ROAD TRANSPORT SYSTEMS SAFETY CRITERIA

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Abstract

Identification of boundary values and features which describe a system operation safety is a crucial problem for assessment of the system operation safety. In this article, an attempt to match features necessary for a description of a given system operation safety and determine their boundary values, has been made. Determination of boundary values of safety features will allow to evaluate the system safety level. The following variables have been accepted as safety features: the number of accidents, the number of fatalities, and the number of people injured in those accidents. According to these values, probability values of the numbers of people who were killed and who were injured in those accidents have been established. Probability value equal to zero has been accepted as the intentional state, the interval between 0 and the mean value of a given feature determines the acceptable state, the interval between the mean value of a given feature probability and value 0.1 determines the boundary state, whereas all features assuming values higher than 0.1 refer to the system critical state. The presented research results are considered as directives for development of safety criteria for road transport systems and determination of their critical values. The proposed method of boundary values determination can be used for assessment of safety for different transport systems.

Keywords: *safety, intentional state boundary state critical state*

Introduction

The theory of safety involves description of events that pose threat to human health, technical objects, and natural environment, and it provides methods for analyses of systems from the point of view of safety [3].

In literature, dedicated to the issue of safety of systems, there are two basic notions:

- Safety of a system is defined as its feature which conditions its existence and functioning in such a way that it does not pose threat to life or health of the operator and other people involved in the system operating, does not threaten itself, or does not disrupt functioning of other systems including the environment that surrounds it [1, 2, 4, 5].
- Safety is a relative property- its level depends not only on the values of features describing the system but also on the impact of the environment and actions of its operator [2].
- Safety of a system is referred to as its state $S_{T_{ti}}$ in time $t_i \in \langle t_p, t_k \rangle$ determined by temporary values of features $x_j, j = 1,2,\dots,k$ of set X formulated from the point of view of its safety [6].

1. Boundary values of safety features

Since a system, under the influence of forcing factors, changes its states in time, it is necessary to establish boundary values x_{gr} and critical values x_{kr} of features determining its states. Safety is a feature assuming different values depending on safety states:

1 – intentional state in which the values of features describing a system have reached expected values,

2 – acceptable state, in which the values describing a system are contained within established boundaries,

3 – boundary state, in which at least one of the features describing a system has reached a boundary value,

4 – critical state being in which may mean destruction of a system.

In states 1 and 2, the system possesses safety features, whereas in states 3 and 4 it does not. In Fig. 1, there is a proposal of the described safety states interpretation. The system state is a vector space; the features describing the system state are vectors. Values such as: number of accidents, number of fatalities, number of people injured in those accidents, which change the vector space into a scalar space, have been accepted for a description of the system state. On this basis, there have been determined boundary values of the accepted scalars, to obtain an n- dimensional safety space within the states of safety. The following variables have been accepted as the features describing the system state:

X– number of accidents which occurred in the analysed system,

y – number of people injured in those accidents,

z – number of fatalities of these accidents.

