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.

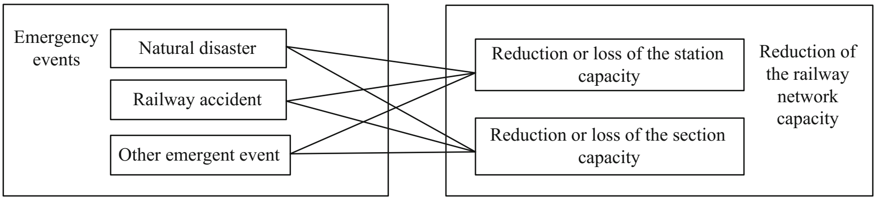


Fig. 2.1 Relation between the emergency and the effects on the railway network

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 $S_{\text{trans}} = (S_{\text{station}}, R_{\text{rail}}, T_{\text{train}}, R'')$ 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.

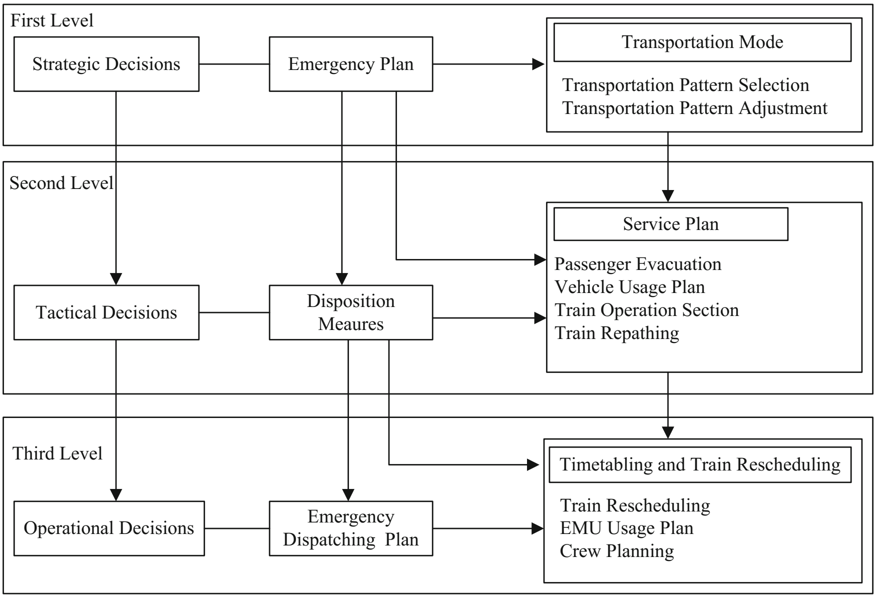
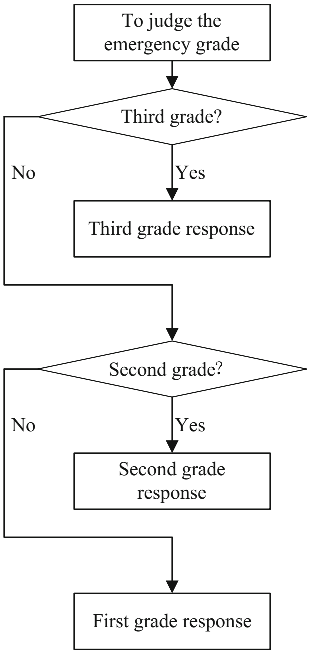


Fig. 2.2 Structure of macroscopic model of railway transport organization in emergencies

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.

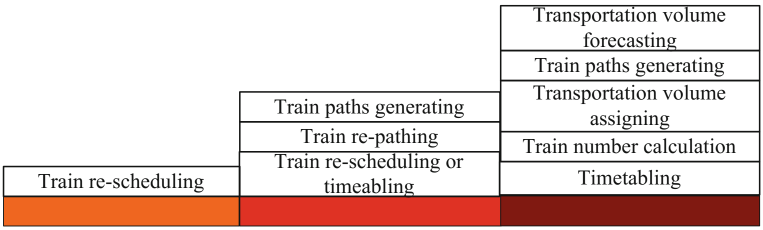


Fig. 2.4 Train operation organization in different grade emergencies

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.

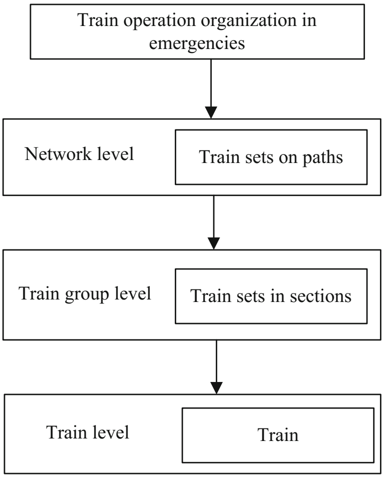


Fig. 2.5 Hierarchical structure of train operation organization problem in emergencies

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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