analytic hierarchy process; AHP; road traffic safety, RTS

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APPLICATION OF THE AHP METHOD TO ANALYZE THE SIGNIFICANCE OF THE FACTORS AFFECTING ROAD TRAFFIC SAFETY

Summary. Over the past twenty years, the number of vehicles registered in Poland has grown rapidly. At the same time, a relatively small increase in the length of the road network has been observed. As a result of the limited capacity of available infrastructure, it leads to significant congestion and to increase of the probability of road accidents. The overall level of road safety depends on many factors - the behavior of road users, infrastructure solutions and the development of automotive technology. Thus the detailed assessment of the importance of individual elements determining road safety is difficult. The starting point is to organize the factors by grouping them into categories which are components of the DVE system (driver - vehicle - environment).

In this work, to analyze the importance of individual factors affecting road safety, the use of analytic hierarchy process method (AHP) was proposed. It is one of the multi-criteria methods which allows us to perform hierarchical analysis of the decision process, by means of experts' opinions. Usage of AHP method enabled us to evaluate and rank the factors affecting road safety. This work attempts to link the statistical data and surveys in significance analysis of the elements determining road safety.

ZASTOSOWANIE METODY AHP DO ANALIZY ISTOTNOŚCI CZYNNIKÓW WPŁYWAJĄCYCH NA BEZPIECZEŃSTWO RUCHU DROGOWEGO

Streszczenie. Na przestrzeni ostatnich dwudziestu lat liczba pojazdów rejestrowanych w Polsce dynamicznie rośnie. Jednocześnie obserwowany jest stosunkowo niewielki wzrost długości sieci drogowej. W wyniku ograniczonej przepustowości dostępnej infrastruktury prowadzi to do znacznego zatłoczenia i zwiększenia prawdopodobieństwa wystąpienia zdarzeń drogowych. Na ogólny poziom BRD wpływa wiele czynników – zachowania uczestników ruchu, rozwiązania dotyczące infrastruktury, a także rozwój techniki motoryzacyjnej. Szczegółowa ocena istotności poszczególnych elementów determinujących stan BRD jest więc trudna. Punktem wyjścia jest uporządkowanie czynników przez grupowanie do kategorii skumulowanych stanowiących składowe systemu UPO (uczestnik ruchu drogowego – pojazd – otoczenie).

W niniejszym artykule do analizy istotności poszczególnych czynników wpływających na stan BRD zaproponowano wykorzystanie metody analitycznego procesu hierarchicznego (AHP). Jest to jedna z metod wielokryterialnych, która pozwala na hierarchiczną analizę problemu decyzyjnego na podstawie opinii eksperckich. Wykorzystanie metody AHP umożliwiło ocenę i uszeregowanie czynników wpływających na stan bezpieczeństwa ruchu drogowego. Artykuł stanowi próbę powiązania danych statystycznych i ankietowych w ramach analizy istotności elementów determinujących BRD.

1. INTRODUCTION

On the roads of the European Union about 26000 people die every year. Therefore road safety is an important issue. The lowest fatalities number is recorded in Great Britain, Sweden and the Netherlands, while most people die on roads of Romania, Latvia, Poland and Lithuania [6]. Referring to the number of deaths to the population, Poland is one of the last countries among the EU and is well above the EU average. The fatalities number for selected EU countries with reference to population in 2013 is shown in Fig. 1 [6].

