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MODELLING OF CRITICAL RAILWAY TRANSPORT INFRASTRUCTURE RENEWAL

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Abstract: *The paper examines a number of problems connected with the critical railway transport infrastructure renewal in Slovak Republic. To calculate the risk, it is proposed to multiply the occurrence rate and financially estimated total consequence. The assessment includes risks based on consequences to safety and health of people as well as risk for third parties based on the increase of transport costs.*
Key words: *critical railway infrastructure, renewal, modeling, risk assessment, transport costs.*

1. INTRODUCTION

An issue of critical infrastructure became very important after 11th September 2001. The world powers started to think about vulnerability of their own land. This issue was theoretically solved mainly in USA and Australia. European Union focused its attention to critical infrastructure issue in the end of last decade. New directives were introduced in order to identify elements of European critical infrastructure (next ECI). Afterwards were introduced national laws and regulations, which are defining particular tasks for public and private companies and institutions. Critical transport infrastructure is one part of national infrastructure, which includes also energetic infrastructure, telecommunications, banks, health care system, etc. At this time, there is no methodology for evaluation of critical infrastructure elements, which could be applied for this task without taking any adjustments. Authors of this paper are contributing on solution of different projects, which are oriented on defining of critical infrastructure elements in transport segment. According to the education and experiences of authors, their attention is focused mainly on railway transport. The aim of author’s effort is to develop theoretical knowledge in order to create map of risks for critical railway infrastructure.

2. CRITICAL RAILWAY TRANSPORT INFRASTRUCTURE

The elements of critical infrastructure are defined according to cross-section and segment criteria. Cross-section criteria on national level are defined by the number of victims (more than 250 dead persons) and injured persons (more than 2500 injured persons) and economical consequences of crisis situation, which is in central European countries defined as 0,5 % of GDP. Segment criteria for railway transport are multicriterial, focused on main transit routes. Those routes are surrounded by numerous objects, which importance is crucial and their renewal is very difficult. Therefore are they considered to be indispensable for functioning of railway network.

Selection of those objects, identification of risk sources and technology of renewal are determining. In order to model renewing of critical railway infrastructure it is required:

- to set relationships and to define criteria for choosing evaluated objects,
- to identify risk sources with focus on the most probable and most destructive consequences,
- to create list of initiating events, mainly those, which are probable at selected location,
- to define libraries of measures, which could be used to decrease risks in particular object,
- to analyze risk for particular objects,
- to evaluate risks with clear conclusion if the risk is acceptable or unacceptable.

2.1 ASSESSED FACTORS

Risk assessment has to be based on the principles of combination of probability and consequences. Further categorization of the probability in assessment process is not advisable, the attention should be focused on the consequences resulting from the assessed undesired occurrences.

It is advisable to substitute the non-dimensional probability by the frequency of occurrence, which, assuming the real values, is expressed by the time units [h^{-1}]. By doing this it won't be necessary to relate the assessed factor to the a particular time period, e. g. 1 year.

Evaluation of consequences could be separated to the infrastructure operator's costs related to an object reconstruction and the total expenses of road traffic participants varying in dependence on the length of a potential diversion route, traffic density and the time required for the particular object reconstruction.

2.2 ASSESSED OBJECT

Crisis management of the Czech Republic considers the road and railway infrastructure to be critical. From the national point of view the railway infrastructure is more critical than the road one, but regarding to the territorial division of a country, the road infrastructure appears more critical and will be further presented. Selected types of road infrastructure objects to be assessed are as follows: bridge, tunnel, junction, stretch of road, railway crossing.

Points and lines as the map symbols represent the particular types of objects. Line objects assessment has to respect the length of assessed object, but it is not necessary to separate the results of line objects analysis from those obtained by performing the point object analysis.

