Modelling of Road Safety Evaluations at the Regional and Local Level in Czech Republic

Tomáš Kořínek, Jiří Křupka, and Radovan Soušek

***Abstract*—**Road safety is a topic, that is very much and for already long period of time, in the centre of attention, especially in the developed countries. The objective of this article is to introduce two alternative approaches to evaluation of road safety, its risks respectively. The first objective focuses on the evaluation of the overall road safety in Czech regions based on the so called Road safety rate. The second approach focuses on a much smaller segment of road transportation, the transportation of dangerous substances, and also on concrete dangerous locations/spots along the transportation route. The objective is to define the probability of an accident arising and of its potential impacts on the environment.

***Keywords*—**Dangerous substance, ecological risks, regional comparison, road safety rate.

I. INTRODUCTION

CURRENTLY there is a trend to see road safety responsibility as a shared and cross sector issue and it is also considered to be more and more ambitious matter concerning the results. The effort to keep the road safety level high is evident in particular in the developed countries and it requires management system based on an effective institution management that can bring about the desired results [1]. The fulfilment of the main objective, that is to prevent death and serious injuries caused by a traffic accident, requires uninterrupted implementation of the already tested procedures and processes and targeted programs jointly with innovative solutions that are so far based on the tested fundamental safety principles.

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There is a generally accepted view that safety plans and objectives must be regularly monitored and the obtained results must be analyzed and evaluated to test the obtained progress and to adopt essential changes according to the current observed trends. The progress in road safety measures is usually evaluated from the view point of the number of accidents, injuries and their social costs. However, simply calculated accidents and injuries may often be less than perfect indicators of the road traffic safety level. It is typical that accidents and injuries are only the top of an iceberg since they happen as the „worst case scenario“ in dangerous operational conditions on the road system. For a high quality road safety management we must take into consideration the most diverse scope of factors that influence safety or mainly those factors that we can directly influence or at least regulate.

Evaluation is, next to decision making and predicting, one of the basic elements of the road safety management process. The evaluation can be generally done from two different views on the area evaluated. Firstly this issue can be observed from a broad view where, in a majority of cases, selected territories (countries or regions) are compared by utilizing aggregated data and indicators. Secondly it can be done from a more narrow view where the attention is given to concrete dangerous places/spots, segments or regions and it is based on concrete data collected on individual accidents (localization of traffic accidents, spatial analysis of traffic accidents groups, developing relation between individual accidents on the road network and the volume of traffic (intensity, traffic performance) [2]. Recently, a number of studies were carried out aiming at the evaluation of road safety, which enabled meaningful international [3]-[5] or subnational (e.g. regional, local etc.) [6]-[10] comparisons and monitoring of road safety performance.

For a detailed analysis it is suitable to segment the accident indicators total values according to individual partial characteristics related both to communication and to traffic participants [11]. In this way it is possible to obtain much more exact and detailed picture on individual causes and consequences of accidents and then based on this knowledge it is possible to implement suitable security measures that can be much better targeted to individual road traffic participants groups, or sections of the communication network respectively. The elementary sorting of indicators is done by the type of communication (in municipality, out of municipality, highway, or other types of categorization – highway, 1st class, 2nd class, 3rd class, local communication, specific purpose communication, or by the shape characteristics of communications (straight line, road curve, intersection), type of participant (foot passenger, cyclist, motorcyclist, driver or passenger in a car, lorry/transport vehicle, bus, other), or by participant age (age groups 0-14, 15-24, 25-64, over 64 years; possible is also some other division – e.g. by five-year intervals) and by sex. For a deeper analysis there are possible combinations of the individual types of categories. For the evaluation and comparison of the individual target groups risks we introduce risk rate indicator as a rate of the base accident characteristics (e.g. number of deaths) related to transport functions (exposition) or potentially to another quantitative indicator (number of cars or number of inhabitants).

In the Czech Republic (CR) the Transport Research Centre (CDV) researches into the road safety evaluation issue. CDV cooperated, on the international level, in project SUNflower+6 [12], in which, next to the CR, another 8 European countries participated. This project focused on road transportation safety. Following on that activity, CDV employees took part in the development of methodology, design and creation of a compound road traffic safety index. 27 selected European countries were compared by means of this index. The Centre also focuses on research into road safety on the local and regional levels [2], [13], [14]. Under its activities the Centre also researches into the road transportation environmental impacts issue [15]-[18].

The first objective of this paper is the introduction of the proposed approach to the evaluation and comparison of the overall development of road safety among the CR regions in years 2007 to 2009 based on the calculation of so called regional road traffic safety rate.

Another objective is to introduce selected outcomes from the already completed project BIOTRA [19] and mainly to introduce the issue of defining dangerous substance transportation (ADR-Accord Dangereuses Route) accident probability in relation to the road/communication character and risk integration methodology for the environment along the transportation route, this includes also the evaluation of possible impacts on the environment due to accidents.

II. Problem Formulation

The content of the first part of this Chapter is mainly the road safety management pyramidal concept characterization, this concept creates the theoretic base for a road safety evaluation tool developed by ourselves.

In the second part of this Chapter there is briefly described the issue of transportation environmental impact and also the main objectives of BIOTRA project are introduced there.

A. The road safety management system

Since 1950, the approach to the road safety management has come through four main phases of development (focused on driver → system intervention → institutional management → shared responsibility), which tried or are trying to increase the traffic safety by many different ways. Gradually there is a change from the problematic of decreasing the number of accidents to the prevention of the injuries and partly also to change in responsibility from the user to the system petitioner. Now there is a more common opinion, that the responsibility of the road safety is shared and more sectored. From the required results point of view the policy of the road safety is more and more ambitious, which reflects in accepting the international strategies and their implementation to the national strategies.

Safety in the traffic is long-lastingly considered as a very important and if it is adequate, it means that the society is developed well. As a result of the accidents is a high social cost. Decreasing the number of accidents has become the objective of all developed countries since the 70s of the last century.

