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THE APPLICATION OF RISK ANALYSIS IN THE ASSESSMENT AND MANAGEMENT OF ROAD SAFETY IN ROAD TUNNELS

ZASTOSOWANIE ANALIZY RYZYKA DO OCENY I ZARZĄDZANIA BEZPIECZEŃSTWEM RUCHU W TUNELACH DROGOWYCH

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Abstract: Road tunnels are highly sensitive to disturbance caused by road accidents. The most serious accidents occurring in tunnels involve trucks carrying hazardous materials. Europe has been developing methods of risk analysis and building models for traffic management in tunnels. Poland is only just beginning to build road tunnels and the area of tunnel safety has not been given adequate attention yet.

Key words: road safety, tunnels, risk management

Streszczenie. Tunele drogowe są najbardziej wrażliwymi na zakłócenia, spowodowane wypadkami, elementami sieci drogowej. Najpoważniejszymi wypadkami w tych obiektach są zdarzenia z udziałem samochodów ciężarowych przewożących materiały niebezpieczne. Od kilku lat zatem rozwijane są w Europie metody analizy ryzyka i budowane narzędzia do zarządzania ryzykiem w tunelach drogowych. W Polsce zaczyna się budować tunele drogowe, a problem bezpieczeństwa w tych obiektach jest jeszcze mało rozpoznany.

Słowa kluczowe: bezpieczeństwo ruchu drogowego, tunele, zarządzanie ryzykiem.

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1. Introduction

Norway is the country with the highest number of tunnels in Europe. There are 844 road tunnels of total length of 768 km, including 309 tunnels of the length over 500 m. Within the framework of fire safety in road tunnels in Norway since the beginning of the 1990's the compulsory risk analyses for the tunnels over 500 m have been conducted. The risk analysis is carried out for the existing and planned tunnels as well as for the tunnels through which the hazardous substances are transported. The assessment of safety concerns the construction of a tunnel, its equipment and the plan of emergency action [1].

Since the implementation of the Zero Vision Programme the risk analysis in Norway has been used more and more often as the basis for selection of priorities in road transport. In spite of the fact that accidents in tunnels do not contribute largely to the general number of accidents on the road network of Norway, the Norwegian Ministry of Transport and Communication decided in a new Plan of Transport Development for 2006 – 2015 of the importance of improving tunnel safety because of the severity of consequences of a potential accident [2].

In the European Union there are 512 tunnels (mainly in Italy, Austria, Germany, France and Greece). Heavy goods vehicles, especially vehicles transporting dangerous goods present the main danger in tunnels. The basic cause of the accidents is the dangerous behaviour of drivers i.e. exceeding speed limit and drunk driving. The fire of a passenger car in a tunnel lasts about 10 – 30 minutes and release the energy of about 3 – 10 MW, whereas the fire of a heavy duty vehicle lasts from 1 – 4 hours and releases the energy of 30 – 150 MW. The temperature up to 700 degrees Celsius reaches even 500 meters into the tunnel depending on the direction of air-flow [3].

During several past years few extremely dangerous accidents occurred, which took place among others: in the Mont Blanc tunnel in France in 1999, where 39 people died as a result of few days long fire, in the St. Gotthard tunnel caused by a drunk driver where 11 people died (fig.1) and in the Tauren tunnel where 12 people died. The estimates are that the annual losses in fires and due to the reconstruction of the tunnels at that time amounted to 210 million Euros per year. Whereas the losses related the tunnels' closure amounted to 450 million Euros per year. [4].

Fig. 1. The scene of accident in St. Gotthard road tunnel which was caused by a drunk driver [5]

As the result of the accidents the European Union, apart from the existing national regulations, developed and issued a special Directive 2004/54/EC EU on minimal safety requirements in road tunnels belonging to the Trans-European Road Network TERN [6]. The Directive defines the guidelines concerning: the construction of a tunnel and safety equipment, safety management, requirements for participants and accidents management.

