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A new Approach to Identification of Critical Elements in Railway Infrastructure

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Abstract

The paper contains a presentation of new approaches to solving the problem of identifying critical infrastructure elements in the railway sub-sector. The research objective was to analyse the procedures which are used to identify the potential elements of critical infrastructure in the transportation sector. Specific attention is paid to criteria of methods developed in Germany, the Czech Republic and Slovakia. The objective of the work is based on the analysis of the current state of art. The research also attempted to design an effective methodology which allows assessing the significance of rail infrastructure elements. The developed methodology should help to set a group of potential elements of critical infrastructure in the railway sub-sector.

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1. Introduction

The problem of Critical Infrastructure (CI) and its security, especially the resilience assessment of most important elements and services of infrastructure systems and their efficient protection is a topical problem nowadays. The crucial problem here is how to identify the potential CI elements, based on their parameters and properties or mutual

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relations [1]. The Slovak methodology of the national and the European CI elements determination is regulated by the Act No. 45/2011 on critical infrastructure [2]. Due to this act, the proposal of procedures for objective determination of the set of so-called "*potential CI elements*" is an important objective not only of field experts but also in academic environment. The paper focuses on the problem of identification of important infrastructure elements in the transport sector – railway sub-sector. It contains characteristics and main features of the proposed theoretical approach to the identification of importance of defined typological elements of railway transport infrastructure. By applying the original developed procedure, it is possible to decide objectively about the structure of the subset of potential CI elements in the railway sub-sector. At present, a software support for its practical application is being developed.

2. Procedure for identification of potential CI elements in the railway sub-sector

The procedure is based on the assessment according to [3] and applies multi-criteria assessment. The purpose of the multi-criteria assessment of selected sections and objects is to select the most significant ones from the point of view of maintaining railway operability. The criteria generally focus on assessment of transport infrastructure performance [4] and at the same time on its possible failure impact [5]. On the basis of the above mentioned approaches [6–9] a universal procedure for identifying the set of potential CI elements in the railway sub-sector was designed and verified. The selection is conducted using the assessment of a section or an object following pre-defined criteria. The structure of proposed criteria for importance assessment is demonstrated by Fig. 1.

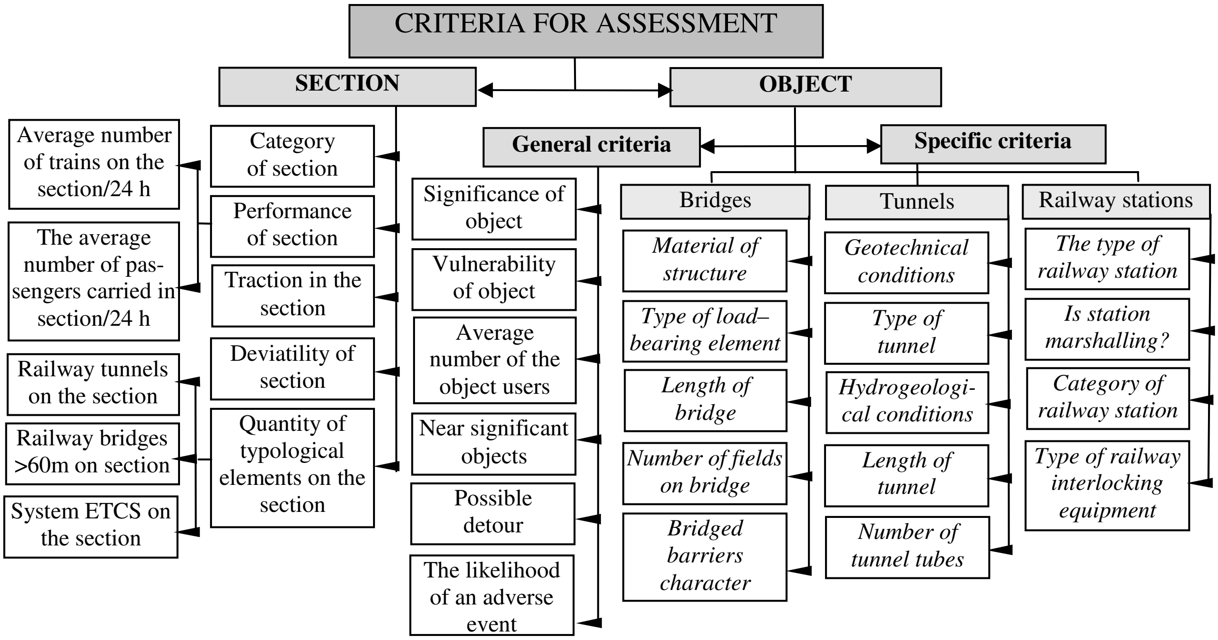

Fig. 1. Structure of assessment criteria used in the proposed procedure.