The Czech Republic (CR) belonged to the most progressive countries till the half of the 80s in this field. Since then there have been several changes during the following years and the CR has become the worst from the European countries, in the studied indicators of the accidents frequency. The attempt about leaving this position is clearly declared also by the CR government. In the National Road Safety Strategy (NRSS) 2004-2010 [20], which was accepted by the government in April 2004, CR claimed to meet this objective with other European countries, declared primarily in the White Paper about the transport policy of EU [21], i.e. decreasing the number of dead people in the traffic by the year 2010 to the half of the statistics of the year 2002. An important part of this strategy is to use a system approach and its continuous application to achieve the objectives. The system approach is applied mainly to solve complex problems that cut across the various areas of human knowledge and cognition [22]-[25]. According to the statistics, it is now known, that this objective has not been met at last. New appeals were accepted by the government in published NRSS 2011-2020 [26].

To increase the level of safety of the traffic, it is important to study different factors influencing the safety itself. As the safety of the traffic presents the complex multidimensional problem, the very good knowledge of this field is needed for its complex understanding. For the analysis and evaluation of the traffic risks, it will not be rational to take into consideration only several selected simple indicators. On the other hand the long experience proves that 10 to 15 indicators can be evaluated lucidly. With the higher number of the indicators it is less tabular, less understandable in needed context and the explanatory power of the analysis. Similarly as in other fields, the attempts to make and use composite indicators are becoming to be used in the last decade, mainly in comparing the road safety among the selected countries [3], [27], [28].

Because of the complex multidimensional problem of the road safety, there was a hierarchy structure for objectives setting in the field of the road safety developed in the form of pyramid. This pyramid concept was developed in New Zealand and originally had four layers [29]. The model was widely adopted in several European projects. The pyramid is still being developed, widened and adapted [3] , [30] , [31]. Within the SUNflower project [30] the pyramid was widened by another lower level. This pyramid is therefore formed by the following levels (mentioned in the order from the top to bottom):

- Social cost
- Number of killed and injured
- Safety performance indicators (SPIs)
- Measures and programs
- Structure and culture

Shown concept is broadly accepted and used by many experts in the field of road safety. Comparing the targeted objectives can be done in three dimensions: vertical one for each levels of the pyramid, horizontal one for each territorial unit and also in time, for recording the trends [3].

Because the model in the form of the pyramid cannot always clearly define the effects and relationships between each element, we can also represent it in the form of series (Fig. 1), where each element is firmly bonded with the others and its performance is significantly influenced by the previous element, the same way as the element itself influences the following one.

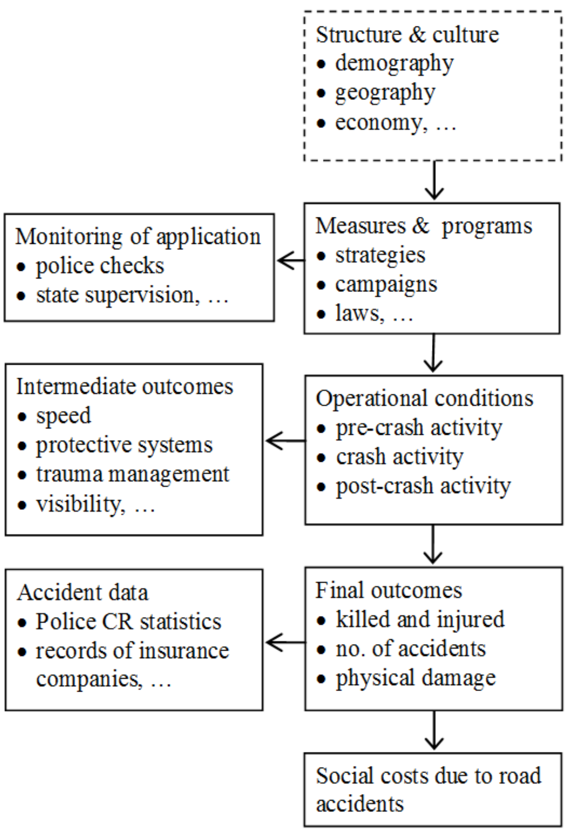

Fig. 1 Model of the road safety management system (road safety pyramid in the form of series)

Before the enlargement of the pyramid by adding the bottom layer (structure and culture), there was put legislation in this series into the beginning and then the measures of the road safety representing the general operating conditions for the road safety (e.g. speed limit in the towns and villages, point system start). Successfulness of the programs in place and measures can be evaluated via indirect indicators of the road safety. This safety performance indicators taking into account those operating conditions (intermediate outputs) which have the influence to the final performance influencing the whole system (final outputs). These indicators are the important source of information reflecting the effectiveness and assets of those precautions of the road safety which are embedded in legislation and whose application is checked e.g. via Police work. The basic feature of these indicators is their ability to measure dangerous operating conditions of the traffic system and their independence on the specific safety intervention. The other groups of indicators are the final outputs expressed by mainly numbers of killed and injured road users. These outputs should not be analysed separately without deeper understanding of which elements of the system prepared conditions for their occurrence. The series is closed with overall social cost, which are the costs imposed to the society, road users, providers of the emergency services etc. as a result of accidents.

In CR the Transport Research Centre has already proposed and used the tool [14] for this purpose. The basis of the comparison was the data about numbers of accidents with personal results, which relates to relativized indicators, i.e. number of inhabitants, region area, length of the roads, the amount of registered cars. In every indicator there is learnt an average value for CR, which every regions' values relate to. For the overall comparison of every region signifies that the more the value differs from the republic's average, the more positive or negative signs the regions get. In the overall comparison the number of negative signs is deducted from the number of positive signs.

B. Transportation Environmental Impact Assessment

Transportation Environmental Impact Assessment is currently focused primarily on the assessment of parameters that are directly related to transportation intensity – air pollution, dustiness, noisiness, possibly also the accident rate. When planning further development of transportation infrastructure-both when developing new capacities and extending existing capacities or when deciding on allowing concrete types on transportation on the existing roads, it is essential to take into consideration also the impact of dangerous substance transportation on population and on the environment along the transportation communications. A number of experts from a couple of universities (The Technical University in Liberec, Jan Perner Institute in Pardubice, The South Bohemia University in České Budějovice and J.E. Purkyně Univerzity in Ústí nad Labem) as well as some professionals from the practical walk of life researched into this issue under the BIOTRA project. The main objective of the BIOTRA project was to create methodology for evaluation of ecology risks related to dangerous substance transportation on transportation infrastructure, that done with a specific focus to environment biotic components in its environment and to create a tool for decision making over environmentally friendly transportation alternatives choices.

