Risk Reduction in Critical Road Infrastructure in Central Europe

Zdenek DVORAK
Department of Crisis Management Research, University of Zilina
Zilina, 010 26, Slovakia

and

Maria LUSKOVA
Department of Crisis Management Research, University of Zilina
Zilina, 010 26, Slovakia

and

Zoran CEKEREVAC
Union University Beograd
Beograd, 11000, Serbia

ABSTRACT

Risk reduction in critical infrastructure is one of the important parts of the critical infrastructure protection. The each EU country has an interest to prepare adequate own criteria for integration of potential objects into the European, national or regional critical infrastructure. The implementation of different methods for risk reduction in road transport in the European Union leads the individual member countries to seek ways to effectively and timely implement new procedures to risk identification and critical infrastructure protection. Individual subsystems of road transport should be analysed and assessed separately. The authors draw attention to the large and rich results of research in the field of risk assessment in road transport infrastructure with focus on bridges and tunnels (road transport objects). The results of the examination are published for the first time and should lead to professional public debate.

Key words
Road infrastructure objects, bridges, tunnel, risk reduction, risk analysis

1. INTRODUCTION

Current applied sciences and the need for practical knowledge are leading to the cooperation of academic and research teams with the experts on practise. Safety of transport and of critical infrastructure (next CI) in road transport leads to gradual implementation of the different methods. However, the very first step is the applied research in the given field. As part of national and international research projects [3,4], partial tasks have been solved which are applicable in the implementation of adequate methods. The counterpart of transport safety is the hazard or threat of maintenance processes. Risk is the potential possibility of violation of the transport system safety which can be calculated by multiplying the likelihood of incident and the amount of its negative impact. Hazards, threats and risks in transport are mutually conditional. The real incidents usually happen when more threats are combined as well as when being in function. Safety and risk possess a probabilistic character. Their values lie in the range from 0 to 1 and their sum is always equal to 1. Analysis of potential impacts, that is subject of many recent researches, is also very important task. [5]

2. SPECIFIC RISK ASSESSMENT IN ROAD TRANSPORT

Significant part of the risk assessment in the road transport is the usage of adequate methods. 2500 theoretically possible threats have been defined in our large research, which have been subsequently reduced to 585 threats concerning the road transport. Theoretically as well as practically, various threat classifications are being used. One of the possibilities is dividing them in the following way:

- according to the object of threat activity, there are threats of non-military, military and combined character,
- according to the range of shielded interests, there are partial and complex threats,
- according to the location of threat source in the given system, there are internal and external threats,
- according to the threat source, there are anthropogenic threats and threats not dependent on human activity. [6]

Determination of causes of critical situations on roads and highways

The "cause" has been perceived by the investigators as primary action which activated the risk. Causes have been divided into two basic groups (natural and human). The next step was to allocate the causes to their risk origin activation, which had already been referred to a location in the previous step, such as road infrastructure, interchanges, tunnels, bridges and constructions of vehicles. Substantiality of these generated combinations always needs to consider. For the cause selection, existing list of causes has been used which respected the causes of critical situations filed in the type plans created by competent body and therefore, even causes which are improbable and their effect on road transport is negligible have been worked with. More causes have been calculated with while creating the name of type threats. By their analysis and classification, 14 groups of causes were generated according to their common significances, which can be found in Table 1. They are inscribed in the type threat name with their title in column „cause name“. [3, 4, 7, 8]

Table 1 Analysis of the most dangerous locations on roads and highways according to the causes

Cause	Change in maintenance conditions				Together
	Objects infra-structure	Tunnel	Vehicle	Surround-ings	
Atmospheric and cosmic defects	13	6	7	2	28
Collective public dissatisfaction	2	6	8	4	20
Criminal activity	32	25	17	7	81
Defects on Earth‘s surface	18	22	4	3	47
Errors in supplies essential for maintenance	7	7	1	2	17
Errors of transport crew	12	13	4	2	31
Extreme natural phenomenon and weather	32	22	14	5	73
Human factor failures	26	26	10	3	65
Negative situation in nearby countries	0	7	8	1	16
Problems in state administration	4	5	0	1	10
Public unrests	5	21	9	5	40
Special biological events	5	7	5	3	20
Technical error	27	27	11	3	68
War conflict	27	27	10	5	69
Together	210	221	108	46	585

After the threat assessment it is crucial to follow the ISO norms (also National Technical Norms) concerning risk management. According to these norms, following steps must be implemented:

- definition of the connectivity and identification of risk sources, see Fig.1,
- estimation of probability and consequences (risk calculation),
- risk evaluation – risk matrix , see Table 2.

