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An Urban Rail Transit Hazard Evaluation Methodology Based on Grey System Theory

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Abstract

Identification and evaluation of urban rail transit operating hazard can prevent accidents, and minimize damages caused by the accidents. In the process of urban rail transit operations, various factors may interact with each other that they function with. After analyzing the security factors of urban rail transit, the urban rail transit hazards are identified. According to the characteristics of urban rail transit systems, three hazard factors such as the potential risk, the existence conditions and trigger factors are chosen as the evaluation indicators. The approach of Grey Correlation Analysis is introduced and used for analyzing and determining the extent of the influences among the factors in a system and the degree of correlation among these factors. The grey incidence method is used for evaluating the hazards of urban rail transit dynamic operating systems and conducting quantitative analysis of risks in the operation process. By studying the actual operating situation of Tianjin metro, the risk points and the hazards of correlation degree are identified in this paper; and the relative high risk hazards are obtained. The calculated results of hazards show consistency between the model and the real situation and feasibility of the method. This research provides a new way to identify and evaluate the hazard of urban rail transit.

Keywords：urban rail transit; Hazard identification; grey system theory; grey correlation degree; Hazard evaluation

1. Introduction

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Urban rail transit plays an important role in relieving the urban traffic pressure. Though it brings convenience to residents, the security problem has been more and more pressing. Identification and evaluation of the hazards of urban rail traffic can guarantee the safe operations in urban rail transit, to some extent. It is not only the basic prevention of all kinds of accidents, but also the premise that the loss falls to the lowest.

Based on the field research, the author analyses both the accidents in the operation and the impact factors in the safety of urban rail transit. Through comparing the hazard identification and evaluation methods both in China and overseas, the urban rail transit hazards are collected and sorted in the paper. Finally, according to the characteristics of the urban rail traffic system, the urban rail hazards have been evaluated using the grey correlation degree analysis method; and furthermore, the Tianjin metro hazards are taken for example to demonstrate the feasibility of the method proposed in this paper.

2. Analysis on urban rail transit safety factors

The analysis of the urban rail transit safety is the foundation and basis of the identification and evaluation of the urban rail transit hazard. It is also the key part in developing the urban rail hazard evaluation model. The basic elements that impact the rail traffic safety are human, machine, environment and management. People are divided into persons in and out of the system. Machine risk factors mainly refer to an unsafe state of object which is divided into line, rail, equipment, vehicles. The factors in management are the weak responsibility of leaders in safety, the imperfect safety management institution, the imperfect safety education and training system, the unclear safety standard, the unscheduled implementation of the safety countermeasures, the unreasonable labor organization and so on. The environmental risk factors include internal environment and external environment; the external environment can be divided into the natural environment and social environment. The city rail transit operation safety factors are shown in Fig.1.

