Reach on Fault Tree Analysis of Train Derailment in Urban Rail Transit

Wang Ming-yan（汪明艳）
College of Management
Shanghai University of Engineering Science
Shanghai 201620
China
&
Antai College of Economics and Management
Shanghai Jiaotong University
Shanghai 200240
China

WANG Hong（汪泓）
Antai College of economics and management
Shanghai Jiaotong University
Shanghai 200240
China

LIU Zhi-gang（刘志钢）
College of Urban Rail Transit
Shanghai University Of Engineering Science
Shanghai 201620
China

Abstract

The train derailment is one of the major accidents in rail transit safety system. The reach uses collision accident of rail transit train in Tokyo and Shanghai as the case. Firstly, it present fishbone diagram to qualitatively analysis main factors in derailment. Then it set up a derailment accident tree model with the qualitative and quantitative analysis of. The results show that illegal operations and unfamiliar operation are the most dangerous causes in train derailment event. Meanwhile, pre-construction design of site also has important impact on security of the track derailment. Finally, combined with the present situation of Shanghai urban rail traffic safety management, prevent the risk management of derailment accidents prevention countermeasures are put forward.
Keywords: fault tree analysis; fishbone diagram; urban rail transit; derailment accident

Introduction

Urban rail transit operation safety involves factors with people, vehicles and train operation signal power supply system, natural environment, social environment and management. Dai baoqian[1] summarize the subway major accidents mainly for the following seven categories through anaylizing 63 typical subway accidents death toll, the frequency statistics analysis at home and abroad in 1903-2004: subway fire accident, arson or terrorist attack, the train derailment accident, train crash, crowded stampede asphyxiation and poisoning accidents. Korea rail road research Institute[2]（2006）divided accident into five types: train collision accident, the train derailment accident, train fire accident casualties, level crossing accidents and railway accident through the train accident scene statistical analysis,

Train derailment accident frequency is not the highest in rail transit train accident, but still can lead to personnel casualties. On December 22, 2009, Shanghai rail transit line 1 power failures occur; causing two trains collided in later. Due to the accident, it leads to line 1 shut down about 4 hours, about 500000 residents travel.

Foreign rail transit operation management attaches great importance to train operation safety, pay attention to risk management and standardized development; it also makes track traffic emergency management research more scientific, standardized and efficient. At present the safety management of urban rail transit system specification are mainly composed of the European Union (European Union) standard, the content including each stage of planning and design, construction, operation, safety risk management[3,4].The train derailment accident early main research object is railway transportation system. Scholars of the United States, Europe, Russia and Japan, South Korea and Chinese research on railway system of derailment accidents from early track field test of derailment accident analysis to the development based on relevant technology such as computer technology, mechanical, image study, simulation shows that the operation of the train accident, thus visually observed train accident risk accident process with computer simulation research [5,6].

In recent years, domestic scholars have conducted the study on urban rail transit operation accidents. Xue Liang Liu Xiaoling [7] from the perspective of system engineering use the method of accident tree analysis to analyze the derailment accident research in urban rail transit. They concluded that urban rail transit derailment accident probability is small, the conclusion of the prevention and control is difficult. Li Yongsheng [8] illustrates the application of fault tree analysis technology in railway vehicle through analyzing actual situation of railway vehicle,

According to the theory of accident causation by Heinrich, behind the seemingly accidental incident is the inevitable rule. To draw a lesson from the accident, to avoid the similar accident from happening again, this is the important way of train operation safety implementation under control. Therefore, this article analyses the main cause of rail transit operation accidents caused factors with analysis of Tokyo Hibiya lines and the "12.22" of Shanghai rail transit train derailment accident collision accident as an example. Analyzing the main cause of rail transit operation accidents caused factors from the social environment, natural environment of operating system, engineering structure, railway equipment, equipment, and consider the human factor in the accident and train the influence of the coupling effect in derailment accidents. Through the qualitative and quantitative analysis of derailment accidents with fishbone diagram and fault tree, analyze the basic events of derailment accidents and the influence of each event of derailment accidents. Combined with the present situation of Shanghai metro operation management, targeted preventive measures and suggestions are put forward.

