



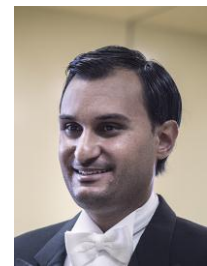
A COMMON OPERATIONAL PICTURE IN SUPPORT OF SITUATIONAL AWARENESS FOR EFFICIENT EMERGENCY RESPONSE OPERATIONS

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ABSTRACT

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Efficient emergency response needs a multi-disciplinary approach which in turn calls for a high level of collaboration and coordination among the involved safety agencies. Furthermore, in order to cope with the complexity, uncertainty and dynamic nature of an emergency, flexible information and communication systems are required. Based on experiences from the military domain, strategic concepts which can improve information sharing and collaboration can be derived and adapted towards enhancing emergency response information systems and operational effectiveness. This study purports to review the state of the art in this field providing recommendations for emergency response policy makers, professionals and researchers.

Contribution/Originality: The paper contributes in the existing literature by reviewing the state-of-the-art in the field of emergency response and provides recommendations for policy makers, professionals and researchers towards enhancing emergency response information systems and operational effectiveness.

1. INTRODUCTION

Natural disasters strike since the ancient times and despite the advancements in science and technology, they still have enormous socioeconomic and environmental impacts each year [1, 2]. In the context of the dynamic and complex task environment of a disaster, multiple organizations and stakeholders are required to convert from autonomous actors to interdisciplinary and interdependent emergency response teams [3]. The probably most significant question that arises for these responding teams is what is going on [4]? For the latter, timely access to all relevant geo-information is critical [5].

During an emergency, several operational field units at different levels with various functional command structures coming from different organizations which may have different backgrounds, professional languages and operational expertise, they should share information acquired from various sources, communicate, co-operate and coordinate their actions within a short period of time towards normalizing an emergency situation [6]. The quality and timeliness of information can shape the effectiveness of the emergency response operations [7]. Furthermore,

accurate and relevant information can play a pivotal role towards reducing the potential damages in lots of threatening situations [8] since the response operations base on relevant facts regarding the situation concerned [9]. Finally, the need of coordination in emergency response is axiomatic as its absence drives to a number of possible failures which often result in the escalation of an incident to a disaster and even higher number of victims [10]. In this connection it should be mentioned that a number of studies (e.g. [11-14]) verify that poor information sharing and coordination during inter-organization emergency response has a negative impact on decision making and actions. In addition, information gaps along with lack of fluent communication and absence of a common operation picture in use have been identified as the major factors that hinder the emergency response organization [15].

Information sharing and coordination stay at the top of the research agenda, despite the progress that may have been done through time [10]. In addition, the growing attention on the improvement of the protection from natural hazards in Europe and beyond, led to an increasing demand for information sharing [16]. In order to overcome the information management and dissemination problems, the emergency response organizations support the employment of more advanced and better equipped information systems derived from the logic of network enabled capabilities [17, 18]. Such systems should assist emergency response stakeholders to achieve shared situational awareness by deploying a Common Operational Picture [17, 19, 20]. Having shared situational awareness, the responding organizations can dynamically understand “what is going on” while their subsequent decisions and actions highly depend on it.

In short, emergency response organizations still struggle with information sharing, communication and coordination [10, 17, 21-23]. The unforeseen, dynamic and complex nature of an emergency in which multiple groups of professionals need to cooperate is seen by various scholars (e.g. [24, 25]) as the reason for which the responding agencies battle to share and coordinate information. Although information sharing and coordination in emergency response are of apparent importance, they have received relatively little scientific attention [10, 26, 27]. Consequently, the main goal of this study is to provide through extensive literature survey an objective and systematic overview of strategic information concepts and to illustrate their empirical usefulness and benefits for effective emergency response.

In this context, the paper commences its mission by presenting in section 2 a literature review on natural disasters providing a thorough classification of their different types as well as numbers and losses worldwide. Moreover, after distinguishing between incident and disaster a detailed description of the different phases of an emergency followed by characteristic types of delays during emergency response operations is provided. Next, in section 3 the design premises of a flexible and dynamic emergency response system are delineated based on literature. Thereafter, in section 4 the network centric enabled capabilities for information sharing during emergency response are analyzed and their real benefit which is reflected in their value chain is explained. Then, in section 5 situational awareness and in particular individual, shared and team situational awareness and models are explored. Afterwards, in section 6 a background to a common operation picture is presented and challenges in its achievement are identified. Furthermore, the added value service of a common operation picture in emergency response is theoretically investigated and a basis for its qualitative and quantitative assessment is proposed. Finally, this contribution concludes by discussing the main findings and providing recommendations for emergency response policy makers, professionals and researchers.

2. NATURAL DISASTERS

Natural disasters have stigmatized the human history, causing peaks in terms of mortality and morbidity [28]. The Centre for Research on the Epidemiology of Disasters (CRED) [29] defines disaster as “a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering”. The United

Nations International Strategy for Disaster Reduction (UNISDR) terminology [30] determines disaster as “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”. The International EMergency Disasters DATabase EM-DAT [31] classifies natural disasters in 5 groups which in turn cover 12 disaster types (see table 1).

Over the past five decades (see figure 1), the number of the overall natural disasters present an increasing linear trend causing severe economic losses while the hydro-meteorological disasters are the most dominant in terms of numbers and economic damages. Biological events are not considered here, as they require specific approaches and often are not directly related to geophysical and hydro-meteorological events [28].