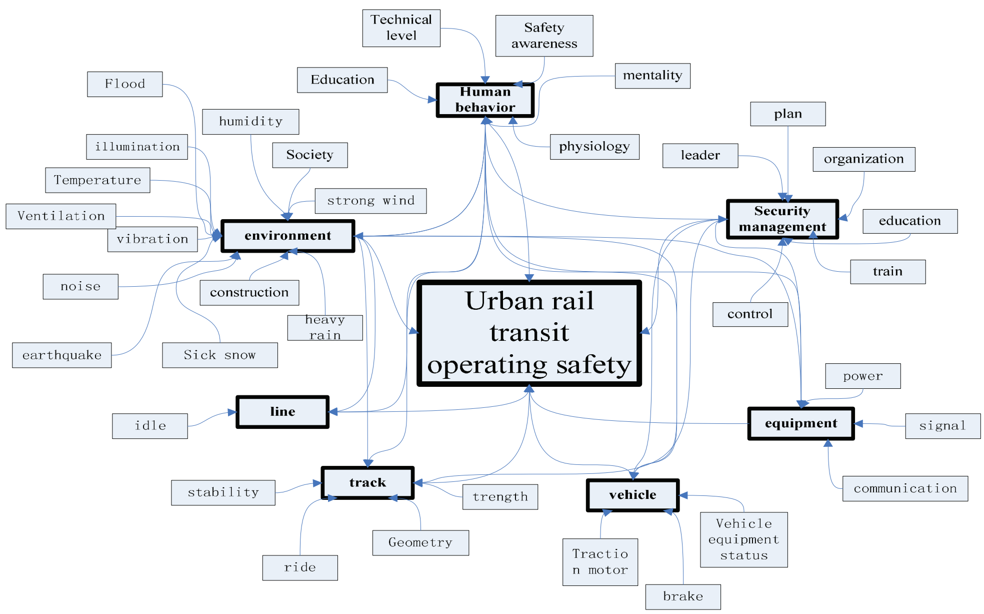

Fig.1. Urban rail transit operating safety factors

Through the analysis of the impact factors and the consideration of common accidents in the urban rail operation, the cause of the accident can be found out; and identification of hazards can be realized by combining the accident and safety factors.

3. Evaluation of urban rail transit hazard based on the grey system theory

The evaluation system of urban rail transit hazards is a gray system in which some part of information section is known, while the other part is unknown. The evaluation of hazards identification involves all aspects of urban rail operation and it is difficult to fully analyze and control, due to all kinds of factors which play a key role in reliability, security and economy. Gray correlation analysis method is based on the similar or different development trend of the degree among factors to measure the degree of association between factors. This method dose not required excessive amounts of sample, typical distribution or large amount of computation. In this paper, the gray correlation analysis method is used for evaluation of the hazards classification.

3.1. The evaluation indicator

Three composition elements of hazards have been chosen. Potential risk, existing conditions and triggering factors are used as risk assessment indicators, when evaluating the hazards using gray system correlation analysis method.

First the following parameters are given:

L–The possibility of accident or hazardous events(potential risk);

E–Frequency of exposure to hazardous environments(existing conditions);

C–The possible outcomes of accident or hazardous events (triggering factors).

For the identification of hazards i, take $X_i=\{x_i(1), x_i(2), x_i(3)\}=$ {potential risk *L*, existing conditions *E* and triggering factors *C*} as identification indicators. The values of indicators are shown in Table 1.

Table 1. The values of LEC

L value		E value		C value	
Score	The possibility of accident	Score	Frequency	Score	Outcomes
10	Entirely possible	10	Continuous exposure	100	A great many people dead or huge damage to property
6	Likely	6	Exposed every working hours per day	40	Many of people dead or major property damaged
3	Possible, but not often	3	Exposed once a week	15	One person dead or property damage greater
1	Small possibility, completely unexpected	2	Exposed once a month	7	Serious injury accidents
0.5	Very unlikely, conceivable	1	Exposed once a year	3	Major disability
0.1	Impossible	0.5	Rare	1	Striking minor accident

3.2. Data acquisition and sorting

The acquisitions of indicators' value come from the evaluation when assessors evaluate the object. As the LEC method has a strong subjective scoring, the choice of assessors has a great impact on the effectiveness of evaluation results. Therefore, when calculating the indicator parameters, this paper uses the methods by several different assessors including the management of Tianjin Metro, operators, designers and researchers. Each kind of assessors has a different weight, and in order to improve the reliability and validity of evaluation, weighted average is used to obtain the specific value of different indicators after scoring (Table 2).

Table 2. Weights table

Assessors	Management	Operators	Designers	Researchers
Weights	0.3	0.3	0.2	0.2

3.3. Evaluation steps

The basic idea of using gray correlation analysis for urban rail transit hazards evaluation is: First determine each indicator value of hazards for evaluation. Second form a reference sequence using the relative optimization principles and then finds the correlation between the sequences of which composed every indicator of hazards for evaluation and the reference sequence. Last compare the value of each correlation, and then obtain the evaluation results of the risk degree of each hazard.

