ANTICIPATION AND SYSTEMS THINKING: A KEY TO RESILIENT SYSTEMS

Gerhard Chroust
Johannes Kepler Univ. Linz, gerhard.chroust@jku.at

Dennis Finlayson
Consultant, UK, dennisfinlayson56@yahoo.com

ABSTRACT

Due to many factors (larger population, more dependency on technology, more human interference with the natural systems and their equilibrium, like in climate change, ...) the number and the severity of disasters seem to grow, exaggerated additionally by the media coverage. The basic and ultimate goal in case of disaster is to ensure an at least acceptable level of survival of the population together with keeping societal structure, infrastructure and environment as intact as possible. This implies that a system possesses to a certain extent stability and security with respect to endangering incidents. Three overall factors are significant in causing an incident: a hazard, a vulnerability of the system and an insufficient capacity to shield or recover from an incident. Two factors are essential in order to withstand an incident: Anticipation in order to provide adequate preparation and Systems Thinking to be able to understand the relationship of cybernetic loops within the components of the affected system.

In this paper we analyze the factors potentially leading to a system disturbance. We classifying these disturbances with respect to their severity, and we analyze the different reactions of a system, from fragility to resilience and robustness. By discussing the phases of disaster management (from Anticipation to Restauration) we identify the respective information needs.

Keywords: anticipation, systems thinking, crisis, disaster, resilience, vulnerability, hazard, antifragility, response

INTRODUCTION

Disasters often endanger the foundations of our society. Nowadays disasters seem to occur more often and with greater destructive potential, especially observing the media coverage. Several facts are responsible for this feeling:

- We receive much prompter and more detailed information concerning distant disasters. Many media reports wallow in the details of disasters ("*bad news are good news*").
- Human activities have an bad influence on environment many disasters are triggered by human activity, be it by changes to the environment or by interfering with natural processes without full understanding and consideration of the consequences. Flooding caused by excessive logging of hillsides is possibly the best example.

- An increasing number of humans live in areas which were originally avoided (in the bed of a river or next to a mountain slope). In the quest for more space, geographic safety buffers are often eliminated, increasing the hazards.
- The lack of systemic thinking often induces decision makers to 'improve' a wrong approach by 'doing more of the same'. Attempts to repel the "Rise of the Islamic State" by bombing may be a good example (Cockburn, 2015).
- The Western World often has the false belief that technology can prevent any kind of risk. Therefore the error margins are reduced for the sake of cost and/or efficiency leaving less tolerance for adverse deviations.
- A blind believe in the infallibility of technology made us become less tolerant when the technological infrastructure breaks down.
- etc.

The basic and ultimate goal in case of a disaster is to provide an acceptable level of survival of the affected population together with its societal structure, its infrastructure and environment ("resilience"). Nature is an experienced and creative teacher with respect to survival of a species, but is willing to sacrifice individuals. A key to resilience is preparation ("Facing the Unexpected" (Tierney et al., 2001)). Anticipation is significant in initiating preparation of response to future disasters early enough in order to avoid the worst possible consequences and improve the chances for survival (Singh, 2015). Additionally we need a better understanding of the long-term effects of our interventions in nature, human society, and environment. These interventions can have strong effects on the structure of the society. Additionally there are always groups willing to exploit situations for their own benefit regardless of those badly affected (Loewenstein, 2015).

In a situation of that kind it is often necessary to reconsider our whole approach to crises, conflicts, and system behavior. We may need to revisit the vocabulary we have become used to as it may have become too common place and blurred with a loss of its original meaning. Systems thinking will often offer new terms and ideas but even here there should be some renewing on the words we tend to (over-)use. A good example might be the terms "resilience" or "disaster" (Chroust et al., 2015).

The paper is structured as follows: In chapter 2 we describe the key factors leading to a system disturbance, classify these disturbances and discuss the available reactions of a system. Chapter 3 looks at the phases of Disaster Management, stresses the need for and the function of Anticipation. It identifies the source of information needed for successful anticipatory considerations. Chapter 4 discusses systemic problems encountered during disaster management, especially in view of anticipatory actions.

CRISIS OR DISASTER?

