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GENERIC RESILIENCE INDICATORS OF CRITICAL INFRASTRUCTURES

Nenad Petrović, Alen Stranjik, Renata Peternel

University of Applied Sciences Velika Gorica, Velika Gorica, Croatia

Abstract

The capacity of critical infrastructure is one of the main components for infrastructure resilience. By improving the capacity increased resilience, and reduce the risks and impacts. There are several dimensions of resilience that need to be taken into consideration when trying to achieve a holistic approach for infrastructure resilience. One of this components anyway are the resilience parameters: anticipation, absorption, coping, restoration and adaptation. These parameters correspond to the critical infrastructure capacities and are a possible way to quantifying these capacities, with appropriate measurable resilience indicators. This paper presenting a list and description of possible generic resilience indicators, that are the same for all type of hazard and all type of critical infrastructure. This work is the result of scientific research in the EU-CIRCLE project, that is financed through the Horizon 2020 program of the European Union.

Keywords: Resilience indicators, critical infrastructures, EU-CIRCLE project.

Adress for correspondence: Nenad Petrović, University of Applied Sciences Velika Gorica, Zagrebačka c. 5, Velika Gorica, Croatia, e-mail: neno.petrovic@gmail.com

1. INTRODUCTION

Infrastructure systems, commonly referred to as the energy production and distribution systems, the chemical industry, water system, transportation, ICT Networks and public sectors, are one of the defining features of modern societies as they rely heavily upon them and their smooth operation to carry out our day-to-day activities [1]. Infrastructures thus facilitate economic growth, protect human health and the environment and promote welfare and prosperity [2].

When infrastructure systems are damaged or fail, the smooth functioning of society is disrupted, with negative impacts on our ability to continue in our daily activities, well-being and security [3,4]. Critical Infrastructure systems do not act alone. Therefore, a disruption in one system will create cascading impacts and consequences to the networked infrastructure system [5]. The social disruption caused by infrastructure failures can frequently be disproportionately higher in relation to actual physical damage [6].

Various disasters over past few decades including man-made and natural disasters, have highlighted that avoidance of all threats at all times for all infrastructures is impossible [4,7].

This paper presenting a list and description of possible generic resilience indicators, that are the same for all type of hazard and all type of critical infrastructure and is based on comprehensive literature review and synthesis.

This paper is developed as part of an ongoing collaborative project titled „Pan-European framework for strengthening Critical Infrastructure resilience to climate change (EU-CIRCLE), which is funded European Union´s Horizon 2020 research and innovation programme.

2. METHODS

The initial list of potential generic resilience indicators was made on the basis of an intensive review and systematization of existing literature. From this initial list, final indicators are selected on the following criteria:

1. Resilience indicators should not be related to specific hazard,

2. Resilience indicators should not be related to specific infrastructure sector,
3. Resilience indicators should not be redundant,
4. Resilience indicators should be understandable,
5. Resilience indicators should be measurable with simple metrics.

Based on these criteria, a total of 18 generic resilience indicators were selected, which are shown below.

3. RESILIENCE INDICATORS

In order to put resilience into practice, we want to know what properties indicate resilience, how to measure or assess their resilience, and how to manage for resilience [4]. There are several dimensions to resilience that need to be taken into consideration when trying to achieve a holistic approach for infrastructure resilience. Resilience framework developed in EU-CIRCLE project recognises five types of generic resilience parameters: anticipation, absorption, coping, restoration and adaptation. These parameters correspond to the critical infrastructure capacities and are a possible way to quantifying these capacities, with appropriate measurable generic resilience indicators, thay are shown in Table 1.

Table 1. Generic resilience indicators.

Resilience parameters	Generic resilience indicators
Anticipation	Awareness of potential hazards Quality / extent of mitigating features Quality of disturbance planning / response Communication Systems / Information sharing Learnability / Training
Absorption	System failure (integrity of the CI affected) Severity of failure (services of the CI affected) Resistance Robustness and redundancy
Coping	Response Economics of response Interoperability with public sector
Restoration	Post-event damage assessment Recovery time Economics of restoration
Adaptation	Adaptability and flexibility Impact / consequences reducing availability Economics of adaptation

The resilience indicators can be qualitative, quantitative or binary according to the type of data they utilize and may be absolute (e.g., speed of critical infrastructure failure) or relative (e.g., recovery/loss ratio) [8,9].

Quantitative indicators (e.g. the average annual temperature, the number of projects developed in response to a policy, or the number of bridges constructed) are often preferred for monitoring and evaluation. Quantitative resilience indicators might be most appropriate for technical features of infrastructure. Where quantitative data is not available, and the issue is still considered important for monitoring purposes, qualitative or binary indicators may be utilized.