A lot of attention was given to the issue of defining the probability of an accident when transporting dangerous substance (ADR) in dependence to the communication characteristics. Another important partial objective of the project was to elaborate environment risk along the transportation route integration which is assessed on the accident frequency rate, negative impact on partial area probability and environmental/ecological damage. Integration is done in the GIS environment and the identification of the potential damage territory/area biotope is an integral part of this integration. Risk integration utilizes the results of all already solved partial project objectives and the resulting risk is expressed in financial units. More detailed information is stated in Chapter III.B.

During solving the project's individual tasks some supporting software tools were created. These SW tools solve calculation of gas dispersion in the marginal/limit atmosphere layer, dispersion of liquid in terrain, calculation of frequency of hitting partial areas along the route of the mobile source by negative impact, definition of unit risks in individual areas and the total society risks along the route.

The standard environmental impact assessment evaluation methodology used for the already existing and planned transportation routes is focused on assessment of air pollutants, dustiness and noisiness of regular traffic. However also the possibility of a transportation vehicle's accident resulting into dangerous substance leak into the environment is also part of transportation traffic risks. This is a multi-disciplinary issue that includes technical, natural science, ecology and social and economic issues.

According to police statistics, there were in total 1437 road accidents with participation of vehicles transporting dangerous substances in the Czech Republic between years 2002 and 2009. Out of this number of accidents nearly every tenth accident included leakage of transported dangerous substance. The probability of a serious accident is relatively low but its consequences can be dramatic thus it is essential to prevent such accidents and to take essential measures to prevent such accidents.

Risks can be quantified and to make decisions on such risk acceptability a certain quantification is even essential. The rate of the risk is demonstrated by the quantitative evaluation. It is a numeric value (e.g. estimated number of deaths caused by accidents per year) or a numerical function which describes the relationship between the probability and the impacts of the given risk. The sources of risk may vary-it can be an equipment, an activity or technology, but also other types of objects or processes that endanger a human being or the environment.

In our case as risk R we understand the product of the probability of dangerous situation arising P and its impacts (outcomes) N [32]. This can be expressed by a symbolic recording of a relation (1):

$$R = P \cdot N \tag{1}$$

The stated relationship represents only the basic approach. Possible impacts (death, injury, permanent damage to person's health, but also the damage to soil, air and vegetation, surface and subsurface waters and damage to material objects) have also their probability. The probability component in the relationship has on the general level a relation not only to the origination of the events but also to the issuing impacts.

The evaluation of risk is defined as a set of risk evaluation procedures, as a rate of potential danger upon the execution of activity analyzed and thus the determination of the probability of unwelcome negative phenomena origination, its impacts and their mutual combinations [32].

A more independent task is the determination of traffic accident probability. It is dependent mainly on the transportation vehicle, transportation infrastructure, traffic situation, human being, climatic conditions. The result of the modelling is the probability that in a certain point (on the traffic infrastructure) there happens a certain defined consequence/impact (e.g. human being death and similar). This probability is described as an individual risk.

The total individual risk thus expresses the probability of a certain consequence for an individual from the endangered population or for a unit land area/volume of the environment located in a certain distance (in more general the location) from the accident's point. The total individual risk can be found by a cumulating of partial risks for all considered combinations of current existing conditions with the weight of the probability of their incidence [32]. In case of a mobile source it is possible to cumulate also potential contributions of risks issuing from the possibility that an accident happens in various different locations on the route. An individual risk is linked to coordinates. Its value does not depend on the fact if the subject or object for which we evaluate the risk is at all present in the given location. The product of an individual risk and the presence of subjects/objects in the partial area represents a partial society risk. Calculation by partial areas is essential there where the individual risk is dramatically dependent on the location against the source. The total society risk is obtained by the cumulating of partial risks. [32]. First the cumulating is done separately by individual subjects and objects. Only then it is possible to transfer the risks for individual entities to comparable description level (probably semi quantitative, by means of a point allocation) and to execute the evaluation of society risks of transportation on a concrete route.

III. Problem Solution

Also this chapter is divided into two parts. In the first part we introduce the tool we have designed for the evaluation of road transportation safety and then we use this tool to compare and show the trends in road safety in the CR regions in years 2007-2009.

In the second part there are described two of the already mentioned outcomes of the BIOTRA project in more detail. First the solution of the accident probability issue and after that the risk integration as a consequence of an unwelcomed event along the route and the evaluation of its acceptability.

A. *The evaluation of road safety level in Czech regions*

Our first aim is to propose the evaluation tool, based on the wider spectre of the indicators. For the evaluation of the regional road safety in CR it is necessary to form a tool with sufficient explanatory power for interregional comparison, easy to be counted and for the receivers of information also understandable enough. The objective of the comparison of the road safety in the regions of CR is to form the space for demonstrating the situation in this field including the regional differences and specifications. This comparison can be a tool for increasing the road safety especially via targeting the safety campaigns and police supervision, investment into suitable precautions etc. Setting the form of the mentioned tools can result of the analysis of the road safety in the regions and their development in time.

For reaching our objective the following steps were realized:

1. Defining the theoretical framework
2. Proposal of the wide set of indicators
3. Data collection
4. Data analysis
5. Selection of the best commonly accessible indicators
6. Weighing and aggregation of the indicators
7. Calculation of the road safety rate of every region
8. Results analyse

The scheme of proposed road safety evaluation model is shown in Fig. 2.