1. Case Analysis of Urban Rail Train Derailment Accident

1.1**Train crash analysis of Hibiya Tokyo**

At around 9 March 8, 2000, at Naka-Meguro Station in Hibiya Tokyo, running in the line of A line section 8 car bogie derailed, collided with running on the B line section 5 and section 6 B80lT trains. The accident killed five people and injuring more than 60 major accidents.

The accident investigation committee analyzed the derailment accident and put forward the main causes of as follows:

(1) Static wheel load is unbalanced

Due to the damage, derailment of vehicle can not measure the static wheel load. But according to the result of measuring the same models and manufacturing records, it indicates that the derailed wheel has great imbalance. So this factor is considered to be the main cause of the derailment.

(2) coefficient of friction between the wheel/rail vehicles

Due to the number of train vehicles increasing, it leads to rail temperature rise. The friction coefficient increases and the transverse pressure increases. So the accident occurs,

(3) Performance of curve bogie

The spring stiffness of vehicle is bigger when the beginning of derailment, through the curve, the horizontal pressure increases. At the same time because of the change in the line of planar linear round lightening ratio is bigger, so it leads to derailment.

1.2 Analysis of "12.22" Shanghai Rail Transit Train Collision Accident

On December 22, 2009, at Shanxi south road of Shanghai, rail transit line 1 to people's square interval suddenly happened power supply net accident.

Management department launched the emergency plan, the use of improper way turn back, but due to system error signal transmit train speed code, cause the turn-back section, two trains side collision accident caused a large number of residents travel affected, and widespread social concern is caused. After the accident, the accident investigation team analyzed the direct reason is due to the design defects, accident cause send the wrong instruction signal system, the lack of train braking distance, make side collision between down train and turn-back train, eventually lead to the accident.

Through the above two typical train derailment conflict can be found that the cause of incident in addition to defect and engineering structure with the device itself quality problem, man-made wrong operation or lack of responsibility will cause further influence on equipment failure.

2. Train Derailment Accident Analysis with Fishbone Diagram

2.1 Fishbone Diagram

Fishbone Diagram (Cause & Effect/Fishbone Diagram)can analyze the main factors and secondary factors of system. It seriously investigates the cause of the accident analysis system, and distinguishes the causal relationship between the various factors. In figure, the "results" means not safety, accident or disaster."Main factors" is the main factor to decide the result; "Medium", "small" is to guide "main factors" factors. The trunk and branches respectively the relationship between the cause and effect. The development of event is marked with arrow.

2.2Derailment accident fishbone diagram

According to the derailment accidents common causative factor and combining with the actual equipment of Shanghai rail transit, the main bone is the urban rail transit train derailment. Secondary bone is aggressive signal, engineering structure damage, natural disaster. The small bones in aggressive signal are a single event trigger and joint events trigger. The small bone in engineering structure damage is tunnel structure damage and line structure damage. According to the above method of urban rail transit train derailment with fishbone diagram, as shown in figure 1.

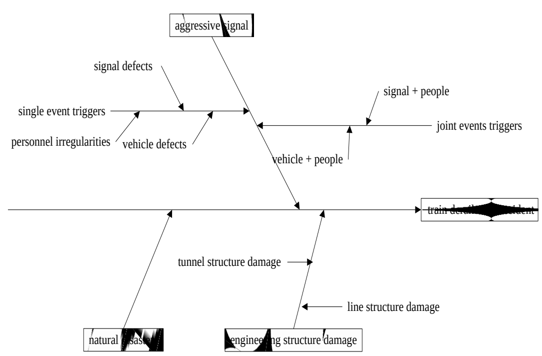

Fig. 1 Fishbone Diagram of Train Derailment Accident

3. Research on the Train Derailment with Fault Tree Model

3.1Analysis of Train Derailment with Fault Tree Model

On the basis of the analysis fishbone diagram in derailment accidents, train derailment accident is the top vents of fault tree, namely the object to be analysis. Major events related to the top event are mainly: aggressive signal, natural disasters and engineering structure damage.

