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Bases for Modelling the Impacts of the Critical Infrastructure Failure

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Critical infrastructure represents a complex system that is constantly exposed to negative effects and threats from both external and internal environment. The consequences of the action of these effects and threats cause disruptions or failures of operational parameters of the critical infrastructure elements. Such failures are then reflected in negative impacts on other critical infrastructure elements or directly on the protected interests of society, i.e. security of the state, the economy and basic needs of the population. Modelling the impacts of the critical infrastructure failure thus constitutes a very complex process which must take into account the considerable amount of internal and external factors affecting the functioning of critical infrastructure system.

In research of the bases for modelling the impacts of the critical infrastructure failure, this article focuses on crucial factors that shape the nature of impacts and defines the environment in which their modelling is examined. In particular, this relates to the application of a systems approach to research of phenomena in the critical infrastructure system and the need for research of impacts using a bottom-up approach. In this context, the article presents a proposal for the transformation of cross-cutting criteria to the regional level. An important role is also played by the need to define a unified framework for security and risk management of the European critical infrastructure. The last important starting point is the need to implement preference assessment because an important group of owners includes private entities whose preferences are significantly different compared to subjects of public administration. Through meeting the above objective, the article markedly contributes to increasing the resilience of critical infrastructure and its capability of responding to a variety of emergency or crisis situations.

1. Introduction

Predicting and modelling the impacts of disruption or failure of critical infrastructure is an important part of the research of critical infrastructure resilience. Recently, the issue of the research of critical infrastructure resilience has been addressed by a variety of professional publications. The most important publications include: A holistic framework for building critical infrastructure resilience (Labaka et al., 2016), A quantitative method for assessing the resilience of infrastructure systems (Nan et al., 2014), A system dynamics framework for modelling critical infrastructure resilience (Cavallini et al., 2014), A resilience assessment of interdependent infrastructure systems: With a focus on joint restoration modelling and analysis (Ouyang and Wang, 2015) and Interdependent critical infrastructure resilience: A methodology and case study (Robert et al., 2015). Although the quality of these publications is very high, none of them is based on modelling the impact of the failure of critical infrastructure or defining the mechanisms to quantify resilience. Pursuant to this fact, the article presents bases for modelling the impacts of critical infrastructure failure.

2. Linkages and impacts in critical infrastructure system

The critical infrastructure system must be viewed comprehensively; it is necessary to respect its network arrangement in which individual elements and sectors are interconnected by different types of linkages. The basic structure of these linkages results from their nature and includes one-way linkages that can either influence or be dependent on other connections, and two-way linkages involving interdependence (see

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Figure 1). The issue of interdependencies is addressed in detail by Rinaldi et al. (2001) who divided their classification into physical, cyber, geographical and logical linkages, and stated that interdependencies increase the risk of failure or disruptions in multiple areas of infrastructure. A further categorization of these linkages for lower-level details was subsequently done by Pederson et al. (2006).

