IMPROVED RISK EVALUATION AND IMPLEMENTATION OF RESILIENCE CONCEPTS TO CRITICAL INFRASTRUCTURE

D1.3 Final lexicon of definitions

related to Critical Infrastructure Resilience

M. Theocharidou[1], Laura Melkunaite[2], Kerstin Eriksson[3], David Winberg[3], Daniel Honfi[3], David Lange[3], Fanny Guay[2], Lexin Lin[3]

Contributors: Peter Gattinesi[1], Georgios Giannopoulos[1], Laura Petersen[4]

1. European Commission, Joint Research Centre, Ispra, Italy
2. Danish Institute of Fire and Security Technology, Hvidovre, Denmark
3. SP Technical Research Institute of Sweden, Borås, Sweden
4. European-Mediterranean Seismological Centre, Arpajon, France

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Coordinator:	David Lange at SP Sveriges Tekniska Forskningsinstitut (SP Technical Research Institute of Sweden)

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1 Executive Summary

IMPROVER is a Horizon 2020 project focusing on how to improve European critical infrastructure resilience to crises and disasters through the implementation of resilience concepts to real life examples of pan-European significance, including cross-border examples.

The project will develop methodologies for the implementation of societal, organisational and technological resilience concepts to critical infrastructure. To this end, it requires several resilience-related concepts to be identified and defined.

This is the final version of the IMPROVER Lexicon of Definitions. It is the result of the international survey conducted by the project and it gathers several resilience concepts and their definitions, as well as other key related terms from all the current, completed deliverables in the project.

In this final version of the document, we offer a list of terms and their definitions which will reflect the assumptions of the proposed IMPROVER methodology and will be used by the project partners for the duration of the project. This lexicon will also serve as a recommendation for terminology towards the project partners, the associated partners, the collaborating projects and the CIP community in general.

2 Nomenclature

CascEff`	Modelling of dependencies and cascading effects for emergency management in crisis situations (FP7 Project)
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CI	Critical Infrastructure
CIP	Critical Infrastructure Protection
CIPRNet	Critical Infrastructure Preparedness and Resilience Research Network (FP7 project)
CIR	Critical Infrastructure Resilience
DARWIN	Expecting the unexpected and know how to respond (H2020 project)
DBI	Danish Institute of Fire and Security Technology
DRIVER	DRIVing innovation in crisis management for European Resilience (FP7 project)
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
JRC	Joint Research Centre, European Commission
MCEER	Multidisciplinary Center for Earthquake Engineering Research
RESILENS	Realising European ReSiliencE for CritIcaL INfraStructure (H2020 project)
RESOLUTE	RESilience management guidelines and Operationalization appLied to Urban Transport Environment (H2020 project)
SMR	Smart Mature Resilience (H2020 project)
SP	SP Technical Research Institute of Sweden

3 Introduction

IMPROVER aims to develop a lexicon of definitions that are relevant for critical infrastructure resilience. During the project, the focus will be placed on different types of infrastructure and on a variety of assets in different countries, as the intention of the consortium is that the definitions, which are used in the lexicon, will be transferable across borders, infrastructures and between the asset level and the policy level.

The objective of Task 1.2 is to select critical infrastructure resilience related official definitions for the IMPROVER project. This deliverable is based on comments and contributions from all the IMPROVER partners and were agreed on the plenary meeting of the project on the 30th of November 2016, in Tromsø, Norway. This deliverable reflects all the work performed by the consortium during the first half of the project (Month 18). Therefore, the consortium foresees that the lexicon will be further updated and complemented throughout the second half of the project and if needed, an updated version will be made available.

4 Methodology

As mentioned above, the objective of this task was to gather available information on definitions of resilience and resilience related concepts, which could be implemented for critical infrastructure. To this end, the consortium has planned a methodology that was followed, which is described below.

The steps to create the lexicon are described below and summarised in Figure 1. One should note that the steps are not sequential, but that this is a recursive process of several iterations.

4.1 Step 1: Collect definitions

1a. Creation of a shared document of definitions

A shared list was created in order to record definitions as they become identified and to enable the group to collaborate and comment on the definitions. Besides the definition of the related term, additional information about the context have been noted such as: which dimension (societal, organisational or technological) of resilience the definition or term is related to; measures, indicators, special aspects considered; problems with the definition and/or limitations; focus and general view; relation to risk; connection to critical infrastructure; connection to hazards; other relevant comments; referencing information (author, year, source, keywords, citation, etc.). In the future, the group will discuss if this shared list needs to be simplified or enriched, based on how the group is using these attributes or not.

1b. Collect definitions while performing Task 1.1 (International survey)

This task entails an extensive international survey of the field, which are performed during WP1. During this process, DBI, SP and JRC use the shared document of step 1a to record the definitions they come across. The definitions are obtained by two types of sources:

- From the *literature review* on the use of resilience concepts.
  The review covers different contexts or disciplines, trying to address how resilience is defined in the fields of ecology, economy, crisis management, etc. and how such concepts can be applied for defining CIR. The review examines any type of material relevant to this topic:
    - Academic literature, e.g. books, journal articles and conference proceedings
    - Popular and scientific media reports and articles

- Official EU, UN and other international reports
- National policy documents.

- From *stakeholders* participating in the various events of the IMPROVER project. These are the IMPROVER associated partners series of workshops and the annual ERNCIP operators' workshops.

4.2 Step 2: Review, update and discuss the definitions

During this task, the group focused on the definitions acquired, grouped them and elaborated on them in order to observe the various approaches followed for defining CIR. This is an on-going process for the duration of the project.

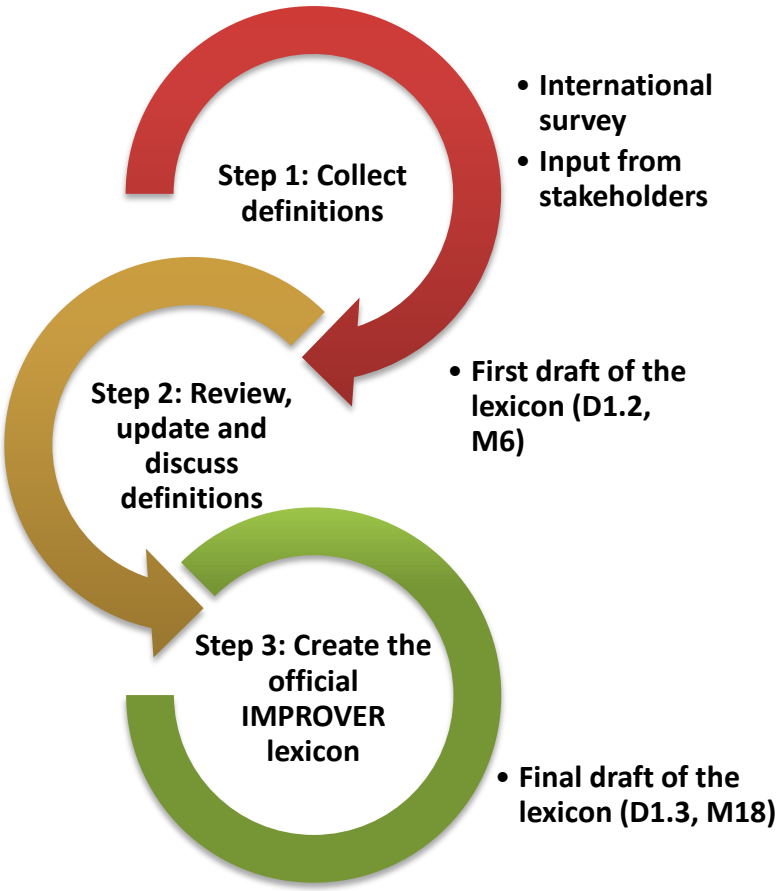

Figure 1: Lexicon Methodology

4.3 Step 3: Create the official IMPROVER lexicon

In month 6, the First draft of the lexicon, Deliverable D1.2 has been published. Since then, more efforts have been devoted to update the lexicon, together with the input from partners and all the published IMPROVER deliverables from work-packages WP1, 2 and 4. In some parts, through discussions, the list of definitions has also been simplified, based on how the group is using these concepts. All these changes are reflected in this final version of the lexicon (D1.3).

Towards M18, the project consortium formally defined the terms to be used for the project during a plenary meeting that took place in Tromsø, Norway. The consortium agreed on a set of basic definitions, which are published in this deliverable.

Because the project continues for another 18 months after the publication of D1.3, we foresee that the lexicon will be updated and enriched at later stages, as the IMPROVER methodology is formalised and applied in different settings.

4.3.1 Selection criteria for definitions

The consortium respected European definitions as far as possible, i.e. if there is a European definition for a term then this should take precedent over any other definition, unless the project team have a strong argument for changing it. If there are definitions from standardization bodies then these should take precedent next. The standardization bodies include European Standards Organizations (CEN, CENELEC) or international ones (ISO, IEC, etc.). National standards could also be a source for definitions, in the absence of an international or European one. When no definition is currently available according to this hierarchy, we present definitions from the literature.

4.4 Collaboration with other projects and Dissemination

It should be noted that the lexicon is not created in vacuum. Through the JRC, the consortium will benefit from existing experience in creating a publicly available CIP wiki (named CIPedia®[1]) of the CIPRNet FP7 project[2]. The two projects will exchange knowledge in terminology. For example, the IMPROVER consortium benefited from the definitions already available on CIPedia on CIP related terms (see section 6) and the IMPROVER project will update the entries related to CIR, which at this moment (November 2015) are not elaborated in detail on the wiki.