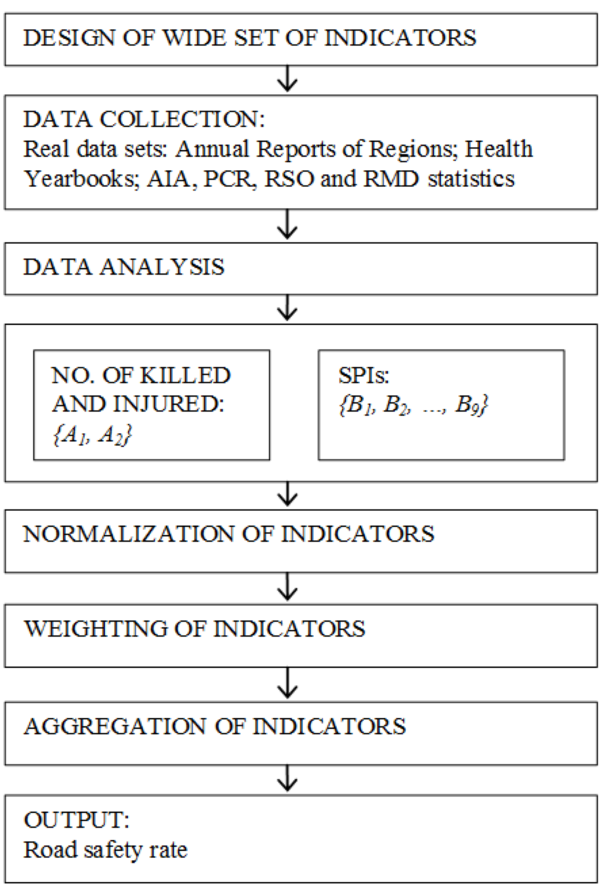

Fig. 2 Proposed road safety evaluation model

Before the calculation of RSR in the CR regions were firstly defined groups of indicators that creates the main structure of the conceptual framework and also have a significant role for the analysing the results. For our purpose there were preferably proposed 4 groups of indicators that come out of the pyramid concept of the road safety [30]:

- Group A - Number of killed and injured (final outputs).
- Group B - Safety performance indicators (intermediate outputs).
- Group C - Measures and programs (political outputs).
- Group D - Structure and culture (political inputs).

Then the wide file of 50 possible indicators was defined, which were put to each of the above mentioned groups. Safety performance indicators were then divided to seven related risk areas [33]: alcohol and drugs, speed, protective systems, daytime running lights, vehicle, roads and trauma management. The shorter selection of the indicators representing every levels of the pyramid ran on the basis of 8 criteria evaluation [4]: accessibility, relevance, measurability, understandability, reliability, comparability, certainty and sensibility.

We worked with real data of the CR regions (CBM is Central Bohemia, HRK is Hradec Králové, KVA is Karlovy Vary, LIB is Liberec, MSL is Moravia-Silesia, OLM is Olomouc, PAR is Pardubice, PLZ is Plzeň, PRG is Prague, SBM is South Bohemia, SMV is South Moravia, UST is Ústí, VYS is Vysočina and ZLN is Zlín) from years 2007 to 2009. During the data gaining the series of commonly accessible sources and databases were used - Annual Reports of the Regions [34], Health Statistics Yearbooks [35], CR Police Statistics [36], Statistics of the Road and Motorway Directorate [37], results of the measuring of the Road Safety Observatory (RSO) [38] and News Releases of Automotive Industry Association [39]. The big problem resulted to be mainly the accessibility of the data related to political precautions and programs of the road safety. There appeared considerable differences of the claims to the indicators during the evaluation of every country among each other and evaluating smaller territorial units within one country especially in their comparability.

Because of the complete absence of the needed data or their incompleteness, this group of indicators was useless for meeting our objectives. On the basis of this finding, we didn't use also structural and cultural indicators. The accessible information for forming the safety performance indicators for the risk area, relating to alcohol and drugs (road users under its impact) were not also found. This did not prevent to use of other indicators of second group.

We have utilized direct (group A) and indirect (group B) indicators for the comparison of road safety levels in the individual regions. Of course it is suitable to use objective indicators for such comparison. The comparison of regions on the basis of the absolute number of killed, slightly and severely injured and on the number of road accidents is not suitable for these purposes. Individual regions differ by the number of inhabitants, their area, population density, length of roads, by the numbers of registered cars and other indicators.

When using these variables we can obtain relative indicators that take into account the individual differences between the regions and thus can be after that considered to be objective indicators. Using the comparison of the individual characteristics allows us to compare the levels of road safety in each region. When monitoring these individual characteristics in time sequence we can follow the trends in road safety in each region and in the CR at the same time. The most suitable direct indicators seem to be the number of victims with impact on their life or health within 30 days for the road accident. These data have been relativized to the number of inhabitants in each territory unit (personal safety) and to the number of vehicles registered in the territory unit (traffic safety). From among the indirect indicators it is useful to take into account those that have any relation to the already mentioned seven road safety risks areas.

The shorter set of the selected indicators was tested by the statistical analysis. Increased attention has been given from the very beginning to the region Prague, the capital city. The basic descriptive statistics confirmed the already expected specific features of this region; those features are in the majority cases very different from other regions. First, it was revealed outliers in the data that were already used for the derivation of the indicators (e.g. number of inhabitants, region area, number of registered vehicles) and in connection with that also the resulting indicators (population density, highway density, personal safety). Therefore this region has not been taken into account for and in the overall comparison. Then selected indicators were tested by the statistical analysis. In Table I is shown final set of 11 indicators divided into two groups. The last column contains the expected target values of indicators (more information below).

Table I Final set of the selected indicators

Indicator	Indicator description	Target
A_1	Personal safety	10
A_2	Traffic safety	20
B_1	Exceeding of speed limit in extra-region (%)	0.5
B_2	Exceeding of speed limit in intra-region (%)	0.5
B_3	Using of seat belts by adults on front seat in extra-region (%)	99.5
B_4	Using of seat belts by adults on front seat in intra-region (%)	99.5
B_5	Daytime running lights in extra-region (in %)	100
B_6	Daytime running lights in intra-region (in %)	100
B_7	Average age of cars (years)	6
B_8	Highway density (km per 100 km^2)	4
B_9	Number of beds of intensive care per 10,000 inhabitants	2

Since the individual indicators have various scales and units it was necessary to normalize these values. We have used the approach based on the method Distance to a target [27], that takes into account also the development of indicators in time and is related to the defined target indicators values.

For the definition of the individual indictors' weight we have used the Saaty´s matrix [40].