Only in 2014, the NatCatSERVICE of the Munich [32] has recorded 980 loss events distributed all over the world (see figure 2) that have caused overall 7 700 human fatalities and losses of around \$110 billion of 2015 US dollars. From these, 900 were hydro-meteorological events which caused 6 900 human deaths and losses of \$97 billion of 2015 US dollars. Looking at the geographical distribution of the events in 2014, Asia following the trend of the past three decades [33] is the most disaster-prone region with the largest number of people killed and the greatest economic damages. In particular, according to Munich [32] (see figure 3) Asia was the continent hit by most of the natural disasters (37%) followed by North America including Central America and Caribbean (20%), Europe (16%), Africa (10%), South America (9%) and Oceania (8%). In addition, Asia in 2014 accounted for 75% of global disaster victims followed by Africa (10%). Furthermore, Asia suffered from the 46% of the global damages followed by North America including Central America and Caribbean (29%) and Europe (16%).

Table-1. Classification of natural disasters.

Biological	Geophysical	Hydro-Meteorological		
		Hydrological	Meteorological	Climatological
Epidemic Infectious Disease • Viral • Bacterial • Parasitic • Fungal • Prion Insect Infestation Animal Stampede	Earthquake • Ground Shaking • Tsunami	Flood • General River Flood • Flash Flood • Storm Surge/Coastal Flood Mass Movement (Wet) • Rockfall • Landslide • Avalanche • Subsidence	Storm • Tropical Storm • Extra-Tropical Cyclone • Local/Convective Storm	Extreme Temperature • Heat Wave • Cold Wave • Extreme Winter Conditions
	Volcano Mass Movement (Dry) • Rockfall • Landslide • Avalanche • Subsidence			Mass Movement (Wet) • Rockfall • Landslide • Avalanche • Subsidence

Source: EM-DAT [31]

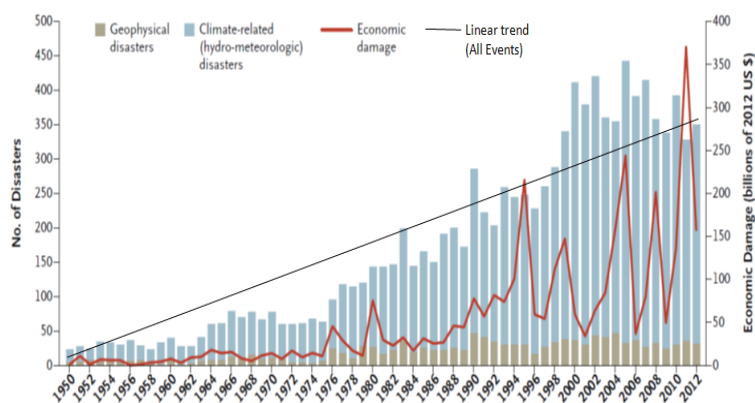


Figure-1. Numbers and types of historical natural disasters.

Source: (Adapted from Leaning and Guha-Sapir [28]).

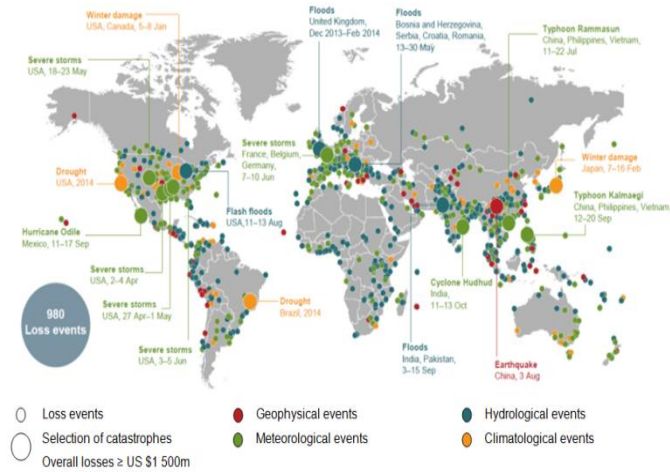


Figure-2. Geographical distribution of loss events during 2014. Source: Munich [32]

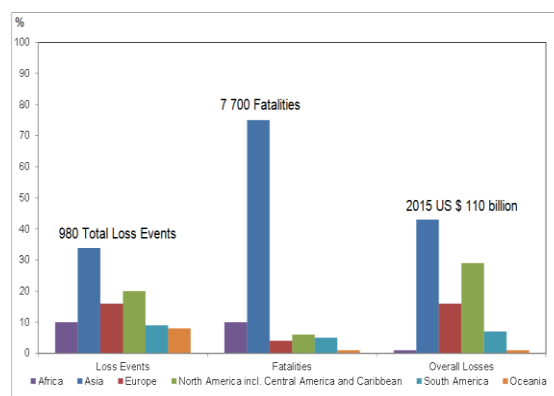


Figure-3. Loss events in 2014 ordered by continent. Source: (Adapted from Munich [32])

Natural disasters, particularly floods and storms present an increasing trend in terms of frequency and seriousness affecting the mortality, morbidity and welfare of the society. Montanari and Koutsoyiannis [34] mention that the growing impacts of extreme events, along with the observation that the environment alters in a phenomenal manner, stresses that human facilities are becoming more exposed to natural hazards and risks. Furthermore, the level of vulnerability of an exposed community to such hazards, it specifies the extent to which a hazard can cause a disaster [35]. In the years ahead, the international community should face the root causes of crises [28]. In this context, transnational solutions enabled via an effective framework for regional cooperation by allocating resources towards better preparedness as well as by reinforcing the early warning systems are needed [33]. Humanitarian relief is and will always be required due to unforeseen natural events which call for effective emergency response during a crisis situation.

2.1. Incidents versus Disasters and Emergency Response

Oxford Dictionaries [36] determine incident as “an instance of something happening; an event or occurrence” while disaster as “a sudden accident or a natural catastrophe that causes great damage or loss of life”. In order an incident not to escalate to a disaster effective emergency response is required. According to UNISDR [30] response is “the provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people”. In this context, plans and institutional arrangements that involve and guide the efforts of the multiple safety agencies in a comprehensive and a coordinated fashion towards responding to the entire spectrum of emergency needs are engaged.

