CHARACTERISTICS AND METHODOLOGICAL FOUNDATIONS OF RISK MANAGEMENT-BASED APPROACH FOR THE ANALYSIS OF OPERATIONAL RELIABILITY IN TRANSPORT

Assoc. Prof. Georgiev N. PhD.[1]
Faculty of Transport Management – Higher School of Transport, Bulgaria [1]

Abstract*: As the relatively constant level of number and characteristics of accidents (including all their effects on people, businesses, society and environment), as well as many cases of ineffective measures for accident prevention, led to the need for a new approach for analysis and evaluation of the operational reliability and safety in various transport modes. In this sense, the concept of system safety and reliability enters increasingly into the field of the technical exploitation of transport. Based on the principles of risk management, this concept offers a great opportunity for development of theoretical foundations, methods and algorithms for solving many technical and technological problems. This article discusses the characteristics and common methodological foundations for the application of a risk management-based approach for analysis of operational reliability and safety in the area of transport - analysis based on losses (consequences) of accidents.*

Keywords: OPERATIONAL RELIABILITY AND SAFETY, ACCIDENT COST, RISK, SIMULATION ANALYSIS

1. Introduction

Transportation of passengers and goods inevitably involves the possibility of accidents that have the potential to cause death or injury to people, material damage or harm to the environment. Each mode of transport is a complex technological system operating in conditions and under the influence of many technical, social, economic and even political factors. Its operational reliability and safety is characterized by a set of specific characteristics and the most important of these can be defined as follows:

-The hazard sources are not located in the same place (with the exception of pipeline transport).

-The level of individual risk may sometimes be very low but there is a very high societal risk.

-People living or working close to transport facilities or technological centres are in close proximity to hazard sources.

-Inability to build "barriers" (precautions) to prevent the occurrence of all possible hazards or reduce their possible effect after occurrence.

-Lack of people with specialized knowledge, skills and experience in all cases of abnormal or emergency operational situations to take appropriate actions and prevent accidents.

-Providing higher reliability of particular transport subsystems and hence of the entire transport system does not necessarily mean smaller losses from technical failures or human errors.

For a long time, the conventional approaches and methods of reliability theory (intended mainly to maximize the reliability of individual components and subsystems of the transport systems) were used to analyse the reliability of the transport process. However, as the relatively constant level of number and characteristics of accidents (including all their effects on people, businesses, society and environment), as well as many cases of ineffective measures for accident prevention, led to the need for a new approach for analysis and evaluation of the operational reliability and safety in various transport modes. In this sense, the concept of system safety and reliability enters increasingly into the field of the technical exploitation of transport. Based on the principles of risk management, this concept offers a great opportunity for development of theoretical foundations, methods and algorithms for solving many technical and technological problems.

This article discusses the characteristics and common methodological foundations for the application of a risk-based approach for analysis of operational reliability and safety in the area of transport - analysis based on losses (consequences) of accidents.

2. Essence and characteristics of the approach

2.1. Basic principles

The main purpose of risk assessment is to provide an analytical basis for making correct management decisions. It allows the definition of this alternative (from a variety of alternatives associated with the respective risk) which most satisfies stakeholders in accordance with predefined criteria and constraints.

The concept of risk is subject to definition and interpretation in many scientific publications. According to [1] it is a combination of the rate of occurrence of a type of accident (incident) resulting in harm (caused by a hazard) and the degree of severity of that harm. Mathematically and in accordance with the characteristics of technical exploitation in the field of transport this definition could be represented as:

$$r_i = p_i c_i \quad (1)$$

where:

r_i -individual risk associated with i -th type of scenario of transport accident (for instance: train and car collide at unprotected level crossing due to failure of level crossing actuating equipment);

p_i -probability of occurrence of i -th type of scenario of transport accident;

c_i -consequence (loss) resulting from the occurrence of i -th type of scenario of transport accident;

The loss c_i could be classified in several major categories:

-Loss of life or harm to health of passengers, operational staff, local people, etc.

-Material damage to community infrastructure, rolling stock or other transport facilities.

-Loss associated with damage to the environment.

-Financial loss (e.g. loss of production, costs of intervention and repair, etc.).

-Loss of business image (e.g. loss of customers, loss of contracts, etc.).

Depending on the category and analysis purposes, the losses can be expressed in number of deaths (injuries), duration of traffic interruption, volume of unrealized transport production, volume of pollutants released into the environment, etc. For the purpose of comparability of individual cases, the losses from transport accidents are usually expressed in monetary form (although there are some difficulties).

2.2. Conditional and potential losses

In essence, the expression (1) characterizes the average potential loss from a transport accident. But to achieve a qualitative analysis of operational reliability, it is often of primary importance to have not only information about the average (expected) loss, but also knowledge regarding the deviation from the expected loss (the unexpected loss). For example, a transport operator (transport carrier, transport infrastructure manager) would like to determine the probability that the loss from transport accidents will exceed a certain threshold value. This and many other issues related to correct decision-making in the field of operational safety and reliability would receive a positive outcome when information about the characteristics of loss is available.