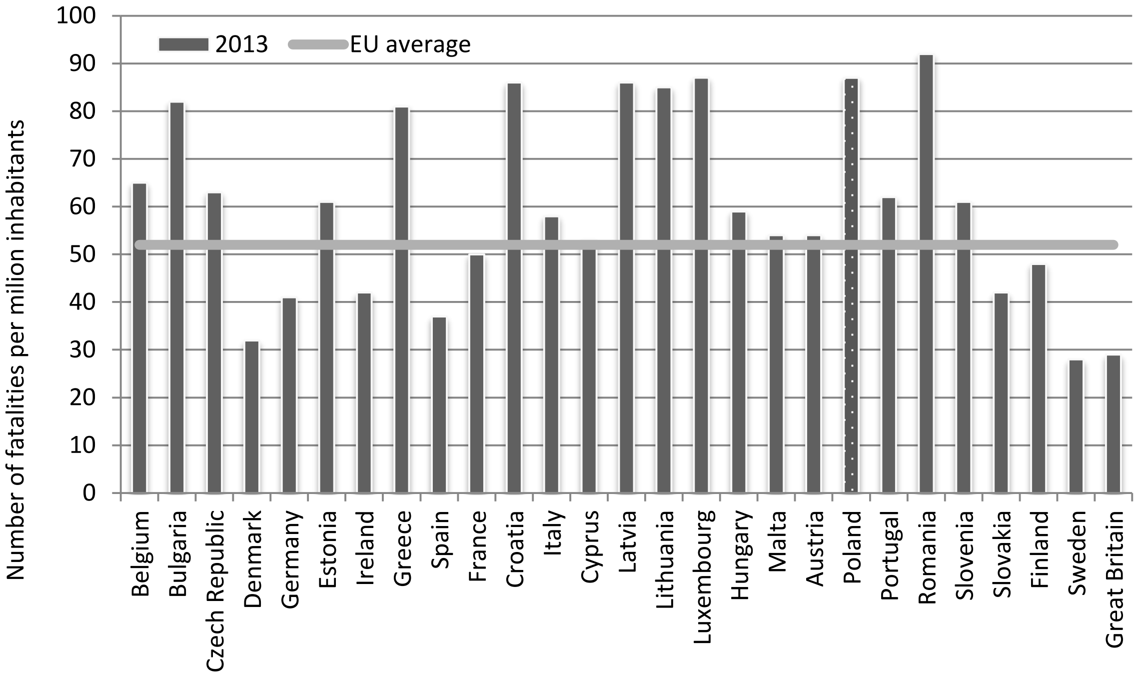

Fig. 1. Mortality rate in road accidents in 2013
Rys. 1. Współczynnik śmiertelności w wypadkach drogowych w 2013 roku

The concern about road safety is important not only because of the value of human health and life. One has to take into account that the long term social losses also generate quantifiable financial losses in the economy. There are certain methods to estimate the cost of road accidents and collisions. The method used for Poland's needs is Pandora 2013, developed at the Road and Bridge Research Institute. Road accidents and collision costs calculated by this method for Poland for year 2012 are at the level of 34.5 billion zloty [4]. This is almost 2% of GDP for the year 2012. However, due to traffic incidents, uncountable social costs are also incurred. These include the costs of:

– a sense of grief after the loss of relatives,
– physical and mental suffering of victims,
– support and time dedicated to the victims by relatives,
– decreasing the work effectiveness of relatives.

There is an urgent need to reduce the number and consequences of road accidents. To achieve this, it is necessary to identify the main factors affecting road traffic safety (RTS). The ranking of these factors in terms of their significance can be performed by using one of the multi-criteria analysis methods, which are widely used to solve decision problems. In this work, to analyse the influence of selected factors on RTS, the analytic hierarchy process method (AHP) was proposed [1].

2. STATING THE PROBLEM

The road safety problem is highly complex due to the large number of affecting factors. These can be put in order, by grouping them as DVE (driver - vehicle - environment) system components. Particular groups of the system are:

- factors related to a road user and his condition in holistic (psycho - physical - emotional) meaning, further known as factors ’D’,
- factors related to a technical condition of the vehicle, further known as factors ‘V’,
- factors related to an environment of the road in the broad sense of the word (along with the geometrical features of the road, weather, traffic organization and surroundings), further known as factors ‘E’.

To analyse the importance of factors affecting the RTS for the purposes of this work, selected factors were decomposed in DVE system groups.

