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Cause analysis and countermeasures of locomotive runaway accident based on fault tree analysis method

XIA Meiqiong, LI Xiangyang*, JIANG Fuliang, WANG Shuyun
School of Environment Protection and Safety Engineering, University of South China, Hengyang 421001, Hunan, China

Abstract

August 12, 2011, a locomotive runaway has happened on the local railway named Xihe railway of a certain city, it led to a death of an older person and serious damage of four automobiles. The causing factors of the runaway accident have been comprehensively analyzed, which respectively include four aspects: human, machine, environment and management. By using the principle of fault tree analysis (FTA), the locomotive runaway accident fault tree has been set up after the accident investigation. Based on the corresponding formula, the authors have calculated the structure importance coefficient of each basic event. By analyzing the causation of the events, the minimal path sets have been obtained, and the order of the structure importance has also been obtained. Through the above analysis, the reasons of this accident have been analyzed systematically and the corresponding safety countermeasures have been proposed. The thesis can provide reference for prevention of similar accidents.

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Keywords: locomotive runaway accident; fault tree analysis; cause analysis; safety countermeasure.

1. Introduction

Runaway of vehicle means that vehicles skidding without aim, otherwise the measures used for preventing runaway lose efficacy, and accident finally happens because of the vehicle losing control [1]. Runaway accident, with considerable harmfulness, is one of the driving accidents due to inertia, which accounts for a great proportion in traffic accidents. There are few studies about runaway accidents home and abroad, even in some certain industry some abstract analyses have been made by most of them. This article use logical tree (fault tree analysis) to discuss this accident from consequence to reason. The direct reasons of accident have been described, and the potential reasons have been analyzed, and at last the best way to prevent the happening of top event has been put forward [2]. Basing on the example about locomotive runaway accident of Xihe railway, the fault tree about accident of runaway has been structured, the reasons of runaway with a systemic way have been analyzed, and put forward the safety countermeasures.

2. Brief introduction of runaway accident in Xihe railway

2.1. Basic information of Xihe railway

Xihe railway is the only local railway line in this city. Its largest gradient is 1.6 percent. The facilities and locomotive are old and obsolete. Without repair for a long time the railway line is in bad condition. There are no basic equipments at the

* Corresponding author. Tel.: +86-13786480277.
E-mail address: lcczclxy@126.com

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road junction, such as railings, signals and traffic signs. Besides, the possibility of runaway accidents is increasing year by year.

2.2. Process and site survey of accident

On August 13, 2011, when two train compartments drawn by No. 0166 locomotive of Xihe railway was being unloaded in the national grain storage, the locomotive driver put handbrake on holding position, and he got off the locomotive and smoked without permission. About four minutes later, the locomotive was found, in uncontrolled circumstances at a high-speed to runaway 1.5 km away from the station toward Dayuantou intersection. Fig.1 is the current situation of Xihe railroad; Fig.2 is the unattended railway crossing.

As a result, this general safety accident caused a passer-by dead and four motor vehicles impaired by the force of the locomotive’s collision at the intersection of Dayuantou and Hongxiang Road. Fig.3 described the route of this accident exactly.

3. Structure and Analysis of Fault Tree on Accident

There have been lots of factors accounting for the runaway accident of Xihe railway. Based on the consequence of site survey, the thesis focuses on searching for basic reason associated to the occurrence of top event. Additionally, some corresponding safety countermeasures have been proposed according to the structure importance of elementary events.

3.1. Structure of fault tree

Based on theoretical analysis of typical runaway accidents and site survey on the certain accident in Xihe railway, the thesis structures a fault tree (Fig.4) of runaway accident in compliance with some specific logical relations [3]. Meanings of each basic event can be seen in Table 1. Due to existing more quantities of or gates, the minimal path sets play an irreplaceable role in analyzing the fault tree of this accident. Success tree can be concluded by means of the fault tree. And the structure function is listed as follows:
\[
T' = X'_1 + A'_2 + X'_3 + X'_4,
\]
\[
= X'_1 + A'_2 + A'_3 + X'_{12} + X'_{13},
\]
\[
= X'_1 + A'_2 + A'_3 + X'_{12} + X'_{13} + X'_{10} + X'_{11} + X'_{12} + X'_{13},
\]
\[
= X'_1 + A'_2 * X'_3 * X'_4 + A'_6 * X'_5 + A'_6 * X'_5 * X'_9 * X'_{10} + X'_{11} + X'_{12} + X'_{13},
\]
\[
= X'_1 + X'_2 * X'_3 * X'_4 + X'_5 * X'_6 * X'_7 * X'_8 * X'_9 + X'_{10} + X'_{11} + X'_{12} + X'_{13},
\]

The orders of basic events’ structure importance are listed as follows:

\[
I(X_i) = I(X_{ii}) = I(X_{i1}) = I(X_{i2}) > I(X_{i3}) > I(X_{i4}) = I(X_{i5}) = I(X_{i6}) = I(X_{i7}) = I(X_{i8}) = I(X_{i9}) = I(X_{i10})
\]