It is also the intention of the beneficiaries within IMPROVER responsible for this deliverable to collaborate with other European projects which are looking at resilience of critical infrastructure. Specifically the other topics which are funded under the same topic within the same work programme as IMPROVER, these are RESILENS, SMR, RESOLUTE, and DARWIN. Together with these projects and the ongoing FP7 projects DRIVER and CascEff, we have a general agreement to share the final draft of the lexicon and to invite comment on the definitions which are reported therein. This is not exclusive and we also intend to approach other relevant Horizon 2020 and FP7 projects to invite them to comment on this lexicon. This has the advantage of ensuring a common terminology between related ongoing projects, and serves to enhance not only the impact of this deliverable but also of this and the other projects. Once comments have been received on this lexicon then input from the IMPROVER stakeholders and associate partners as well as the other projects listed will be sought to ensure that the recommended definitions are relevant and appropriate for all as far as is possible.

The lexicon will be posted in the website, announced on LinkedIn and Twitter and we will have it as a topic for the first newsletter of IMPROVER.

[1] http://www.cipedia.eu

[2] http://ciprnet.eu/

5 Resilience dimensions and definitions (Glossary)[3]

5.1 Engineering resilience

5.1.1 Selection of definitions

- Resilience is a **process** to estimate how fast a variable that has been displaced from **equilibrium** returns to it[4]. Therefore, resilience can be estimated by a **return time**, the amount of time taken for the displacement to decay to some specified fraction of its own initial value.

- Similarly, resilience focuses on a system's behavior near a stable equilibrium and **the rate at which a system returns to steady state** following disturbance; Resisting change and disturbances in order to conserve what you have[5].

- Resilience focuses on **efficiency**, **constancy**, and **predictability**, and concentrates on **stability** near an **equilibrium steady state**, where **resistance to disturbance** and **speed of return** to the equilibrium are used to measure the property[6].

- Resilience is an **outcome**, the **capacity** of the system to cope with **unanticipated** danger after they have become manifested, learning to **bounce back**. Resilience is an inferior **strategy** under strict conditions[7].

- Resilience is the **ability** of the system to **withstand** a major disruption within an **acceptable degradation** of parameters and to **recover at acceptable time**, **cost** and **risks**[8]. Resilience is a **state of a system's capacity** to withstand forced changes to its organizational **structure**, **functionality**, and **operational continuity**.

- A resilient control system is one that maintains **state awareness** and an **accepted level of operational normalcy** in response to **disturbances**, including **threats** of an **unexpected** and **malicious nature**[9].

- According to the MCEER, resilience is ‘‘the ability of the system to **reduce the chances of shock**, to **absorb a shock** if it occurs and to **recover quickly** after a shock (**re-establish normal performance**)’’[10].

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[3] Please note that the use of ‘bold’ in the definitions was introduced by the authors of the deliverable to highlight concepts and not by the authors of the original source.

[4] Pimm, S. L. (1991). The Balance of Nature? Issues in the Species and Communities. University of Chicago Press, Chicago.

[5] Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change*, 16(3), 253–267. http://doi.org/10.1016/j.gloenvcha.2006.04.002

[6] Holling, C. S. (1996). Engineering resilience versus ecological resilience. In P. Schulze (eds.). Engineering Within Ecological Constraints. National Academy Press, Washington DC.

[7] Wildavsky, A. (1991). Searching for Safety. Transaction, New Brunswick, NJ.

[8] Haimes, Y. Y. (2009). On the definition of resilience in systems. *Risk Analysis*, 29(4), 498–501. http://doi.org/10.1111/j.1539-6924.2009.01216.x

[9] Craig G. Rieger, David I. Gertman, Miles. A. McQueen, Resilient Control Systems: Next Generation Design Research, HSI 2009 Catania, Italy, May 21-23, 2009.

- Finally, resilience in the research field of resilience engineering refers to the intrinsic **ability** of a **system** to **adjust its functioning prior to, during, or following changes and disturbances**, so that it can **sustain** required **operations** under both **expected** and **unexpected** conditions. [11]

5.1.2 Discussion

The term "engineering resilience" falls usually under the technological dimension of resilience as it relates to a mathematical description of an "engineered system". Several of the above approaches focus on a **single equilibrium,** where a system is considered to be in a steady state. Resilience focuses on **resisting** any disturbances in order to maintain this equilibrium, i.e. its **current state**, its **functionality** or its **consistency**. It essentially focuses on maintaining **efficiency** of a function. Moreover, minimising the **time, costs** and **risks** needed to return to this equilibrium are other key factors to be measured. Engineering resilience can thus be described as the "bounce back".

We also observe the different notions appointed to the concept, which can be considered the **desired outcome**, a **process**, a **capacity** or a **state** of a system. Moreover, several researches make the distinction between **anticipated** or **unexpected** changes or threats. If we summarize the engineering resilience literature, three views of resilience emerge.

Resilience as bounce back (or bounce forward)

A common view of resilience is to understand it as **bounce back** or **recovery** to previous or normal activities after a disturbance. When working with this view of resilience, the focus is on what makes some systems better than others and what resources and capabilities were present before the disturbance occurred. Resilience is accordingly seen as a capability or a characteristic of the system that can be **measured based on data from the past**. Another aspect, which has been discussed in the literature, is how important the **time or speed of recovery** to a desired equilibrium is. Within this view of resilience the parameter of **time** is seen as important[12]. However, is a shorter time always better? Furthermore, does a system always return (and aims to return) to the same condition as before, a previous stable equilibrium? A related understanding is to describe resilience as **bounce forward** instead of just bouncing back. The idea is that when adapting to a new challenge, even if the system draws on its past, the system becomes something new. The process of "bouncing" transforms both the environment and the system, thus the system ends up in a new place [16, 13]. The system may fulfil the same needs but in a new or in a better way.

Resilience as robustness

Another view of resilience is to see it as robustness. The idea is that an increase of **robustness** makes the system more effective to respond to disturbances and thus more resilient[16]. It is about the amount of disturbance the system can handle and still remain within the threshold. Further, one can understand

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10 Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., … Von Winterfeldt, D. (2003). A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. *Earthquake Spectra*, 19(4), 733–752. http://doi.org/10.1193/1.1623497

11 Hollnagel, Erik. 2011. Prologue: the scope of resilience engineering. In: Hollnagel, E. Pariès, J. Woods, D.D. Wreathall, J., eds. Resilience engineering in practice: A guidebook. Surrey: Ashgate, pp. xxix-xxxix.

12 Davoudi, S., Shaw, K., Haider, L. J., Quinlan, A. E., Peterson, G. D., Wilkinson, C., et al. (2012). Resilience: A bridging concept or a dead end? "Reframing" resilience: Challenges for planning theory and practice interacting traps: Resilience assessment of a pasture management system in northern afghanistan urban resilience: What does it mean in planning practice? Resilience as a useful conceptfor climate change adaptation? The politics of resilience for planning: A cautionary note. Planning Theory & Practice, 13(2), 299-333.

13 Manyena, S. B., O'Brien, G., O'Keefe, P., & Rose, J. (2011). Disaster resilience: A bounce back or bounce forward ability. Local Environment, 16(5), 417-424.

resilience as a **buffer capacity** for perceiving the existing system[12]. A challenge with the view of resilience as robustness is that it is hard to develop the robustness if the system and especially the disturbance are not well **modeled**. The usefulness of this view is thus in the cases where the systems studied (including the disturbance) are well known and thus can be modeled[16]. If the disturbance is an event that is outside the ones that the system is modeled for, the system might not be able to manage the disturbance. This view of resilience thus becomes dependent on its boundaries[16,]. Handmer and Dovers[14] describe this way of viewing resilience as a **reactive resilience** where status quo is strengthened and the idea is to make the present system **resistant to change**. It is also quite common with definitions that view resilience as a combination of bounce back and robustness. Examples of such a definition is to "define resilience as the capacity of a system to prevent a crisis occurrence and, if an event impacts the system, the capacity of the system to absorb the impact and recover rapidly" [15].

Resilience as adaptation to handle surprises

The third view of resilience is to understand it as the ability or capacity to adapt to handle surprises. Woods[16] describes this with the concept "**graceful extensibility**" and describes it as the opposite to brittleness i.e. systems have the ability to stretch to handle surprises that are outside the normal boundaries and do not break down when new challenges occur. When working with this view of resilience, the interesting question is "how do systems stretch to handle surprises?" [16] Compared to the view of resilience as bounce back where the question is more about why or how something bounces back, this view of resilience focuses on how a system performs near and beyond its boundaries. This is also different from the view of resilience as robustness that focuses on the systems performance within its boundaries. The need for clear boundaries and well-modeled systems is therefore not as essential when using this adaptation point of view. When taking resilience as **adaptation** to handle surprises, user perceptions of the world make great differences. Instead of seeing the world as something orderly, mechanical and predictable, the world today is complex, emergent, uncertain and unpredictable. Similarly, the systems we are dealing with are becoming more complex, and the boundaries of the systems are uncertain and changing. Therefore, resilience can be understood as the ability to **manage adaptive capacities** of **complex adaptive systems** or the **adaptive ability in a environment**, where conditions continuously change[16]. This view puts focus on that the system needs to be treated as a whole and the property of a system is not the sum of components and actions.

However, the engineering approach to resilience has some drawbacks. Due to its reactive stance towards resilience it is more applicable to objects that are capable of returning or regaining their original shape after some deformation. The idea of '**equilibrium'** or **'steady state'** indicates that the system does not change over time, which is commonly the case. It is also argued that this view of resilience by focusing on capabilities and resources existing before the rebound to the "steady state" miss to recognize why some organisations are better at recovering or rebounding than others. In addition, that it becomes too focused on specific events and thus not acknowledge that these events represent surprises[16].

Moreover, as this is a broad field, there are significant differences among the **various engineering fields** and this is reflected in their understanding of resilience. If one considers the various sectors of CI, one would find quite different engineering branches to be relevant, e.g. electrical, mechanical,

14 Handmer, J. W., & Dovers, S. R. (1996). A typology of resilience: Rethinking institutions for sustainable development. Organization & Environment, 9(4), 482-511.

15 Labaka, L., Hernantes, J., & Sarriegi, J. M. (2015). A framework to improve the resilience of critical infrastructures. International Journal of Disaster Resilience in the Built Environment, 6(4), 409-423.