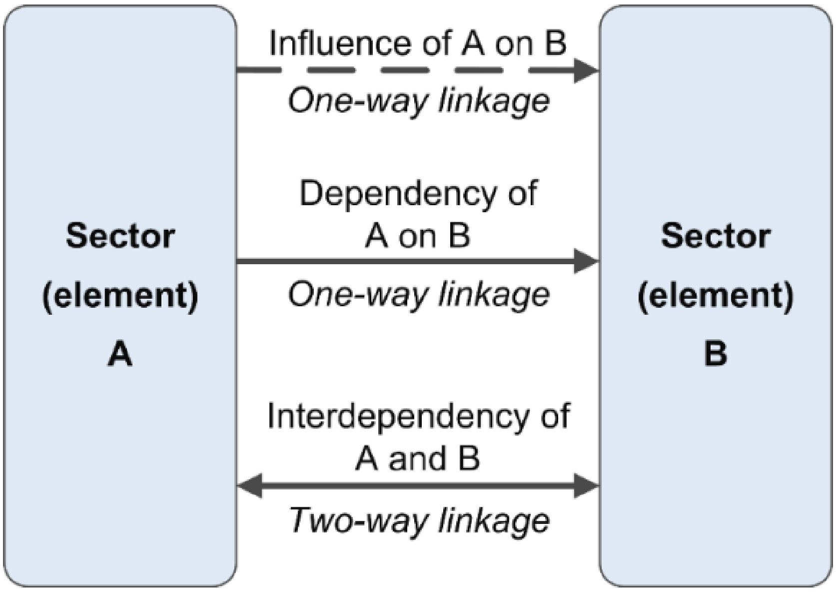

Figure 1: Types of linkages in the critical infrastructure system (Rehak et al., 2016a)

In the critical infrastructure system, all the above presented types of linkages are found both at the vertical level (area-sector-element) and the horizontal level, which includes linkages between the already-presented interrelation cause-failure-impact. These linkages occur at the following levels:

- Among the elements of a critical infrastructure's various sectors (i.e. cross-sectoral linkages).
- Among the elements within a critical infrastructure sector (i.e. sectoral linkages).
- Among a critical infrastructure's elements and the society.

In the critical infrastructure system, as well as in any other network, there are places that have a different level of importance (criticality). The damage, disruption or failure of an important (critical) element has a more or less significant impact depending on the number and nature of linkages determining the degree of its influence, dependence or interdependence. Such a failure could cause not only a serious disruption to the respective sector or entire system of critical infrastructure, but could also affect the interests protected by the state, i.e. security of the state, the economy and the basic needs of the population (Council Directive, 2008).

Predicting the impact of the failure of individual elements, sectors or entire critical infrastructure is an important part of exploring the issue of critical infrastructure security (analogous in Rey et al., 2013). The essence of such predictions is an analysis of all available information about the nature of impacts, which is dependent on many external and internal factors within the system. While the external factors mainly include the resilience of society and the nature, scope and duration of the emergency, the key internal factors include the type and extent of the failure within the system (more detail can be found in Rinaldi et al., 2001), the arrangement of linkages in the system (see above) and the resilience of the system. The very nature of the impacts is characterized by the area of the action, the structure of the action, the intensity and duration of the action, and the effect of the action (see Figure 2).

In principle, the failure in the critical infrastructure system can indicate a double character of impacts. In the first case, the impacts are within the system when the failure of one sector of critical infrastructure induces a failure in another sector/sub-sector/element, i.e. the cascade effect (Rinaldi et al., 2001). In the second case, the impacts act outside the system, on society, with negative effects on the interests protected by the state, i.e. security of the state, the economy and the basic needs of the population (Rehak et al., 2016a).

In both cases, the action of impacts can be structurally divided into either direct or indirect. The direct or primary action means an immediate effect of the disturbed sector on another sector or directly on society. The indirect action of impacts takes place vicariously through any sector of the critical infrastructure, whether it ultimately affects another sector or society. The indirect action of impacts can be of a secondary (via one sector) or multi-structural character (via multiple sectors) (Rehak et al., 2016a).

Figure 2: Aspects shaping the nature of impacts in the critical infrastructure system (Rehak et al., 2016a)

Other important factors forming the nature of impacts are their intensity and duration of action. The intensity of impacts depends not only on the failure range in the sector, which further acts on another sector of critical infrastructure, but also on the level of their mutual linkage. If this linkage is weak, the intensity of action is low and the subsequent effects on the affected sector are only partial. Conversely, if this linkage is strong, then the intensity of the action is high and its effects on the affected sector can be devastating (i.e. absolute). In connection with the intensity of the action, another important variable is the time of its duration, which can be short, medium or long term. A typical time frame of the distortion of critical infrastructure is presented by M. Ouyang et al. (2012) who divide it into a prevention period, a propagation period, and damage, assessment and restoration period (Rehak et al., 2016a).

An indispensable factor determining the nature of impacts is the effect of their action. If the impacts of a disrupted sector act upon another sector or society in only one way (one-way action), then we are talking about simple impacts. However, if the effect of action is of a multiway nature (e.g. a combination of direct and indirect actions) and takes place simultaneously in real time, then we are observing a synergic action (Rehak et al., 2016a).

