Research on Emergency Capability Evaluation of Network Operation-Based Urban Rail Transit

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ABSTRACT

In the process of network operation, it is of great significance to evaluate the emergency capability for the safety and resilience of urban rail transit. In this work, we proposed an emergency capability evaluation model of network operation-based urban rail transit by building a four-level index system. AHP (Analytic Hierarchy Process) method demonstrated the effectiveness of the evaluation index system. The ranking of index importance W_i characterizes the emergency capability of network operation-based urban rail transit. Taking Shenzhen Metro as an example, this study analyzed the risk in the actual network operation, evaluated the emergency capability of network operation and calculated the comprehensive score of emergency capability. Furthermore, based on the correlation analysis results from the emergency capability indexes, we put forward some measures to improve the weaker indexes in the evaluation. The results indicate that the emergency capability evaluation method of network operation-based urban rail transit proposed in this study can better guide the emergency management of network operation-based urban rail transit.

Keywords

Urban Rail Transit; Network Operation; Emergency Capability Evaluation; Evaluation Index System.

INTRODUCTION

At present, urban rail transit in China is coming into a new network era with the characteristics of line interconnection and seamless transfer (Saidi et al., 2017; Xiao et al., 2018; C. Yang et al., 2018; Z. Yang & Chen, 2018). Resource integration and sharing, centralized operation management and the overall coordination in the whole network are emphasized and significant in network operation-based urban rail transit (S. Li et al., 2019; Ren, 2016). Especially in the case of degraded condition or emergency condition, it can make the most of the advantages of the whole network with the comprehensive monitoring, coordination and efficient emergency management capabilities and then the spread of crisis events can be effectively controlled. Thus, the safety and resilience level of urban rail transit can be improved in the process of network operation (Q. Li et al., 2017).

Due to the complexity of network structure, the various and relevant functions of different lines, the increasing density and unbalance distribution of passenger flow and the diversification of train operation organization (Ren, 2016), network operation-based urban rail transit is confronted with the dual challenges of daily safety management and emergency disposal in case of emergencies (L. Sun et al., 2018). Therefore, it is of great significance to conduct the emergency capability evaluation work for network operation-based urban rail transit and it can improve the accident prevention university capability and emergency response capability for network operation management department in urban rail transit (Wen, 2013).

Heretofore, research abounds on emergency capacity evaluation of urban rail transit, especially in risk evaluation and emergency rescue disposal of different kinds of hazards in urban rail transit. For instance, based on the experiences of terrorist attacks and other emergency situations in metro, the critical systems were identified and some improvements to the design of metro coaches were proposed (Bruyelle et al., 2014). In terms of metro construction, pre-construction risk identification and risk warning in construction are very important, so the safety risk identification system and early warning system for China's metro construction can be designed for China's metro construction based on Building Information Modeling (BIM) platform (M. Li et al., 2018) or an internet/intranet integrated platform (L. Y. Ding & Zhou, 2013). For fire or explosion emergency in metro operation, we can analyze subway fire emergency response process by modeling and numerical simulation (Ma et al., 2017; Zhong et al., 2008). When it comes to natural disasters in metro, we can make use of a variety of risk assessment technical means to study in a comprehensive way, such as statistical methods, multi-criteria analysis, Geographic Information System (GIS) and/or Remote Sensing (RS) analysis, and scenario-based analysis (Lyu et al., 2019). In brief, there are many subway-related injuries and fatalities happening due to various reasons every year. So we can also assess the metro risk and emergency capability from the perspective of analyzing the accident records and the data of injuries and deaths (Rodier et al., 2018).

With regard to emergency capacity evaluation methods of urban rail transit, some noticeable progress has been achieved by scholars at home and abroad. There exist several approaches to research emergency capacity evaluation, including establishing evaluation index system (Huang & Li, 2006; N. Sun, 2010; Yan et al., 2019; G. S. Yang & Xu, 2011), conducting questionnaire survey (Guo et al., 2016; Mu et al., 2014), building metro risk network (Q. Li et al., 2017), designing operation incident database (Zhang et al., 2016), utilizing operation fault log (Avci & Ozbulut, 2018), modeling the QuEP framework (Núñez et al., 2016), et al. Among them, evaluation index system method is the most widely adopted. Furthermore, different quantitative methods are utilized to better process the indexes, such as AHP (Chen & Zhang, 2009; G. S. Yang & Xu, 2011), the fuzzy matter-element model (Yan et al., 2019), , extension distance function (Xu, 2012), structure entropy weight method (Xu, 2012; Yan et al., 2019), subway risk factor function (Avci & Ozbulut, 2018) and other methods.

In summary, it can be obtained from the above studies that research on emergency capacity evaluation of rail transit present diverse and rich both in content and in method. However, few studies emphasize the emergency capacity evaluation of rail transit under the condition of network operation. On the other hand, the validity of the established indicator system is rarely demonstrated. Therefore, it is necessary to choose an appropriate method to evaluate emergency capability of network operation-based urban rail transit and demonstrate its validity. At the same time, as a decision-making method, AHP (Wind & Saaty, 1980) has the characteristics of strong applicability, simple calculation, good practicability and systematization (J. Ding, 2009). Especially in the case of few objective data, the complex problems are decomposed layer by layer according to the relationship of indexes in AHP. Then the comprehensive evaluation results can be gained based on the relative importance degree among indicators through the expert scoring method. In this regard, AHP has a wide practical applicability and can be used to demonstrate the effectiveness of the index system (Wind & Saaty, 1980).

This purpose of this study is to propose a method with strong applicability to evaluate emergency capability of network operation-based urban rail transit. By this means, we can discover some shortcomings and then find out some measures to deal with them. Therefore, in view of this above research background, combined with the theory of risk analysis, accident prevention and emergency management, the requirements of *Regulations for operation management of urban rail transit (GB/T 30012-2013)* and *Specifications for developing plan to urban rail transit operation emergency (JT/T 1051-2016)*, the relevant industry standards and regulations as well as the characteristics of network operation in urban rail transit, this work proposes an emergency capability evaluation model of network operation-based urban rail transit by building a four-level index system and AHP method is used to demonstrate the effectiveness of the evaluation index system. Besides, taking Shenzhen Metro as an example, the emergency capability in network operation is evaluated in this way. Furthermore, the improvement measures for the weaker indexes in the evaluation are put forward in combination with the practical situation of Shenzhen Metro. This emergency capability evaluation method of network operation-based urban rail transit is proved to be of high application value in urban rail transit.

