Assessment of retaining levels of safety barriers

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Abstract

Thousands of human lives are annually lost on European roads including the Czech Republic. The main risk associated with the car collisions is the harm to people traveling in the vehicle or to people in the road surroundings. It follows that the main priority in performing risk analysis is to minimize this risk. In order to determine the potential costs due to casualties in car accidents, the concepts of the Implied Costs of Averting Fatality (ICAF) and Life Quality Index (LQI) are applied.

It is shown that current standards do not provide sufficient information for the optimal decision about the retaining capacity of road safety barriers close to the resources of drinking water, railways, roads and other hazardous types of road surroundings. The Bayesian network method is applied representing a suitable tool for risk analysis in accidental design situations.

The objective of submitted risk assessment is to optimize the selection of the retaining levels of safety barriers taking into account different categories of roads and bridge surroundings.
Keywords: safety barriers, retaining level, categories of roads, risk assessment.

1 Introduction

Road safety barriers provide protection of traffic on roads as well as their close surroundings. Various aspects have to be considered for selection of appropriate types of safety barrier including road categories, surface characteristics, allowable velocity of cars, types of road surroundings and traffic intensity including expected future trends. For selection of appropriate safety measures, the retention level for a road barrier has to be determined considering danger sections of roads and protection of road surroundings.

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The presented study is focused on the optimization of the retention level of safety barriers taking into account accident data recorded in the Czech Republic in the last few years. Results of analyses and further information are expected to be used as background materials for the revision of the Czech Technical requirements TP 114 [7].

2 Risk analysis

The Bayesian network is applied for analysis of the retention level of safety barriers facilitating to describe various accidental scenarios and for verification of event tree method used in previous studies (Markova and Jung [5]). Individual risk R_i is given as

$$R_i = p_i \times C_i \tag{1}$$

where p_i is the probability of occurrence of accident i and C_i its expected consequence. The total risk R is specified as a sum of all considered risks given as

$$R = \sum_i p_i \times C_i \tag{2}$$

Five types of vehicles are considered in analyses:

- heavy goods vehicles (HGV),
- danger goods vehicles (DGV),
- buses,
- cars,
- motorcycles.

The traffic composition needs to be based on traffic data, (Markova and Jung [5]).

The number of accidents n_{veh} for considered type of vehicles per one year is expressed as

$$n_{veh} = N \times L \times p_{veh} \times p_a \tag{3}$$

where N is the intensity of all vehicles on the road, L is the length of the considered road section, p_{veh} is the ratio between the number of relevant type of vehicles to the total number of all vehicles in the road, p_a is the annual probability of accident occurrence for the type of vehicle.

For the analysis of retention level of safety barriers, the data of accidents are available, recorded in electronic version in the last few years. Different causes of car impacts are distinguished including impacts to bridge columns, safety barriers, walls, buildings, car collisions etc. Three types of roads are considered: motorways, and roads of 1st and 2nd class (country national and main roads). Figure 1 indicates that the main risk with respect to the obstacles near roads is associated with impact to trees, bridge piers and walls.

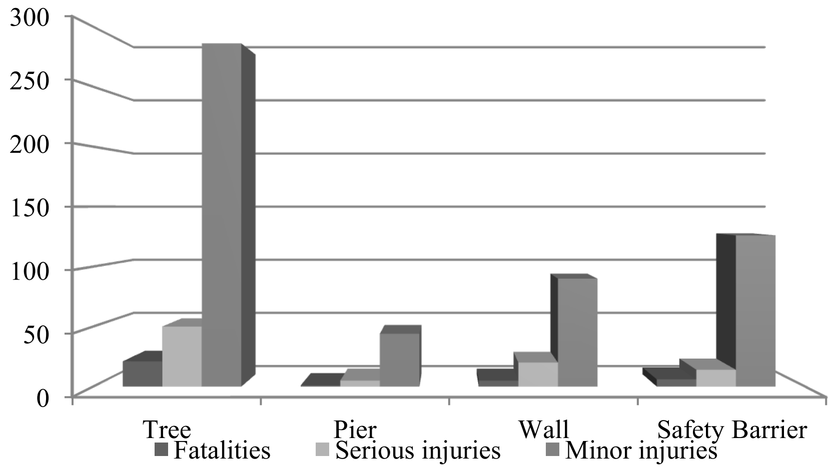

Figure 1: Number of fatalities, serious and minor injuries for roads of first classes in the Czech Republic (year 2011).