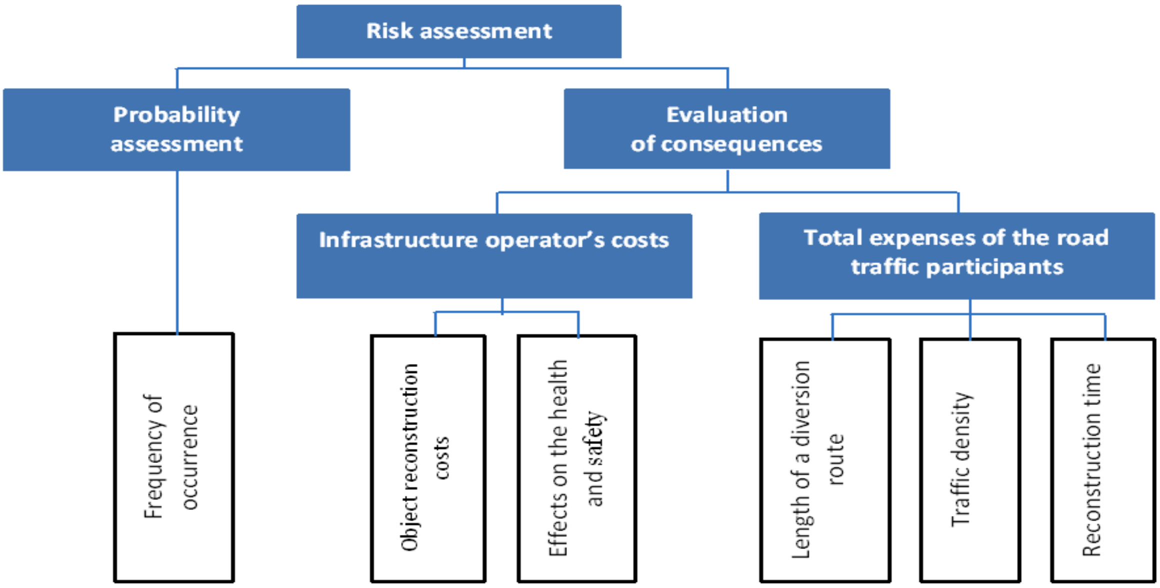

Fig. 1 *Risk assessment processes*

2.3 ASSESSED OCCURRENCES

Any undesired occurrence pertaining to the traffic infrastructure objects, such as ordinary wear and tear, wrong or defective construction, natural phenomena, traffic accidents, etc. can be assessed. Wear, accident, and other causes a partial or total closure. Considering the risk it is possible to compare undesired occurrences of exanimate objects globally as well as separately in defined categories in regard to a kind of undesired occasion.

2.4 VALUE SCALES

All of the valuation scales are of five points. Evaluation of the factors does not primarily take into account the complicated risk/risk value assessment. If there are more factors to be assessed than the standard calculation methods usually use, the calculation would not be a simple sum or product of values although a value scale would be adjusted. Primarily it is important to adapt the scales to the real values as the output data and also to the commonly used terms (timescale constructed of the time periods such as day, week, month, etc., instead of 1 hour, 10 hours, 100 hours, etc.), and also to the anticipated probability distribution identifying probability of the value falling into a defined interval.

All of the designed scales are five-point. Analysis and evaluation do not require the scales to be of the same number of levels, but it seems useful for those performing the evaluation. It is recommended to define a designation for each scale value.

Occurrence rate

- Designation of the factor (indicator): F_1
- Number of scale levels: 5
- Designation of real substitution value: X_1
- Real parameter measurement unit: h^{-1}
- Approximating real function: f_1

Designated time data have been chosen in consideration of commonly used ones, range and form of arithmetic progression is then identified in regard to the anticipated rate of evaluated occurrences.

Table 1 *Approximating functions*

F_1	Occurrence rate	X_1 [h^{-1}]	f_1
1	negligible (cca once per 100 years or less)	1,1E-06	$f_1 = 10^{F_1 - 7}$
2	low (cca once per 10 year)	1,1E-05	
3	medium (cca once per year)	1,1E-04	
4	high (cca once per month)	1,4E-03	
5	abundant (cca once per week or more)	6,0E-03	

