STRUCTURING OF THE SAFETY EVALUATION MODEL FOR THE ROAD TRANSPORT SYSTEM

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Abstract

The transport system are sociotechnical systems in which the direct realization of the tasks is dealt with by an executive subsystem consisting of the elementary subsystems of a human - a technical object (an operator - a means of transport) type realizing the tasks within the system environment. In respect of a human located within a transport system the most significant criterion in the evaluation of the transports being realized is their safety.

The safety level of the task realization is influenced by the risks resulting from the interaction of the forcing factors, affecting an elementary executive subsystem.

These factors may be divided into [8]:
- *working,*
- *External,*
- *antropotechnical.*

In order to structure safety evaluation model of the road transport system we need to:
- *build the algorithm for evaluating safety of analysed system,*
- *establish safety criterion for the system's performance,*
- *structure a model using the algorithm of safety evaluation of the system.*

Due to the complexity of the systems being analysed in the paper, it has been attempted to evaluate the influence of the forcing factors on the safety of this system operation.

Key words: *transport system, folded system, forcing factors*

1. Introduction

The transport systems are the systems the aim of which is to realize transports over the determined area, using the means of transport. The essential requirements regarding the transport systems are:
- transportation safety,
- means of transport reliability,
- transportation punctuality,
- transportation adequate frequency,
- adequate standard of the services provided.

The transport systems are an example of the sociotechnical systems of a Human - a Technical Object - an Environment <H - TO - E> type in which the direct realization of the system tasks is dealt with by an executive subsystem consisting of the elementary subsystems of a human - a technical object (an operator - a means of transport) type realizing the tasks within the system environment. Moreover, a human within the transport system may be located:
- inside the means of transport (a passenger),
- within the means of transport environment, other drivers, pedestrians, etc.

In respect of a human located within a transport system the most significant criterion in the evaluation of the transports being realized is safety.

The safety level of the task realization is influenced by the risks resulting from the interaction of the forcing factors, affecting an elementary executive subsystem.

These factors may be divided into [8]:
- working (within a system) - forcing factors affecting a means of transport as a result of realization of the usable functions,
- external - forcing factors being characteristic for interaction of the environment affection a means of transport (not depending on its functioning),
- antropotechnical - forcing factors affecting a means of transport as a result of human actions, e.g. due to an operator's faults.

The authors of the works regarding safety of the transport systems and safety of a road traffic, e.g.: [4-7] evaluate the safety level of the road traffic on the basis of the databases provided by the police. These bases include data regarding the number of the road accidents which occurred within the time interval under analysis and number of fatalities and injured people resulting from the accidents occurred.

The essential source document of the accident registration system is a road events card which is filled in by the Police officers at the event site, according to their subjective judgment of the course and accompanying circumstances.

It should be noted that due to lack of diagnostic measures and no time, the state of a vehicle is not evaluated after a road event, therefore the Police reports mostly provide inappropriate driver's actions, such as (overspeeding, driving speed not adjusted to the existing road conditions etc.) as a most frequent cause of a road event.

A road event is a complex phenomenon which may result from the interaction of the aforementioned forcing factors: working (resulting from a vehicle serviceability condition), external (resulting from the environmental interaction) and antropotechnical (being a result of faults of a driver and people located in the system and within its environment).

When analysing the causes of the road accidents occurrence they should be treated as independent events which may occur individually or jointly, as shown in the Tab. 1.

Tab. 1. Possible sequences of events leading to a road accident occurrence

Pos.	Working factors interaction	External factors interaction	Antropotechnical factors interaction
1	1	1	1
2	1	0	1
3	1	1	0
4	1	0	0
5	0	1	1
6	0	1	0
7	0	0	1
8	0	0	0

The table represents sequences of the events leading to the risk states of a transport system safety, where:

1 - an event in which interaction of the chosen forcing factors had an influence on the road event occurrence,

0 - an event in which interaction of the chosen forcing factors had no influence on the road event occurrence.

The risk state of the system safety No. 8 is an abstract state, the occurrence of which was affected by none of the system elements.