MODELING AND VALIDITY DEMONSTATION

Emergency capability evaluation modeling for network operation-based urban rail transit

As a direct and effective method, establishing the index system is most widely used in evaluating emergency capability of operation company. On the basis of the organization system, operation mechanism, legal basis and emergency guarantee system, the construction of emergency capability evaluation system in operation company should comprehensively consider the situation of enterprise emergency response plan, actual production and operation. In this case, combined with safety system engineering, risk analysis, accident prevention theory, relevant standards and specifications and the characteristics of network operation-based urban rail transit, the emergency capacity evaluation index system in network operation-based urban rail transit can be modeled.

In this model, emergency response capacity in urban rail transit is seen as the overall index. According to the process of accident emergency management (J. Ding, 2009), there are four first-level indexes under the overall index, including accident prevention capacity, emergency preparedness capacity, emergency response capacity and emergency recovery capacity (U1~U4). On this basis, it is further decomposed, layer by layer, into 21 second-level indexes (T1~T21), 55 third-level indexes (X1~X55) and 160 fourth-level indexes (Q1~Q160). The fourth-level indexes represent the specific performance of emergency response capability in urban rail transit enterprises. Because of a tremendous number of third-level and fourth-level indexes, here one or two examples are given to illustrate the concreteness of these indexes down to level four. For instance, under the U1 (accident prevention capability), there is a second-level index T1 (emergency plan), likewise, the third-level index X1 (emergency plan system) is under T1. More specifically, X1 is composed of the fourth-level indicator Q1 and Q2, where Q1 means that emergency plan should be compiled in accordance with the *Specifications for developing response plan to urban rail transit operation emergency (JT/T 1051-2016)* and the other industry standards or regulations and Q2 means that comprehensive contingency plans, special contingency plans and on-site handling plans have been formulated. As another example, T13 (network coordination and rescue mechanism) is subordinate to U3 (emergency response capability). Further, the third-level index X40 (emergency coordination) belongs to T13 and one of the indexes under the T13 is the fourth-level index Q118 which means that the mechanism for reporting, transmitting and sharing emergency information has been established among departments.

AHP demonstration of emergency capability evaluation model

The effectiveness of the emergency capability evaluation index system in network operation-based urban rail transit needs to be demonstrated before its practical application. Through conducting the investigation and interview for emergency management experts or scholars and operation management professionals in urban rail transit, the scientific determination and importance ranking of the weights for the above-mentioned indexes can be carried out to ensure the effectiveness and applicability of the index system. In this research, AHP analytic hierarchy process (AHP) is adopted to determine the index weight Wi. With the 1~9 sign method, complex problems are decomposed step by step, and the relative importance of each index in the hierarchy is compared in pairs to determine the comprehensive importance order of each index. The specific steps are as follows:

(1) As presented in Figure 1, an AHP demonstration model for the index system is built based on the emergency capability assessment index system. In the AHP model, the target layer (A) is emergency capacity. According to the process of emergency management, the criterion layer consists of four first-level indicators, including accident prevention capability (U1), emergency preparedness capability (U2), emergency response capability (U3) and emergency recovery capability (U4). And the scheme layer is the secondary index corresponding to U1~U4.

(2) Based on the AHP demonstration model for the emergency capability index system, the relative importance comparison of the indexes in the criterion layer and scheme layer are given by emergency management experts or scholars and operation management professionals in urban rail transit with the consistent matrix method and 1-9 sign method. Thus, the judgment matrixes of the criterion layer-target layer and the scheme layer-criterion layer can be respectively constructed.

(3) The maximum characteristic roots and eigenvectors of the above judgment matrixes are calculated and normalized. The results are the weights of indexes, that is, the influence degree of importance. The weight ranking of the criterion layer, the scheme layer to the target layer is respectively shown in Figure 2 (a) and (b). It can be

seen from Figure 2 (a) that the weight of accident prevention capability (U1) to the emergency capability of the whole urban rail transit is maximum and 0.555, the second one is the emergency response capability (U3) with 0.252, and the emergency preparedness capability and emergency recovery capability have the lowest influence on the overall emergency capability. In the Figure 2 (b), compared with other indicators, emergency response plan is the most important to the assessment of the whole emergency capacity, accounting for 22.84%. The following elements are emergency command, risk analysis and hidden danger detection, monitoring and early warning, network coordination and rescue mechanism, etc., indicating that the prevention before the accident is crucial to the whole emergency work. Once an accident occurs, in order to improve the ability of emergency rescue and disposal, and then minimize the loss, how to carry out emergency response in a timely and effective manner, reasonably command and coordinate the line network are the major tasks of emergency work.