The proposed procedure consists of subsequent steps:

1. Defining and assessment of basic characteristics of line elements – sections – in the area of infrastructure,
2. Identification of important sections and determination of the "*Index of Section Importance I_U*" – it means selection of the most important sections,
3. Defining and assessment of basic typological objects in a section (tunnels, bridges, stations, centralized traffic Control and other important technological elements of railway infrastructure,

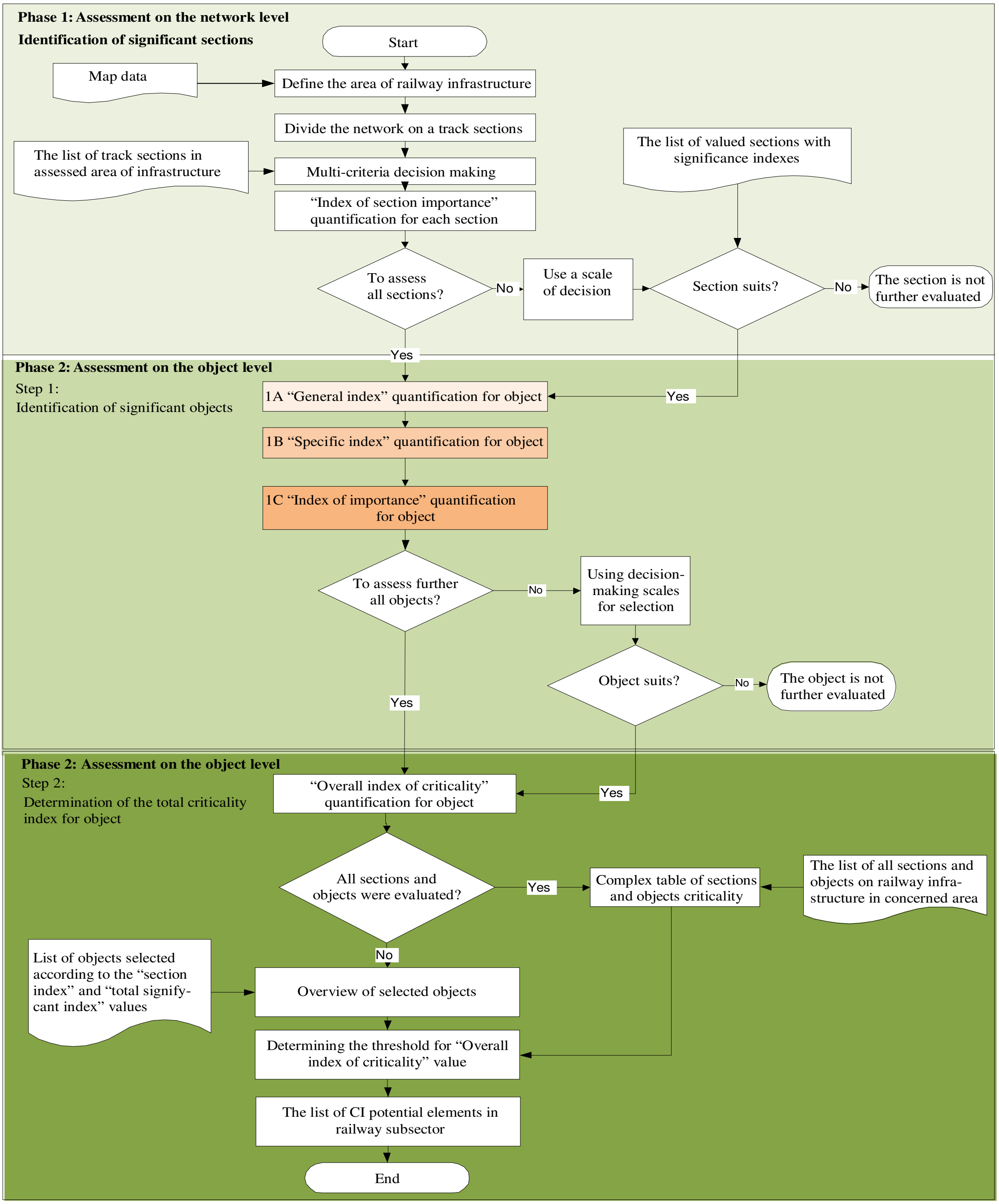

Fig. 2. Procedure for CI elements identification in railway sub-sector.

4. Identification of important elements and determination of the "*Index of Object Importance* I_O", based on the calculated values of "*General Index of Object Importance* I_V" and "*Specific Index of Object* I_S" – it means selection of the most important objects,
5. Quantification and interpretation of "*Overall Index of Criticality* I_K".