Factors causing a Disturbance

Adverse situations, crisis and disasters usually result from an unfortunate combination of 3 major factors (Khan et al., 2008), see fig. 1. An example is a river delta in which high tide, extreme rainfall and overflowing tributaries sometimes coincide (Syvitski, 2009). Often one disaster triggers off a more severe one (see the tsunami of 2011 in Japan and its consequences on the atomic reactor disaster at Fukushima (Atsuji et al., 2011)).

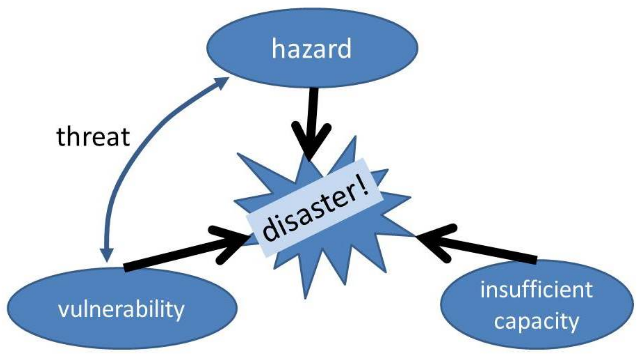

Fig. 1: Factors contributing to disasters

hazard: A hazard is a natural, physical, technological, or intentional agent such as an earthquake, industrial explosion, or terrorist bombing. ... Hazards exist for many different reasons. Some hazards occur naturally in the environment, whereas others are the result of human activity, mistaken or malicious intent (McEntire, 2007, p.6), (Svata, 2012). A hazard may trigger an emergency, a crisis, or a disaster,

We distinguish, following (McEntire, 2007):

- Natural hazards (including biological hazards and environmental hazards)
- technological hazards (including computer hazards, nuclear hazards and transportation hazards)
- Civil/Conflict hazards (including panics, terrorism, and war)

vulnerability of the affected system: Vulnerability is "the extent to which a community, structure, services or geographic area is likely to be damaged or disrupted by the impact of a particular hazard, on account of their nature, construction and proximity to hazardous terrains or a disaster prone area." (Organisation, 2003).

capacity of the affected system identifies "resources, means and strengths which exist in household and communities enabling them to cope with, withstand, prepare for, prevent, mitigate or quickly recover from a disaster"

