fuzzy programming problems in railway transportation. We first present a model for distributing trains on paths, offering the theory basis for train dispatching on Chinese railway network. Then we integrate the *transferring cost*, running cost, and social effect punishment cost to design the objective of the train distribution model. The character of the coefficient of the costs is described with fuzzy membership function. And we present a method to expand the fuzzy number value range, supporting the algorithm to solve the model. A triangular membership function is designed to turn the fuzzy programming model into definitive programming problem. And the detailed steps to solve the model are given.

The method presented can also be used to solve other problems in railway transportation organization. We can deal with the fuzzy character of the passenger transportation and freight transportation requirement in service planning. It also may work in fuzzy objectives in the Electric Multiple Units timetable designing, the work time in crew schedule designing. And in solving the routing problem of trains at stations, we can also hire the method to describe the fuzzy character when the operation time has the fuzzy characters.

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Chapter 7
Train Re-scheduling Based on an Improved Fuzzy Linear Programming Model

Abstract Train re-scheduling remains a long-standing challenge in railway operation. To design high-quality timetable in fuzzy environment, this chapter studies train re-scheduling problem under the fuzzy environment, in which the fuzzy coefficients of the constraint resources have the fuzzy boundaries. Based on the improved fuzzy linear programming, the train re-scheduling model is constructed. Aiming at dealing with the fuzzy characteristics of the constraint coefficients value range boundaries, the description method of this kind of objective function is proposed and the solving approach is presented. The model has more adaptability to model a common train re-scheduling problem, in which some resources of the constraints are uncertain and have the characteristics of fuzziness and the boundaries of the resources are fuzzy. Two numerical examples are carried out and it shows that the model proposed in this chapter can describe the train re-scheduling problem precisely, dealing with the fuzzy boundaries of the fuzzy coefficients of the constraint resources. The algorithm present is suitable to solve the problem. The approach proposed in this chapter can be a reference for developers of railway dispatching system.

7.1 Introduction on Train Re-scheduling

Railways are typically operated according to a planned (predetermined) timetable, which determines the amount of trains and the dwell on the railway line. However, railway accidents and natural disasters often affect the train operation, which makes it a must to re-schedule the trains, through adjusting the inbound and outbound time of the trains at the stations. So it is seriously important to study of train re-scheduling problem.

The survey of Cordeau et al. reviewed a large number of papers dealing with different problems arising in timetable design and train re-scheduling (Cordeau et al. 1998). Narayanaswami and Rangaraj (2011) also presented a review on scheduling and re-scheduling of railway operations, which classified the railway

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operations into four levels: strategic, tactical, operational control, and real-time control. The train re-scheduling is taken as the operational control level problem.

In view of their extensive survey, we limit our review to recent papers dealing with train re-scheduling problems. Şahin studied the real-time conflict resolution problem on a single-track railway. Conflicts between trains are resolved in the order in which they appear. An algorithm based on look-ahead strategies predicted potential consecutive delays and takes ordering decisions of merging or crossing points. The problem was formulated as a job shop scheduling problem, and the objective is to minimize average consecutive delays (Şahin 1999). Schobel (2001) proposed an approach which aimed to decide which connections had to be maintained or canceled to minimize the inconvenience for the passengers. Dorfman and Medanic (2004) proposed a discrete-event model for scheduling trains on a single line and a greedy strategy to obtain suboptimal schedules. The model behavior was similar to that of human dispatchers. The authors showed that adding nonlocal information can prevent deadlocks. The approach could quickly handle timetable perturbations and performs satisfactorily on three time-preference criteria. Tőrnquist and Persson (2007) discussed how disturbances propagate and which actions to take in order to minimize the consequences for multiple stakeholders. They presented an optimization approach to the problem of re-scheduling railway traffic in an *N*-tracked network when a disturbance has occurred. Computational results from experiments using data from the Swedish railway traffic system are presented along with a discussion about theoretical and practical strengths and limitations. They came to the conclusion that there is a relation between certain disturbance characteristics and the ability to find appropriate solutions sufficiently fast, which can be utilized to configure and improve the suggested approach further. Chang and Kwan (2005) described the application of evolutionary computation techniques to a real-world complex train schedule multi-objective problem. They proposed three established algorithms (Genetic Algorithm GA, Particle Swarm Optimization PSO, and Differential Evolution DE) to solve the scheduling problem. They drew a conclusion that DE is the best approach for this scheduling problem. D'Ariano et al. (2007) viewed the train scheduling problem as a huge job shop scheduling problem with no-store constraints. They utilized a careful estimation of time separation between trains, and described the scheduling problem with an alternative graph formulation. They developed a branch and bound algorithm, which included implication rules enabling to speed up the computation. Kroon et al. (2009) generated several timetables utilizing sophisticated operations research techniques and utilized innovative operations research tools to devise efficient schedules for rolling stock and crew resources. They provided a new method to generate train timetables, taking rolling-stock and crew into consideration. Kroon et al. (1997) proved the NP-completeness of the general problem of routing trains through railway stations to design a conflict-free timetable and show solvable special cases.

There are also some publications on the real-time re-scheduling problem. Mazzarello and Ottaviani (2007) described the architecture of a real-time traffic management system that had been implemented within the European project

COMBINE to test the feasibility of a completely automated system for conflict resolution and speed regulation. Rodriguez (2007) proposed a heuristic approach to train routing problems and consequent train reordering problems with operational purposes. The algorithm was tested on a complex rail junction and can provide a satisfactory solution within three minutes of computation time for instances involving up to 24 trains. Adenso-Díaz et al. (1999) considered the problem of managing real-time timetable disturbances for a regional network. They proposed an automated conflict resolution system for the Spanish National Railway Company and a mixed-integer programming model was adopted to describe the problem.

It is easy to see from the literature that most of researches have been carried out under the specified environment, in which all the parameters involved are fixed quantities. Actually, since the railway transportation system is complex, dispatchers inevitably meet uncertain parameters when re-scheduling trains on the dispatching sections, such as random parameters and fuzzy parameters. However, some researchers ignored the existence of the uncertainty in the literatures, which probably caused poor quality of the re-scheduled timetable in the real applications.

Yang et al. (2011) studied the railway freight transportation planning problem under the mixed uncertain environment of fuzziness and randomness based on the optimization methods under the uncertain environments. They proposed a hybrid algorithm integrating simulation algorithm and a genetic algorithm, to find optimal paths, the amount of commodities passing through each path and the frequency of services. It was a typical publication in which the mixed uncertain environment of fuzziness and randomness was taken into consideration in railway operation.

Acuna-Agost et al. (2011a, b) investigated the solution of train re-scheduling problem through a mixed-integer programming (MIP) formulation. They proposed an approach called SAPI (Statistical Analysis of Propagation of Incidents) to limit the search space around the original nondisrupted schedule by hard and soft fixing of integer variables with local-branching-type cuts and proved the model effectiveness with the computation cases on the railway networks of France and Chile. Krasemann (2012) developed a greedy algorithm which performs a depth-first search using an evaluation function when conflicts arise and then branches according to a set of criteria to solve the train re-scheduling problem. Dündar and Şahin (2012) developed artificial neural networks (ANNs) to mimic the decision behavior of train dispatchers so as to reproduce their conflict resolutions.

Castillo et al. (2011) dealt with the timetabling problem of a mixed multiple- and single-tracked railway network. Min et al. (2011) proposed a column-generation-based algorithm that exploits the reparability of the problem. Cacchiani et al. (2010) studied the problem of freight transportation in railway networks, where both passenger and freight trains are run. Almodóvar and García-Ródenas proposed an online optimization model based on a discrete-event simulation model to provide and support decisions about reassigning vehicles from other lines of the transport system to the disturbed line. Meng et al. (2013) constructed a hybrid timed event graph model for networked train operation simulation and timetable stability optimization.

An assumption is made in the above publications, which is that the value range boundaries of the fuzzy coefficients are identifiable. In the reality, especially in engineering calculation, the value range boundaries of the fuzzy resources coefficients are not clear; sometimes they also have the fuzzy characteristics. In train re-scheduling problem, the interval between the foregoing train's departure from a station and the backward train's arrival can be seen as a fuzzy number, and even the boundaries of the interval are fuzzy. Then it is necessary to study the train re-scheduling problem with fuzzy linear programming model, in which the right-hand side coefficients are fuzzy numbers, with the fuzzy value range boundaries of the fuzzy coefficients.

In view of this fact, we will consider the problem under the fuzzy environment in this chapter, which intends to make service strategies on the train re-scheduling problem.

There are also numerous publications about the fuzzy linear programming problem in recent years. The ANN was trained and tested with data extracted from conflict resolutions in actual train operations in Turkish State Railways. A genetic algorithm (GA) was developed to find the optimal solutions for small-sized problems in short times, and to reduce total delay times by around half in comparison to the ANN. Fuzzy linear programming with fuzzy resource constraints coefficients is a typical fuzzy linear programming. The key characteristic of this kind of programming is that the coefficients of the resource are fuzzy, and the coefficients of objectives are clear. The researchers have paid considerable attention to the constraint-coefficient-linear fuzzy programming (Tanaka 1984; Delgado et al. 1993). Delgado et al. (1993) considered the use of nonlinear membership functions in fuzzy linear programming problems to solve the linear programming problems with fuzzy constraints. Gasimov and Yenilmez (2002) proposed the "modified sub-gradient method" to solve linear programming problems with only fuzzy technological coefficients and linear programming problems in which both the right-hand side, and the technological coefficients were fuzzy numbers. Ebrahimnejad (2011) generalized the concept of sensitivity analysis in fuzzy number linear programming (FLNP) problems by applying fuzzy simplex algorithms and using the general linear ranking functions on fuzzy numbers. Kazuo (1984) proposed two extensions on the fuzzy linear programming proposed by Zimmermann. He proved that fuzzy goals and fuzzy constraints expressed as fuzzy relations with fuzzy parameters can be considered as fuzzy sets on different real lines under some assumptions. And optimization in the case where the membership functions of the fuzzy goals and the fuzzy constraints given in a piecewise linear form can be achieved by using a standard linear programming technique. Frank et al. (2008) proposed a fuzzy linear programming model which included optimizing fuzzy constraints and objectives that consist of a triplet, and they gave a modified simplex algorithm to address these problems.

Kaur and Kumar presented a new method to find the fuzzy optimal solution of fully fuzzy path, i.e., critical path problems in which all the parameters are represented by LR flat fuzzy numbers. Dubey and Mehra (2014) proposed an approach to model fuzzy multi-objective linear programming problems (FMOLPPs) from a perspective of bipolar view in preference modeling. Bipolarity was used to distinguish between the negative and the positive preferences.