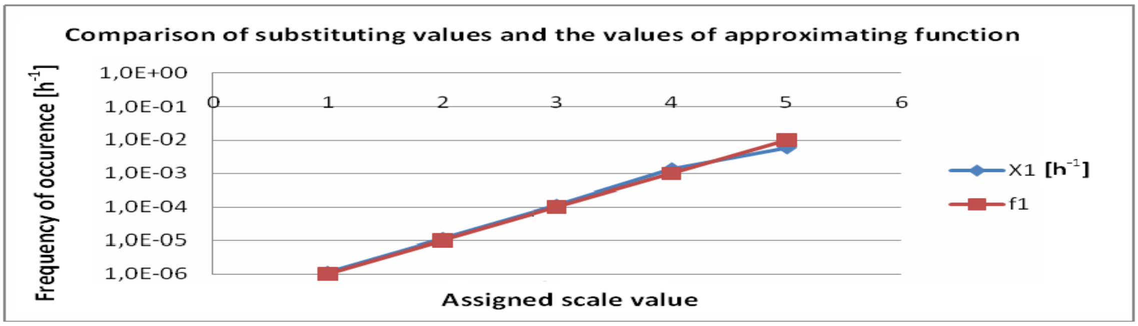

Fig. 2 *Frequency values comparison*

Object reconstruction costs

- Designation of the factor (indicator): F2
- Number of scale levels: 5
- Designation of real substitution value: X2
- Real parameter measurement unit: CZK
- Approximating real function: . f_2

Values fall into the range of scale with the ratio equal to 10. This high-value coefficient allows the diametrically different occurrences in terms of costs to be evaluated, e. g. ice layer vs. reconstruction of a section.

Table 2 *Approximating functions*

F_2	Object reconstruction costs	X_2 [CZK]	Approximating functions
1	negligible (cca 1 000 CZK or less)	1,00E+03	$f_2 = 10^{F_2 + 2}$
2	low (cca 10 000 CZK)	1,00E+04	
3	medium (cca 100 000 CZK)	1,00E+05	
4	high (cca 1 000 000 CZK)	1,00E+06	
5	extremely high (cca 10 000 000 CZK or more)	1,00E+07	

Comparison of substitution values and the ones of approximating functions is not necessary, because these are equal for each point of evaluation.

Effects on the health and safety

- Designation of the factor (indicator): F3
- Number of scale levels: 5
- Designation of real substitution value: X3
- Real parameter measurement unit: CZK
- Approximating real function: f3

If we express the impact on healt in financial terms it can be included into the risk associated with undesired occassion as well. The price of health or life is disputable and markedly varies in different studies. There are many studies on the price of human life regarding the age of people or a country where they live, etc. Estimation of values for each level shown in the table bellow is not an issue to be worked out in this text so the data valuated by RRM software (Risk and Reliability Management) have been used without the detail analysis.

Table 3 *Approximating functions*

F_3	Effects on the health and safety	X_3 [CZK]	Approximating function
1	negligible (health threats without persistent effects)	1,0E+04	$f_3 = 8.10^{F_3+2}$
2	small (persistent injury)	8,0E+05	
3	medium (persistent injury of more people)	8,0E+06	
4	large (death)	8,0E+07	
5	death (death of more people)	2,5E+08	

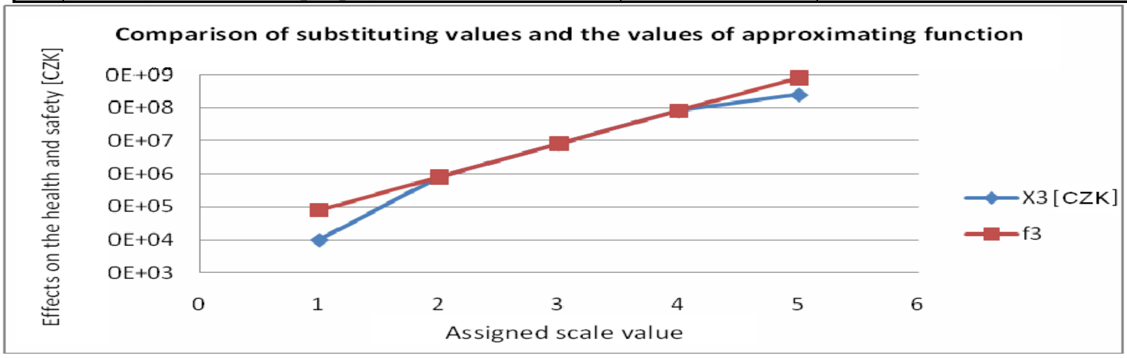

Fig.3 *Effects values comparison*

Length of a diversion route

- Designation of the factor (indicator): F4
- Number of scale levels: 5
- Designation of real substitution value: X4
- Real parameter measurement unit: km
- Approximating real function: f4

Table 3 Approximating functions

F_4	Length of a diversion route	X_4 [km]	Approximating function
1	negligible (cca 5 kms or less)	5	$f_4 = 3.2^{F_4}$
2	small (cca 10 kms)	10	
3	medium (cca 25 kms)	25	
4	large (cca 50 kms)	50	
5	extraordinary (cca 100 kms or more)	100	

