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Critical Element Designation System in Rail Transport in the Czech Republic

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In EU countries, the railway sector is referred to as a sub-sector of transport critical infrastructure. However, in addition to the critical infrastructure elements, the railway infrastructure also includes elements which do not meet given cross-cutting and sectoral criteria, but are nonetheless essential or even critical for a given area (region). These elements must therefore be identified in a timely and correct manner so that adequate security measures can be adopted. Yet one of the major issues with regard to protecting these elements at regional level remains the lack of a complex approach to and criteria for their evaluation and designation.
In consideration of the above, the article aims to introduce a system for designating critical elements in railway transport in the Czech Republic, as developed by VSB – Technical University of Ostrava. The basis for the designation system constitutes a framework which defines the principal areas determining, limiting and influencing the process of critical element designation. This process is based on the identification and analysis of key elements, the determination of the level of criticality and, subsequently, the designation of critical elements with a view to ensuring their protection. The evaluation process hinges on evaluation criteria which are specific for line, point and areal elements of railway infrastructure. In conclusion, the article suggests some useful ways in which the critical element designation system in rail transport in the Czech Republic can be modified and utilized.

1. Introduction

At present, there are numerous approaches to critical element designation. These approaches can be divided into general and specific ones, i.e. those related to the transport sector. General approaches often focus on assessing the criticality of a given system element which is evaluated based on selected factors. The most common factors include the evaluation of potential impacts of element failure (e.g. Robinson et al., 1998; Luiijf et al., 2003; Jönsson et al., 2008; Egan, 2007; UK CO, 2010; Zhang et al., 2015), monitored element dependencies (e.g. Rinaldi et al., 2001; Luiijf et al., 2003), element significance (e.g. Egan, 2007; Fekete, 2011; Alsubaie et al., 2015; Zhang et al., 2015), element vulnerability (e.g. FMI, 2009; Theoharidou et al., 2009) or risks in relation to the monitored element (e.g. Vrijling et al., 2004; FMI, 2008; Fekete, 2011).
Another group consists of specific approaches to critical element designation, focusing on the transport sector. Babebeik et al. (2017), for example, identify critical elements by calculating the increased costs as a result of element disruption or the ensuing delay. An approach to identifying significant components of the railway infrastructure has also been put forward by Leitner et al. (2017). Here the authors evaluate the relevance of a particular element (i.e. its performance or category) or also the significance aspect (i.e. the availability of an alternative route or the likelihood of a disruptive event occurring). Additional important approaches include the designation of critical locations based on anticipated accident data (Striegler et al., 2012) or based on a vulnerability analysis of interdependent technical infrastructures (Johansson et al., 2011).
Considering the aforementioned, it seems reasonable to conclude that while these approaches are functional and their applicability trouble-free, they only factor in specific aspects, which most often are the impacts, dependency, significance, risks and/or vulnerabilities of a given element. On that account, this article presents a complex system of critical element designation in railway transport, taking into consideration all of the aspects mentioned above. This designation system factors in both legislative and technical issues existing in the Czech Republic.

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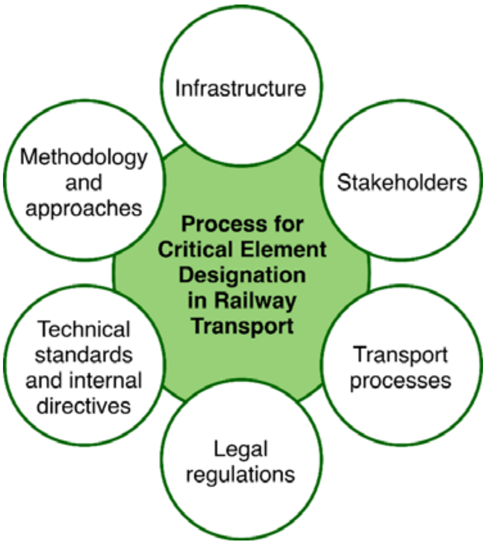
2. Framework for Critical Element Designation System in Railway Transport



The unambiguous definition of the basics forms the pillar of the system of critical element designation in railway transport. For this reason, we first established a general framework for critical element designation in the railway transport sector which incorporates inputs essential to the correct application of the designation process (see Figure 1).