Wan and Dong (2014) constructed an auxiliary multi-objective programming to solve the corresponding possibility linear programming with trapezoidal fuzzy numbers. Simic proposed a fuzzy risk explicit interval linear programming model for end-of-life vehicle (ELV) recycling planning in the European Union, which had advantages in reflecting uncertainties presented in terms of intervals in the ELV recycling systems and fuzziness in decision-makers' preferences. Ebrahimnejada and Tavana (2014) proposed a new method for solving fuzzy linear programming problems in which the coefficients of the objective function and the values of the right-hand side are represented by symmetric trapezoidal fuzzy numbers while the elements of the coefficient matrix are represented by real numbers. Rena and Wangga (2014) considered a kind of bi-level linear programming problem where the coefficients of both objective functions are fuzzy random variables and developed a computational method for obtaining optimistic Stackelberg solutions to such a problem. Jin et al. (2014) developed a new Robust Inexact Joint-optimal α cut Interval Type-2 Fuzzy Boundary Linear Programming (RIJ-IT2FBLP) model for planning of energy systems by integrating both the interval T2 fuzzy sets and the Inexact Linear Programming (ILP) methods. Kumar and Kaur (2013) pointed out that the existing general form of such fully fuzzy linear programming problems in which all the parameters are represented by such flat fuzzy numbers which are valid only if there is no negative sign. They proposed a new general form of linear programming to solve this problem. Kaur and Kumar (2013) also proposed fully fuzzy linear programming (FLP) problems in which some or all the parameters are represented by unrestricted L-R flat fuzzy numbers. Yano and Matsui (2013) proposed an interactive decision-making method for hierarchical multi-objective fuzzy random linear programming problems (HMOFRLP), in which multiple decision makers in a hierarchical organization had their own multiple objective linear functions with fuzzy random variable coefficients. Hajiagha et al. (2013). proposed a model to extend the methodology for solving multi-objective linear programming (MOLP) problems, when the objective functions and constraints coefficients are stated as interval numbers. Fan et al. (2013) developed a generalized fuzzy linear programming (GFLP) method for dealing with uncertainties expressed as fuzzy sets. Sakawa and Matsui (2013) proposed an α-level sets of fuzzy random variables and defined an α-stochastic two-level linear programming problem for guaranteeing the degree of realization of the interactive fuzzy random cooperative two-level linear programming problem. Dubey et al. (2012) studied the linear programming problems involving interval uncertainty modeled using IFS. The nonmembership of IFS was constructed with three different viewpoints viz., optimistic, pessimistic, and mixed. Ebrahimnejad (2011) generalized the concept of sensitivity analysis of fuzzy number linear programming (FLNP) problems by applying fuzzy simplex algorithms and using the general linear ranking functions on fuzzy numbers.

These publications on fuzzy linear programming problems give us much enlightenment on the application of the fuzzy linear programming in the engineering computation. We improve the fuzzy linear programming in this chapter and apply it in the train re-scheduling problem.

This chapter is structured as follows. Section 7.2 first introduces the problem in a mathematical way, and then constructs a mathematical model under the specified environment. In Sect. 7.3, to model the problem under the random fuzzy environment, we improve the typical fuzzy linear programming with fuzzy resources. Section 7.4 constructs the improved fuzzy linear programming model for train re-scheduling. In Sect. 7.5, a computation case is presented, based on the data of Beijing–Zhengzhou railway section to show the effectiveness of the model. Section 7.6 draws conclusions.

7.2 Problem Statement

There are numerous methods for re-scheduling, including reduction of dwell time on stations, reduction of the running time in sections, and change of the surpassing stations. The goal is to recover the state in which the trains run according to the planned timetable. In reality, the interval time and the buffer time are determined by the train operating matrices. The elements of the inbound and outbound time matrix are adjusted to change the running time in the sections, the dwell time at the stations and the operation type when disruptions occur in real-world operations. This is the essence of re-scheduling. A real-time re-scheduling plan must be proposed in a very short period. On some occasions, the train's track can coincide with the lines on the planned timetable after some adjustments; sometimes it cannot.

7.2.1 Objective of Train Re-Scheduling Model

The goal of train operation adjustment is to make the actual dwell time accord with the time as planned, when the trains are perturbed and delays occur. It is possible to adjust the dwell of the trains so that there is a gap between the planned dwell and the minimum time, as well as between the planned running time and the minimum running time. The wider the gap, the less complicated the operating adjustment work will be.

Thus, the train operation adjustment model with minimal summary delay time as the destination can be defined as follows:

$$\min z = \sum_{i=1}^{N} \sum_{k=1}^{M} [\max(a_{i,k} - a_{i,k}^{0}, 0) + (d_{i,k} - d_{i,k}^{0})], \tag{7.1}$$

where $a_{i,k}$ stand for the inbound time of train i at station k and $d_{i,k}$ stand for the outbound time of train i at station k. $a_{i,k}^{0}$ and $d_{i,k}^{0}$ stand for the original planned inbound and outbound times respectively. Then the objective is to minimize the gap between the re-scheduled timetable and the original timetable. Because that a passenger train can arrive at a station earlier than it is planned and we do not care about it when calculating the delayed time, the gap between the re-scheduled arrival time and the original planned arrival time is described as $\max(a_{i,k} - a^0_{i,k}, 0)$. And $d_{i,k} \geq d^0_{i,k}$ is a constraint for the passenger trains, so the gap between the re-scheduled departure time and the original departure time is set to be $d_{i,k} - d^0_{i,k}$.

7.2.2 System Constraints

There are numerous prerequisite rules in railway operation to ensure the safety, which are determined by the facilities such as the blocking systems. The most important rule is to determine the relations between the inbound and outbound time of all the trains, to separate the trains in space. So the system constraints are designed as follows.

The difference between a backward train arriving time and a forward train arriving time at the same stations must be longer than the technical intervals, which produces the constraint.

$$a_{i+1,k} - a_{i,k} \geq I_a, \quad i = 1, 2, \ldots, N-1, \ k = 1, 2, \ldots, M, \tag{7.2}$$

where I_a is the interval time between the two inbound times of train i and train $i+1$ at Station k.

Likewise, the difference between a backward train departing time and a forward train departing time from the same stations must be longer than the technical intervals. The constraint can be described as

$$d_{i+1,k} - d_{i,k} \geq I_d, \quad i = 1, 2, \ldots, N-1, \ k = 1, 2, \ldots, M, \tag{7.3}$$

where I_d is the interval time between the two outbound times of train i and train $i+1$ at Station k.

The interval between two trains must satisfy the departing arriving interval and arriving departing interval. Set $\tau_{\text{depart}-\text{arrive}}$ to be the minimum time interval between a train leaving a station and another train arrival the same station. The constraints are defined in Eq. (7.4).

$$a_{i+1,k} - d_{i,k} > \tau_{\text{depart}-\text{arrive}}, \quad i = 1, 2, \ldots, N-1, \ k = 1, 2, \ldots, M \tag{7.4}$$

The running time of each train according to the re-scheduled timetable must be longer than the minimum running time, which can be formulated as follows:

$$a_{i,k+1} - d_{i,k} \geq t_{i,k}^{\min,\mathrm{run}}, \quad i = 1, 2, \ldots, N, \; k = 1, 2, \ldots, M - 1, \tag{7.5}$$

where $t_{i,k}^{\min,\mathrm{run}}$ is the minimum time of train i on the section between station k and $k + 1$.

Again, the dwelling time of each train must be longer than the minimum dwelling time, which produces the constraint

$$d_{i,k} - a_{i,k} \geq t_{i,k}^{\min,\mathrm{dwell}}, \quad i = 1, 2, \ldots, N, k = 1, 2, \ldots, M, \tag{7.6}$$

where $t_{i,k}^{\min,\mathrm{dwell}}$ is the minimum dwelling time of train i at station k.

Passenger trains must not leave the stations before the time as it is planned on the timetable, which is made available to the public. So there is a constraint as follows:

$$d_{i,k} - d_{i,k}^0 \geq 0, \quad i = 1, 2, \ldots, N, \; k = 1, 2, \ldots, M \tag{7.7}$$

7.2.3 Mathematical Model

The mathematical model of this problem is constructed as follows:

$$\begin{cases} \min z = \sum\limits_{i=1}^{N} \sum\limits_{k=1}^{M} \max[(a_{i,k} - a_{i,k}^0, 0) + (d_{i,k} - d_{i,k}^0)] \\ \text{s.t.} \\ a_{i+1,k} - a_{i,k} \geq I_a, \quad i = 1, 2, \ldots, N - 1, \; k = 1, 2, \ldots, M \\ d_{i+1,k} - d_{i,k} \geq I_d, \quad i = 1, 2, \ldots, N - 1, \; k = 1, 2, \ldots, M \\ a_{i+1,k} - d_{i,k} > \tau_{\mathrm{depart-arrive}}, \quad i = 1, 2, \ldots, N - 1, \; k = 1, 2, \ldots, M \\ a_{i,k+1} - d_{i,k} \geq t_{i,k}^{\min,\mathrm{run}}, \quad i = 1, 2, \ldots, N, \; k = 1, 2, \ldots, M - 1 \\ d_{i,k} - a_{i,k} \geq t_{i,k}^{\min,\mathrm{dwell}}, \quad i = 1, 2, \ldots, N, \; k = 1, 2, \ldots, M \\ d_{i,k} - d_{i,k}^0 \geq 0, \quad i = 1, 2, \ldots, N, \; k = 1, 2, \ldots, M \end{cases} \tag{7.8}$$

where $a_{i,k}$ and $d_{i,k}$ are the inbound and outbound times of the ith train at kth station.

It is easy to see that all the parameters in the model (8) are supposed to be fixed quantities. In the authentic conditions, a rescheduled timetable is usually designed after the occurrence of an emergency. Thus, the concrete values of some parameters actually cannot be obtained in advance, especially the parameters on the right side of the constraints equations. To deal with the problem in a mathematical way, we usually treat these parameters as fuzzy variables according to the experts' experience when we cannot get enough real sample data to calculate out the parameters by statistical ways.

To solve the model, we changed the styles of the objective and the constraints into standard styles, reconstructing the model (7.8) as follows:

$$\begin{cases} \max z = C_{\max} - \sum\limits_{i=1}^{N}\sum\limits_{k=1}^{M}[\max(a_{i,k} - a_{i,k}^{0}, 0) + (d_{i,k} - d_{i,k}^{0})] \\ \text{s.t.} \\ a_{i,k} - a_{i+1,k} \leq -I_a, \quad i = 1,2,\ldots,N-1, \ k = 1,2,\ldots,M \\ d_{i,k} - d_{i+1,k} \leq -I_d, \quad i = 1,2,\ldots,N-1, \ k = 1,2,\ldots,M \\ d_{i,k} - a_{i+1,k} < \tau_{\text{depart-arrive}}, \quad i = 1,2,\ldots,N-1, \ k = 1,2,\ldots,M \\ d_{i,k} - a_{i,k+1} \leq -t_{i,k}^{\text{min,run}}, \quad i = 1,2,\ldots,N, \ k = 1,2,\ldots,M-1 \\ a_{i,k} - d_{i,k} \leq -t_{i,k}^{\text{min,dwell}}, \quad i = 1,2,\ldots,N, \ k = 1,2,\ldots,M \\ d_{i,k}^{0} - d_{i,k} \leq 0, \quad i = 1,2,\ldots,N, \ k = 1,2,\ldots,M \end{cases} \tag{7.9}$$

7.3 Fuzzy Linear Programming with Fuzzy Resource Constraints Theory

7.3.1 Fuzzy Linear Programming with Fuzzy Resources

Typical fuzzy linear programming with fuzzy resources can be described as follows:

$$\begin{cases} \max \quad \mathrm{z} = c^T x \\ \text{s.t.} \\ Ax \underset{\sim}{\leq} b \\ x \geq 0 \end{cases} \tag{7.10}$$

where b is the fuzzy resources coefficients vector. For the fuzzy constraints $Ax \underset{\sim}{\leq} b$, the ith constraint is

$$(Ax)_i \underset{\sim}{\leq} b_i, \quad i = 1,2,\ldots,m \tag{7.11}$$

Set the maximal tolerance to be p_i, the fuzzy function is defined as follows:

$$\alpha = \mu_i(x) = \begin{cases} 1, & (Ax)_i \leq b_i \\ 0, & (Ax)_i > b_i + p_i \\ 1 - ((Ax)_i - b_i)/p_i, & b_i \leq (Ax)_i \leq b_i + p_i \end{cases} \tag{7.12}$$

Then, the fuzzy linear programming model (1) can be remodeled as follows:

$$\begin{cases} \max z = c^T x \\ \text{s.t.} \\ (Ax)_i \leq b_i + (1-\alpha)p_i, \quad i - 1,2,\ldots,m \\ x \geq 0 \end{cases} \tag{7.13}$$

Set $\theta = 1 - \alpha$, the model is turned to be

$$\begin{cases} \max z = c^T x \\ \text{s.t.} \\ Ax \leq b + \theta p \\ x \geq 0 \end{cases} \tag{7.14}$$

The optimal solution to the model is

$$\tilde{S}^* = \{(x^*(\theta), 1 - \theta) | \theta \in [0, 1]\} \tag{7.15}$$

7.3.2 *Fuzzy Linear Programming of Resources with Fuzzy Coefficients Boundaries of Fuzzy Resources*

There is a kind of fuzzy linear programming problem for the engineering computation, which has the fuzzy boundaries of the coefficients value range. The boundaries can be described as fuzzy numbers. That is to say, the upper and lower boundaries of b are fuzzy numbers.