Classification of System Disturbances

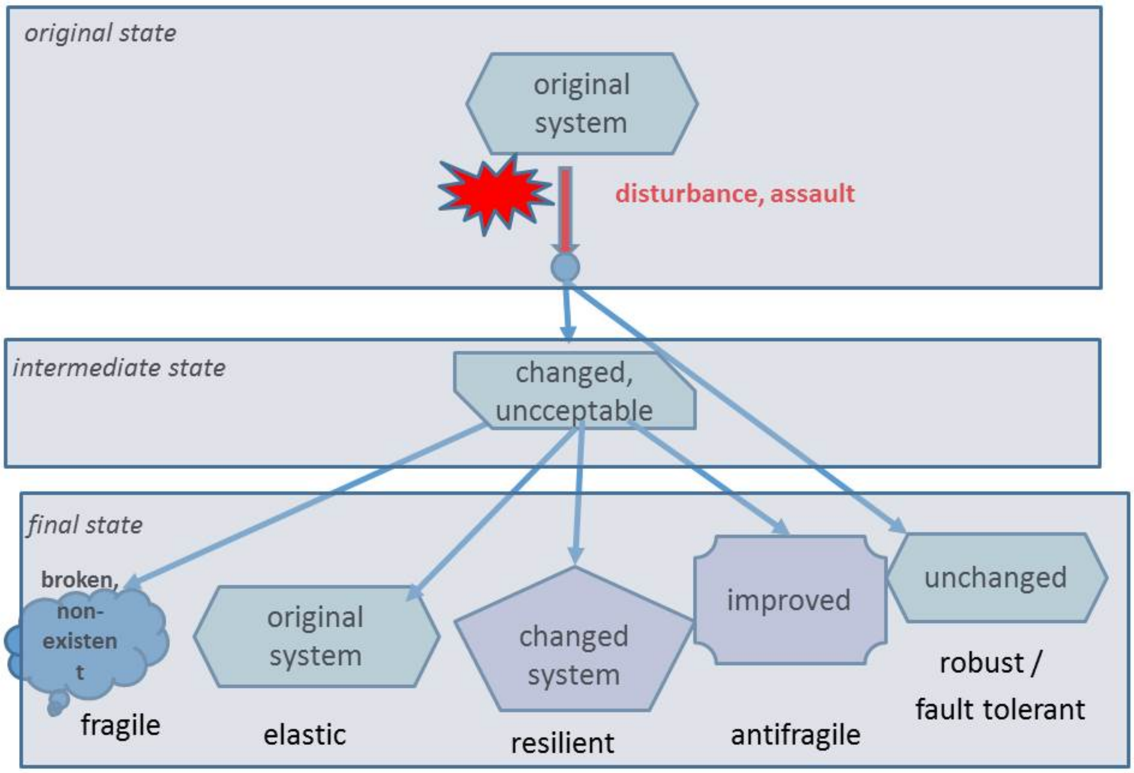

Fig. 2: Vulnerability classes

We define following (Svata, 2012; McEntire, 2007):

an incident is an occurrence by chance or due to a combination of unforeseen circumstances, which, if not handled in an appropriate manner, can escalate into a crisis, an emergency, or disaster (Svata, 2012).

an emergency is a sudden, unexpected event requiring immediate action due to its potential threat to health and safety, the environment, or property.

a crisis is a critical event that may have an impact on an organization's profitability, reputation, or ability to operate. It is not necessarily time-critical and usually does not deny access to facility and infrastructure.

a disaster is a sudden unplanned event that causes great damage or serious loss to an organization. It results in an organization failing to provide critical functions for some predetermined minimum period of time. It is common to distinguish natural, technological and social disasters, natural and accidental. One usually assumes that the affected society cannot survive without external help.

catastrophe is a disaster on a large scale involving hundreds/thousands of injuries and death, severe damages and severe destructions of environment and infrastructure. External support and aid for interventions is necessary (McEntire, 2007) .

Reaction of Systems

Basically most stakeholders (probably excluding terrorists, anarchists, etc.) are interested in maintaining a system in a certain state of stability and security. This implies that the system possesses a certain amount of resistance against the consequences of incidents. An incident at least temporarily puts the affected system into different state. Following the incident possible future states of the affected system are shown, see fig. 2.

Depending on the final state, systems can be classified as:

fragile: The system breaks down or becomes non-existent for the future. In general fragility is to be avoided.

fault tolerant: The system has "*the ability ... to absorb changes of state variables, driving variables, and parameters, and still persist*" (Holling, 1986). For a limited set of pre-defined hazards ('faults') the system is able to cope with or handle the disturbance successfully. Fault tolerance is not sufficient in those cases, in which full control or knowledge over the environment is not available/possible, or in which certain hazards are excluded from considerations.

elastic: After a short period of time in the changed state the system returns to its original state. Physics tell us that, strictly speaking, elasticity is usually not 100%.

resilient: Resilience is "*the capacity of an adapting and/or evolving system to bounce back to dynamic stability after a disturbance*"(Francois, 2004, p. 504).The system, when damaged, is able to be brought into an acceptable state, most likely not the same as before (fig. 3). Resilience over a wide (and even not fully known) range of possible hazards is a highly desirable property of a system and therefore the most worthwhile objective of system design with respect to Disaster Management (Brose, 2015). Resilience, however, like many desirable aspects of Disaster Management, does not come free: it entails cost and effort and needs preparation before a disaster strikes. Note that sometimes resilience is meant to be what we in this paper call elastic (Wikipedia-english, 2013, keyword 'Resilience').

robust: The system is unchanged and remains unchanged by an incident, it is basically not affected. Robustness might be too difficult to achieve due to the cost and effort for the current system. Additionally maintenance and evolution of this type of system might become too difficult. This term has become over-used in the past and needs some clarification. It should therefore be reconsidered or at least an explanation given. We understand as 'robustness' (Albino et al., 2016) the property of a system to remain 'practically' unaffected by an assault. In comparison a resilient system is effected and put into another state but is able to 'bounce-back' to an acceptable state, perhaps even more resilient than the first one.

antifragile: Antifragility is "*the capacity of an adapting and/or evolving system to bounce back to dynamic stability after a disturbance. In a more general meaning, resilience* [we call this antifragility] *includes the system's ability to create new conditions of fitness for itself whenever necessary*" (Francois, 2004, p. 504). The system is not only resilient but additionally "learns" to better counter a similar disturbance in the future, possibly becoming fault tolerant or even robust (Taleb, 2012). Due to the complexity of the world's political and economic situation military planners seem to prefer antifragile options over robust options in their strategies (Albino et al., 2016; NECSI (ed.), 2016). Antifragility might not be achievable because its implementation might require too many additional complex system components or overheads to exhibit the learning effect.