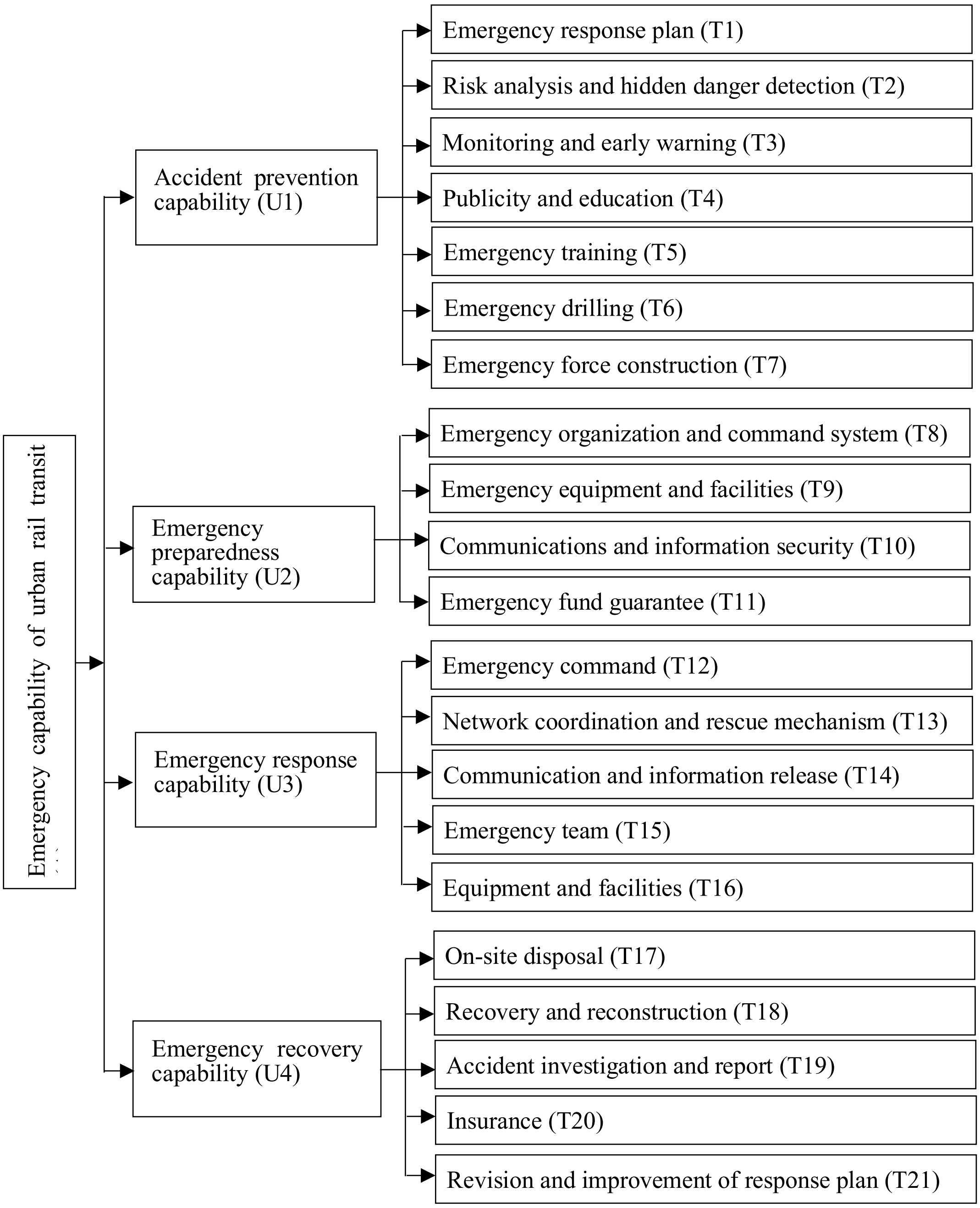


Figure 1. The AHP demonstration model for the emergency capability index system

At the same time, according to the judgment matrix, the weight ranking results of each scheme layer to the corresponding criterion layer can be obtained respectively, as clearly presented in Figure 3. From Figure 3, emergency response plan (the weight ratio of 41.2%), monitoring and early warning (the weight ratio of 17.7%)

and risk analysis and hidden danger detection (the weight ratio of 17.7%) have great impacts on accident prevention ability. For emergency preparedness capability, emergency equipment and facilities (the weight ratio of 50.9%) and emergency fund guarantee (the weight ratio of 28.4%) are more important. Moreover, the weight proportion of emergency command, network coordination and rescue mechanism on emergency response capacity is 46.8% and 32.0% respectively. However, the joint impact degree of on-site disposal, post-recovery and reconstruction on emergency recovery capacity reaches 75.3%, directly affecting the strength of emergency recovery capacity.

(4) In consistency test, the consistency index CI is generally within 0.1, which can be considered acceptable for the consistency of judgment matrix. The lower the CI value is, the higher the consistency degree of the judgment matrix is (J. Ding, 2009). In the AHP demonstrate model for the emergency capability index system of urban trail transit, the results indicate that the consistency ratio of emergency capacity A in urban rail transit is 0.0163. And the consistency of accident prevention capacity (U1), emergency preparedness capacity (U2), emergency response capacity (U3) and emergency recovery capacity (U4) account for the proportion of 0.0055, 0.0172, 0.0110 and 0.071, respectively. All the above consistency indicators demonstrate that the constructed judgment matrixes have the higher consistency degrees. As a result, the weight ranking results of indexes (i.e. importance degree of indexes) given by this AHP evaluation model have certain validity. Therefore, emergency management experts can grade the actual situation of network operation-based urban rail transit professionally based on the above results. Furthermore, the emergency capacity of rail transit in the actual network operation can be evaluated, which is scientific and applicable.

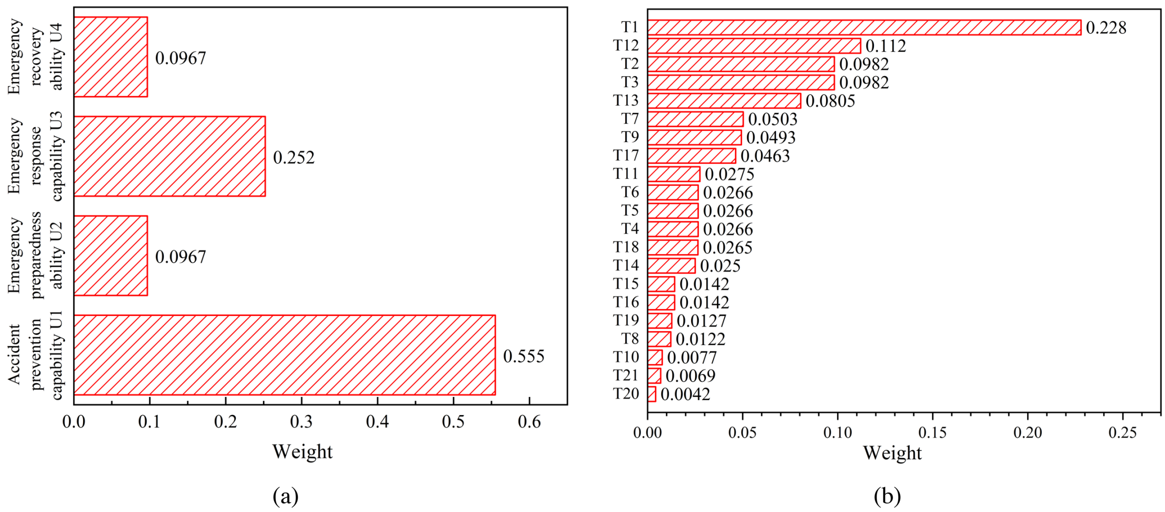
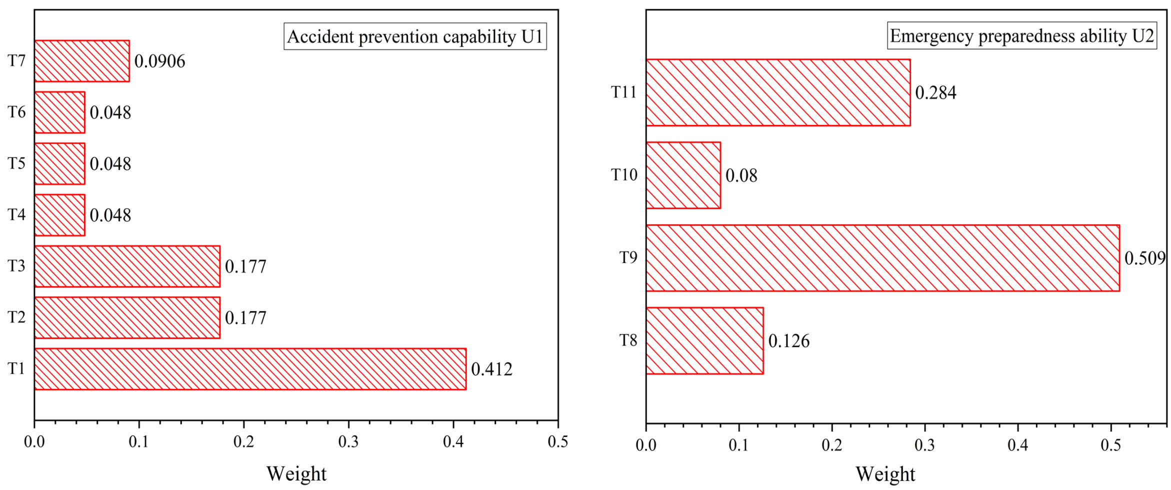
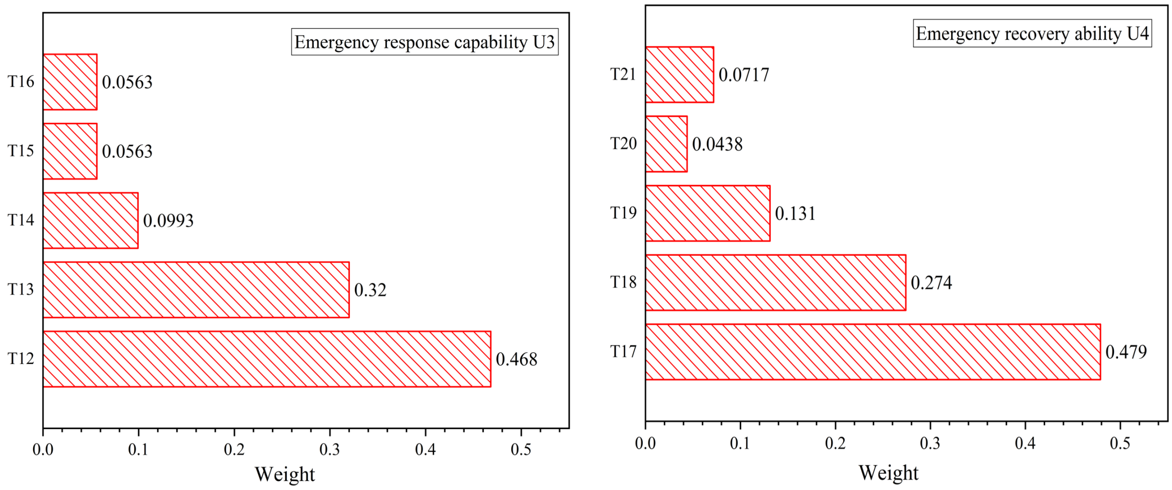