Analytic hierarchy process method enables us to rank factors influencing the RTS with reference to their importance. However, due to create a final rank, it is required to define the weight (level of importance) of each of the considered groups. For the purpose of the article, the importance of particular groups was based on accident statistics for Poland in 2013 [5]. It was calculated as the share of each group in the total number of road accidents.

Factors that may be included in the driver’s group are:

- forcing the right-of-way,
- inappropriate speed to traffic conditions,
- incorrect overtaking,
- driving after alcohol or drugs,
- incorrect lane changing,
- not keeping a safe distance between vehicles,
- passing at a red light,
- not granting priority to pedestrians,
- failing to comply with other signs and signals,
- hard braking,
- tiredness, falling asleep,
- incorrect turning,
- driving without required lights,
- incorrect reversing.

Factors related to the technical condition of the vehicle are:

- defects in lights,
- defects in tires ,
- malfunction of the braking system,
- malfunction of the steering system.

With road environment, factors related to pedestrian traffic were linked. They are such as:

- walking the wrong side of the road,
- stepping onto the street at a red light,
- crossing the road in front of a moving vehicle,
- crossing the road from behind an obstacle,
- crossing the road in an unauthorized location,

and factors resulting from other causes:

- weather conditions such as sun blinding, fog, rain, snow, etc.
- improper condition of the road,
- incorrect traffic management,
- improperly secured roadworks,
- objects / animal on the road,
- being blinded by another vehicle.

The general form of a hierarchical structure, representing the issue discussed in the paper, is shown in Fig. 2.

Fig. 2. Scheme of decomposition of ranking factors influencing the RTS referring to their importance
Rys. 2. Schemat dekompozycji zadania szeregowania czynników wpływających na stan BRD w odniesieniu do ich istotności

Factors presented in Fig. 2 are analysed due to the level of importance within the group to which they belong. The final ranking of particular factors affecting status of RTS in terms of their importance can be defined after assigning weights to the considered groups – ‘D’, ‘V, ‘E.

3. DETEMINING RELATIVE RATINGS MATRIX

Ranking of particular factors influencing the RTS in terms of their importance in AHP requires to determine the matrix of relative importance ratings of each of the considered factors. These ratings are made by direct comparison in pairs of all the factors regarding the criterion of importance within the groups. To quantify the relative ratings the Saaty's scale was used. It leads to the distinction of five basic situations:

– equivalence, when level of importance of both compared factors is identical,
– weak preference, when level of importance of one of the factors is only slightly larger than the other,
– significant preference, when level of importance of one of the factors is noticeably greater than the other,
– clear preference, when level of importance of one of the factors is significantly larger than the other,
– absolute preference, when level of importance of one of the factors is much higher than the other.

An adequate numerical value is assigned to each of the five situations. If a pair of factors for which the comparison is performed is denoted as $\{e_1, e_2\}$, the numerical values as in Table 1 are used, to quantify particular ratio.

Table 1

The numerical values corresponding each of the situation for the basic Saaty's scale

Situation	equivalence	weak preference	significant preference	clear preference	absolute preference
Ratio value $\frac{e_1}{e_2}$	1	3	5	7	9

The intermediate numerical values may be also used to quantify the rate. Based on pairwise comparisons of the factors determining the state of RTS the matrixes of relative ratings are made, as described in the next section.

3.1. Relative ratings matrix for the group of factors relevant to the driver

The pairwise comparison of the 'D' factors was made on the basis of the survey. The respondents indicated how often each of these factors is the cause of road accidents, committed by the driver. Numerical values were assigned to responses. It allowed to calculate the percentage of the response indications. The value of indications of particular factors is presented in Table 2.

Table 2

The values of indications of factors related to road user

Factor affecting the RTS	Percentage of answers
forcing the right-of-way	10%
inappropriate speed to traffic conditions	10%
incorrect overtaking	9%
driving after alcohol or drugs	9%
incorrect lane changing	8%
not keeping a safe distance between vehicles	8%
passing at a red light	7%
not granting priority to pedestrians	7%
failing to comply with other signs and signals	6%
hard braking	6%
tiredness, falling asleep	5%
incorrect turning	4%
driving without required lights	3%
incorrect reversing	2%

The value of matrix indications, determined on these basis, is shown in Table 3.