In the scope of connectivity definition, it is crucial to set a concrete object of examination. Risk source identification of road tunnels is focusing on examination of:

- floods,
- landslides/mass unrest,
- avalanches,
- other natural forces (e.g. ice),
- terrorist attacks,
- explosion, fire or leakage of transported material,
- suicides,
- vandalism – criminality,
- wild animals injuries,
- technical malfunction/defects,
- human factor fault,
- vehicle or plane crash on the road transport objects, etc. [5, 6]

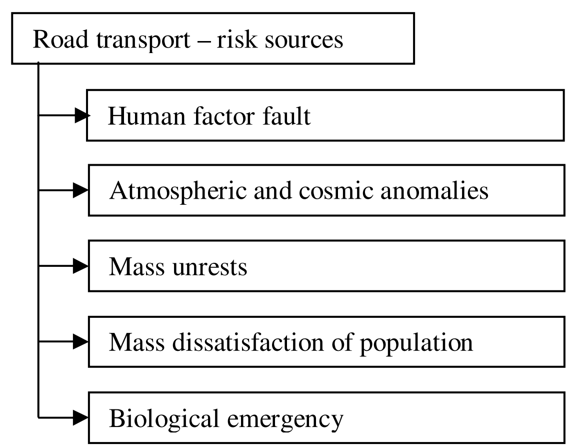

Fig.1 Road transport risk sources

The above listed threats are the cross section of possible launching events which might consequently lead to an incident. It is feasible to divide them into the categories according to the impact they have on tunnels as constructions, meaning whether the threat arises from the surroundings of the tunnel or from the processes or conditions inside the tunnel tube. [8]

Table 2 Fragment syntax of creating the name for hazard type according to the developed matrix

Event	Risk source activation	Location	Cause
Change of operational conditions due to	Bombardment of road vehicle	Outside of road tunnel	Atmospheric and cosmic anomalies
Change of operational conditions due to	Immobility of vehicle	Inside of road tunnel	Mistake caused by human factor.

3. RISK ANALYSIS OF INCIDENT OCCURRENCE INSIDE THE ROAD INFRASTRUCTURE

3.1. Probability of incident occurrence inside the tunnel

While solving the research tasks we have come to conclusion that the most suitable procedure for the calculation of incident formation probability inside tunnels consists of 2 parts. Firstly, it is crucial to calculate the probability that an incident is formed directly inside the tunnel. Secondly, the probability of an incident in road transport as such.

Incident location probability (hereinafter ILP) can be calculated by dividing the total length of objects by the total length of roads. The result indicates probability of objects being the area of an incident. We also need to consider the probability of a road incident having an impact on the incident occurrence probability inside objects. The actual calculation of incident occurrence probability inside tunnels emerges from the total length of tunnels in Slovakia roads (7,41 km) divided by the total length of roads (17787 km) [5, 6, 17, 18].

ILP = 7,41/17787 (1)

ILP = 0,000417

This result shows that the probability of a road incident which is formed directly in an road tunnel is $4{,}17 \cdot 10^{-4}$.

3.2. Probability of an incident occurrence in road transport

The statistics show that average transport distance of goods transport is 59,5 km. In 2011, the total number of performances for transport goods in Slovakia was 29093 mil ton-km. [14] The number of realized goods transportation in Slovakia was calculated as the ratio between road performance for transport goods (in ton-km) and average transport distance:

29 093 000 000/59,5 = 986 203 389 (2)

In 2011, number of 13252 road incidents took place. Probability of an incident occurrence in road transport is calculated as the ratio between the number of road incidents and the number of realized goods transportation:

$13252 / 986\,203\,389 = 1{,}34.10^{-5}$ (3)

Then the total probability of an incident happening in road tunnel is:

$PVMUT = 4{,}17.\ 10^{-4} * 1{,}35.10^{-5}$ (4)

$PVMUT = 5{,}62.10^{-9}$

The value of $5{,}62.10^{-9}$ shows the probability of an incident in road goods transportation in road objects of roads and motorways of the Slovak Republic.