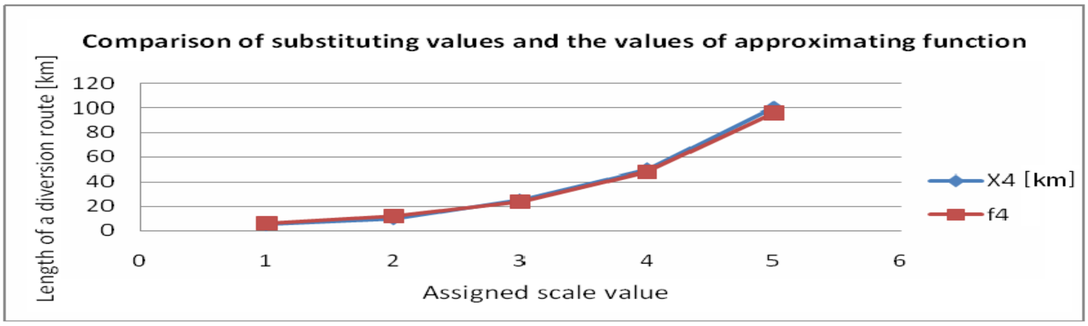

Fig. 4 *Length of a diversion route values comparison*

Traffic density

- Designation of the factor (indicator): F5
- Number of scale levels: 5
- Designation of real substitution value: X5
- Real parameter measurement unit: pc(24h)-1
- Approximating real function: f5

Value scale presented bellow has been designed in accordance with results of the periodical traffic density statistics made by the Roads and Motorways Agency of the Czech Republic. Annual average of the vehicles on the motorways and main roads during the 24 hours period is being considered. If the exact values of traffic density on particular road stretches are known, it is better to abandon a semiquantification of this factor and use the statistical density values.

Table 4 *Approximating functions*

F_5	Traffic density	X_5 [wagon units/ 24 hrs]	Approximating function
1	negligible (cca 500 wagon units/24hrs or less)	500	$f_5 = 500.2{,}5^{F_5-1}$
2	low (cca 2 000 wagon units /24hrs)	2000	
3	medium (cca 6 000 wagon units /24hrs)	6000	
4	High (cca 12 000 wagon units /24hrs)	12000	
5	extremely high (cca 30 000 wagon units /24hrs or more)	30000	

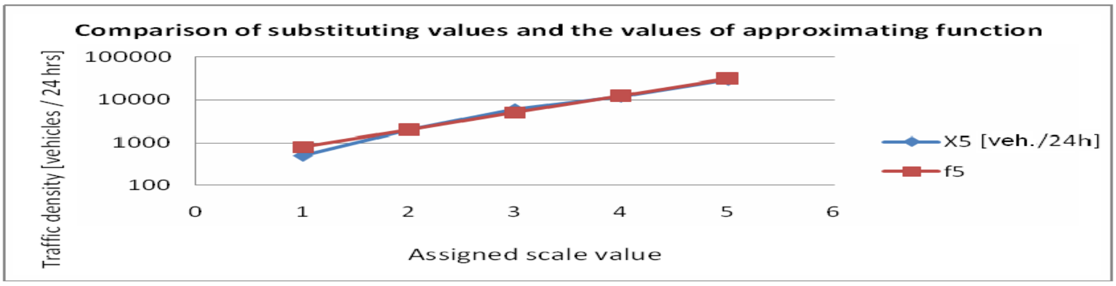

Fig. 5 *Traffic density values comparison*

Reconstruction time

- Designation of the factor (indicator): F_6
- Number of scale levels: 5
- Designation of real substitution value: X6
- Real parameter measurement unit: h
- Approximating real function: f_6

Table 4 *Approximating functions*

F_6	Reconstruction time	X_6 [hrs]	Approximating function
1	negligible (cca 8 hours or less)	8	$f_6 = 6^{F_6}$
2	short (cca 1 day)	24	
3	medium (cca 1 week)	168	
4	long (cca 1 month)	730	
5	extremely long (cca 1 year or more)	8760	