Table 3

The matrix of relative ratings for factors referring to the driver

	forcing the right- of- way	inappropriate speed to traffic conditions	incorrect overtaking	Driving after alcohol or drugs	incorrect lane changing	not keeping a safe distance between vehicles	passing at a red light	not granting priority to pedestrians	failing to comply with other signs and signals	hard braking	tiredness, falling asleep	incorrect turning	driving without a required lighting	incorrect reversing
forcing the right- of- way	1	1	2	2	3	3	4	4	5	5	6	7	8	9
inappropriate speed to traffic conditions	1	1	2	2	3	3	4	4	5	5	6	7	8	9
incorrect overtaking	1/2	1/2	1	1	2	2	3	3	4	4	5	6	7	8
driving after alcohol or drugs	1/2	1/2	1	1	2	2	3	3	4	4	5	6	7	8
incorrect lane changing	1/3	1/3	1/2	1/2	1	1	2	2	3	3	4	5	6	7
not keeping a safe distance between vehicles	1/3	1/3	1/2	1/2	1	1	2	2	3	3	4	5	6	7
passing at a red light	1/4	1/4	1/3	1/3	1/2	1/2	1	1	2	2	3	4	5	6
not granting priority to pedestrians	1/4	1/4	1/3	1/3	1/2	1/2	1	1	2	2	3	4	5	6
failing to comply with other signs and signals	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	1	2	3	4	5
hard braking	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	1	2	3	4	5
tiredness, falling asleep	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	2	3	4
incorrect turning	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1	2	3
driving without required lights	1/8	1/8	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/4	1/3	1/2	1	2
incorrect reversing	1/9	1/9	1/8	1/8	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/3	1/2	1

3.2. Relative ratings matrix for the group of factors referring to technical condition of the vehicle

The evaluation of the next group of factors was performed on the basis of statistical data which define the ratio of particular factor in the total number of road accidents caused within the group [5]. Among the factors related to the technical condition of a vehicle:

– defects in lighting are responsible for 53% of accidents,
– defects in tires are responsible for 22% of accidents,
– malfunction of the braking system is responsible for 18% of accidents,
– malfunction of the steering system is responsible for 4% of accidents.

The analysis omitted other causes which in total represent about 3% of accidents among the considered group of factors.

The most important factors in RTS within this group are defects in the lighting of the vehicle. The next two factors – defects in tires and malfunction of the braking system - are almost equivalent to each other. The least important factor is malfunction of the steering system. The matrix determined on the basis of statistical data is shown in Table 4.

Table 4

The matrix of relative ratings of factors referring to the technical condition of the vehicle

	defects in lighting	defects in tires	malfunction of the braking system	malfunction of the steering system
defects in lighting	1	5	5	9
defects in tires	1/5	1	1	6
malfunction of the braking system	1/5	1	1	6
malfunction of the steering system	1/9	1/6	1/6	1

3.3. Relative ratings matrix for the group of factors referring to the environment of the road

The pairwise comparison of the 'E' factors was also made on the basis of the survey. The respondents indicated how often each of these factors is the cause of road accidents. Again, numerical values were assigned to the responses. The value of indications of the particular factors is presented in Table 5.

Table 5

The values of indications of factors related to the environment of the road

factor affecting the RTS	Percentage of answers
crossing the road in front of a moving vehicle	12%
improper condition of the road	12%
crossing the road from behind an obstacle	11%
weather conditions such as sun blinding, fog, rain, snow, etc.	11%
stepping onto the street at a red light	11%
crossing the road in an unauthorized location	10%
incorrect traffic management	8%
objects / animal on the road	7%
walking the wrong side of the road	7%
being blinded by another vehicle	6%
improperly secured roadworks	5%

The value of matrix indications, determined on these basis, is shown in Table 6.

