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HAZARD ANALYSIS AND RISK ASSESSMENT MODEL FOR THE RAILWAY SYSTEMS

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Key words: *Railway System, Hazardous Event, Risk Assessment, Accident Scenario.*
Abstract: *The paper shows the developing process of the railway system risk assessment models and the indication of their applicability to the Slovakian railways. The risk assessment models are based on the accident scenarios. Various hazardous events, which have the potential to lead directly to casualties, were defined by gathering various accident reports and having workshops with railway safety experts. The developed models will be used to assess the accident risk of the Slovak railway system. The frequency of each hazardous event was evaluated from the historical accident data and structured expert judgments by using the FTA technique, ETA technique and other safety techniques were applied.*

INTRODUCTION

The Slovakian railway area has undergone rapid changes such as structural reform and interoperability conditions in common railway system in European Union. In order to manage increased hazard factors, Directive 2004/49/EC on safety on the railways focused on the risk-based safety management. According to this directive, railway operators and infrastructure managers should get the government's approval for their safety management plans, which are prepared by the risk assessment results. In this reason, since 2005, Slovakian railway and research institutions started to develop the common hazard analysis and risk assessment models for the railway systems in Slovakia. This paper introduces the developing process of these models and the results of possibilities of their application to the Slovak railway.

The develop risk assessment models based on the accident scenarios. The accident scenarios were set up by gathering various accident reports and having several workshops with railway safety experts. According to the accident classification of "Railway Accident Report Regulation", the scenarios were divided into the five main areas. In each area, various hazardous events, which have the potential to lead directly to casualties, were defined. Then, for each hazardous event, the railway accident appearance scenarios and railway accident progress scenarios were developed. The railway accident appearance scenarios provide the base of accident causal analysis models for the frequency evaluation.

The railway accident progress scenarios provide the base of accident consequence analysis models for the severity evaluation and developed models will be applied to assessing the accident risk of the Slovakian railway. The frequency of each hazardous event was evaluated from the historical accident data and structured expert judgments by using the FTA technique. In addition, to assess the severity of each hazardous event, the ETA technique and other safety techniques were applied. Finally, the risks for passengers, staff, and member of public can be estimated as the number of equivalent fatalities.

1. BACKGROUND OF DEVELOPED RISK ASSESSMENT PROCEDURE

To develop the Slovak railway risk assessment models, various risk management procedures were reviewed such as ISO/IEC Guide 51 [1] and the risk management procedure applied to this study was developed. It is similar to the common approach risk management [2] suggested in EU.

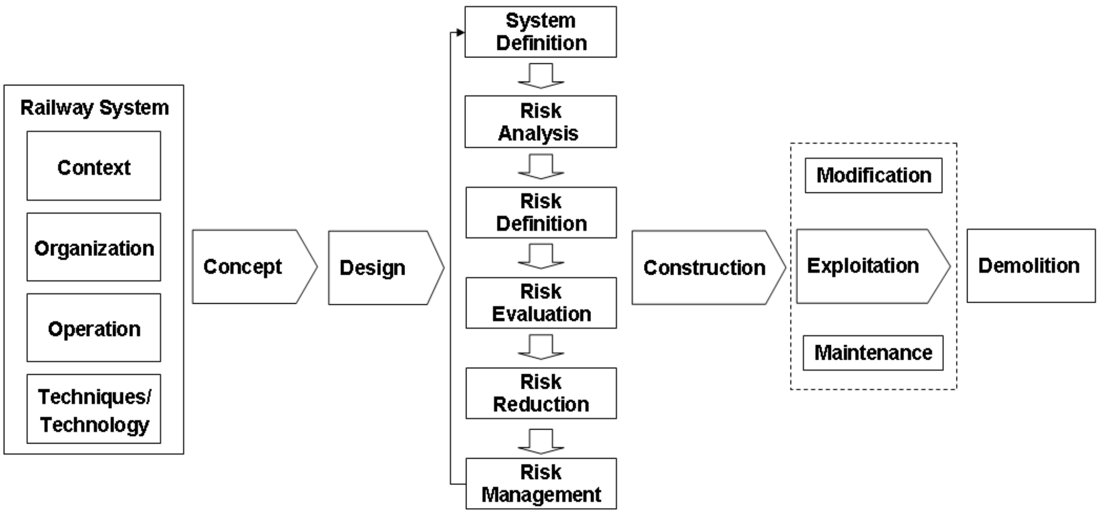


Fig.1. Common Approach Risk Management [3]

