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NEW METHOD FOR BENCHMARKING TRAFFIC SAFETY LEVEL FOR THE TERRITORY

Dalibor Pešić[1], Milan Vujanić[2], Krsto Lipovac[3], Boris Antić[4]

The Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305, Belgrade, Serbia
E-mails: [1]d.pesic@sf.bg.ac.rs (corresponding author); [2]m.vujanic@sf.bg.ac.rs; [3]k.lipovac@sf.bg.ac.rs; [4]b.antic@sf.bg.ac.rs

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Abstract. Evaluation, monitoring and comparison of traffic safety in various territories presents a major challenge to the traffic safety researches. Recently a large number of studies are focused on finding an appropriate method for the calculation of the traffic safety level which uses a single numerical value for its assessment. For that purpose, traffic safety indicators are combined into a single numerical value by appropriate techniques in order to represent a grade of the traffic safety level. This paper contains, after the summary of contemporary tendencies in the evaluation of traffic safety levels, the analysis of methods used in the evaluation of traffic safety levels so far in Serbia with the emphasis on their values and deficiencies. Considering those analyses, this paper introduces a new method for traffic safety level evaluation the so called Benchmarked Traffic Safety Level (BTSL). BTSL implies selection of appropriate indicators, transformation of chosen indicators, assigning weights and aggregation. The proposed scale appliance enables traffic safety level to define for the territory, and also compares it with a similar one. BTSL provides a single numerical value so that to evaluate the traffic safety level for the territory, derived from the aggregation of previously transformed and 'weighted' three outcomes indicators and three safety performance indicators.

Keywords: benchmarking, traffic safety level, outcomes, safety performance indicators, territory.

Introduction

According to the data from the World Health Organization (WHO 2009) over 1.2 million people die each year on the world's roads and between 20 and 50 million suffer from non-fatal injuries. In the European Union (EU-27) there were about 56500 fatalities recorded due to traffic accidents in the year 2000 and about 39000 fatalities in the year 2008 (ERF 2010). Another data (ERSO 2008) show that in the European Union more than 1.8 million people are injured in traffic accidents, and costs of traffic accidents are estimated at 160 billion euro annually, which represents about 2% of gross national product of the European Union.

Earlier researches used Haddon's Matrix to determine basic road safety elements: driver, vehicle, road design, environment and their interrelation between each other and how those elements could affect road safety level (Haddon 1972). Rumar (1999) has described the problem in the road safety as a function of three dimensions: exposure, risk and consequences. Those methods were very helpful for the road safety assessment. Al-Haji (2007) summarized four stages for generation of road safety benchmarking models: the first generation compares countries' road safety performance in terms of risk and exposure, the second generation is similar to the first one except using the time, the third generation uses integration between accident consequence rates and other indicators (i.e. strategies) and the fourth generation focuses on the three types of benchmarking: Product, Practices and Strategic Benchmarking. Product benchmarking is used to compare road accident death rates, Practices benchmarking is used to compare activities related to human-vehicle-road performance and Strategic benchmarking is used to compare management, enforcement, organizational framework etc.

There are many factors which influence traffic safety, and Zhang *et al.* (2010) stated that economic growth influences the number of motorized vehicles, traveled mileage, a road infrastructure, and that the culture is a factor which has a long term influence on views and safe behavior in traffic. Numerous studies and researches have identified factors which are statistically related to mortality rates in traffic accidents and that are why those factors represent a helpful tool in defining the level of traffic safety (Traynor 2009). Knowing the level of traffic safety for a territory facilitates tracking and comparing traffic safety of that territory to itself, but also to other territories.

Not only defining, evaluating, estimating levels of traffic safety, but also the comparing of traffic safety is often done due to the consequences of traffic accidents (which are divided to fatal, severe and light injuries) in relation to the population numbers (Hermans *et al.* 2009a). Hermans *et al.* (2009a) have considered that it would be interesting to define the traffic safety index (combination of relevant traffic safety information in a single index) which would enable a general comparison of entities (states for example). Also, Hermans *et al.* (2009a) suggests that the process of aggregation of parameters into a single indicator or index should consist of two phases, where the first phase is the grouping of individual indicators into one according to the territory, and the next phase would be the grouping of so defined indicators into a single traffic safety index, with one of the most important aspects in the grouping being the assignment of appropriate weight factors to each of the indicators. A larger weight factor of a corresponding indicator means that it has a higher importance (Hermans *et al.* 2008). For the purposes of evaluating the traffic safety level of a country Hermans *et al.* (2008) has considered that their goal is to assign a country with an index in an appropriate way which describes all information relevant to the traffic safety of that country.

Gitelman *et al.* (2010) has concluded that it is important to define the combined traffic safety indicator which contains relevant information regarding traffic safety and which has assigned an appropriate weight factor. In that way, one can get a clearer and more realistic picture of the traffic safety compared to, for example, the analysis of traffic safety based on traffic mortalities rate. Gitelman *et al.* (2010) states that the phenomenon of traffic safety has a complex character and that the tendency today is to determine as many indicators as possible, which are able to measure the factors contributing to the occurrence of accidents and which identify the conditions related to the risk of accident occurrence. For this reason, the indicators can be used as a support for the creators of policies and strategies of traffic safety in the process of decision making. Gitelman *et al.* (2010), Wegman and Oppe (2010) propose that the output indicators could be used for evaluating traffic safety levels, which are related to accident consequences, intermediate output indicators, for example the use of seat belts and so on, but also social costs.

Wegman and Oppe (2010) have raised a question regarding all kinds of traffic safety comparisons: 'Which country is going to be compared?'. They also state that this question is of the great importance dealing with comparisons, because it is only adequate to compare countries with similar traffic systems or the level of traffic safety of similar surroundings. It is realistic to compare countries with similar economic situation, similar historical and geographical background, similar degrees of motorization and development in the area of traffic safety, as it is represented in the SUNflower+6 study (Wegman, Oppe 2010). Also, in SUNflower+6 project, Morsink *et al.* (2009) highlight importance is for ~~a~~ developing a methodological framework for a country's road safety footprint. Such a footprint will be able to help to understand strong and weak points of the road safety system. According to that, a road safety footprint can be described as a representation of its own road safety status, which is a multiple score of standardized key indicators (Morsink *et al.* 2009).