The ith constraint of $Ax \underset{\sim}{\leq} b$ is

$$(Ax)_i \underset{\sim}{\leq} b_i, \quad i = 1, 2, \ldots, m \tag{7.16}$$

Then, $b_i \in [L_i, U_i]$, L_i, U_i are the lower and upper boundaries of b_i respectively. Set

$$\beta_i = f(U_i), \tag{7.17}$$

where f is a fuzzy membership function. It can be a triangle, a trapezoid or Gaussian function.

Then, U_i can be described as

$$U_i = f^{-1}(\beta_i), \tag{7.18}$$

where f^{-1} is the inverse function of f.

Likewise, set

$$\gamma_i = g(L_i) \tag{7.19}$$

g is a kind of fuzzy membership function, similar with f.

Then

$$L_i = g^{-1}(\gamma_i), \tag{7.20}$$

where g^{-1} is the inverse function of g.

As it is known,$b_i \in [L_i, U_i]$, then set

$$\alpha = \mu(b_i) = q(L_i, U_i), \tag{7.21}$$

where q and μ are similar with f. They are also fuzzy membership functions. Then b_i can be described as

$$b_i = q^{-1}(L_i, U_i) = q^{-1}(g^{-1}(\gamma_i), f^{-1}(\beta_i)), \tag{7.22}$$

where q^{-1} is the inverse function of q.

So the model can be changed as

$$\begin{cases} \max z = c^T x \\ \text{s.t.} \\ (Ax)_i \underset{\sim}{\leq} q^{-1}(L_i, U_i) = q^{-1}(g^{-1}(\gamma_i), f^{-1}(\beta_i)), \quad i = 1, 2, \ldots, m \\ x \geq 0 \end{cases} \tag{7.23}$$

7.4 Improved Fuzzy Linear Programming Model for Train Re-scheduling

By using the theory in Sect. 7.3, model (7.9) can be remodeled as a fuzzy linear programming model with fuzzy resources' boundaries constraints.

The $\tau_{\text{depart-arrive}}$ is a fuzzy number. Even the boundaries of value range of $\tau_{\text{depart-arrive}}$ are fuzzy. So we can remodel the problem as follows:

$$\begin{cases} \max z = C_{\max} - \sum\limits_{i=1}^{N} \sum\limits_{k=1}^{M} \left[\max(a_{i,k} - a_{i,k}^0, 0) - (d_{i,k} - d_{i,k}^0) \right] \\ \text{s.t.} \\ a_{i,k} - a_{i+1,k} \leq -I_a, \quad i = 1, 2, \ldots, N-1, \ \ k = 1, 2, \ldots, M \\ d_{i,k} - d_{i+1,k} \leq -I_d, \quad i = 1, 2, \ldots, N-1, \ \ k = 1, 2, \ldots, M \\ d_{i,k} - a_{i+1,k} < q^{-1}(g^{-1}(\gamma), \ f^{-1}(\beta)), \quad i = 1, 2, \ldots, N-1, \ \ k = 1, 2, \ldots, M \\ d_{i,k} - a_{i,k+1} \leq -t_{i,k}^{\text{min,run}}, \quad i = 1, 2, \ldots, N, \ \ k = 1, 2, \ldots, M-1 \\ a_{i,k} - d_{i,k} \leq -t_{i,k}^{\text{min,dwell}}, \quad i = 1, 2, \ldots, N, \ \ k = 1, 2, \ldots, M \\ d_{i,k}^0 - d_{i,k} \leq 0, \quad i = 1, 2, \ldots, N, \ \ k = 1, 2, \ldots, M \end{cases} \tag{7.24}$$

where γ is the membership of the lower boundary of $\tau_{\text{depart-arrive}}$ and β is the membership of upper boundary of $\tau_{\text{depart-arrive}}$. $g^{-1}(\gamma)$ is the lower boundary of $\tau_{\text{depart-arrive}}$ and $f^{-1}(\beta)$ is the upper boundary of $\tau_{\text{depart-arrive}}$. $C_{\max}$ is an enough large number which is much larger than $\sum_{i=1}^{N} \sum_{k=1}^{M} \max(a_{i,k} - a_{i,k}^0, 0)$ and $d_{i,k} - d_{i,k}^0$.

In this chapter, the membership functions, q, g and f are designed as the triangle functions. The upper bound of $\tau_{\text{depart-arrive}}$ is U, which is a triangle fuzzy member. $U \sim [2, 4]$, and the average value of U is 3. The lower bound of $\tau_{\text{depart-arrive}}$ is L, whose average value is 2. β is the value of membership.

$$\beta = f(U) = \begin{cases} 0, U \geq 4 \\ (4 - U)/(4 - 3), 3 \leq U < 4 \\ (U_1 - 2)/(3 - 2), 2 < U < 3 \\ 0, U_1 \leq 2 \end{cases} \tag{7.25}$$

Since the constraints in this problem are resources constraints, then the more the resources are, the bigger the objective value will be. So when the membership value is β, the left part of the polyline in Fig. 7.1 is useless when solving the problem. Then the useful part is kept, as below.

$$\beta = f(U) = \begin{cases} 0, U \geq 4 \\ (4 - U)/(4 - 3), 3 \leq U < 4 \end{cases} \tag{7.26}$$

Then the upper bound of $\tau_{\text{depart-arrive}}$ is $U = 4 - \beta$.

In the like manner, γ is set to be the membership value for the lower bound of $\tau_{\text{depart-arrive}}$.

$$\gamma = g(L) = \begin{cases} 0, L \geq 3 \\ (3 - L)/(3 - 2), 2 \leq L < 3 \end{cases} \tag{7.27}$$

The lower bound of $\tau_{\text{depart-arrive}}$ is $L = 3 - \gamma$.

Additionally, $\tau_{\text{depart-arrive}}$ is also described as a triangle fuzzy number. The membership value α is

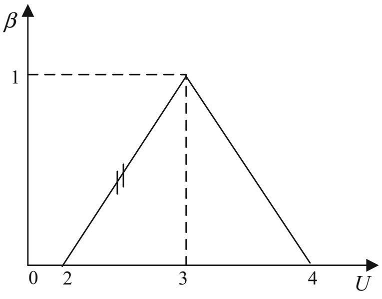

Fig. 7.1 The left line is not available when the objective function is triangle function

$$\alpha = \mu(\tau_{\text{depart-arrive}}) = \begin{cases} 0, \tau_{\text{depart-arrive}} \geq U \\ (U - \tau_{\text{depart-arrive}})/(U - (U+L)/2), (U+L)/2 \leq \tau_{\text{depart-arrive}} < U \end{cases} \tag{7.28}$$

Then we get

$$\tau_{\text{depart-arrive}} = 4 - \beta - \frac{1}{2}\alpha(1 - \beta + \gamma)$$

Then the model can be changed into

$$\begin{cases} \max z = C_{\max} - \sum_{i=1}^{N}\sum_{k=1}^{M}[\max(a_{i,k} - a_{i,k}^0, 0) - (d_{i,k} - d_{i,k}^0)] \\ \text{s.t.} \\ a_{i,k} - a_{i+1,k} \leq -I_a, \quad i = 1,2,\ldots,N-1, \ k = 1,2,\ldots,M \\ d_{i,k} - d_{i+1,k} \leq -I_d, \quad i = 1,2,\ldots,N-1, \ k = 1,2,\ldots,M \\ d_{i,k} - a_{i+1,k} < 4 - \beta - \frac{1}{2}\alpha(1 - \beta + \gamma), \quad i = 1,2,\ldots,N-1, \ k = 1,2,\ldots,M \\ d_{i,k} - a_{i,k+1} \leq -t_{i,k}^{\text{min,run}}, \quad i = 1,2,\ldots,N, \ k = 1,2,\ldots,M-1 \\ a_{i,k} - d_{i,k} \leq -t_{i,k}^{\text{min,dwell}}, \quad i = 1,2,\ldots,N, \ k = 1,2,\ldots,M \\ d_{i,k}^0 - d_{i,k} \leq 0, \quad i = 1,2,\ldots,N, \ k = 1,2,\ldots,M \end{cases} \tag{7.29}$$

In this model, a resource constraint is analyzed and seen as a fuzzy constraint. Even the boundaries of the resource $\tau_{\text{depart-arrive}}$ are described as the fuzzy numbers. All the fuzzy numbers are transferred into certain numbers to be ready to be solved. This treatment makes the constraint and the model more accordance with the actual case. In reality, some of the resources are actually very difficult to obtain and have the fuzzy characteristics. So it is necessary to do such process. The most important improvement compared to the existing fuzzy linear model for train re-scheduling is also such process.

7.5 Computation Cases and Analysis

7.5.1 Results of the Computation Cases

There are 13 stations and 12 sections on the section between Beijing and Zhengzhou. We apply the model into two computation cases. The first one is that we assume several trains are delayed for a period of time. The second one is that we assume that a track in a section is affected by an emergency and the two-track railway section becomes a single-track railway.

Fourteen trains are planned at the down-going direction and another 14 trains at the up-going direction on the working diagram from 8 a.m. to 12. a.m. The original planned timetable is shown in Tables 7.1 and 7.2, and Fig. 7.2. The minimum dwelling time of all the trains at each station are listed in Table 7.3. The data in Table 7.4 are the minimum running time of all the trains in each railway section. The trains are divided into two grades. G71, G83, G79, G90, G92 belong to the first grade, which requires less running time on each section that the trains G507, G651, G501, 653, G509, G571, G511, G655, G513, G657, G515, G560, G508, G562, G652, G502, G654, G512, G672, G6732, G6734, G6704, G602, and G92 which belong to the second grade.

Case 1 In computation Case 1, we take it for granted that five trains at the down-going direction, G83, G571, G511, G79, G655, and four trains at the up-going direction, G90, G508, G562, G652 are disturbed when running on section between Beijing and Zhuozhou. They are later 9, 13.5, 10, 10.5, 20, 10, 10, 10, and 10 min respectively than as planned.

In the computation, we use a computer with a CPU of i5-2400 and 2G RAM. The software is Matlab 6.0.

In this experiment, the optimal solution is obtained with the parameters $\alpha = 1$, $\beta = 1$. $I_a = I_d = 3$. $t_{i,k}^{\min,\text{run}}$ and $t_{i,k}^{\min,\text{dwell}}$ are set as the data shown in Tables 7.3 and 7.4.

Since $C_{\max}$ is set to be 5000, the optimal objective of the model is calculated to be 4197.5 according to model (7.29). The summary delayed time of the down-going trains is 485 min and the summary delayed time of up-going trains is 317.5 min. The total delay time of all the trains at all the stations is 802.5 min, including the arriving delay time and the departing delay time.