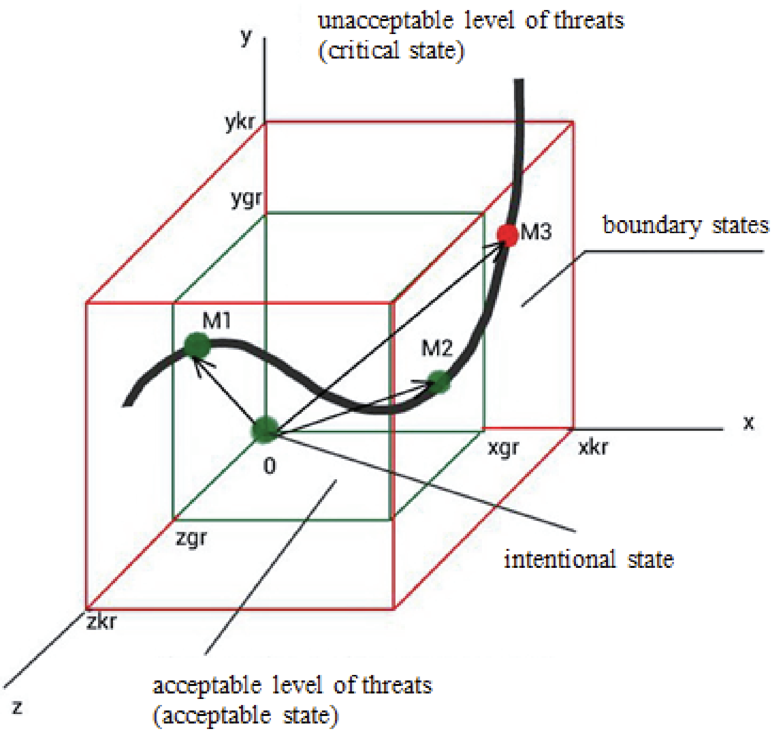

Fig. 1. Graphic interpretation of the system safety states

The state in which the discussed variables assume the following values: x = 0, y = 0, z = 0 is referred to as *intentional safety state SB$_i$*, this state is defined by dependence (1)

$$SB_i = \{x_i(t_i) = 0, y_i(t_i) = 0, z_i(t_i) = 0\}. \tag{1}$$

Whereas, the system state in which the values of defining it safety features do not exceed boundary values are called *the system operation acceptable safety state SB$_{ds}$* (2).

$$SB_{ds} = \{0 < x_i(t_i) < x_{gr}, 0 < y_i(t_i) < y_{gr}, 0 < z_i(t_i) < z_{gr}\}. \tag{2}$$

The state in which the values of safety features assume boundary values or exceed them is called *boundary safety state SBgr,* it is defined by dependence (3).

$$SB_{gr} = \{x_{gr} \le x_i(t_i) < x_{kr}, y_{gr} \le y_i(t_i) < y_{kr}, z_{gr} \le z_i(t_i) < z_{kr}\}. \quad (3)$$

The system state in which values of safety features defining the system reach or exceed the value of critical features is called *critical state of safety SBkr* (4).

$$SB_{kr} = \{x \ge x_{kr}, y \ge y_{kr}, z \ge z_{kr}\}. \quad (4)$$

Graphic interpretation of the system operation safety is presented in Fig. 1. It shows that the intentional state of safety occurs when values of the identified features are equal to zero. If the values of safety features are higher than zero, though lower than those of boundary values, then the system is in the acceptable state. It means that possession or loss of a safety feature depends on the system state. In states 1 and 2 the system is characterized by safety, whereas when its state changes into 3 or 4 loss of its safety follows which means that the system is in the boundary or critical state. Reaching the boundary safety state means that the decision makers need to undertake actions in order to restore the acceptable or intentional state. If no actions are undertaken, the system will enter the critical safety state in which no further operation is possible.

2. Determination of numerical values of boundary features defining the system operation safety state

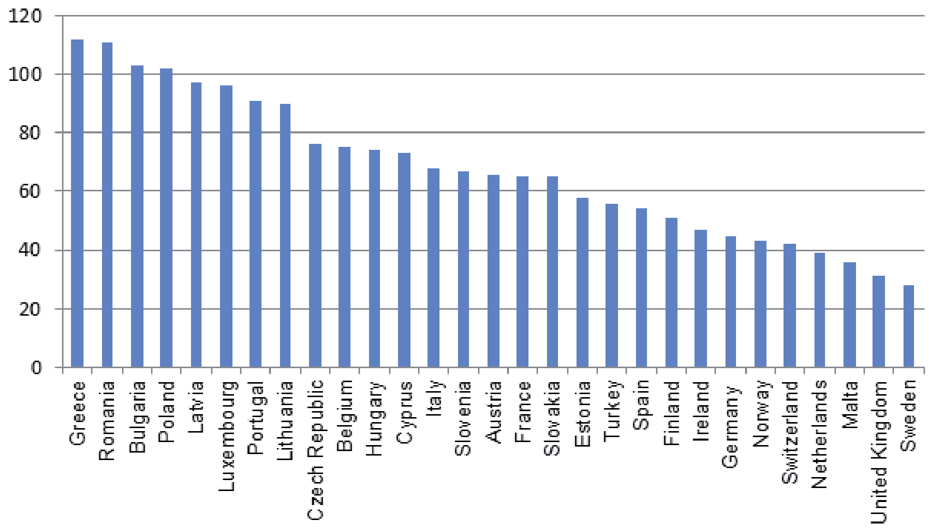

Fig. 2. Number of fatalities of road accidents per one million inhabitants in selected countries of Europe

According to the carried out assessment of safety level of road transport systems in selected countries in Europe, an attempt to establish boundary and critical safety values have been made. Fig. 2 shows the number of people killed in road accidents per one million of inhabitants of selected countries in Europe. It can be seen that the number of people killed in road accidents varies considerably from country to country.