Figure 2. (a) The weight ranking of the criterion layer (U1~U4) to the target layer. (b) The weight ranking of the scheme l layer (T1~T21) to the target layer



(a) (b)



(c) (d)

Figure 3. (a) The weight ranking of the scheme layer (T1~T7) to the criterion layer U1. (b) The weight ranking of the scheme layer (T8~T11) to the criterion layer U2. (c) The weight ranking of the scheme layer (T12~T16) to the criterion layer U3. (d) The weight ranking of the scheme layer (T17~T21) to the criterion layer U4.

EMERGENCY CAPABILITY EVALUATION METHOD

Emergency capability index scoring method of network operation-based urban rail transit

Combined with the established emergency capability assessment index system, 10 experts are selected who are with emergency management experience in urban rail transit, like university professor, operation management personnel on field (such as station administrator on duty), metro engineer and project manager, etc. After understanding the background, content and scoring method of the questionnaire, they can grade160 four-level indicators item by item according to the scoring standard (as shown in Table 1). Validity test is implemented based on the scoring results of each expert X_i and all the valid score ratio is determined to be 100%. Meanwhile, in order to reduce the subjective difference in 160 fourth-level indicators scored by different experts, the scores of 160 fourth-level indicators were averaged step by step. Thus, we can get the scores of 55 third-level indicators, 21 second-level indicators and 4 first-level indicators successively.

Table 1. The scoring standard of emergency capability evaluation

Score	Degree of conformity
1	Inconformity
2	25% conformity
3	50% conformity
4	75% conformity
5	100% conformity

Emergency capability calculation method of network operation-based urban rail transit

By means of emergency capability evaluation modeling and AHP demonstration, the Wi ranking of index importance that evaluates network operation-based urban rail transit can be obtained. According to the obtained index weight (importance degree Wi and index score Xi, the comprehensive score Y (full score is 5) of network operation-based urban rail transit can be obtained with Eq. (1).

$$Y = \Sigma_{i=1}^{n} X_i W_i \tag{1}$$

Correlation analysis method of emergency capability evaluation indexes

Pearson correlation coefficient is used to judge the significance of the correlation among the different characteristics in the same indicator or the same level of indicators. The correlation coefficient γ is between -1 and 1. When γ is greater than 0, it's positively correlated. Otherwise, it's negatively correlated. If $|\gamma|$ (the absolute value of γ) is close to 1, the correlation is good. And the correlation is poor when $|\gamma|$ is close to zero. The calculating formula for the correlation coefficient is shown in Eq. (2). By combining the correlation coefficient γ and p value, we can carry out t test for the significance of the correlation results of each indicator.

$$\gamma = \frac{l_{xy}}{\sqrt{l_{xx} l_{yy}}} = \frac{\sum_{i=1}^{n} \frac{(X-\bar{X})(Y-\bar{Y})}{n-1}}{\sqrt{\sum_{i=1}^{n} (X-\bar{X})^2 / n-1} \sqrt{\sum_{i=1}^{n} (Y-\bar{Y})^2 / n-1}} \quad (2)$$

Based on the mean value and standard deviation of the low-level indexes, correlation analysis and significance test can be conducted to the high-level indexes by combining Pearson correlation coefficient and significance (double tail) coefficient (i.e., P value). Then, the influence factors of the weaker indexes can be acquired. At last, we can find out targeted measures to improve the weaker indexes of emergency capability in urban rail transit.

CASE STUDY AND DISCUSSIONS

Emergency management condition in Shenzhen Metro

According to the accidents types and the identification results from dangerous sources in the metro operation headquarters, the risks in metro operation mainly include emergent events in operation production and passenger service, natural disasters, public health events, social security events, fire and explosion events, personal injury events, et al. In accordance with the harm degree of events, influence range and controllability, emergency in network operation-based urban rail transit are divided into the general emergency (IV level), the large emergency (III level), the severe emergency (II level) and the extremely severe emergency (I level). Under the overall emergency response plan of the metro operation headquarters in this city, there are six types of special emergency plans, different on-site disposal plans and all kinds of emergency response guidelines. Among them, six types of special emergency plans are used to dispose the natural disasters, public health events, social security events (including terrorist attacks), fire and explosion emergencies, personal injuries and passenger transport incidents. Besides, various spot emergencies or system failures can be disposed with the on-site disposal plans. Furthermore, emergency response guidelines are responsible to provide the references for those emergencies happening at special times, places or posts.