Specific steps are as follows:

Step 1 Using minimum value method for data pre-processing.

$$X_i = \frac{x_i(k)}{x_{max}(k)} \tag{1}$$

Step 2 Determine the reference sequence X_0 and the compare sequence X_i. The reference sequence is formed by each optimal value of indicators.

Step 3 Calculate the absolute value of the difference between the reference sequence in each point and each sub-sequence $\Delta_i(k)$, also mean

$$\Delta_i(k) = |x_0(k) - x_i(k) \tag{2}$$

Step 4 Calculate the two level biggest differences and two level smallest differences.

First-level-biggest difference

$$\Delta_i(\max) = \max_k \Delta_i(k) \tag{3}$$

Second-level-biggest difference

$$\Delta_{\max} = \max_i \max_k \Delta_i(k) \tag{4}$$

First-level-smallest difference

$$\Delta_i(\min) = \min_k \Delta_i(k) \tag{5}$$

Second-level-smallest difference

$$\Delta_{\min} = \min_i \min_k \Delta_i(k) \tag{6}$$

Step 5 Calculate the correlation coefficients of each points between reference sequence and each sub-sequence. The calculate formula is as follows:

$$\varepsilon_i(k) = \frac{\Delta_{\min} + \rho \bullet \Delta_{\max}}{\Delta_i(k) + \rho \bullet \Delta_{\max}} \tag{7}$$

ρ is resolution factor， $\rho \in [0,1]$， usually take $\rho = 0.5$， also in this paper ρ takes 0.5.

Step 6 Calculate the correlation, calculate the average correlation coefficient.

Compare the correlation between the compared sequence X_i and the reference sequence X_0 as follow:

$$\gamma_i = \frac{1}{m}\sum_{k=1}^{m}\varepsilon_i(k) \tag{8}$$

Step 7 Sort the correlation.

4. Example application—Take Tianjin Metro for example

Based on the field research of Tianjin Metro, Reference to relevant national standards and reference to the results of hazards theoretical studies in both same industry and other industry, conclusions can be drawn, that the main existing risk points in Tianjin Metro are: Driving organization, passenger services, fire control, dispatch management, equipment management, operator safety, seasonal safety risks and other safety risk factors. In this paper, the evaluation for hazards based on the above risk points is studied. The table of indicator values for hazards evaluating is shown.

4.1. Indicator values of hazards

Table 3. Indicator values of hazards

NO.	Risk Point	Hazards	Weighted data values		
			L	E	C
1	Operator safety	Illegal use of fire	4.90	3.10	51.70
2	Passenger services	Throw cigarette butts	5.10	5.10	22.30
3	Passenger services	Smoking in no-smoking area	5.15	4.25	16.10
4	Passenger services	Deliberately arson	5.17	1.75	44.50
5	Passenger services	Personal mental disorders cannot self-control	3.92	1.90	11.60
6	Passenger services	Safety signs wear or lack	5.30	4.10	4.40
7	Passenger services	Do not security or not complete	3.75	2.15	10.60
8	Equipment management	Improper use of electrical equipment in station	5.30	4.10	40.30
9	Fire control	Not regular maintenance the fire-fighting equipment	3.50	2.10	15.70
10	Fire control	Fire and flammable materials(paper products, etc.) not cleared in time	3.30	2.20	20.00
11	Equipment management	Not regularly use of switches and sockets	2.50	2.00	13.90
12	Passenger services	Safety publicity inadequate or missing	2.50	1.50	8.40
13	Dispatch management	Send the wrong command scheduling	5.30	2.35	22.50
14	Dispatch management	Emergency (fire, derailment and other accidents) Emergency Command improper	5.20	1.20	35.00
15	Dispatch management	When train equipment failure, emergency command improper	5.20	1.60	25.00
16	Equipment management	Special operations illegal operations	4.00	1.20	33.70
17	Other	No well-developed security management and practices	1.90	1.00	5.60
18	Driving organization	Excessive stress, mood disorders	2.60	3.50	5.60
19	Operator safety	Operating personnel physical load gauge	3.20	3.70	3.20
20	Operator safety	Operate person abnormal state of health or sick to posts	3.00	4.10	4.00
21	Other	No plan or exercise of the prevention and control development	2.45	0.80	7.60
22	Other	Inadequate or missing safety training	4.55	0.70	6.00
23	Driving organization	Driver inattention	6.70	6.80	25.10
24	Driving organization	Drivers speeding violation	6.10	5.80	62.50
25	Driving organization	Driver aggressive violations	6.10	4.35	37.70
26	Driving organization	Drivers regression illegal	6.10	4.05	36.10
27	Driving organization	Driver fatigue	5.90	6.00	12.60
28	Driving organization	Brake too fast	5.63	1.35	13.90
29	Passenger services	Passenger grilled and kick the door, the door does not shut down normal	4.13	1.55	1.60