Table 1 shows the number of road accidents and people killed and injured in them. According to the table the lowest number of accidents took place in Luxemburg, - 787, whereas the highest in Germany -288297 which accounts for 26% of the road accidents which were reported in the analysed countries in 2010.

Most people who sustained injuries in result of road accident were also in Germany, i.e. 371170, which accounts for 26% of all people injured in road accidents. Whereas, the lowest number of people injured in road accidents were also in Luxemburg. In 2010, in Europe 30662 people were reported to have been killed in road accidents, most of whom, 4172 in France. Again, the fewest fatalities were reported in Luxemburg.

Tab. 1. Number of road accidents and people killed an injured in them in selected European countries in 2010

Country	Number of accidents	Number of the injured	Number of fatalities
Austria	35348	45858	552
Belgium	39360	58894	812
Bulgaria	6610	8078	776
Czech	19675	24384	802
Estonia	1347	1712	78
Finland	6072	7673	272
France	67288	87173	**4172**
Germany	**288297**	**371170**	3648
Greece	15032	18882	1265
Hungary	16308	21657	740
Ireland	6615	8270	212
Italy	211404	302735	4090
Latvia	3193	4023	218
Lithuania	3530	4230	299
Luxemburg	787	1156	48
Holland	10778	-	640
Poland	38832	48952	3907
Portugal	35426	48573	967
Romania	25995	32414	2377
Slovenia	7659	10316	138
Spain	85503	120345	2478
Sweden	16504	2888	266
Great Britain	160080	215700	1905

The number of road accidents and people killed and injured in them fully reflects the situation of safety on the roads of particular countries. The number of killed and injured people per 100 accidents is a significant index of accident rate. Numerical values of these indices have been presented in Fig. 3 and 4. As Fig. 3 shows, the mean value of the number of people killed and injured in road accidents, in selected countries of Europe, was 121 persons per 100 road accidents. The highest number of people injured in road accidents was reported in Belgium – nearly 150 persons, the lowest number in Sweden-nearly 18 persons. In Poland, it was 126 injured per 100 accidents.