By means of this method various weights are assigned to the selected indicators in relation to their impact on the road safety. The result is the following vector w (2) of the individual indicators weights:

$$\mathbf{w} = [0.259, 0.259, 0.115, 0.067, 0.115, 0.067, 0.035, 0.023, 0.023, 0.016, 0{,}023], \quad (2)$$

where maximal eigenvalue λ_{max} is 11.714, consistency index CI is 0.071 and consistency ratio CR is 0.047 if RI is 1.51.

Further, based on a simple formula (3) the calculation of RSR has been done for the individual regions:

$$\text{RSR} = \sum_{i=1}^{n} w_i \cdot I_i , \quad (3)$$

where n is number of indicators, I_i are normalised indicators, w_i are the weights for I_i .

The results may range from 0 to 100. The higher values mean the higher road safety in the given region. And vice versa, lower values indicate lower road safety in the region. The target value of the RSR is 100 and it shows how close or how far the region is from the defined road safety targets. In theory the result may be higher than 100 if the road safety is on an even higher level that the defined and expected level. The RSR results should motivate and influence regions to improve their activities in the road safety area and help to define the performance gap between their actual results and the pre-defined targets. The concrete results are shown in Table II.

Table II Road safety rates of regions in 2007-2009

Region	Year					
	2007		2008		2009	
	RSR	Rank	RSR	Rank	RSR	Rank
SMV	52.77	1	54.93	1	56.80	1
ZLN	50.33	3	52.02	3	56.28	2
VYS	46.86	8	48.65	8	52.41	3
MSL	49.65	5	50.41	6	51.85	4
OLM	47.19	7	49.29	7	51.58	5
KVA	48.71	6	51.48	4	51.36	6
HRK	49.70	4	50.99	5	50.45	7
UST	51.14	2	54.01	2	49.91	8
CBM	45.21	13	47.11	10	48.55	9
PLZ	45.97	10	47.69	9	47.82	10
PAR	45.86	11	46.18	13	47.19	11
SBM	45.72	12	46.70	12	46.96	12
LIB	46.77	9	47.02	11	46.93	13

In Fig. 3 we can see road safety evolution between years 2007 and 2009 in a form of column chart.

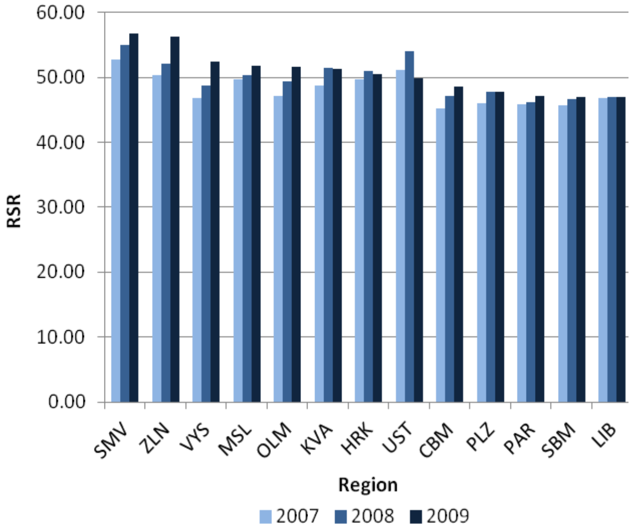

Fig. 3 Regional road safety comparison

From the stated results it is obvious that the best results are achieved by the bordering regions in the south end of Moravia (SMV and ZLN). On the contrary the worst results have the northwest bohemian regions (LIB and PAR) and also the SBM region. Two significant changes in ranking of road safety occurred in 2009. VYS region had significantly mend its ways, while the UST region greatly fallen down. VYS region upward shift was due to more significant improvements in several areas studied in comparison with other regions (a significant improvement of indicator B1, then also visible improvements of indicators A2, B3 and B4). The cause of the fall of the UST region from the second position in 2007-2008 to the eighth was a very significant deterioration of the value of a single indicator (B1) in 2009 compared to previous years. The trend in road safety is, with some exceptions, moderately increasing.

B. Determination of accident probability, integration of risks issuing from an unwelcomed event along the route and the evaluation of its acceptability

The impossibility to forecast the concrete place of a traffic accident in the transportation process is the complication of risk forecasting. The more dense is the traffic the higher the rate in accident incidence. A Framework procedure for calculation of risk incidence probability [41]:

1. Acquisition of statistical data on the number of accidents for the past period.
2. Categorization of traffic accidents by the place of their origination, time, causes and participants.
3. Determination and description of the risk situation origination.
4. Drawing of an accident/error tree with YES – NO decision nodes.
5. Calculation of probability of vehicles traffic accidents.
6. Allocation of the acquired probability values to intervals.
7. Composition of surface road dangerous sections chart.
8. Drawing of risk chart/map (dangerous).

For research purposes it is essential to have data on participants, time and causes of traffic accidents. There was a problem with serious lack of individual reliable statistical data on the number of traffic accidents (TA) and on the transportation intensity. Data from various sources (the CR Police, Road and Highways Directorate, the CR Ministry of Transport, Firemen directorate) led in many cases to significantly different results. It was only in the last year of the project that we were able to gather the essential data in such quality that frequency values derived from the data could be considered highly credible.

After evaluation of information on traffic accidents rate it is possible to calculate the probability of traffic accidents of vehicles transporting dangerous substances on the individual route sections P(A) according to this formula (4):

$$P(A) = \frac{m_{DNPNV}}{n_{VDNPNV}}, \tag{4}$$

where m_{DNPNV} is the number of traffic accidents with the participation of vehicles transporting dangerous substances on a concrete section of a surface communication per year, and n_{VDNPNV} is the number of all traffic accidents with participation of vehicles transporting dangerous substance per year.

The starting point to the quantification of essential accident indicators with ability to define all different causes of accidents is to secure traffic accidents data evidence and that by the place of origination, the time, the causes and the participants. The place of the accident is in this case an individual section of the transportation network for each concretely delimitated transportation rule. These sections can be in an optimal situation defined from obtained statistical data with the utilization of GIS and thus to provide for unambiguous link between individual sections identification and terrain morphology, by identification of environment components, transportation infrastructure characteristics and accidents reporting in a given section.

The place of the accident origination is, in our case, an individual section of traffic network for each concrete delimitated transportation route. These sections can be in an optimal situation determined from the obtained statistical data by means of GIS and thus provide for an unambiguous interlink between the identification of sections with terrain morphology data, identification of the environment components, transportation route characteristics and the recording of accident statistics in a given section.