Figure 4 graphically illustrates the emergency organization system of metro operation headquarters in Shenzhen. There is a commander in chief in the emergency leading group of operational headquarters in Shenzhen Metro. When an emergency occurs, on-site headquarters organize different emergency groups to conduct emergency rescue work. Among them, the comprehensive coordination group, passenger transport group, resource support group, treatment and recovery group, news and information group and logistics support group are mainly responsible for the field comprehensive coordination and command. Besides, emergency rescue group consists of passenger transport center rescue team, vehicle center rescue team, maintenance center rescue team, ticketing center rescue team and signal center rescue team. The technical expert group, emergency monitoring group and emergency rescue group are mainly responsible for technical rescue work. In the emergency work, the on-site command group and emergency rescue group mainly carry out resource deploying through the control center and all departments work hard together to deal with emergencies.

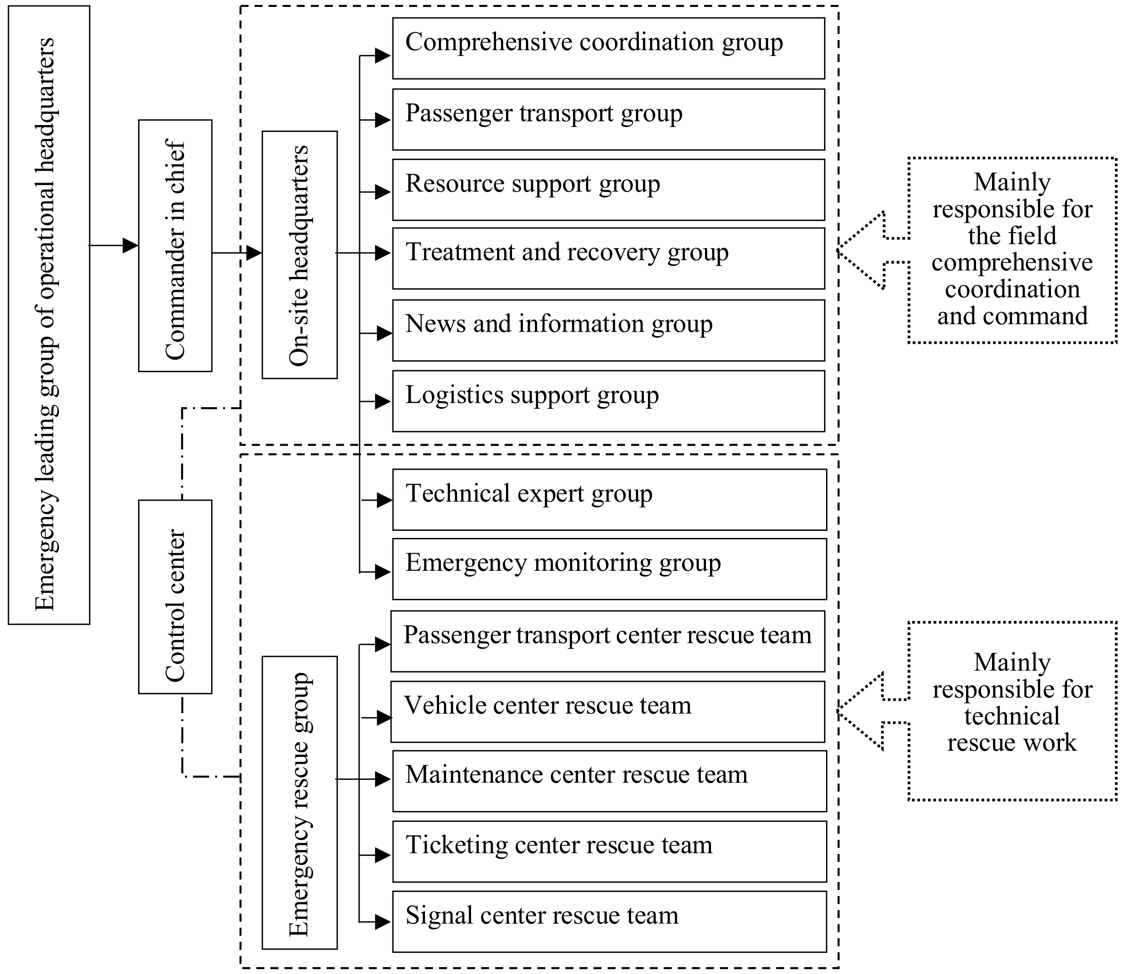


Figure 4. The emergency organization system of metro operation headquarters in Shenzhen

Evaluation results and analysis of emergency capability in Shenzhen Metro

Combined with emergency capability evaluation index system and the general situation of emergency management of network operation-based urban rail transit in Shenzhen, the above evaluation methods are used to evaluate emergency capability of network operation in Shenzhen Metro. In accordance with the scoring criteria in Table 1, the full score of 166 four-level indicators is 830. As a result, the total score of 10 experts ranges from 578 to 764 with an average total score of 690.4. That is, the average score of all indexes is 4.16 and the total score of six experts is above the average. As presented and visualized in Table 2 and Figure 5, the comprehensive score of emergency capability in network operation-based Shenzhen Metro can be calculated to be 4.362 (full score is 5) by Eq. (1) and Table 2, indicating that the overall emergency capacity of network operation-based metro in this city is above the average level and still needs to be improved. Also, the scores of the first-level index U1~U4 in Shenzhen Metro are respectively 4.320, 4.273, 4.266 and 4.385. Compared with accident prevention ability and emergency recovery ability, the average scores of the emergency preparedness ability and emergency response ability are slightly lower. On the other hand, the average scores of 21 second-level assessment indicators are all above 4.0, indicating that 75% of the actual situation is consistent. The emergency force construction (T7) under the accident prevention capacity (U1) and recovery and reconstruction (T18) under the emergency recovery capacity (U4) are slightly lower than others, with the average score of 4.100. Besides, the average score of emergency fund guarantee (T11) in emergency preparedness capacity (U2) is 4.183 and the one of equipment and facilities (T16) in emergency response capacity (U3) is 4.063. In short, there are still some deficiencies in the above aspects on the metro in this city. Therefore, it is necessary to focus on strengthening the construction of emergency force, emergency fund guarantee, the provision and maintenance of emergency rescue equipment and materials as well as the after-event recovery and reconstruction. More importantly, we need to clarify the specific requirements of disaster prevention and reduction.