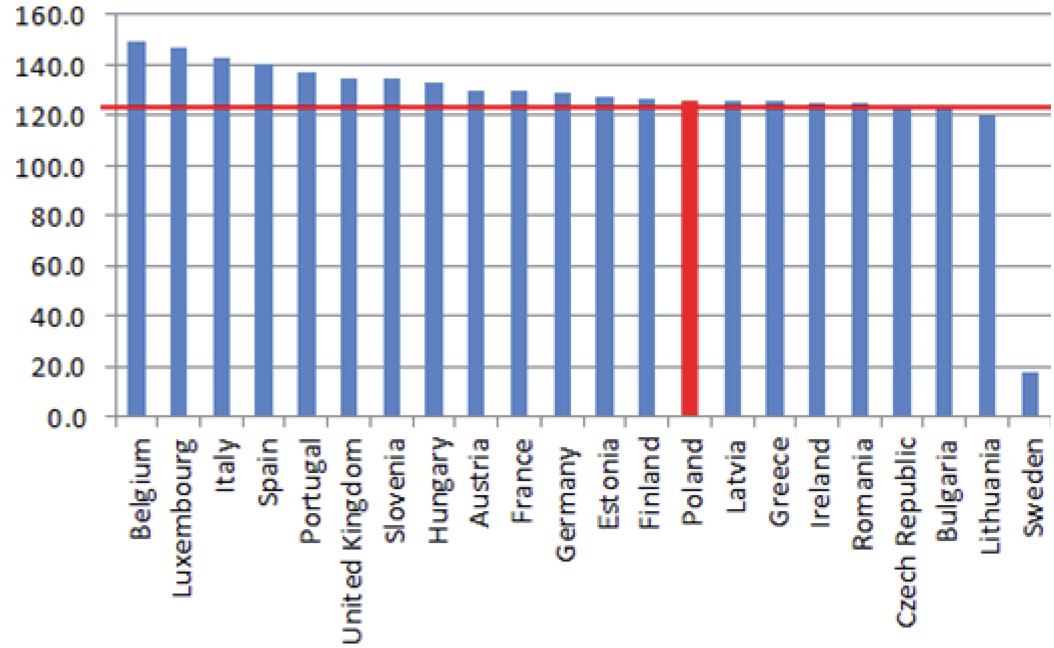

Fig. 3. Number of injured people per 100 road accidents

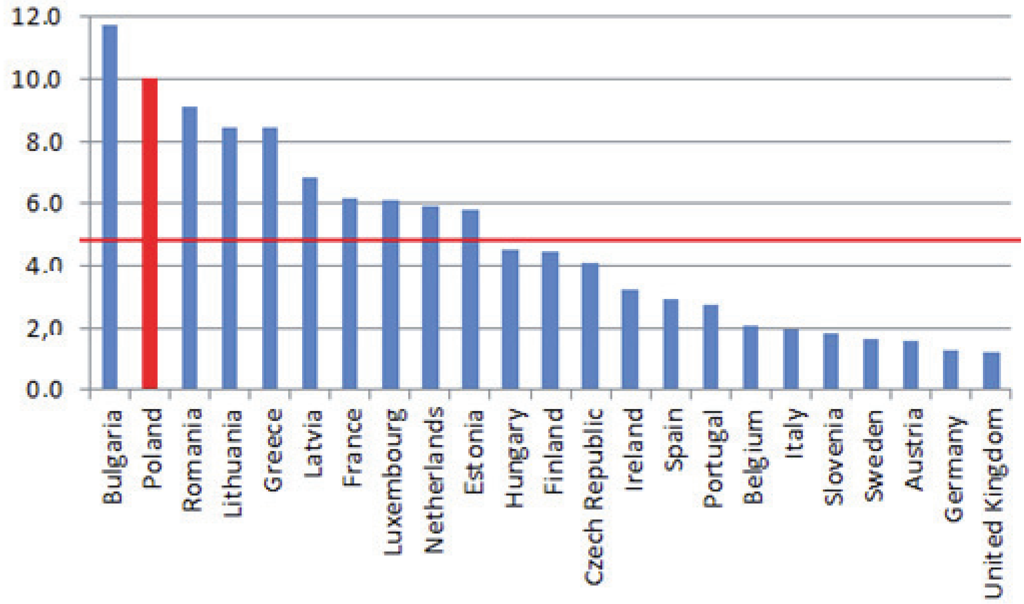

Fig. 4. Number of people who were killed per 100 road accidents

Another index for road traffic safety is the number of people killed in road events per 100 accidents. Values of this index for the analysed countries are shown in Fig. 4. As the figure shows, Poland occupies the second position in terms of road accidents fatalities. The mean value of this index is 4.75 fatalities per 100 road accidents. In Poland, this value is 10.1. It should be noted that in countries with a bigger number of accidents, that is Germany and Great Britain, this index has the lowest value, for Germany 1.3 and Great Britain 1.2. The value of this index in Great Britain is four times lower than the mean value for the European Union.

In work [7] an attempt to identify the critical value of adverse event occurrence probability and effects of these events, is made. It is assumed that the value of adverse event occurrence probability P(ZN) =0.1 is a critical value whose exceeding is not acceptable and corresponds to the unacceptable level of threats. Knowing the critical value of an adverse event occurrence probability, one needs to determine boundary P(ZN) and acceptable (intentional) values.