For different groups of parameters, the computational results are presented in Fig. 7.3.

According to the parameter linear programming algorithm, the solution to the train re-scheduling model is shown in Tables 7.5 and 7.6, and Fig. 7.4. The inbound and outbound times in Tables 7.5 and 7.6 in italic type are the re-scheduled time based on the data in Tables 7.1 and 7.2.

It is easy to see that all the delayed trains recover the operation according to the original timetable before 11:40. G83 is planned to overtake G509 at Dingzhou at 9.5830. Since G83 arrived late at Shijiazhuang station, it is designed to overtake G509 at Shijiazhuang according to replanned timetable. It recovers to operate according to the original timetable at Hebi at 11:0330. The other four trains at the down-going direction eliminate the delays at Shijiazhuang station.

G90 is re-scheduled to reduce the delayed time in the whole section and arrives at Beijing in time as it is planned. It still dwells on Shijiazhuang for 2 min. G560 is affected by G90 because the minimum interval between departures is 3 min and G90 departures from Shijiazhuang at 9:5800. G560 has to start off not earlier than 10:01. G508 and G562 recover the operation according to the original timetable at Shijiazhuang station and G652 fulfills the process at Gaoyi station.

Table 7.1 The planned timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the down-going direction

	G507		G651		G501		G71		G653	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing								8.0000		8.2100
Zhuozhou							8.2400	8.2400	8.4600	8.5400
Gaobeidian							8.2900	8.2900	8.5900	8.5900
Baoding			7.4600	7.4800	8.0900	8.0900	8.4100	8.4300	9.1100	9.1100
Dingzhou	7.5400	7.5600	8.0800	8.0800	8.2400	8.2600	8.5800	8.5800	9.2600	9.2600
Shijiazhuang	8.1900	8.2300	8.2400	8.2800	8.4900	8.5200	9.1900	9.2200	9.4600	9.4900
Gaoyi	8.3700	8.3700	8.4200	8.4200	9.0600	9.0600	9.3600	9.3600	10.0100	10.0100
Xingtai	8.5200	8.5200	8.5600	8.5800	9.2000	9.2200	9.5100	9.5100	10.1500	10.1500
Handan	9.0200	9.0400	9.1400	9.1600	9.3200	9.3200	10.0100	10.0300	10.2400	10.2400
Anyang	9.1800	9.1800	9.3000	9.3000	9.4700	9.4900	10.1700	10.1700	10.3700	10.3900
Hebi	9.3100	9.3300	9.4400	9.4600	10.0100	10.0100	10.3000	10.3000	10.5300	10.5300
Xinxiang	9.4900	9.5200	9.5700	9.5700	10.1100	10.1100	10.4100	10.4300	11.0500	11.1800
Zhengzhou	10.1300		10.1900		10.3100		11.0400		11.3900	
	G509		G83		G571		G511		G79	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing		8.4300		9.0000		9.2700		9.3700		10.0000
Zhuozhou	9.0700	9.0700	9.2100	9.2100	9.4630	9.4630	10.0200	10.0400	10.2130	10.2130
Gaobeidian	10.1100	10.1100	9.2500	9.2500	9.5200	9.5200	10.0830	10.0830	10.2530	10.2530
Baoding	9.2400	9.2600	9.3600	9.3600	10.0800	10.1000	10.2100	10.2100	10.3700	10.3700
Dingzhou	9.4400	9.5100	9.4830	9.4830	10.2500	10.2500	10.3600	10.3600	10.4950	10.4950
Shijiazhuang	10.1400	10.1700	10.0700	10.0900	10.4600	10.5000	10.5600	10.5900	11.0700	11.0900
Gaoyi	10.3000	10.3000	10.2030	10.2030	11.0330	11.0330	11.1300	11.2500	11.2030	11.2030
Xingtai	10.4300	10.4300	10.3200	10.3200	11.1800	11.2000	11.4230	11.4230	11.3200	11.3200

(continued)

Table 7.1 (continued)

Handan	10.5400	10.5400	10.4100	10.4100	11.3600	11.4500	11.5500	11.5500	11.4030	11.4030
Anyang	11.0600	11.0600	10.5230	10.5230	11.5800	11.5800			11.5200	11.5200
Hebi	11.1800	11.2000	11.0330	11.0330						
Xinxiang	11.3000	11.3000	11.1200	11.1200						
Zhengzhou	11.5000		11.3000							
	G655		G513		G657		G515			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing		10.0500		10.4800		11.0600		11.5000		
Zhuozhou	10.3000	10.3000	11.1300	11.1300	11.3000	11.3000				
Gaobeidian	10.3500	10.3700	11.1800	11.2000	11.3500	11.3500				
Baoding	10.5300	10.5500	11.3130	11.3130	11.4700	11.4900				
Dingzhou	11.1000	11.1000	11.4500	11.4500						
Shijiazhuang	11.3100	11.3400	12.0700	12.1100						
Gaoyi	11.5030	11.5030								

note aa.bbcc stands for bb minutes cc seconds at aa o'clock

Table 7.2 The planned timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the up-going direction

	G560		G90		G508		G562		G652	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing			11.3000							
Zhuozhou	11.3700	11.3900	11.0900	11.0900						
Gaobeidian	11.2600	11.2800	11.0430	11.0430						
Baoding	11.0700	11.1000	10.5300	10.5300	11.5100	11.5100				
Dingzhou	10.5300	10.5300	10.4100	10.4100	11.3700	11.3700	11.5130	11.5130		
Shijiazhuang	10.3400	10.3400	10.2100	10.2300	11.1300	11.1700	11.2800	11.3100	11.5500	11.5800
Gaoyi	10.2030	10.2030	10.0830	10.0830	11.0000	11.0000	11.1400	11.1400	11.3800	11.4000
Xingtai	10.0700	10.0700	9.5600	9.5600	10.4300	10.4500	10.5930	10.5930	11.2400	11.2400
Handan	9.5500	9.5700	9.4700	9.4700	10.3300	10.3300	10.4700	10.4900	11.1400	11.1400
Anyang	9.3000	9.3800	9.3400	9.3400	10.1830	10.1830	10.2800	10.3000	11.0000	11.0000
Hebi	9.1300	9.1500	9.2400	9.2400	10.0300	10.0500	10.1300	10.1300	10.4500	10.4700
Xinxiang	8.5500	8.5700	9.1600	9.1600	9.5330	9.5330	10.0000	10.0200	10.3400	10.3400
Zhengzhou		8.3500		9.0000		9.3200		9.4000		10.1400
	G502		G654		G512		G672		G6732	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing									10.2300	
Zhuozhou									9.5900	9.5900
Gaobeidian									9.5430	9.5430
Baoding									9.3900	9.4200
Dingzhou									9.2400	9.2400
Shijiazhuang									9.0000	9.0300
Gaoyi									8.4300	8.4500
Xingtai									8.1730	8.1730

(continued)

Table 7.2 (continued)

Handan			12.0000	12.0000						8.0600
Anyang	11.5600	11.5600	11.4800	11.4800						
Hebi	11.4400	11.4400	11.3830	11.3830						
Xinxiang	11.2100	11.3400	11.2900	11.2900	11.5000	11.5200	12.0000	12.0200		
Zhengzhou		11.0100		11.1200		11.3000		11.4000		
	G6734		G6704		G602		G92			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing	12.1900		8.5700		9.5300		11.0000			
Zhuozhou	11.5200	11.5400	8.2900	8.3200	9.2900	9.2900	10.3800	10.3800		
Gaobeidian	11.4100	11.4300	8.1800	8.2000	9.2500	9.2500	10.3400	10.3400		
Baoding	11.2800	11.2800		8.0100	9.1000	9.1200	10.2100	10.2100		
Dingzhou	11.1330	11.1330			8.5600	8.5600	10.0900	10.0900		
Shijiazhuang	10.5100	10.5300				8.3400		9.5000		
Gaoyi	10.3730	10.3730								
Xingtai	10.2300	10.2300								
Handan		10.1300								

note aa.bbcc stands for bb minutes cc seconds at aa o’clock

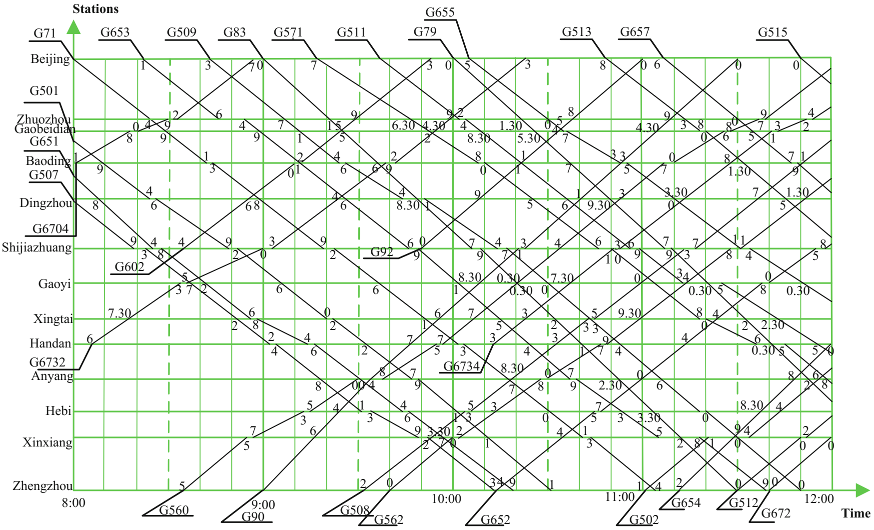

Fig. 7.2 The planned train working diagram from 8 to 12 a.m. in section between Beijing and Zhengzhou

In addition, it is needed to analyze the sensitivity of optimal objectives with respect to the parameters. We set α and β respectively and solve the fuzzy linear programming, as shown in Fig. 7.3. We can see the larger the membership is, the larger the objective value is. When $\alpha = \beta = 1$, the programming degenerates into a typical fuzzy linear programming. With α and β rise, the objective value becomes larger and larger. When $\alpha = \beta = 1$, the objective value is the maximal, 4197.5. At this point, the membership is the biggest. The interpretation is, the objective value is reaching the maximal value gradually with the more possibility that the objective coefficient is set to be the biggest.

To show the advancement of the improved fuzzy linear programming proposed in this chapter, we also did the data experiments with the typical fuzzy linear programming model. The re-scheduled timetables are shown in Tables 7.7 and 7.8 and Fig. 7.5.

Case 2 In this case, the relevant basic data are the same as those in computation. We assume that an emergency occurs in the section between Beijing and Zhuozhou, causing a failure of one of the tracks. Then the section between Beijing and Zhuozhou becomes a single-track rail section. The time interval for two meeting trains at a station is set to be 1 min. Then the computing results of Case 2 are listed in Tables 7.9 and 7.10 and Fig. 7.6.