The basic structure of the proposed procedure of potential CI element identification and assessment in the field of railway infrastructure [10] is shown in Fig. 2.

The above mentioned activities help identify the important sections of railway infrastructure on ***the network level*** and on ***the object level***. The output of the assessment process is a set of important sections and objects located on them – as potential CI elements in the railway sub-sector. For more objective assessment of sections applying individual criteria, it is necessary to determine weight coefficients of particular criteria. This is conducted on the basis of their (pair-wise) comparison following the Saaty methodology. On the basis of weight coefficients of criteria and the attributes of the assessed sections/objects expressed by the point value, it is then possible to acquire the ***Index of section importance*** I_U and ***Index of object importance*** I_O. Their calculation is based on the relation formed by the sum of products of the point value for section/object and the weights of their individual criteria w_i.

PHASE 1: Assessment on section level = line infrastructure elements

The aim of the first phase is to identify the most important sections of railway track in the area of interest and to determine the ***Index of section importance*** I_U. The selected sections are assessed according to five criteria (K_1 – K_5) that are assigned points following the scale designed by authors. The following order of importance of the section criteria is used: ***K_1 = section performance, K_2 = section category, K_4 = occurrence of important typological elements, K_5 = deviatility and the least important criterion K_3 = traction on section***. Naturally, the individual assessment criteria could become a subject of discussion. For example, the K_1 – section performance does not have to be the most important criterion. The load of 50000 t of cars would not be of the same importance for the society as 50000 t of coal for a power plant. The outcome is the list of all sections of railway infrastructure in the area of interest and the corresponding value of the *Index* I_U which can be expressed as follows:

$$I_U = \sum_{i=1}^{5} \frac{(K_i \times w_i)}{5}, \qquad (1)$$

where K_i is point value of the i-th criterion for a given section, w_i is weight coefficient of the i-th criterion. The theoretical – benchmark – section (max. possible value) reached the value $I_U = 12.6$ and the following relation is valid:

$$I_U = \frac{K_1 \times w_1 + K_2 \times w_2 + K_3 \times w_3 + K_4 \times w_4 + K_5 \times w_6}{5} = \frac{5\times5+5\times4+2\times1+2\times3+5\times2}{5} = \frac{63}{5} = 12.6 .$$

PHASE 2: Assessment on the object level = point infrastructure elements

The aim of the second phase is to identify the most important objects in the sections, selected in the first phase – i.e. in the most important railway sections in the area of interest, as well as to determine the ***Overall Criticality Index*** I_K. The most important elements of railway infrastructure will be understood as typological objects. It is possible to assume that the primary typological objects – ***railway bridges, railway tunnels, railway stations, dispatching centers for remote-controlled tracks etc.*** – will probably form a set of potential CI elements for the railway sub-sector.

Step 1: Determination of the Index of object importance Iv

An expected outcome is a list of all objects in the most important sections (selected in Phase 1). Each object is assigned a respective value of *Index* I_O and for its quantitative expression it is necessary to determine:

1A. General index of object importance I_V: detailed section analysis in order to create a list of section objects and define their operational and security attributes. The objects are assigned points according to defined scales for individual criteria (VK_1 – VK_6). The order was determined by pair wise comparison of criteria. The most important criterion is ***VK_6 – probability of occurrence of an undesirable event***. The other criteria: ***VK_3 – number of object users, VK_4 – object environment, VK_2 – object vulnerability, VK_5 – possible detour and VK_1 – object importance.***

For the sake of further clarification, e.g. in criterion VK_5, it is possible to consider replacing railway transport by road transport (which is besides detour the most frequent method how to provide transport in case of distortion or destruction, etc. of an important element of transport infrastructure. On the basis of the assigned points *VK* and the weight coefficient of the criterion *w*, for the General index of object importance the following relation is valid:

$$I_V = \sum_{i=1}^{5} \frac{(VK_i \times w_i)}{5}, \tag{2}$$

where VK_i is value of the *i*-th criterion for the given object, w_i is weight coefficient of the *i*-th criterion.

1B. Specific index of object importance I_S: detailed analysis of an object for the purpose of defining its typology and attributes. On the basis of assessment of specific parameters of typological objects – bridges, tunnels, stations, etc., it is possible to determine the value of the Index I_S, following the predefined matrices of individual groups of typological groups (Fig. 3).