The relevant system inputs are individual elements of the railway infrastructure as infrastructure constitutes the central component of each system (Rehak et al., 2016a). This input is based on the identification of all elements of the railway infrastructure. As part of element identification, all of their linkages and dependencies should be considered (Rinaldi et al., 2001).

It is therefore vital to identify all railway transport stakeholders and to understand both the characteristics of their relationship to this type of transport and the specification of their requirements. In the Czech Republic these are the railway operator, railway transport operators, passengers and the Ministry of Transport of the Czech Republic.

Figure 1: Framework for Critical Element Designation System in Railway Transport

The basic component of the railway transport system also includes transport processes forming this system. Their requirements will thus constitute another input in the designation process.

Moreover, railway transport is subject to an additional group of requirements, many of which are stipulated by legal regulations; e.g. Act on Rail Systems (1994).

Another important process input are requirements laid down in technical standards and internal directives of the leading railway operator in the Czech Republic, i.e. Railway Infrastructure Administration (e.g. Directive, 2013).

The last major input into the process of critical element designation is methodology. In this respect, appropriate inputs include not only the methods (e.g. reliability evaluation or risk assessment methods) but also approaches to resilience assessment (e.g. Rehak et al., 2018; Novotny et al., 2017) or approaches to preventing or managing emergencies (Directive, 2013).

All of the aforementioned aspects play an essential role in ensuring railway transport security and safety. As such, they can form the basis for establishing the process of critical element designation in railway transport.

3. Critical Element Designation Process

The defined system framework and its individual components made it possible to determine the individual steps of the process of designating critical elements in the railway infrastructure. The presented process is primarily designed for nationwide or regional application. For the proposed process structure see Figure 2.

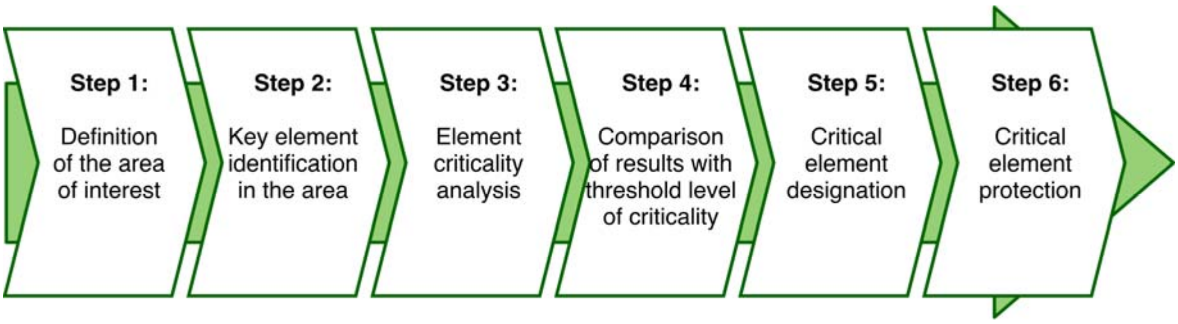


Figure 2: Process of critical element designation in railway transport

Step 1: Definition of the area of interest
The process of critical element designation in railway transport must start with the definition of the area of interest. This may cover one entire region (e.g. the transport system of a single region) or a part thereof (e.g. a rail connection between two cities).

Step 2: Key element identification in the area
All key elements of the railway infrastructure, i.e. traffic control elements (e.g. traffic control systems), elements essential to ensuring its safety (e.g. safety and warning devices) and difficult to replace elements (e.g. tunnels and bridges), existing in the defined area or part thereof were identified. The key elements were selected in consultation with the rail operator (Pittner, 2018). These elements were subsequently classified into line, point and areal elements (Rehak et al., 2016a) as follows:

- line elements, i.e. individual railway tracks, track sections, track zones and inter-station sections;
- point elements, e.g. level-crossing safety systems, stops, level crossings without a warning system, rail structures (i.e. bridges, tunnels, culverts), rail traffic control rooms;
- areal elements, i.e. level crossings with a safety system and railway stations with station safety systems.