16 Woods, D. D. (2015). Four concepts for resilience and the implications for the future of resilience engineering. Reliability Engineering & System Safety 141: 5-9. doi: http://dx.doi.org/10.1016/j.ress.2015.03.018. http://www.sciencedirect.com/science/article/pii/S0951832015000848

civil, chemical, etc. Within these branches there are fundamental differences with respect to the understanding of some related terms.

5.2 Critical infrastructure resilience

5.2.1 Selection of definitions

- A resilient infrastructure is a **component**, **system** or **facility** that is able to withstand damage or disruption, but if affected, can be **readily** and **cost-effectively restored**[17].

- Resilience is: "(a) coordinated **planning** across sectors and networks, (b) **responsive**, **flexible** and **timely recovery measures**, and (c) development of an **organisational culture** that has the ability to provide a minimum level of service during interruptions, emergencies and disasters, and return to full operations quickly"[18].

- Resilience is "the **ability** to reduce the **magnitude** and/or **duration** of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its **ability** to **anticipate**, **absorb**, **adapt** to, and/or **rapidly recover** from a potentially disruptive event"[19].

- The US Department of Homeland Security defines resilience as "the **capacity** of an **asset**, **system**, or **network** to **maintain its function** during or to **recover** from a terrorist **attack** or other **incident**"[20].

- Resilience is the **joint ability** of infrastructure systems to **resist** (**prevent** and **withstand**) any possible hazards, **absorb** the initial damage, and **recover** to normal operation[21].

- Resilience is **capacity** of a system to **prevent** a crisis occurrence, and when a crisis occurs, the **capacity** to **absorb** the impact and **recover rapidly** to the normal state[22].

- Resilience is the **ability** of a system to **recover** from adversity, either back to its **original** state or an **adjusted state** based on new requirements; building resilience requires long-term effort involving reengineering fundamental processes, both technical and social[23]

[17] Critical Thinking: Moving from Infrastructure Protection to Infrastructure Resilience, CIIP Resilience Series Monograph. CIP Program discussion paper series. Virginia: George Mason University

[18] Australian government, Critical Infrastructure Resilience Strategy, 2010. url: http://www.tisn.gov.au/Documents/Australian+Government+s+Critical+Infrastructure+Resilience+Strategy.pdf

[19] National Infrastructure Advisory Council (2009). CRITICAL INFRASTRUCTURE RESILIENCE FINAL REPORT AND RECOMMENDATIONS. url: http://www.dhs.gov/xlibrary/assets/niac/niac_critical_infrastructure_resilience.pdf

[20] US Department of Homeland Security, National infrastructure protection plan, partnering to enhance protection and resiliency, 2009.

[21] Ouyang M., Dueñas-Osorio, L. & Min, X. (2012). A three-stage resilience analysis framework for urban infrastructure systems, Structural Safety, Volumes 36–37, May–July 2012, Pages 23-31, ISSN 0167-4730, http://dx.doi.org/10.1016/j.strusafe.2011.12.004.

[22] Labaka, L., Hernantes, J., & Sarriegi, J. M. (2015). Resilience framework for critical infrastructures, International Journal of Disaster Resilience in the Built Environment, vol. 6(4).

[23] J.A. McCarthy (2007). From protection to resilience: injecting 'Moxie' into the infrastructure security continuum. Critical Infrastructure Protection Program at George Mason University School of Law, Arlington, VA.

- The overarching goal of a system is to **continue to function** to the fullest possible extent in the face of stress to **achieve its purpose**, where resilience is a **function** of both the **vulnerability** of the system and its **adaptive capacity**[24].

- Similarly, the objective of resilience is to retain predetermined dimensions of **system performance** and **identity or structure** in view of forecasted scenarios[25].

- [A resilience assessment framework] should encompass the following attributes:

    - **Systems structure** (the physical static parameters of the infrastructure, i.e. design and topology parameters of the system),

    - **Systems dynamic** (the dynamic behavior of the infrastructure systems, e.g. emergency preparedness, response management, and recovery activities) and

    - **Human and Organizational capacities** (human and organizational factors whose contributions are essential to the overall infrastructure resilience)."[26]

- The "**operability state** [of each infrastructure component], when exposed to the effects of a critical event affecting the network, depends on the following factors:

    - its **static resilience** (the ability to continue its operation despite the event)

    - its **dynamic resilience** (the ability to promptly recover to a serviceable status after the impacting event.)"[27].

5.2.2 Discussion

Most definitions refer to an infrastructure component, system or network, and they fall usually under the technological dimension of resilience. Technical resilience views and analyses resilience from engineering approach point of view and therefore is closely related to the concept of engineering resilience already discussed. In the context of CI, technical resilience refers to the ability of all the physical components within a particular CI facility to **retain** and/or **restore** the **functionality** after some disturbing event as soon as possible.

Most of the definitions found refer to the importance of preserving key societal functions, as maintaining a minimum level of such services ensures that significant impacts do not occur (see definition of a CI). This is the reason why in this field, a key parameter to be examined and associated with resilience is the **performance** of the system and its acceptable level of **degradation** or **inoperability**. Resilience is addressed under this view as a system attribute or characteristic that needs

[24] Dalziell, E., McManus, S. (2004). Resilience, vulnerability, and adaptive capacity: implications for system performance. Presented at the International Forum for Engineering Decision Making (IFED), Stoos, Switzerland. December 6–8, 2004.

[25] Francis, R. & Bekera, B. (2014). A metric and frameworks for resilience analysis of engineered and infrastructure systems. Reliability Engineering & System Safety, 121 (January), 90–103. http://dx.doi.org/10.1016/j.ress.2013.07.004

[26] Alsubaie, A., Alutaibi, K., & Marti, J. (2015). Resilience Assessment of Interdependent Critical Infrastructure, In Rome, E., Theocharidou, M., & Wolthusen, S. (eds.) Proceedings of CRITIS 2015 , Critical Information Infrastructure Security, LNCS-9578, pp 43-55, Springer Berlin Heidelberg.

[27] Galbusera, L., Azzini, I., & Giannopoulos, G. (2015). A methodology for resilience optimisation of interdependent critical infrastructures. In Rome, E., Theocharidou, M., & Wolthusen, S. (eds.) Proceedings of CRITIS 2015, Critical Information Infrastructure Security, LNCS- 9578, pp 56-66, Springer Berlin Heidelberg.

to be measured, strengthened or achieved. However, this approach faces the problem that the performance level differs for each type of infrastructure system examined. This makes the definition of resilience for critical infrastructures even more complex.

Looking at the different definitions and approaches, one can notice commonalities and differences. In a recent review of the terminology[26], the authors observe that properties such as '**ability to recover**' and '**ability to adapt**' were incorporated in several definitions. Some consider the long term resilience by including a **planning** component, referring to 'building resilience' by reengineering fundamental processes, both technical and social[28]. Others think about resilience as **an emerging behavior** after a disturbance. They also observe that most include '**the ability to withstand**' or '**absorb'** a disturbance as a key attribute. However, some argue that this attribute is the definition of '**survivability'** while resilience is the '**ability to bounce back'**.

In another review of resilience concepts used for critical infrastructures[25], observe the evolution in the resilience concept and also conclude that the definitions seem to converge "in the direction of a common definition, as these definitions share several common elements: **absorptive capacity**, **recoverability** (or **restorative capacity**), **adaptive capacity**, and **retention of identity** (structure and functions[29]). The three identified resilience capacities[30], i.e. **absorptive, adaptive,** and **restorative** capacities are at the center of these approaches and are linked with the various stages of typical infrastructure **response cycle** to disruption (before, during and after the event). The time to recovery is sometimes viewed separately from restorative capacity.

However, most approaches in the field highlight the importance of **dependencies** and a **'systems-of-systems' approach**. [26,31] In this respect, proposed resilience concepts need to incorporate CI interdependencies, considering the cascade of a failure through multiple CIs, even though this is not currently reflected in most definitions.

5.3 Ecological resilience

5.3.1 Selection of definitions

- Resilience is the amount of **stress** or **disturbance** that can be sustained before a **change** in system **control** and **structure** occurs.[32]

- Resilience is an emergent **property** of **ecosystem** and is related to **self-organized behaviour** of those ecosystems **over time**. [33]

[28] McCarthy, J.A. (2007). From protection to resilience: injecting 'Moxie' into the infrastructure security continuum. Critical Infrastructure Protection Program at George Mason University School of Law, Arlington, VA.

[29] Two approaches are observed, i.e. structure-based vs. performance-based.

[30] Ouyang M., & Dueñas–Osorio, L. (2014). Multi-dimensional hurricane resilience assessment of electric power systems. Structural Safety, 48 (May), 15–24. http://dx.doi.org/10.1016/j.strusafe.2014.01.001.
Ouyang M., Dueñas–Osorio, L. & Min, X. (2012). A three–stage resilience analysis framework for urban infrastructure systems. Structural Safety, 36–37 (May–July), 23–31. http://dx.doi.org/10.1016/j.strusafe.2011.12.004
Francis, R. & Bekera, B. (2014). A metric and frameworks for resilience analysis of engineered and infrastructure systems. Reliability Engineering & System Safety, 121 (January), 90–103. http://dx.doi.org/10.1016/j.ress.2013.07.004

[31] Ouyang, M. (2014). Review on modeling and simulation of interdependent critical infrastructure systems. *Reliability Engineering & System Safety*, 121 (January), 43–60. http://dx.doi.org/10.1016/j.ress.2013.06.040

[32] Holling, C. S. (1973). Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics, 4, 1–23.
Holling, C. S. (1996). Engineering resilience versus ecological resilience. In P. Schulze (eds.). Engineering Within Ecological Constraints. National Academy Press, Washington DC.