3 Consequences

Social, economic and ecological consequences should be considered in accidental situations due to car collisions. Social consequences are the most significant in this consideration as human lives are endangered during accidents.

Consequences of car accidents and probabilities of serious injuries or fatalities are based on comparison of the kinetic energy E_k of considered type of vehicle and the capacity of safety barriers. The kinetic energy of impacting vehicle is given as

$$E_k = \frac{1}{2} m \times (v \times sin\, \alpha)^2 \tag{4}$$

where m is the vehicle mass, v its velocity and α a direction angel of impact. The maximum permitted velocities for vehicles in relevant types of roads are considered.

It is assumed that the structure reacts to rigid plastics, and the maximum displacement follows from

$$\frac{1}{2} m \times \varepsilon \times (v \times \sin \alpha)^2 = F_c \times u_d \tag{5}$$

where F_c is the static force and u_d is the deformation of the structure at fracture.

Failure occurs if u_d exceeds the deformation capacity of the barrier. This deformation capacity depends on materials properties. A perfectly elastic collision has a coefficient of restitution of $\varepsilon = 1$. Typical collision has coefficient of restitution ε between 0.55 and 0.8 (Coon and Reid [1]). It is clear that barriers made of materials with higher deformation capacity could provide better protection and due to a minor force lower danger for passengers.

The capacities of safety barriers for several levels of retention N1 to H4b are given in Table 1 according to standard EN 1317-1 and also national prescriptive document TP 114.

Table 1: Capacity of safety barriers E_k [kNm].

Type	N1	N2	H1	H2	H3	H4a	H4b
E_k	43.3	82.9	126.6	287.5	426.1	527	724.6

The total risk R may be determined from formula

$$R = 1000 \times C_s \times L + \sum p_{f,n} \times C_n + \sum p_{f,en} \times C_{en} \tag{6}$$

where C_s are the costs for acquisition of road safety barriers, L is the length of road section, $p_{f,n}$ is the probability of human fatalities or injuries, C_n are the relevant social costs, $p_{f,en}$ is the probability of accident occurrence for different types of vehicles, C_{en} are economical or ecological loses due to accident, expressed in monetary units.

The main risk is connected with lose of human lives. The costs applied in presented analysis are based on information of the Transport Research Center of the Czech Republic (www.cdv.cz). The economical loss for one fatality is considered here as 333,000 EUR, for serious injury as 112,000 EUR and minor injury as 12,500 EUR.

It should be noted that these values seem to be rather low. Each fatality prevented on British roads represents an approximate overall saving of £1.3m and each serious injury prevented represents a saving of £150,000 (Farmer [4]). These analyses are based on economic as well as social and environmental factors including loss of earnings, costs of hospital treatment and other social costs. The value of preventing the road traffic accident may be estimated on the basis of the cost-benefit analysis.

Other possibility to describe loses due to accidents may be also based on ICAF (Implied Cost of Averting a Fatality) given as

$$\mathrm{ICAF} = g \times e \times (1 - w) / (4 \times w) \tag{7}$$

where g is the gross domestic product per person per year [€/year], e is the life expectancy at birth [year] and w is the proportion of life spent in economic activity (Diamantidis [3]).

4 Risk assessment

The presented study is focused on the determination of retention levels of safety barriers taking into account accident data recorded in the Czech Republic in the last few years. The aim is to provide basic background for selection of safety barriers.

Accidents involving impact from vehicles can be caused by many factors and encompass many consequences.

The main parameters affecting accidents include

– Speed, mass and direction of impacting road vehicle,
– Rigidity and construction of the structural elements of barriers,
– Roads layout and geometry (curves, slope),
– Usage of roads surrounding at time of the incident.

The main parameters affecting accidents which are not covered in this analysis include

– Act of sabotage,
– Human failure.