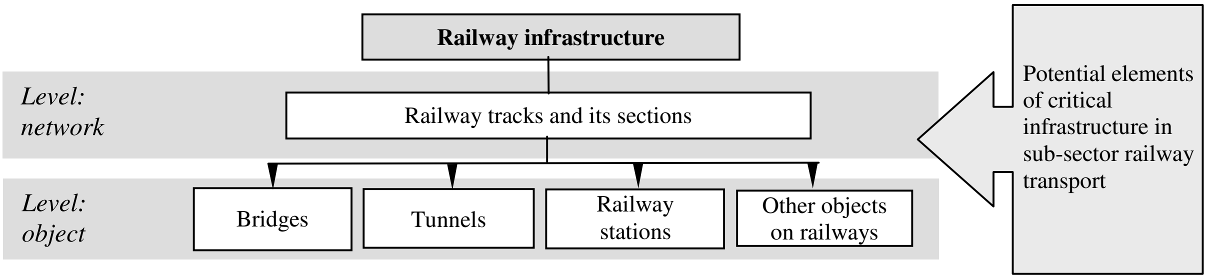

Fig. 3. Typological objects.

For each typological group, the *Specific Index of Object Importance Is* is determined by the relation:

$$I_S = \sum_{i=1}^{5} \frac{(SK_i \times w_i)}{n}, \tag{3}$$

where SK_i is value of the *i*-th specific criterion for the given object, w_i is weight coefficient of the *i*-th criterion and *n* is number of relevant specific criteria selected for the object. Based on the set of specific criteria SK_i [10], their combinations and object types, 12 types of bridge structures, 6 types of tunnels and 8 types of railway stations were defined. Each object was clearly assigned a specific value of the index I_S, specifying its vulnerability (or resilience) level. The determined value was based on specific object properties and parameters.

1C. Index of object importance I_O: summary value of the object importance. The following relation is valid:

$$I_O = \frac{I_V + I_S}{2}, \tag{4}$$

where I_V is the value of General index of object importance; I_s is the value of the Specific index of object importance.

Table 2. Maximum values of the Object importance index I_O.

Typological group	Maximal value of General index of object importance I_V	Maximal value of Specific index of object importance I_S	Maximal value of Total index of object importance I_O
Bridges		8.4	11.7
Tunnels	I_V max = 15	7.4	11.2
Railway stations		7.5	11.25

The Index I_O must be determined separately for each typological group, because the specific criteria of each typological group are different, featuring different point values and different maximum value each typological object can reach. The maximum possible (reference) values of the I_O for each typological group are stated in Table 2.

Step 2: Calculation of the Overall Criticality Index I_K (Fig. 2)

The ***Overall Criticality Index I_K*** is determined on the basis of the above mentioned data and is determined by the following relation:

$$I_K = \frac{I_{U_i} + I_{O_i}}{\max(I_{U_i} + I_{O_i})}, \quad (5)$$

where I_{Ui} is a resulting value of Index of Importance for section i, I_{Oi} is a resulting value of the Index of Importance for object i, $\max(I_{Ui} + I_{Oi})$ is a maximum possible value of the sum of values of indices I_U and I_O for a particular object i. The Index I_K always acquires values from the interval <0; 1>. The principle of identification or determination of the object importance lies in comparing the acquired number of points of the assessed object with the maximum number of points a given typological object is able to reach. To determine the level of criticality, a scale with value range of I_K was defined according to Table 3.

Table 3. Scale for assessing – Overall criticality index of object.

Level	Scale for assessing	Index I_K
1	Very important/Very critical	0.90–1.00
2	Important/Critical	0.75–0.90
3	Moderately important/Moderately critical	0.65–0.75
4	Low important/Low critical	0.50–0.65
5	Insignificant/not critical	0.00–0.50

In a conducted case study, the authors decided that the objects reaching values over 0.75 can be considered objects that compose a set of potential CI elements. Why the value 0.75? Interestingly, the users can define the limit values according to their needs and according to the desired size of the set of important elements. If the criterion limit for including the object to the list is set arbitrarily, (e.g. value 0.5 or 0.95), and the group of potential CI elements includes arbitrarily high number of elements, the final range of carried out measures will always depend on financing possibilities of their protection [10]. It also means that the value 0.75 – benchmark selected authors by developed methodology cannot be understood dogmatically.

3. Conclusions

The aim of presented methodology is to identify important railway sections and determine values of section importance. The authors are aware of the fact that the designed procedure is only one of possible steps applicable in a comprehensive process of CI element selection, specifically in railway infrastructure (bridges, tunnels and railway stations). It is necessary to realize here that the proposed procedure does not include all the important attributes of conducted transport services, e.g. characteristics or commodity mix transported in individual track sections, redirecting the flow of goods or people to another track section. Systematic solution of above mentioned areas of problems and partial activities in the processes of identification and importance assessment and object resilience in infrastructure networks can contribute to more efficient processes of security management and protection of important sections and elements of transport infrastructure.

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