Tab. 2. Values probabilities of fatal accidents P(Z) and accidents with injured people

STATE OF SYSTEM	Country	P(R)	P(Z)	Country	State of system
Critical state	Germany	0.218	0.117	France	Critical state
	Italy	0.178	0.115	Italy	
	Great Britain	0.127	0.113	Turkey	
	Turkey	0.124	0.110	Poland	
Boundary state	Spain	0.071	0.102	Germany	
	France	0.051	0.069	Spain	Boundary state
	Belgium	0.035	0.067	Romania	
Acceptable state	Poland	0.029	0.053	Great Britain	
	Portugal	0.029	0.035	Greece	
	Austria	0.027	0.027	Portugal	
	Romania	0.019	0.023	Belgium	
	Czech	0.014	0.022	Czech	
	Switzerland	0.014	0.022	Bulgaria	
	Hungary	0.013	0.021	Hungary	
	Greece	0.011	0.018	Holland	Acceptable state
	Slovenia	0.006	0.015	Austria	
	Norway	0.005	0.010	Slovakia	
	Ireland	0.005	0.009	Switzerland	
	Slovakia	0.005	0.008	Lithuania	
	Bulgaria	0.005	0.008	Finland	
	Finland	0.005	0.007	Sweden	
	Lithuania	0.002	0.006	Latvia	
	Latvia	0.002	0.006	Ireland	
	Sweden	0.002	0.006	Norway	
	Cyprus	0.001	0.004	Slovenia	
	Estonia	0.001	0.002	Estonia	
	Luxemburg	0.001	0.002	Cyprus	
	Malta	0.001	0.001	Luxemburg	

On the basis of this study results, probabilities of occurrence of people injured P(R) and killed in road accidents P (Z), have been determined which is shown in Tab. 2. The mean values of probability have been determined for both cases. These values determine the maximal value of the system safety feature. In Fig. 5 and 6, the values of (intentional) safety features are marked in green and boundary values $x_{gr}min$ and $x_{gr}max$, which reflect the acceptable level of the system threats, are in orange. Exceeding the boundary value means that the critical state has been reached and the systems operates at an unacceptable level of threats, is marked in red colour in Fig. 5 and 6.

Conclusion

In this work, an attempt to determine boundary and critical values defining operation safety of road transport systems has been made. The proposed approach can be used for identification of other indices defining safety of this type of systems. The discussed research results are directives for development of safety criteria for assessment of road transport systems and determination of their critical values. The proposed method for determination of boundary values can be used for safety assessment of diversified road transport systems.

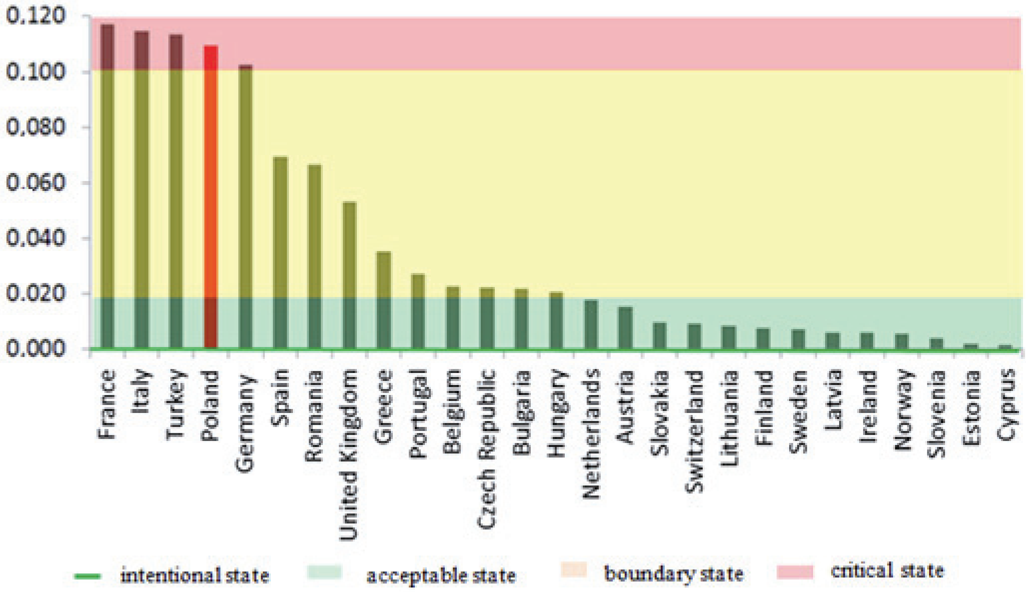

Fig. 5. Probability of sustaining injuries in a road accident P(R)