Step 3: Element criticality analysis
The criticality analysis of railway transport infrastructure elements in the given area will be carried out in three phases: Phase I: Criticality analysis of line elements, Phase II: Criticality analysis of point elements, Phase III: Criticality analysis of areal elements. In dividing this step into individual phases will afford the evaluator some degree of variation while designating the critical elements in the area of interest.
The criticality evaluation criteria, established for each phase, are specified in the following subchapter. Each key element, identified within a particular group, must be evaluated as part of the given phase. In evaluating each criterion, it is necessary first to determine the simple element criticality with respect to the given criterion. This represents the percentage rate at which the criterion value approaches the imaginary highest criticality possible. This value is then multiplied by the criterion weighting preference, expressing the weighted criticality. The sum of weighted criticalities calculated for a given criterion then determines the resulting element criticality.

Step 4: Comparison of results with threshold level of criticality
The fourth step consists of comparing the resulting element criticality with the established threshold level of criticality. A clearly defined threshold level is crucial to proper designation of critical elements, as confirmed for example by Luiijf et al. (2003) and Fekete (2011). The threshold level of criticality was established for all three phases of the evaluation process based on the acceptability level of each criterion.

Step 5: Critical element designation
Elements exceeding the established criticality threshold in the given phase will be designated as critical elements of the respective area or its part. All specific values, including individual criteria, have been addressed in detail in the author's dissertation (Slivkova, 2018).

Step 6: Critical element protection
The final phase of the process involves the introduction of measures aimed at protecting all critical elements in the area of interest. This step should also be undertaken within the context of a cross-sectoral approach, especially with respect to the electricity sector (Oulehlova et al., 2015) which is of paramount importance to railway transport in the Czech Republic. Moreover, this process should be repeated at periodic intervals, such as annually. This will ensure that all preventive and protective measures adopted to safeguard railway infrastructure elements are evaluated.

4. Element Criticality Assessment Criteria

An important aspect of the process of critical element designation is the definition and correct setting of evaluation criteria, primarily in accordance with the requirements of the rail operator (Pittner, 2018). Established for each group of elements (i.e. line, point and areal), the varying significance of the criteria was factored in by using weighting coefficients. Due to the different expression units of natural criteria values, these values were converted to a uniform rating scale expressed as a percentage rate.

Line Element Analysis Criteria
The following part specifies in more detail individual criteria for analysing the criticality of line elements. For each presentation of the criteria, a possible evaluation of its simple criticality is outlined.
L1 criterion: The railway line significance is primarily determined by the respective railway category (Act, 1994) to which the line element belongs. This includes national railway lines, regional railway lines or sidetracks (secondary, industrial tracks). From the rail operator's perspective (Pittner, 2018), national (100%

simple criticality) and regional railways (90%) are of greatest significance as they primarily provide transport services across the state and/or region. The significance of sidetracks for the rail operator lies in that they help meet national economy needs (50%).

L2 criterion: Transport performance is evaluated dependent on the number of freight or passenger transport connections operating on a given railway track per a unit of time, i.e. the railway capacity per 24 hours. The simple criticality value of this criterion is based on the performance of the top-performing railway line in the region, rated at 100%. In comparison with the performance of the top-performing railway line, it is possible to determine the simple criticality of all the other railway lines being rated as a proportion of their performance (e.g. half performance will be rated as 50%).

L3 criterion: Possible diversion refers to the existence of an alternate route. Simple criticality values thus reflect these conditions:

- the monitored railway line has an alternate route with parameters fully corresponding to those of the section being diverted - the simple criticality = 0%;
- the monitored railway line does not have an alternate route (i.e. carriers must use an alternative road transport in the event of a railway line closure) - the simple criticality = 100%.

L4 criterion: Railway line risks are a major component of the line element criticality analysis as suggested, for example, by Vrijling et al. (2004), Sun (2017) or Fekete (2011). A list of potential disruptive events, compiled by the railway operator, is used to evaluate this criterion. This step determines the simple criticality of each element depending on the resulting risk of individual event occurrences for the observed element.