2. Risk management in tunnels

The road tunnels are the element of road network where the occurring accidents involve large number of victims and high cost. Therefore, for many years various guidelines, rules, recommendations and handbooks have been developed and improved for the assessment and management of road safety in that kind of objects. The introduction of the methods of analysis and assessment of the risk in safety management of chemical works and atomic plants brought about the adaptation of this method in the safety management in road tunnels.

The works have been carried out both on the grounds of particular, interested countries and international organizations. The example is the project designed by the OECD. The studies, which covered 33 long road tunnels, lead to development of quality method of risk assessment in QRAM tunnels and was used to select the most efficient actions to decrease the risk of accident in a tunnel [7].

2.1 The risk analysis

In the road tunnels risk analyses the risk standards are selected depending on the method: personal risk, social risk, economical as well as risk of damage on tunnel construction and on environment.
In 1991 in Switzerland the regulation on protection against major risks (OPAM), which introduced the obligation to carry out risk analyses also on the roads where hazardous goods are transported. The method applied consists in the setting the probability of the major transportation catastrophe occurrence (the death of at least 10 people, significant surface water or groundwater contamination).
In the risk-based analyses several groups of representative scenarios are analysed:

1. The risk related to people: (scenario „fire", „explosion", and "toxic gases release"),
2. The risk for surface water
3. The risk for groundwater

The probability of the occurrence of the emergency scenarios is calculated in relation to many factors i.e. the traffic volume, the share of heavy duty vehicles in the traffic, the share of vehicles transporting hazardous substances, the indicator/ ratio of accident occurrence on selected road type, probability of the release of hazardous substance, population in the vicinity of a road and the type of tunnel [8].
In the QRAM method developed by OECD the four groups of risk indicators were assumed: social risk (group), personal risk, risk of damage on tunnel construction and on environment. The 13 representative scenarios of dangerous incident in a tunnel were developed and divided into three basic categories: fire, explosion (fire plus fumes e.g. benzine) and release of toxic gases (chlorine, ammonia). Figure 2 presents the example of supplementary distributant F/N for selected hazardous substances transportation on roads [9].
The calculation of scenario occurrence probability is realized in the following steps:

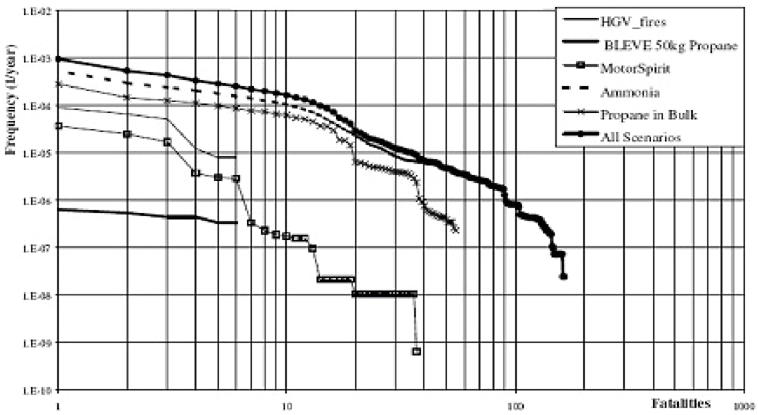

Fig. 2. The example of supplementary distributant F/N for selected hazardous substances transportation [9].

1. First the indicator of accidents with heavy duty vehicles (carrying or not dangerous goods) is defined for particular countries, built-in area, rural area, separated or not separated carriageways, the type of road surface.
2. Then the share of heavy duty vehicle and vehicle transporting dangerous goods in a year on analysed road is defined.
3. Then the share of accidents with heavy duty vehicles where the fire reaches the energy up to 20 MW and 100 MW is defined.
4. Finally the probability of scenario with the specific type of accident is defined.

Steps 1, 3 and 4 are carried out with the use of a model, whereas step 2 is defined by a person performing calculation.
The important factor which has an impact on the consequences of dangerous accident in road tunnel is the number of tunnel "pipes" and the distance from the fire or explosion epicenter. Figure 3 presents the dependence of the injured and fatalities share in accident from the distance to the epicenter of the accident.