Qualitative indicators provide narrative or summary information regarding an item of concern. Qualitative indicators may be most appropriate when examining the quality of infrastructure organisation, operation, maintenance or management, or when assessing users interactions with infrastructure. Adaptation indicators, because they relate to processes, are more likely to be qualitative than climate change or climate impact indicators.

Binary indicators have a yes/no answer. Several indicators appropriate for climate adaptation could be binary, e.g. early warning systems in place (yes/no).

In principle, the strategy for measuring resilience is to quantify the difference between the ability of a critical infrastructure to provide services prior to the occurrence of an event and the expected ability of that infrastructure to perform after an event [10]. Good metrics are: comprehensive, understandable, practical, non-redundant and minimal [11].

3.1. Description of the generic resilience indicators

A) Anticipatory capacity

A.1. Awareness of potential hazards: Awareness of the community or awareness of the owners and operators of critical infrastructures about potential hazards that could endanger their infrastructure is an important factor of comprehensive resilience. It can be seen as a relationship between all the possible further hazards and hazards to which is the community currently prepared.

A.2. Quality/extent of mitigating features: Assessing the quality and extent of features associated with an infrastructure that can mitigate the consequences of disturbance or shock is an important a-priori resilience indicator. Mitigating features add to the robustness of the infrastructure, and an early assessment of their quality and extent can be useful in improving these features where the necessity exists. Mitigating features will be specific both to the type of infrastructure and the nature of disturbance the infrastructure is likely to be subject to [9].

A.3. Quality of disturbance planning/response: Technical assessments of infrastructure are perhaps the most obvious when considering resilience, yet considering organisational planning for preparedness and response are also important. Assessing the value of pre-determined policies that increase or maintain the quality and functionality of infrastructure can be a useful indicator of resilience. In addition, the nature and availability of repair facilities, resources or personnel can also increase the speed of recovery [9].

A.4. Communication Systems / Information sharing: The quality and nature of crisis communication structures, and organisational information sharing between managers of CI and government agencies can be a useful indicator of the CI resilience. Where crisis communication methodologies and technologies are of high functionality, their deployment at times of disturbance or shock may limit loss of functionality, and speed up the recovery of infrastructure function. Making either qualitative or quantitative assessments of information sharing processes and practices can be particularly good indicators of the strength of relationships of the managers of infrastructure systems that are characterised by significant interdependencies [9].

A.5. Learnability/Training: Learnability is the ability of organisation to use the lessons of their own and others' experiences to better manage the prevailing circumstances, including using lessons in real time as they emerge [12].

B) Absorptive capacity

B.1. Systems failure (integrtity of the CI affected): Observing an actual failure in an infrastructure can provide a clear indication of its resilience, and specifically what characteristic of the infrastructure, or its relationship to the disturbance, may have led to the failure. Many factors may influence the likelihood that a system fails completely, but also interdependencies, lack of security, poor management and disturbance planning, poor communications, etc. Systems failure can be measured in a binary fashion: fail, or not fail [9].

B.2. Severity of failure (services of the CI affected): For instance, old or poorly maintained infrastructures are likely to fail such that they lose functionality completely following disturbance, and consequently require a complete rebuild during recovery. By contrast, well-managed, newer infrastructure that is designed to cope with disturbance (the most likely to occur in any given location) is likely to suffer less as a result of disturbance, and some functionality may persist [9].

B.3. Resistance: Resistance is focused on providing protection. The objective is to prevent damage or disruption by providing the strength or protection to resist the hazard or its primary impact. Resistance has significant weaknesses as protection is often developed against the kind of events that have been previously experienced, or those predicted to occur based on historic records [13-15]. Probability of failure is an estimation of the expected impact and degradation of an infrastructure following a disturbance or shock. This probability will vary depending on the nature of the disturbance or shock, but also on the nature of the critical infrastructure itself [9]. Quality of infrastructure indicated by how well an infrastructure performs. Performance is influenced by design, materials, age, service life, and the quality of management and maintenance. Infrastructures with lower quality are likely to be less operable after disturbance.

B.5. Robustness and redundancy: The robustness component of resilience is the ability to maintain critical operations and functions in the face of a crisis. It is directly related to the ability of the system to absorb the impacts of a hazard and to avoid or decrease the importance of the event that could be generated by this hazard. This can be reflected in physical building and infrastructure design (office buildings, power generation and distribution structures, bridges, dams, levees), or in system redundancy and substitution (transportation, power grid, communications networks) [14-17]. Redundancy is concerned with the design and capacity of the network or system. The availability of backup installations or spare capacity will enable operations to be switched or diverted to alternative parts of the network in the event of disruptions to ensure continuity of services [13-15,17]. Substitutability is an aspect of a CI system's redundancy, and a key characteristic associated with resilience in infrastructure. Substitutability reflects the possibility that the functional aspects of an infrastructure or infrastructure system can be replaced by back-up infrastructure or by other components in the system [9].

