1. Introduction

The problem of Critical Infrastructure (CI) and its security, especially the resilience assessment of the most important elements and services of infrastructure systems and their efficient protection is a topical problem nowadays. Despite the numerous publications [1], [2], [3] and proposed approaches [4], [5], one cannot apply any universally accepted approach to understand the relations between individual infrastructures. The crucial problem here is how to identify the potential CI elements, based on their parameters and properties or mutual relations. Several influential papers [1], [2], [3], [6], [7] focus on identification methodology of critical sections and elements of the transport infrastructure. The Slovak methodology of the national and the European CI elements determination [8] is regulated by the Act 45/2011 Coll. on Critical Infrastructure [9]. The Government of the Slovak Republic (hereinafter SR), based on the proposal of the Slovak Ministry of Interior, according to § 4 letter c) of the Act No. 45/2011 Collection of Laws on critical infrastructure, determined the so-called sector criteria, European sector criteria, cross-sectional criteria and European cross-sectional criteria that are at present classified. Due to this reason, the proposal of procedures for objective determination of the set of the so-called “potential CI elements” is an important objective not only of field experts, but in academic environment, as well. The paper focuses on the problem of identification of important infrastructure elements in the transportation sector - railway sub-sector. It contains characteristics and main features of the proposed theoretical approach to identification of importance of defined typological elements of the 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 respective software support for its practical application is being developed.

2. The current state of the railway infrastructure elements significance valuation

The main objectives of all participating countries of the EPCIP (European Program for Critical Infrastructure Protection) [10], in the transportation sector are to identify the most important elements of transport infrastructure, to reveal and assess their risks that can possibly negatively affect the transportation system functioning and also to prepare efficient protection measures. However, the EPCIP countries often apply different procedures for selection of significant infrastructure elements and their risk and resilience assessment. Nowadays,
it is possible to use a wide variety of different methods for risk assessment or comprehensive parametric assessment of infrastructure element resilience. The CI experts are continuously creating or modifying approaches that enable them to conduct more specific assessment of system parameters of selected groups of elements, the so-called typological objects. They have been frequently involved in designing procedures for selecting potential CI elements, identifying the active factors, assessing the risk level and proposing measures for protection of the most significant/important CI systems and services [11].

The European cross-sectional criteria are identical in all the participating countries, but they are not defined clearly, e.g. by determining the limit values of observed parameters. The cross-sectional criteria mostly focus on failure impact of a significant infrastructure element only. On the contrary, the sector criteria in the railway sub-sector (but also in other transport sub-sectors) do not primarily focus on the assessment of an element failure impact, but they represent specific technical parameters for infrastructure element assessment. The sector criteria, except for the Czech Republic, are classified in all the EU countries and that is why it is only possible to assume and not clearly state which criteria were applied for identification and selection of the set of CI elements [4], [5], [7], [12], [13].

The approaches and methodology for identification of the CI set elements generally depend on the country as each country uses a specific methodology. Table 1 shows a basic comparison of approaches used in various countries.

### Table 1 An example of the hazardous events

<table>
<thead>
<tr>
<th>Methodical / procedure</th>
<th>Slovakia - Risk analysis in sector Transport</th>
<th>Czech rep. - CritInfo</th>
<th>Germany - SECMAN</th>
<th>USA - RAMCAP</th>
<th>Denmark - RVA</th>
<th>Germany - SeRoN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector / sub-sector of Critical infrastructure</td>
<td>Road and railway transport subsector</td>
<td>Transport - all subsectors</td>
<td>Road transport</td>
<td>Transport - all subsectors</td>
<td>Transport - all subsectors</td>
<td>Road transport</td>
</tr>
<tr>
<td>Approach to determine</td>
<td>Sections, objects</td>
<td>Sections, objects</td>
<td>Sections, objects</td>
<td>Particular element</td>
<td>Particular element</td>
<td>Sections, objects</td>
</tr>
<tr>
<td>Determination of criteria</td>
<td>Yes</td>
<td>Yes</td>
<td>Partially</td>
<td>No</td>
<td>No</td>
<td>Partially</td>
</tr>
<tr>
<td>Evaluation of criteria</td>
<td>Threshold limits</td>
<td>Point scale</td>
<td>Qualitative</td>
<td>Not defined</td>
<td>Not defined</td>
<td>Qualitative</td>
</tr>
<tr>
<td>Risk assessment</td>
<td>Yes</td>
<td>Yes</td>
<td>Partially</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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 \( I_w \)” - 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,
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 \( I_g \)” and “Specific Object Index \( I_s \)” - it means selection of the most important objects,
5. quantification and interpretation of “Overall Index of Criticality \( I_k \)”.

