Linkages Types with an Emphasis on Important Critical Infrastructure Sectors

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***Abstract*— This paper presents and evaluates theoretical approaches applied to the interdependencies description of important critical infrastructure areas. It describes the theoretical basis, and, in some cases, their practical application, with an emphasis on the important critical infrastructure sectors (e.g. Energy, Transport, Information and Communication Technologies). Other important critical infrastructure sectors (e.g. Water Management, Health Care, and Emergency Services) are not emphasized in this publication because they are addressed in the security research project RESILIENCE 2015. The aim of the article is to define the linkage types as a framework and baseline for resilience functional parameters definition, which is crucial for objective and relevant critical infrastructure resilience establishment. The article outcomes can also be seen as an analytical input to the above mentioned project activities.**

***Keywords-** critical infrastructure; important critical infrastructure sector; linkage; dependence; interdependence.*

I. INTRODUCTION

One of the basic attributes of the critical infrastructure is its network nature. Therefore, the interdependence of the various sectors and elements contained in it creates logical patterns.

In the Czech Republic, considerable attention has been given to important sectors of critical infrastructure (CI) in recent years. In the process of identifying a designation of CI elements, and addressing their protection, however, only individual sectors were taken into account and impacts of inter-linkages at inter-sectoral level were not considered. In addition, research into this issue has not been adequately developed. Reflection necessity of basic CI attribute, which is the interaction between the different sectors and their elements, was not been taken into account when assessing the criticality of the process or in providing protection. Recent prevailing approach, when the important CI sectors protection of major is dealt separately [1], [2], with regards to the basic characteristics of the system, need to be perceived as a weak and unsustainable.

The following text summarizes selected theoretical approaches to the classification of types of linkages between important CI infrastructure sectors/elements, published in domestic and foreign scientific literature, and, therefore offers the possibility of their further use for the needs of the research project. The rest of the paper is divided in three sections The first section discusses and presents the theoretical and philosophical framework in context of critical infrastructure dependencies and interdependencies in the wider context. The second and main section presents the outcomes of our state of the art analysis in connection with types of linkages classification approaches. The analysis structure represents the needs of security project RESILIENCE 2015 which was mentioned above. The last section presents the synthesis of the analysed solutions and analysis in selected areas.

II. TYPES OF LINKAGES CLASSIFICATION APPROACHES ANALYSIS

Critical infrastructure is seen as a System of systems, and, therefore a fundamental condition that must be met is the linkages between the system's elements.

Generally, for linkages of any type within any system, it is necessary to distinguish with regard to the designed level. Figure 1 [3] illustrates this approach and distinguishes linkages between the CI systems and linkages inside the system between the individual elements.

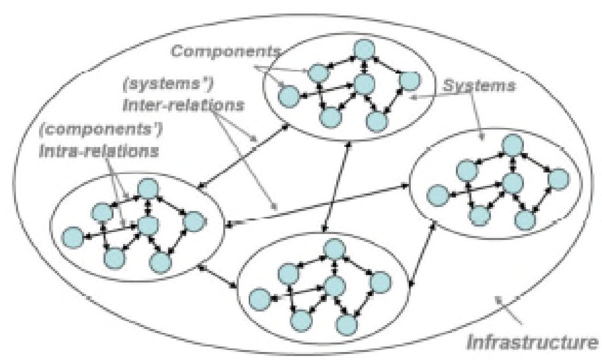

Figure 1. Linkages inside the CI [11]

Research on dependency linkages between the important CI and their elements in the Czech Republic is still a subject of scientific interest. Therefore, in the literature, this topic is addressed only marginally. The fundamental works published [4][5][6] are generally analysing the existing foreign sources. Foreign research studies that could significantly contribute to addressing the typology of linkages were also published in the Czech Republic.

In the foreign literature, the topic of linkages in CI sectors is widely addressed. One of the most important sources can be considered an article by Rinaldi et al. [7]

which bring together experts from the Czech Republic well as foreign experts. The approaches in that publication are also reflected partly or completely in published practical applications [8][9][10], as well as in conceptual documents [11].

Rinaldi et al. [7] offer several possible approaches to categorizing linkages. In terms of the direction of functional failure, linkages can be of type dependency or interdependency.

A linkage dependency is an expression that applies when infrastructure B is affected by infrastructure A, but infrastructure A is not within the same infrastructure linkages affected by B. Dependence is a one-sided type of linkage. An example of such a link is shown in Figure 2.

