ACCIDENTAL RISK ANALYSIS FOR RAIL TRANSPORT OF DANGEROUS GOODS

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Abstract – This paper presents the identification and analysis of causal factors that cause accidents in the rail transport of dangerous goods. The proposed model of risk assessment is based on knowledge of the conditional probabilities of events that precede the realising of hazardous substances from the tank cars. The probability of occurrence of accidents requires the definition of conditional distributions related to the position of the train derailment, the number of derailment wagons, as well as tank cars and tank cars where the releasing occurred. Distribution of conditional probabilities are defined on the basis of statistical analysis of accidents in the software module Analytic Solver Platform V2016-R2, according to the database FRA REA for last ten years (2006 - 2015). A procedure is proposed for the application of the presented probabilistic-statistical model in accordance to the variation of transport conditions, condition of the vehicle and railway infrastructure.

Keywords – Railway accident, dangerous goods, risk assessment, derailment, tank cars.

1. INTRODUCTION

The intensive development of chemical process industries requires effective engagement of transportation capacity within the system of hazardous materials. Modern conditions of production process are supported with flexible logistics systems where the transport subsystems have the important role. The choice of means of transport is carried out on the basis of technological, transport and economic indicators according to the type (class) of hazardous substances. Therefore, the transport risk is treated as a dominant criterion in the selection of transport modalities.

The comparative advantages of rail transport have influenced to its significant share in the land transport of dangerous goods on medium and longer distances. The safety aspect of these facts should be interpreted in terms of reduction transport risk within individual and socially acceptable limits, and not as the possibility of its complete elimination. For example, transport of liquid nitrogen through rail and road tunnel monitors risk that can not be avoided in an economically acceptable way, but the risk of congestion is slightly lower for the rail transport compared to road for the same type and quantity of hazardous substances and thus becomes more acceptable with individual and social aspects of safety [1]. The main cause that leads to accidents in the rail transport of dangerous goods refers to the phenomenon of derailment [2]. Although the risk assessment of railway accidents, over the past decades, have been the subject of numerous studies, it should be noted that the most significant results have been achieved in recent years, mainly thanks to the FRA REA database [3].

Two basic approaches used in previous research train derailment include simulation models and statistical analysis [2]. The simulation models related to the non-linear dynamic response to the movement of vehicles on specific driving conditions and environments, and are based on a detailed interaction of wheel-rail. Analyzed are also the influence of friction torque due to the traction device, sluggish operation of the brake force and speed of the train to derailment the wagon number. Subsequent studies have conducted the effects of supplementing simulation independent frees movement of wagons due to failure of the towing devices [4-5]. Contemporary trends in the dynamic simulation and analysis of train derailment are based on the use of software packages, such as SYMPACK [6].

Software simulation train derailment due to earthquakes have special significance during transport

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dangerous substances in earthquake areas, such as eg. Japan, California and similar region [7]. Transport accidents of this kind are quite rare events (extremely low frequency of occurrence), but their formation following catastrophic consequences.

Statistical models of risk assessment in the transport of dangerous goods are based on data from extraordinary events occurring due to the derailment of the train taken from appropriate sources (databases). Saccomanno and El-Huge on the basis of truncated geometric distribution developed model estimates the average number of derailed vehicles depending on the speed of movement, the residual length of the train and accident causes [8-9]. Significantly improve the flow of statistical models is carried out through a modification proposed by Bagheri et al. [10]. Using the methodological approach from previous studies, Liu et al. showed that the most common cause of broken rail derailment of freight trains on the main lines of class I in the US [11]. The average number of derailed vehicles due to broken rails is 14, while in the case of damage to wagons bearing that number is 7. Damage beds represent a potentially serious cause of a train derailment than the ruptured rail, or statistical analysis shows a favorable condition for this causative factor. Previous result is best illustrated by the obvious importance of statistical models compared to the simulation approach, which does not have the adequate techniques to identify these or similar parameters.

Studies by the statistical method to treat a spectrum of development and implementation, such as [8-10] are based exclusively on the use of FRA REA database [3] and therefore the results of such research are limited to US railways. Implementation of statistical methods to countries outside the US require the use of appropriate data bases, but failing that we have very low coverage for most national railways worldwide. It should be borne in mind that the application of statistical methods is not enough only the existence of any database, but it must be designed at least approximately as FRA REA in order to be represented all aspects of the accident (number of derailed vehicles, point of derailment, etc.), and what is not the case with the European database EUROSTAT [11]. In this regard, it should be emphasized that according to the research database of transport accidents in the Iranian railways benefits CRISP-DM methodology to extract the unknown relationship between the available data [12]. The significance of this methodology is reflected in the potential compensating possibly missing data on accidents (eg. doubts about the cause) with the aim of achieving more effective preventive measures.

2. FACTORS OF TRAIN DERAILEMENT

The phenomenon of the derailment of the train is a complex problem that requires a systematic approach to the analysis of influencing factors, especially when it comes to the transport of dangerous goods. Derailment are a common type of railway accidents in freight transport in the US [2], which is in respect of dangerous goods initial event for the eventual emergence of a domino effect [13]. Accidental risks of rail transport of hazardous materials is much less favorable compared to the road in the context of domino effect. Therefore, risk assessment must include a process of escalation of accidents which is very pronounced in the rail transport of flammable and explosive substance (petrol, LPG, etc.) and key role in this process has the derailment. A typical example is the railway accident in Viareggio (2009) when the derailment occurred due to an explosion 45 tones of LPG where 13 persons were injured, while material losses estimated at € 32 million [14].