Fig.1 show this procedure. The schemes show three dimensions: a railway system, the life cycle of this system and the process of risk management. Although unwanted events occur during the construction and exploitation phase, it is most helpful to take into account the whole lifecycle of a railway. Therefore, the risk management must start from the system design phase considering both the normal mode and the degrade mode for this system [3]. Then, the results of the risk management in the system design phase are transmitted to the involved organization of the construction phase and the similar approach is applied to the next stage as loop. The National Railway Risk Management System Architecture will be utilized for the construction of a nation-wide railway risk management program and the execution of safety regulations. Fig.2 presents the hazard analysis and risk assessment procedure.

The hazard identification of railway accidents had been carried out by gathering various accident reports and information and having several workshops with railway safety experts. The railway accident scenarios are consisted of railway accident appearance scenarios and railway accident progress scenarios. Both scenario groups are divided by initiating hazardous events. Here, a hazardous event means one that has the potential to lead directly to death or injury. The railway accident appearance scenarios refer to the occurrence processes of accidents before hazardous events [4]. These scenarios provide the base of FTA model structure for frequency evaluation on railway accidents. The railway accident progress scenarios mean the progress processes of accidents after hazardous events and they provide the base of ETA model for severity evaluation on railway accidents.

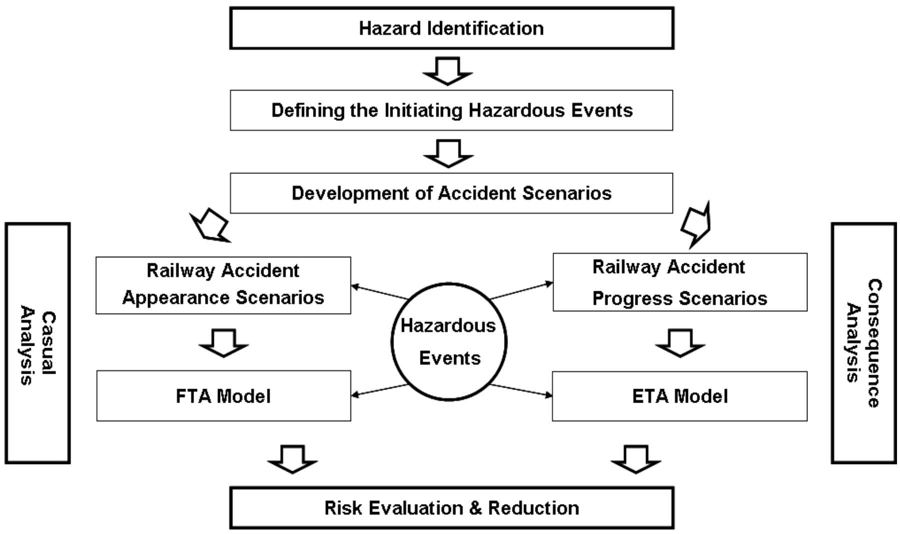


Fig.2. Railway Risk Assessment Procedure

2. HAZARD IDENTIFICATION USING RAILWAY ACCIDENT SCENARIOS

To perform hazard identification, it is required to understand what consist of hazards, how to recognize it and how to define it. That is, the understandings of accident appearance and progress sequences are needed. The following procedure was used in hazard identification stage and the railway accident scenarios were developed to define these sequences:

1. System definition, boundary: setting up objective of hazard identification and its boundary.
2. Identifying hazardous events, hazards and barriers: Including the definition of measures which stops the increases of accident.
3. Developing accident appearance scenarios: defining relationships among hazardous events, hazards and barriers.
4. Developing accident progress scenarios: considering the relevant key influential factors.
5. Accident scenario management: drawing up hazard log.