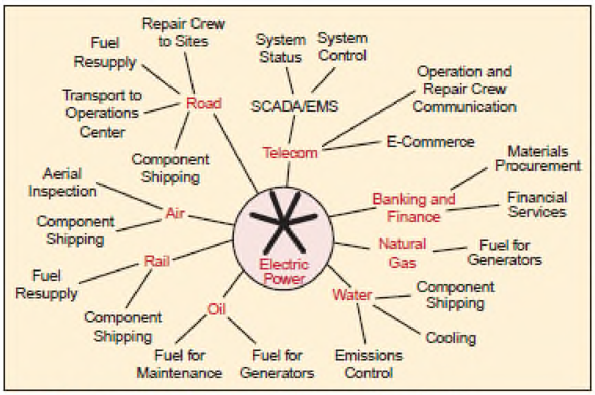

Figure 2. Example of dependency - dependency on electricity [7]

Linkage interdependency is an expression that applies when CI A is dependent on CI B through a certain linkage, and CI B is dependent on CI A through other linkage. Linkage of interdependence is a two-sided type of linkage. An example of such a linkage is shown in Figure 3.

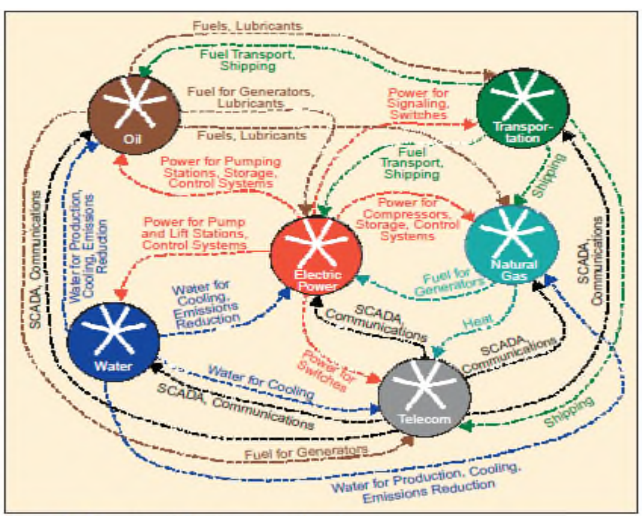

Figure 3. Example interdependency - the interdependence between selected CI sectors [11]

Regarding categorization of linkages in terms of their action direction, Rostek, Markuci & Adamec [6] report that, if CI A positively / negatively affects CI B through a linkage, it is not a requirement that CI B was dependent on CI A. It is, therefore, a sign that expresses a kind of precursor patterns of dependency and its ability of stimulatory or inhibitory effect.

Rinaldi et al. [7] exclusively emphasize the use of the term interdependency whose content concept corresponds to the most real systems and their holistic perspective.

In the same publication from Rinaldi et al. [7], another possible approach is further hinted at, which is based on the ability of CI sectors and their components interactions. Despite the fact that this case only dealt with the individual sectors, respectively their elements characteristics, and did not deal with direct linkages typology, this approach can be considered inspirational to the general perception of linkages between the CI sectors. From this perspective, it provides the following types of sectors:

- Supported,

The industry is dependent on the function of other sectors and their role is predominantly passive.

- Supportive,

The industry is able to influence the function of other sectors and their role is predominantly active.

Categorization of linkages within the systems is not addressed exclusively as part of research activities targeted at CI analysis. For example, it is possible to include the publication of Bühne et al. [12], which gives basic linkages typology used in the process of phenomena modelling. Bühne et al. [12] indicate linkages:

- Requirements,

Requires the existence / need another object (required).

- Exclusivity,

Linkage to selected object precludes the selection of another object.

- Help / advice,

It describes the positive relationship - object has a positive influence on another object.

- Obstacles,

It describes the relationship when the object has a negative impact on another object.

Another approach to linkages classification was presented by Rinaldi et. al [7] . In relation to the general classification, according to the direction of dependency linkage and interdependence linkage, in this context there is more evolved the interdependency linkage types and further categorized into the following classes of linkages, through

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which they are transmitted effects between different CI sectors and its elements:

• Physical,

The state of the CI sector is dependent on the material output of other CI sectors.

• Cybernetic,

The state of the CI sector is dependent on information linkage to other CI sectors.

• Geographical,

The state of the CI sector is dependent on emergencies arising in the territory.

• Logic,

The CI sector is dependent on the status of a second CI sector, and the linkage mechanism is not physical, cybernetic or geographical (dependence transmitted via streams, which are for example legislation, financial instruments).

The same linkages typology was presented by Peerenboom et al. [13] or Chien-Cheng & Ssu-Min [14]. Dudenhoeffer, Permann & Boring [15] present their own interdependence linkages typology, which, however, only slightly differs from the classification referred by Rinaldi et al. [7]. Dudenhoeffer, Permann & Boring [15] distinguishe the following types of linkages:

• Physical,

Direct linkages between the CI sectors affecting the flow of supply - consumption - production.