Emergencies are considered as high stress situations which need organizations to respond in a way that is different from their normal operating procedures [37-40]. Walle and Turoff [41] note that emergencies are by definition situations in which the stakeholders are not familiar with nor likely to become familiar with; and their occurrence evokes intense feelings of stress, anxiety and uncertainty. During an emergency situation, not only will they have to manage these feelings, but also they should comprehend the situation among conflicting or missing information, deciding for the appropriate response actions in a short period of time.

Jennex [42] see emergencies as a series of four phases (see figure 4) i.e. Situational Analysis (SAn), Initial Response (IR), Emergency Response (ER) and Recovery Response (RR) and five decision points i.e. the Initiating Event (IE), the Control Event (CE), the Restoration Event (RE), the Normalizing Event (NE) and a Terminating Event (TE) which are described below in details:

- *SAn phase*: During this first phase, information is acquired and assessment of the situation is performed by the safety agencies. It has a base level of activities which include monitoring and analysis of a set of predetermined conditions for detection of unusual or pre-identified deviations, identification of the IE and training and preparation of the emergency responders. When an IE is determined during the SAn phase, an emergency is considered that initiates and it causes the start of the IR phase.
- *IR phase*: This is a short duration phase in which verification of the emergency is being done, followed by generation of early warning notices, initialization of preplanned preliminary actions and introduction of the emergency response plan.
- *ER phase*: It begins directly after assuming control by the emergency response teams i.e. after a CE and in general after the completion of the immediate response actions and early warning notifications. This phase implements the emergency response plan and begins the coordination of the responders, the deployment of the assets and the allocation of the resources. Being the command and control phase of emergencies, it requires from the emergency responders to monitor conditions and progress of the response operations, adjusting them accordingly. The ER phase reaches the maximum activity level during an emergency, ending with the RE. At this point, the emergency responders deduce that the emergency conditions are under control and hence no further response actions are needed leading to the termination of the command operations of the emergency control center and the entrance of the emergency into the RR phase.
- *RR phase*: This phase has a declining level of activities during which is verified that the emergency is under control and organization, management and coordination of long term activities and reconstruction for the normalization of the situation takes place. Furthermore, lessons learned from the management of the emergency are identified and documented towards better preparation for potential future emergencies. The RR phase ends when the NE is formally declared. At this point, all the emergency response actions are completed. Moreover, long term response activities as well as a basic level of restoration have been made, the situation is normalized and the safety agencies are operating in their routine procedures being in the SAn phase.

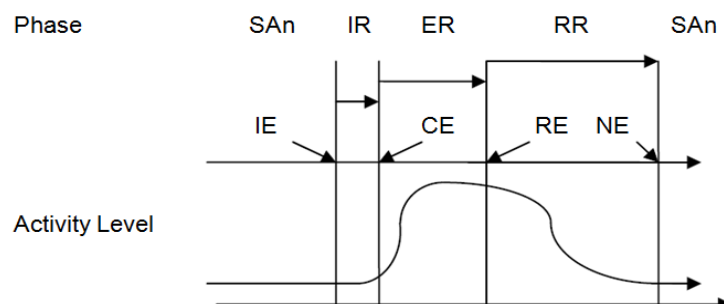


Figure-4. Phases and decision points with indicative amount per unit time of immediate response and decisions that need to be made following an IE. The figure does not correspond to scale and it is a general illustration of an emergency timeline. Source: Jennex [42]

TE can occur in the case of a false detection of an incident or in the case where another emergency has been prioritized or in the case of any event that could cause the suspension of the response. In general, TE can take place in any phase and time denoting the termination of an emergency. This is also the reason for which is not illustrated in the diagram of phases and timelines of activity levels of a typical emergency (see figure 4).

2.2. Delays during Emergency Response Operations

Chen, et al. [43] see emergency response as a social activity where multiple agencies across functional disciplines and jurisdictions are involved. In particular, during an emergency, several response teams from various safety agencies with different organizational goals and cultures must cooperate in order to minimize the potential negative effects of an emergency [44]. For this, good coordination and communication not just within a response team, but also among the several teams involved is required.

During the emergency response operations, Chen, et al. [43] identify three characteristics types of delay:

- *Type 1:* This delay is related to the dispatch process of the emergency responders due to a limited Situational Awareness (SA) and comprehension of the extent of an incident. Coordination and decision making in a limited amount of time lacking relevant, complete and accurate geo-information is crucial. Novel information concepts with the capability to integrate and present up-to-date information about the incident, the surrounding environment and the response operations in real time are often needed. Furthermore, decision support systems which build upon such information concepts incorporating and adjusting decisions are often necessary. As the understanding of the situation may change and improve through time, the capacity of adjusting the decisions accordingly is of critical importance. Such a change can occur as individual observations of the scene are often biased by the observer's comprehension, background, reminiscence and verbiage. First responders, mention that these observations are frequently contradictory resulting in delays in regards to actionable decisions, as puzzling out conflicting information is hard and time consuming. Finally, the systems used to support decisions for emergency response should not refuse information seemingly useless, but maintain and analyze such information for potential useful content.
- *Type 2:* This refers to the time spent on the preparation of the responders for the implementation of their tasks and it can be reduced by organizing ex ante relevant training exercises. This preparation time can include identification of proper outfit and suitable equipment related to the type and severity of the emergency to be managed and travel time required to reach the hot zone (location awareness). Better preparedness for emergency response as well as better coordination during the emergency may contribute to the minimization of this delay.
- *Type 3:* This delay can occur during the process of information acquisition, communication and decision making. It can be addressed by facilitating Shared Situational Awareness (SSA) among the responders. SA and SSA are defined and discussed in a later section.