![Fault tree of locomotive runaway accident](image)

Table 1. Basic events of locomotive runaway accident in Xihe railway

| Sign | Intermediate or basic event | Sign | Intermediate or basic event |
|------|-----------------------------|------|-----------------------------|
| $X_1$ | Cars and people streaming at the traffic crossing | $X_{11}$ | 1.6 percent gradient of the line |
| $X_2$ | Without rigid implement of equipment’s maintenance system | $X_{12}$ | Without base facilities at the crossing such as railings or indicators |
| $X_3$ | Supervisory authorities’ slack regulation | $X_{13}$ | Colliding with people or cars |
| $X_4$ | Technical defects of the turnout | $A_1$ | Runaway away of vehicle |
| $X_5$ | Failures to find the locomotive runaway timely | $A_2$ | Breakdown of turnout |
| $X_6$ | Lack of the inadequate equipments to prevent runaway | $A_3$ | Workers’ negligence |
| $X_7$ | Without a strong sense of responsibility | $A_4$ | Handbrake’s malfunction |
| $X_8$ | Inadequate training | $A_5$ | Bad maintenance of turnout |
| $X_9$ | Workers’ operation errors | $A_6$ | Taking improper measures after finding runaway accident |
| $X_{10}$ | Technical defects of handbrake | $A_7$ | Bad maintenance of handbrake |
|     |                             | $A_8$ | Lack of emergency’ experience |
3.2. Analysis of fault tree

By solving the minimal path set, it is not difficult to obtain the result that basic events $X_1$, $X_{11}$, $X_{12}$ and $X_{13}$ come to be the largest structure importance. Through the comprehension on the definition of minimal path set, it can come to the conclusion that if any of the minimal path sets has not happened, a runaway accident wouldn’t take place [4–5]. Therefore, only if the four crucial events are controlled will we prevent runaway accident. Whereas, gradient of the line is 1.6 percent ($X_{11}$) as well as cars and people streaming at this traffic crossing which are hard to change as some historical reasons. So we conclude that setting security devices and signal facilities are the most efficient countermeasures to prevent runaway accident, such as rail, signal light etc. Furthermore, $X_2$, $X_3$ and $X_4$ are to be the second structure importance. Thus, immediate attention is necessary for strengthening supervision, guaranteeing strict implementation of equipment maintenance system and overcoming the technical difficulties in turnout and brake technology.

4. Preventive measures on runaway accident

Depending on the analysis result and the character of minimal path set, and combining with the order of events’ structure importance, it is advisable to take the following measures.

4.1. Management measures

(1) Improving the mechanisms of supervision over relevant departments; implementing the duties on supervision strictly in accordance with the requirement of related regulations.
(2) Responsibility system for safety in production and management system needs to be further sturdy; Acting on safety rules of operation strictly; strengthening personnel vigilance.
(3) Continuous work safety promotion/education and safety training to personnel; improving personnel capabilities on distinguishing and resolving potential safety hazards; Enhancing their obligation consciousness and safeguard consciousness. Operating workers’ pre-job education on preventing runaway of locomotive and lessons on runaway accident as well as memorizing of regulations on Railway Technical management and station operation detailed rules would be a significant guarantee [6–7].

4.2. Technical measures

(1) Reinforcing the way of scientific development as to ensure safety. For example, improving automatic anti-sliding performance within easy-slide lines based on the adoption of advanced technologies and new facilities. Exactly, with the installation of scotch blocks in easy-slide lines, making it sure that locomotives posses double insurance when braking [8].
(2) Installing safety facilities, such as rails and signal lights, ameliorating communication and signal facilities. Locomotives, lines and intersections must be regularly serviced and kept in good repair in order to maintain excellent technical or service performance, to ensure a safe systematical operation.
(3) Applying rewards and punishment system. Those personal who carry out rules and regulations strictly could receive appropriate economic rewards in order to improve their passion for work, subsequently ensuring safety production.

5. Conclusions

The Fault Tree of runaway accident describes the basic events clearly. After a careful analysis, it appears that $X_1$, $X_{11}$, $X_{12}$, $X_{13}$ are of the largest structure importance. Then key links which result in system fault could be easily found out. Under this foundation, to remove hidden hazards and guarantee safe operation of Xihe railway, we need concentrate on inspection of these basic events. We should build dynamic system of preventing runaway: check by professionals→ put forward the measures to prevent runaway→ revise the relevant standards→ practical test→ check. Continuous recurrence and improvement should be requisite, only if the four aspects-human, machine, environment and management get mutually fused to the greatest degree could the railway lines optimize on safety.

By referring to interrelated literatures and by summarizing that runaway accident accounts for a large proportion of local railways and that there are various factors as reasons for runaway. However, part of this article has a certain limitations. Therefore, to avoid runaway accidents, corresponding safety countermeasures must be taken and associated with the exact actual situation by removing hidden hazards.
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