2. Object of the study

The object of the study is a generally defined transport system being a sociotechnical system of a Human - a Technical Object - an Environment <H - TO - E> type, the main task of which is to transport people safely within the determined quantitative and territorial range, using the means of transport being operated and maintained inside this system.

The system under investigation is included in the class of the complex real systems, performing their tasks in the defined environment [8-11].

A complex system is such a system which includes sets of elements that can in turn be also complex systems interlinked by their functions and subordinated to the realization of the assigned tasks [12, 15].

An element (an elementary subsystem) is called such a system in which it is impossible to distinguish the subsystems of a lower level [14].

The complexity of a system depends both on the number of its subsystems, located on different decomposition levels, and the number of these levels.

The location of each subsystem in the system structure and its operation aim are to be taken into account when performing investigations of the system.

The subsystems located on the successive decomposition levels may be treated as indivisible objects, depending on the problem consideration circumstantiality. The features of the system as a whole are determined not only on the basis of the features of its individual subsystems, but also on the basis of its structure.

An example of such a transport system type is a collective urban transport system. The transportation inside an urban transport system may be performed using different means of transport. The most popular, however, is a bus transport system.

The following subsystems may be distinguished on the individual decomposition levels (Fig. 1):

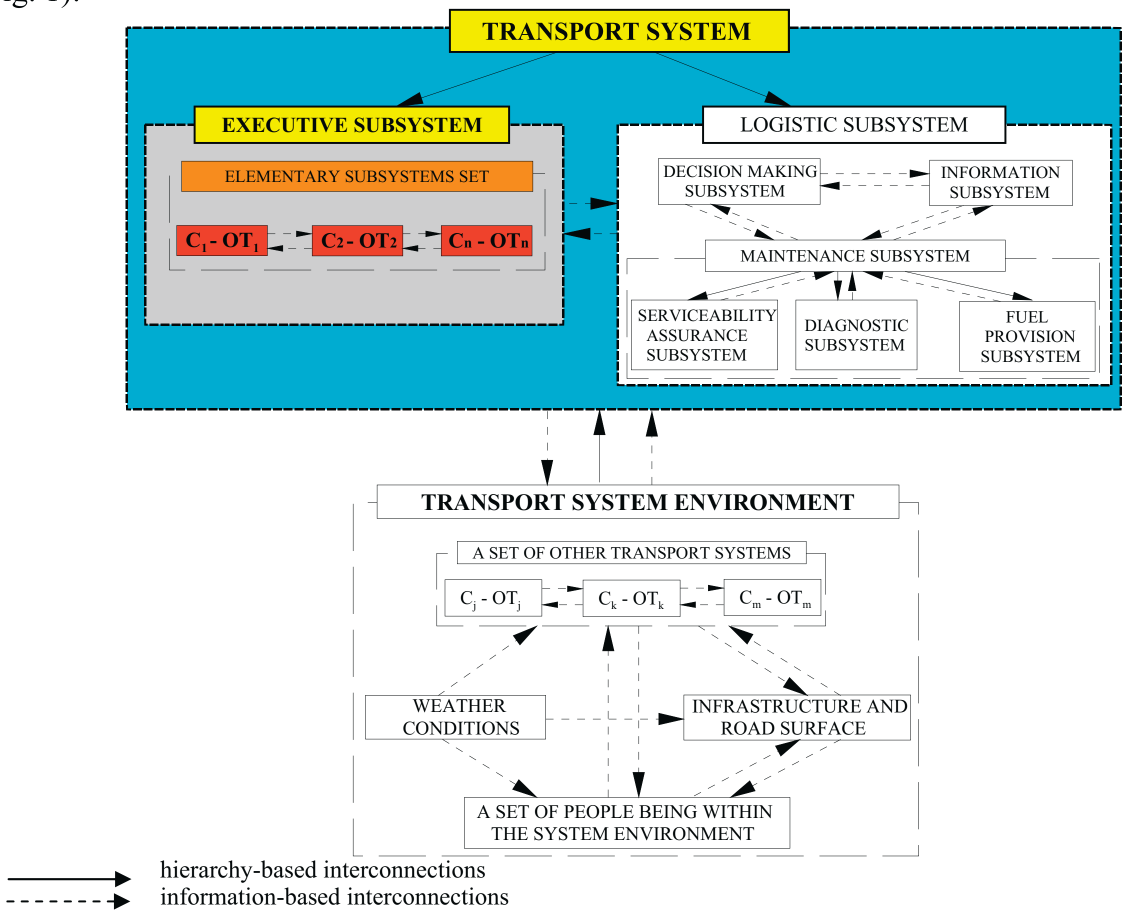

Fig. 1. Means of transport operation and maintenance system model

As it results from the above diagram, a human inside a transport system under analysis may be located inside the system (a bus driver or a passenger), as well as he/she may be located within the system environment (other vehicle drivers, bikers, pedestrians).

Due to differentiated location of a human and his/her safety, there is a need to build a method which would comprehensively include the forcing factors affecting this system safety operation.

3. Aim of the study

The aim of the study is to build an algorithm to evaluate the forcing factors affecting the road transport system operation safety.

4. Structuring of the safety evaluation model for the road transport system

In order to structure safety evaluation model of the road transport system we need to:
- build the algorithm for evaluating safety of analysed system,
- establish safety criterion for the system's performance,