3. DESIGN PRINCIPLES FOR AN EMERGENCY RESPONSE SYSTEM

Information and communication of varying scopes and proportions are of utmost importance during crisis situations [41]. Furthermore, teams of people who often represent different organizations, resources and roles are required to work effectively in a coordinated fashion supporting each other's' objectives even when they have never before worked together [45]. For this, flexible and dynamic emergency response information systems resting on generic design principles and tailored to the needs of the different safety organizations are required. Based on historic experience, Turoff *et al.* [46, 47] suggest nine design premises for a Dynamic Emergency Response Information System (DERMIS) (see table 2).

Table-2. Design premises for a DERMIS.

Design premises	Discussion
System training and simulation	An emergency response system which has functions for the day-to-day operations, it partly eliminates the need for training and simulation. This occurs due to the fact that the professionals who must operate the system, they already gain extensive experience with it just by using it for their daily routine.
Information focus	The professionals dealing with the emergency response are often flooded with information and hence the emergency response systems should filter information according to the needs of the different actors. However, these should still be able to access all contextual information related to an emergency as information elements that are filtered by the system may be of utmost importance under unforeseen conditions.
Crisis memory	The system should enable logs of the events' chain during an emergency, without charging the emergency responders with extra workload. The information included in these logs can be used for system improvements for future emergencies as well as for analysis of the emergency situation itself.
Expectations as norms	Most of the emergencies are unique and hence a planned response to an emergency is not feasible to be followed in details. Furthermore, the majority of the actions are expectations to the earlier defined norms. Therefore, an emergency response system should be flexible enough to enable alterations in the configuration and allocation of resources during response operations.
Scope and nature of crisis	Depending on the nature of an emergency, the different response teams may have to be structured with members who will provide the appropriate knowledge and experience for fulfilling the teams' tasks. In addition, attention should be paid on the fact that some teams may operate for a specific amount of time transferring their tasks to other teams or actors. This applies also for individual team members who due to exhaustion may need to be replaced by others.
Role transferability	Emergency responders must be able to pass their roles to others when they are not capable to deal with an emergency. This means that an emergency response system's software should explicitly describe these roles and also the tasks, responsibilities and information needs of each of them.
Information validity and timelines	During emergency situations, actions are taken based on incomplete information. Thus, it is of utmost importance for an emergency response system to be capable to store all the available information in a central database equally open to all those involved in the management of an emergency situation. In this manner, all the involved stakeholders can count on a wide base of information which in turn it may support them towards more effective and efficient decision making for the management of an emergency. Furthermore, when these stakeholders require unexpected (unpredicted by humans or technology i.e. the system) information, they need to be able to identify whether this exists or not and also who can or must be providing it.
Free exchange of information	During an emergency response, a vast amount of information should be shared and exchanged between the involved stakeholders in order these to become aware, gain control of the situation and supervise the response operations. However, a large amount of exchanged information can lead to information overload which can have negative contribution to the emergency response. Hence, the system must prevent the information overload of its users by assuming all the bookkeeping of communications and all the organization occurred.
Coordination	Due to the unforeseen nature of an emergency, the actions that should be taken as well as the responsibilities of the emergency response teams and individuals cannot be predetermined. In this context, an emergency response system should support flow of authority towards where the actions take place (usually on a low level of hierarchy) and simultaneously reverse flow of accountability and situational information upward and sideways through the organization.

Source: [41, 46, 47]

People can deal with a high degree of uncertainty to make timely decisions as long as they know that these are not based on hidden information which will make their actions to look wrong later. In this context, the persons required to make decisions during an emergency should be ensured that they can find and precisely understand all

the information relevant to their decision in a timely manner; as in an emergency what might be considered the most relevant, may simply not exist [47].

An emergency management system should face the reality of an emergency situation which requires movement of authority to lower levels and rapid responses [47]. Otherwise, the system will be designed inadequately without being capable enough to handle the oversight function in a timely and effective manner during an emergency. As many serious decisions are irreversible [48] the latter can lead to incorrect decisions which cannot be altered or to delays in making a decision that eliminates the opportunity for choosing the best alternatives.

The nine design premises suggested by Turoff *et al.* [46, 47] can lead to an emergency response system flexible, robust, dynamic and capable to support the information and communication needs of the emergency responders at all the levels. Furthermore, according to Eede, *et al.* [49] they can allow the development of a dynamic emergency response information system capable to support and be integrated across different organizations.

4. NETWORK CENTRIC ENABLED CAPABILITIES FOR EMERGENCY RESPONSE

When a disaster strikes, coherent coordination requires acquisition of relevant information from multiple sources, verification of its accuracy and sharing among responding organizations, all within a short period of time [3]. Information quality and timeliness can shape the effectiveness of the emergency response operations [7]. Furthermore, accurate and relevant information can significantly reduce the potential losses in lots of threatening situations [8]. Lack of information and knowledge, their incorrect interpretation or discharge as irrelevant are among the main reasons of disaster management failure [50-53]. Furthermore, at the peak of an emergency when information accessibility, flow and distribution are of utmost importance; the lack of interoperability among the variety of databases, the information generation systems and the telecommunication platforms utilized by these systems are some of the most obtrusive contributors to mismanagement [54-59].

Architectures to support complex problems solving as well as coordination and information sharing during emergencies can be traditionally characterized as hierarchical solutions [60, 61]. Furthermore, Janssen, *et al.* [3] state that hierarchical control is often viewed as a necessity for managing disasters. However, Comfort and Kapucu [6] mention that under the urgent and dynamic conditions of a disaster, such procedures almost always crash. In addition, Comfort [62] points out that under cumulative stress, the hierarchical organization tends to fail and personnel are obstructed by a lack of information, constraints on innovation and an inadequacy to shift resources and actions to timely meet new demands. Schraagen, *et al.* [63] experimentally demonstrated that in complex environments, the network centric structures were more efficient in terms of speed, accuracy, information distribution, knowledge sharing and decision making compared to the hierarchical structures.