Al-Haji (2007) in his doctors dissertation among other things thoroughly analyses the degree of motorization, traffic and public risk, as well as trends of the degree of motorization, traffic and public risks and the ability of grading the state of traffic safety. He also emphasizes that it is necessary to establish and separate those indicators that represent the current traffic safety development. This means the establishment of the state of traffic safety and also the establishment of traffic mortalities risk.

Zhang *et al.* (2010) has used the comparison of two countries (China and USA) analyzing their traffic risk (the number of fatalities relative to the number of motorized vehicles and relative to the number of passenger cars), public risk (number of fatalities relative to the population) and the relation of the number of fatalities to the gross national product (GNP in latter references) and the consideration for more detailed analyses including such indicators as drivers' age, alcohol usage, seat belt usage, time of accident ect., was taken as well.

Methodologies for evaluating the safety performance could be applied for different road safety problems. So, Wang *et al.* (2011) proposes methodology for the evaluation safety performance of road intersection in a vehicle platoon environment based on linear regression, and several different explanatory models to identify risk level for drivers and also for pedestrians, according to annual average daily traffic, number of junctions and a traffic volume/capacity.

From the previously stated data it can be concluded that, in recent times, there are many studies which are focused on finding and defining the way of calculating traffic safety level for a territory and the main problems are the choice of relevant indicators, then assignment of weight coefficients to those indicators and lastly the choice of an appropriate method for relating the indicators into a single numerical value.

In this paper, two methods of calculating and ranking traffic safety levels of territories, which have been used during the last decade in the Republic of Serbia, has been analysed together with perceived advantages and disadvantages for both methods. Also, considering the advantages and disadvantages of methods and many studies used so far in the worldwide, this paper will present a new method for the evaluation of traffic safety level for the territory.

Both methods of calculating traffic safety levels used so far in Serbia (Traffic safety level – TSL by Vujanić and Jovanov (1998), and so called *ROSA* (ROad SAfety) index, by Sutiwipakorn and Prechaverakul (2002)), for the calculation of traffic safety level for the territory, propose the aggregation of certain traffic safety indicators. Those indicators, among other things, consider mobility, or exposure of population in traffic, also the risk of fatalities in traffic accidents. Both methods use the traditional approach to grade the state of traffic safety, based on output (number of traffic accidents, number of fatalities, number of casualties, etc.). It is concluded that both methodologies are sufficiently appropriate for the ranking of traffic safety levels of territories. Also because of the traffic safety index derived from application of both methods cannot be considered as a realistic representation of the state of traffic safety, because both methods base their calculation on the correlation of data from different territories.

In Table 1 we present basic characteristics of road safety level methods referenced in this paper.

Table 1. Basic characteristics of some methods for calculating road safety level

Author(s)	Method's name	Used indicators	Processes to assess road safety level	Possible application	Major disadvantages
Hermans *et al.* (2009b)	Road safety index	• alcohol and drugs; • speed; • protective system; • vehicle; • infrastructure; • trauma management; • crashes; • causalities	• indicator selection; • imputation of missing data; • normalization; • weighting; • aggregation; • uncertainty and sensitivity analysis; • DEA	• comparison across entities; • express the performance of a country in terms of road safety; • assist in prioritizing actions based on the safety performance of other countries	• DEA 'measures' only relative efficiency; • results are sensitive to measurement error, input and output specification and sample size
Gitelman *et al.* (2010)	Composite road safety indicator	• indicators from road safety pyramid; • road safety policy performance – safety measures and programmes; • final outcomes – consequences; • intermediate outcomes – SPIs	• standardize the data; • multiply standardized variables; • weighting summing	• comparison of countries' rankings; • grouping countries with similar composite indicator	• comparison countries with similar levels of safety performance; • indicators have to be more consistent
Wegman and Oppe (2010)	Road safety composite index	• road safety performance indicator – SPIs, consequences, etc.; • implementation performance indicator – SPIs, consequences, etc. ; • policy performances indicator – safety measures and programmes	• identifying the key road safety performance components; • constructing indicator for comparisons; • combining indicators in composite index	• evaluate effects of safety programs; • comparisons between countries and regions; • identifying components that contribute the score of composite index	• selection of indicators have to be careful; • some indicators are descriptive (policy performance)
Al-Haji (2007)	Road safety development index	• product – risks and trends; • human – behavior; • system – vehicles, roads, enforcement, etc.	• finding key indicators; • normalizing; • weighting; • combining	• indicates and communicates the severity of the road safety situation in a specific country and/or in comparison to other countries in time	• number and type of indicators depend on the availability and quality of data
Vujanić and Jovanov (1998)	Traffic safety level	• crashes and consequences – risks, frequency, etc.	• normalizing; • weighting; • aggregation	• comparisons between countries, regions, cities and other areas	• invalid in measuring level of road safety for specific country, just do comparing between countries; • sensitive on input
Sutiwipakorn and Prechaverakul (2002)	*ROSA* index	• crashes and consequences – risks	• standardize the data; • weighting; • aggregation	• comparisons between countries, regions, cities and other areas	• could not measure level of road safety for specific country, just do comparing between countries; • sensitive on input

Considering the contemporary trends in traffic safety analyses (considering other traffic safety indicators such as intermediate outcomes, or safety performance indicators and so on), there is a need for the development of a newer, more modern method in order to evaluate the traffic safety level for the territory, which aside from the position of the territory on the ranking scale gives a realistic ranking of the state of traffic safety in that territory. The new method, presented in this paper, as a ranking of the state of traffic safety in a territory (BTSL – Benchmarked Traffic Safety Level), considers six parameters, three related to outcomes and other three are safety performance indicators.

BTSL method proposed in this paper differs from other methods because one of our key ideas in defining new method is that it has to be easy for using by others (decision makers and practitioners). This is because decision makers and practitioners usually are not from the field of road safety, statistical methodology, etc. Besides, BTSL is calculated by output indicators and safety performance indicators that are available in databases or could be easily measured by usually techniques (i.e. measuring speed with speed cameras, etc.).

Chapter two of this paper is the presentation of the analysis of the methods for ranking traffic safety levels of territories (TSL and ROSA), along with numerical examples. In chapter three of this paper there is a presentation of a new method for calculating traffic safety level for the territory, which considers both traditional and contemporary approach to rating traffic safety. Chapter four presents the discussion of results of previously conducted analyses and the chapter five brings the listing of the conclusions.