For the national wide risk assessment model, the definitions of a generic railway system, technical specifications and system operation environment are essential and should be considered. According to the railway accident classification in Slovakia, the scenarios were divided into the five main areas of accidents as follows: 1. train collision, 2. train derailment, 3. train fire, 4. level crossing, 5. railway (traffic/safety) casualty accident. Tab. 1 contains the example of the hazardous events.

Tab.1. Example of the Hazardous Events

Category	Hazardous Events	
Train Collision	misrouted train	mistaking in dealing points, point faults, mistaking in dealing blockage, interlocking system faults
	faults in driving	signal/direction violation, signal fault, mistaking in dealing braking system, braking system fault, over speeding
	abnormal train	train separation, car rolling, train stop, backward moving
	obstacles on the track	external obstacles, parts from train/freight falling, infrastructure collapsing/obstruction
Level Crossing Accident	being trapped in level crossing	engine stop; deviation of pathway; gangway blocking; lack of propulsion/braking; violation entry;;limit interference,; breaking or detour and more
	crossing during warning signal breaking through	
	or detour the barrier	

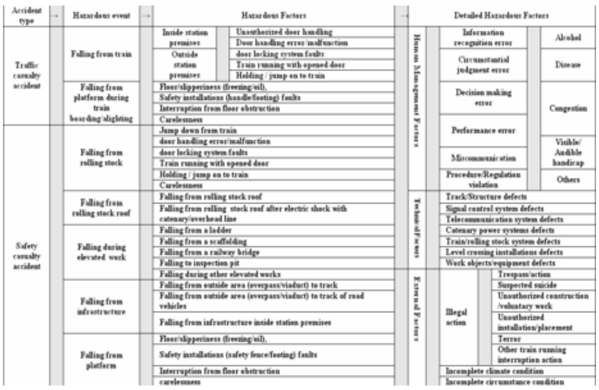
Railway Traffic Casualty Accident	People struck/crushed	striking with train, striking with objects
	Trip/Slip	trip/slip during train boarding/alighting, trip/slip by train emergency braking/emergency start
	Falling	falling from train, falling from platform during train boarding/alighting
	Caught/Dragged	caught in a train door, caught between platform and train
	Others	electric shock, burn, suffocation

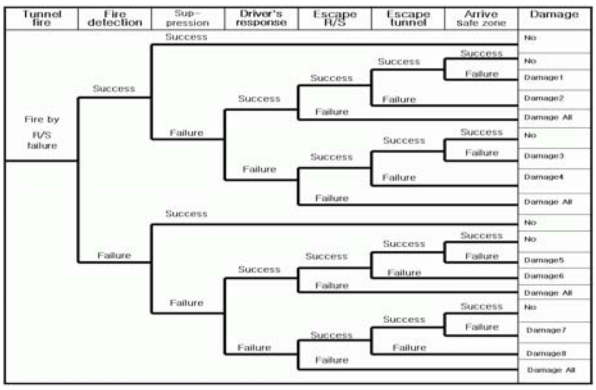
The railway accident appearance scenarios were built up by classifying properly the immediate causes (hazardous accident) and underlying causes [5].

The ***immediate causes*** are classified according to characteristics of each hazardous event (conditions which immediately cause hazardous events):
1. *Substandard Acts* - substandard acts/behavior of who can cause hazardous events
2. *Substandard Conditions* - physical conditions which can cause hazardous events

The ***underlying causes*** are applied to all hazardous events with an identical structure (reason or source of substandard acts and conditions):
1. *Human Management Factors* - capability, skill, physical/mental state of concerned peoples
2. *Technological Factors* – control, maintenance and legal criteria related to conditions of the technical environment including tools and machines [6]
3. *External Factors* – illegal action, substandard climate and circumstance condition

The accidents can be considered as the knot between causes and consequence. Thus, after a hazardous event, there are several processes which lead to the final consequence [7]. In this models, critical factors influencing the final consequence of each hazardous event were identified and the relationships among these factors were defined in the accident progress scenario. Fig. 3 shows the summarized structure of the developed accident scenarios.