Table 3. Indicator values of hazards (continued)

NO.	Risk Point	Hazards	Weighted data values		
			L	E	C
30	Passenger services	Passengers fall into the clearance or the vehicles' site	1.33	2.15	3.80
31	Passenger services	Unauthorized access to the prohibit equipment and facilities	1.33	0.65	4.00
32	Driving organization	Inexperienced drivers	2.45	2.25	51.70
33	Driving organization	Unrecognized occlusive conditions for sending and receiving train	1.67	2.40	54.70
34	Dispatch management	Stop or delivery electricity error	1.03	0.65	8.80
35	Dispatch management	Scheduling order delivery errors	1.50	2.15	40.30
36	Fire control	Subway station, train investigation and management of security risks are not in place	2.50	3.10	17.70
37	Fire control	Abnormal condition of the subway supervision and administration not in place	3.60	5.60	9.80
38	Operator safety	Illegal use of explosive materials	0.90	2.25	57.50
39	Passenger services	Passenger crowded	9.20	7.40	7.00
40	Passenger services	Passenger congestion, divert large passenger does not timely	8.00	5.80	32.90
41	Passenger services	Running, chasing	5.30	5.80	5.20
42	Passenger services	Officers stir, spread false news, causing panic	1.85	2.25	31.90
43	Passenger services	Assault and fighting	2.60	3.00	5.20
44	Dispatch management	Not correctly handle the emergency ventilation	2.10	3.90	13.10
45	Fire control	Occupancy, blocking indoors evacuation routes	3.90	4.80	32.90
46	Fire control	Fire people on duty drunk, absence or sleep	1.35	1.05	16.70
47	Fire control	Damage to water supply system for fire	2.20	2.70	8.00
48	Passenger services	Vagrants and beggars begging behavior of the entertainer	5.30	6.20	1.00
49	Operator safety	Did not recover after the switch manually to move away	1.35	2.15	58.30
50	Operator safety	Staff swap sleeper illegal	2.80	1.20	58.90
51	Other	Foreign body placed in orbit	0.38	0.50	58.90
52	Other	Human deliberate destruction of infrastructure along the track	2.33	0.95	88.00
53	Other	Human poisoning	0.63	0.95	81.40
54	Operator safety	Without protection into the generation, storage place for toxic and hazardous substances place	1.03	0.60	6.20
55	Construction management	Illegal construction	2.53	2.50	18.50
56	Passenger services	Passengers step into the station and drive by the train with flammable, explosive and other dangerous items	3.00	5.60	43.10
57	Passenger services	Passengers play with fire at station or in the train	1.30	4.00	38.10
58	Operator safety	Using equipment comes to spark	3.90	4.20	7.00
59	Operator safety	Not removal static electricity before safety operation	2.85	1.53	7.40
60	Equipment management	Electrical equipment room smoke appear	0.65	0.65	9.20
61	Fire control	Fire alarm system failure	2.90	2.30	5.60
62	Fire control	Fire service system failure	1.50	2.30	10.60
63	Fire control	Smoke control system failure	1.50	2.30	4.00
64	Fire control	Fire Alarm Failure	1.50	2.30	11.80
65	Fire control	Flammable, explosive materials sealed adverse	1.60	2.15	14.20
66	Fire control	Flammable, explosive materials inadequate protection	1.50	2.15	14.20
67	Fire control	Flammable, explosive materials is not enough protection	1.50	2.15	21.70
68	Equipment management	Defects in communications equipment	2.10	2.70	37.70
69	Equipment management	Defect signal facilities	4.20	2.70	45.60
70	Fire control	Range fire pipe rupture	1.40	3.80	33.10
71	Fire control	Emergency lighting failure	3.40	3.00	25.00
72	Fire control	Various types of fire equipment and facilities signage, nameplates off, lost	4.40	1.70	13.00
73	Fire control	Lack of fire-fighting equipment, damage, loss	4.40	1.80	20.50
74	Equipment management	Overrun service equipment	5.10	2.55	40.70
75	Equipment management	Traveling component failure	5.20	4.00	43.10
76	Equipment management	Brake equipment failure	4.20	4.00	38.10