Table 6

The matrix of relative ratings of factors relevant to the environment of the road

	crossing the road in front of a moving vehicle	improper condition of the road	crossing the road from behind an obstacle	weather conditions such as a sun blinding, a fog, a rain, a snow, etc.	stepping onto the street at a red light	crossing the road in an unauthorized location	incorrect traffic management	objects / animal in the road	walking the wrong side of the road	being blinded by another vehicle	improperly secured roadworks
crossing the road in front of a moving vehicle	1	1	2	2	2	3	5	6	6	7	8
improper condition of the road	1	1	2	2	2	3	5	6	6	7	8
crossing the road from behind an obstacle	1/2	1/2	1	1	1	2	4	5	5	6	7
weather conditions such as sun blinding, fog, rain, snow, etc.	1/2	1/2	1	1	1	2	4	5	5	6	7
stepping onto the street at a red light	1/2	1/2	1	1	1	2	4	5	5	6	7
crossing the road in an unauthorized location	1/3	1/3	1/2	1/2	1/2	1	3	4	4	5	6
incorrect traffic management	1/5	1/5	1/4	1/4	1/4	1/3	1	2	2	3	4
objects / animal on the road	1/6	1/6	1/5	1/5	1/5	1/4	1/2	1	1	2	3
walking the wrong side of the road	1/6	1/6	1/5	1/5	1/5	1/4	1/2	1	1	2	3
being blinded by another vehicle	1/7	1/7	1/6	1/6	1/6	1/5	1/3	1/2	1/2	1	2
improperly secured roadworks	1/8	1/8	1/7	1/7	1/7	1/6	1/4	1/3	1/3	1/2	1

4. COHERENCE ANALYSIS OF THE MATRIXES OF RELATIVE RATINGS

In the next step, the local priority vectors were determined (vectors for each matrix of relative ratings) and the consistency of the evaluations for each obtained matrix was checked.

Assuming that the $\gamma_{i\,j}^{(k)}$ is a relative rating of *i*-th step in comparison to the step *j* according to the criterion *k*, created matrix of relative ratings $R^{(k)}$ for $k = 1, 2, 3$ are square matrixes as:

$$R^{(k)} = \begin{bmatrix} \gamma_{1,1}^{(k)} & \cdots & \gamma_{1,n}^{(k)} \\ \vdots & \gamma_{ij}^{(k)} & \vdots \\ \gamma_{n,1}^{(k)} & \cdots & \gamma_{n,n}^{(k)} \end{bmatrix}, \tag{1}$$

where: n – matrix dimension.

Each element of the matrix $R^{(k)}$ corresponds to the quotient of the absolute ratings of steps regarded to the k-th criterion, i.e. the element $\gamma_{i\,j}^{(k)}$ can be represented as:

$$r_{ij}^{(k)} = \frac{w_i^{(k)}}{w_j^{(k)}}, \tag{2}$$

where: $w_i^{(k)}$, $w_j^{(k)}$ are the unknown absolute evaluation of steps i and j with respect to criterion k. To determine an absolute ratings vector $W^{(k),}$ it is required to solve such matrix equation as:

$$R^{(k)}W^{(k)} = \lambda W^{(k)}, \tag{3}$$

where: $W^{(k)} = \left[w_1^{(k)},\ldots,w_n^{(k)}\right]^T$ and $\sum_i w_i^{(k)} = 1$.

Determined local priorities vectors $W^{(k)}$ allow us to rank the factors affecting RTS due to their significance. In this paper local priorities vectors were calculated in iteration steps [3], with permissible error not greater than $\varepsilon = 10^{-4}$.