[33] Gunderson,L. H. (2000). Ecological Resilience - In Theory and Application. Annu. Rev. Ecol. Syst., 31, 425-439

- The measurement of ecological resilience is the **magnitude** of **disturbance** that can be **absorbed** before a system changes the variables and processes that control its behaviour. [32]

5.3.2 Discussion

Ecological resilience assumes that stability domains are multiple and variable. The outlined definitions indicate that it focuses on persistence and robustness of a certain ecological system. Ecological resilience is a way to understand nonlinear dynamics, such as the processes by which ecosystems maintain themselves in the face of perturbations and change.[34]

There is also a close link between the resilience of ecological and social systems.

5.4 Social-ecological resilience

5.4.1 Selection of definitions

- Resilience is the amount of change that the system can undergo and retain the same controls on structure and function, the degree to which the system is capable of self-organization, and the degree to which the system can build the capacity to learn and adapt. [35] It is a phenomenon that has three main characteristics:

    1. the amount of change the system can undergo and still remain within the same domain of attraction, meaning that it retains the same controls on structure and function,

    2. the degree to which the system is capable of self-organizing versus lack of organization, or organization forced by external factors, and

    3. the degree to which the system can build the capacity to learn and adapt.

- The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks.[36]

- The three crucial aspects of resilience are[37]:

    1. latitude (maximum amount a system can be changed before losing its ability to recover),

    2. resistance (the ease or difficulty of changing the system), and

    3. and precariousness (how close current state of the system is to a limit or threshold).

[34] Gunderson, L. H. (2003). Adaptive dancing: Interactions between social resilience and ecological crises". In F. Berkes, J. Colding and C. Folke (eds.) Navigating Social-Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge, UK

[35] Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From Metaphor to Measurement: Resilience of What to What? Ecosystems, 4(8), 765–781. http://doi.org/10.1007/s10021-001-0045-9

[36] Walker, B., Gunderson, L. Kinzig, A., Folke, C., Carpenter, S., & Schultz, L. (2006). A handful of heuristics and some propositions for understanding resilience in social-ecological systems. Ecology and Society, 11(1).

[37] Walker, B., Holling, C.S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. Ecology and Society, 9(2).

A fourth aspect of resilience is panarchy (a nested set of adaptive cycles operating at discrete ranges of scale).[38] Panarchy is about how longitude, resistance and precariousness are influenced by the states and dynamics of the (sub)systems at scales above and below the scale of interest. [37]

5.4.2 Discussion

The above outlined definitions indicate that social-ecological concept of resilience incorporates not only system's capacity to persist, but also its ability to adapt, learn, and self-organise. In this case, resilience is a process which has a futuristic dimension due to the fact that adaptation occurs in the post disturbance phase as a strategy to mitigate future disturbances.[39] Instead of seeing resilience as a 'bounce back' phenomenon, it is seen as a 'bounce forward' process.[40]

The most recent advancement in the theory of social-ecological resilience is the notion of **transformation**. Contrary to **adaptation**, where the system shifts to a different state within the same regime, in the case of transformation, the system can transform to a new regime altogether.[41] Due to the existence of human factor in social-ecological resilience, the concepts of **adaptability** and **transformability** are important for understanding self-organisation in social-ecological systems. Adaptability is described as the collective capacity of human actors in the system to manage and build resilience through collective action.[37] Accordingly, transformability is the capacity to create an entirely new stability landscape. [37]

5.5 Community resilience

5.5.1 Selection of definitions

- Resilience refers to the existence, development, and engagement of **community resources** by community members to thrive in an environment characterized by **change**, **uncertainty**, **unpredictability**, and **surprise**. [42]

- Resilience as the ability of **social system** to **respond** and **recover from** disasters and include those **inherent conditions** that allow the system to **absorb impacts** and **cope** with an event, as well as post-event, **adaptive process** that facilitates the ability of the social system **to re-organize, change and learn in response to threat**[43]. Six dimensions of community resilience are identified: ecological, social, economic, institutional, infrastructure, and community competence.

[38] Gunderson & Holling 2002Gunderson, H. L., & Holling, C. S. (2002). Panarchy: Understanding Transformations in Human and Natural Systems. A Synopsis of the Seminal Work From Islands Press, Washington DC.; Allen, C. R., Angeler, D. G., Garmestani, A. S., Gunderson, L. H., & Holling, C. S. (2014). Panarchy: Theory and Application. Ecosystems, 17(4, 578-589. http://doi.org/10.1007/s10021-013-9744-2) et al. 2014

[39] Manyena, S. B. (2009). Disaster Resilience in Development and Humanitarian Interventions. University of Northumbria. Retrieved from: http://nrl.northumbria.ac.uk/661/

[40] Manyena, S. B., O'Brien, G., O'Keefe, P., & Rose, J. (2011). Disaster resilience: a bounce back or bounce forward ability? Local Environment, 16(5), 417-424. http://doi.org/10.1080/13549839.2011.583049

[41] Davidson, D. J. (2010). The Applicability of the Concept of Resilience to Social Systems: Some Sources of Optimism and Nagging Doubts. *Society & Natural Resources*, *23*(12), 1135–1149. http://doi.org/10.1080/08941921003652940

[42] Magis, K. (2010). Community Resilience: An Indicator of Social Sustainability. Society & Natural Resources: An International Journal, 23(5), 401–416. http://doi.org/10.1080/08941920903305674

[43] Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global Environmental Change, 18(4), 598-606. http://doi.org/10.1016/j.gloenvcha.2008.07.013, p. 599

- Resilience is the collective ability of **neighbourhood** or **geographically defined area** to deal with stressors and efficiently resume the rhythms of daily life through cooperation following shocks. [44]

- Resilience is the **community's** or **region's capability** to **prepare for**, **respond to**, and **recover from** significant **multi-hazard threats** with minimum danger to **public safety and health**, the **economy** and **national security**. [45]

- Resilience as the **national security adaptive** and **learning capacity** of **communities** to **self-organize** in a way that maintains system **function** in the face of **change** or in response to **disturbance**. [46] (Note: Emphasis on adaption)

- Community **seismic** resilience as the ability of social units to **mitigate** hazards, **contain** the **effects** of disasters when they occur, and carry out **recovery** activities in ways that minimize social disruption and mitigate effects of future earthquakes.[10]

- Resilience is perceived as the **process** that leads to **adaption** (not an outcome, not stability). A process linking a set of **networked adaptive capacities** (resources) to a positive trajectory of **functioning** and **adaption** in constituent populations after disturbance.[47]

- Resilience is the ability of locals to **withstand** a natural disaster without suffering devastating losses, damage, diminished productivity, or quality of life, and importantly without much assistance from the outside communities[48]

5.5.2 Discussion

As it is evident from the above outlined definitions, the concept of community resilience is primarily concerned with community-level processes. Community resilience raises several definitional challenges. First of all, the definition is complicated by the variation in the meaning of community per se. Secondly, the terms of community and **social resilience** are often used as synonyms.[49]

[44] Alderich, P. D., & Meyer, A. (2015). Social Capital and Community Resilience. American Behavioral Scientist, 59(2), 254-269. http://doi.org/10.1177/0002764214550299, p.255

[45] Colten, C. E., Kates, R. W., & Laska, S. B. (2008). Three years after Katrina: Lessons for Community Resilience. Environment, 50(5), 36-47.

[46] Boon, H. J., Cottrell, A., Stevenson, R. B., & Millar, J. (2012). Bronfenbrenner's bioecological theory for modelling community resilience to natural disasters. Natural Hazards, 60(2), 381-408. http://doi.org/10.1007/s11069-011-0021-4; Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global Environmental Change, 18(4), 598-606. http://doi.org/10.1016/j.gloenvcha.2008.07.013; Maclean, K., Cuthill, M., & Ross, H. (2014). Six attributes of social resilience. Journal of Environmental Planning and Management, 57(1), 144-156. http://doi.org/10.1080/09640568.2013.763774; Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., … Von Winterfeldt, D. (2003). A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. *Earthquake Spectra*, *19*(4), 733–752. http://doi.org/10.1193/1.1623497

[47] Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness. *American Journal of Community Psychology*, 41(1-2), 127–150. http://doi.org/10.1007/s10464-007-9156-6

[48] Zhou, H., Wang, J., Wan, J., & Jia, H. (2010). Resilience to natural hazards: A geographic perspective. *Natural Hazards*, *53*(1), 21–41. http://doi.org/10.1007/s11069-009-9407-y

[49] Boon, H. J., Cottrell, A., King, D., Stevenson, R. B., & Millar, J. (2012). Bronfenbrenner's bioecological theory for modelling community resilience to natural disasters. *Natural Hazards*, *60*(2), 381–408. http://doi.org/10.1007/s11069-011-0021-4

Community resilience is a **multidimensional** concept, thus it is further complicated by diverse set of dimensions described throughout the resilience literature. Community resilience has been described as having six dimensions: ecological, social, economic, institutional, infrastructure, community competence[43]; four dimensions: economic, social, organisational, technical[10]; or three dimensions: social, ecological, and economic[50].

Community resilience paradigm centers on the assumption that communities are primary active agents in creating their own resilience and general well-being.[51]

Resilience prevents **disaster-related health or mental problems** of community members.[52]

Finally, resilience is related to effective **organisational behavior** and **disaster management**. [53]

5.6 Social resilience

5.6.1 Selection of definitions

- **Ability** of **human groups** or **communities** to **cope** with external stresses and disturbances as a result of **social**, **political** and **environmental change**.[54]

- The way in which **individuals**, **communities** and **societies adapt**, **transform**, and **potentially become stronger** when faced with environmental, social, economic or political **changes**. [55]

[50] Wilson, A. G. (2012). Community Resilience and Environmental Transitions. Routledge.