For complex, time dependent operations carried out in dynamic environments, the concept of “network-centric warfare” based on extensive use of information technology, information management and progressively increasing incorporation of knowledge management techniques, it has been introduced several years ago by the US Department of Defense (DoD) [64]. In particular, the Network Centric Operations (NCOs) have emerged as the solution to the major information and knowledge deficiencies and requirements during complex, large-scale crisis management operations [55-58, 65]. The NCOs' concept recognizes the need of empowering humans during emergency response. By incorporating NCOs, the military aimed at a broad sharing of situational awareness through the utilization of a Joint Operational Picture [66]. According to Alberts and Hayes [67] DoD has identified four propositions of a NCO and a set of governing principles for a network centric force which are the tenets of netcentric warfare: i) a robustly networked force improves information sharing; ii) information sharing and collaboration reinforce the information quality and share situational awareness; iii) shared situational awareness allows self-synchronization and strengthens sustainability and command speed; iv) All these in turn are significantly increasing the mission effectiveness.

Lubitz, et al. [54] mention that the concept of network-centricity has emerged in two parallel approaches. These are the Doctrine of Network-centric Warfare (DNW) [68] and the Network Enabled Capabilities (NEC) [69] also known as Network Enabled Operations (NEO). From the two approaches, Lubitz, et al. [54] identify that the NEC concept is more adaptable to the conditions of emergency response in which multiple uncoordinated and disorganized governmental, non-governmental, local and volunteer organizations are required to collaborate within the same operational environment, yet entirely without common information sharing capability. This is because unlike the network centric doctrine, NEC enables effects-based operations at the level of command and control as well as on the level of operational capability. Lubitz, et al. [54] state that the “NEC may be the essential tool required to change the persisting individualism of the participating organizations”. Furthermore, NEC is a potential enabler of an adaptive management philosophy which can allow collaborative and flexible responses to future disasters [51].

Networks, information and humans are the three overlapping and mutually dependent dimensions of NEC, which need continuous development for achieving full realization of the concept [70]. The networked information environment offers the capability to acquire, generate, manipulate and distribute information which in turn is crucial for the decision makers. The real value of NEC is reflected in its value chain (see figure 5). In essence, NEC value chain corresponds to the tenets of net-centric working [71, 72] and it attempts to indicate the NEC cause and effects chain that leads in “Better effects” i.e. the desired emergency response outcomes.

NEC timely provides and exploits information and intelligence to enable effective decision making and versatile actions [70]. However, despite the fact that they offer decisive advantages in emergency response, they have some deficiencies. For example, Lubitz, et al. [54] mention that these concepts are technology driven, with technology itself being one of the first victims of a major emergency. As a solution to this, Patricelli, et al. [73] suggest that preparation and planning can contribute in assuring that in spite of severe infrastructure damage, the essential network capabilities either keep operational or are timely restored to an acceptable functional level. Some other issues on NCO have been identified by Bharosa *et al.* [74, 75] who have done field research and in particular empirical analysis on the implementation of NCO and the resulting problems. Through their research, they identified that the implementation of NCO can unveil some shortcomings which cannot be addressed by NCO descriptions. In addition, they found that NCO can highlight some issues such as information overload making also the validation of information quality a difficult task. Furthermore, they acknowledged that despite the technological advances, the NCO concept’s effectiveness depends on the formulation of new institutional policies and roles in regards to information sharing. For all these matters, further research needs to be carried out. Therefore, the concept of net-centricity is not a panacea which solves all the crisis management problems, but it is a part of the solution.

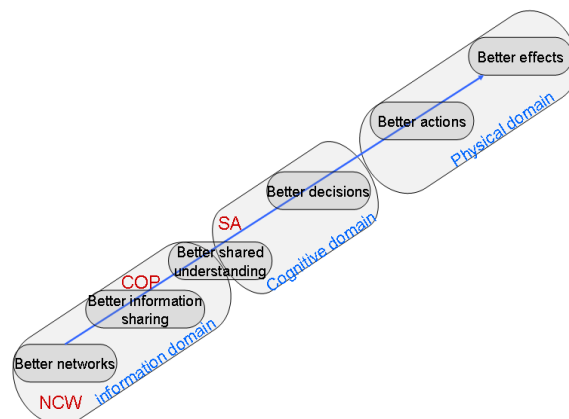


Figure-5. The value chain of Network Enabled Capabilities (NEC)
Source: [70, 76]

5. SITUATIONAL AWARENESS

Many definitions of Situational Awareness (SA) exist [77, 78]. Most of them converge that SA is about “knowing what is going on” [20]. According to Gilson [79] the concept of SA has been identified during the World War I by Oswald Boelke who understood “the importance of gaining an awareness of the enemy before the enemy gained a similar awareness, and devised methods for accomplishing this” [80, 81]. In technical and academic literature, the area did not receive much attention until the late 1980s, but thereafter diligent work has been done [81]. The aviation industry where pilots and air traffic controllers are required to develop better SA has been the driving force for research and development in this domain [82]. In this context, Nofi [83] mentions that the concept of SA entered military usage through the aviation community. Both the concepts of SA and Common Operational Picture (COP) have been employed by the military as a guiding principle to define and/or supervise warfare operations [76].

Lack or inadequate SA has been found as one of the main causal factors in accidents attributed to human error (see [76, 84-87]). For example in the aviation industry, a review of over 200 aircraft accidents revealed that their main cause was the poor SA. Despite the fact that SA has its roots in aviation, the concept is equally applicable to human supervisory control for ground based industries [88]. Some researchers criticize the concept for being very subjective [79] very intuitive and lacking a coherent definition [89] while other researchers overcome these accusations, claiming that SA is a useful concept with utmost importance for operational settings Gilson [79]. Steenbruggen, et al. [76] see SA as especially important in work domains where the information flow can be quite high and poor decisions can cause disastrous results. Klein [90] considers SA as a critical concept because: it is linked to performance; limitations in SA may result in errors; it may relate to expertise; it forms the ground for decision making. SA can be distinguished as individual or shared/team SA which will be analyzed in the following sections.