Obviously systems usually show different behavior to different types of incidents.

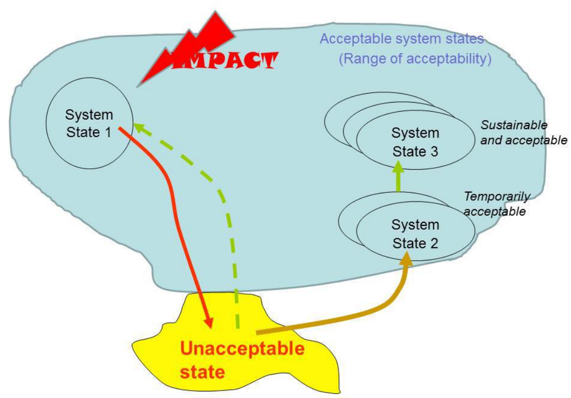

Fig. 3: State transition: unacceptable/acceptable

The Influence of Boundaries

The definitions above strongly depend on the definition of the system boundary. The definition of disaster includes the need of the society for external help: a compensation system, cf. fig. 4. This means that for the definition of the vulnerability the compensation system has to be included in the analysis.

For example, a house itself might be fairly fragile with respect to fire, but if we consider the city's fire brigade as a part of the threatened system, then it can be classified as fault tolerant or resilient, see fig. 4.

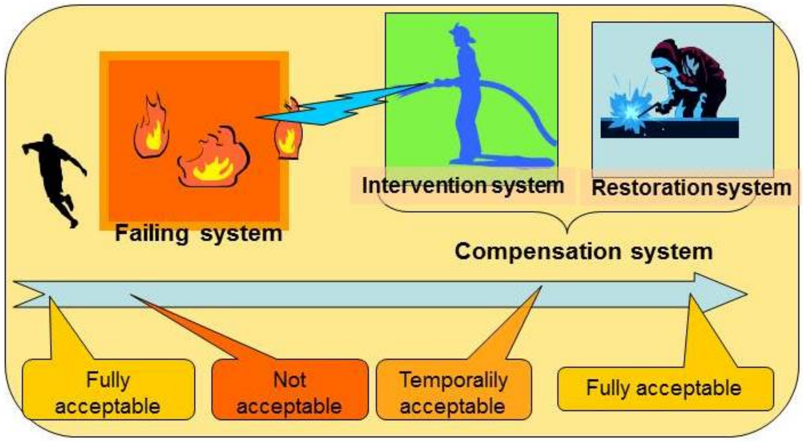

Fig. 4: Intervention and Restoration System

ANTICIPATION AND DISASTER MANAGEMENT

The ultimate goal of Disaster Management is the survival of the affected population in the case of disaster. Several phases of Disaster Management can be identified, but the classifications, the borders between the phases, their names and the comprised activities are not uniformly accepted yet (Tierney et al., 2001; Khan et al., 2008; McEntire, 2007; INSARAG (ed.), 2012). It can be hoped that the new standard ISO 22320 (Lazarte, 2013; ISO, 2011) will bring some uniformity.

The Disaster Incident is the pivot point, although it might be difficult to identify the actual starting point, especially when talking about slow-onset disasters like global warming. This is also true for hazards growing inside a given system.

Fig. 5 shows the phases of Disaster Management together with the main foci on top.

1. Anticipation This encompasses all activities which are undertaken before any specific hazard threats (IFRC (ed.), 2007b,a; McEntire, 2007; Tierney et al., 2001; Poli, 2014). Three different aspects have to be considered:

> **1A: Hazard, vulnerability, capability and risk assessment:** Based on existing data the risks faced by a region/society must be analyzed based on the identification of hazards, analyzing the vulnerabilities and the capabilities (IFRC (ed.), 2007b).
>
> **1B: Mitigation/prevention**: This encompasses any planning activity that reduces the chance of a damaging coincidence of the three disaster factors (see fig. 1) by modifying the basis of one or more of them (Tierney et al., 2001; Syvitski, 2009).