Widely used in all fields of modern society (including in the field of technical exploitation of transport), the concept of system reliability and safety considers the losses from process failures such as transport accidents basically as: *conditional loss, given that a transport accident has occurred* (due to failure of technical device or human-operator error) and *potential losses, related to multiple transport accidents within a certain interval of time.*

Both the conditional and potential loss can be considered as random variables, the values of which depend on the influence of a number of factors. For example, in the case of a derailment of rolling stock due to failure of its undercarriage, the value of loss (damage) will depend on the function of the failed element, the place of derailment, speed, etc. The conditional loss can be determined on the basis of available statistical data regarding transport accidents which have occurred (according to their characteristics: type, location, causation, etc.). Adequate decision-making in the field of technical exploitation of transport requires examination and analysis of the characteristics of potential loss. These are the distribution functions of potential loss (an approach for their determination is shown below), by the use of which it becomes possible to avoid the limitations of traditional risk assessment.

As random variables both the potential and conditional losses can be represented by their probabilistic characteristics, namely:

- $F(x)$ and $f(x)$-cumulative distribution function and probability density function of the potential loss (before transport accident occurrence);

- $F(x/accident)$ and $f(x/accident)$-cumulative distribution function and probability density function of the conditional loss (given that a transport accident has occurred).

The cumulative distribution functions $F(x)$ and $F(x/accident)$ characterise the probability that the potential loss X (respectively, the conditional loss $X/accident$) will be smaller or equal to a predefined value x (argument of the functions): $F(x) = P(X \le x)$,
$F(x/accident) = P(X/accident \le x)$.

The probability distribution functions $f(x)$ and $f(x/accident)$ characterise the probability that the potential loss X (respectively, the conditional loss $X/accident$) will be within the infinitesimal interval ($x, x+dx$): $P(x < X \le x+dx) = f(x)dx$,

$P(x < X/accident \le x+dx) = f(x/accident)dx$.

The transport technological (operational) subsystems (e.g. railway station) may lose their operability (and thus cause an accident) due to the occurrence of n different modes of failures (technical failures or human errors). Let $F_i(x/accident)$ be the cumulative distribution function of the conditional loss associated with the i-th failure mode and $q_{i/accident}$ be the conditional probability that exactly the i-th failure mode has caused failure (accident) of the technological subsystem first (obviously $\sum_{i=1}^{n} q_{i/accident} = 1$).

Following these assumptions, the function $F(x/accident)$ can be described by the union of the elements of set S. Set $S = \{s_1, s_2, ..., s_i, ..., s_n\}$ is a set of n mutually exclusive and exhaustive events, where s_i is the event that i-th failure mode has created operability disturbance of the transport subsystem (due to which transport accident has occurred) and the loss X from this disturbance is smaller or equal than x. The probability of event s_i is $F_i(x/accident)q_{i/accident}$. In accordance with the rule for computing the probability of a union of mutually exclusive and exhaustive events we can write the next expression regarding the cumulative distribution function of the conditional loss:

$$(2) \quad F(x/accident) = \sum_{i=1}^{n} F_i(x/accident) q_{i/accident}.$$

In general, many transport systems may be considered as repairable systems with m logically arranged in series (regarding reliability of the transport process) subsystems. This means that the transport system fails if at least one of its subsystems fails (e.g. a railway section, consisting of several stations and inter-stations, will not function properly if at least one of stations or inter-stations loses its operability due to any mode of failure - technical failure of any railway equipment or human error). Hence, such a transport system can be regarded as equivalent to an element which may change its operable state to an inoperable one due to at least one of n possible to occur (and typical for this element) and mutually exclusive failure modes [3]. In this case and by analogy with expression (2), the cumulative distribution function of the potential loss from transport accidents within a certain time interval $(0,t)$ can be presented as:

$$(3) \quad F(x) = \sum_{i=0}^{\infty} q_i F(x/i),$$

where:

q_i -probability of occurrence of i transport accidents within time interval $(0,t)$;

$F(x/i)$-probability that the loss from transport accidents X will be smaller than x given that exactly i transport accidents have occurred within time interval $(0,t)$.

2.3. Approach to determining potential losses from transport accidents

The main difficulty associated with calculating the potential losses from transport accidents is the determination of the distribution function of conditional losses - $F(x/i)$. This function can be obtained either on the base of statistical information in respect to transport accidents which have occurred and been registered or by using simulation (Monte Carlo Method). The main stages of a simulation algorithm for determination of the potential losses are shown in Figure 1. With the help of graphically oriented simulation program *Oracle ® Crystal Ball* (a spreadsheet-based *software* running in the environment of "MS Office Excel 2003) the algorithm is applied to model a transport system (e.g. railway section, consisting of a number of stations and inter-stations). The studied transport system is assumed to have a homogenous Poisson flow of transport accidents (due to given failure mode) with parameter $\lambda = 7$ accidents per year (Figure 2).