1. Analysis of TSL and ROSA Methods of Rating Traffic Safety Levels

In current practice in Serbia, for the purposes of rating traffic safety levels, two methods have been used, the so called TSL method and the *ROSA* index. Both methods, which are depending on the needs and available data, have been used for rating traffic safety levels, monitoring the state traffic safety and determining the effect of the traffic safety improvements.

Considering and analyzing the possible ways of defining the existing state of traffic safety, Vujanić and Jovanov (1998) have noticed that there is a significant complexity in the choice of relevant indicators, in assignment of weight coefficient, but also in defining the way of calculating traffic safety levels. Vujanić and Jovanov (1998) considered, the defining of traffic safety indicators which have been proposed by some authors (Ogden 1995; Rothe 1994) for calculating traffic safety level for the territories, regions, cities or city parts. Because of this, for the purpose of rating traffic safety levels, Vujanić and Jovanov (1998) has proposed and used the following indicators for TSL method:

- number of fatalities per 10^8 vehicle kilometers;
- number of injuries per 10^8 vehicle kilometers;
- number of accidents per 10^8 vehicle kilometers;
- number of fatalities per 1 km of road network length;
- number of injuries per 1 km of road network length;
- number of accidents per 1 km of road network length;
- number of fatalities per 100000 inhabitants;
- number of injuries per 100000 inhabitants;
- number of fatalities per 100 traffic accidents;
- number of injuries per 100 traffic accidents.

The established traffic safety level via the TSL method for several territories enables the comparison of those territories by traffic safety levels. For the purposes of comparison it is advised that the indicators are related to a predefined time period (one year, five years and so on).

TSL method includes the establishment of minimal and maximal reference values for each of the indicators. Minimal value is zero (0), while the maximal reference value is two times larger than the maximal value of the particular indicator. The relation of the value of indicator and the maximal reference value represents the h coefficient. Weight factor k has been assigned to each of the indicators by an expert choice method, such that $1 < k < 2$, which defines the importance or significance of the indicator.

In order to establish an overall traffic safety level, the following calculation is needed:

$$TSL = \sum_{i=1}^{10} h_i \cdot k_i, \tag{1}$$

where: h_i – coefficient of the indicator which is calculated as indicator value divided by maximal reference value, and maximal reference value is twice larger than the maximal indicator value (Vujanić, Jovanov 1998); k_i – weight factor of indicator i, taking value between 1 and 2 and it is determined by authors of the TSL method using an expert choice method (Vujanić, Jovanov 1998); i – indicator.

TSL value derived in this way represents traffic safety level of a territory (region, city, part of a city and so on), but it is also appropriate for comparison to other territories or ranking in the following classification (Vujanić, Jovanov 1998):

- territories with a very low traffic safety level ($TSL > 7$);
- territories with a low traffic safety level ($6 < TSL < 7$);
- territories with a medium traffic safety level ($5 < TSL < 6$);
- territories with a high traffic safety level ($4 < TSL < 5$);
- territories with a very high traffic safety level ($TSL < 4$).

The results of the application of traffic safety level calculation according to TSL methodology are contained in Table 2, and the values of indicators (number of fatalities, injuries etc), which have been used in calculations are taken from the official statistic (Inić 1995) and are used as an exemplary numerical value.

Table 2. Values of the chosen traffic safety indicators, with coefficients h and k, reference values and TSL values for six cities (Vujanić, Jovanov 1998)

Indicators	Beograd index value (coef. h)	Ljubljana index value (coef. h)	Sarajevo index value (coef. h)	Skoplje index value (coef. h)	Podgorica index value (coef. h)	Zagreb index value (coef. h)	Reference index value	Coef. k (1 – 2)
Fatalities 10^8 vehicle kilometers	5 (0.21)	3 (0.13)	12 (0.50)	10 (0.42)	8 (0.33)	4 (0.17)	0 – 24	1.9
Injuries per 10^8 vehicle kilometers	71 (0.24)	42 (0.14)	146 (0.50)	98 (0.34)	91 (0.31)	68 (0.23)	0 – 292	1.9
Accidents per 10^8 vehicle kilometers	358 (0.41)	316 (0.36)	395 (0.45)	440 (0.50)	360 (0.41)	412 (0.47)	0 – 880	1.8
Fatalities per 1 km of road/street network	0.06 (0.50)	0.03 (0.25)	0.05 (0.42)	0.06 (0.50)	0.03 (0.25)	0.06 (0.50)	0 – 0.12	1.5
Injuries per 1 km of road/street network	0.89 (0.24)	0.59 (0,16)	1.88 (0.50)	1.19 (0.32)	0.44 (0.12)	1.00 (0.27)	0 – 3.76	1.5
Accidents per 1 km of road/street network	5.31 (0.27)	3.4 (0.18)	9.7 (0.50)	5.5 (0.28)	3.1 (0.16)	3.13 (0.16)	0 – 19.4	1.4
Fatalities per 100000 inhabitants	15 (0.33)	18 (0.39)	12 (0.26)	9 (0.20)	18 (0.39)	23 (0.50)	0 – 46	1.7
Injuries per 100000 inhabitants	210 (0.26)	349 (0.42)	411 (0.50)	183 (0.22)	254 (0.31)	399 (0.49)	0 – 822	1.7
Fatalities per 100 accidents	1.22 (0.32)	0.89 (0.24)	0.56 (0.15)	1.03 (0.27)	1.00 (0.27)	1.88 (0.50)	0 – 3.76	1.6
Injuries per 100 accidents	16.96 (0.27)	17.34 (0.27)	19.41 (0.30)	21.65 (0.34)	14.23 (0.22)	31.99 (0.50)	0 – 63.98	1.5
TSL value	5.00	4.19	6.77	5.62	4.69	6.22	–	–
State of *TSL*	Medium	High	Low	Medium	High	Low	–	–
Rank	3	1	6	4	2	5	–	–

Example of calculation of *TSL* value for Beograd for case of six cities:

$$TSL_{Beograd} = 0.21 \cdot 1.9 + 0.24 \cdot 1.9 + 0.41 \cdot 1.8 + 0.50 \cdot 1.5 + 0.24 \cdot 1.5 + 0.27 \cdot 1.4 + 0.33 \cdot 1.7 + 0.26 \cdot 1.7 + 0.32 \cdot 1.6 + 0.27 \cdot 1.5 = 5.00. \quad (2)$$

For the purpose of checking the calculated values of traffic safety levels, the existing number of cities has been expanded by two cities and calculated again. The results are represented in Table 3.