1C: General Planning, Preparedness: This includes anticipatory measures and actions, action plans, listing and provisioning of necessary resources and equipment, organizing training, etc. for all anticipated hazards (Singh, 2015). It should also include documentation (e.g. pictures, records, ...) the affected system as an anticipative measure for the future restoration phase.

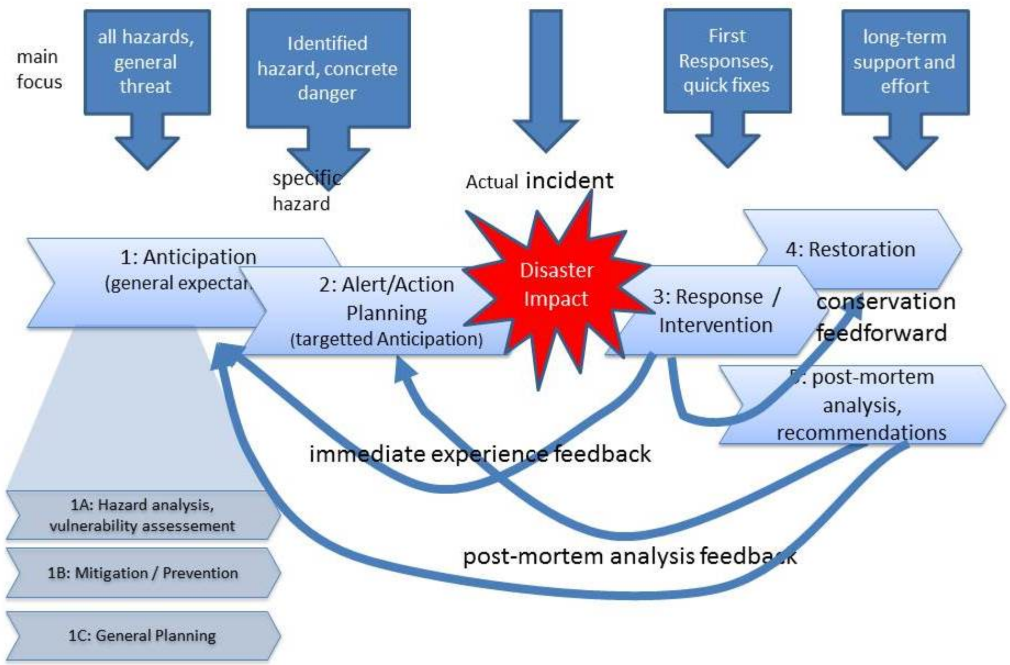

Fig. 5: Disaster Phases and corresponding response processes

2. Alert / Action Planning: Using the general information from subphase 1A (Assessment) and based on concrete thread the plans, rules, and strategies of how to react, to save lives or property are prepared. Based on these preparation decisions are made how the rescue services are to be coordinated and executed. This phase covers realization/operation, refreshing of training, issuing of early warnings, capacity building so that the population will react appropriately when an actual immediate warning is issued.

3. Response/Intervention: This is primarily concerned with rescuing people and bringing the system into a temporarily stable state ('quick fixes') in most cases with external help. This phase is the realization of the action plans conceived in Phase 2. Science plays an important role in this phase, both by providing data from past events and by allowing (via simulation) support of decision making based on computed scenarios and trajectories (Wood, 2013).

4. Recovery/Restauration: The often long-lasting Restoration Phase intends to bring the system into a long-term acceptable state (Chroust et al., 2015) in parallel trying to reduce vulnerability, trying to improve maintainability and introducing antifragility features. It includes actions that assist a community to return to a sense of normality after a disaster.

5. Post-mortem Analysis and Recommendations: This is the path to future improvement by collecting, analyzing and aggregating lessons learnt, making recommendations for the system in general, and in particular for the continuing Phase 1 ("after the disaster is before the disaster").

The phases of Disaster Management (fig. 5) show clearly the need for Anticipation (Poli, 2014; Rosen, 1985) which must heavily rely on information passed forward and backward.

The feed-back from the post-mortem analysis is usually well established. Nowadays it is also necessary to collect data even during the early Intervention phases for several reasons:

- information may get lost or be distorted when waiting for the post-mortem analysis
- information can be useful and or even necessary for the restoration phase, e.g. pictures of damaged buildings before they collapsed complectly or were torn down, etc.