The main parameters that influence the derailment include are: the speed of the train, class track, the length of the train and the point of derailment. Interdependence of these parameters affects the complexity of the derailment which this phenomenon becomes more difficult to identify and adequate assessment of accidental risks. The most pronounced is the dependence between speed and class of train tracks. Smaller classes give the track a larger number of derailment at low speed, while the speed increases we have a tendency of decreasing number of derailment. Number derailment at a higher class track increases with increasing speed.

Practical experience has shown that the larger the length of trains accompanied by greater likelihood of derailment. This hypothesis was confirmed by statistical analysis conducted by FRA REA database. Trains are characterized by small length less risk of derailment, but then brings into question their viability. This is one of the very obvious why the situation does not aspire to the complete elimination of risk, but by reduction to an acceptable level of which has previously been discussed. In this regard, the procedure criteria optimization determines the optimal length of the train derailment that minimizes the risk to an acceptable level.

Previous studies have shown that the first railway vehicle is usually subject to a freight train derailment near. Liu et al. showed that the point of derailment of the train may be best approximated by Beta distribution, using K-S test on a set of common distribution {Normal, Logistic, Weibull, Uniform, Beta, Gamma} [15]. Through this distribution can be identified causes of the train derailment and for frontal position it is mainly broken rails, while uniform distribution corresponds to failures of wagon.

3. PROBABILITY MODEL FOR ACCIDENTAL RISK ASSESSMENT

Probabilistic models of risk assessment are based
on the using of the conditional probability distribution of the events that preceded the accident, which are formed in accordance with the relevant statistical data. The probability of occurrence of chemical accidents due to derailment of a train wagon for heterogeneous composition is given by the conditional probability formula [16]:

\[ P(X_i, X_j, X_k, X_l) = P(X_i | X_j, X_k, X_l) \cdot P(X_j | X_k, X_l) \cdot P(X_k | X_l) \cdot P(X_l) \]  

Fig. 1. The causal dependence of events that precede the railway accident involving hazardous substances

Discrete random probability distribution are:

\( X_i \) – derailment initiated in the \( i^{th} \) position of the train, 
\( X_j \) – derailment of \( j^{th} \) railway vehicle from the train, 
\( X_k \) – derailment of \( k \) tank cars, 
\( X_l \) – releasing the dangerous goods from \( l \) tank cars, 
\( i \) – the position of the first of the derailed vehicle, 
\( j \) – the total number of derailed the cars \( (0 < j \leq n) \), 
\( k \) – the number of derailed the tank cars \( (0 \leq k \leq j) \), 
\( l \) – the number of tank cars exposed to release or leak dangerous substances \( (0 \leq l \leq j \leq n) \), 
\( n \) – total number of railway vehicles \((n \geq 2)\).

The outcome of the chemical contamination depends on the potential emergence of sequential events that precede it (Fig. 1) and are interpreted through the mathematical probability of partial with the following meanings:

Discrete distribution \( P(X_i | X_j, X_k, X_l) \) is related to conditional probability of occurrence of chemical accidents provided that the derailment was initiated on the \( i^{th} \) position of the train and if there were \( k \) tank cars from a total of \( j \) derailed railway vehicle. Discrete distribution \( P(X_j | X_i, X_k) \) is the conditional probability of derailment tank cars provided that the derailment was initiated on the \( i^{th} \) position of the train causing the derailment of \( j \) railway vehicles. Discrete distribution \( P(X_k | X_i, X_j) \) is the conditional probability of derailment \( j \) railway vehicles from the composition of the train provided that the derailment was initiated on the \( i^{th} \) position. Discrete distribution \( P(X_l) \) is the probability initialization derailment in the \( i^{th} \) position of the train.

The formation of discrete distributions referred to in (1) is carried out according to data from FRA REA database for the period 2006-2015. Generating conditional probability distribution is done in the software module Analytic Solver Platform-V2016 R2.

4. RESULTS

Distribution of conditional probabilities of (1) are given in Fig. 2-5, and representing a sequential series of events preceding the occurrence of in rail accidents.

Fig. 2. The distribution of derailed train position

Fig. 3. Distribution of the number of derailed cars
The probability of rail accidents during transport HAZMAT is obtained from (1) under the conditions of Fig. 2-5 and eg. for $P(X_2, X_6, X_{10}, X_I)$ is $1.23 \times 10^{-5}$.

5. CONCLUSION

Derailment plays a significant role in transport accidents, while the presence of flammable and explosive substances affect to their escalation. Their mutual influence of the parameters of derailment is not enough identified, so the latent factors contributing to greater uncertainty about the potential occurrence of accidents or affect the higher level of risk. Adequate risk assessment requires the integration of simulation techniques, statistical analysis and QRA model in the methodological framework for posterior updates of the level of risk. The development of such methodological approaches requires the improvement of existing statistical and probabilistic model and its implementation for specific exploitation conditions.

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