Table 3. Indicator values of hazards (continued)

NO.	Risk Point	Hazards	Weighted data values		
			L	E	C
77	Equipment management	Traction-free flow	4.20	4.00	17.70
92	Equipment management	Gate failure	4.70	7.20	1.00
93	Equipment management	Evacuation signs (light) masking, damage, pointing to the incorrect	4.25	3.15	12.70
94	Fire control	Safe exit locking or plug	5.90	4.80	12.60
95	Fire control	A strong impact	3.25	0.95	28.90
96	Other	Heating pipe explosion	3.25	0.50	38.10
97	Other	Slope soil, materials, buildings, construction, load collapse	1.90	2.15	50.60
98	Other	The collapse of underground space rock	0.75	0.65	68.60
99	Other	Unstable roof	0.65	0.65	63.60
100	Construction management	Construction quality is not high	0.53	0.65	76.00
101	Passenger services	Toxic gas leak	0.38	0.50	58.00
102	Passenger services	Poor ventilation	4.00	6.40	8.40
103	Equipment management	Environmental control (HVAC smoke control system) failure	3.80	4.20	20.90
104	Other	Metro design flaws	2.93	0.50	76.00
105	Equipment management	The equipment for generation, storage, accumulation of toxic and hazardous substances are damage	1.03	2.15	58.00
106	Equipment management	The failure of power generation's drive equipment	2.00	3.55	34.70
107	Other	Lifted heavy objects fall off	2.50	2.15	12.60
108	Equipment management	Power supply unit is damaged or leakage	3.80	4.20	33.10
109	Passenger services	Unprotected close to the electrified body, high step voltage region	1.50	4.20	11.00
110	Passenger services	Touch the stove and other heat source equipment	0.53	0.75	9.20
111	Passenger services	Touching hot objects	0.53	0.75	9.80
112	Operator safety	Inadequate supplies of emergency rescue facilities	4.70	0.85	25.10
113	Seasonal safety risks	Bad weather	7.40	6.30	40.30

4.2. Tianjin Metro hazards evaluation algorithm based on gray correlations

Based on the above table, the hazards evaluation parameter sequences of Tianjin Metro are:

$$X_1 = \{x_1(1), x_1(2), x_1(3)\} = \{4.90, 3.10, 51.70\} \quad X_{21} = \{x_2(1), x_2(2), x_2(3)\} = \{5.10, 5.10, 22.30\}$$

Other hazards parameter sequence follows the same mode.