It is essential to divide the transportation route into relatively small sections, for each such section then determine the probability of accident and the unit society risk (for a certain load and defined risk recipient) and to sum partial society risks along the route. We can use (5) to calculate risk R:

$$R = \sum_s P_s \,.\, N_s, \tag{5}$$

where s is the index of route section, P_s is traffic accident probability in s-th segment and N_s is the outcome of the traffic accident in s-th segment.

If our intention is to precede for the derivation of individual and society risk value along partial sections of communication, then all data must be transposed into a length unit. It must be stressed that we are aiming to express the probability of one vehicle with a concrete load's accident. The total environmental risks are then the product of all risks arising from each individual load. That shall be transported over a given route (across the interest area).

When defining the frequency of accidents per one kilometre we take as a basis the following relationship (6):

$$F = X/L, \qquad (6)$$

where F is frequency of accidents per one kilometre section, X is the number of accidents per period and L are kilometres done per the given period.

This general relationship is valid for all types of traffic accidents including cargo transportation. However, must know the relevant X and L in the structure essential for the given tasks/problem. The probability of an accident can be influenced in particular by the following factors: traffic intensity, road category, straight section, crossroads, curve, and municipality.

Under the BIOTRA project the accident frequencies are modified according to concrete local conditions. Accident frequencies are set separately for individual types of communications (highways, 1st class roads, 2nd class roads) and they can be modified according to local situation with division to straight sections, crossroads and curves and also to parts of the route that go through municipalities.

A number of factors have an influence over the frequency of accidents on the individual classes of roads. This is e.g. traffic intensity, section of road going via a municipality, occurrence of junctions, curves, straight sections, or of other critical sections with a higher rate of accidents respectively. The time of day factor is also important – day or night as well as the time of year factor. The objective of the modification is to amend the accident frequency according to the local conditions. In this sense it is essential to research into the accident rate in dependence to traffic intensity on individual communications under the given categories (highway, 1st class, 2nd class roads, 3rd class respectively), accidents in municipality cadastres and outside municipalities and accidents with understanding the type of road section-that is accidents in junctions, in curves and on straight sections. The modification is done according to additional parameters by means of modification coefficient. The modification means to rearrange accidents frequencies between individual roads, their sections respectively so that the total frequencies remain unchanged.

Other sections critical for road traffic accidents (RTA), that are recorded and tracked by the CR police, are junctions, curves and straight sections. Number of traffic accidents according to critical spots on the individual types of road communications in year 2009 are stated in Table III. The modification of accident frequencies according to critical sections (junctions, curves, straight sections) shall be done only for the outside of municipalities road sections.

Table III Number of Accidents by Critical Spots

RTA Frequency (2009)	RTA outside municipality total	RTA outside municipality according to critical spots/sections			
		Straight section	Straight section after curve	Curve	Junction
RTA total	22561	11552	3290	5033	2538
RTA-cargo transport	3885	2356	423	705	387
- out of that highways	545	523	6	11	4
- out of that 1st class	1556	965	139	247	194
- out of that 2nd class	894	382	160	234	116
- out of that 3rd class	615	300	98	167	49

It is evident that it is to no value to consider local situations on highways since local situations have hardly any influence on the individual accidents. On first class roads the frequency of accidents in junctions is above average level compared to situation on second and third class roads. The recalculation of frequency of accidents by critical spots for example on 1st class roads is documented in Table IV [42]. Modified frequencies results stated in the table below are only an example documenting the manner of deriving accident probabilities according to concrete defined critical communication spots/sections. They point also to the fact that accident frequencies are not by themselves sufficient for deriving real frequencies for specific communication sections.

Table IV Modified Frequencies of Accidents on 1st Class Roads

RTA Intensity for 1st Class Roads					RTA Frequency	
Critical spots/sections	RTA total	Comun. length (km)	RTA Frequency ADR	RTA Frequency per 1 km	Gas	Liquid
In municipality	871	40.38	2.21E-05	5.47E-07	1.33E-06	2.87E-07
Outside municipality - straight section	1104	63.54	2.80E-05	4.41E-07	1.07E-06	2.31E-07
Outside municipality - curve	247	10.00	6.27E-06	6.27E-07	1.52E-06	3.28E-07
Outside municipality - junction	194	0.60	4.92E-06	8.20E-06	1.99E-05	4.30E-06
Total	2416	113.92	6.13E-05	5.38E-07	1.31E-06	2.82E-07

Definition of the primary event frequency on road communications (transport vehicle traffic accident with a leak of dangerous substance) is based on traffic accidents statistics and on traffic intensity. Despite the incompleteness of statistical data we managed to express frequencies separately for highways, 1st and 2nd class roads and to modify them according to local conditions (municipalities, straight sections, curves and junctions). Till year 2012 the outlines of the endangered territory in case of leakage of toxically gas were set on the basis of individual risk for inhabitants calculations.

For this purpose it was assumed that endangered territory defined in this way can be applied also to the environment. The disadvantage of this approach was the fact that inside the territory there were no partial sections/areas earmarked as varying levels of damage to the biotope thus it was necessary to state the same level of damage for each type of biotope for the entire area. The new approach is based on exposition rates to which the biotopes along the route are exposed. The impacts for individual biotopes are set for certain intervals of exposition rates. Endangered section contours are then defined according to marginal negative impact intensity and inside the area there are calculated frequencies with which this intensity is reached. The exposition rates are dependent on the gas toxical characteristics because generally speaking for the individual types of gas the contours are different. Frequency maps are the background for the evaluation of both the unit and the total ecological damage to the environment. As a unit damage is understood the ecology biotope damage per $1m^2$, the total potential damage is related to the entire endangered territory/section-belt. Application possibilities are so far limited by lack of relevant data for about the level of damage on various types of vegetation upon acute toxic gas exposition.

For more accurate evaluation of risks modification of vehicle frequency on roads according to local situation was introduced [43]. In Fig. 4 there are drawn isolines of frequencies of exposition to low rate of ammonia.