- structure a model using the algorithm of safety evaluation of the system.

4.1. Algorithm structuring

The algorithm presented in the figure 2 reflects the operational procedure used when evaluating the road transport operation safety, taking into account the major forcing factors described herein.

Three essential members A, B and C may be distinguished in this algorithm, they are related to:
A - evaluation of the means of transport operation safety,
B - evaluation of the interaction of the system environment affecting the operation safety of that system,
C - evaluation of the interaction of the humans located inside the system and within its environment affecting the operation safety of that system.

The individual members of the algorithm may form separate algorithms to evaluate interaction of the forcing factors affecting the operation safety of the system under analysis. When combined they constitute a comprehensive evaluation of the transport system operation safety.

In terms of the algorithm complexity the individual blocks have been presented in a simplified form using a symbolic description, all the symbols have been explained in the Tab. 2.

Tab. 2. Description of the algorithm to evaluate the transport system operation safety

Block code	Code description
1	Determine a set of the road events occurred within the analysed time interval Zi; i = {1, 2, 3, …, k}.
2	Select the events being significant from the point of view of the system operation safety being analysed.
3	Arrange in series the events according to their occurrence date Z_1, Z_2, Z_3, …, Z_k.
4	Select the first event to be evaluated Z_i, i = 1.
5	Select another toad event to be analysed $Z_i + 1$.
6	Make collective evaluation of the transport system operation safety
7	Evaluate the costs due to the events occurred
8	Show the result
A	Did a damage to a subsystem of a means of transport cause the occurrence of the event under analysis ?
A1	Determine the criteria to evaluate the significance of the damaged subsystem.
A2	Evaluate the significance of the damaged subsystem.
A3	Is the damaged subsystem significant from the point of view of the means of transport operation safety?
A4	Did the damage to the significant subsystem affected the improper operator's actions?
A5	Evaluate the change level to the means of transport serviceability state as a result of the damage to the analysed subsystem.
A6	Determine a set of indices to evaluate the means of transport operation safety.
A7	Determine the criteria to evaluate the means of transport operation safety.
A8	Determine the set of indices being representative for the evaluation of the means of transport operation safety.
A9	Evaluate safety of the means of transport operation.
A10	Is the analysed event $Z_i = Z_k$? where i = {1, 2, 3, …, k}