Information flow has to be provided

- from Intervention Phase to the next Anticipation Phase
- from Intervention Phase to Restoration Phase (anticipation of restoration)
- from Post-Mortem Phase to Anticipation Phase and Preparation Phase
- from Post-Mortem Phase to Preparation Phase ("lessons learnt")

For many of these information paths Information Technology can be of great help by automating some of these information collection tasks (Chroust and Aumayr, 2015).

SYSTEMIC CHALLENGES

Many of the challenges posed for Disaster Management have been amply discussed in the literature. They concern human, technical, logistic and environmental problems. In the sequel we will only mention a few which are of essential importance for anticipation and resilience.

emergence: Despite the fact that many (most?) of the actors and triggers of a crisis are somehow known, their interplay is often not understood and can result in emergent situations, confronting the rescuers with unexpected situations ("Facing the Unexpected" (Tierney et al., 2001))

sizing: For economic reasons all planning must be based on assumptions about the maximal size of the expected impact. These estimates are sometimes wrong with dire consequences (actual strength of an earthquake, speed of a hurricane, ...).

drastic differences in time behavior: A further difficulty is the highly different time-behavior of disasters, from starting at the spur of the moment without any warning (e.g. comets), to slow unnoticed on-set of a disaster where it is even difficult to identify the point where a seemingly normal situation gradually changes into a path leading to disaster (e.g. global warming or floods), see (Mrotzek and Ossimitz, 2008; Mrotzek, 2009; Syvitski, 2009).

human short-sightedness: Humans are usually not very good at long-term planning and in taking into consideration slow but irreversible developments

discounting of the future: Humans are usually not very good at estimating the effects of dramatic disasters of almost zero probability ('black swans' (Taleb, 2012)).

political/administrative (non-)priorities: Long term investments for anticipation are often rerouted to near-term 'hot' topics, despite the saying that "*an ounce of prevention is better than a pound of cure*".

cost: Investment into anticipatory-related projects are often very expensive and are difficult to justify politically in times of scarce money.

lack of holistic thinking: Many of the anticipated disasters are the result of an unusual configuration of effects, which might get overlooked with out holistic thinking.

destruction of compensation systems: The compensation systems (including support personal themselves, fig. 4) are often themselves victims of a disaster, as a consequence are disabled and therefore cannot provide their compensation work. Especially Information and Communication Technologies might suffer from 'secondary drop-outs' like lack of electricity.

missing historical data: ICT allows us to fast and effective comparisons of a current situation with historical ones, if these data were saved and are readily provided ("science during crisis" (Wood, 2013)).

SUMMARY

Resilience of systems is a highly desirable goal. Anticipation and System Thinking are closely intertwined activities when aiming at improving the reaction to a dangerous incident and thus to secure the the stability and survivability of systems. We have discussed some of the theoretical underpinnings of resilient systems and their relation to and their need for anticipation. The classification of systems according to their vulnerability can be useful by indicating on what and how scarce budgetary resources should be spent.We have shown some research challenges especially with respect to the support of anticipation during a disaster incident.

We hope that this paper will trigger an interdisciplinary discussion, perhaps exhibiting new approaches and new methods and so as to improve the situation for humans affected by a disaster.

REFERENCES

Albino, D., Friedman, K.and Yaneer Bar-Yam, Y., and Glenney, W. I. (2016). Military strategy in a complex world. Technical report, England Complex Systems Institute, arXiv:1602.05670v2,May 18, 2016.

Atsuji, S., Cook, N., Ueda, K., Ueda, K., and Fujimoto, R. (2011). Fukushima nuclear catastrophe 3.11: System pathology of social organizations. In *Proc. 55th Annual Meeting of the ISSS, Hull, 2011*. ISSS.

Brose, D. (2015). *Developing a Framework for Measuring Community Resilience: Summary of a Workshop*. The National Academies Press 2015, (http://www.nap.edu/catalog.php?record_id=20672.

Chroust, G. and Aumayr, G. (2015). Resilience 2.0: ICT for Resilience of Systems. In Doucek, P., Chroust, G., and Oskrdal, V., editors, *IDIMT-2015, Information Technology and Society Interaction and Interdependence*, pages 13–22. Trauner Verlag Linz, Sept. 2015.