[51] Magis, K. (2010). Community Resilience: An Indicator of Social Sustainability. *Society & Natural Resources: An International Journal*, *23*(5), 401–416. http://doi.org/10.1080/08941920903305674

[52] Kaniasty, K. & Norris, F. (1993). A test of the social support deterioration model in the context of natural disaster. *Journal of Personality and Social Psychology*, 64, 395-408.; Kimhi, S., & Shomai, M. (2004). Community resilience and the impact of stress: Adult response to Israel's withdrawal from Lebanon. *Journal of Community Psychology*, *32*(4), 439–451. http://doi.org/10.1002/jcop.20012

[53] Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global Environmental Change, 18(4), 598-606. http://doi.org/10.1016/j.gloenvcha.2008.07.013; Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness. *American Journal of Community Psychology*, *41*(1-2), 127–150. http://doi.org/10.1007/s10464-007-9156-6

[54] Adger, W. N. (2000b). Social and ecological resilience: are they related? Progress in Human Geography, 24(3), 347–364. http://doi.org/10.1191/030913200701540465
Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. Global Environmental Change, 16(3), 253–267. http://doi.org/10.1016/j.gloenvcha.2006.04.002
Furedi, F. (2007). The changing meaning of disaster. Area, 39(4), 482–489. http://doi.org/10.1111/j.1475-4762.2007.00764.x
Marshall, N. A. (2007). Can policy perception influence social resilience to policy change? Fisheries Research, 86(2-3), 216–227. http://doi.org/10.1016/j.fishres.2007.06.008
Marshall, N. A. (2010). Understanding social resilience to climate variability in primary enterprises and industries. Global Environmental Change, 20(1), 36–43. http://doi.org/10.1016/j.gloenvcha.2009.10.003
Schwarz, A.-M., Béné, C., Bennett, G., Boso, D., Hilly, Z., Paul, C., … Andrew, N. (2011). Vulnerability and resilience of remote rural communities to shocks and global changes: Empirical analysis from Solomon Islands. Global Environmental Change, 21(3), 1128–1140. http://doi.org/10.1016/j.gloenvcha.2011.04.011
Voss, M. (2008). The vulnerable can't speak. An integrative vulnerability approach to disaster and climate change research. Behemoth: A Journal on Civilisation, 1(03), 39–56. http://doi.org/10.1524/behe.2008.0022

[55] Cutthill, M., Ross, H., Maclean, K., Owens, K., & Witt, B. (2008). Reporting Social Outcomes of Development: An Analysis of Diverse Approaches. *The International Journal of Interdisciplinary Social Science*, 3, 145-158., p. 146

- [Resilience refers to] the **adaptive** and **learning capacity** of individuals, groups and institutions to **self-organise** in a way that maintains system function in the face of some change or in response to any disturbance. [56]

- Social resilience is comprised of three dimensions[57]:

    - **coping** capacities - the ability of social actors to cope with and overcome all kinds of adversities;

    - **adaptive** capacities - their ability to learn from past experiences and adjust themselves to future challenges in their everyday lives;

    - **transformative** capacities - their ability to craft sets of institutions that foster individual welfare and sustainable societal robustness towards future crises

5.6.2 Discussion

These definitions indicate that social resilience is a **dynamic process** and **multiple equilibriums** are possible. However, application of the concept of resilience to social domain is rather problematic due to the high complexity of social systems.[58] Some researchers even suggest avoiding using the notion of social resilience.[59] Moreover, there is a lot of overlapping between the concepts of social and **community resilience**.

Social resilience is composed of a diverse set of components. **Learning** and **flexibility** are seen as the two components composing the core of social resilience as it is the ability of human systems to learn and institute individual and institutional adjustments that segregates them from ecological systems.[60] Other researchers argue that **social capital** (including trust and social networks) and **social memory** (including experience for dealing with change) are essential for the capacity of human systems to adapt and shape change.[61] In order to build adaptive potential of the society, the presence of supportive institutional framework is necessary.[62]

The most recent research within the school of social resilience suggests that **knowledge** and **culture** should also be taken into account when analysing social resilience.[63]

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[56] Maclean, K., Cuthill, M., & Ross, H. (2014). Six attributes of social resilience. *Journal of Environmental Planning and Management*, *57*(1), 144–156. http://doi.org/10.1080/09640568.2013.763774, p.145

[57] Keck, M., & Sakdapolrak, P. (2013). What is social resilience? lessons learned and ways forward. Erdkunde, 67(1), 5–19. http://doi.org/10.3112/erdkunde.2013.01.02

[58] Cannon, T., & Müller-Mahn, D. (2010). Vulnerability, resilience and development discourses in context of climate change. Natural Hazards, 55(3), 621–635. http://doi.org/10.1007/s11069-010-9499-4

[59] Duit, A., Galaz, V., Eckerberg, K., & Ebbesson, J. (2010). Governance, complexity, and resilience. *Global Environmental Change*, *20*(3), 363–368. http://doi.org/10.1016/j.gloenvcha.2010.04.006

[60] Sapountzaki, K. (2007). Social resilience to environmental risks: A mechanism of vulnerability transfer? *Management of Environmental Quality: An International Journal*, *18*(3), 274–297. http://doi.org/10.1108/14777830710731743
Adger, W. N. (2000a). Indicators of social and economic vulnerability to climate change in Vietnam. Retrieved from http://cleanairasia.org/portal/system/files/69516_paper.pdf
Colten, C. E., & Sumpter, A. R. (2009). Social memory and resilience in New Orleans. *Natural Hazards*, *48*(3), 355–364. http://doi.org/10.1007/s11069-008-9267-x

[61] Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change*, *16*(3), 253–267. http://doi.org/10.1016/j.gloenvcha.2006.04.002

[62] Pelling, M. (2003). The vulnerability of cities: Natural disasters and social resilience. Earthscan.

[63] Furedi, F. (2007). The changing meaning of disaster. *Area*, *39*(4), 482–489. http://doi.org/10.1111/j.1475-4762.2007.00764.x

Other researchers argue that the evolution of the concept of resilience in natural sciences makes it inadequate and even false to be transferred to social phenomena[58].

5.7 Economic resilience

5.7.1 Selection of definitions

- Resilience is the **ability** or **capacity** of a system to **absorb** or **cushion itself** against damage or loss"[64].

- Resilience is the **capacity** to **reduce direct** and **indirect** economic **losses** resulting from disaster.[10]

- [A resilience economy is] responding to an external shock by **sustaining a stable state or path growth**, which implies **resistance to the shock**, or by **recuperating** from a downturn and **returning rapidly to a pre-shock equilibrium** state or path growth[65].

- Economic resilience could be divided into[66]:

    - **Static** economic resilience is the **ability** of a system to **maintain function** when shocked. It pertains to making the best of the existing capital stock.

    - **Dynamic** economic resilience implies the **speed of recovery from a shock**. It refers to the efficient utilization of resources for repair and reconstruction, and focuses on enhancing system's capacity.

5.7.2 Discussion

These definitions indicate that resilience in economic terms translates to the **minimization of losses** and **rapid recovery**. Moreover, the **equilibrium** approach is also applied in the field (see engineering resilience). The idea of static and dynamic attributes of resilience that we observed on infrastructure approaches is also applied in the field.

As it is evident from the definitions, economic resilience can take place at **microeconomic**, **mesoeconomic**, and **macroeconomic** level. Consequently, economic resilience is a rather diverse concept, which contains such aspects as economic flexibility, diversity, household income, business size, etc.

Marshall, N. A. (2007). Can policy perception influence social resilience to policy change? *Fisheries Research*, *86*(2-3), 216–227. http://doi.org/10.1016/j.fishres.2007.06.008
Voss, M. (2008). The vulnerable can't speak. An integrative vulnerability approach to disaster and climate change research. *Behemoth: A Journal on Civilisation*, *1*(03), 39–56. http://doi.org/10.1524/behe.2008.0022

64 Rose, A. (2004). Defining and measuring economic resilience to disasters. Disaster Prevention and Management, 13(4), 307–314. http://doi.org/10.1108/09653560410556528
Rose, A. (2006). Economic resilience to disasters: towards a consistent and comprehensive formulation. In D. Paton and D. Johnston (eds.). Disaster Resilience: An Integrated Approach. Charles C. Thomas, Springfield, IL."

65 Xiao, Y., & Drucker, J. (2013). Does Economic Diversity Enhance Regional Disaster Resilience? Journal of the American Planning Association, 79(2), 148–160. http://doi.org/10.1080/01944363.2013.882125

66 Rose, A., & Krausmann, E. (2013). An economic framework for the development of a resilience index for business recovery. International Journal of Disaster Risk Reduction, 5, 73–83. http://doi.org/10.1016/j.ijdrr.2013.08.003

5.8 Organisational resilience

5.8.1 Selection of definitions

- According to ISO, resilience is the adaptive capacity of an organization in a complex and changing environment. [67] The ISO 28002:2011 standard notes that:

  > Resilience is the **ability** of an **organisation** to **prevent** or **resist being affected** by an event or the **ability to return to an acceptable level of performance** in an **acceptable period time** being affected by an event.[68]

- Organizational resilience is the **ability** of an **organization** to **anticipate**, **prepare for**, and **respond and adapt to incremental change** and **sudden disruptions** in order to **survive** and **prosper**. [69]

- Resilience refers **to maintenance of positive adjustments** under some challenging conditions such that the organisation emerges from these conditions **strengthened** and more **resourceful**. [70]

- Resilience is the **capacity** of **people** and **systems** that facilitate organisational **performance** to **maintain functional relationships** in the presence of some significant **disturbance** as a result of **capability** to **draw upon their resources** and **competences** to manage the **demands**, **challenges** and **change** encountered. [71]

- Resilience is the **capability** of an organisation that is responsible for **operating critical emergency functions** to take **action** and induce **decision making**. [72]

- Resilience is the **capacity of organisations** that manage **critical facilities** and have the responsibility for carrying out critical disaster-related functions to make decisions and take actions that contribute to achieving the properties of resilience, that is, that help to achieve g**reater robustness, redundancy, resourcefulness, and rapidity**. [10]

- Resilience is a function of an organisation's overall situation awareness, keystone vulnerability and adaptive capacity in a complex, dynamic and interconnected environment. [73]

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67 ISO Guide 73:2009, Risk management – Vocabulary.