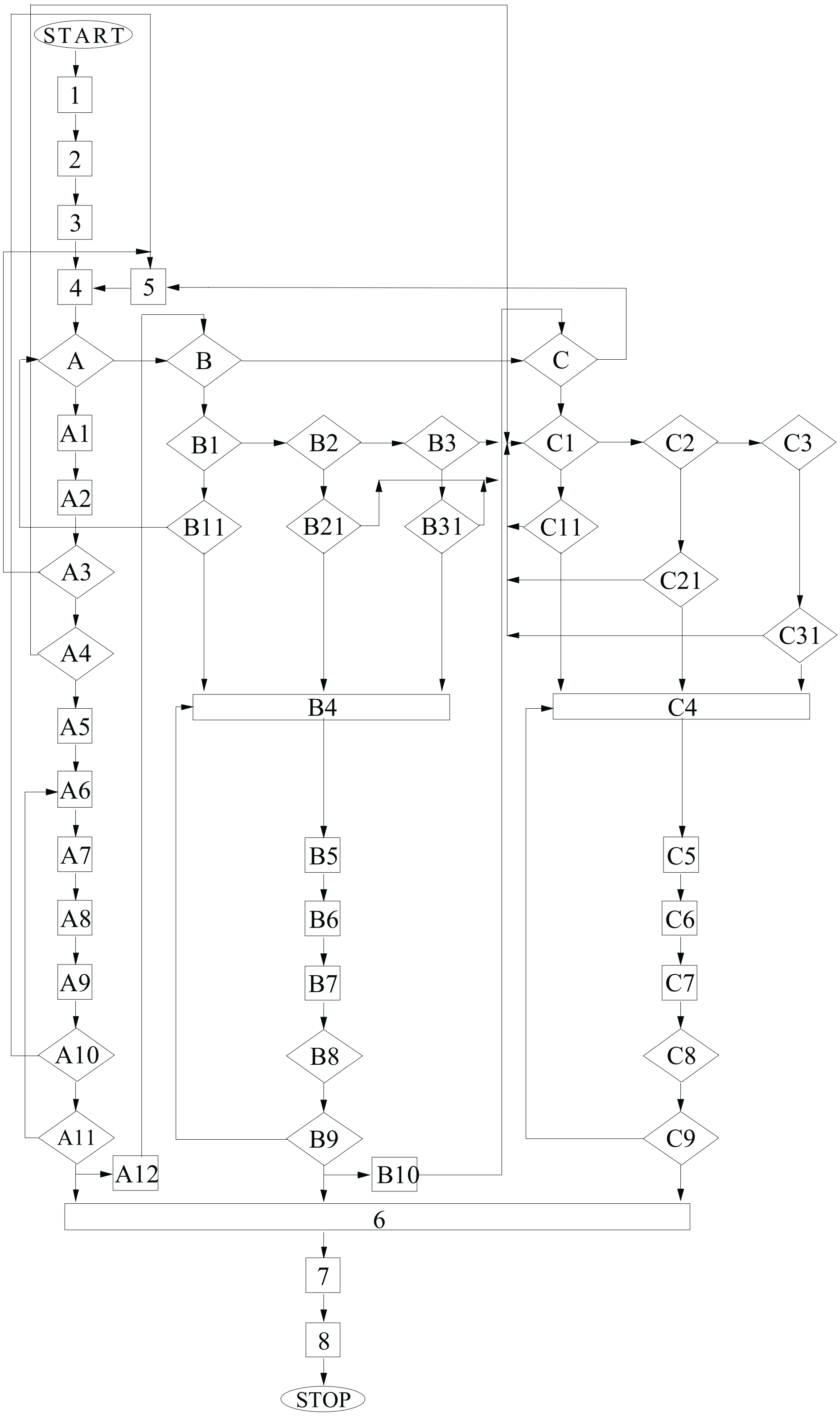

Fig. 2. Algorithm to evaluate the transport system operation safety

4.2. Establishing safety criterion

In order to establish the safety criterion we need to determine a set of significant measurable characteristic X_{Mi} (i = 1,2,...,n) and a set of significant immeasurable characteristics X_{Nj} (j = 1.2,...,m) describing the system in terms of safety. Then for every measurable characteristic we need to set allowable limits $X_{M,i}^{\min}$ and $X_{M,i}^{\max}$ for safe performance of the system (safe realisation of transport task).