The study is based on minimization of risks. Optimal retention level for safety barriers is illustrated in Figure 3. Selection of lower retention level increases risks as the protection could not be sufficient. Selection of higher retention level increases risks for passengers in cars, while the surrounding is more protected.

5 Bayesian network

A Bayesian network was developed for verification and comparison of achieved result by event tree method. The network was developed in program Genie and contains 5 random nodes, 5 utility nodes, and 2 decision nodes illustrated in Figure 2.

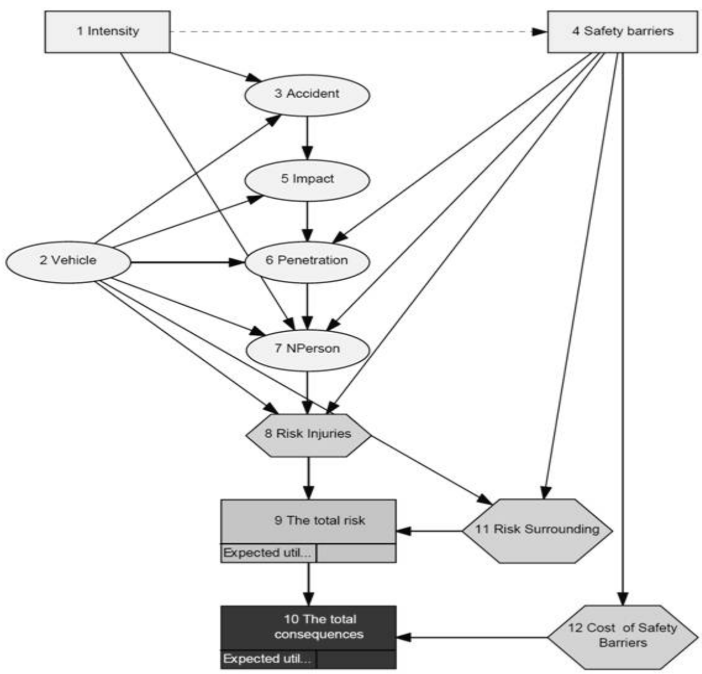

Figure 2: Bayesian network used for the analysis of safety barriers.

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5.1 Decision nodes

There are two decision nodes in the presented study – the *Intensity of traffic* and the proposed type of the road *Safety barriers*. The decision node "*Intensity of traffic*" has three states.

- Small intensity
- Medium intensity
- High intensity.

The decision node "*Type of safety barriers*" has eight states, the first state "No barriers" is unprotected surrounding. Other seven states cover classes of the retention capacity of safety barriers. Individual levels are given in Table 1 according to the standard EN 1317-1. The eighth state is assumed for surrounding without need of protection. No barriers could be accepted only in places not covered by surrounding considered here and where there are sufficient and safe leaving zones.

5.2 Utility/value node

A utility node represents an additive contribution to the utility function in an influence diagram. Thus, the utility function is the sum of all utility nodes in the influence diagram. *Cost of Safety Barriers* – this node describes the cost of new safety barriers. The cost is based on the price per 1 kilometer. The utility nodes represent the economic factors and adverse consequences.

A more detailed description of the nodes is provided in the following list, which also indicates difficulties in input data specification.

The utility nodes describe risks due to economic and environmental lose on surroundings considered as:

- Cost of Safety Barriers,
- Risk Surrounding,
- Risk Injuries,
- The Total Risk,
- The Total Consequence.

The Total Risk is a sum of all risks for each type of safety barriers. The Total Consequence is a sum of all Consequences and Costs of Safety Barriers.

5.3 Random nodes

These nodes describe randomness in the proposed analysis. There are five random nodes

- Collisions,
- Impact,
- Penetration,
- Vehicles,
- NPersons.

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5.3.1 Node "Accident"

Node "Accident" describes probability of a collision per one year and one kilometer of road. Tables 2 to 4 show probabilities for three collision intensities.

Table 2: Probability of collision per 1 kilometer and 1 year – small intensity.

State	**HGV**	**DGV**	**Car**	**Bus**	**Motorbike**
No Collision	0.983	0.999	0.952	0.997	0.993
Collision	0.017	0.001	0.048	0.003	0.007

Table 3: Probability of collision per 1 kilometer and 1 year – medium intensity.