According to the computing results, the departure from Zhuozhou of G6704 is delayed for 15 min to avoid the conflict with G563. Then the chain reaction is caused for the trains from different directions cannot occupy the affected section simultaneously. G509, G83 are postponed for 23.5 and 12 min respectively to

Table 7.3 The minimal dwelling time of all the trains at each station ($t_{i,k}^{\min,\text{dwell}}$)

	G507	G651	G501	G71	G653	G509	G83	G571	G511	G79	G655	G513	G657	G515
Beijing	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zhuozhou	–	–	–	0	8	0	0	0	2	0	0	0	0	–
Gaobeidian	–	–	–	0	0	0	0	0	0	0	2	2	0	–
Baoding	–	2	0	2	0	2	0	2	0	0	0	0	2	–
Dingzhou	2	0	2	0	0	7	0	0	0	0	0	0	–	–
Shijiazhuang	4	4	3	3	3	3	2	4	3	2	4	4	–	–
Gaoyi	0	0	0	0	0	0	0	0	12	0	–	–	–	–
Xingtai	0	2	2	0	0	0	0	2	0	0	–	–	–	–
Handan	2	2	0	2	0	0	0	9	0	0	–	–	–	–
Anyang	0	0	2	0	2	0	0	0	–	0	–	–	–	–
Hebi	2	2	0	0	0	2	0	–	–	–	–	–	–	–
Xinxiang	3	0	0	2	13	0	0	–	–	–	–	–	–	–
Zhengzhou	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	G560	G90	G508	G562	G652	G502	G654	G512	G672	G6732	G6734	G6704	G602	G92
Beijing	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zhuozhou	0	0	–	–	–	–	–	–	–	0	2	3	0	0
Gaobeidian	0	0	–	–	–	–	–	–	–	0	2	2	0	0
Baoding	3	0	0	–	–	–	–	–	–	3	0	–	2	0
Dingzhou	0	0	0	0	–	–	–	–	–	0	0	–	0	0
Shijiazhuang	0	2	2	3	3	–	–	–	–	3	2	–	–	0
Gaoyi	0	0	0	0	2	–	–	–	–	4	0	–	–	–
Xingtai	0	0	2	0	0	–	–	–	–	0	0	–	–	–
Handan	2	0	0	2	0	–	–	–	–	–	0	–	–	–
Anyang	2	0	0	2	0	–	0	–	–	–	–	–	–	–
Hebi	2	0	2	2	2	0	0	–	0	–	–	–	–	–
Xinxiang	2	0	0	2	0	2	0	0	–	–	–	–	–	–
Zhengzhou	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 7.4 The minimal running time of all the trains in each section ($t_{i,k}^{\min,\mathrm{run}}$)

	G507, G651, G501, G653, G509, G571, G511, G655, G513, G657, G515, G560, G508 G562, G652, G502, G654, G512, G672, G6732, G6734, G6704, G602, G92	G71, G83, G79, G90, G92
Beijing-Zhuozhou	21	20
Zhuozhou-Gaobeidian	4	3
Gaobeidian-Baoding Baoding	9	8
Baoding- Dingzhou	10.30	9
Dingzhou- Shijiazhuang	12.30	11
Shijiazhuang-Gaoyi	10	9.30
Gaoyi-Xingtai	12	10.30
Xingtai-Handan	9	7
Handan-Anyang	12	10
Anyang-Hebi	12	9.30
Hebi-Xinxiang	10	8.30
Xinxiang-Zhengzhou	20	18

note dd.ee stands for dd minutes and ee seconds

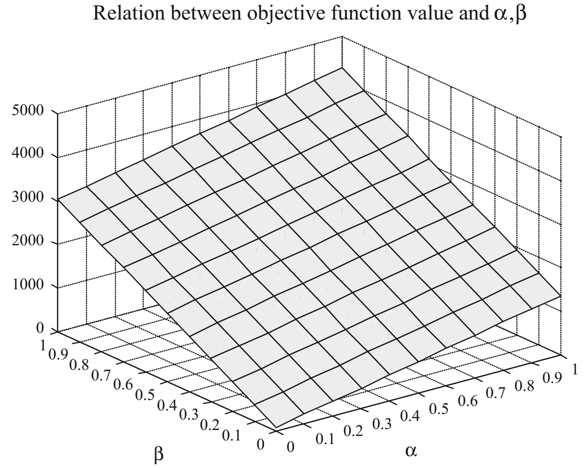

Fig. 7.3 Relation between objective function value and α, β

avoid G6704, and G79, G655 are delayed to avoid G6732, G92 is delayed at Zhuozhou to avoid the conflict with G79 and G655 and so on. G511 is re-scheduled to arrive at Zhuozhou earlier than it is planned to assure that G6732 can run as it is planned.

The summary delayed time of the down-going trains is 1625 min and that of the up-going trains is 125 min. It is because that the emergency occurs at the section

Table 7.5 The re-scheduled timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the down-going direction in computation Case 1

	G507		G651		G501		G71		G653	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing								8.0000		8.2100
Zhuozhou							8.2400	8.2400	8.4600	8.5400
Gaobeidian							8.2900	8.2900	8.5900	8.5900
Baoding			7.4600	7.4800	8.0900	8.0900	8.4100	8.4300	9.1100	9.1100
Dingzhou	7.5400	7.5600	8.0800	8.0800	8.2400	8.2600	8.5800	8.5800	9.2600	9.2600
Shijiazhuang	8.1900	8.2300	8.2400	8.2800	8.4900	8.5200	9.1900	9.2200	9.4600	9.4900
Gaoyi	8.3700	8.3700	8.4200	8.4200	9.0600	9.0600	9.3600	9.3600	10.0100	10.0100
Xingtai	8.5200	8.5200	8.5600	8.5800	9.2000	9.2200	9.5100	9.5100	10.1500	10.1500
Handan	9.0200	9.0400	9.1400	9.1600	9.3200	9.3200	10.0100	10.0300	10.2400	10.2400
Anyang	9.1800	9.1800	9.3000	9.3000	9.4700	9.4900	10.1700	10.1700	10.3700	10.3900
Hebi	9.3100	9.3300	9.4400	9.4600	10.0100	10.0100	10.3000	10.3000	10.5300	10.5300
Xinxiang	9.4900	9.5200	9.5700	9.5700	10.1100	10.1100	10.4100	10.4300	11.0500	11.1800
Zhengzhou	10.1300		10.1900		10.3100		11.0400		11.3900	
	G509		G83		G571		G511		G79	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing		8.4300		9.0000		9.2700		9.3700		10.0000
Zhuozhou	9.0700	9.0700	*9.3000*	*9.3000*	*10.0000*	*10.0000*	*10.1200*	*10.1400*	*10.3200*	*10.3200*
Gaobeidian	10.1100	10.1100	*9.3530*	*9.3530*	*10.0400*	*10.0400*	*10.1600*	*10.1600*	*10.3500*	*10.3500*
Baoding	9.2400	9.2600	*9.4400*	*9.4400*	*10.1600*	*10.1800*	*10.2700*	*10.2700*	*10.4330*	*10.4330*
Dingzhou	9.4400	9.5100	*9.5800*	*9.5800*	*10.2930*	*10.2930*	*10.3900*	*10.3900*	*10.5330*	*10.5330*
Shijiazhuang	10.1400	*10.2200*	*10.1700*	*10.1900*	10.4600	10.5000	10.5600	10.5900	11.0700	11.0900
Gaoyi	*10.3200*	*10.3200*	*10.2900*	*10.2900*	11.0330	11.0330	11.1300	11.2500	11.2030	11.2030
Xingtai	*10.4500*	*10.4500*	*10.3930*	*10.3930*	11.1800	11.2000	11.4230	11.4230	11.3200	11.3200

(continued)

Table 7.5 (continued)

Handan	10.5400	10.5400	*10.4700*	*10.4700*	11.3600	11.4500	11.5500	11.5500	11.4030	11.4030
Anyang	11.0600	11.0600	*10.5700*	*10.5700*	11.5800	11.5800			11.5200	11.5200
Hebi	11.1800	11.2000	*11.0700*	*11.0700*						
Xinxiang	11.3000	11.3000	*11.1430*	*11.1430*						
Zhengzhou	11.5000		11.3000							
	G655		G513		G657		G515			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing		10.0500		10.4800		11.0600		11.5000		
Zhuozhou	*10.5000*	*10.5000*	11.1300	11.1300	11.3000	11.3000				
Gaobeidian	*10.5500*	*10.5700*	11.1800	11.2000	11.3500	11.3500				
Baoding	*11.0600*	*11.0800*	11.3130	11.3130	11.4700	11.4900				
Dingzhou	*11.1830*	*11.1830*	11.4500	11.4500						
Shijiazhuang	11.3100	11.3400	12.0700	12.1100						
Gaoyi	11.5030	11.5030								

note aa.bbcc stands for bb minutes cc seconds at aa o'clock

The time in italics is the rescheduled inbound and outbound time of the trains at stations

Table 7.6 The re-scheduled timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the up-going direction in computation Case 1

	G560		G90		G508		G562		G652	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing	12.0400		11.3000							
Zhuozhou	11.3700	11.3900	*11.1200*	*11.1200*						
Gaobeidian	11.2600	11.2800	*11.0830*	*11.0830*						
Baoding	11.0700	11.1000	*10.5900*	*10.5900*	11.5100	11.5100	12.0600	12.0800		
Dingzhou	*10.5400*	*10.5400*	*10.4800*	*10.4800*	11.3700	11.3700	11.5130	11.5130		
Shijiazhuang	*10.3530*	*10.3530*	*10.3100*	*10.3300*	11.1300	11.1700	11.2800	11.3100	11.5500	11.5800
Gaoyi	*10.2300*	*10.2300*	*10.1900*	*10.1900*	*11.0030*	*11.0030*	11.1400	11.1400	11.3800	11.4000
Xingtai	*10.1000*	*10.1000*	*10.0700*	*10.0700*	*10.4500*	*10.4700*	10.5930	10.5930	*11.2630*	*11.2630*
Handan	9.5500	*10.0100*	*9.5800*	*9.5800*	*10.3730*	*10.3730*	*10.4800*	*10.5000*	*11.1830*	*11.1830*
Anyang	9.3000	9.3800	*9.4600*	*9.4600*	*10.2500*	*10.2500*	*10.3100*	*10.3300*	*11.0730*	*11.0730*
Hebi	9.1300	9.1500	*9.3500*	*9.3500*	*10.1200*	*10.1400*	*10.2030*	*10.2030*	*10.5500*	*10.5700*
Xinxiang	8.5500	8.5700	*9.2600*	*9.2600*	*10.0330*	*10.0330*	*10.1000*	*10.1200*	*10.4400*	*10.4400*
Zhengzhou		8.3500		9.0000		9.3200		9.4000		10.1400
	G502		G654		G512		G672		G6732	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing									10.2300	
Zhuozhou									9.5900	9.5900
Gaobeidian									9.5430	9.5430
Baoding									9.3900	9.4200
Dingzhou									9.2400	9.2400
Shijiazhuang									9.0000	9.0300
Gaoyi									8.4300	8.4500
Xingtai									8.1730	8.1730

(continued)

Table 7.6 (continued)

Handan			12.0000	12.0000						8.0600
Anyang	11.5600	11.5600	11.4800	11.4800						
Hebi	11.4400	11.4400	11.3830	11.3830						
Xinxiang	11.2100	11.3400	11.2900	11.2900	11.5000	11.5200	12.0000	12.0200		
Zhengzhou		11.0100		11.1200		11.3000		11.4000		
	G6734		G6704		G602		G92			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing	12.1900		8.5700		9.5300		11.0000			
Zhuozhou	11.5200	11.5400	8.2900	8.3200	9.2900	9.2900	10.3800	10.3800		
Gaobeidian	11.4100	11.4300	8.1800	8.2000	9.2500	9.2500	10.3400	10.3400		
Baoding	11.2800	11.2800		8.0100	9.1000	9.1200	10.2100	10.2100		
Dingzhou	11.1330	11.1330			8.5600	8.5600	10.0900	10.0900		
Shijiazhuang	10.5100	10.5300				8.3400		9.5000		
Gaoyi	10.3730	10.3730								
Xingtai	10.2300	10.2300								
Handan		10.1300								

note aa.bbcc stands for bb minutes cc seconds at aa o'clock

The time in italics is the rescheduled inbound and outbound time of the trains at stations