5.1. Individual SA: Definitions and Models

A commonly accepted definition of the SA of individuals is still missing [89]. In a high level of simplification, SA can be seen as an appropriate awareness of a situation [91]. Individual SA can be considered as a personal attribute [83]. The world around the individuals is approached in personal terms, based on their cultural background, education and experiences as well as on the strengths and limitations of their senses [83].

According to Stanton, et al. [81] three main definitions dominate in the literature: Endsley [92] which focuses on an information processing framework; Smith and Hancock [91] that pinpoints the reflective quality and Bedney and Meister [93] which presents an embedded world view. In essence, Endsley [92] definition focuses on the perception and understanding of the world employing future projection of its current situation. In contrast to the latter, Smith and Hancock [91] determine SA in terms of the interaction between the person and the world and hence it focuses on the way in which the two main systems cooperate. Bedney and Meister [93] pinpoint the reflective perspective of SA and in particular the relation with mental models incorporating understanding of the present system. The differences between these definitions are identified on the orientation of SA either as cognitive process used to develop and maintain SA or tangible product; as well as in terms of the underlying psychological approach.

As suggested by Stanton, et al. [81] three main theoretical approaches dominate in the SA domain: the information processing approach which is represented by Endsley’s theoretical three - level model [20] the activity theoretic approach which is best described by Bedney’s and Meister’s interactive sub-systems model [93] and the ecological approach which is delineated by the Smith’s and Hancock’s perceptual cycle model [92]. In terms of SA orientation, the interactive sub-systems and the perceptual models focus on the process while the three-level model mainly concentrates on the product. However, Stanton, et al. [81] mention that in measuring SA none of these product-process perspectives should be ignored as the latter can be determined by the former.

From the theories of individual SA, based on Salmon, et al. [94] Endsley's three tier model of information processing has been the most useful for describing SA of an operator as well as for informing system design and evaluation (e.g. Endsley, et al. [95]). In addition, Gorman, et al. [96] mention that many SA researchers have agreed in principle on Endsley's three part definition of SA. Endsley [92] defines SA as: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". Therefore, SA is about perceiving critical factors i.e. status, attributes and dynamics of relevant elements in the environment (Level 1), understanding of the meaning of these elements after being synthesized, in light of the decision maker's goal (Level 2) and at the highest level (Level 3) predicting of what will occur with the system in the near future. Higher SA levels are dependent on the success of the lower levels [97]. An extensive review of Mica Endsley's articles on SA theory and measurement can be found in Wickens [97].

Endsley's theories do not employ concepts such as COP and network centric operations in the definition of individual SA. The latter is more determined as a set of goals and decisions tasks for a certain job or activity of individuals within an organization and thus its context depends on what is the right information to support a SA environment [76]. However, when the individuals work as team members and are required to perform their tasks in a network centric environment based on individual SA, there is an interrelation between the qualities of shared SA in terms of interaction. In addition to the different SA levels of the environment, relevant is the SA of the own organization also known as organizational awareness which is defined by Oomes [4] as "an understanding of the multiple parties that make up the organization and how they relate to each other".

5.2. Shared and Team SA Backgrounds

Perla, et al. [98] mention that "With all the imprecision and debate surrounding the basic meaning of the idea of situational awareness, it is hardly surprising that the broader concept of shared situational awareness suffers from similar conceptual and semantic difficulties". In general, when actors are working together towards achieving a common goal, a "compatible" understanding of the situation is supportive Seppänen, et al. [15]. Endsley, et al. [95] introduce shared SA as the degree to which team members have the same SA on shared SA requirements where shared SA is dependent not on a complete sharing of awareness between team members, but only on a shared understanding of that subset of information which is necessary for each of their goals. Therefore, shared SA is about the level of overlap in common SA elements between team members [15]. However, each team member has specific SA requirements of its task, from which some may overlap with other team members' requirements [15]. The latter is related to what team SA is about. Endsley [20] defines team SA as "the degree to which every team member possesses the situation awareness required for his or her responsibilities". Shared SA and team SA are not the same. Endsley [99] and Endsley and Jones [100], make the distinction between the two. However for successful team performance, the individual team members should have good SA on their specific elements and simultaneously the same SA for those elements that are shared [101].

Seppänen, et al. [15] state that interaction is critical in building SA, while communication is in the heart of interaction being the driving force in the formation of an adequate shared SA. Salmon, et al. [102] identify that most researchers have focused on communication as the key component in the development of team SA. In this line, Nofi [83] finds communication as the most crucial element in the formation of team or shared SA. Endsley [20] reflects the latter by suggesting that a team member's SA of shared elements can provide team coordination or communication. Entin and Entin [103] stress that communication is a prerequisite for achieving a high level of team SA. Furthermore, Salas, et al. [104] pinpoint the significance of communication in the acquisition of team SA.

Nofi [83] point out that "shared situational awareness obviously differs from individual SA because it involves a number of persons trying to form a common picture". For the development of shared SA, Bolstad and Endsley [105] identify four factors: (1) shared SA requirements (e.g. the degree to which team members understand which

information is required by other team members); (2) shared SA devices (e.g. network systems, communication devices, shared displays and the share environment); (3) shared SA mechanisms (e.g. shared mental models) and (4) shared SA processes which is about efficient team processes that enable sharing of relevant information. However, for the development of SA for the team as a whole, Endsley and Jones [100] state that this depends on: (1) a high level of SA among individual team members for the aspects of the situation relevant to their job and (2) a high level of shared SA between members, based on an accurate common operational picture of those aspects of the situation common to the requirements of each member.