State	**HGV**	**DGV**	**Car**	**Bus**	**Motorbike**
No Collision	0.900	0.999	0.723	0.979	0.960
Collision	0.100	0.001	0.277	0.021	0.040

Table 4: Probability of collision per 1 kilometer and 1 year – high intensity.

State	**HGV**	**DGV**	**Car**	**Bus**	**Motorbike**
No Collision	0.730	0.998	0.255	0.946	0.891
Collision	0.270	0.002	0.745	0.055	0.110

5.3.2 Node "Impact"

Random node "*Impact*" describes the probability of vehicle collision with safety barriers. The records in the Czech Republic show that about 60% of all accidents on motorways results from impact into safety barriers".

5.3.3 Node "Penetration"

The impacting vehicle may break through the barrier into opposite carriageway or surrounding, rebounds back into the original carriageway, or remains close to the barrier. Random node "*Penetration*" describes the probability of penetration into surrounding. Williams [10] shows that about 7% of all accidents involved in impacting a safety barrier break through into surrounding.

Further these probabilities are depending on containment level of safety barriers and the type of vehicle.

Probability that the safety barriers might be overcome for each retention capacity and vehicle type should be estimated. Number of endangered passengers is described by probability for each type of vehicle and each type of barriers.

5.3.4 Node "NPersons"

Node "*NPerson*" describes the number of endangered persons for each type of vehicle.

This node has six states (No Person, N1, N2, N5, N10 and N25).

5.3.5 Probability of impact into barriers

It is estimated for different speed categories and types of vehicles.

The main parameters describing the kinematics of vehicle are the velocity and angle. Data concerning velocity are not available. The direction angle α varies from 0 to 30° or 40°; Raleigh distribution could be used for the direction angle with a mean equal to 10–15°.

5.3.6 Probability of barriers penetration

These probabilities are estimated in accordance with the permitted speed and type of vehicle. In case of safety barriers it is supposed that the structure is elastic and the colliding object is rigid. In accordance with EN 1317 it is assumed that the barrier structure is designed to absorb the impact energy by plastic deformations. It shall be ensured that its ductility is sufficient to absorb the total kinetic energy of the colliding object. In the limit case of rigid-plastic response of the structure, the above requirement is satisfied where F is the plastic strength of the structure, i.e. the quasi-static limit value of the force F; y_0 is the displacement of the point of impact that the structure can undergo.

5.3.7 Probability of secondary collision

These probabilities are affected by the intensity of traffic and maximal speed. When the barriers are overcome, the secondary collision means collisions with vehicle going in opposite direction. In case the barriers are not overcome, the secondary collision may be rear or side collision with vehicle in some direction. It is supposed that the consequences of secondary collision are lower than the collision with vehicle going in opposite direction.

This is due to the fact that lower number of rear impacts lead to serious casualties than frontal casualties and due to the less structural possibilities to influence the outcome of a rear impact.

Table 5: Probability of scenarios and extent for vehicles.

Scenarios	S_{Z1}	S_{z2}	S_{z3}	S_{z4}	S_{z5}	S_{z6}
Impact	Yes	Yes	Yes	No	No	No
Penetration	Yes	Yes	No	No	-	-
Secondary collision	Yes	No	Yes	No	Yes	No

6 Results for selected example – central barrier on motorway

Motorway maximal allowed speed is 130 km/h for cars and motorbikes, 80 km/h for HGV and DGV and 100 km/h for buses. Total intensity is 42 500 vehicles per day.

The diagram in Figure 3 shows results for central barriers where safety barriers with retention level H2 are selected as optimal decision which corresponds to E_k = 287.5 kNm.