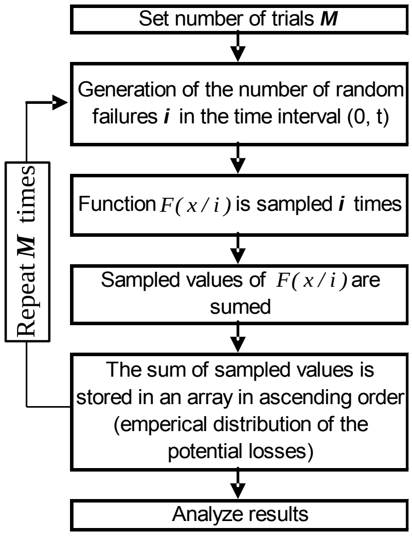

Fig.1.Monte Carlo algorithm for determination of the potential loss

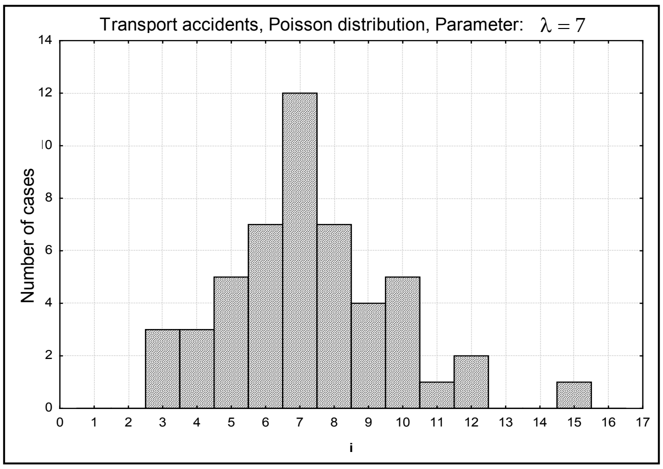

Fig.2.Transport accidents distribution

The conditional loss from this accident mode is assumed to follow a normal distribution with parameters: *mean* $\rightarrow \overline{X}$ */ accident* $= 10000$ (monetary units) and *standard deviation* $\rightarrow \sigma_{X\,/\,accident} = 2000$ (Figure 3). The probability density function of the potential losses obtained by the application of the algorithm mentioned above is shown on Figure 4.

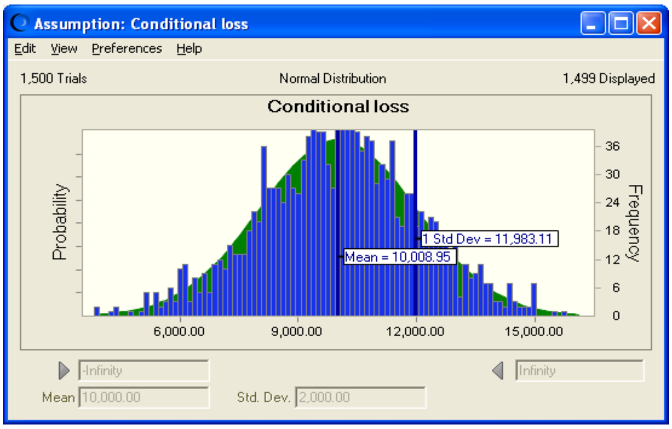

Fig.3.Probability density function of conditional loss

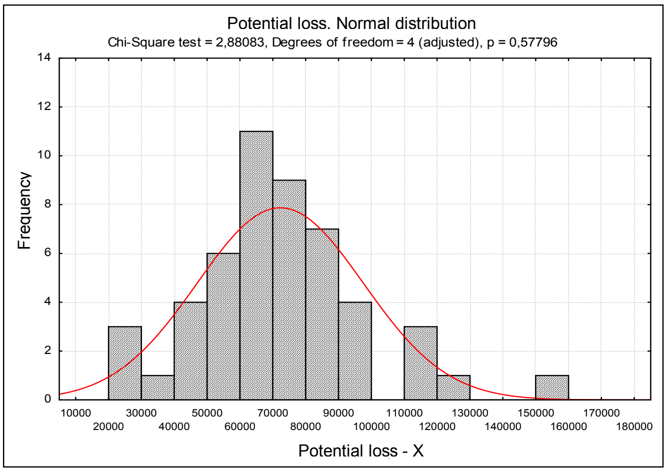

Fig.4.Probability density function of potential loss

As can be seen, the potential loss also follows a normal distribution with parameters: *mean* $\rightarrow \overline{X} = 72267$ units and *standard deviation* $\rightarrow \sigma_{\overline{X}} = 25343$.

3. Conclusion

The characteristics of risk management-based approach offer a very good foundation for qualitative analysis of operational (system) reliability and safety in the field of transport. Its main advantage is related to the opportunity to express losses from transport accidents (the major element of risk) as random variables.

This approach allows not only the use of alternative methods (e.g. simulation), but also obtains more detailed results (good basis for appropriate decision-making), such as: mean of the potential losses, probability that potential losses are (will be) smaller (or larger) than a certain value, etc.

References:

[1] EN 50126:2000: *Railway Applications–The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)*. CENELEC, 2000.

[2]. Ireson, W., C. Coombs, R. Moss. *Handbook of Reliability Engineering and Management*. McGraw-Hill Company, Inc. NY, 1996.

[3] Todinov, M. *Risk Based Reliability Analysis and Generic Principles for Risk Reduction*. Elsevier Science & Technology Books, UK, 2006.