C) Coping capacity

C.1. Response: Response aims to enable a fast and effective response to disruptive events. The effectiveness of this element is determined by the thoroughness of efforts to plan, prepare and exercise in advance of events. Some owners of critical infrastructure understand the weaknesses in their networks and systems and have arrangements in place to respond quickly to restore services [13,14].

C.2. Economics of response: The cost of returning infrastructure to pre-event functionality can be used as an indirect measure of an infrastructure's resilience [9]. This costs including response cost and backup cost.

C.3. Interoperability with public sector: Interoperability is the ability to cooperate at all levels with neighboring cities/states and other levels of government of critical systems and procedures. Interoperability needs to be assessed at multiple levels [18].

D) Restorative capacity

D.1. Post-event damage assessment: Geographic information systems (GIS) and remote sensing technologies can, and have been used in post disaster damage assessments. Such technologies can be used to yield quantitative measures of damage to many forms of infrastructure, and therefore give a direct idea of the robustness of infrastructure affected by the disturbance [9]. Measuring functionality of an infrastructure following a disturbance or shock, and comparing this level to the pre event assessment of functionality will provide an excellent indication of CI resilience. The closer the level of post-event functionality to the assessed pre-event functionality, the more likely the infrastructure is to be resilient (in relation to a consequential disturbance).

D.2. Recovery time: Possibly the most well-known indicator of resilience in CI, the recovery time post-event is a measure of the amount of time it takes for an infrastructure to be brought back to its pre-event level of functionality [9].

D.3. Economics of restoration: Economics of restoration can be also used as an measure of an infrastructure's resilience [9]. This measure assumes that a greater expense (relative to the value of the infrastructure alone, not the value of the service the infrastructure provides to society) equates to more damage, and therefore lower resilience in the infrastructure.

E) Adaptive capacity

E.1. Adaptability and flexibility: Adaptability and flexibility are capacity or ability to change while maintaining or improving functionality, adopting alternative strategies quickly, responding to changing conditions in time, designing open and flexible structures [19].

E.2. Impact/Consequences reducing availability: Impact reducing availability is availability of adaptive processes that reduce the impacts of climate change, e.g. re-allocation of facilities, building new facilities according to climate-ready standards, protection of existing critical infrastructures, etc. [19]. Consequences reducing availability is availability of adaptive processes that reduce consequences of climate change, e.g. rerouting transportation flows, developing flexibility of networks, etc. [20].

E.3. Economic of adaptation: Local communities are interested in ensuring they develop and maintain a vibrant and thriving economy, even amid hazard events [3]. Factors that might affect a community‘s economic sustainability after hazard events include the degree to which the local economy depends on a single industry.

4. CONCLUSION

Resilience, in the context of critical infrastructure, is the ability of a critical infrastructure system to prevent, withstand, recover and adapt from the effects of various natural hazards. One of the possible ways of measuring resilience is their quantification using resilience indicators. The aim of this paper is presenting a list and description of possible generic resilience indicators, that are not related to specific hazard or to specific critical infrastructure sector. This indicators are selected based on comprehensive literature review and clearly defined criteria of elicitation.

The results of this research are constrained to 6 critical infrastructure sectors that are covered by the EU-CIRCLE project. These include: energy production and distribution systems, water systems, transport, ICT networks, chemical industry and public sector. For the purpose of generalizing conclusions on the applicability of the results of this research in other infrastructure sectors, additional research should be carried out.

Future research will be focused on determining the appropriate metrics for quantification of defined generic resilience indicators, in the context of climate related natural hazards and further climate changes.

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GENERIČKI INDIKATORI OTPORNOSTI KRITIČNE INFRASTRUKTURE

Sažetak

Kapacitet kritične infrastrukture jedna je od glavnih komponenti njene otpornosti. Poboljšanjem kapaciteta otpornost se povećava, a rizici i neželjeni učinci se smanjuju. Postoji više dimenzija otpornosti koje treba uzeti u obzir kada se pokušava postići cjelovit pristup otpornosti kritične infrastrukture, a jedan od sastavnih dijelova u svakom su slučaju parametri otpornost: predviđanje, apsorpcija, suočavanje, obnova i prilagodba. Ovi su parametri sukladni definiranim kapacitetima kritičnih infrastruktura te su mogući način kvantificiranja tih kapaciteta, putem odgovarajućih mjerljivih pokazatelja otpornosti. Ovaj rad prezentira popis i opisuje moguće generičke pokazatelje otpornosti, koji su jednaki za sve vrste hazarda i sve tipove kritičnih infrastruktura. Rad je rezultat znanstvenih istraživanja u projektu EU-CIRCLE, financiranom kroz Horizon 2020 program Europske unije.

Ključne riječi: Indikatori otpornosti, kritična infrastruktura, EU-CIRCLE projekt