Example of calculation of *TSL* value for Beograd for case of eight cities:

$$TSL_{Beograd} = 0.21 \cdot 1.9 + 0.24 \cdot 1.9 + 0.36 \cdot 1.8 + 0.33 \cdot 1.5 + 0.24 \cdot 1.5 + 0.27 \cdot 1.4 + 0.28 \cdot 1.7 + 0.22 \cdot 1.7 + 0.32 \cdot 1.6 + 0.26 \cdot 1.5 = 4.49. \quad (3)$$

By comparing the rank of selected cities by *TSL* values, and comparing the classification of cities by *TSL* values (Tables 1 and 2), a conclusion that could be made by the value of traffic safety level has been altered by adding two new cities to the number of observed cities. It can be concluded that by adding two cities to the already existing number of cities, *TSL* value has dropped for all the cities (for example for Ljubljana it is 3.78 instead of 4.19). All the cities retained their rank by *TSL* value, but, by using the proposed scale for defining traffic safety levels, the cities of Ljubljana, Beograd and Zagreb 'skipped' into the higher category of traffic safety levels. Practically, with no real improvement to traffic safety, Ljubljana from a city with a high traffic safety level became a city with a very high traffic safety level only by expanding the number of cities by two.

The other method for rating traffic safety levels used in Serbia is called ROSA index. ROSA index calculation includes the following four indicators (Sutiwipakorn, Prechaverakul 2002):

- number of fatalities per 100000 inhabitants;
- number of fatalities per 10000 registered vehicles;
- number of injuries, which were transferred to hospital treatment, per 100000 inhabitants;
- number of injuries, which were transferred to non-hospital treatment, per 100000 inhabitants.

The procedure of calculating *ROSA* index is as follows: for each of the indicators a mean and standard deviation is calculated. Depending on the values of indicators to each of the indicators is assigned a value of f coefficient, where a higher coefficient points to a less favorable value of an indicator. f coefficient is assigned following a rule stated in Table 4 (Sutiwipakorn, Prechaverakul 2002). f coefficient showed in Table 4 depends on indicator values, and if its condition showed in the first column in the Table 4 fulfilled then coefficient f will get value showed in the second column in the Table 4.

Table 3. Values of the chosen traffic safety indicators, with coefficients *h* and *k*, reference values and *TSL* values for eight cities (Vujanić, Jovanov 1998)

Indexes	Beograd index value (coef. *h*)	Ljubljana index value (coef. *h*)	Sarajevo index value (coef. *h*)	Skoplje index value (coef. *h*)	Podgorica index value (coef. *h*)	Zagreb index value (coef. *h*)	Novi Sad index value (coef. *h*)	Pristina index value (coef. *h*)	Reference index value	Coef. *k* (1 – 2)
Fatalities per 10^8 vehicle kilometers	5 (0.21)	3 (0.13)	12 (0.50)	10 (0.42)	8 (0.33)	4 (0.17)	8 (0.33)	11 (0.46)	0 – 24	1.9
Injuries per 10^8 vehicle kilometers	71 (0.24)	42 (0.14)	146 (0.50)	98 (0.34)	91 (0.31)	68 (0.23)	96 (0.33)	130 (0.45)	0 – 292	1.9
Accidents per 10^8 vehicle kilometers	358 (0.36)	316 (0.32)	395 (0.40)	440 (0.44)	360 (0.36)	412 (0.42)	496 (0.50)	280 (0.28)	0 – 992	1.8
Fatalities per 1 km of road/ street network	0.06 (0.33)	0.03 (0.17)	0.05 (0.28)	0.06 (0.33)	0.03 (0.17)	0.06 (0.33)	0.09 (0.50)	0.04 (0.22)	0 – 0.18	1.5
Injuries per 1 km of road/street network	0.89 (0.24)	0.59 (0.16)	1.88 (0.50)	1.19 (0.32)	0.44 (0.12)	1.00 (0.27)	1.68 (0.45)	0.80 (0.21)	0 – 3.76	1.5
Accidents per 1 km of road/ street network	5.31 (0.27)	3.4 (0.18)	9.7 (0.50)	5.5 (0.28)	3.1 (0.16)	3.13 (0.16)	7.7 (0.40)	2.5 (0.13)	0 – 19.4	1.4
Fatalities per 100000 inhabitants	15 (0.28)	18 (0.33)	12 (0.22)	9 (0.17)	18 (0.33)	23 (0.43)	27 (0.50)	14 (0.26)	0 – 54	1.7
Injuries per 100000 inhabitants	210 (0.22)	349 (0.36)	411 (0.42)	183 (0.19)	254 (0.26)	399 (0.41)	488 (0.50)	257 (0.26)	0 – 976	1.7
Fatalities per 100 accidents	1.22 (0.32)	0.89 (0.24)	0.56 (0.15)	1.03 (0.27)	1.00 (0.27)	1.88 (0.50)	1.19 (0.32)	1.76 (0.47)	0 – 3.76	1.6
Injuries per 100 accidents	16.96 (0.26)	17.34 (0.27)	19.41 (0.30)	21.65 (0.34)	14.23 (0.22)	31.99 (0.50)	21.84 (0.34)	32.11 (0.50)	0 – 64.22	1.5
TSL value	4.49	3.78	6.27	5.15	4.30	5.60	6.87	5.45	–	–
State of *TSL*	High	Very high	Low	Medium	High	Medium	Low	Medium	–	–
Rank	3	1	7	4	2	6	8	5	–	–

Table 4. Values of *f* coefficient

Indicator value	*f* coefficient
$0 \to (\bar{x}-\sigma)$	0.1
$(\bar{x}-\sigma) \to (\bar{x}-\sigma/2)$	0.3
$(\bar{x}-\sigma/2) \to (\bar{x}+\sigma/2)$	0.5
$(\bar{x}+\sigma/2) \to \bar{x}+\sigma$	0.7
$> \bar{x}+\sigma$	0.9

A weight factor is also assigned to each of the indicators, where due to the simplification of the procedure it is suggested by Sutiwipakorn and Prechaverakul (2002) that the sum of weight factors is 10, and according to the authors of ROSA one of the possible combinations would be:

- number of fatalities per 100000 inhabitants $W = 3$;
- number of fatalities per 10000 registered vehicles $W = 4$;
- number of injuries, which were transferred to hospital treatment, per 100000 residents $W = 2$;
- number of injuries, which were transferred to non-hospital treatment, per 100000 residents $W = 1$.