2.2 Risk assessment

In Swiss method accepted risk level related to the occurrence of grave transport catastrophe with hazardous substances, in case of threat for people is: the probability $\leq 1{,}0\ 10^{-5}$ (per 1 km per year) of life loss of at least 10 people [8]. Figure 4, though, presents the criteria of social risk acceptance commonly used in road tunnels.

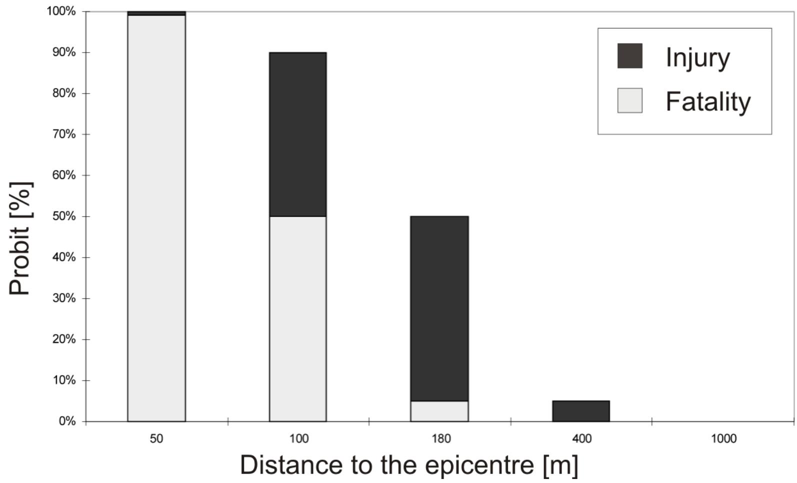

Fig. 3 The share of fatalities and injured in a road tunnel depending on the distance from the epicenter of dangerous accident [7]

2.2 Risk assessment

In Swiss method accepted risk level related to the occurrence of grave transport catastrophe with hazardous substances, in case of threat for people is: the probability ≤ 1,0 10^{-5} (per 1 km per year) of life loss of at least 10 people [8]. Figure 4, though, presents the criteria of social risk acceptance commonly used in road tunnels.

The curve (1) presents the highest limit of acceptance used in Great Britain [11], curve (2) presents the highest limit proposed by Trobjevica [12], curves (3 and 4) are accepted as a high and low risk limit in Holland [13], curve 5 as a high risk limit in Austria [14] and suggested as a low limit by Trojevica. The above comparison proves that particular countries establish individual, very different limits of risk acceptance in road tunnels.

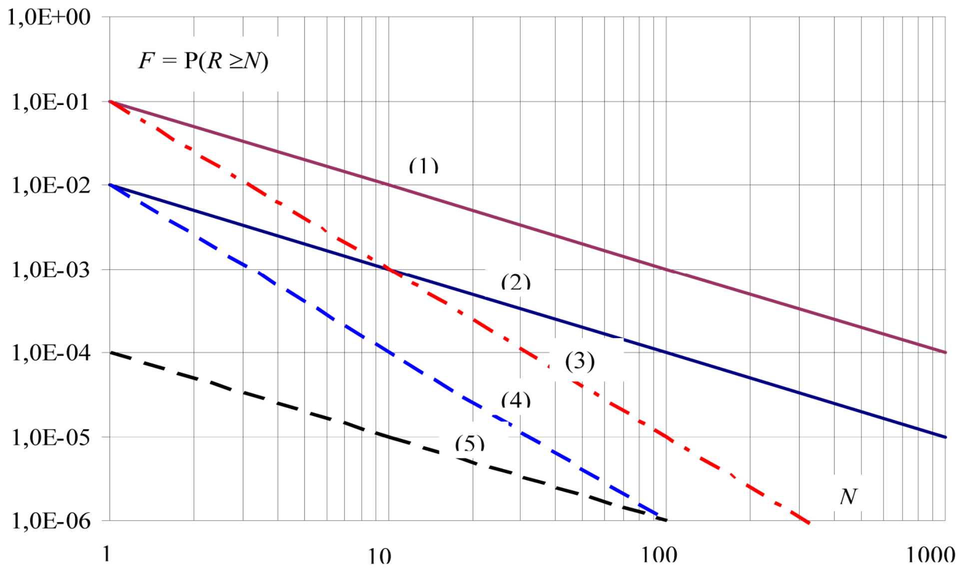

Fig. 4. The criteria of social risk acceptance commonly used in road tunnels [10].