Tab. 2. Description of the algorithm to evaluate the transport system operation safety - continuation

Block code	Code description
A11	Is the resultant model adequate?
A12	Check if the event B occurred as well.
B	Did the interactions of the environment cause the occurrence of the analysed event?
B1	Did the improper state of the pavement surface cause the occurrence of the analysed event?
B11	Did the improper state of the pavement surface cause a damage to the means of transport?
B2	Did the improper road infrastructure cause the occurrence of the event?
B21	Did the improper road infrastructure cause improper actions of the people located within the system and within its environment?
B3	Did the weather conditions cause the occurrence of the event?
B31	Did the weather conditions cause improper actions of the people located within the system and within its environment??
B4	Determine a set of the indices to evaluate safe interaction of the environment affecting people and means of transport.
B5	Determine criteria to evaluate safe interaction of the environment affecting people and means of transport.
B6	Determine a set of the indices representative for evaluation of the safe interaction of the environment affecting people and means of transport.
B7	Evaluate safe interaction of the environment affecting people and means of transport.
B8	Is the analysed event $Z_i = Z_k$? where $i = \{1, 2, 3, \ldots, k\}$
B9	Is the resultant model adequate?
B10	Check if the event C occurred as well.

Tab. 3. Description of the algorithm to evaluate the transport system operation safety - continuation

Block code	Code description
C	Did the actions of the people located inside the means of transport and within its environment cause the occurrence of the event?
C1	Did the improper driver's actions cause the occurrence of the event?
C11	Did the improper driver's actions cause a damage to the means of transport subsystem?
C2	Did the improper actions of the means of transport passengers cause the occurrence of the event?
C21	Did the improper actions of the passengers affect the wrong driver's actions?
C3	Did the improper actions of the people located within the environment of the means of transport cause the occurrence of the event?
C31	Did the improper actions of the people located within the environment of the means of transport affect the wrong driver's actions?
C4	Determine a set of the indices to evaluate undesirable interactions of the people located inside the means of transport and within its environment.
C5	Determine the evaluation criteria of the safe interactions of the people located inside the means of transport and within its environment.
C6	Determine a set of the indices representative for evaluation of the interactions of the people located inside the means of transport and within its environment.
C7	Evaluate safe interaction of the people located inside the means of transport and within its environment.
C8	Is the analysed event Zi = Zk gdzie, i = {1, 2, ..., k}
C9	Is the resultant model adequate?

Similarly for every immeasurable characteristic we need to set the criterion allowing to find if a given characteristic conforms with the conditions of safe performance of the system. This occurrence can be symbolised by $X_{Nj} = 1$, however an opposite occurrence will be described by

X_{Nj}=0. In this case the condition of safe performance of the system at a given time $t, t \in [t_0, t_k]$ can be expressed with the following relation (1):

$$BDS = \begin{cases} X_{M,1}^{\min} < X_{M,1,t} < X_{M,1}^{\max}, ..., X_{M,n}^{\min} < X_{M,n,t} < X_{M,n}^{\max}, \\ X_{N,1,t} = 1, ..., X_{N,m,t} = 1. \end{cases} \quad (1)$$

Safety level at a given time can be represented by a vector which ends in point M ($x_1(t)$, $x_2(t)$, $x_3(t)$, ..., $x_k(t)$) in n-dimensional space. Diagram 2 shows safety level of the system performance at time t in 3-dimentional space. Point M in diagram 2 marks standard level of safety for the system. Boundary values of the characteristics {x_1, y_1, z_1} determine allowable changes ranges of the safety level for given characteristics. In 3-d they form a cube of allowable safety level variations. Point M_1 (fig 3) represents the level of safe performance within the limits of allowable hazards level. Characteristics exceeding limit values endangers safe performance (disallowable hazards level), points M_2 i M_3.