6. A COMMON OPERATIONAL PICTURE FOR EMERGENCY RESPONSE

During emergencies, agencies with heterogeneity in terms of background, specific operational expertise and professional language need to organize their actions across jurisdictional and institutional boundaries in a coordinated fashion for efficient and timely response operations [6]. In this context, a Common Operational Picture (COP) can be utilized for overcoming coordination and information management problems throughout emergency response. Following, the COP concept is introduced and its contribution to emergency response operations is explored.

6.1. Background to a COP

According to Hager [106] early studies of Common Operational Pictures (COPs) were carried out in the eighties. A major milestone was the deployment of a large group display to facilitate the development of SA in military command posts Deschamps, et al. [107]. However, as Wolbers and Boersma [17] suggest, a single definition of a COP does not exist both in the operations field and the literature. Copeland [108] stresses that disagreements exist in terms of COP considerations as it is treated as a product, process or operating environment. In the literature, two types of definitions are the most common: the first focuses on the capabilities of information distribution while the second pinpoints the need for developing an adequate level of shared understanding [17].

Based on Merriam-Webster's Collegiate Dictionary [109] a picture can be seen as a design or representation made by several means or as a description so vibrant or graphic which provides either a mental image or an accurate idea of something. Also, it can be a mental image itself. Similarly, this dictionary defines common as something that belongs to or is shared by two or more individuals or things or by all group members which has a connotation to widespread or general knowledge. Finally operational is of, or relating to, or utilized for or in operations Merriam-Webster's Collegiate Dictionary [109]. Kuusisto, et al. [110] building upon these frames, consider a COP, as a shared representation of widespread and general knowledge regarding operation.

A COP provides stakeholders with a "common picture" of the field of operations at the same time, on a terminal device at their location [106] while the operational picture refers to a predefined representation of information related to the operations. The US military Doctrine for Joint Operations [111] defines COP as "a single identical display of relevant information shared by more than one command". Furthermore, the doctrine sees the COP as a facilitator of collaborative planning which supports all echelons to achieve SA. In emergency response, COP can be seen as an auspicious solution towards improving the quality of information sharing and supporting the development of SA [21].

A COP can also be treated as a boundary object because its deployment is about sharing and building information in regards to the response operations by enabling users to constantly redefine and adapt their relationships [17]. By utilizing a COP, coordination and negotiation of the polyphony of the experts' perspectives via general procedures of exchange without making their points of view uniform or completely transparent to each other are facilitated [112, 113].

A COP often represents geographic information as typical applications are tied to a possible large geographic area (location awareness) [114]. In this line, COP is considered as a geographical representation (geo-COP)

combined with a checklist that delineates the evolution of an emergency along with the characteristics and progress of the emergency response operations. The information tailored in terms of content and detail is merged into a common frame of reference and visualized on a screen, supporting the comprehension by the response organizations of the current view of the situation [114].

The US Department of the Army mentions that a COP which may cross horizontal, vertical and functional boundaries is made of three components [115]: (1) situation maps and overlays (the current status of an emergency, the projected emergency situation and the available resources); (2) friendly battlefield resource report and (3) intelligence products. In a network centric information environment, a COP is fed with (automatically updated) data derived from different sources such as reconnaissance and surveillance assets, emergency response teams in contact, intelligence acquired from analysis, information from higher echelons and estimates about incomplete information [116]. By employing networks as well as emerging technologies, the different emergency response organizations can use current positional information to obtain the desired operational picture on one display. Access to a common picture that displays the evolution of an emergency and the progress of the response operations can enable these organizations to collaboratively plan and execute comprehensive tactical operations [106].

In emergency response operations, a COP depicts static information predetermined in the preparedness phase of emergency management as well as dynamic information related to the evolution of an event which needs to be shared between different emergency response chain members (see table 3). It may contain geographical displays of emergency resources and assets, alternative evacuation routes as well as other tactical information all on a single display. In essence, a COP contains elements common to all the types of emergencies as well as critical variables which can be extracted at the time of the event through different sources of information including emergency responders. For example, by taking advantage of inputs from different intelligence sources all the deployed units in the field of operations can be mapped in real-time [117]. Therefore, with the suitably implemented information/knowledge management services, all the relevant to an emergency factors can automatically be incorporated into a comprehensive, real time description of the present and future needs, which may include availability of resources and assets, their appropriate deployment and field control i.e. actionable knowledge (see Lubitz, et al. [54]). In short, Hager [106] mentions that a COP displays all acquired and combined data derived from different means in a single presentation to the user. As a consequence of realizing a COP, SA can be increased because every emergency responder can have the same information regarding the evolution of an emergency and the progress of the response operations.

Regarding the role and the function of a COP within multi-agency operations, McMaster and Baber [118] suggest that there are several perspectives. The potential alternatives of a COP are delineated in table 4. However, for facilitating multi-agency planning and implementation of response to a complex environment, the distributed cognition point of view can be seen as the only one in which the COP product becomes part of the decision making process enabling the different agencies to share multiple perspectives on the problem and achieve a common understanding of the situation [118].

Table-3. Examples of common and variable elements included in a COP.