Chroust, G., Ossimitz, G., Roth, M., Sturm, N., and Ziehesberger, P. (2015). First responders in regional disasters: a social responsibility. In Mulej, M. and Dyck, R., editors, *Social Responsibility Range of Perspectives per topic and Countries*, page 23. Bentham Science Publishing Ltd., 2015.

Cockburn, P. (2015). *Rise of the Islamic State*. Verso Press, Lo9ndon 2015.

Francois, C. (2004). *International Encyclopedia of Systems and Cybernetics*. 2nd edition, 2 volumes, K.G.Saur, München 2004.

Holling, C. (1986). The resilience and stability of ecosystems. In Clark, W. and Munn, R., editors, *Sustainable Development of the Biosphere*. Cambridge Univ. Press 1986.

IFRC (ed.) (2007a). Contingency planning guide. Technical report, International Federation of Red Cross and Red Crescent Societies, 2007.

IFRC (ed.) (2007b). Disaster response and contingency planning guide. Technical report, International Federation of Red Cross and Red Crescent Societies, 2007.

INSARAG (ed.) (2012). INSARAG Guidelines and Methodology Technical Report. Technical report, International Search and Rescue Advisory Group United Nations Office for the Coordination of Humanitarian Affaires, 2012.

ISO (2011). ISO 22320:2011, societal security – emergency management – requirements for incident response. Technical report, International Organization for Standardization, 2011.

Khan, H., Vasilescu, L., and Khan, A. (2008). Disaster management cycle a theoretical approach. *Management and Marketing Journal, vol. 6(2008) no. 1*, pages 43–50.

Lazarte, M. (2013). New ISO standard for emergency management. http://www.iso.org/iso/home/news_index/ news_archive/news.htm?refid=Ref1496, [Feb. 2014].

Loewenstein, A. (2015). *Disaster Capitalism*. Verso, London 2015.

McEntire, D. (2007). *Disaster Response and Recovery: Strategies and Tactics for Resilience*. Wiley, USA 2007.

Mrotzek, M. (2009). *Catastrophe Dynamics A Systemistic Exploration of Catastrophes towards a Set of Catastrophe Archetypes Using the System Dynamics Simulation Method*. PhD thesis, Alpe-Adria University Klagenfurt, Faculty for Technical Sciences, Feb. 2009.

Mrotzek, M. and Ossimitz, G. (2008). An integrative systemic theory of catastrophes studie für KIRAS nr. 813798 proj. simrad.nbc. Technical report, Inst. f. Mathematik, Univ. Klagenfurt 2008.

NECSI (ed.) (2016). Military. http://www.necsi.edu/research/overview/military.html.

Organisation, W. H. (2003). Words are important – definitions for EHA, http://www.who.int/hac/techguidance/tools/Definitions

Poli, R. (2014). Anticipation: A new thread for the human and social sciences? *Cadmus, vol. 2 (2014), no. 3 , also http:((cadmusjournal.org*, pages 23 – 36.

Rosen, R. (1985). *Anticipatory systems*. Pergamon Press, Oxford 1985.

Singh, R. (2015). Why the strongest hurricane on record was no 'catastrophe'. http://www.ifrc.org/en/news-and-media/news-stories/vamericas/mexico/ why-the-strongesthurricane-on-record-was-no-catastrophe-70736/.

Svata, V. (2012). ICT Methodological support of disaster management. In Doucek, P., Chroust, G., and Oskrdal, V., editors, *IDIMT 2012 ICT Support for Complex Systems, Sept 2012*. Trauner Verlag Linz.

Syvitski, J. (2009). Sinking deltas, encroaching tides. *Nature Geoscience 2, 681 686 (2009)*, page 6.

Taleb, N. (2012). *Antifragile: How to Live in a World We Don't Understand*. Penguin UK 2012.

Tierney, K., Lindell, M., and Perry, R. (2001). *Facing the Unexpected Disaster Preparedness and Response in the United States*. Josef Henry Press, Washington DC, SA 2001.

Wikipedia-english (2013). Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/.

Wood, C. (2013). Science during crisis: Group helps decision-makers with long-term strategy. *Emergency Management, Nov 6, 2013*, page 3.