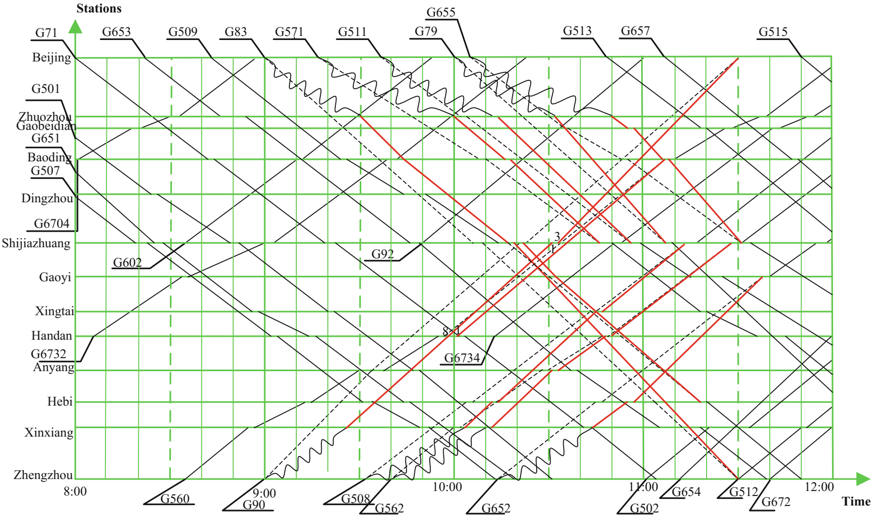

Fig. 7.4 The replanned train working diagram generated with the improved fuzzy linear programming model from 8 to 12 a.m. in section between Beijing and Zhengzhou in computation Case 1. The *dotted lines* stand for the original planned moving trajectories of the disturbed trains. The *red lines* are the re-scheduled moving trajectories of the disturbed trains. The *wavy lines* imply that the trains are disturbed when running in section between Beijing and Zhuozhou

between Beijing and Zhuozhou, which affects the down-going trains more seriously. The total delayed time is 1750 min and the objective value is 3250 min.

In the same manner, we did the data experiments with the typical fuzzy linear programming model on Case 2. The re-scheduled timetables are shown in Tables 7.11 and 7.12 and Fig. 7.7.

7.5.2 Analysis of the Computation Cases

According to the data in Tables 7.7 and 7.8, the summary delayed time of the down-going trains is 590 min and the summary delayed time of up-going trains is 402.5 min. Compared to the results in Tables 7.5 and 7.6, the summary delayed time of the down-going trains calculated out with the typical fuzzy linear programming model is 105 min more than that with the improved fuzzy linear programming model. Similarly, the summary delayed time of the up-going trains is 85 min more. Correspondingly, the optimal objective of the model is calculated to

Table 7.7 The re-scheduled timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the down-going direction with typical fuzzy linear programming in computation Case 1

	G507		G651		G501		G71		G653	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing								8.0000		8.2100
Zhuozhou							8.2400	8.2400	8.4600	8.5400
Gaobeidian							8.2900	8.2900	8.5900	8.5900
Baoding			7.4600	7.4800	8.0900	8.0900	8.4100	8.4300	9.1100	9.1100
Dingzhou	7.5400	7.5600	8.0800	8.0800	8.2400	8.2600	8.5800	8.5800	9.2600	9.2600
Shijiazhuang	8.1900	8.2300	8.2400	8.2800	8.4900	8.5200	9.1900	9.2200	9.4600	9.4900
Gaoyi	8.3700	8.3700	8.4200	8.4200	9.0600	9.0600	9.3600	9.3600	10.0100	10.0100
Xingtai	8.5200	8.5200	8.5600	8.5800	9.2000	9.2200	9.5100	9.5100	10.1500	10.1500
Handan	9.0200	9.0400	9.1400	9.1600	9.3200	9.3200	10.0100	10.0300	10.2400	10.2400
Anyang	9.1800	9.1800	9.3000	9.3000	9.4700	9.4900	10.1700	10.1700	10.3700	10.3900
Hebi	9.3100	9.3300	9.4400	9.4600	10.0100	10.0100	10.3000	10.3000	10.5300	10.5300
Xinxiang	9.4900	9.5200	9.5700	9.5700	10.1100	10.1100	10.4100	10.4300	11.0500	11.1800
Zhengzhou	10.1300		10.1900		10.3100		11.0400		11.3900	
	G509		G83		G571		G511		G79	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing		8.4300		9.0000		9.2700		9.3700		10.0000
Zhuozhou	9.0700	9.0700	*9.3000*	*9.3000*	*10.0000*	*10.0000*	*10.1200*	*10.1400*	*10.3200*	*10.3200*
Gaobeidian	10.1100	10.1100	*9.3630*	*9.3630*	*10.0400*	*10.0400*	*10.1800*	*10.1800*	*10.3530*	*10.3530*
Baoding	9.2400	9.2600	*9.4600*	*9.4600*	*10.1600*	*10.1800*	*10.2900*	*10.2900*	*10.4400*	*10.4400*
Dingzhou	9.4400	9.5100	*9.5900*	*9.5900*	*10.3030*	*10.3030*	*10.4100*	*10.4100*	*10.5430*	*10.5430*
Shijiazhuang	10.1400	*10.2400*	*10.1900*	*10.2100*	*10.4800*	*10.5200*	*10.5800*	*11.0100*	*11.0900*	*11.1100*
Gaoyi	*10.3400*	*10.3400*	*10.3100*	*10.3100*	*11.0500*	*11.0500*	11.1300	11.2500	*11.2100*	*11.2100*

(continued)

Table 7.7 (continued)

Xingtai	*10.4700*	*10.4700*	*10.4130*	*10.4130*	11.1800	11.2000	11.4230	11.4230	11.3200	11.3200
Handan	*10.5600*	*10.5600*	*10.4900*	*10.4900*	11.3600	11.4500	11.5500	11.5500	11.4030	11.4030
Anyang	*11.0800*	*11.0800*	*10.5900*	*10.5900*	11.5800	11.5800			11.5200	11.5200
Hebi	*11.2000*	*11.2200*	*11.0900*	*11.0900*						
Xinxiang	*11.3200*	*11.3200*	*11.1630*	*11.1630*						
Zhengzhou	*11.5200*		*11.3200*							
	G655		G513		G657		G515			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing		10.0500		10.4800		11.0600		11.5000		
Zhuozhou	*10.5000*	*10.5000*	11.1300	11.1300	11.3000	11.3000				
Gaobeidian	*10.5500*	*10.5700*	11.1800	11.2000	11.3500	11.3500				
Baoding	*11.0600*	*11.0800*	11.3130	11.3130	11.4700	11.4900				
Dingzhou	*11.1830*	*11.1830*	11.4500	11.4500						
Shijiazhuang	*11.3300*	*11.3600*	12.0700	12.1100						
Gaoyi	*11.5100*	*11.5100*								

note aa.bbcc stands for bb minutes cc seconds at aa o'clock

The time in italics is the rescheduled inbound and outbound time of the trains at stations

Table 7.8 The re-scheduled timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the up-going direction with typical fuzzy linear programming in computation Case 1

	G560		G90		G508		G562		G652	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing	12.0400		*11.3300*							
Zhuozhou	11.3700	11.3900	*11.1400*	*11.1400*						
Gaobeidian	11.2600	11.2800	*11.1000*	*11.1000*						
Baoding	*11.1000*	*11.1300*	*11.0100*	*11.0100*	*11.5230*	*11.5230*	12.0600	12.0800		
Dingzhou	*10.5600*	*10.5600*	*10.4900*	*10.4900*	*11.3830*	*11.3830*	11.5130	11.5130		
Shijiazhuang	*10.3700*	*10.3700*	*10.3100*	*10.3300*	*11.1500*	*11.1900*	11.2800	11.3100	*11.5700*	*12.0000*
Gaoyi	*10.2400*	*10.2400*	*10.1900*	*10.1900*	*11.0130*	*11.0130*	*11.1430*	*11.1430*	*11.4300*	*11.4500*
Xingtai	*10.1130*	*10.1130*	*10.0700*	*10.0700*	*10.4500*	*10.4700*	*11.0100*	*11.0100*	*11.3000*	*11.3000*
Handan	9.5500	*10.0100*	*9.5800*	*9.5800*	*10.3730*	*10.3730*	*10.4900*	*10.5100*	*11.2100*	*11.2100*
Anyang	9.3000	9.3800	*9.4600*	*9.4600*	*10.2500*	*10.2500*	*10.3300*	*10.3500*	*11.0800*	*11.0800*
Hebi	9.1300	9.1500	*9.3500*	*9.3500*	*10.1200*	*10.1400*	*10.2130*	*10.2130*	*10.5500*	*10.5700*
Xinxiang	8.5500	8.5700	*9.2600*	*9.2600*	*10.0330*	*10.0330*	*10.1000*	*10.1200*	*10.4400*	*10.4400*
Zhengzhou		8.3500		9.0000		9.3200		9.4000		10.1400
	G502		G654		G512		G672		G6732	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing									10.2300	
Zhuozhou									9.5900	9.5900
Gaobeidian									9.5430	9.5430
Baoding									9.3900	9.4200
Dingzhou									9.2400	9.2400
Shijiazhuang									9.0000	9.0300
Gaoyi									8.4300	8.4500

(continued)

Table 7.8 (continued)

Xingtai									8.1730	8.1730
Handan			12.0000	12.0000						8.0600
Anyang	11.5600	11.5600	11.4800	11.4800						
Hebi	11.4400	11.4400	11.3830	11.3830						
Xinxiang	11.2100	11.3400	11.2900	11.2900	11.5000	11.5200	12.0000	12.0200		
Zhengzhou		11.0100		11.1200		11.3000		11.4000		
	G6734		G6704		G602		G92			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing	12.1900		8.5700		9.5300		11.0000			
Zhuozhou	11.5200	11.5400	8.2900	8.3200	9.2900	9.2900	10.3800	10.3800		
Gaobeidian	11.4100	11.4300	8.1800	8.2000	9.2500	9.2500	10.3400	10.3400		
Baoding	11.2800	11.2800		8.0100	9.1000	9.1200	10.2100	10.2100		
Dingzhou	11.1330	11.1330			8.5600	8.5600	10.0900	10.0900		
Shijiazhuang	10.5100	10.5300				8.3400		9.5000		
Gaoyi	10.3730	10.3730								
Xingtai	10.2300	10.2300								
Handan		10.1300								

note aa.bbcc stands for bb minutes cc seconds at aa o'clock
The time in italics is the rescheduled inbound and outbound time of the trains at stations

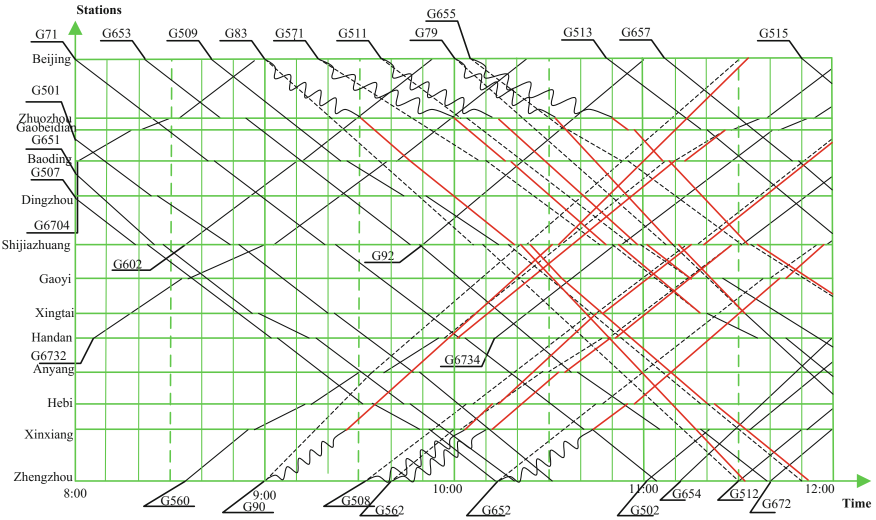

Fig. 7.5 The replanned train working diagram generated with the typical fuzzy linear programming model from 8 to 12 a.m. in section between Beijing and Zhengzhou in computation Case 1. The *dotted lines* stand for the original planned moving trajectories of the disturbed trains. The *red lines* are the re-scheduled moving trajectories of the disturbed trains. The *wavy lines* imply that the trains are disturbed when running in section between Beijing and Zhuozhou

be 4007.5, which is much smaller than 4197.5. We can conclude that the model proposed in this chapter has more preeminent optimizing ability.