68 ISO 28002:2011, Security management systems for the supply chain -- Development of resilience in the supply chain -- Requirements with guidance for use.

69 BS 65000:2014 Guidance on organizational resilience.

70 Vogus, T. J., & Sutcliffe, K. M. (2007). Organizational resilience: Towards a theory and research agenda. Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics, 3418–3422. http://doi.org/10.1109/ICSMC.2007.4414160

71 Paton, D.,& Hill, R. (2006). Managing Company Risk and Resilience Through Business Continuity Management. In D. Paton and D. Johnston (eds.). "Disaster Resilience: An Integrated Approach. Charles C. Thomas, Springfield, IL.

72 Jung, K., & Song, M. (2015). Linking emergency management networks to disaster resilience: bonding and bridging strategy in hierarchical or horizontal collaboration networks. Quality & Quantity, 49(4), 1465–1483. http://doi.org/10.1007/s11135-014-0092-x

73 McManus, S. (2008). Organisational Resilience in New Zealand. University of Catenbury. Retrieved from http://ir.canterbury.ac.nz/bitstream/10092/1574/1/thesis_fulltext.pdf

- Resilient organisation is the one which is able to design and implement effective actions to advance organisational development and ensure survival. [74]

- Organisational resilience is concerned with the development of suitable business development plans (short-term plans) to resume disrupted critical operations of an organisation to their minimum asseptable operating levels as quickly and efficiently as possible and disaster recovery plans (long-term plans) to restore all disrupter operations to their normal operating levels following any disruptive event. [75]

5.8.2 Discussion

Organisational resilience relates to the **organisations** and **institutions** that manage the **physical components of the systems**. [76] Organisational resilience includes institutions and organisations and requires assessments of the physical properties of organisations such as members, communications technology, and number of emergency assets (e.g. vehicles, hospital beds, etc.). [43]

The outlined definitions indicate that the prevailing objective of resilience is the ability of an organisation to survive certain disturbance or shock. [77] However, organisational resilience implies adaptive process encouraging positive adjustments in the composition of organisations.

Some of the outlined definitions draw a close link between organisational and critical infrastructure resilience, especially the ones that refer to the resilience of critical facilities.

Yet others draw a close link between organisational resilience and business continuity by arguing that business continuity as a discipline has organisational resilience as its objective.[78]

5.9 Resilience definitions in national policies and international organisations

These definitions cannot be categorised easily to one type of resilience concept, as they encompass several of them.

5.9.1 Selection of definitions

- Resilience is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.[79] **(UNISDR)**

[74] Mallak, L. (1998). Putting Organisational Resilience to Work. Industrial Management, 40(6), 8–13.

[75] Losada, C., Scaparra, M. P., & O'Hanley, J. R. (2012). Optimizing system resilience: A facility protection model with recovery time. European Journal of Operational Research, 217(3), 519–530. http://doi.org/10.1016/j.ejor.2011.09.044

[76] Tierney, K., & Bruneau, M. (2007). Conceptualizing and Measuring Resilience: A Key to Disaster Loss Reduction. TR News, 14–18. Retrieved from http://onlinepubs.trb.org/onlinepubs/trnews/trnews250_p14-17.pdf

[77] Mallak, L. (1998). Putting Organisational Resilience to Work. Industrial Management, 40(6), 8–13.

[78] Jordan, T., & Alcantara, P. (2014). Conceptualising organisational resilience. Retrieved from: http://static.ow.ly/docs/BCIWorkingPaper3_2JOq.pdf

[79] 2009 UNISDR Terminology on Disaster Risk Reduction, United Nations International Strategy for Disaster Reduction (UNISDR), Geneva, Switzerland, May 2009.

- Resilience is the ability of government, communities, businesses and individuals to "prepare for, respond to, and manage potential hazards and disasters, thereby minimising impacts and rapidly recovering to emerge stronger and better able to cope with future disaster events[80]." **(Australia)**

- **Resilience** is how we withstand, adapt and 'bounce back' in response to a disaster. A resilient community is one which expects and is well prepared for an adverse event; they can cope well with the disruption and recover quickly. Everyone has a role to play in creating a resilient community.[81] **(New Zealand)**

- **Resilience** is an "adaptive capacity" — that is, society's capability to draw on its individual, collective and institutional resources and competencies to cope with, adapt to and develop from the demands, challenges and changes encountered before, during and after a disaster.[82] **(New Zealand)**

- **Community resilience** is the capability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change. This is consistent with WREMO's vision statement: A resilient community, ready and capable.[83] **(New Zealand)**

- Resilience is the capacity of a system, community or society to adapt to disturbances resulting from hazards by persevering, recuperating or changing to reach and maintain an acceptable level of functioning. Resilient capacity is built through a process of empowering citizens, responders, organizations, communities, governments, systems and society to share the responsibility to keep hazards from becoming disasters. Resilience minimizes vulnerability; dependence and susceptibility by creating or strengthening social and physical capacity in the human and built-environment to cope with, adapt to, respond to, and recover and learn from disasters.[84] **(Canada)**

- Resilience is "the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies. Whether it is resilience towards acts of terrorism, cyber-attacks, pandemics, and catastrophic natural disasters, our national preparedness is the shared responsibility of all levels of government, the private and nonprofit sectors, and individual citizens".[85] **(U.S.)**

- Resilience is "the capacity of an asset, system, or network to maintain its function during or to recover from a terrorist attack or other incident". [20]**(U.S.)**

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80 Queensland Government. "Queensland Strategy for Disaster Resilience; to make Queensland the most disaster resilient Statein Australia." Available at: http://www.dilgp.qld.gov.au/resources/plan/local-government/queensland-strategy-or-disaster-resilience.pdf. Accessed 26 October 2015.

81 Hawke´s Bay Civil Defence Emergency Management Group Plan 2014-2019

82 Canterbury CDEM Group plan

83 Wellington region , Community resilience strategy

84 Ministers responsible for emergency management, 2011. An Emergency Management Framework for Canada.

85 DHS (2015b) Resilience, Available at: http://www.dhs.gov/topic/resilience (accessed 26 October, 2015).

- Resilience refers to "the ability of systems, infrastructures, government, business, and citizenry to **resist**, **absorb**, **recover from**, or **adapt to** an adverse occurrence that may cause harm, destruction, or loss of national significance". [86] **(U.S.)**

5.9.2 Discussion

The above list of definitions is not complete, one can identify further approaches in the deliverable D1.1. International Survey.

One observation that can be drawn is that they usually refer to the regional or national importance of resilience, especially in the case of disasters or incidents. They link this goal to all other resilience concepts, including CIR.

6 Other related terms

6.1.1 Absorption

(Alternatively: absorbability, absorptive capacity)

The degree to which a system can absorb the impacts of system perturbations and minimize consequences with little effort. [25]

Similarly, the degree to which the system absorbs the impacts of initial damage and minimizes the consequences, such as cascading failures. [21]

Note: This concept is closely related to system robustness and reliability.

6.1.2 Adaptation

(alternatively: adaptability, adaptive capacity)

System's ability to alter non-essential attributes to adapt in order to survive.[87]

The ability of a system to adjust to undesirable situations by undergoing some changes. [25]

Resilience adaptability is perceived as the collective capacity of the human actors in a system to manage and build resilience through collective action. [37]

6.1.3 Cascade order

The cascade order is the number of stages in a propagation from a directly impacted system to a particular system that is impacted indirectly (for example, an event propagating from one originating

[86] DHS Risk Steering Committee, "U.S. Department of Homeland Security Risk Lexicon," United States Department of Homeland Security. Washington DC; 2008

[87] Giroux, J., & Prior, T. (2012). Expressions of Resilience: From " Bounce Back " to Adaptation. 3RG REPORT Factsheet. Zurich, Switzerland. Retrieved from: http://www.css.ethz.ch/publications/pdfs/Risk_and_Resilience_Report_Practical_Application_of_Resilience_2014.pdf.
Manyena, B. S. (2006). The concept of resilience revisited. Disasters, 30(4), 433–450.
Manyena, B. S. (2009). Disaster Resilience in Development and Humanitarian Interventions. University of Northumbria.
Davidson, D. J. (2010). The Applicability of the Concept of Resilience to Social Systems: Some Sources of Optimism and Nagging Doubts. Society & Natural Resources, 23(12), 1135–1149. http://doi.org/10.1080/08941921003652940"

system to one dependent system represents a first order cascading effect, while the event would be referred to as a second order cascading effect if the same event would further propagate to yet another system) [88].

6.1.4 Cascading effect

A cascading failure or effect occurs when a disruption in one infrastructure causes the failure of a component in a second infrastructure or asset, which subsequently causes a disruption in the second infrastructure[89].

Cascading effects are the impacts of an initiating event where[88]:

1. System dependencies lead to impacts propagating from one system to another system, and;

2. The combined impacts of the propagated event are of greater consequences than the root impacts, and;

3. Multiple stakeholders and/or responders are involved.

6.1.5 Crisis

Situation with high level of uncertainty that disrupts the core activities and/or credibility of an organization and requires urgent action.[90]

6.1.6 Community

A place designated by geographical boundaries that functions under the jurisdiction of a governance structure, such as a town, city, or county. It is within these places that people live, work, play, and build their futures. [91]

Note: FEMA refers to the term of "Whole Community"[92]:

- Individuals and families, including those with access and functional needs
- Businesses
- Faith-based and community organizations
- Nonprofit groups
- Schools and academia
- Media outlets
- All levels of government, including state, local, tribal, territorial, and federal partners

[88] van Heuverswyn, K.(editor), Report on scenarios to be elaborated for testing the incident evolution methodology (D1.4), www.CascEff.eu

[89] Rinaldi, S., J. Peerenboom, and T. Kelly (2001). Identifying, understanding and analysing critical infrastructure interdependencies. IEEE Control Systems Magazine, pp. 11–25.