3. Bases for modelling the impacts of critical infrastructure failure

Modelling the impacts of critical infrastructure failure is a complex process that by should be based not only on mathematical modelling, but also on the integration of new approaches to analysing the critical infrastructure system. The basic starting points of this process should particularly include (1) an early indication of the impacts by applying the “bottom-up” approach; (2) unification and transformation of cross-cutting criteria at the regional level; (3) risk and safety management of European critical infrastructure; and (4) implementation of a preference risk assessment of critical infrastructure.

3.1 Early indication of the impacts by applying the "bottom-up" approach

This approach and evaluation system should be based on determining indicators of resilience disruption for interconnected sectors of critical infrastructure. It is a holistic approach to assess the resilience of critical infrastructure based on a comprehensive perception of area-specific political, economic, social, technological, legal and ecological environments. The essence of this approach is a systematic approach consisting of a cross-sectoral evaluation based on an investigation of mutual linkages between individual sectors of critical infrastructure. It reflects the propagation of cascade impacts and synergies in the critical infrastructure system. The mentioned systemic solution should be applied using the progressive "bottom-up" approach, which is based on an evaluation of critical infrastructure from the lowest levels (city, region) upwards and is currently being implemented in some developed countries (e.g. Switzerland and the Netherlands). This approach can be seen as a logical continuation of existing research activities in the field of exploring the security of critical infrastructure in terms of integrating the results of these activities through identifiers describing the state of critical infrastructure in a composite resilience indicator (see Figure 3). (CIRAS, 2015)

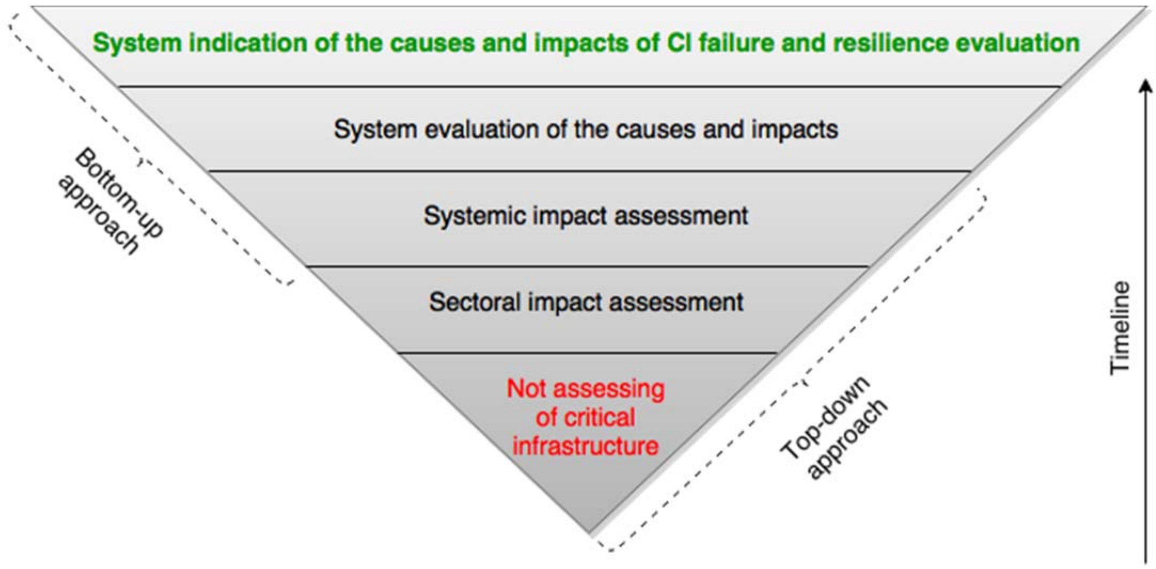

Figure 3: Development of the approach to critical infrastructure research (CIRAS, 2015)