In Case 2, the optimal objective of the model is calculated to be 3183. The summary delayed time of the down-going trains is 1684 min and the summary delayed time of up-going trains is 133 min. Compared to the results in Tables 7.9 and 7.10, the summary delayed time of the down-going trains and the up-going trains calculated out with the typical fuzzy linear programming model is both more than that with the improved fuzzy linear programming model presented in this chapter. It proves again that the model proposed in this chapter has more preeminent optimizing ability.

To compare the computation efficiency of the improved fuzzy linear programming and typical fuzzy linear programming, we recorded the computation time of

Table 7.9 The re-scheduled timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the down-going direction in computation Case 2

	G507		G651		G501		G71		G653	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing								8.0000		8.2100
Zhuozhou							8.2400	8.2400	8.4600	8.5400
Gaobeidian							8.2900	8.2900	8.5900	8.5900
Baoding			7.4600	7.4800	8.0900	8.0900	8.4100	8.4300	9.1100	9.1100
Dingzhou	7.5400	7.5600	8.0800	8.0800	8.2400	8.2600	8.5800	8.5800	9.2600	9.2600
Shijiazhuang	8.1900	8.2300	8.2400	8.2800	8.4900	8.5200	9.1900	9.2200	9.4600	9.4900
Gaoyi	8.3700	8.3700	8.4200	8.4200	9.0600	9.0600	9.3600	9.3600	10.0100	10.0100
Xingtai	8.5200	8.5200	8.5600	8.5800	9.2000	9.2200	9.5100	9.5100	10.1500	10.1500
Handan	9.0200	9.0400	9.1400	9.1600	9.3200	9.3200	10.0100	10.0300	10.2400	10.2400
Anyang	9.1800	9.1800	9.3000	9.3000	9.4700	9.4900	10.1700	10.1700	10.3700	10.3900
Hebi	9.3100	9.3300	9.4400	9.4600	10.0100	10.0100	10.3000	10.3000	10.5300	10.5300
Xinxiang	9.4900	9.5200	9.5700	9.5700	10.1100	10.1100	10.4100	10.4300	11.0500	11.1800
Zhengzhou	10.1300		10.1900		10.3100		11.0400		11.3900	
	G509		G83		G571		G511		G79	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing		*9.0900*		*9.1200*		9.2700		9.3700		*10.2700*
Zhuozhou	*9.3030*	*9.3030*	*9.3530*	*9.3530*	9.4630	9.4630	*9.5800*	10.0400	*10.4830*	*10.4830*
Gaobeidian	*9.3500*	*9.3500*	*9.4000*	*9.4000*	9.5200	9.5200	10.0830	10.0830	*10.5300*	*10.5300*
Baoding	*9.4600*	*9.4800*	*9.5230*	*9.5230*	10.0800	10.1000	10.2100	10.2100	*11.0400*	*11.0400*
Dingzhou	*10.0200*	*10.0400*	*10.0630*	*10.0630*	10.2500	10.2500	10.3600	10.3600	*11.1600*	*11.1600*
Shijiazhuang	*10.2300*	*10.3100*	*10.2600*	*10.2800*	10.4600	10.5000	10.5600	10.5900	*11.3400*	*11.3600*
Gaoyi	*10.4200*	*10.4200*	*10.3900*	*10.3900*	11.0330	11.0330	11.1300	11.2500	*11.4600*	*11.4600*
Xingtai	*10.5330*	*10.5330*	*10.5030*	*10.5030*	11.1800	11.2000	11.4230	11.4230	*11.5630*	*11.5630*

(continued)

Table 7.9 (continued)

Handan	*11.0130*	*11.0130*	*10.5830*	*10.5830*	11.3600	11.4500	11.5500	11.5500	–	–
Anyang	*11.1230*	*11.1230*	*11.0930*	*11.0930*	11.5800	11.5800			–	–
Hebi	*11.2400*	*11.2600*	*11.2100*	*11.2100*						
Xinxiang	*11.3300*	*11.3300*	*11.2800*	*11.2800*						
Zhengzhou	11.5000		*11.3500*							
	G655		G513		G657		G515			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing		*10.3000*		*11.3100*		*11.3400*		11.5000		
Zhuozhou	*10.5200*	*10.5200*	*11.5200*	*11.5200*	*11.5500*	*11.5500*				
Gaobeidian	*10.5600*	*10.5800*	*11.5600*	*11.5800*	*11.5900*	*11.5900*				
Baoding	*11.0900*	*11.1100*	–	–	–	–				
Dingzhou	*11.2300*	*11.2300*	–	–						
Shijiazhuang	*11.3700*	*11.4000*	–	–						
Gaoyi	11.5030	11.5030								

note aa.bbcc stands for bb minutes cc seconds at aa o'clock
The time in italics is the rescheduled inbound and outbound time of the trains at stations

Table 7.10 The re-scheduled timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the up-going direction in computation Case 2

	G560		G90		G508		G562		G652	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing			11.3000							
Zhuozhou	11.3700	–	11.0900	11.0900						
Gaobeidian	11.2600	11.2800	11.0430	11.0430						
Baoding	11.0700	11.1000	10.5300	10.5300	11.5100	11.5100				
Dingzhou	10.5300	10.5300	10.4100	10.4100	11.3700	11.3700	11.5130	11.5130		
Shijiazhuang	10.3400	10.3400	10.2100	10.2300	11.1300	11.1700	11.2800	11.3100	11.5500	11.5800
Gaoyi	10.2030	10.2030	10.0830	10.0830	11.0000	11.0000	11.1400	11.1400	11.3800	11.4000
Xingtai	10.0700	10.0700	9.5600	9.5600	10.4300	10.4500	10.5930	10.5930	11.2400	11.2400
Handan	9.5500	9.5700	9.4700	9.4700	10.3300	10.3300	10.4700	10.4900	11.1400	11.1400
Anyang	9.3000	9.3800	9.3400	9.3400	10.1830	10.1830	10.2800	10.3000	11.0000	11.0000
Hebi	9.1300	9.1500	9.2400	9.2400	10.0300	10.0500	10.1300	10.1300	10.4500	10.4700
Xinxiang	8.5500	8.5700	9.1600	9.1600	9.5330	9.5330	10.0000	10.0200	10.3400	10.3400
Zhengzhou		8.3500		9.0000		9.3200		9.4000		10.1400
	G502		G654		G512		G672		G6732	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing									10.2300	
Zhuozhou									9.5900	9.5900
Gaobeidian									9.5430	9.5430
Baoding									9.3900	9.4200
Dingzhou									9.2400	9.2400
Shijiazhuang									9.0000	9.0300
Gaoyi									8.4300	8.4500
Xingtai									8.1730	8.1730

(continued)

Table 7.10 (continued)

Handan			12.0000	12.0000						8.0600
Anyang	11.5600	11.5600	11.4800	11.4800						
Hebi	11.4400	11.4400	11.3830	11.3830						
Xinxiang	11.2100	11.3400	11.2900	11.2900	11.5000	11.5200	12.0000	12.0200		
Zhengzhou		11.0100		11.1200		11.3000		11.4000		
	G6734		G6704		G602		G92			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing	12.1900		*9.0800*		*10.2600*		*11.1500*			
Zhuozhou	11.5200	11.5400	8.2900	*8.4700*	9.2900	*10.0500*	10.3800	*10.5300*		
Gaobeidian	11.4100	11.4300	8.1800	8.2000	9.2500	9.2500	10.3400	10.3400		
Baoding	11.2800	11.2800		8.0100	9.1000	9.1200	10.2100	10.2100		
Dingzhou	11.1330	11.1330			8.5600	8.5600	10.0900	10.0900		
Shijiazhuang	10.5100	10.5300				8.3400		9.5000		
Gaoyi	10.3730	10.3730								
Xingtai	10.2300	10.2300								
Handan		10.1300								

note aa.bbcc stands for bb minutes cc seconds at aa o'clock
The time in italics is the rescheduled inbound and outbound time of the trains at stations

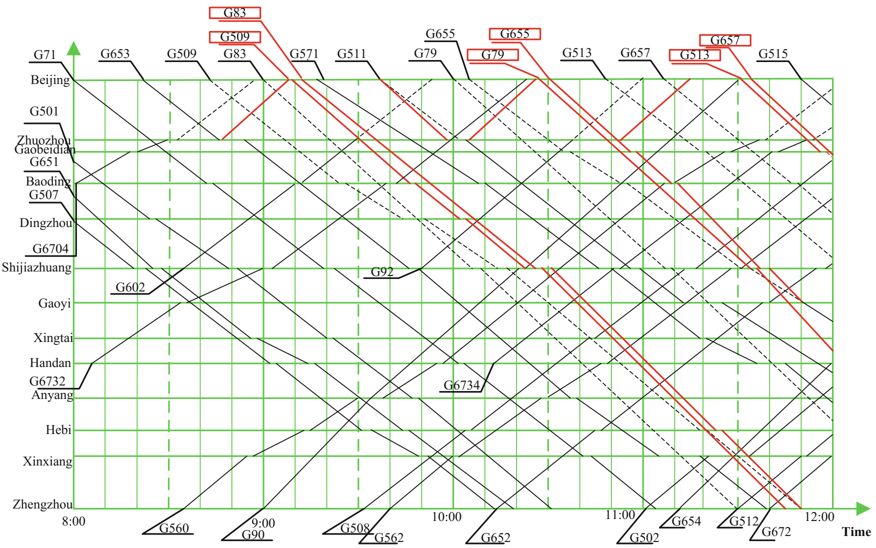

Fig. 7.6 The replanned train working diagram generated with the improved fuzzy linear programming model from 8 to 12 a.m. in section between Beijing and Zhengzhou in computation Case 2. The *dotted lines* stand for the original planned moving trajectories of the disturbed trains. The *red lines* are the re-scheduled moving trajectories of the disturbed trains

the two algorithms when solving the train re-scheduling model in Case 1. We did the data experiments 10 times with the two programming models respectively. The time computation cost with the improved fuzzy linear programming varies from 1828 to 1837 ms, see Table 7.13. The average value is 1832.9 ms. The time cost with typical fuzzy linear programming varies from 1650 to 1660 ms. The average value is 1654.0 ms. The computation time cost with the typical linear programming is 178.9 ms shorter that cost by the improved linear programming. It stems from the fact that the improved fuzzy linear programming dealt with the boundaries of the fuzzy coefficients, which cost the computation time. Even so, the improved fuzzy programming is acceptable because of the computational performance.