Point Element Analysis Criteria

Elements in this group are assumed to exist in relation to a line element on which they perform their specific function. That is why line element evaluation will be reflected in point element evaluation. The following part specifies in more detail individual criteria for analysing the criticality of point elements.

P1 criterion: Line element criticality reflects the fact that an increasing criticality of a line element leads to an increase in the criticality of the respective point element. In this criterion, the resulting criticality value of the line element on which the observed element performs its function is carried over to the point element evaluation.

P2 criterion: Element influence and dependence takes into account all linkages (i.e. influences, dependencies and interdependencies) of an element (Rehak et al., 2016b). The evaluation encompasses a number of elements dependent on a monitored point element (i.e. dependent elements), as well as all elements capable of affecting the monitored element (i.e. influential elements).

P3 criterion: Element substitutability factors in the possibility of replacing the element being observed with another element, with no significant loss of system function, or the possibility of providing a substitute for the function the element performs. For an example of a particular simple criticality specification see Table 1.

Table 1: Simple criticality values for the "Element Substitutability" criterion

Point element	Simple criticality values
Station safety system	90%
Track safety system	90%
Level-crossing safety system	50%
Train stops	20%
Level crossing without a safety system	10%
Railway structures	100%
Rail traffic control rooms	100%

P4 criterion: Element risks relates to the "L4 - Railway line risks" criterion in the line element criticality analysis. In this step, risks that have already been evaluated in relation to the railway line on which the relevant element performs its function can be omitted.

Areal Element Analysis Criteria

The group of areal elements includes level crossings with a safety system and railway stations with station safety systems. These station and level-crossings have been included in the group of areal elements mainly due to them being composed of multiple line and point elements. The following part specifies in more detail individual criteria for analysing the criticality of areal elements.

A1 criterion: Line element criticality reflects the fact that each areal element functions in relation to one or more line elements whose increasing criticality may increase the criticality of the areal element. In cases where the areal element consists of a single line element, the simple criticality value of this criterion will correspond to the resulting criticality value of the respective line element. In the event that the areal element is made up of more than one line element, the simple criticality value of this criterion will correspond to the resulting criticality value of the line element that has the highest resulting criticality with respect to the areal element.

A2 criterion: Point element criticality expresses the criticality of two or more point elements. The simple criticality value of this criterion is based on the weighted average of the resulting criticality values of all point elements that perform their functions within the given areal element. In this step, the weights are determined with respect to the number of dependent elements related to the monitored element.

A3 criterion: Element complexity takes into consideration the number of both point and line elements within one areal element. A higher number may increase the criticality of the monitored element.

A4 criterion: Possible diversion relates to the “L3 - Possible Diversion” criterion included in the line element analysis. However, in this instance the analysis rates the strategic location of the areal element within the railway transport system of the respective region. The evaluation process is similar to that applied to the L3 criterion.

5. Conclusion

The article presents a system for the designation of critical elements in railway transport. The system hinges on the comprehensive evaluation of element criticality from key perspectives, which include the impacts, dependency, significance, risk and/or vulnerability of the given element. The evaluation outcome is a percentage rating of the level of criticality which constitutes the basis for designating critical line, point and areal elements. The evaluation results subsequently provide an input into a process which is primarily focused on setting safety measures designed to ensure element preparedness or its increased resilience.

The presented system is highly variable and, as such, can be readily modified to fit the needs of different evaluators. This modification consists in (1) adjusting, adding or removing any number of criteria, (2) adjusting simple criticality evaluations that often tend to reflect the evaluator's subjective perspective, and (3) incorporating the resulting changes in weighting preferences. Any adjustments should be made by someone knowledgeable in the respective system, especially with regard to the system purpose and the availability of the evaluator's data. This system has been primarily designed for use by the leading rail operator in the CR however, when modified, it can be equally applied by other entities, such as railway transport operators.

The proposed system was practically verified in collaboration with the Directorate General of Railway Infrastructure Administration. For this purpose were selected Breclav railway station and its surroundings. In this area were marked some elements like a critical. For example, the Břeclav railway station, the dispatching centre of the Breclav station or also the security equipment of the Břeclav station. Detailed description and results of this practical verification are published in the author's dissertation thesis (Slivkova, 2018).

Acknowledgments

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