(a) accident appearance scenario example



(a) accident progress scenario example

Fig. 3. Summarized Structure of Railway Accidents

3. DEVELOPMENT AND DESIGN OF RISK ASSESSMENT MODEL

The risk assessment model is based on observations in the form of a cause and consequence analysis using fault trees and event trees to represent each of the hazardous events. The railway accident appearance scenarios provide the base of accident causal analysis models for the frequency evaluation. The railway accident progress scenarios provide the base of accident consequence analysis models for the severity evaluation. Under this approach, "Risk" relates purely to safety risk in terms of an estimate of the potential for harm to passengers, staff and members of the public from the operation and maintenance of the railway. The risk is expressed as the FWI (Fatalities and Weighted Injuries) per year in which ten major injuries and 200 minor injuries are both equal to one equivalent fatality [8].

The risk associated with a particular hazardous event is calculated in terms of:

$$CR = F \times C \quad (1)$$

where CR is collective risk (the average number of FWI/year), F is frequency (the average frequency at which the hazardous event occurs), C is consequences (the number of FWI/event).

The fault trees and event trees have been consisted of data relating to the frequency or probability of various failures (or faults) and the consequences of each scenario sequence. Thus, data was obtained from a wide variety of railway industry data sources. Where data was not available for the quantification of the cause and consequence precursors, use was made of:

- human error probability assessments using a Human Reliability Analysis or technique for Human Error Assessment and Reduction
- safety expert judgment from in-house expertise within Slovakian railway and
- selected statistical methods including Monte Carlo simulation.

To assess the accident risk of the Slovakian railway has an important role in the improvement of railway safety in the most effective manner. To do this, a dedicated railway risk assessment and information management system is being developed. The structure of system is shown in Fig. 4. One purpose of the accident information system is to provide fundamental information for an in-depth risk assessment of railway accidents. This is a planned as a railway risk assessment software package. This will be composed of several modules (Fig.4) and each module provides such as editing ET (Event Tree) and FT (Fault Tree).