The procedure is based on the assessment according to [14], [15] 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 the railway operability [16]. The selection is conducted using the assessment of a section or an object following...
The aim of the first phase of the assessment procedure is to identify the most important sections of railway track in the area of interest and to determine the Index of Section Importance $I_U$.

In the proposed procedure, the selected sections are assessed according to five criteria (K1 – K5) that are assigned points following the scale designed by authors. The pairwise comparison makes possible to state the order of importance of the assessment criteria for sections. The following order of importance of the section criteria is used:

1. K1 = section performance
2. K2 = section category
3. K3 = traction on section
4. K4 = occurrence of important typological elements
5. K5 = deviation from the orthodrome and the least important criterion

Naturally, the individual assessment criteria could become a subject of discussion. For example, the section performance does not have to be the most important criterion. From the point of view of maintaining primary functions of the state, it is important what is being transported in a given section. The load of 50,000 tons of cars would not be of the same importance for the state as 50,000 tons of coal for a power plant. The outcome of the first phase is the list of all sections of the railway infrastructure in the area of interest and the corresponding value of the Index of Section Importance $I_U$ which can be expressed as follows:

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

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
Figure 2 Procedure for CI elements identification in railway sub-sector
element of transport infrastructure. Based on the assigned points \( VK \) and the weight coefficient of the criterion \( w_i \), for the General index of object importance the following relation is valid:

\[
I_v = \frac{\sum VK_i \times w_i}{\sum w_i} = \frac{5 \times 5 + 5 \times 4 + 2 \times 1 + 2 \times 3 + 5 \times 2}{5} = \frac{63}{5} = 12.6
\]

**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 Index of object criticality \( I_o \). 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 in the railway sub-sector. The phase of assessment on the object level consists of two steps:

**PHASE 2 - Step 1: Determination of the Index of object importance \( I_v \)**

An expected outcome is a list of all objects in the most important sections (selected in the 1st phase). Each object is assigned a respective value of Index of object importance \( I_v \), and for its quantitative expression it is necessary to determine:

A. **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 (VK1 – VK6). The order was determined by pair wise comparison of criteria. The most important criterion is VK6 – probability of occurrence of an undesirable event.

The other criteria, respectively, are: VK3 – number of object users, VK4 – object environment, VK2 – object vulnerability, VK5 – possible detour and VK1 – object importance.

For the sake of further clarification, e.g. in criterion VK5, 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. Based on the assigned points \( VK \) and the weight coefficient of the criterion \( w_i \) for the General index of object importance the following relation is valid:

\[
I_v = \frac{\sum VK_i \times w_i}{\sum w_i}
\]

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

B. **Specific index of object importance \( I_s \)**: detailed analysis of an object for the purpose of defining its typology and attributes. Based on assessment of specific parameters of typological objects – *bridges, tunnels, stations, terminals or other objects*, it is possible to determine the value of the Index \( I_s \), following the predefined matrices of individual groups of typological groups (Figure 3).

For each typological group, the Specific Index of Object Importance \( I_s \) is determined as:

\[
I_s = \frac{\sum \left( SK_i \times w_i \right)}{\sum w_i}
\]

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.

C. **Summary value of the object importance**: it’s called Index of object importance \( I_o \). Here, the following relation is valid:

\[
I_o = \frac{I_v + I_s}{2}
\]

where \( I_v \) is the value of the General index of object importance, \( I_s \) is the value of the Specific index of object importance. The Index of object importance \( I_o \) 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 Index of object importance \( I_o \) for each typological group are stated in Table 2.
It is thus possible to select hundreds of elements and label them as "vitally important". If financial support for security measures is not available, the fact whether the object is on the CI element list or not will not protect it against any potential threat. It also means that the value 0.75 - benchmark selected by methodology authors, cannot be understood dogmatically. A set of railway infrastructure objects acquired in the stated way needs to be further assessed applying objective risk assessment methods [19]. Based on results of the risk assessment and the resilience level assessment of the CI systems and services, it is possible to decide objectively about the size and structure of CI system in a specific sector/sub-sector on national and European level.

4. Conclusions

The procedure was designed in the way to provide an assessment of railway infrastructure on the network and object levels. The aim of this methodology is to identify important railway sections and determine values of section importance. Subsequently, it is necessary to define and assess typological objects in the section and set the values of object importance. This enables us to focus attention on prevention checks, maintenance and organizational measures for securing the desired protection level. The authors are aware of the fact that the designed procedure is only one of possible steps applicable in a comprehensive process of the 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.