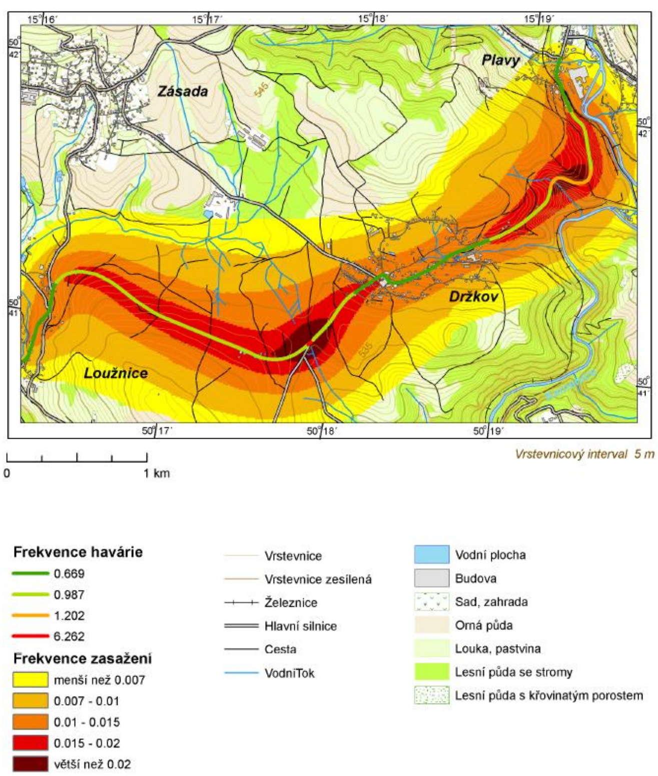

Fig. 4 Scaled frequencies of partial areas exposure in case of transport of 20 tons of ammonia upon introduction of local situation modification

Sections with varying levels of modification are marked directly in the route line.

Another issue researched into under the project was the quantification of risk resulting from unwelcome event along the route and the evaluation of its acceptability. The quantification of risks generally included the probability of unwelcome event and its consequence. This approach is the base for recommended approaches to risks evaluation under Act. 59/2006 Coll. While the risks for inhabitants are already methodologically worked out into a big level of detail, the determination of risks for the environment were based so far on qualitative or semi-qualitative evaluation of the consequences. Such evaluation is not, however, objective enough and its results are hardly comparable which to a large extend complicates decision making processes. Integration of risks for the environment along the transportation route extends the general quantification principle on/to the environment. The probability of an unwelcomed event is replaced by accident frequency on the communication and it depends on the probability of hitting/spotting partial areas in its surroundings by a negative impact of the leaked dangerous substance. Biotopes are the representatives of the environment elements, they characterize the quality of the surroundings for organisms development and at the same time provide ecosystem services in a symbioses with solar energy, water and vegetation. Areas hitted from in the individual leakages spots are overlapping and the probability of hitting get even cumulated in the nods of a regular network. In the individual nods there can be a modification of accident executed according to local situation (junctions, curves and similar.) To every nod of the raster network belongs a certain partial area. In those areas it is essential to identify biotopes that are present here. Each biotope has a set value and also the value of ecosystem services. In connection with that the values of unit damage for various levels of negative impact hitting are set. The cumulated value of the product of damage and frequency of hitting on partial areas for defined influence intervals expresses the unit damage on 1 m^2.

The calculation of damage is done based on degradation and regeneration lines. Degrading is the lowering of the biotope value, its transformation to another, less valuable, on the axis „natural – close to natural – artificial (not close to nature) – artificial with limited biotope“ and related to this limitation of ecotype services. The level of degradation is dependent on the level of the impacting negative influence and on the biotope sensitivity to the impact. In the 30 years interval, in which the damage is evaluated, there is jump degradation to step by step regeneration with increasing value of the biotope and its services.

The sum of values from all partial areas (society risk) multiplied by the size of the partial area represents quantified risk of load transportation along the defined route. For practical reasons it is suitable to do the calculation on the level of standardized risks, that is risk related to 1 accident per 1 km of the route per year. Only at the end the multiplication by a medium accident frequency is done for the given type of communication. For a risk defined in the described way there are valid the following limitations:

- The risk is set separately for each substance and its prepared volume,

- It is set for a certain scenario of substance leak,
- When there is more scenarios it is cumulated with weighting its relative frequencies.

Risks defined in this way methodologically respond to principles and procedures used in risk evolution for dramatic accidents under Act. 59/2006 Coll. and extend these procedures also to the environment area. The advantage against the so far used semi-quantitative, very often very difficult to compare evaluations, is the quantification of risks on comparable level for all biotope types. The risk can be calculated for sections of any length without any limitation. Then the transportation risks for a certain load can be minimalised by selecting the sections of routes with the lowest risk rates.

In Fig. 5 there is illustrated a detail of a belt of hazard along 1st class road between Držkov and Plavy with one of its important characteristics – a standardized frequency of impacted areas along the route [43]. Frequencies are standardized with respect to one accident per 1 km of the route.

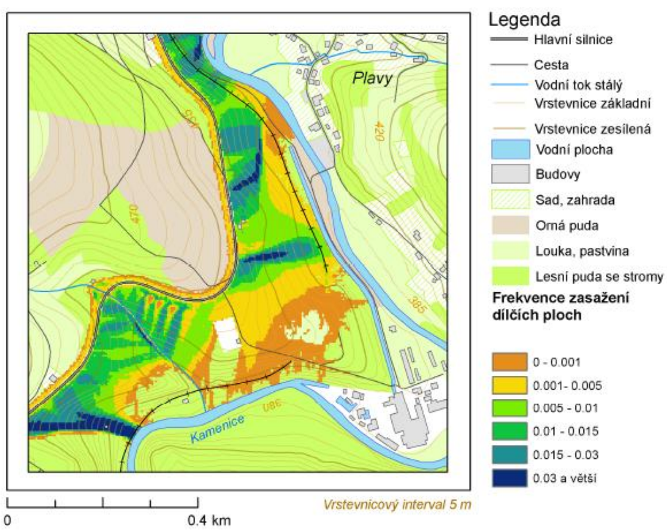

Fig. 5 Standardized impact frequencies for partial areas upon leakage of 30m of liquid

The resulting risk can be expressed also in financial units relating to the impacted area (ecological damage in CZK/m^2) and it has a comparable value for all biotopes [43]. The comparison of proposed alternative routes is thus very simple. The demonstration of the resulting risk detail along 1st class transportation route/road between municipality Držkov and Plavy expressed as ecological damage in CZK per m^2 is illustrated below in Fig. 6.