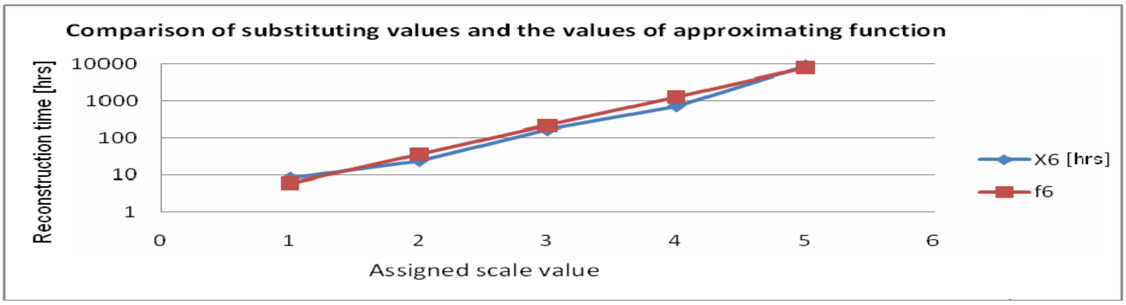

Fig. 6 *Reconstruction time values comparison*

3. CALCULATION OF AN EVENTUAL RISK IN RAILWAY TRANSPORT

Value scales including the substitution values and approximating functions enable us to define a function for estimating an eventual risk of undesired occurrence. The risk is calculated by multiplying the occurrence rate and financially estimated total consequence. Cumulative distance of the diversion of all vehicles during the reconstruction time is calculated by multiplying the X_4, X_5 and X_6 factors. For the calculation purposes it is necessary to determine the costs per 1 kilometre, symbolized by k_4. Example: following inputs can be used for k_4 calculation:

- Proportion of a freight traffic 0,66
- Proportion of a passenger traffic 0,34
- 1 km long freight traffic rate 700 CZK, approx. 28,5 Euros.
- 1 km long passenger traffic rate 150 CZK, approx. 6,1 Euros.

Average costs per one kilometre (k_4) are approx. 513CZK (= 0,66*700+0,34*150), it is approx.21 Euros

Eventual risk is expressed by following term:

$$R = X_1 \cdot (X_2 + X_3 + k_4 \cdot X_4 \cdot X_5 \cdot X_6)$$

X1 to X6 values are the substituting real values. In case that requires the use of function, the eventual risk can be estimated by using the approximating functions f1 to f6, thus:

$$R \cong f_1 \cdot (f_2 + f_3 + k_4 \cdot f_4 \cdot f_5 \cdot f_6)$$

After the substitution of particular functions we get:

$$R \cong 10^{F_1-7}.(10^{F_2+2} + 8.10^{F_3+2} + 9.3.2^{F_4}.500.2{,}5^{F_5-1}.6^{F_6})$$

One option is to end the estimation after assigning the risk R to the undesired occurrence. If necessary it is possible to transform the eventual risk back to the value scale, which is useful especially for the colour plotting on a map or easy comparison of assessed occurrences by comparing two integral numbers falling into a defined range. Regarding to a geometric character of the scale designed for the factor evaluation and probable distribution of a risk associated with assessed occurrences, the value scales, after the transformation of a risk to a risk priority number (RPN), should be geometric as well. Common ratio of a geometric scale q with a desired number of levels n is being derived from the following term, assuming that substituting value of a first level is *min(R)*, i. e. representing the minimum risk in the term

$$q = \sqrt[n]{\frac{\max(R)}{\min(R)}} = \sqrt[n]{\frac{X_1(5).[X_2(5)+X_3(5)+k_4.X_4(5).X_5(5).X_6(5)]}{X_1(1).[X_2(1)+X_3(1)+k_4.X_4(1).X_5(1).X_6(1)]}}$$

For example: for n=100 the common ratio is approximately equal to 1,25 (q=1,25)

Period waste of function (hours)	Segments of sector / weight of segment				Sector Transport
	Road / 0,45	Railway / 0,35	Air / 0,15	Inland Water / 0,05	
1	11,25	12,25	6,45	0,5	30,45
10	23,85	42,00	22,50	2,10	90,45
100	81,00	98,00	46,50	7,50	233,00
1000	117,00	119,00	57,00	11,00	304,00
10000	135,00	119,00	57,00	14,00	325,00
∑	368,10	390,25	189,45	35,10	982,90

In relative expression - the highest contribution towards point value of sector

Fig. 7 *Example of relative sector assessment*

Implementation of those procedures to praxis of Ministry of Transport of Czech Republic and other governmental institutions is based on evaluating of segments in particular sectors, which enables to reach authentic evaluation for sector's sensibility. It is not necessary to create other input data; it is done according to existing absolute values of particular segments of critical infrastructure. There exist very useful tool for praxis. It is programme product designed for needs of Czech Railways. Its particular windows are presented on figures 8-9.