In calculation of *ROSA* index we use the same weights as Sutiwipakorn and Prechaverakul (2002), but those weights are just possible from the expert choice method and could be changeable.

The procedure of calculating *ROSA* index is derived from the following form:

$$ROSA = \sum_{i=1}^{n} W_i \cdot f_i, \qquad (4)$$

where: W_i – is the weight factor; f_i – is the coefficient formed on the basis of the indicator value; n – is the number of indicators.

Calculated *ROSA* index could have the value of 1 to 9, where a higher value of ROSA index points to a less favorable state of traffic safety within the analyzed territory. In other words, territory with a lower ROSA index is safer than a territory with a higher *ROSA* index.

A numerical example of the calculated values of *ROSA* index is given in Table 5.

Example of ROSA index calculation for Beograd in case of six cities:

$$ROSA_{Beograd} = 0.5 \cdot 3 + 0.5 \cdot 4 + 0.1 \cdot 2 + 0.3 \cdot 1 = 4. \quad (5)$$

Similarly as TSL, for the purpose of testing the calculated values of *ROSA* index, the existing number of cities is expanded by two cities and the calculation is repeated. The results for the expanded number of cities are represented in Table 6.

Example of *ROSA* index calculation for Beograd in case of eight cities:

$$ROSA_{Beograd} = 0.1 \cdot 3 + 0.1 \cdot 4 + 0.1 \cdot 2 + 0.1 \cdot 1 = 1. \quad (6)$$

The calculation of *ROSA* index has, considering the results represented in Tables 4 and 5, also shown changes in the values of *ROSA* index, by adding two new cities to the existing number of cities. *ROSA* index has, by adding two new cities, dropped for all cities (for example the new value of *ROSA* index for Beograd is 1, and the old is 4). With the *ROSA* index method, by adding two new cities to the existing number of cities, the rank of cities had also changed (for example Skoplje was in the first case safer than Beograd, and in the second case Skoplje and Beograd had the same *ROSA* index. Also Ljubljana was safer than Sarajevo in the first case, while it is the other way around in the second case). Similar to the TSL methodology, with no realistic traffic safety improvement, the ranking of cities changed according to the traffic safety level, by simply expanding the number of analyzed cities.

By comparative analysis of the results of implementation of TSL and *ROSA* index methods for calculating traffic safety levels for a territory (comparing Tables 1 and 4 and Tables 2 and 5) a conclusion that could be made is the cities Beograd and Ljubljana are in the top half of the rankings, and safer than other cities, while Sarajevo and Zagreb are in the lower half of the rankings, so a similarity can be observed in the output of TSL and ROSA methods. Contrary to the above mentioned similarity Skoplje is by applying TSL method among is the least safe cities, while by applying the *ROSA* index Skoplje is the safest city. It is exactly the opposite for the city of Podgorica, which is by applying TSL methodology is one of the safer cities, and by applying *ROSA* index is opposite – the one of the unsafe cities. Everything stated previously points to the conclusion that TSL and *ROSA* index methods can provide large differences in output data.

Table 5. Traffic safety indicator values, average values, standard deviation, *f* coefficient and *W* and *ROSA* index for six cities (Vujanić, Jovanov 1998)

Indicators	Beograd index value (coef. *f*)	Ljubljana index value (coef. *f*)	Sarajevo index value (coef. *f*)	Skoplje index value (coef. *f*)	Podgorica index value (coef. *f*)	Zagreb index value (coef. *f*)	$\bar{x}$ σ	Coef. *W*
Fatalities per 100000 inhabitants	15 (0.5)	18 (0.5)	12 (0.3)	9 (0.1)	18 (0.5)	23 (0.9)	15.83 4.52	3
Fatalities per 10000 registered vehicles	6.53 (0.5)	4.89 (0.3)	6.71 (0.5)	4.26 (0.1)	11.71 (0.9)	9.73 (0.7)	7.31 2.62	4
Hospitalized injuries per 100000 inhabitants	47 (0.1)	77.9 (0.7)	67.6 (0.5)	41.3 (0.1)	66.8 (0.5)	88.4 (0.9)	64.83 16.38	2
Unhospitalized injuries per 100000 inhabitants	163.4 (0.3)	271.5 (0.5)	343.3 (0.9)	142 (0.1)	187.2 (0.3)	311 (0.7)	236.4 76.3	1
ROSA index	4	4.6	4.8	1	6.4	8	–	–
Rank	2	3	4	1	5	6	–	–

Table 6. Traffic safety indicator values, average values, standard deviation, coefficient *f*, *W* and *ROSA* index for eight cities (Vujanić, Jovanov 1998)

Indicators	Beograd index value (coef. *f*)	Ljubljana index value (coef. *f*)	Sarajevo index value (coef. *f*)	Skoplje index value (coef. *f*)	Podgorica index value (coef. *f*)	Zagreb index value (coef. *f*)	Novi Sad index value (coef. *f*)	Pristina index value (coef. *f*)	$\bar{x}$ σ	Coef. *W*
Fatalities per 100000 inhabitants	15 (0.1)	18 (0.3)	12 (0.1)	9 (0.1)	18 (0.3)	23 (0.5)	27 (0.7)	14 (0.1)	22.67 5.48	3
Fatalities per 10000 registered vehicles	6.53 (0.1)	4.89 (0.1)	6.71 (0.1)	4.26 (0.1)	11.71 (0.5)	9.73 (0.5)	7.3 (0.1)	12.1 (0.7)	10.54 2.77	4
Hospitalized injuries per 100000 inhabitants	47 (0.1)	77.9 (0.3)	67.6 (0.1)	41.3 (0.1)	66.8 (0.1)	88.4 (0.5)	111.9 (0.7)	59.6 (0.1)	93.42 21.31	2
Unhospitalized injuries per 100000 inhabitants	163.4 (0.1)	271.5 (0.3)	343.3 (0.5)	142 (0.1)	187.2 (0.1)	311 (0.5)	376.5 (0.7)	197.0 (0.1)	332.0 82.8	1
ROSA index	1	2.2	1.4	1	3.2	5	4.6	3.4	–	–
Rank	1	4	3	1	5	8	7	6	–	–

The main advantages perceived of both methods are the efficient defining the ranks of territories according to traffic safety, and the main disadvantage is providing a nonrealistic picture of the state of traffic safety. In other words, by adding, or by subtracting territories from the number of analyzed territories, *TSL* value differs significantly. It is apparent that the used methodologies provide different results, so that is an additional motive for the creation of a new methodology for calculating traffic safety levels. New, independent methodology would, aside from ranking traffic safety levels of analyzed territories by a numerical value, realistically represent the state of traffic safety in the analyzed territories.