Table 2. The weight and score of emergency capability evaluation indexes in Shenzhen metro

Index	The scheme layer	Weight W_i	Score X_i
T1	Emergency response plan	0.2284	4.528
T2	Risk analysis and hidden danger detection	0.0982	4.317
T3	Monitoring and early warning	0.0982	4.422
T4	Publicity and education	0.0266	4.250
T5	Emergency training	0.0266	4.283
T6	Emergency drilling	0.0266	4.342
T7	Emergency force construction	0.0503	4.100
T8	Emergency organization and command system	0.0122	4.100
T9	Emergency equipment and facilities	0.0493	4.194
T10	Communications and information security	0.0077	4.310
T11	Emergency fund guarantee	0.0275	4.183
T12	Emergency command	0.1178	4.475
T13	Network coordination and rescue mechanism	0.0805	4.303
T14	Communication and information release	0.0250	4.333
T15	Emergency team	0.0142	4.158
T16	Equipment and facilities	0.0142	4.063
T17	On-site disposal	0.0463	4.325
T18	Recovery and reconstruction	0.0265	4.100
T19	Accident investigation and report	0.0127	4.650
T20	Insurance	0.0042	4.450
T21	Revision and improvement of response plan	0.0069	4.400

Correlation analysis of emergency capability evaluation indexes in Shenzhen Metro

As clearly shown in Figure 6 (a), we can learn the correlation results with scatter fitting diagram and heat map between the first-level indexes U1~U4 of Shenzhen Metro. From that, the correlation among accident prevention ability, emergency preparedness ability and emergency response ability is more obvious, and the scatter fitting curve tends to be linear. Meanwhile, the redder in the heat map is, the higher the correlation coefficient is. From another perspective, in the emergency theory, pre-accident prevention emphasizes strengthening monitoring and early warning after the investigation of possible hidden dangers and risks, so as to prevent them from happening in the first place. Once an emergency occurs, targeted preparation and response can be made to effectively reduce the loss of the accident.

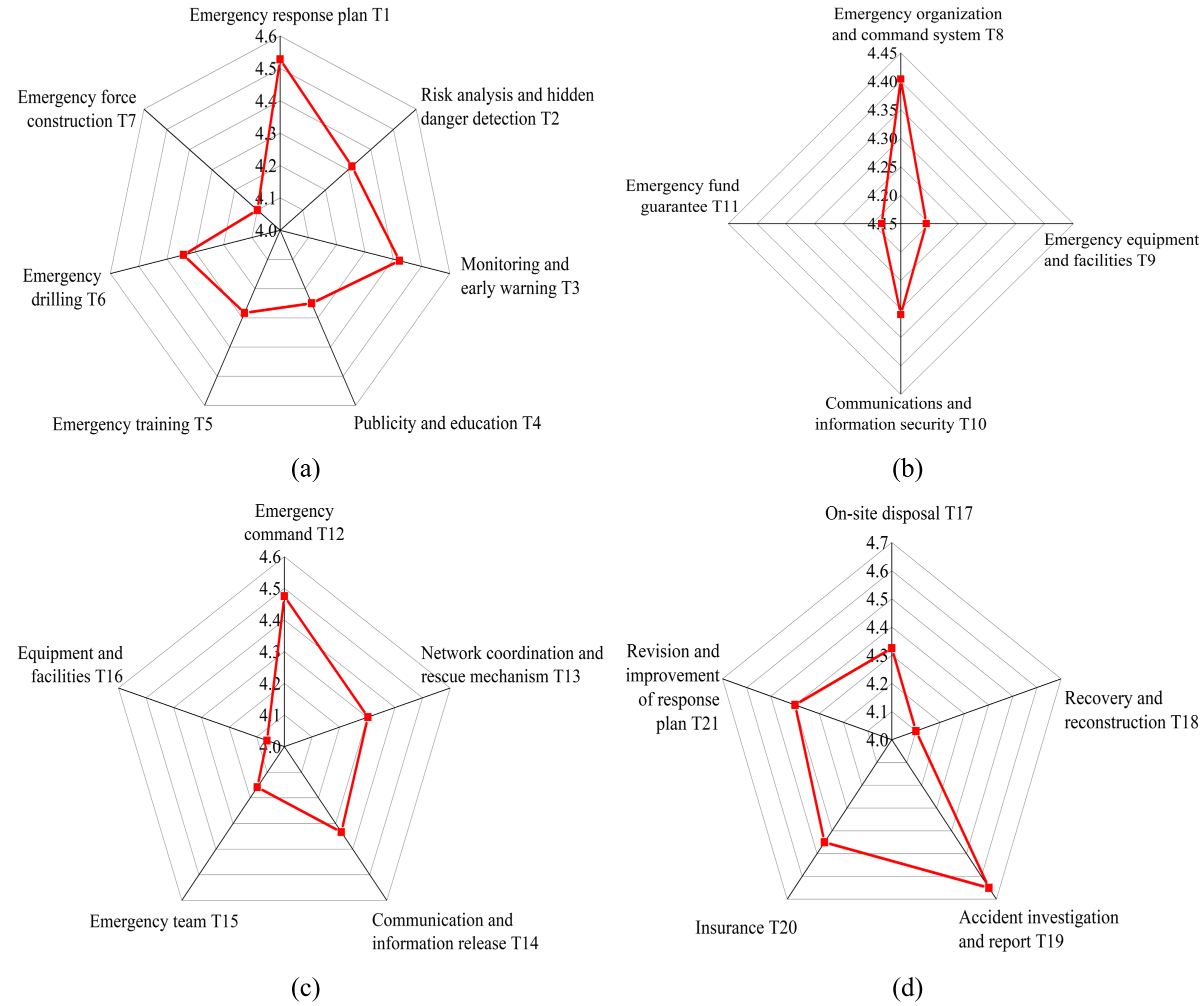
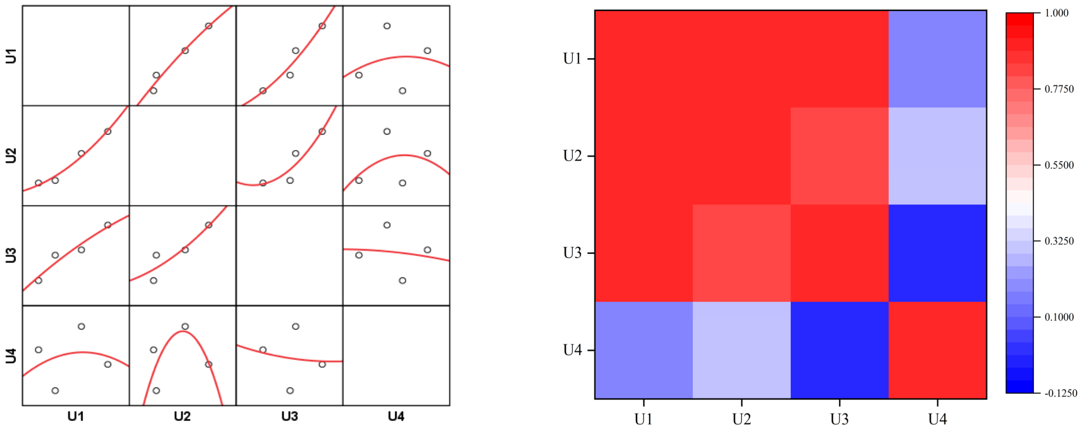