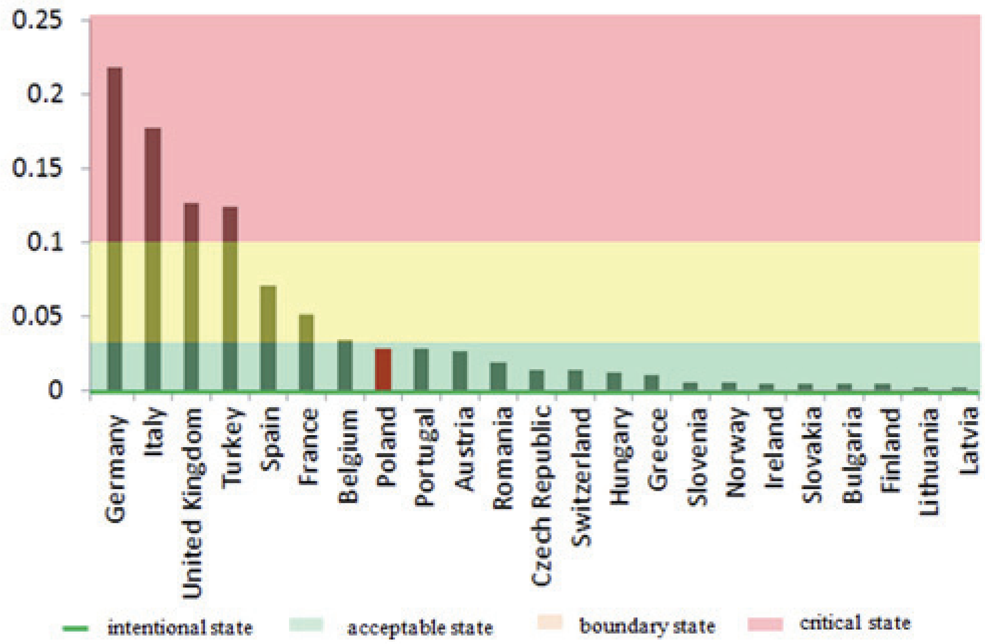

Fig. 6. Probability of fatal road accidents occurrence P (Z)

References

[1] Smalko, Z., *Studium terminologiczne inżynierii bezpieczeństwa transportu,* Oficyna Wydawnicza Politechniki Wrocławskiej, pp. 45-48, Wrocław 2010.
[2] Bojar, P. Woropay, M., *Bezpieczeństwo procesu transportowego w świetle różnorodnych wymuszeń*, Praca zbiorowa pod redakcją Tadeusza Dąbrowskiego, Badanie i Wnioskowanie Diagnostyczne – wybrane zagadnienia, Wydawnictwo WAT, Warszawa 2013.
[3] Jaźwiński, J., Ważyńska – Fiok K., *Bezpieczeństwo systemów*, PWN, Warszawa 1993.
[4] Radkowski, S., *Podstawy bezpiecznej techniki*, Oficyna wydawnicza Politechniki Warszawskiej, Warszawa 2003.
[5] Smalko, Z., *Charakterystyki spolegliwości układu Człowiek – Maszyna – Otoczenie,* XXXV Zimowa Szkoła Niezawodności, Szczyrk 2007.

[6] Smalko, Z., *Relacje między pojęciami bezpieczności i bezpieczeństwa w układach technicznych*, Materiały Sympozjum Bezpieczeństwa w Transporcie Morskim, Gdynia 2007.
[7] Bojar, P., *Wpływ wybranych czynników wymuszających na bezpieczeństwo przewozów realizowanych w systemie transportu zbiorowego*, Logistyka w dobie zrównoważonego rozwoju Wydawnictwo BSW, Bydgoszcz 2012.
[8] Bojar, P., Woropay, M., Szubartowski, M., *Systemowa ocena bezpieczeństwa działania wybranego systemu transportowego,* XXXIX Ogólnopolskie Sympozjum Diagnostyka Maszyn, Politechnika Śląska, Wydział Transportu, Katowice 2012.