3.3. Theoretical aftermath of an incident occurrence in road transport

Total aftermath is calculated as the sum of death and injury casualties and material damage. Since there has been no evaluation of life in the Slovak Republic, I have used the method of scientific evaluation from the Czech Republic. The life value has been determined to 700 000 EUR. Total number of death casualties is 223 excluding the ones at roads and highways in 2013: 223*700 000 = 156 100 000 EUR [12]
This value divided by the number of unit vehicle is 156 100 000/2 622 939 = 59,5 EUR/unit vehicle.

Total number of 1086 injuries excluding those at roads and highways:

10 886*70 000 = 762 020 000 EUR.

Idealised value of injury for the purpose of research was calculated to be 10% of the life loss value which means 70 000Eur, the exact value is: 762 020 000 /2 622 939 = 290,5 EUR/unit vehicle. 13]

Material damages excluding those at roads and highways are 4 533 693 EUR.
Total damages are sum of death, injuries and material damages: 156 100 000 + 762 020 000 + 4 533 693 = 922 653 693 EUR.

Very important part of research was oriented on accident black spots. Solving the black spot which are on Trans European Networks (TEN) is the most important task in enhancing road safety and security. From all the achieved results, it is feasible to calculate the risk of an incident in road tunnels from the following:

R = probability * aftermath

$R = 5{,}62.10^{-9} * 1{,}85.10^{-2}$ (5)

$R = 1{,}04.10^{-10}$

The evaluated risk of an incident occurrence in railway tunnel being $1{,}04.10^{-10}$ is relevant to recommended values which are being used by German and English transport systems. (in the level from 10^{-9}). [15]

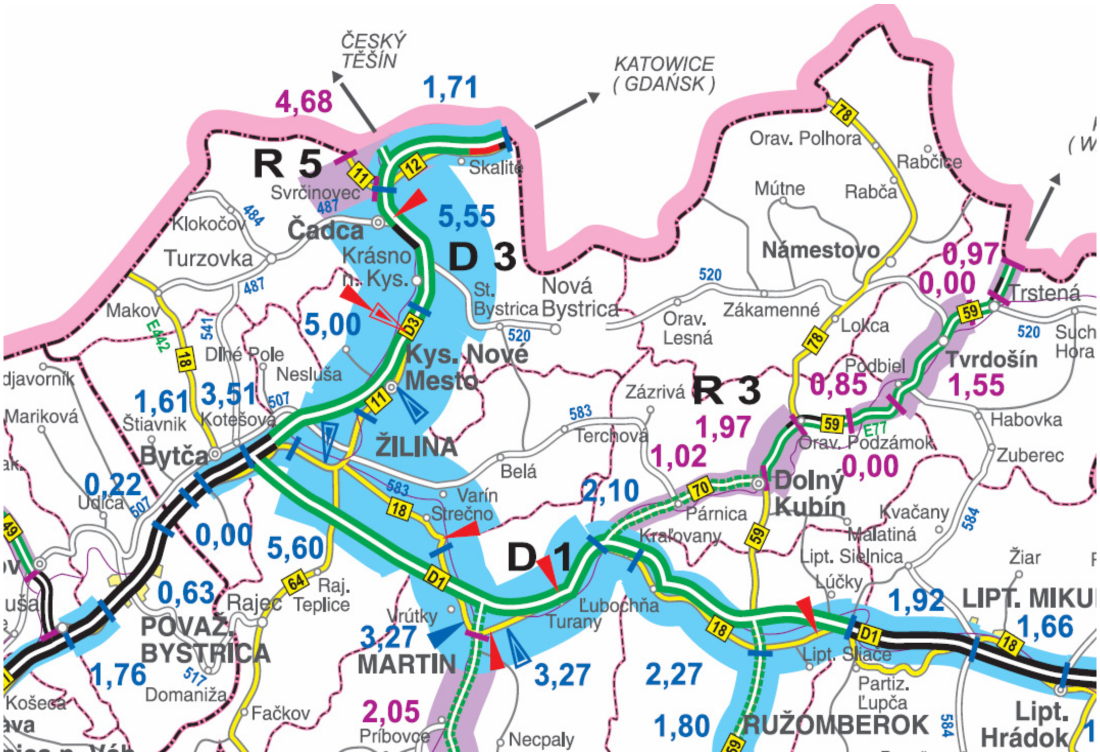

Fig. 2 Actual black spots on North West Slovakia Source [17]

3.4 Determining potential elements of CI according to sectorial criteria and their thresholds

Sectorial criteria - set out specific conditions under which the individual elements of the infrastructure in the sector can be identified as potential elements of CI. These criteria establish conditions to assess the effects of the disruption or destruction of the elements of the entire sector, or assess the impact on other sectors. An example of such sectorial criteria for determining which elements of CI in the sector transport are in focus is allowing a preliminary assessment of the consequences of their disruption or destruction on the functioning of the sector. The sectorial criteria shall also determine their quantifiable thresholds. Critical infrastructure for the transport sector in general is made up four sub sectors and our attention is oriented on sub sector road transport. Individual modes are complex stochastic systems consist of transport infrastructure, means of transport technologies to manage traffic, carriers, legal and technical standards, as well as staff and customers in the transport system.