Single event trigger of aggressive signal, namely, equipment failures and malicious irregularities, in such events as long as an event occur alone can lead to the occurrence of aggressive signal directly.

Joint event trigger of aggressive signal, namely the signal or the vehicle failure and human error occur at the same time, the events leading to failure. Such accident generally divided into signal failure and human error command and vehicle failure and human error operation.

Major natural disasters such as earthquake, flood, typhoon, its frequency is not high, so in the fault tree they are the basic event of natural disasters.

Engineering structure damage may cause the train derailed, conflict and subversion, mainly due to tunnel damaged or line structure damage. The line structure damage is mainly includes the objective environment and the use of improper maintenance.

The fault tree of train derailment accident is shown in figure 2.

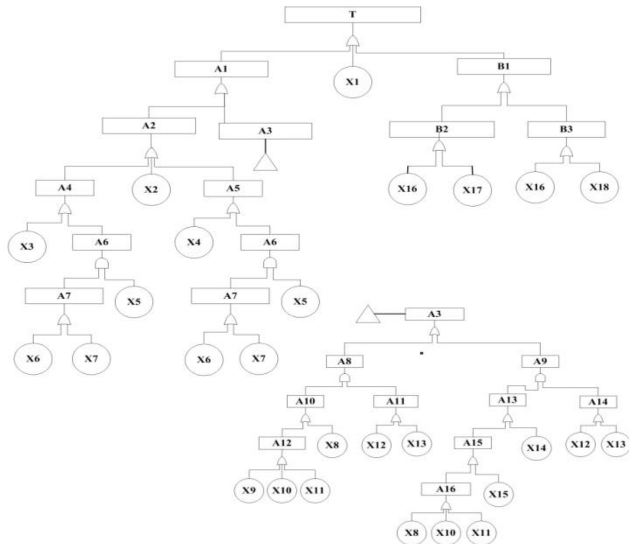

Fig. 2: Fault Tree of Rail Derailment Accident

From shown in figure 2, the 18 basic events of the urban rail transit train derailment accident is shown in table 1, the middle events is shown in table 2.

Table 1 Basic Events of Derailment Accident

No	Basic event	No	Basic event
X1	natural disasters	X10	maintenance staff negligence
X2	personnel malicious irregularities	X11	dereliction of duty maintenance
X3	signal design flaws	X12	irregularities
X4	vehicle design flaws	X13	unfamiliar operation
X5	install check negligence	X14	no ATP protection train driving mode
X6	installation personnel negligence	X15	operation failure
X7	installation manual defect	X16	objective environment
X8	signal failure	X17	engineering design flaws
X9	maintenance manual defect	X18	improper maintenance

Table 2: Middle Events of Derailment Accident

No	Basic event	No	Basic event
A1	aggressive signal	A11	scheduling controllers
A2	single event trigger	A12	signal maintenance errors
A3	joint events trigger	A13	vehicle
A4	signal defects	A14	operator (driver)
A5	vehicle defects	A15	vehicle failure
A6	installation error	A16	vehicle maintenance error
A7	installation personnel negligence	B1	engineering structure damage
A8	signal + person	B2	tunnel（bridge）structure damage
A9	vehicle + person	B3	line structure damage
A10	signal failure		

These factors may lead to accidents independently or in combination with each other, so the system can be dangerous to cause enough attention. At the same time, by the fault tree it can directly see the top event and cause the accident has logical relationship the between middle events and the initial reason.

3.2 Analysis of the Fault Tree

3.2.1 Qualitative Analysis of Fault Tree

By using Boolean algebra algorithm, minimum cut sets:

$$\begin{aligned} T &= A1 + X1 + B1 \\ &= (A2 + A3) + X1 + (B2 + B3) \\ &= [A2 + (A8 + A9)] + X1 + [(X16 + X17) + (X16 + 18)] \end{aligned} \quad (1)$$