The next step was a verification of coherence. For each matrix the relative consistency ratio *CR* was calculated according to the equation:

$$CR = \frac{CI}{RI}, \tag{4}$$

where: *RI* – random consistency index, *CI* – consistency index calculated as:

$$CI = \frac{\lambda_{max} - n}{n-1}, \tag{5}$$

where: λ_{max} is the maximum value of the matrix.

For this purpose, after determining local priorities vectors $W^{(k)}$, λ_{max} and the consistency ratio were calculated for each matrix. The obtained values for each matrix of relative ratings are shown in Table 7.

Table 7

The obtained values for matrixes of relative ratings

Group:	consistency index *CI*	matrix dimension *n*	random consistency index *RI*	consistency ratio *CR*	acceptable value of consistency ratio *CR* [2]
factors ‘D’	0,04	14	1,58	0,03	≤ 0,10
factors ‘V’	0,06	4	0,89	0,07	≤ 0,08
factors ‘E’	0,03	11	1,52	0,02	≤ 0,10

Analysis of coherence of each matrix of relative ratings shows that the acceptable value of CR is not exceeded. It means that the matrixes fulfil the formal criterion of the AHP method [1] Therefore, local priorities were used to determine a final ranking of factors affecting RTS with regard to their importance.

5. FINAL RANKING OF THE FACTORS DETERMINING RTS

The next step is to determine the absolute ratings referring to the relevance of each of the three criteria considered in the paper. Weights assigned to each criterion are based on statistical data [5]. Weights of the criteria are shown in Table 8.

Table 8

Weights assigned to each criterion

Group	Weight
factors ‘D’	0,819
factors ‘V’	0,004
factors ‘E’	0,177

The final ranking of factors affecting status of RTS requires the aggregation of rating factors (weight of local priorities) with respect to the relevance of particular groups of factors (weight of criteria). Global priorities for factors influencing RTS and determined by using AHP method are shown in Table 9.

Table 9

Global priorities for factors influencing RTS

Group	Factors	Global priorities
factors 'D'	forcing the right- of -way	0,145
	inappropriate speed to traffic conditions	0,145
	incorrect overtaking	0,099
	driving after alcohol or drugs	0,099
	incorrect lane changing	0,066
	not keeping a safe distance between vehicles	0,066
	passing at a red light	0,044
	not granting priority to pedestrians	0,044
	failing to comply with other signs and signals	0,029
	hard braking,	0,029
	tiredness, falling asleep	0,020
	incorrect turning	0,015
	driving without required lights	0,011
	incorrect reversing	0,009
factors 'V'	defects in lighting	0,003
	defects in tires	0,001
	malfunction of the braking system	0,001
	malfunction of the steering system	0,000
factors 'E'	crossing the road in front of a moving vehicle	0,035
	improper condition of the road	0,035
	crossing the road from behind an obstacle	0,023
	weather conditions such as sun blinding, fog, rain, snow, etc.	0,023
	stepping onto the street at a red light	0,023
	crossing the road in an unauthorized location	0,015
	incorrect traffic management	0,008
	objects / animal on the road	0,005
	walking the wrong side of the road	0,005
	being blinded by another vehicle	0,004
	improperly secured roadworks	0,003

6. CONCLUSIONS

As a result of procedure described in the work, the ranking of factors determining the road traffic safety was made. Analysis of global priorities shows that the most significant factors having impact on RTS are: forcing the-right-of-way, inappropriate speed to traffic conditions, incorrect overtaking, driving after alcohol or drugs, incorrect lane changing and not keeping a safe distance between vehicles. All these most important factors are from 'D' group of factors. Within this group there is

82% of global priorities value. We can conclude that this group is the most important of the three considered.

All factors related to the environment of the road are in the middle of the rank therefore we can conclude that they have moderate importance. It is worth noticing that all factors related to the technical condition of the vehicle, are not considered as significant in relation to other factors. A comparison of the value of global priorities for each group of factors is shown in Fig. 3.