2.3 Risk reduction and control

One of the analyses conducted as a part of safety assessment of a tunnel under construction is the risk assessment in a planned tunnel and on the possible alternative roads. The assessment procedure adopted in France has few stages. In the first one, the IR indicator is calculated and it is assessed whether passing through the analysed tunnel with dangerous materials fulfills the accepted safety criteria. If not, the alternative roads for dangerous materials transportation are analysed and the consequences of passing through them are compared with the consequences of passing through the tunnel. If there is no alternative roads or the consequences of passing through them is more dangerous than through the tunnel then the additional protection measures are applied which allow for reduction of risk during the transport of dangerous materials [15].

Within the framework of the studies with the use of QRAM method, OECD carried out the assessment of effectiveness of 27 different activities which influence the reduction of risk in road tunnels [7]. On this ground they developed the tools supporting decision making and the selection of effective activities. Among analysed and recommended activities for the reduction of risk in road tunnels the following were distinguished:

- Activities to reduce the accident risk:
  - Related to tunnel design and exploitation: cross-section, (separated carriageways), visibility, geometrical parameters, lighting and road surface (tightness)
  - Related to vehicles and road traffic: speed limit, no overtaking, convoy assembly, distance between vehicles, vehicles control,
- Activities to reduce the accident consequences:
  - transferring information to operator and emergency system: internal television, automatic accident detection, fire detection, local radio (service), automatic vehicles identification, emergency telephones,
  - information for tunnel users: emergency telephones, local radio (tunnel users), alarms and signals, speakers,
  - users evacuation and protection: safety exits, smoke control, lighting (emergency), rescue equipment, error management,
  - reducing the severity of accidents: fire equipment, rescue team, draining off water, road surface, emergency plan, escort,
  - reducing the consequences in tunnel: fire brigade structure, anti-explosion service structure.

The following tools will help decision makers to:

- assess the risk in existing and planned road tunnels,
- select the variant of road with or without tunnel,
- select effective activities to reduce the risk in case of construction of a tunnel,
- inform local society about possible threats resulting from tunnel exploitation.

4. Conclusion

Recently in Poland the tunnels over 500 metres long have been built in Warsaw and Katowice and the further are planned, among others 3 tunnels in Tricity. One of them which will run under the Martwa Wisła (Dead Vistula) in the scheme of Sucharski Route (linking Gdańsk Port with the national roads network) will be about 0.8 km long and will take over the transit traffic (including vehicles with dangerous good to the port and factories situated in the port district of the city) from densely populated centre of Gdańsk.

The analysis of Sucharski Route efficiency (including tunnel) shows that its construction will cause in the year of the opening for traffic (2012) [16]:

- Shortening the total journey time by 7.9 mln hours/year,

- Decrease in the use of fuel by 10.8 mln l/year,
- Decrease in the emission of CO_2 by 0.7 mln tonnes/year, a NOx by 0,1 mln tonnes/year,
- Decrease in the number of road incidents by 313 accidents and collisions/year and accidents victims by 44 persons/year,
- Decrease in the total costs of traffic by 166 mln PLN/year.

Whereas the risk of occurrence of catastrophe with more than 10 fatalities per 1 km per year (according to Swiss method) may amount to:

- In the tunnel under the Martwa Wisła:
  - In case of two separated carriageways: $P = 1.36\ 10^{-6}$,
  - In case of one carriageway: $P = 2.62\ 10^{-6}$,
- On the alternative router through the city centre: $P = 5,38\ 10^{-6}$.

The above calculations show that the risk of the occurrence of catastrophe with more than 10 fatalities in a planned tunnel is low and does not exceed the risk accepted according to criteria presented in fig. 4.
The calculation are, however, simplified and do not consider Polish conditions. Therefore it is necessary to elaborate Polish method of risk management in road tunnels including conditions of Polish traffic and the behaviour of traffic participants.

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