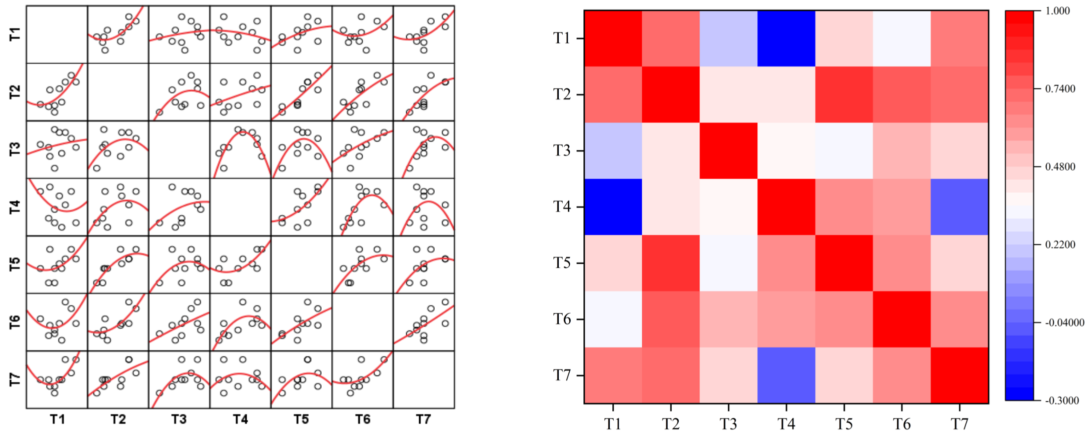
Figure 5. (a) The radar chart of T1~T7 scores under accident prevention capability (U1). (b) The radar chart of T8~T11 scores under emergency preparedness capability (U2). (c) The radar chart of T12~T16 scores under emergency response capability (U3). (d) The radar chart of T17~T21 scores under emergency recovery capability (U4).

Figure 6 (b)-(e) respectively depicts the correlation between the corresponding second-level indexes under U1~U4. Clearly, it can be demonstrated from Figure 6 (b) that, under accident prevention capacity (U1), the correlation among T1~T2 (emergency response plan-risk analysis and hidden danger detection), T1~T7 (emergency response plan-emergency force construction), T2~T5 (risk analysis and hidden danger detection-emergency training), T2~T6 (risk analysis and hidden danger detection-emergency drilling), T2~T7 (risk analysis and hidden danger detection-emergency force construction), T5~T6 (emergency training-emergency drilling) is more obvious.

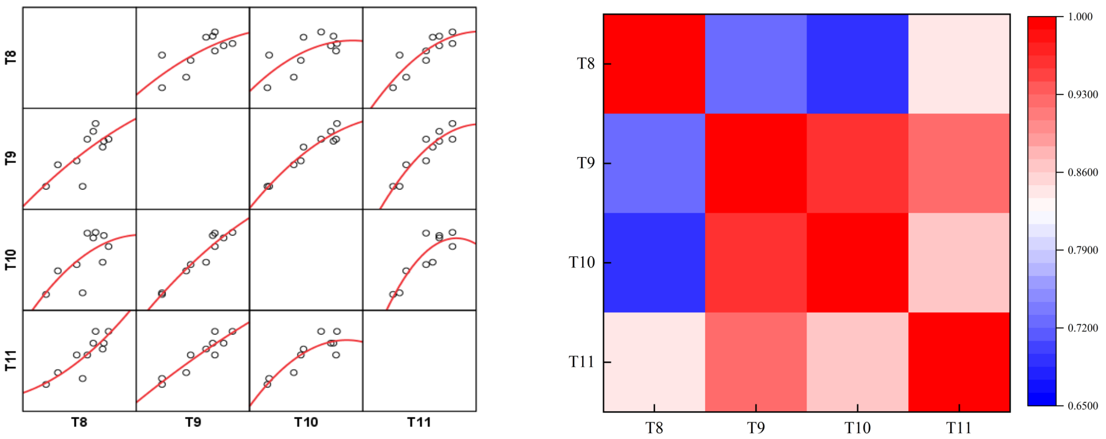
In addition to this, as visualized in Figure 6 (c), the scatter fitting diagrams among T8-T11 present pairwise linear, that is to say, under emergency preparedness capability (U2), the evident correlation happens pairwise among the indexes, including emergency organization and command system (T8), emergency equipment and facilities (T9), communications and information security (T10) and emergency fund guarantee (T11). Likewise, the second-level indexes T12~T16 under emergency response capacity (U3) are also significant pairwise correlations as shown in Figure 6 (d). Moreover, combined with Figure 6 (e), in emergency recovery work, the quality of on-site disposal (T17) directly determines the efficiency of recovery and reconstruction (T18), which afterwards determines how to do accident investigation (T19) well. Finally, the preliminary work indirectly affects the revision and improvement of response plan (T21).


U1
U2
U3
U4
1.000
0.7750
0.5500
0.3250
0.1000
-0.1250

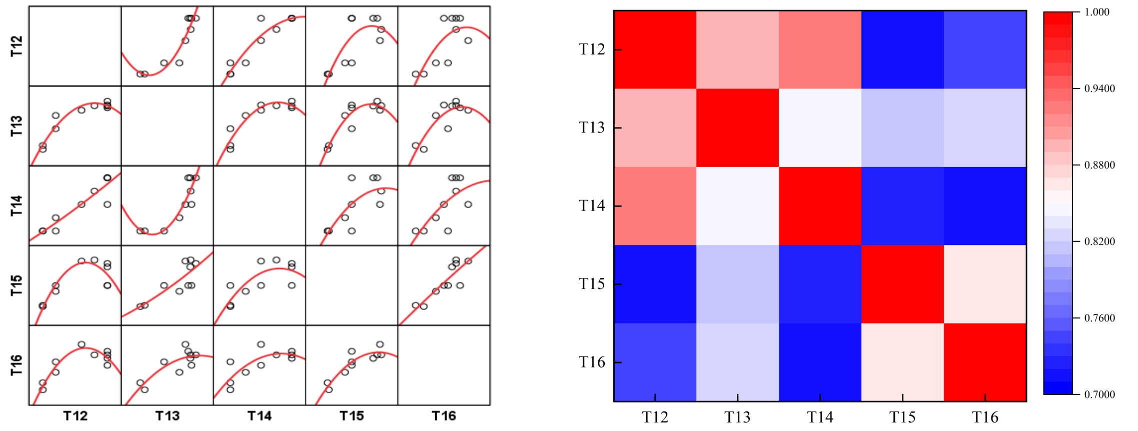
(a)