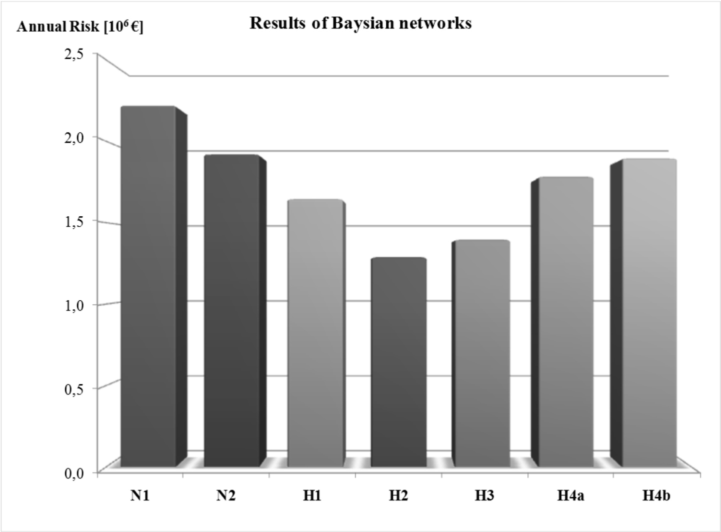

Figure 3: Results of the analysis based on Bayesian network.

Table 6: Proportion of vehicles.

Type of vehicles	Number	Ratio
HGV	13081	30.78%
DGV	9	0.02%
Buses	3400	8.00%
Cars	25925	61.00%
Motorbike	85	0.20%

7 Recommended retention level of safety barriers

A proposal for the retention level of safety barriers has been prepared in co-operation with Czech authorities, taking into account the results of risk assessment (see Tables 7 and 8). Several classes of dangerous surroundings, intensity of heavy vehicles and two hazard levels (common and higher level) are considered.

Similarly, Table 8 was proposed for retention levels of safety barriers on bridges taking into account eight classes of surroundings.

Table 7: Recommended retention levels of road safety barriers in common hazard rate.

Class	Surrounding	Mean value of heavy vehicles per 24 hours		
		<1000	1000–5000	>5000
1.	Drinking water resources	H2	H2	H3
2.	Railways	H1	H2	H2
3.	Place with high frequency of pedestrians	H1	H2	H2
4.	Buildings	H1	H1	H2
5.	Central barriers	H1	H1	H2
6.	Parallel roads	H1	H1	H2
7.	Roads in different level	H1	H1	H2
8.	Rivers or water reservoirs	N2	H1	H2
9.	Scarps, embankments	N2	H1	H1
10.	Other danger places (trees, portals)	N2	H1	H1
11.	Noise barriers	N2	N2	N2

Table 8: Recommended retention levels of safety barriers on bridges in common hazard level.

Class	Surrounding	Mean value of heavy vehicles per 24 hours		
		<1000	1000–5000	>5000
1.	Drinking water resources	H2	H2	H3
2.	Railways	H2	H2	H2
3.	Places with high frequency of pedestrians	H1	H2	H2
4.	Buildings	H1	H2	H2
5.	Rivers or water reservoirs	H1	H1	H2
6.	Parallel or crossing roads	H1	H1	H2
7.	Central barriers	H1	H1	H2
8.	Other danger places, portals	H1	H1	H2

8 Conclusions

Risk assessment based on accidental data for motorways and main roads facilitates to propose the new retention levels of safety barriers to the revision of the national prescriptive document TP 114.

Several classes of road environment are updated or refined. For decision on the retention levels of safety barriers several significant basic variables are identified including the daily average intensity of heavy vehicles, maximal permitted car velocities and the level of potential risk.

The retention level is analysed by Bayesian network taking into account the road category, heavy car intensity and various types of road or bridge surroundings. The higher intensity of heavy goods vehicles increases the probability of accident and usually also increases the needs for higher retention level of safety barriers. Therefore, for the passenger cars or motorbikes, it leads to significant risk increase.

Analyses of data indicate in some cases discrepancies on reported accidents including location of accidents, impacted safety barriers (central or lateral barriers) and description of consequences.

Many questions and uncertainties remain still open in the risk analysis of road safety barriers. The behaviour of the barriers made from different materials should be analysed in more detail. Wire-rope barriers represent special problem. Are the wire-rope barriers dangerous for motorcyclist and could they endanger a convertible car? Is it acceptable to use on our roads the safety barriers which could protect one type of passengers however be danger for other passengers?

It should be noted here that implementation of safety measures is a complex process involving official authorities, designers, road maintenance service, producers of safety barriers, testing institutions etc. It is expected that newly proposed provisions for retention levels will facilitate selection of appropriate types of safety barriers.

Acknowledgement

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