From the above calculation can get 21 K1 ~ K21 of minimum cut sets is as follows:

$$\begin{array}{ll} K1 = \{X1\} & K11 = \{X10, X12\} \\ K2 = \{X2\} & K12 = \{X10, X13\} \\ K3 = \{X3\} & K13 = \{X11, X12\} \\ K4 = \{X4\} & K14 = \{X11, X13\} \\ K5 = \{X5, X6\} & K15 = \{X14, X12\} \\ K6 = \{X5, X7\} & K16 = \{X14, X13\} \\ K7 = \{X8, X12\} & K17 = \{X15, X12\} \\ K8 = \{X8, X13\} & K18 = \{X15, X13\} \\ K9 = \{X9, X12\} & K19 = \{X16\} \\ K10 = \{X9, X13\} & K20 = \{X17\} \\ & K21 = \{X18\} \end{array}$$

Calculation of 21 minimum cut set may lead to the top event. According to the basic events of minimal cut set contains less, may cause the top event occurrence: X1, X2, X3, X4, X16, X17, X18 can directly lead to train derailed conflict and subversion. They are relatively dangerous basic event, so operators need to take the necessary measures to control them.

Next, 12 of 20 minimum cut setcut contain X12 and X13, their frequency is higher. So it should pay attention to event of X12，X13.

Calculate the path set: $$\begin{aligned} T' &= A1' \bullet X1' \bullet B1' \\ &= A2' \bullet A3' \bullet X1' \bullet B2' \bullet B3' \end{aligned}$$

From the above calculation can get 4 minimum path sets W1,W2,W3,W4 are as follows:

$$\begin{aligned} W1 &= \{X1', X2', X3', X4', X6', X7', X8', X9', X10', X11', X14', X15', X16', X17', X18'\} \\ W2 &= \{X1', X2', X3', X4', X6', X7', X12', X13', X16', X17', X18'\} \\ W3 &= \{X1', X2', X3', X4', X5', X8', X9', X10', X11', X14', X15', X16', X17', X18'\} \\ W4 &= \{X1', X2', X3', X4', X5', X12', X13', X16', X17', X18'\} \end{aligned}$$

From the concept of path set and the calculation result shows that there are W1, W2, W3, W4 the four schemes can guarantee not derailed, conflict, subversion. But each scheme of W1 ~ W4 contained more basic events. Only to ensure that these basic events did not happen, it may guarantee the safety of system.

3.2.2 Quantitative Analysis of Fault Tree

(1) important degree of the structure

According to the minimum cut sets, the of structure important degree conflict, train derailed, subversion is as follows:

$$I_1 = I_2 = I_3 = I_4 = I_{16} = I_{17} = I_{18} > I_{12} = I_{13} > I_{15} = I_8 = I_9 = I_{10} = I_{11} = I_{14} = I_{15} > I_{16} = I_7$$

(2) important degree of the probability

$$I_g(i) = \frac{\partial P(T)}{\partial q_i} \quad (\text{ i=1,2,3,…, n}) \quad （2）$$

In formula: P (T) is the top event probability.q_i is basic probability of Xi.

Importance sequence of probability is as follows:

$$\begin{aligned} & I_g(1) = I_g(2) = I_g(3) = I_g(4) = I_g(16) = I_g(17) = I_g(18) > I_g(12) = I_g(13) > I_g(8) = I_g(9) \\ & = I_g(10) = I_g(11) = I_g(14) = I_g(15) > I_g(5) > I_g(6) = I_g(7) \end{aligned}$$

Through the importance degree of probability analysis of each basic event, if reduce the probability of each basic event, the probability of top event will reduce accordingly.

Through the above analysis, we can find the design problems such as location, personnel operation is very important, as long as reduce the likelihood of occurrence, it can greatly improve the security of the top event.

(3) critical importance

$$I_g^c(i)=\frac{q_i}{P(T)}\bullet I_g(i) \quad (3)$$

In the formula:

$I_g^c(i)$ is the the critical importance coefficient of i basic events.

$I_g(i)$ is the the probability importance coefficient of i basic events.

$P(T)$ is the top event probability.

q_i is occurring probability of basic events.