The sectorial criteria are strict on the optimal selection of the critical elements of transport infrastructure on the basis of international experience and the state of current knowledge including: basic measurable parameters of transport (particularly intensity, event. throughput), technical parameters and environmental conditions (load trucks, the length of the tunnel and nature of the bridge structure, etc.), intensity necessary to restore (cost and duration of the recovery of the original operating parameters), the total cost of the ruined building a temporary detour, or other such e.g. cultural and historical uniqueness of the building, and so on. [1, 2]

It is obvious that precisely determined sectorial and cross-cutting criteria are relatively complicated, especially with regard to complexity and structure of stochastic transport system. Their determination is affected by subjective opinion of expert who usually assigns different weight to particular criterions.

Evaluation of sector criteria in the road transport

Based on scores of sub-criteria evaluation it is possible to determine the total score criterion by which the element can be assigned to road traffic in CI. The sum of all the criteria K1-K8 is in the range (8-56). If we assume that objects relevant for international corridors will obtain average values four points in each sub-criterion, then the resulting value will be 28 points. The boundary for inclusion of object into the components of CI should be at higher level. If we choose a threshold of 38 points, it will mean that at least six values will be with 5 points (large) and two points at level 4 (medium). A priori we do not expect individual assessment at 7 points (extreme), because in normal conditions, it is not happening.

$$K = K1 + K2 + K3 + K4 + K5 + K6 + K7 + K8 \quad [-] \quad (6)$$

If the calculated value is below 38 points, considered object should not be included as the potential element of national critical infrastructure of Slovakia.

Table 3 Point evaluation criteria for road traffic I. class (criteria K1 – K4)

Value of criteria	K1 - transport parameters	K2 - size and character of object	K3 - cost to restore functionality	K4 - material value of the object
1 minimum	300 cars/24 hours	300 euros/ 1 day	50 euros/ 8 hour and small)	up to 300 euros
2 negligible	1000 cars/24 hours	1000 euros/ 1 day	100 euros/ 8 hour	up to 1000 euros
3 small	5000 cars/24 hours	10 000 euros/ 1 week	1000 euros /1 day	up to 10 000 euros
4 medium	10 000 cars/24 hours	100 000 euros /1 month	10 000 euros /1 week	up to 100 000 euros
5 high	20 000 cars/24 hours	1 mil. euros /1 year	100 000 euros /1 month	up to 1 mil. euros
6 very high	40 000 cars/24 hours	10 mil. euros / 1 year and more	1 mil. euros / 1 year	more than 1 mil. euros
7 extreme high	80 000 cars/24 hours	30 mil. euros / 1 year and more	10 mil. euros / 1 year	more than 10 mil. euros

Table 4 Point evaluation criteria for road traffic I. class (criteria K5 – K8)

Value of criteria	K5 - economic impact	K6 – uniqueness of the object	K7 – probability of an attack on the object	K8 – probability of an extraordinary event
1 minimum	up to 0,001 % GDP	minimum	> 1x in 300 years	> 1x in 300 years
2 negligible	up to 0,01 % GDP	negligible	> 1x in100 years	> 1x in 100 years
3 small	up to 0,1 % GDP	small	> 1x in 10 years	> 1x in10 years
4 medium	up to 0,5 % GDP	medium	> 1x in one year	> 1x in one year
5 high	up to 0,7 % GDP	high	> 1x in one month	> 1x in one month
6 very high	Up to 1 % GDP	very high	> 1x in one week	> 1x in one week
7 extreme high	more than 1 % GDP	extreme high	> 2x in one week and more	> 2x in one week and more

4 CONCLUSIONS

Implementation of adequate methods in road transport and infrastructure companies in the European Union is one of the crucial objectives. While doing the risk research it is important to have all relevant information about the probability of occurrence and the aftermath of each risk available. Calculations presented in Chapter 3 are the contribution of authors from international discussion about the evaluation of road transport risks. Mutual activity of several factors usually leads to the occurrence of an incident. Therefore, it is important to implement adequate safety measures into the risk management in order to decrease if not completely eliminate the risks.