3.2 Unification and transformation of cross-cutting criteria at the regional level

The application of the "bottom-up" approach is closely related to the need to integrate and transform cross-cutting criteria at the regional level. The values of cross-cutting criteria for the elements of national critical infrastructure have already been realized by individual Member States of the European Union. The vast majority of states, however, have not disclosed these values, which highly complicates the follow-up research in the field of modelling the impacts on society. For this purpose, it is possible to use results of the international project (RAIN Project, 2015) that was implemented under the 7th Framework Programme for Research and Technological Development of the European Union. Based on the recommendations arising from a directive of the European Union (Council Directive, 2008) and regulation of the government of the Czech Republic on the criteria for determining the elements of critical infrastructure (Government Decree, 2010), the following cross-cutting criteria were defined for a wider international debate within the RAIN project (2015):

- Health impacts – the number of victims with a limit value of more than 25 dead persons or more than 250 persons with subsequent hospitalization lasting longer than 24 hours per one million inhabitants within the evaluated region.
- Economic impacts with a limit value of economic losses to the state over 0.5 % of gross domestic product.
- Impacts on the public with a limit value of the extensive restrictions on the provision of essential services or other serious intervention in everyday life involving more than 12 500 persons per one million inhabitants within the region under review.

The starting point for adjusting the cross-cutting criteria at the regional level could be an interim transformation of national criteria (Note: This method is not very suitable for applying the "bottom-up" approach because the transformation of national criteria shifts this method of adjusting the regional values to the "top-down" approach). This transformation consists in a dynamic conversion of the limit values of national cross-cutting criteria into regional criteria. This ratio is mainly applied in terms of the number of inhabitants of the given state to the population of the region of interest, and the limit values of national cross-cutting criteria to the limit values of regional cross-cutting criteria. Converting static limit values into dynamic values is done not only due to the different populations in different regions, but also due to the different levels of gross domestic product produced in these regions. (Novotny et al., 2014)

3.3 Risk and safety management of European critical infrastructure

Risk and safety management of European critical infrastructure is an important aspect for modelling the impacts of critical infrastructure failure. Applying this approach leads to an early detection of risks, contributing to an early indication of impacts on independent sectors of critical infrastructure. In order to optimize the system of risk and safety management, and to meet the requirements for emergency preparedness plans in entities that are part of the critical infrastructure as equivalents of the Operator Security Plan, it is appropriate to implement the following methodologies (Rehak et al., 2016b):

- Methodology for selected CIs System Resilience Element Evaluation (Hromada and Lukas, 2015),
- Methodology for ensuring the protection of CIs in the production, transmission and distribution of electricity (Deloitte Advisory, 2012).

3.4 Implementing a preference risk assessment of critical infrastructure

Security and risk management is also related to the preference risk assessment of critical infrastructure (Rehak and Senovsky, 2014). This allows the reviewer to implement subjective conditions into an otherwise objective risk assessment process. The reviewer can thus partially influence the evaluation process by preferring certain factors over others. This part of the evaluation process is important because every entity perceives certain risks from a different perspective, which subsequently creates a space for discussion between all stakeholders and the selection of the most appropriate safety measures to be taken (Hromada and Lukas, 2012). Preference risk assessment of critical infrastructure is also an important starting point for modelling the impacts of critical infrastructure failure as its results determine vulnerabilities enabling the spread of impacts throughout the infrastructure system.

4. Conclusion

Predicting the intensity of a problem and modelling the propagation line of its impacts during disruptions or failures of critical infrastructure is an important part of the research surrounding critical infrastructure resilience. The results of this process are significant factors in the decision-making of stakeholders regarding the timely and effective implementation of security measures. However, the level and applicability of these results is conditioned by the quality of the process by which they were created. For this reason, the article presents a proposal for integrating new approaches to exploring critical infrastructure resilience. The basic starting points of this proposal are mainly (1) an early indication of the impacts by applying the “bottom-up” approach; (2) unification and transformation of cross-cutting criteria at the regional level; (3) risk and safety management of European critical infrastructure; and (4) implementing a preference risk assessment of critical infrastructure.

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