2. New method for benchmarking traffic safety level (BTSL)

Considering best practices, or rather studies concluded up to date, scientific and professional papers (Al-Haji 2007; Hermans *et al.* 2008, 2009a; Traynor 2009; Zhang *et al.* 2010; Wegman, Oppe 2010; Gitelman *et al.* 2010), as well as so far used methodologies in Serbia (TSL and ROSA methods), the authors of this paper suggest forming a new, so called independent, general method for evaluating traffic safety levels. The new method would, in addition to rank, in the cases of defining traffic safety levels for a group of territories, define a numerical value, which would realistically describe the state of traffic safety. The usefulness of the model is, among other things, shown in the fact that the calculated numerical value of traffic safety level would not change regardless to the number evaluated territories.

By analyzing the experiences in defining and calculating traffic safety levels for territories, several key steps could be observed. Firstly, it is necessary to select from the many possible relevant indicators those relevant indicators which would, on one hand, facilitate a numerical definition of a problem, while on the other hand, and realistically describe the state of traffic safety. Then, it is necessary to, due to the difference in measuring units, and for the sake of aggregation, transform the indicators and reduce them to the same span. Other than that, since some indicators are more important in defining and rating traffic safety levels, it is necessary to assign the appropriate weight factors to each of the indicators and finally define the way of aggregation of those data which would provide a single numerical value. That numerical value would contain information of the state of traffic safety for a territory and would practically describe the traffic safety level in that territory. The described process is illustrated by Fig.

Step 1 – The selection of relevant indicators. Starting from the fact that there are a large number of indicators which can describe traffic safety and that some of those indicators are more significant than others, or that they better show the state of traffic safety, it is necessary to choose indicators that can define traffic safety level more precisely. As the traditional approach was based to a large extent upon the indicators which describe so called outcomes (number of traffic accidents, number of fatalities, etc.) the newer approach is also based on the indicators which describe the state of traffic safety indirectly by using so called intermediate outcomes, or safety performance indicators (for example the percentage of obeying traffic regulations and so on). By 'combining' indicators from both groups it is possible to get a more realistic picture about the state of traffic safety for a territory.

Most used outcomes indicators are related to traffic accidents fatalities and three of the most commonly used indicators are annual number of traffic accident fatalities per 100000 inhabitants (so called public risk), annual number of traffic accident fatalities per 10000 registered vehicles (so called traffic risk) and the annual number of traffic accident fatalities per 100000000 vehicle kilometers (so called dynamic traffic risk). Each of the listed indicators is important by itself, but all of them together practically take into account the risk of traffic accident fatalities in relation to mobility and exposure in traffic.

Out of the safety performance indicators the ones which have the most influence on traffic safety are: the percentage of seat belt usage, the percentage of drivers who speeding and the percentage of drivers who drive under the influence of alcohol. Practically, each of the three listed indicators are also the most common violations that drivers make in traffic and at the same time non safe behaviors, which are easily detected (by recording, observing, controlling and so on). Besides that, the more important characteristic of listed behaviors in traffic is that if drivers do not abide the regulations associated with those behaviors and a traffic accident occurs, then the consequences of those traffic accidents would be significantly greater.

When a number of relevant indicators is observed it is necessary, on one hand, to pick a large enough number of indicators, and on the other hand, a small enough number of indicators. Namely, a larger number of indicators would more realistically paint a picture of the state of traffic safety, while a smaller number will allow easier and simpler consideration of all the indicators at once. The important thing in choosing indicators no matter to which group of indicators they belong to, is to have all of the chosen indicators 'move in the same direction', which means that for example a larger value of an indicator means a lager unsafety or vice versa.

Having in mind all previously considered, the applying of the expert choice method has shown that:

- annual number of traffic accident fatalities per 100000 inhabitants (PR);

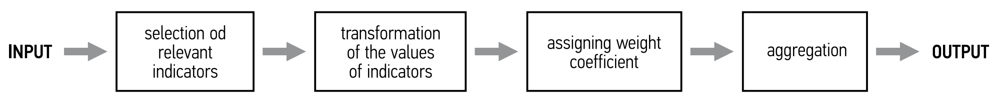

Fig. The process of defining and rating traffic safety levels

- annual number of traffic accident fatalities per 10000 registered vehicles (TR);
- annual number of traffic accident fatalities per 100000000 vehicle kilometers (DTR);
- percentage of drivers and passengers in front seats that use seatbelts ($SB_{\%}$);
- percentage of drivers that do not drive under the influence of alcohol ($IA_{\%}$);
- percentage of drivers that non speeding ($NS_{\%}$);
- are traffic safety indicators which are relevant to the rate of traffic safety level of a territory.

Step 2 – Transformation of the indicator values. After the selection of relevant indicators, it is necessary to transform and adjust them to the same measurement units. Namely, for example, public risk, of the annual number of traffic accident fatalities per 100000 inhabitants in Serbia within the last few years was around 10, while for example, the percentage of seat belt usage on front seats is about 60%. Merging these two data, without a previous transformation would not be possible. The new method includes the transformation of indicator values in an interval of 0 to 1, while for the transformation of data itself the following procedures have been used:

- For indicators which are expressed in numerical values within the interval of 0 to a certain large number (for example 5000) it is best to transform the values of indicators using a so called reciprocity transformation, because some indicator values could take large number, it is possible that maximum possible indicator value could be unknown and simply reciprocity transformation function transform values into interval of 0 to 1. We have proposed transformation as follows:

$$TVI = \begin{cases} 1/x, x > 1; \\ 1, x \le 1. \end{cases} \quad (7)$$

- For indicators which are expressed in percentages the transformation is as follows:

$$TVI = \frac{x_{[\%]}}{100}, \quad (8)$$

where *TVI* is the transformed value of the indicator.

Step 3 – Assigning the weight coefficients. Authors of this paper believe that, in practical sense, above mentioned indicators do not bear the same significance and that it is necessary to allocate adequate weight factor to each indicator, as a part of the calculated traffic safety level. For allocating weight factors in traffic safety, the following wide-known methods are mostly used: Data Envelopment Analysis (DEA), Analytical Hierarchical Process (AHP), Factor Analysis (FA), Budget Allocation (BA), Equal weighting (EW) (Hermans *et al.* 2008).