[90] ISO (2012) ISO 22300:2012(en) Societal security — Terminology

[91] NIST Special Publication 1190, Community Resilience Planning Guide for Buildings and Infrastructure Systems, Volume I, U.S. Department of Commerce, October 2015.

[92] https://www.fema.gov/whole-community-0

6.1.7 Consequence

The outcome of an event affecting objectives. [93]

Note[1]: The term "consequence" is not well-defined in the literature and confusion arises when compared to the terms "impact", "harm" or "effect". For example, the ISO definition found above is very general and does not distinguish between consequences for critical infrastructure, for people, for the environment, or for the economy. Such distinctions are required for two reasons:

- For the CIP domain, consequences for critical infrastructure are of supreme importance, and other consequences may be ignored for certain applications (for example, when assessing the consequences of cascading effects).
- For consequence analysis in the meaning of the ECI directive, assessment of consequences for people, the environment and the economy is needed according to the cross-cutting criteria mentioned there.

6.1.8 Critical Infrastructure

Asset, system or part thereof located Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions[94].

6.1.9 Critical Infrastructure Protection

All activities aimed at ensuring the functionality, continuity and integrity of critical infrastructures in order to deter, mitigate and neutralise a threat, risk or vulnerability. [94]

6.1.10 Dependency

Dependency is a uni-directional relationship of two infrastructures through which the state of the depending infrastructure is influenced by or is correlated to the state of the other.

Note: The terms interdependency and dependency are often used in the CIP literature as synonymous. See also interdependency.

6.1.11 Dependent / Impacted system

A dependent or impacted system is a system that is negatively affected by either an initiating event or an originating system[88].

6.1.12 Disaster

A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

[93] ISO/IEC 27000:2014, Information technology -- Security techniques -- Information security management systems -- Overview and vocabulary.
ISO/IEC 31000:2009, Risk management -- Principles and guidelines.

[94] Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection.

Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences. Disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation[79].

6.1.13 Emergency

Major emergency means any situation which has or may have an adverse impact on people, the environment or property and which may result in a call for assistance under the Mechanism. [95]

Note: Mechanism refers to a Community Mechanism to facilitate reinforced cooperation between the Community and the Member States in Civil Protection assistance intervention in the event of major emergencies, or the imminent threat thereof, is hereby established.

6.1.14 Event

An event is a singular instance of a phenomenon negatively affecting a system[88].

Note: See also incident.

6.1.15 Exposure

People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses. [79]

6.1.16 Functionality

Functionality refers to the ability to provide a predetermined function e.g. providing drinking water to the inhabitants of a region or area[96].

6.1.17 Graceful extensibility

How a system extends performance, or extend adaptive capacity in face of surprise[16].

6.1.18 Hazard

An accidental or naturally occurring phenomenon with the potential to cause physical or psychological harm to humans including loss of life, damage or losses of property, and/or disruption to the environment or to structures (economic social, political) upon which a community's way of life depends.[97]

A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. [79]

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[95] 2007/779/EC, Euratom: Council Decision of 8 November 2007 establishing a Community Civil Protection Mechanism (recast).

[96] Lindström, J. et. al., Tactical First Responder Operations and Effects of Human Activities on the Course of Events, www.CascEff.eu

[97] JRC (2012) European Commission's CBRN Glossary, https://cbrn.jrc.ec.europa.eu/xwiki/bin/view/Main/

6.1.19 Impact

Impact describes the effect (usually negative) of an incident on a system or, where systems are dependent, on multiple systems[88].

Consequences of a hazardous event once it materializes, i.e. actually affects a societal system[98].

6.1.20 Incident

An incident is a chain of events affecting multiple systems either in series or spreading in parallel[88].

6.1.21 Incident management

Incident management is the management of appropriate measures to deal with a (potential) situation characterised by (high) complexity, uncertainty and time pressure, that could lead to possible large scale damages and requires a specific organisation and coordination to ensure the restoration of the situation[88].

6.1.22 Initiating event

An initiating event is the first in a sequence of natural (e.g. flood), accidental (e.g. fire) or intentional (e.g. bombing) events that may affect one or several systems[88].

6.1.23 Interdependency

Interdependency refers to the mutual functional reliance of essential services on other networks, utilities, services, or auxiliary nonutility systems. Interdependency suggests that a disruption or outage in one operation will affect another, and vice versa[99]

Interdependency is a bi-directional relationship between the state of multiple infrastructures.[100]

Rinaldi identified four types of infrastructure interdependencies[101]. By his definitions: Physical interdependency occurs when the state of different types of infrastructure are dependent on the output(s) of another. Cyber interdependency occurs when the state of one infrastructure depends on information transmitted through the information or telecommunications infrastructure. Geographic interdependency occurs when infrastructures are located in one region and where changes in the local environment can create state changes in all of them. Logical interdependency occurs when a state change in one infrastructure results in a state change in another, without any of the other interdependencies occurring.

Note: The terms interdependency and dependency are often used in the CIP literature as synonymous. See also dependency.

6.1.24 Likelihood

Chance of something happening. [67]

[98] Taveter, K. et.. al., Simulations tool for crisis management strategies and planned actions V2, www.crismaproject.eu

[99] Technical Assistance Briefs: Utility and Network Interdependencies: What State Regulators Need to Know; The national association of regulatory utility commissioners; April 2005

[100] IMPROVER Grant agreement

[101] Steven M. Rinaldi, James P. Peerenboom, and Terrence K. Kelly; Identifying, Understanding, and Analyzing critical infrastructure interdependencies; IEEE Control Systems Magazine December 2001

6.1.25 Media (traditional)

Media introduced before the advent of the internet that are for the purposes of mass communication e.g. billboards, magazines, newspapers, radio and television broadcasting. [102]

See also social media.

6.1.26 Mitigation

Mitigation refers to the lessening or limitation of the adverse impacts of hazards and related disasters. It may be synonymous with prevention, which is one of the phases of the Crisis Management Cycle[98].

6.1.27 Originating system

An originating system is a system in which a failure propagates to another system[88].

6.1.28 Performance

Performance level is usually measured by the number of normally operating components within an infrastructure system. [21]

6.1.29 Preparedness

The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions[98].

6.1.30 Rapidity

Capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption. [10]

6.1.31 Rebound

How a system rebounds from disrupting or traumatic events and returns to previous or normal activities[103]

Comment: An entity's ability to return quickly after a shock to its pre-defined state is referred to as the ability to "**bounce back**".[104] See also Recovery.

[102] Lee, F. L. F., L., Qiu, J.L. & Chu, D.S.C. (2013) Frontiers in new media research. New York:Taylor&Francis.

[103] Woods, David D. (2015). Four concepts for resilience and the implications for the future of resilience engineering, Reliability Engineering & System Safety, 141: 5-9
Manyena, B. S. (2006). The concept of resilience revisited. Disasters, 30(4), 433–450.
Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. Ecology and Society, 9(2).
Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. Global Environmental Change, 16(3), 253–267. http://doi.org/10.1016/j.gloenvcha.2006.04.002.

[104] Giroux, J., & Prior, T. (2012). Expressions of Resilience: From " Bounce Back " to Adaptation. 3RG REPORT Factsheet. Zurich, Switzerland. Retrieved from:
http://www.css.ethz.ch/publications/pdfs/Risk_and_Resilience_Report_Practical_Application_of_Resilience_2014.pdf

6.1.32 Recovery

The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors. [79]

See also restorative capacity.

6.1.33 Redundancy

Extent to which elements, systems, or other units of analysis exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality. [10]

6.1.34 Resilience design

The intentional design of buildings, landscapes, communities, and regions in order to respond to natural and manmade disasters and disturbances…[105] It is assumed that resilience design is about intentionally design the technical aspect of a (part of a) system in response to vulnerabilities to disaster and disruption.

6.1.35 Resourcefulness

Capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis. [10]

6.1.36 Restorative capacity

The ability of the system to be repaired quickly and effectively. [21]

Note: [Restorative capacity of a resilient system] is often characterized by rapidity of return to normal or improved operations and system reliability. This capacity should be assessed against a defined set of requirements derived from a desirable level of service or control. [25]

6.1.37 Risk

Effect of uncertainty on objectives.[106] Alternatively, the combination of the probability of an event and its negative consequences. [79]

Risk is the potential for realization of unwanted, negative consequences of an event.[107]

6.1.38 Risk analysis

Risk analysis is the process to comprehend the nature of risk and to determine the level of risk [108]

6.1.39 Risk assessment

Risk assessment is the overall process of risk identification, risk analysis and risk evaluation[109]

[105] http://www.resiliencetdesign.org/

[106] ISO/IEC 31000:2009, Risk management -- Principles and guidelines.

[107] Rowe, W. D. (1977). An anatomy of risk. New York: John Wiley & Sons.

[108] ISO.IEC 31010:2009 – Risk management – Risk assessment techniques

[109] ISO Guide 73:2009 - Risk Management - Vocabulary

6.1.40 Risk evaluation

Risk evaluation is the process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable[108]

6.1.41 Risk identification

Risk identification is the process of finding, recognizing and describing risks[108].

6.1.42 Robustness

The ability to absorb perturbations. [16]

Note: Robustness is often seen as the insensitivity to changing conditions, especially in product, process or component development. In a system perspective robustness is usually defined as some kind of ratio between direct and indirect risks, i.e. how a system can tolerate local failure without failure propagation and disproportionate consequences. A robust system does not only tolerate failure of its components, but fails in a safe manner. A robust system is will not lose its functionality at a rate or extent disproportional to the cause of the change in the state variables. "The robustness of a system is defined as the ratio between the direct risks and the total risks, (total risks is equal to the sum of direct and indirect risks), for a specified time frame and considering all relevant exposure events and all relevant damage states for the constituents of the system."[110]

Strength, or ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function. [10]

Some also refer to *resistant capacity*[21], as the ability to prevent potential hazards and reduce the initial damage level if a hazard occurs.