• Information,

Direct linkages between the CI sectors are given by the information flow. An example might be the SCADA systems.

• Geospatial,

Linkages between the CI sectors spatially tied.

• Political,

Linkages between the CI sectors affect decisions framework.

Physical, geospatial and information linkage can be considered equivalent to physical, cyber and geographic linkages. Political linkage can be described in terms of content meaning linked with subordinated logical linkage featured by Rinaldi et al. [7], which has a more general meaning.

The typology by Dudenhoeffera, Permanna & Boring [15] extends Pederson's et al. [16] typology by the type of social linkages, which they perceive as the influence of factors (public opinion, public trust, and sharing cultural values) able to transfer to other CI sectors. In terms of content focus, it can again be social linkage subsume, as in the previous case by political linkages, under the logic linkage.

In comparison with previously presented approaches, Zhang & Peeta [17] present a completely different concept of CI sectors linkages typology definition. According to this concept the following types of linkages are proposed:

• Functional,

System functionality requires outputs from the other system or it possibly can be substituted by a different system.

• Physical,

Some systems are connected by physical attributes. Strong linkage, therefore, exists when systems jointly share the right to flow, leading to the mutual capacity constraints.

• Budget,

Systems functionality is largely influenced by the flow and distribution of public funds, especially in the context of centrally controlled economies or in the recovery phase after crisis or a disaster.

• Market,

The existence of shared market sources indicates that all systems interact in the same economic environment. It means that the systems always serve the same end-users, who determine the final consumption of the commodity / services - according to market opportunities.

A possible example of practical application of the mentioned approaches to the linkages classification between the CI sectors is also published in the defence research project dealing with the so-called Location - Based Critical Infrastructure Interdependence [8]. In this research, the dependencies identification were reflected by Rinaldi et al. [7] presented concept and consider the possible impact of interdependence between various important CI sectors through physical, cyber, geographical and logical linkages. Within the model, some scenarios were simulated. One scenario was the simulation of a shallow earthquakes with an intensity of 7.3 modified Mercalli scale (scale was compiled and based on observations of the earthquake effects and is used to measure macro-seismic intensity) in a seismically active region situated in the Strait Georgia, British Columbia, Canada.

The functional earthquake effect was spatially visualized in the project. High risk has been identified or a total of 23 objects important to the water infrastructure sector near Vancouver, Canada. Severe damage is also expected near Vancouver airport. Spatial analysis helped identify the level of risk with regard to population density. Simulations showed that, due to electricity supply failure, the functionality of another important CI will be disrupted.

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According to the findings above, high pressure will be faced from the part of emergency services, as an element of one CI sectors (class no. 9 - Safety). Significant impact in this field is also foreseen to the transport sector.

III. Synthesis of Analysed Approaches

An overview of the approaches discussed for the linkages type's classification between different CI sectors is presented in Table. 1.

TABLE 1. OVERVIEW OF SELECTED APPROACHES TO LINKAGES CLASSIFICATION

Author	Linkages types
Rinaldi et al.	a) Dependency b) Interdependency 1. Physical, 2. Cybernetic 3. Geographical, 4. Logic,
Bühne et al.	• Requirements, • Exclusivity, • Help / advice, • Obstacles,
Dudenhoeffer, Permann & Boring	• Physical, • Information, • Geospatial, • Political,
Pederson et al.	• Physical, • Information, • Geospatial, • Political, • Social,
Zhang & Peeta	• Functional, • Physical, • Budget, • Market,

The classifications are generalized expression of the possible types of addictions and transmission effects between the CI sectors.

Current literature offers several possible approaches to classifying linkages between the CI sectors and their elements. From selected international sources as well as from the Czech Republic, we conclude that the most frequently cited classification is the one presented by Rinaldi et al. [7]. This classification distinguished the linkages as physical, cyber, geographic and logical. This is developed not only in the theoretical research, but it is also used for practical applications needs and the assessment of CI individual relations.

IV. Conclusion

This article has possible applicability in the project RESILIENCE 2015. Dynamic resilience evaluation of interrelated critical infrastructure subsystems should be through the prism of this classification in order to see how the flows within important CI sectors, particularly in the sectors of energy, transport and information and communication technologies affect each other and how they affect the other important CI sectors through interdependencies. The recommended theoretical concept of reflection on the issue of CI sectors interdependence is also used in the strategy plan of the new approach to the critical infrastructure sectors protection at EU level [11]. The article goal is to identify basic understanding of linkages type modelling in the context of critical infrastructure. Linkage type's definition is seen as a significant input to the security research project RESILIENCE 2015, mostly in relation to functional parameters identification for the domino and synergy effect assessment process. This article outcome provides a philosophical and theoretical framework and analysis implementation in the context of interdependencies impact in connection with critical infrastructure resilience assessment.

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