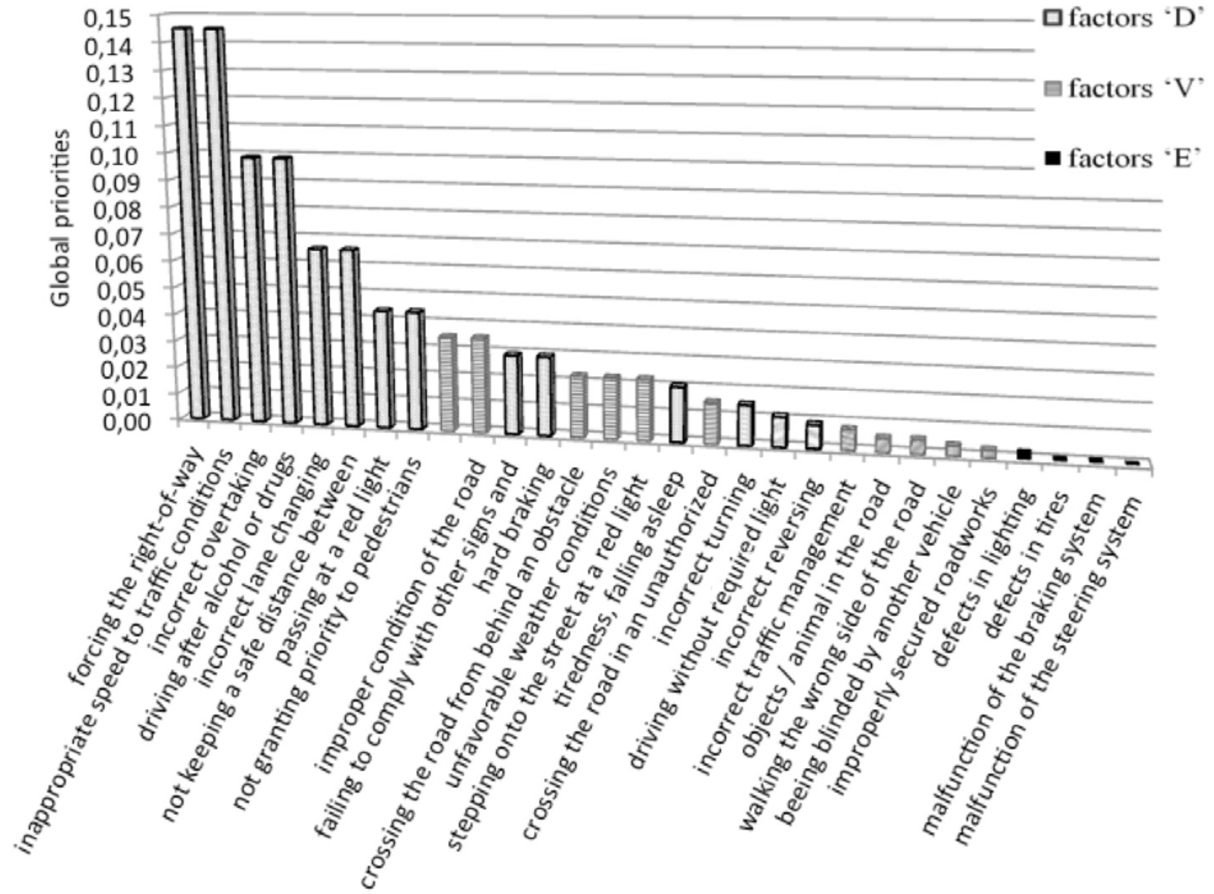

Fig. 3. The ranking of the factors determining the RTS with regard to the level of importance
Rys. 3. Uszeregowanie czynników determinujących stan BRD w odniesieniu do poziomu istotności

In conclusion, it is worth emphasizing that the presented ranking depends not only on an assessment of the relative ratings of factors, but also on the assumed importance criteria (for groups of factors). The main objective was to show one of the possible approaches to assess factors affecting road safety by using the AHP method.

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Received 06.03.2014; accepted in revised form 02.06.2015