PHASE 2 - Step 2: Calculation of the Overall Criticality Index $I_K$

The Overall Criticality Index $I_K$ is determined based on the above mentioned data and is determined by the following relation:

$$I_K = \frac{I_{iv} + I_{io}}{\max(I_{iv}, I_{io})}$$

where $I_{iv}$ is a resulting value of Index of Importance for section $i$, $I_{io}$ is a resulting value of the Index of Importance for object $i$, $\max(I_{iv}, I_{io})$ is the maximum possible value of the sum of values of indices $I_{iv}$ and $I_{io}$ for a particular object $i$. The Overall Criticality 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.

In a conducted case study, the authors decided that the objects reaching values over 0.75 can be considered as 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.

It is obvious that if the set of important elements of transport infrastructure is too large, the costs for securing prevention or subsequent protection measures will be higher. 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 transport infrastructure elements, the final range of carried out measures will always depend on financing possibilities of their protection. For example, in compliance with § 9, para. 4 of the Act [9], the operator of a CI element is entitled to a financial support (from the respective Ministry) to meet the duties related to performing security measures for a CI element protection. It is thus possible to select hundreds of elements and label them as "vitally important". If financial support for security measures is not available, the fact whether the object is on the CI element list or not will not protect it against any potential threat. It also means that the value 0.75 - benchmark selected by methodology authors, cannot be understood dogmatically. A set of railway infrastructure objects acquired in the stated way needs to be further assessed applying objective risk assessment methods [19]. Based on results of the risk assessment and the resilience level assessment of the CI systems and services, it is possible to decide objectively about the size and structure of CI system in a specific sector/sub-sector on national and European level.

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Table 2 Maximum values of the Object importance index

<table>
<thead>
<tr>
<th>Typological group</th>
<th>Maximal value of General index of object importance $I_{iv}$</th>
<th>Maximal value of Specific index of object importance $I_{io}$</th>
<th>Maximal value of Total index of object importance $I_{io}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridges</td>
<td>8.4</td>
<td>11.7</td>
<td></td>
</tr>
<tr>
<td>Tunnels</td>
<td>$I_{iv} = 15$</td>
<td>7.4</td>
<td>11.2</td>
</tr>
<tr>
<td>Railway stations</td>
<td>7.5</td>
<td>11.25</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Scale for assessing - Overall criticality index of object

<table>
<thead>
<tr>
<th>Level</th>
<th>Scale for assessing</th>
<th>Index $I_K$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very important / Very critical</td>
<td>0.90 - 1.00</td>
</tr>
<tr>
<td>2</td>
<td>Important / Critical</td>
<td>0.75 - 0.90</td>
</tr>
<tr>
<td>3</td>
<td>Moderately important / Moderately critical</td>
<td>0.65 - 0.75</td>
</tr>
<tr>
<td>4</td>
<td>Low important / Low critical</td>
<td>0.50 - 0.65</td>
</tr>
<tr>
<td>5</td>
<td>Insignificant / not critical</td>
<td>0.00 - 0.50</td>
</tr>
</tbody>
</table>
In the moment of redirecting the flow, the importance of element value changes (the criterion values for selected elements of railway infrastructure change) and the original element that seemed to be critical loses its importance. There are also problems of possible impact of replacement of the railway transport by the road transport and assessment of railway infrastructure elements in terms of their uniqueness. For example, the only 100-m-long bridge on a 100-km-long section will be of different importance than a 100-m-long bridge on a 20-km-long section with 5 other bridges, even if the tracks were loaded identically.

The most significant deficiency of the CI element determination and protection is the fact that no EU document states exhaustively the required level of the CI element protection in the transport sector, either on the European or national level. The need is even more obvious if we realize that it was the EU that started discussing this problem. From this point of view, it is not clear what final state of element protection should be reached. There is space for more extensive research (e.g. scientific project, study, final thesis, etc.). For example, it should be possible to quantify that a railway station with more than 30 000 passengers per day must have a CCTV and a security guard service and a different station with more than 15 000 passengers per day at least a CCTV, etc. A similar system can be adopted as a protection measure for other typological elements, e.g. bridges, tunnels, etc. Our research has revealed other areas that need to be focused on in terms of functionality and versatility:

- adding more typological objects to typological groups and determination of their specific parameters and criteria (e.g. energy supplying systems, controlling systems, etc.),
- detailed definition of main criteria and vulnerability analysis for each object type in each typological group,
- completing the next process step: comparison of objects based on another index that would consider some risk factors of objects,
- creation of software tool enabling automated assessment of object criticality that would be based on developed procedure and current railway infrastructure databases,
- cooperation with GIS systems in presentation of object location in the area of interest and criticality parameters of the analyzed sections / objects on a map.

Systematic solution of the 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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References