T1
T2
T3
T4
T5
T6
T7
1.000
0.7400
0.4800
0.2200
-0.04000
-0.3000

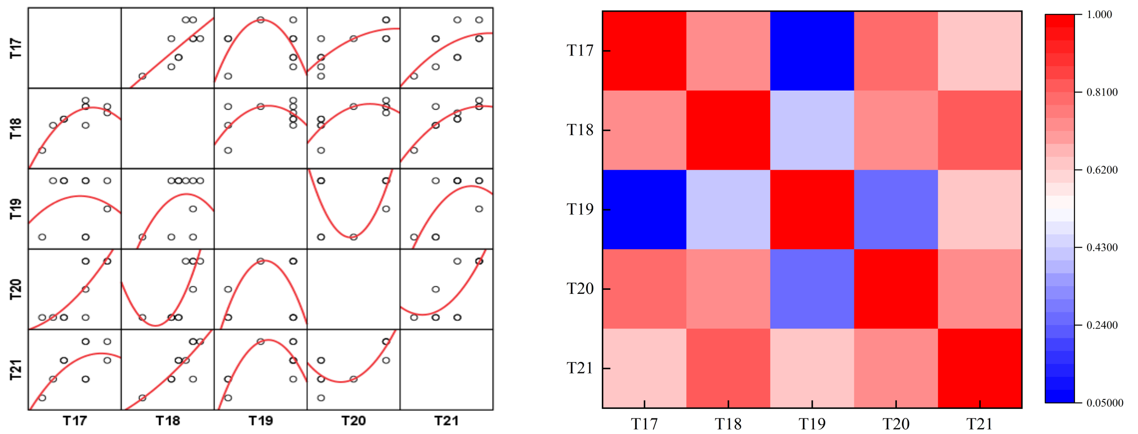
(b)


T8
T9
T10
T11
1.000
0.9300
0.8600
0.7900
0.7200
0.6500

(c)



(d)



(e)

Figure 6. (a) The scatter fitting diagram and heat map among U1~U4. (b) The scatter fitting diagram and heat map among T1~T7. (c) The scatter fitting diagram and heat map among T8-T11. (d) The scatter fitting diagram and heat map among T12~T16. (e) The scatter fitting diagram and heat map among T17~T21.

At last, some targeted measures can be proposed based on the correlation results of the above indicators and the weaker indicators obtained from the emergency capacity assessment. That is to say, the emergency management department in Shenzhen Metro should strengthen the prevention before the accident, conduct comprehensive investigation on possible hidden dangers and risks, strengthen monitoring and early warning and prevent them from happening in the future. At the same time, the emergency response plan should be improved as far as possible (Chen & Zhang, 2009; Girard et al., 2016) and make it digital and dynamics (Luo et al., 2016; Yu et al., 2017). Also, more public education and emergency drilling should be strengthened. Besides, we should ensure the timely availability of emergency materials, financial resources and manpower. What needs to be pointed out is that the coordination ability of the line network is particularly important in all emergency work, in order to ensure the timely transmission of emergency information. And the emergency response system (Abdul Majid et al., 2016; Zhong et al., 2010) needs to be also improved unceasingly.

CONCLUSIONS

In this work, an emergency capability evaluation model of network operation-based urban rail transit was proposed by building a four-level index system. Then, AHP method was used to demonstrate the effectiveness of the evaluation index system. At the same time, combined with the evaluation method, calculation method and correlation analysis method for emergency capability of network operation-based urban rail transit, the practical application was carried out in Shenzhen Metro. Several conclusions could be draw as follows.

(1) In emergency management work, the prevention capability before accident has a direct influence on the level of emergency preparedness and response ability. There exists a stronger correlation among emergency response

plan, risk analysis and hidden danger detection, emergency training, emergency drilling and emergency force construction. Besides, emergency manpower, material resources, financial resources and information are related to each other, which directly affecting the coordination ability of the line network in urban rail transit. At the same time, the quality of on-site disposal directly determines the efficiency of recovery and reconstruction, which afterwards determines how to do accident investigation well. Finally, the preliminary work indirectly affects the revision and improvement of emergency response plan.

(2) The following suggestions for network operation-based safety management department in Shenzhen Metro can be put forward. In the first place, the improvement of emergency preparedness and response capacity should be attached more importance. Some weaker indicators, such as emergency force construction, emergency funding guarantee, emergency equipment and facilities and emergency information, ought to be strengthened. What's more, a dual prevention mechanism for grading and controlling safety risks and identifying and controlling hidden dangers can be built and put into practice. Risk analysis and emergency response capability assessment are supposed to be carried out regularly in metro. Once again, the update and improvement of emergency response plan should be emphasized and make its digitization and dynamics realizable and feasible as soon as possible. Last but not least, the emergency coordination and linkage among various departments ought to be reinforced and the coordination and rescue mechanism of subway line network should be improved. As the same time, the timeliness of emergency communication and information release should be intensified. Only in this way, when faced with emergencies, we can start the three-level passenger flow control measures timely. That is, we can evacuate the passenger flow in metro station, divert passengers through other stations in metro line and allocate various resources flexibly in the network, so as to improve the network operation-based emergency capacity of Shenzhen Metro.

(3) The emergency capability evaluation method of network operation-based urban rail transit proposed in this study proved effective through theoretical analysis and practical application, including the construction of evaluation index system, AHP effectiveness demonstration, expert scoring method and comprehensive scoring calculation. The results indicate that it can better guide the emergency management work of network operation-based urban rail transit.

The method proposed in this paper has some adaptability and practical significance. However, the AHP method adopted in this paper is relatively simple, and there are some shortcomings in the expert scoring method. At the same time, data processing should be more rigorous and accurate. In the future research, we will look for other evaluation methods, like Delphi method, Fuzzy comprehensive evaluation method, TOPSIS method and so on, for comparative analysis to confirm the applicability of the methods. Besides, the shortcomings and improvements of each method will be analyzed and extensive research on practical application in urban rail transit will be conducted.

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