One of the possibilities is to create a generally usable list of safety measures to enhance the safety of road bridges and tunnels in the time of transport. As the research shows, the highest risk of an incident in road tunnels is being formed especially during the transport. Needless to say, the aftermath can be catastrophic if dangerous materials are being transported. One of the solutions could be to prepare technical measures, such as using the RFID technology. Installation of a single chip enables the monitoring of a road vehicle.

References

[1] **Act 179, 2011 about economic mobilization**. Bratislava, Slovakia: National Council.

[2] **Act 45, 2011 about critical infrastructure**. Bratislava, Slovakia: National Council.

[3] **Annual Report** from project KISDIS - VG20122015070/Ministry of Interior of Czech Republic – The Complex Automated Information System for Remote Management of Crisis Situations in Rail Transport with focus on Critical Infrastructure, Prague, 2012.

[4] **Annual Reports** from project OKID- APVV-0471-10 Critical Infrastructure Protection in Sector Transportation, Zilina, 2010, 2011, 2012.

[5] Barčiaková, M., 2011. **Risk assessment of critical infrastructure road elements**, dissertation thesis, in Slovak. Zilina: University of Zilina, 126 p.
[6] Dvořák, Z., Fuchs, P., Novák, J., Soušek, R.: Individual and social risk during transportation of dangerous substances, **Communications** - Scientific letters of the University of Zilina - vol. 13, No. 2, 2011.
[7] Dvořák, Z., Leitner, B., Sventeková, E., Soušek, R.: **Managing of risks in railway transport**, monograph Institute J. Pernera, University of Pardubice, 2011.
[8] Dvořák, Z., Soušek, R. Englich, J.: Preparation for solution of crisis situations in railway transport in the Czech Republic. **Logistyka i Transport**, Poland, 2007.
[9] Leitner B., Míka. V.: Reliability and safety of technical means in critical infrastructure with respect to fatigue damage processes In: **Logistics and transport.** Nr. 1 (14) / 2012, p. 103-110.
[10] Němec,V., Vittek, P., Straková, E., Krula, L.: New approach to aviation safety; In: 9th international scientific conference - **New trends in aviation development**; Gerlachov – High Tatras, Slovak Republic; p. 226 – 229.
[11] Němec,V., Vittek,P., Krula,L.: Security management tools and UML standard at international airport; In: 9th international scientific conference - **New trends in aviation development;** Gerlachov High Tatras, Slovak Republic, p. 230 – 232.
[12] Soušek R., Fuchs P., Kelemen M., Havlíček J., Zajíček J., Kováčová L.: Appraisal of Critical Transportation Infrastructure - **Risk and Safety. Science & military**, 2009, 2, p. 112-118.
[13] Soušek R., Kelemen M., Kamenický J., Balatka M., Fuchs P.: Exposure of the environment and surface water by dangerous liquids - the slop outflow model. 8th symposium **Risk management and Cyber-Informatics**, Orlando, USA, 2011.
[14] Soušek R., Saska T., Vališ D.: Accident Probability Assessment by Dangerous Goods Road Transport, Advances in Risk and Reliability Technology Symposium, p. 73-84, Stratford Upon Avon, 2011.
[15] Soušek R.: Transport Measures in the Case of Crisis Situation on the Level of Regions of the Czech. International Scientific Conference MOSATT 2007 - **Modern Safety Technologies in Transpo**rtation, Košice, Slovakia, p. 264-265.
[16] Vidriková, D., Dvořák, Z., Kaplan, V.: The current state of protection of critical infrastructure elements of road transport in conditions of the Slovak Republic, **Transport means 20**11 - proceedings of the 15th international conference Kaunas University of Technology, 2011.

Other internet sources:

[17] http://www.ssc.sk/sk/Bezpecnost-ciest/Kriticke-nehodove-lokality/KNL-mapove-prehlady.ssc
[18] http://www.minv.sk/?celkovy-pocet-evidovanych-vozidiel-v-sr
[19] http://www.ndsas.sk/prehlad-tunelov/44806s

This paper was supported by project:
APVV 0471-10 Critical Infrastructure Protection in Sector Transportation