6.1.43 Satisfactory level

Satisfactory level is the level of functionality where the preventative measures have reached the lowest acceptable limit required for the function. It is important to remember that the satisfying level can be a preventative goal to reach in the future and that incidents can occur before the goals are reached. It is important to state that the satisfying level differs over time[96].

6.1.44 Service

A service is a distinct part of functionality that is provided by an entity through interfaces[111].

6.1.45 Social media

The collection of software that enables individuals and communities to gather, communicate, share and in some cases collaborate or play. [112]

[110] JCSS (2008) Risk Assessment in Engineering - Principles, System Representation & Risk Criteria, ISBN 978-3909386-78-9, June 2008.

[111] EN ISO 19119:2006, Geographic information – Services

[112] Boyd, D. (2009) Social media is here to stay…now what? (http://www.danah.org/papers/talks/MSRTechFest2009.html)

6.1.46 Sustained adaptability

The ability manage/regulate adaptive capacities of systems that are layered networks, and are also a part of larger layered networks, so as to produce sustained adaptability over longer scales. [16]

6.1.47 System

Any combination of facilities, equipment, personnel, procedures, and communications integrated for a specific purpose[113].

6.1.48 Threat

Potential cause of an unwanted incident, which can result in harm to individuals, a system or organization, the environment or the community. [90]

6.1.49 Transformability

The capacity to configure an entirely new stability landscape, defined by new state variables, or the old state variables supplemented by new ones. [37]

6.1.50 Transformation

Change of the state space of the system by the addition of new state variables or the loss of others, which will most likely change the scales and the nature of the cross-scale relationships of the panarchy as well. It requires the emergence or development of a new kind of system, or a fundamentally new way of "making a living. [37]

6.1.51 Vulnerability

A characteristic of an element of the CI's design, implementation, or operation that renders it susceptible to disruption or destruction by a threat and includes dependencies on other types of infrastructure.[114]

The degree to which system acts adversely to occurrence of hazardous events[115]. Similarly, intrinsic properties of something resulting in susceptibility to a risk source that can lead to an event with a consequence. [90]

The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. [79]

In a system perspective vulnerability is sometimes seen as the attitude of a single component to be damaged by an exposure, thus as an indicator of direct risks. "The vulnerability of a system is defined as the ratio between the risks due to direct consequences and the total value of the considered asset or portfolio of assets considering all relevant exposures and a specified time frame."[110]

Note:

[113] DHS Risk Lexicon 2010 Edition, September 2010. Retrieved from: http://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf

[114] COM (2006) 787 final, Directive of the Council on the identification and designation of European Critical Infrastructure and the assessment of the need to improve their protection, EC, Brussels 12.12.2006.

[115] Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change*, 16(3), 253–267. http://doi.org/10.1016/j.gloenvcha.2006.04.002

Vulnerability and resilience are perceived as positive and negative poles on the same continuum.

Vulnerable system is a system that has lost resilience.[116]

Resilience is related to the capacity of response component of vulnerability.[117]

In engineering risk assessment vulnerability is considered as an indicator of direct risks.

[116] Timmerman, P. (1981). Vulnerability, Resilience and the Collapse of Society: A Review of Models and Possible Climatic Applications. *Environmental Monograph*, 1, 1–45. http://doi.org/10.1002/joc.3370010412

[117] Gallopín, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, 16(3), 293–303. http://doi.org/10.1016/j.gloenvcha.2006.02.004

7 IMPROVER Official Glossary

In this section the official definitions to be used by the IMPROVER consortium are listed. These were agreed on the plenary meeting of the 30th of November 2016, in Tromsø, Norway.

Terms	Definition	Source
Absorptive capacity	The degree to which the critical infrastructure can absorb the impacts of initial damage and minimize the consequences, such as cascading failures. Note: This concept is closely related to system robustness and reliability.	Adapted by Ouyang et al. [21]
Adaptive capacity	The degree to which the critical infrastructure can adjust to undesirable situations by undergoing some changes.	Adapted by Francis & Bekera [25]
Cascading failure or effect	A cascading failure or effect occurs when a disruption in one infrastructure causes the failure of a component in a second infrastructure or asset, which subsequently causes a disruption in the second infrastructure.	Rinaldi et al. [89]
Community	A place designated by geographical boundaries that functions under the jurisdiction of a governance structure, such as a town, city, or county. It is within these places that people live, work, play, and build their futures.	NIST[91]
Critical Infrastructure	Asset, system or part thereof located Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions.	Council Directive 2008/114/EC [94]
Critical Infrastructure Protection	All activities aimed at ensuring the functionality, continuity and integrity of critical infrastructures in order to deter, mitigate and neutralise a threat, risk or vulnerability.	Council Directive 2008/114/EC [94]
Dependency	A uni-directional relationship of two infrastructures through which the state of the depending infrastructure is influenced by or is correlated to the state of the other. Note: The terms interdependency and dependency are often used in the CIP literature as synonymous. See also interdependency.	Rinaldi et al. [89]
Interdependency	A bi-directional relationship between the state of multiple infrastructures.	Rinaldi et al. [89]
Living Lab	A living lab in this project comprises representatives from the consortium as well as critical infrastructure stakeholders represented by associate partners. Based around either an entity or a clustering of critical infrastructures, the living labs are	IMPROVER

	conceived to study different technological, organisational and societal resilience concepts within the project; and for the methodology for implementation of resilience concepts to be developed.	
Organizational resilience (for CI)	The ability of an organization who operates or owns a critical infrastructure exposed to hazards, to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, for the preservation and restoration of essential societal services.	Adapted by UNISDR[79]
Resilience	The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of essential basic structures and functions. Resilience is a complex construct of multiple resilience concepts.	UNISDR[79]
Resilience analysis	The process to comprehend and to determine the level of resilience based on selected resilience indicators.	Equivalent to ISO/IEC 31010:2009 [108]
Resilience assessment	The overall process of resilience analysis and evaluation.	Equivalent to ISO/IEC 31010:2009 [108]
Resilience assessment approach	Any framework, methodology, method or tool that can be used to assess infrastructure resilience.	IMPROVER Deliverable D2.3
Resilience domain	Separate, but overlapping area, of critical infrastructure resilience. Note: IMPROVER considers the domains of technological, organizational and societal resilience.	IMPROVER Deliverable D2.3
Resilience evaluation	The process of comparing the results of resilience analysis with criteria or objectives to determine whether resilience level is acceptable and to identify areas for improvement.	Equivalent to ISO/IEC 31010:2009 [108]
Resilience Indicator	Qualitatively or quantitatively measurable entity that constitutes part of the overall critical infrastructure resilience	IMPROVER Deliverable D2.3
Restorative capacity	The degree to which the critical infrastructure can be repaired quickly and effectively. Note: [This capacity should be assessed against a defined set of requirements derived from a desirable level of service or control.	Adapted by Ouyang et al. [21], Francis & Bekera [25]
Risk	Effect of uncertainty on objectives. Alternatively, the combination of the probability of an event and its negative consequences.	ISO/IEC 31010:2009 [108] UNISDR[79]

Risk analysis	The process .to comprehend the nature of risk and to determine the level of risk.	ISO/IEC 31010:2009[108]
Risk assessment	The overall process of risk identification, risk analysis and risk evaluation.	ISO Guide 73:2009 [109]
Risk evaluation	The process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable.	ISO/IEC 31010:2009[108]
Risk identification	The process of finding, recognizing and describing risks.	ISO/IEC 31010:2009 [108]
Societal resilience	The ability of a community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of essential basic structures and functions.	Adapted by UNISDR[79]
Technological resilience (for CI)	The ability of a CI system exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, for the preservation and restoration of essential societal services.	Adapted by UNISDR[79]

8 Conclusions and future steps for the lexicon

Resilience concepts encompass **several dimensions**, such as technical, organizational, social, and economic ones[76]. The technological dimension refers primarily to the physical properties of infrastructure components, systems, networks or 'system-of-systems' and refers to the characteristics and behavior of these in the case of a change or incident. This dimension is very prominent when referring to engineering resilience or to CIR. Another aspect relevant to CIR is the organizational one, as it relates to the organizations and institutions that manage the physical components of the systems, i.e. CI operators or owners. It covers aspects such as culture, people, business continuity, risk and disaster management at the organizational level. The social dimension encompasses population and community characteristics that render social groups either more vulnerable or more adaptable to hazards and disasters. We observe that national resilience policies include social aspects in their definitions of resilience, as CI are vital for maintaining key societal functions. In some cases, they may include the ecological dimension if the environmental impact is considered. Moreover, a prominent parameter is the economic, as the priority is to reduce both direct and indirect economic losses resulting from disasters, in various levels (household, business, sectors/markets, nation, European, etc.).

In summary, **societal resilience concepts are strongly linked to the community, whereas organizational and technological resilience concepts are strongly related to the infrastructure systems themselves**. For IMPROVER, it is important to define clearly for each of the identified systems and infrastructures, technological and organizational resilience concepts, but these may be implemented differently in the different systems or their respective sectors. This means that the definition of the overall resilience of the dependent systems is not trivial. It should also be considered within the community which is reliant upon the infrastructure. This observation should be also reflected in the chosen definitions of the IMPROVER project to cover all mentioned dimensions.

The main goal of deliverable **D1.3 "Final lexicon of definitions"** (based on outcomes from Task 1.2) is to select the official definitions of IMPROVER. In this deliverable, we offer a list of terms and their definitions, which are necessary for comprehending the proposed method of the project and for the communication among the partners. This official lexicon serves as a recommendation for terminology towards the project partners, the associated partners, the collaborating projects and the CIP community in general.

Finally, following the submission of this deliverable, the consortium will ensure the dissemination and collaboration actions are performed. These include the communication of these first results to the **dissemination** channels of the project and to the other **collaborating projects**, including the **CIPedia** wiki.