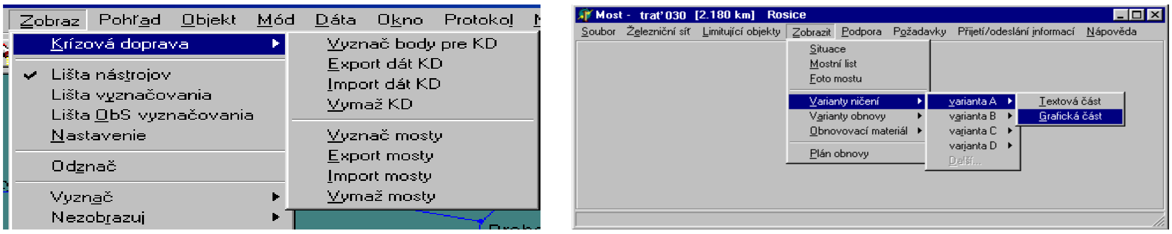

Fig. 8 *Windows from Crisis transport program tool*

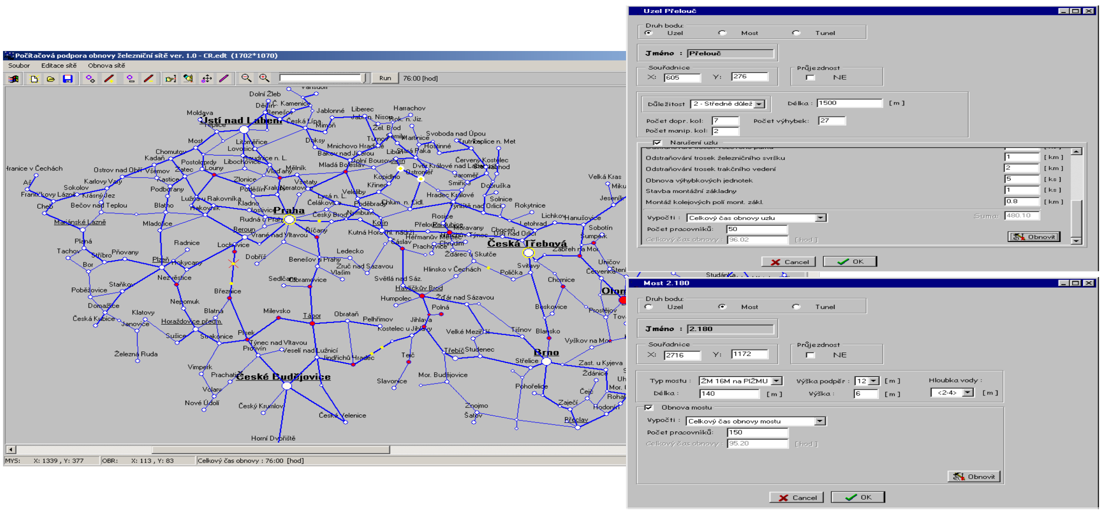

Fig. 9 *Fragments of computing support of railway renewal*

4. CONCLUSION

It is possible to evaluate input data according to mentioned procedure, or according to particular request for output. With deterministic approach can user evaluate and compare consequences of adverse events regardless their probability or to assess risk connected to object renewal. The assessment includes risks based on consequences to safety and health of people as well as risk for third side based on the increase of transport costs.

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МОДЕЛИРАНЕ НА ПОДНОВЯВАНЕТО НА КРИТИЧНА ЖЕЛЕЗОПЪТНА ИНФРАСТРУКТУРА

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Ключови думи: *критична железопътна инфраструктура, подновяване, моделиране, оценка на риска, разходи за транспорт.*

Резюме*: Статията разглежда проблеми, свързани с обновяването на критичната железопътна инфраструктура в Словашката република. За да се изчисли рискът, се предлага да се умножат честотата на настъпването и финансовото оценяване на общото следствие. Оценката включва рисковете, които се основават на последствията за безопасността и здравето на хората, както и риска за трети страни на базата на увеличението на транспортните разходи.*