In three evaluate indicators, the optimal value is the smallest, which means that the reference sequence is made of each indicator's optimal value, so the hazards evaluation reference sequence of Tianjin Metro is : $X_0 = \{x_0(1), x_0(2), x_0(3)\} = \{0.38, 0.50, 1.00\}$.

Based on the step for evaluation in section 2.3, the sort of risk degree for each hazards are obtained, which is shown in Table 4.

4.3. Evaluation conclusion

Based on the above calculation here comes to the conclusion:

Among the hazards for evaluation, the most dangerous item is drivers' driving at high speed which can easily lead to collision, derailment and other traffic accidents. Compared with the accidents which has already occurred, it can be seen that the evaluation conclusion is basically in consistent with the actual situation.

The number of the hazards which have the correlation below 0.5 are: 88, 89, 25, 23, 82, 83, 40, 113, 24, which are: Flammable materials inside the station equipment, Electrical equipment wear and tear, leakage, Driver aggressive violations, Driver inattention, ATO automatic control system failure, ATS automatic protection system failure, Passenger congestion, divert large passenger does not timely, Bad weather, Drivers speeding violation. The results show that the drivers play a vital role in city rail safety, and also should be bring attention on training and education of drivers and passengers.

Table 4. The sort table for risk degree of hazards

NO.	Degree value	NO.	Degree value	NO.	Degree value	NO.	Degree value	NO.	Degree value
110	0.9154	66	0.7529	9	0.6788	68	0.6308	27	0.5469
60	0.9152	65	0.7483	44	0.6754	14	0.6287	2	0.5350
54	0.9139	61	0.7394	35	0.6723	33	0.6282	45	0.5334
111	0.9120	47	0.7334	42	0.6723	57	0.6275	84	0.5333
31	0.9078	53	0.7298	81	0.6703	48	0.6238	76	0.5314
34	0.8945	43	0.7260	38	0.6696	92	0.6220	39	0.5218
17	0.8446	67	0.7230	104	0.6693	106	0.6154	56	0.5201
21	0.8266	11	0.7209	80	0.6658	71	0.6131	91	0.5170
30	0.8186	107	0.7202	105	0.6656	37	0.6116	1	0.5159
101	0.8110	86	0.7196	36	0.6631	32	0.6085	8	0.5032
51	0.8097	96	0.7176	10	0.6626	13	0.6046	75	0.5016
46	0.8095	18	0.7086	16	0.6557	41	0.6002	26	0.5013
63	0.8027	95	0.7043	73	0.6530	102	0.5981	88	0.4956
22	0.7889	109	0.7042	49	0.6483	77	0.5924	89	0.4940
12	0.7740	19	0.7009	58	0.6466	103	0.5847	25	0.4908
99	0.7715	5	0.6965	52	0.6412	4	0.5775	23	0.4764
29	0.7705	7	0.6943	50	0.6404	90	0.5764	82	0.4691
59	0.7667	20	0.6913	78	0.6398	3	0.5747	83	0.4691
100	0.7653	112	0.6897	70	0.6393	94	0.5670	40	0.4530
62	0.7640	72	0.6892	6	0.6373	79	0.5615	113	0.4351
98	0.7590	28	0.6823	93	0.6361	69	0.5539	24	0.4218
64	0.7579	87	0.6796	97	0.6353	74	0.5515		
85	0.7548	55	0.6796	15	0.6329	108	0.5478		

5. Conclusions

The conclusion is that the calculated results are basically in line with the actual situation, which verifies that the theory using the grey theory for hazard evaluation is feasible to some extent. Through combining the cause of the accident and security elements, this paper identifies the hazards, and also figures out three indicators value for the evaluation of hazards. Using grey correlation analysis method for risk evaluation of Tianjin Metro hazards, the correlation of each hazard can be calculated and the high or low risk degree among each hazard can be further obtained. More importantly, some pre-selected ranges of representative hazards have been researched, and the hazards which cannot be quantified still need in-depth studies.

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