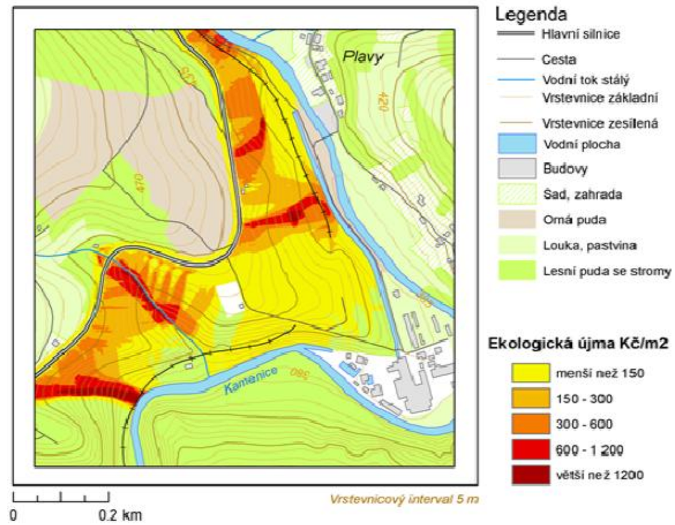

Fig. 6 Unit Damage to Biotopes – low infiltration of oil substance

The utilization of the developed methodology is wider than was the original objective of the project. Next to decision making on the optimal routes of transportation for a concrete load it could be also used for the purpose of risk evaluation from stationary sources, evaluation of critical infrastructure and accident planning.

IV. Conclusion

The main objective of this contribution is to introduce two alternative approaches to road safety evaluation in which we participated as authors or co-authors.

Firstly we have presented newly developed complex tool for the evaluation of road safety based on commonly available data. From the beginning we have worked with four groups of indicators however during the process we have decided to concentrate on two groups of indicators due to the lack of accessibility of suitable data. Herein above we have demonstrated only one from possible methods. When using other indicators and other methods the results would be probably intention to continue in this research in the future in the same way since the findings show that there is still a lot of challenges in front of us in the area of road safety evaluations.

The objectives of our future work in the field of evaluation of the road safety in the Czech regions are mainly:

- Create the file of best available and the best needed indicators for setting the objectives and evaluation the road safety in CR at the regional level. and culture
- Create the aggregate index on the basis of the best accessible indicators for the road safety in the regions, due to which can be then compared the state and the development of the safety in the regions of CR.
- Propose the methodology procedure of the aggregate index construction for evaluating the road safety at the level of smaller territorial units with aimed at the specifications and differences in comparison with other known procedures at the level of countries.

Further selected outputs of the BIOTRA project were presented. To achieve the ultimate project objective which was to create methodology for evaluation of ecological risks related to dangerous substances transportation with specific focus on biotope environment components, it was essential to solve a number of partial tasks. The outputs of these tasks were some original solutions that can be used also for totally different purposes.

One of the original results is the model of liquid leaked in an accident spreading on the terrain. In the CR there does not exist a similar model and worldwide only very gross models for large leakages from oil piping exist. This model also allows to set the rate of impact on surface waters. The presented model has also superstructure for the calculation of standardized frequency of impact on partial areas along the transportation route where one point can be hutted from more potential leakage points. The belts for the evaluation of dangerous substance leakage impacts were in the starting phases understood as individual objects delimitated by the relevant contour. In the course of the solution it became obvious that the definition of ecological damage requires resolution by the intensity of negative impact. This requirement led to re-evaluation of how belts are understood, belts are now described by its structure. The frequencies of impacting partial areas are distributed according to negative impact intensity which is the toxic exposition rate for gas and infiltrated volume for liquids. Belts defined in this way allow for the determination of risks for the environment not only along road and railway communications but also with stationary industrial sources.

What is new is the utilization of the Biotope Valuation Method (BVM) and valuation of ecosystem services for definition of ecological damage as a result of acute contamination. This method had been utilized only for considerations and comparisons of biotope values in the national and regional levels. Its application in relatively narrow belts along communications required a number of amendments. These amendments were related mainly to situations where in one defined area in the map background there is a couple of borderless biotopes. We had to describe/allocate keys to these so called mosaics and set their initial values. The main benefit is the monetary valuation of individual biotopes and ecosystem services that provides an objective comparable level upon solving partial decision making tasks from the environment area.

A significant initiation is the determination/expression, already described in the article, of unit ecological damage/impact (per 1 m^2) on the individual biotopes. Also the issuing definition of the time distributed biotope for acute exposition belongs to the original project outcomes. It could be further spread to scarcely existing biotopes and also on damage by other substances. The summit of the pyramid is then the integration of risks along the transportation routes.

In the course of the project work a large number of various supporting testing tools were created. Without them it would not be possible to execute verification calculation for partial tasks, as well as not the testing of inter-relationship of the individual modules and their composition into larger units up to the elaboration of the final methodology. In calculations we obtain various large data sets. Because a large number of data is linked to geographical coordinates, the final phases of processing are done in GIS environment. Simple creation of maps is then the advantage of this.

The importance of the described methodology of environment damage to biotopes and ecosystems quantification is in the possibility of adding of requirements required by the legislation concerning the acceptability of serious accidents risks and of other unwelcome events in industry and in transportation. According to current norms and according to recommended methodologies the valuation of environment risks is done only based on semi-quantitative criteria. The developed methodology thus can play an important role for the environment protection on the national level. The elaborated methodology may also well serve to military parts of the integrated rescue units for preparation for extraordinary and crisis situations that could happen and which can be included into crises and emergency plans. It also allows us to create maps of risks for the transportation of dangerous substances, according to which recommended transportation routes for the transportation of various matter can be elaborated. This can be a background information for an objective definition of ADR transportation routes in the CR, and it allows the CR to become the member of the group of countries where such rules are applied.

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