Therefore, the critical importance analysis as follows:

$$I_g^c(12)=I_g^c(13)>I_g^c(18)>I_g^c(10)=I_g^c(11)=I_g^c(14)>I_g^c(5)>I_g^c(6)=I_g^c(16)=I_g^c(17)$$
$$=I_g^c(3)=I_g^c(4)>I_g^c(9)>I_g^c(8)=I_g^c(15)>I_g^c(1)=I_g^c(2)>I_g^c(7)$$

Through the above analysis, we can know that irregularities and person who is not good at operation is the most sensitive of the basic events, they are the most dangerous in the basic event.

Then, incorrect use and maintenance, maintenance staff negligence, improper maintenance check dereliction of duty and so on are also personnel reason. Through the critical analysis, we can also find that no ATP protection of train driving mode has to a significant impact to cause the train derailment events.

3.3 Improve the Mechanism of Train Derailment Emergency Response

(1) Function mechanism

Based on analysis of the train derailment basic events by fault tree, we can find that the design defects and personnel operations are two main aspects. Through making functional mechanism, it not only can quickly find out the cause of the accident and determine the responsibility of the accident, but also can properly repair and disposal process.

For example, accidents due to design flaws, operators can clear responsibility fault if it is derived from the signal, the vehicle or project, as soon as possible operators can take corresponding measures. Managers can also trace the accident from which department, thus through education or punishment in eliminating hazards in the future.

Urban rail transit is a complex system; any negligence could lead to serious consequences. Therefore, the establishment of the function mechanism and the standardization of the work content will have a positive role on after the accident disposal.

(2) Daily prevention mechanism

According to the above calculating critical analysis of important degree of train derailment event, irregularities caused by unfamiliar personnel operation are the important factor of the incident.

Therefore, daily prevention mechanism for employees to develop the necessary specifications. Such as attention switch frozen in winter, tunnel water in summer, daily strengthen rail detection, and after the incident to strengthen education study and training and other kinds of problems.

4. Conclusion

Through the analysis of the Japanese and Shanghai rail transit train collision accident, fishbone diagram and fault tree method is used to analyze the qualitative analysis of the cause of Shanghai rail transit accident and the basic events. By using the quantitative analysis to determine the weak link of derailment accidents and the cause of vehicle derailment sensitive and dangerous cause factors.

Aiming at the possible risk, together with the present situation of Shanghai rail transit operation management, we put forward the targeted mechanism of emergency preparedness. Such as establishing emergency function mechanism and management measures, daily education training implementation before the accident or eliminating hidden dangers, so as to the purpose of preventing accidents and reduce accident loss.

References

Dai Baoqian. Identification of dangerous and harmful factors analysis of metro operation system [J]. China safety science journal, 2005 (10) : 80-83.

Korea rail road research Institute,"Establishment of Risk Analysis and Assessment System for Railway Accidents and Hazards"[R],Annual report of an Integrated R&D Plan for the Railway Safety,Ministry of Construction and Transportation,Korea,2006.

European Committee for Electrotechnical Standardization(CENELEC), Railway The Specification and Deriionstration of Reliability, vailability, Maintainability Applications and Safety (RAMS) Part 1:Basic quirements and generic process[R], EN50126-1,1999.

International ElectrotechnicalCommission(IEC)[R],Standard Electrical/Electronic/Programmable Electronic Safety-Related Systems,for Functional Safety of IEC61508, 2005.

Sitarz M, Chruzik K, Mańka I. Integrated safety management system of the railway transport[J]. Journal of KONBIN, 2010, 14(1): 223-234.

Nicholas Wilson.Assessment of safety against derailment using simulations and vehicle acceptance tests: a worldwide comparison of state-of-the-art assessment methods[J].Vehicle System Dynaics - VEH SYST DYN.2011,49(7):1113-1157

Xue Liang,Liu Xiaoling. The Application of FTA Method in Analysis of Urban Rail Transit[J].Technology & Economy in Areas of Communications,2011, 13 (3) : 98-101.

Li Yongsheng,etc.Application of Fault Tree Analysis Technology in the Rolling Stocks[J]. Journal of Urban Mass Transit. 2012.10:122-124.