Opinion of the authors of this paper is that Budget Allocation is the simplest method for allocating weight factors that do not demand special knowledge about weighting methods, because decision makers and practitioners, who will use this method, are usually not from the field of statistics. On the other hand, Budget Allocation method could allocate weight factors to each of indicators in a fast, efficient manner and with high precision. Five university professors in the field of traffic safety in Serbia were asked to allocate €10000 to the significance of above mentioned indicators. After the data were obtained, BA method was carried out as well as the data normalization on the scale from 0 to 1. BA method results showed that traffic safety experts gave the highest importance to outputs, followed by safety performance indicators. Namely, BA method showed that annual number of fatalities in traffic accident on 100000000 vehicle kilometers had weight factor of 0.23, annual number of fatalities in traffic accident on 100000 inhabitants had weight factor of 0.19 and annual number of fatalities in traffic accident on 10000 registered vehicles had weight factor of 0.18. Also, BA method showed that safety performance indicators – percentage of drivers and passenger on front seat who use seat belt had weight factor of 0.17, percentage of drivers who do not speed had weight factor of 0.15 and percentage of drivers who do not drive under the influence of alcohol had weight factor of 0.08.

Step 4 – Aggregation of data. Final step is the aggregation of previously transformed and weighted indicators. For the aggregation it is possible to use sums or multipliers or the combination sums and multipliers. Having in mind indicator transformations (on the scale of 0 to 1), as well as weight factors (also on the scale of 0 to 1), we have concluded that appropriate aggregation is as follows:

$$BTSL = \sum_{i=1}^{6} TVI_i \cdot w_i, \quad (9)$$

where: *BTSL* – benchmarked traffic safety level; TVI_i – transformed value od indicator *i*; w_i – weight of indicator *i*.

As could be seen, the maximum value of *BTSL* is 1, and the minimum is 0, where a higher value points to a higher safety. BTSL calculated in this way facilitates ranking and comparison of traffic safety of multiple territories.

Considering the experiences of the most developed countries in the means of the traffic indicator's values, such as Sweden, Japan, Great Britain, USA but also EU countries, or OECD (international databases IRTAD and CARE), the authors of this paper suggest a scale by which whether a surveyed territory is safe or not. For a calculated *BTSL*, according to form (9), traffic safety scale would be:

- $BTSL \ge 0.9$ – very highly safe territory;
- $0.7 \le BTSL < 0.9$ – highly safe territory;
- $0.3 \le BTSL < 0.7$ – medium safe territory;
- $0.1 \le BTSL < 0.3$ – low safety territory;
- $BTSL < 0.1$ – very low safety territory.

Considering the proposed method of rating traffic safety levels Table 7 contains a numerical example of rating traffic safety levels for cities, as in Table 2.

Table 7. Application of the *BTSL* method in rating traffic safety levels

	Ljubljana	Podgorica	Beograd	Skoplje	Zagreb	Sarajevo
DTR	3.0	8.0	5.0	10.0	4.0	12.0
TVdtr	0.33	0.13	0.20	0.10	0.25	0.08
Wdtr	0.23	0.23	0.23	0.23	0.23	0.23
PR	18.0	18.0	15.0	9.0	23.0	12.0
TVpr	0.06	0.06	0.07	0.11	0.04	0.08
Wpr	0.19	0.19	0.19	0.19	0.19	0.19
TR	4.9	11.7	6.5	4.3	9.7	6.7
TVtr	0.20	0.09	0.15	0.23	0.10	0.15
Wtr	0.18	0.18	0.18	0.18	0.18	0.18
$SB_{\%}$	7.0	4.0	7.0	4.0	5.0	3.0
$TVsb_{\%}$	0.07	0.04	0.07	0.04	0.05	0.03
$Wsb_{\%}$	0.17	0.17	0.17	0.17	0.17	0.17
$NS_{\%}$	80.0	77.0	85.0	80.0	80.0	73.0
$TVns_{\%}$	0.80	0.77	0.85	0.80	0.80	0.73
$Wns_{\%}$	0.15	0.15	0.15	0.15	0.15	0.15
$IA_{\%}$	93.0	89.0	93.0	87.0	89.0	88.0
$TVia_{\%}$	0.93	0.89	0.93	0.87	0.89	0.88
$Wia_{\%}$	0.08	0.08	0.08	0.08	0.08	0.08
BTSL	0.3303	0.2482	0.3002	0.2824	0.2840	0.2469
State of *BTSL*	Medium	Low	Medium	Low	Low	Low
Rank	1	5	2	4	3	6

Example of *BTSL* calculation for Beograd: according to proposed BTSL method calculation process is as follows: Annual number of traffic accidents fatalities per 100000000 vehicle kilometers (DTR) is 5, that means the transformed value of the indicator is 0.2 (1:5). Weight for this indicator is 0.23, according to Budget Allocation. Further, similar calculation is conducted for other indicators, and at the end, when all transformed indicator values and all weights are calculated, BTSL is calculated as follows:

$$BTSL = 0.33 \cdot 0.23 + 0.06 \cdot 0.19 + 0.20 \cdot 0.18 + 0.07 \cdot 0.17 + 0.80 \cdot 0.15 + 0.93 \cdot 0.08 = 0.3303. \quad (10)$$

Considering the values of *BTSL* it is possible to rank the selected cities (column 'rank' in Table 7), and it is also possible to define a state of traffic safety in the selected cities (column 'state of *BTSL*'). Practically, the *BTSL* value numerically describes traffic safety level, and 'state of *BTSL*' describes the state of traffic safety, or traffic safety level of a territory.

Reliability of the proposed method was tested through the example of Sweden comparing it with the already examined cities, because Sweden is one of the best ranked countries due to the road safety. According to IRTAD (2010) Annual Report, Sweden is the second safest country if we look at fatalities per inhabitants and the safest country if we look at fatalities per billion vehicle kilometers.

Therefore, using the BTSL method points to the conclusion that only the cities of Belgrade and Ljubljana are medium safe, and all the rest of the cities have a low degree of traffic safety. This result is more realistic than the results obtained through TSL and *ROSA* index methodologies. By using the BTSL method for rating of traffic safety for example on Sweden in a same time period (1995) *BTSL* equals 0.77, which puts Sweden in a group of highly safe territories. Also, if we input the values of present day indicators for the most developed countries in the world into the BTSL method, for example the data for Sweden from the year 2010 then the value of *BTSL* will be a little over 0.9, that put Sweden in a group of highly safe territories, and Sweden is really safe territory today. Namely, according to all parameters Sweden is at the very top of the scale regarding the state of traffic safety, so this only confirms that the chosen five degree scale could be efficiently used.