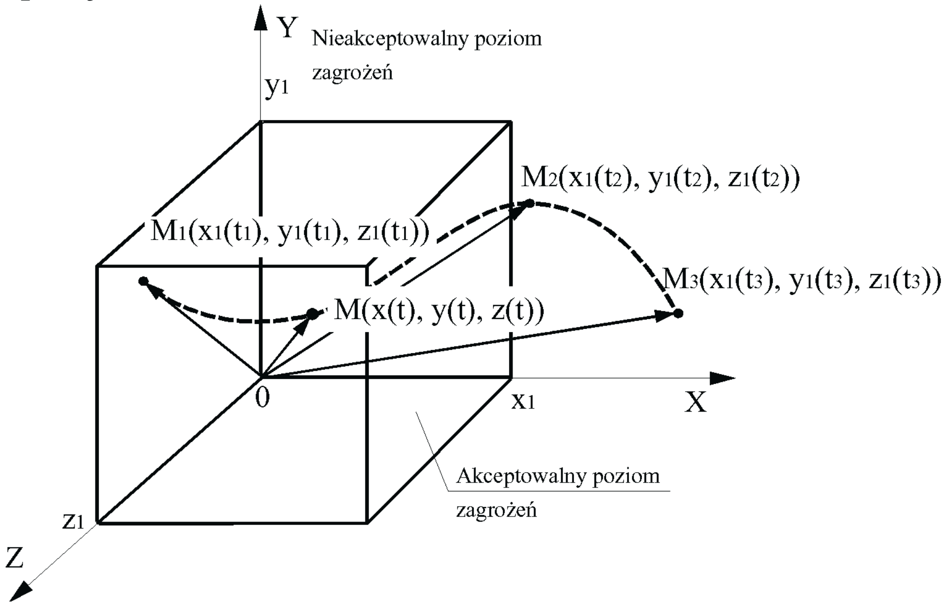

Fig. 3. Graphic representation safe performance level for road transport system

Taking into account above hazards, the performance of the system is in state of limited fit for use down to its damages of key elements. Such state consists of different safety levels depending on the significance of damaged element and the level of damage.

Possible results of such state are:

- injury or death of road transport users,
- damage to means of transport,
- financial damages to surrounding environment (damage to properties, telecommunication network, electrical infrastructure, forestry etc.).

For this reason safe transport system performance criterion should apply to its individual elements and their functions in that system.

1. Means of transport requirements:
- high safety performance level,
- high resistance,
- high reliability,
2. Environmental requirements for road transport system:
- correct design of road infrastructure,
- proper road coverage in good condition,
- meteorological conditions allowing safe realizations of transport task.

3. Operating staff requirements:
- appropriate qualifications,
- approved health conditions,
- good stress tolerance level,
- good reflexes.

Above requirements are the criterion for safe performance of the road transport system. They can be described by a set of indicators.

4.3. Choice of measures for building system performance safety model.

In order to build road transport safety model it is required to analyse indicators described in this subject's literature and formulate such indicators that will create full evaluations set measures used to evaluate safety of transport system performance should take into account: the assessment of serviceability and aptitude of individual means of transport, environmental interaction assessment and the assessment of people's actions when placed inside the system and its environment. This set will be called safe system performance indicators set. WBDS is represented by relationship (2):

$$W_{BDS} = \{W_{1n}, W_{2n}, W_{3n}\}, \qquad (2)$$

$$W_{1i},\ i = 1,2, ..., n. \qquad (3)$$

W_{1i} is a set of indicators relating to means of transport safety assessment

$$W_{2i},\ i = 1,2, ..., n. \qquad (4)$$

W_{2i} is a set of indicators that relate to environmental influence assessment, influence on people and means of transport

$$W_{3i},\ i = 1,2, ..., n. \qquad (5)$$

W_{3i} is the set of indicators relating to people placed in the system and its environment.

Fundamental stage of building a result model for the safety of road transport system is to determine a set of representative indicators used to assess and evaluate safety of performance and to make appropriate decisions relevant to steering of the safety level.

Due to the lack , in analysed literature, of models and methods of assessment for safety performance of systems on the basis of technical condition of means of transport it is required to build such model.