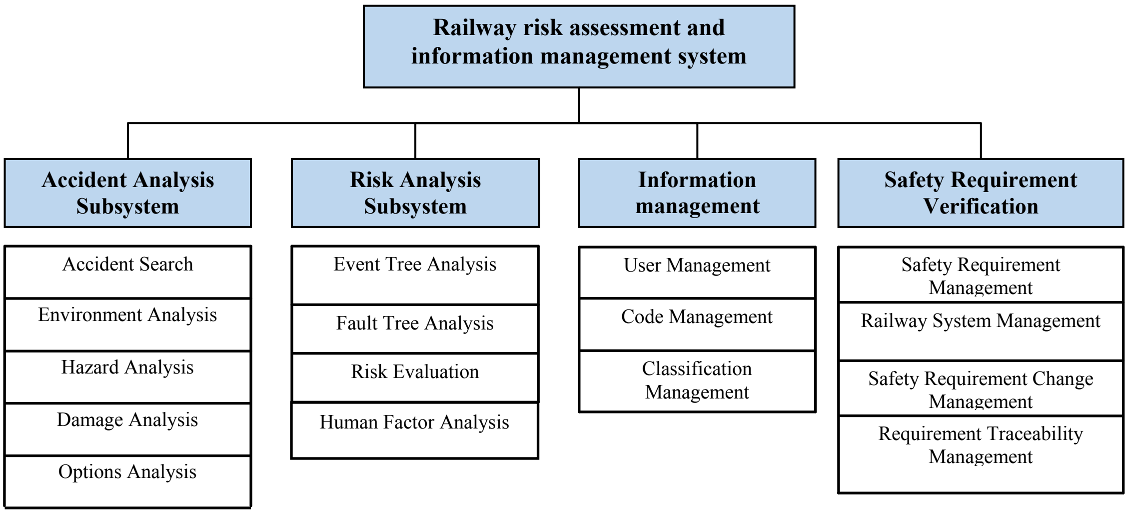


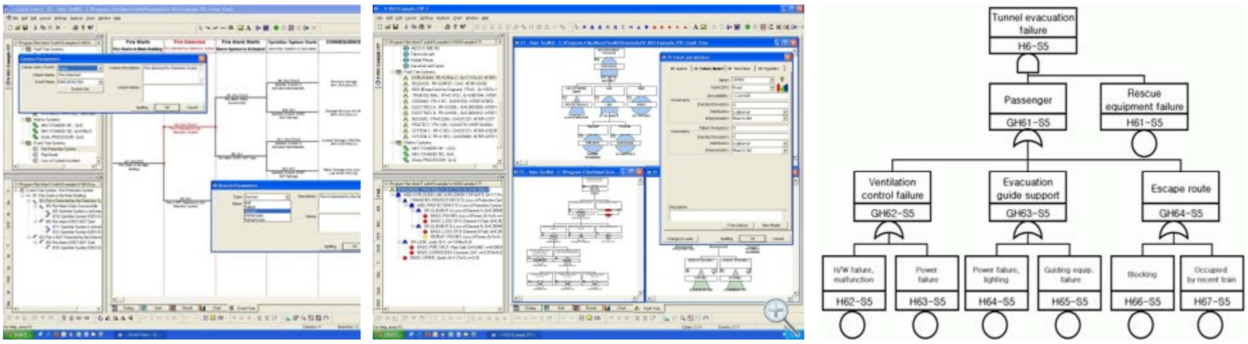
Fig. 4. Functional Structure of Railway risk assessment and information management

In future, the risk of the railway systems can be assessed by the ET/FT linking approach usually used for complex systems [9]. Accident scenarios that can lead to an undesirable consequence should be defined as event trees, using an event tree editor. Each branch of the accident sequences requires one or more supplementary fault trees, which can be developed by a fault tree editor. Sum of the frequency of each sequence becomes the total frequency of the accident of concern. Where data was not available for the quantification of the cause and consequence precursors, it was needed to support the analysts in an effective and efficient way in analyzing human error potential in railway event.

CONCLUSIONS

This paper has proposed the development procedure for Risk Assessment Model by Railway Accidents as a common approach for hazard analysis and risk assessment. It is a start point of railway system safety management and presented a quantitative risk assessment model which is based on accident scenarios.

The overall risk contributions for the hazardous events are made up from different profiles of frequency and consequences [10]. The Railway traffic casualty accident and railway safety casualty accident tend to consist of high frequency low consequence type events eg. slips, trips and falls, while the train accidents tend to have a risk contribution from the low frequency high consequence type events eg. train derailment and train collision. The effect of these low frequency high consequence events is to increase the risk contribution for the hazardous events above the level that may have been seen in practice project. The presented model will provide a planned generic model of the safety risk on the Slovakian railways. The frequency of each hazardous event was evaluated from the historical accident data and structured expert judgments by using the FTA technique. In addition, to assess the severity of each hazardous event, the ETA technique and other safety techniques were applied. Fig.5 shows some pictures of the risk analysis system.



(a) Event tree editor view (b) Fault tree editor view (c) Fault tree of hazard scenario

Fig.5. Illustrations of the risk analysis subsystem

Finally, the risks for passengers, staff, and member of public will be estimated as the number of equivalent fatalities. This work was supported by Scientific Grant Agency of Slovak republic within the project no.1/0240/15 "Process model of critical infrastructure safety and protection in the transport sector”.

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ПРИМЕРЕН МОДЕЛ ЗА АНАЛИЗ И ОЦЕНКА НА РИСКА ПРИ ЖЕЛЕЗОПЪТНИ ТРАНСПОРТНИ СИСТЕМИ

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Ключови думи: *железопътни транспортни системи, рискови ситуации, оценка на риска, сценарии за анализ на произшествията.*

Резюме: *Настоящият доклад има за цел да представи усъвършенстван модел за оценка на риска в железопътния транспорт и да покаже неговото практическо приложение при Словашките железници. Моделите за оценка на риска се базират на различни сценарии за анализ на възникналите произшествия. Представени са рискови ситуации, благодарение на събрана информация от отчетни доклади и консултации с експерти по безопасността, чрез която е оценено до каква степен съответната рискова ситуация би довела до възникването на инцидент. Разработеният усъвършенстван модел за оценка на риска ще бъде апробиран в Словашките железници. Честотата на възникване на рискови ситуации се определя чрез анализиране на възникнали инциденти в миналото по съответната железопътна отсечка и експертната оценка на специалисти, като се използват FTA и ETA техники.*