3. Discussion

Considering the indicators that were used in rating traffic safety levels, so called outputs, and considering a modern trend of rating traffic safety levels on the basis so called indirect indicators, a need has arisen for an innovation of the method for calculating traffic safety levels in Serbia. There is a need for defining a so called independent methodology, where the output data (rating of traffic safety level) would be constant in relation to the change of the input data (for example the extension of the number of analyzed territories) and which describes the rank of traffic safety levels of analyzed territories, but also the state of traffic safety of the analyzed territories through a calculated numerical value.

The new method for benchmarking traffic safety levels, presented in this paper, considers both so called output indicators and intermediate indicators (so called SPIs) into the calculation. Output indicators are related to the number and consequences of traffic accidents, and most commonly used output indicators for rating and monitoring the state of traffic safety are in fact the risks like: public traffic and dynamic traffic which represent an annual number of traffic accident fatalities in relation to the population, the number of registered vehicles and the number of traveled vehicle kilometers, respectively. Considering that the speed, seatbelts and alcohol are the three areas of traffic safety which are given the most attention worldwide, and which, on the other hand have the most direct and profound influence ~~as~~ to the number of consequences of traffic accidents, that is why these three SPIs are chosen to participate in forming the rate of traffic safety level.

The model for Benchmarking Traffic Safety Level (BTSL) for the territory, presented in this paper, includes several steps: the selection of indicators, the transformation of indicator values, the assignment of weight factors and the aggregation into a single numerical value. In the process of choosing indicators it is very important to pay attention to the large number of chosen indicators, because of a more realistic view and grade of the state of traffic safety, while on the other hand the number of indicators must be small enough, because of easier considerations. The chosen indicators must 'all face the same way', for example, a larger value of all indicators should mean a greater safety. Due to further calculations, the value of an indicator should be previously transformed and thus reduced to a same measurement unit, on the scale of 0 to 1. Each of the indicators has a specific weight, or influences in a different way the grade of traffic safety level. Therefore, it is necessary to distribute weight factors to chosen indicators, which was, in the presented model, implemented through the Budget Allocation (BA) model. The last step in the calculation of the rate of traffic safety level is the aggregation of previously transformed and weighted indicators.

The results obtained through the implementation of BTSL method for the rating of traffic safety levels, facilitate the rating of traffic safety levels but also the comparison and monitoring of traffic safety levels in different territories, as well as tracking the effects of implemented measures. Considering the state of traffic safety in the selected cities, by numerical examples, this paper has demonstrated that only two cities (Ljubljana and Beograd) from the observed group are classified as territories of medium traffic safety levels. All other cities are classified as territories of low traffic safety. Namely, on the scale of 0 to 1, Ljubljana and Belgrade have a *BTSL* of 0.33 and 0.3 and thus are territories of medium traffic safety. The rest of the cities are in a zone of 0.1 to 0.3, so those are territories with low traffic safety. Results of BTSL method are more realistic than the results of the TSL or ROSA methods. Namely, by the implementation of, for example TSL method, even several cities, including Ljubljana and Belgrade, are in a group of territories with high traffic safety level or very high traffic safety level. But, in comparison to some other cities, for example, in Sweden or the USA, Ljubljana and Beograd are really on a lower degree of traffic safety level, so it is expected that the method will precisely define the place (rank) of a territory on the scale of traffic safety levels. BTSL method enables precisely defining traffic safety level, and because of that BTSL method is more appropriate method for the benchmarking traffic safety levels for the territories.

Conclusions

1. Benchmarking of road safety is one of the latest occupations of researchers in the field of road safety, and as a result of that there are many methods proposed for calculating or benchmarking road safety level. The main goals for creating method for benchmarking road safety are to measure road safety level of a territory and to compare it to other similar territories. The main idea is to find appropriate method that gives such results which describe road safety level in the best way.
2. Main steps in defining appropriate method for benchmarking traffic safety level on territory are: to find adequate, so called relevant indicators, because of availability and possible misunderstanding about basic definition (i.e. accident, fatality, injury, etc.), to find appropriate transformation method for data, to find appropriate weighting method, because all indicators are not equally important, and at the end, to find appropriate method to aggregate previously transformed and weighted indicators.
3. In BTSL method we have proposed six indicators that fulfill necessary condition of availability and data quality. First three indicators are final outputs (output indicators): public risk (annual number of fatalities per 100,000 inhabitants), traffic risk (annual number of fatalities per 10000 registered vehicles) and dynamic traffic risk (annual number of fatalities per 100000000 vehicle kilometers). Second three indicators are seatbelt usage, speeding, and driving under influence of alcohol.
4. We find reciprocity transformation could transform indicators that are expressed in numerical values on scale from 0 to 1, because maximum value of some indicators is not known, and could be a large number, i.e. 5000 or 100000000, etc. For indicators expressed in percentages the simple linear transformation is proposed.
5. For the weighting we have examined several wide-known methods, and we have found, like Hermans *et al.* 2008, 2009b), that Budget Allocation is the weighting method that gives good estimate of weights, and one of the simplest for application.
6. We propose aggregation of transformed and weighted indicators by sum of transformed value of indicator, multiple by weight of indicator.
7. One of the benefits of BTSL method is defining the level of traffic safety level of particular territory, which by using proposed scale, defines whether territory is very highly safe, highly safe, medium safe, low safe or very low safe territory.
8. Reliability of proposed method has been tested through example of Sweden, compared to already examined cities and it is shown that proposed BTSL method give good results of road safety level.
9. In future works, the ways of measurement and data gathering which are used in the calculations of ratings of traffic safety levels should be more thoroughly researched, analyzed and uniformed. It is necessary to define individual indicators precisely, for example, what does 'traffic accident fatality' represent etc. and then to define the ways of measuring individual indicators, for example, the percentage of seatbelt usage, etc. In future researches it would be necessary to define the way of selecting indicators more precisely, so that they could realistically represent the traffic safety levels. It is necessary to choose those indicators which best represent the state of traffic safety at that time (Al-Haji 2007).

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