In the process of building preliminary model it is required to choose set of indicators $W_{1i} = \{W_{1\text{-}1}, W_{1\text{-}2}, W_{1\text{-}3}, \dots , W_{1\text{-}15}\}$, present in analysed literature as well as to formulate and develop own indicators useful for assessment. This way one will have created full set of evaluation indicators. This set needs then to be verified in terms of evaluation and assessment of usability and if needed reduced. Reduction of such set should take place in to stages:

a. Establishing usability criterion for the indicators
b. Analysing the independence of the indicators

1. The first stage of set reduction uses the following criterion:
- usability of assessment of performance safety resulting from its specificity,
- subject of research adapted,
- usability for assessment of the subjects performance safety resulting from damages to its subsystems.
2. Evaluation of damages to people and means of transport.

The second stage of reduction consists of analysing the indicators in terms of their independence and determining which of them carry excessive information.

Above criterion of analysis are the basis of reduction of the full set of indicators and it results in determining a set of indicators useful to evaluate performance safety of analysed system. Further reduction of the set of indicators possible through establishing correlation between the values of individual indicators. Obtained values of correlation coefficients is described by correlation matrix K represented by the following relation:

$$K = \begin{bmatrix} W_{1.1} - W_{1.1} & W_{1.1} - W_{1.2} & W_{1.1} - W_{1.3}; & ...; & W_{1.1} - W_{1.n} \\ W_{1.2} - W_{1.1} & W_{1.2} - W_{1.2} & W_{1.2} - W_{1.3}; & ...; & W_{1.2} - W_{1.n} \\ . & . & . & & . \\ . & . & . & & . \\ . & . & . & & . \\ W_{1.n} - W_{1.1} & W_{1.n} - W_{1.2} & W_{1.n} - W_{1.3}; & ...; & W_{1.n} - W_{1.n} \end{bmatrix}. \tag{6}$$

Matrix K = [K_{ij}], where $K_{ij} = K_i/K_j$, i, j = 1, 2, 3,…, n, is on the main diagonal 1 in this case elements of the lower matrix triangle K (that is elements under the diagonal) are the reverse of appropriate elements of the upper matrix triangle.

For this reason further consideration involves only elements above the main diagonal quantity of the elements can be determined by relation (7):

$$L_W = \frac{n(n-1)}{2}, \tag{7}$$

where:

n - number of indicators giving a representative set of safety evaluation measures.

In order to check correlation between independent indicators a significance test has been conducted, described by equation (8):

$$t = \frac{r}{\sqrt{1-r^2}}\sqrt{n-2} \quad . \tag{8}$$

Significant indicators of the whole set of indicators useful for safety assessment are independent indicators, that is indicators that do not correlate whit others because they carry significant information on the condition of safety of analysed system. The set of independent indicators formulates representative set of assessment indicators RZWO can be represented by reduced matrix correlation (9)”

R_{ZWO} = [K_{ij}], where $K_{ij} = K_i/K_j$, i, j = 1, 2, 3,…, m, where m‹n,

$$R_{ZWO} = \begin{bmatrix} W_{1.1} - W_{1.1} & W_{1.1} - W_{1.2} & ; & ...; & W_{1.1} - W_{1.m} \\ W_{1.2} - W_{1.1} & W_{1.2} - W_{1.2} & ; & ...; & W_{1.2} - W_{1.m} \\ . & . & . & & . \\ . & . & . & & . \\ . & . & . & & . \\ W_{1.m} - W_{1.1} & W_{1.m} - W_{1.2} & ; & ...; & W_{1.n} - W_{1.m} \end{bmatrix}. \tag{9}$$

5. Summary

- The method to analyse safety of the transport system operation safety suggested herein is an innovative approach of the road transport system safety evaluation.
- The method is an universal one and it may be applied to evaluate operation safety of various types of the road transport systems.
- The components of the algorithm may constitute separate methods to evaluate interactions of the individual forcing factors affecting the safety level of the system operation under analysis.
- There is a necessity to continue further analysis of the problem described herein, in order to show precisely all the relations taking place between the individual elements of the system under analysis.

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