We also recorded the computation time of the two algorithms when solving the train re-scheduling model in Case 2. The average time cost with typical fuzzy linear programming is 1332.6 ms, while it cost 1523.2 ms with the improved fuzzy linear programming averagely. Case 2 also proved the improved linear programming is considered acceptable.

From the computing results, we also conclude that the performance of the proposed model on the two numerical examples is steady and robust because that the cost time in the computations varies slightly in the two cases.

Table 7.11 The re-scheduled timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the down-going direction with typical fuzzy linear programming in computation Case 2

	G507		G651		G501		G71		G653	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing								8.0000		8.2100
Zhuozhou							8.2400	8.2400	8.4600	8.5400
Gaobeidian							8.2900	8.2900	8.5900	8.5900
Baoding			7.4600	7.4800	8.0900	8.0900	8.4100	8.4300	9.1100	9.1100
Dingzhou	7.5400	7.5600	8.0800	8.0800	8.2400	8.2600	8.5800	8.5800	9.2600	9.2600
Shijiazhuang	8.1900	8.2300	8.2400	8.2800	8.4900	8.5200	9.1900	9.2200	9.4600	9.4900
Gaoyi	8.3700	8.3700	8.4200	8.4200	9.0600	9.0600	9.3600	9.3600	10.0100	10.0100
Xingtai	8.5200	8.5200	8.5600	8.5800	9.2000	9.2200	9.5100	9.5100	10.1500	10.1500
Handan	9.0200	9.0400	9.1400	9.1600	9.3200	9.3200	10.0100	10.0300	10.2400	10.2400
Anyang	9.1800	9.1800	9.3000	9.3000	9.4700	9.4900	10.1700	10.1700	10.3700	10.3900
Hebi	9.3100	9.3300	9.4400	9.4600	10.0100	10.0100	10.3000	10.3000	10.5300	10.5300
Xinxiang	9.4900	9.5200	9.5700	9.5700	10.1100	10.1100	10.4100	10.4300	11.0500	11.1800
Zhengzhou	10.1300		10.1900		10.3100		11.0400		11.3900	
	G509		G83		G571		G511		G79	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing		*9.0900*		*9.1200*		9.2700		9.3700		*10.2700*
Zhuozhou	*9.3030*	*9.3030*	*9.3530*	*9.3530*	9.4630	9.4630	*9.5900*	10.0400	*10.5000*	*10.5000*
Gaobeidian	*9.3500*	*9.3500*	*9.4000*	*9.4000*	9.5200	9.5200	10.0830	10.0830	*10.5430*	*10.5430*
Baoding	*9.4700*	*9.4900*	*9.5230*	*9.5230*	10.0800	10.1000	10.2100	10.2100	*11.0600*	*11.0600*
Dingzhou	*10.0300*	*10.0500*	*10.0800*	*10.0800*	10.2500	10.2500	10.3600	10.3600	*11.2000*	*11.2000*
Shijiazhuang	*10.2400*	*10.3200*	*10.2700*	*10.2900*	10.4600	10.5000	10.5600	10.5900	*11.3600*	*11.3800*
Gaoyi	*10.4200*	*10.4200*	*10.3900*	*10.3900*	11.0330	11.0330	11.1300	11.2500	*11.4800*	*11.4800*

(continued)

Table 7.11 (continued)

Xingtai	*10.5330*	*10.5330*	*10.5030*	*10.5030*	11.1800	11.2000	11.4230	11.4230	*11.5800*	*11.5800*
Handan	*11.0130*	*11.0130*	*10.5830*	*10.5830*	11.3600	11.4500	11.5500	11.5500	–	–
Anyang	*11.1230*	*11.1230*	*11.0930*	*11.0930*	11.5800	11.5800			–	–
Hebi	*11.2400*	*11.2600*	*11.2100*	*11.2100*						
Xinxiang	*11.3300*	*11.3300*	*11.2800*	*11.2800*						
Zhengzhou	11.5000		*11.3500*							
	G655		G513		G657		G515			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing		*10.3000*		*11.3100*		*11.3400*		11.5000		
Zhuozhou	*10.5300*	*10.5300*	*11.5230*	*11.5230*	*11.5530*	*11.5530*				
Gaobeidian	*10.5800*	*11.0000*	*11.5900*	*11.5900*	*12.0000*	*12.0000*				
Baoding	*11.1100*	*11.1300*	–	–	–	–				
Dingzhou	*11.2400*	*11.2400*	–	–						
Shijiazhuang	*11.3700*	*11.4000*	–	–						
Gaoyi	11.5030	11.5030								

note aa.bbcc stands for bb minutes cc seconds at aa o’clock
The time in italics is the rescheduled inbound and outbound time of the trains at stations

Table 7.12 The re-scheduled timetable from 8 to 12 a.m. in section between Beijing and Zhengzhou in the up-going direction with typical fuzzy linear programming in computation Case 2

	G560		G90		G508		G562		G652	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing			11.3000							
Zhuozhou	11.3700	–	11.0900	11.0900						
Gaobeidian	11.2600	11.2800	11.0430	11.0430						
Baoding	11.0700	11.1000	10.5300	10.5300	11.5100	11.5100				
Dingzhou	10.5300	10.5300	10.4100	10.4100	11.3700	11.3700	11.5130	11.5130		
Shijiazhuang	10.3400	10.3400	10.2100	10.2300	11.1300	11.1700	11.2800	11.3100	11.5500	11.5800
Gaoyi	10.2030	10.2030	10.0830	10.0830	11.0000	11.0000	11.1400	11.1400	11.3800	11.4000
Xingtai	10.0700	10.0700	9.5600	9.5600	10.4300	10.4500	10.5930	10.5930	11.2400	11.2400
Handan	9.5500	9.5700	9.4700	9.4700	10.3300	10.3300	10.4700	10.4900	11.1400	11.1400
Anyang	9.3000	9.3800	9.3400	9.3400	10.1830	10.1830	10.2800	10.3000	11.0000	11.0000
Hebi	9.1300	9.1500	9.2400	9.2400	10.0300	10.0500	10.1300	10.1300	10.4500	10.4700
Xinxiang	8.5500	8.5700	9.1600	9.1600	9.5330	9.5330	10.0000	10.0200	10.3400	10.3400
Zhengzhou		8.3500		9.0000		9.3200		9.4000		10.1400
	G502		G654		G512		G672		G6732	
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Depart
Beijing									10.2300	
Zhuozhou									9.5900	9.5900
Gaobeidian									9.5430	9.5430
Baoding									9.3900	9.4200
Dingzhou									9.2400	9.2400
Shijiazhuang									9.0000	9.0300
Gaoyi									8.4300	8.4500

(continued)

Table 7.12 (continued)

Xingtai									8.1730	8.1730
Handan			12.0000	12.0000						8.0600
Anyang	11.5600	11.5600	11.4800	11.4800						
Hebi	11.4400	11.4400	11.3830	11.3830						
Xinxiang	11.2100	11.3400	11.2900	11.2900	11.5000	11.5200	12.0000	12.0200		
Zhengzhou		11.0100		11.1200		11.3000		11.4000		
	G6734		G6704		G602		G92			
	Arrive	Depart	Arrive	Depart	Arrive	Depart	Arrive	Arrive		
Beijing	12.1900		*9.0900*		*10.2800*		*11.1700*			
Zhuozhou	11.5200	11.5400	8.2900	*8.4800*	9.2900	*10.0500*	10.3800	*10.5500*		
Gaobeidian	11.4100	11.4300	8.1800	8.2000	9.2500	9.2500	10.3400	10.3400		
Baoding	11.2800	11.2800		8.0100	9.1000	9.1200	10.2100	10.2100		
Dingzhou	11.1330	11.1330			8.5600	8.5600	10.0900	10.0900		
Shijiazhuang	10.5100	10.5300				8.3400		9.5000		
Gaoyi	10.3730	10.3730								
Xingtai	10.2300	10.2300								
Handan		10.1300								

note aa.bbcc stands for bb minutes cc seconds at aa o'clock
The time in italics is the rescheduled inbound and outbound time of the trains at stations

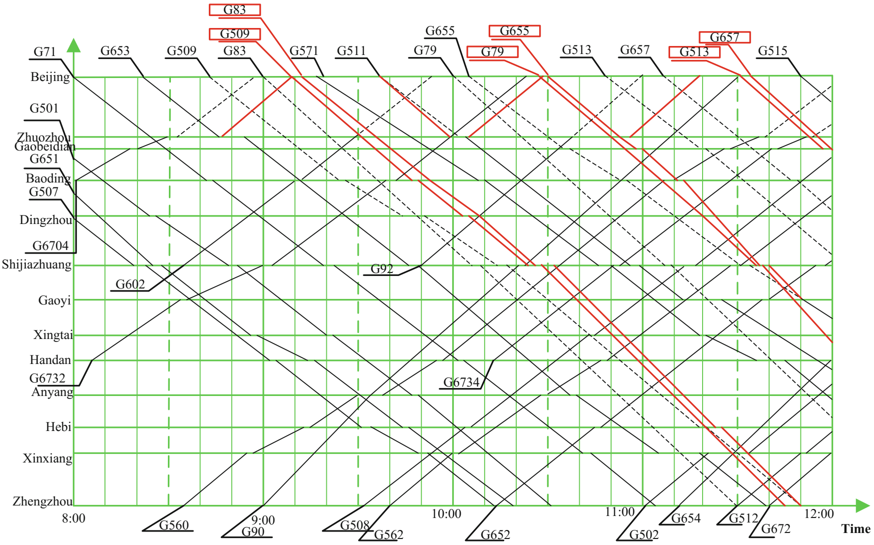

Fig. 7.7 The replanned train working diagram generated with the typical fuzzy linear programming model from 8 to 12 a.m. in section between Beijing and Zhengzhou in computation Case 2. The *dotted lines* stand for the original planned moving trajectories of the disturbed trains. The *red lines* are the re-scheduled moving trajectories of the disturbed trains

Table 7.13 The computation time in the two cases

	Case 1		Case 2	
	With improved fuzzy linear programming	With typical fuzzy linear programming	With improved fuzzy linear programming	With typical fuzzy linear programming
1	1832	1654	1524	1331
2	1836	1653	1526	1332
3	1834	1650	1530	1333
4	1830	1654	1520	1332
5	1831	1658	1524	1334
6	1828	1660	1521	1332
7	1837	1650	1524	1331
8	1832	1654	1521	1335
9	1834	1652	1522	1332
10	1835	1654	1520	1334
Average	1832.9	1654.0	1523.2	1332.6

7.6 Brief Summary

On the operational planning level, a railway train re-scheduling problem is investigated under the uncertain environment of fuzziness. In the problem, the coefficients of the resources, which are on the right side of the constraints, are supposed to have the fuzzy boundary value ranges. For this case, the traditional linear fuzzy programming model will turn meaningless, and we improve the model, describing the boundaries of the coefficients as fuzzy numbers.

On the basis of the improved fuzzy linear programming, the train re-scheduling problem with fuzzy constraints is studied, which belonged to the operational level of railway operation. For the convenience of solving models, some coefficients on the right side of the constraints equation were simplified. The train re-scheduling model was turned to a parameter linear programming model with the triangle membership function. Two computation cases in different scenarios are listed and used to verify the model. The numerical examples show that the designed algorithm is steady and robust for not very large-scale problems.

Additionally, it is worth pointing out that the main focus of this chapter is to provide the different decision-making methods for train re-scheduling problem under the fuzzy environment. Generally, it is not easy to determine which model is the best, and the applications of models are dependent on decision-makers' preferences. The approach to re-scheduling trains can help the dispatchers to redesign the high-quality timetable.

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