COP considerations	Common elements	Specific elements (related to an emergency)
Incident/Disaster	<ul style="list-style-type: none"> Digital maps at national level which include hazards, vulnerable objects and risk analysis results related to different potential types of events. 	<ul style="list-style-type: none"> The nature and the magnitude of the critical event; Geographic location of the event, size of the affected area, location and magnitude of the affected population.
Networks (e.g. streets)	<ul style="list-style-type: none"> Networks infrastructure is depicted in maps; Networks accessibility, condition and capacity are known; Alternative evacuation routes are predetermined during the preparedness phase of emergency management. These take into account the nature of a potential emergency, estimated numbers of evacuees based on the population of different areas as well as time availability for the evacuation. 	<ul style="list-style-type: none"> The maximum size of an area affected by the emergency and consequently the networks became or about to become inaccessible; Degraded and destructed networks due to event related conditions, weather; Non-forecasted networks' degradation due to traffic congestion.
Resources	<ul style="list-style-type: none"> Material resources such as ambulance and police vehicles, fire brigade engines, trucks, aerial means, supplies. 	<ul style="list-style-type: none"> Degradation due to event related specific factors which can cause for example damage of the resources, inaccessibility of the place(s) in which they are located; Due to allocation of the emergency resources to the response operations' scene, the number of the available resources changes dynamically as the response operations escalate.
Assets	<ul style="list-style-type: none"> The number of personnel in all categories (e.g. policemen, firemen, field medics, support staff) available for deployment to the response operations' scene is known; Personnel requirement for traffic control, barrier maintenance, evacuated territory security patrol; Deployment sites for personnel predetermined in the preparedness phase of emergency management; based on different types of events with different magnitudes and the associated evacuation sizes. 	<ul style="list-style-type: none"> The required personnel number for the emergency response operations which depends on the nature of the event. Due to allocation of the personnel to the operations' scene, its availability changes dynamically as the response operations escalate. The unavailable personnel who are unable to reach the deployment sites due to specific factors related to the evolution of the emergency.
Shelters/ Healthcare Units	<ul style="list-style-type: none"> Location and capacity of available short/long term shelters and field medical facilities as well as optimal access routes predetermined during the preparedness phase of emergency management; Location and capacity of local and national healthcare resources/advanced treatment facilities and triage/treatment/evacuation plans. 	<ul style="list-style-type: none"> Need for ad-hoc facilities arising from the evolution of an event; Unavailability of facilities due to event-related specific factors (e.g. location within a radius of influence, damaged).
Spatial models' outputs	<ul style="list-style-type: none"> Simulations' forecasts based on hypotheses related to different types of emergencies. Risk maps are based on such forecasts. 	<ul style="list-style-type: none"> Forecasts based on dynamic inputs (real observations) derived from the evolution of an event.

Source: (Adapted from Lubitz, et al. [54])

Table-4. Potential roles and functions of a COP.

Nature of interaction	Product	Process
Passive	Static view	Live COP (observe the dynamic COP as it is updated)
Active	Demand feeding (COP as the product of information, surveillance, target of emergency response operations acquisition and reconnaissance).	Distributed cognition (process of command driven by the COP).

Source: (Adapted from McMaster and Baber [118])

A robust network for information sharing can contribute in achieving shared SA based on a COP which in turn will result in improved decision making. Nevertheless, in order the emergency response organizations to gain maximum advantage from the network centric working logic; they should attempt to implement self-synchronization which can lead to improved use of capabilities to control the situation. Self-synchronization needs a level of shared SA which means cross-domain SA as well as SA across domains Ven, et al. [119]. To achieve shared awareness, all teams are required to share information and share understanding of the situation [67]. Self-synchronization is described in a maturity model (see figure 6) suggested by Alberts, et al. [66]. In essence, this model proceeds from the traditional command and control process (Level 0) to self-synchronization (Level 4).

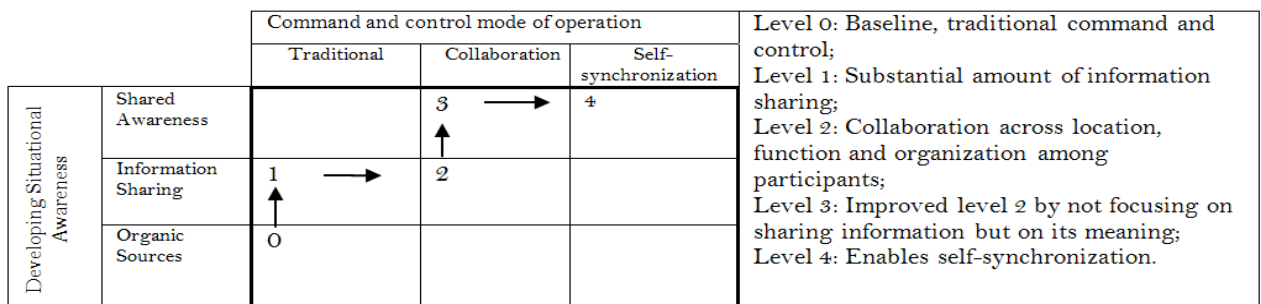


Figure-6. Network-Centric Maturity Model.

Source: (Adapted from Alberts, et al. [66])

The implementation phase of network centric working for achieving shared SA based on a COP by the emergency response organizations is not easily described. In order to move on to the different levels of the maturity model, the focus of the response organizations should not only be on technical capabilities but also on the preparation and training of the emergency responders employing operating procedures which will eventually enable their self-synchronization. The latter is not always easy as it may stumbles upon legal issues related for instance to the structure of the emergency response organizations. Emergency response organizations have to become capable in responding to an emergency using network centric approach for information sharing as it intends to improve information processes, communication and coordination leading to the development of a COP-based shared SA. However, this requires the development of individual network centric capabilities in the emergency response stakeholders' cognitive domain.

6.2. Challenges in Achieving a COP

Coherent, accurate and timely SA as well as vertical and horizontal information integration at all command levels; they enable the emergency responders to share common knowledge at the operations' field. However, one of the major challenges is information overload [120]. In the context of a COP, all information is made available to everyone, but not all information is relevant to the tasks of the different emergency organizations [106]. Also,

different command levels do not need the same level of detail and hence it must be determined which level of information is relevant to their duties.

Coordination between actors with heterogeneity in terms of institutional background can be seen as a process of dialogic coordination where professionals can confront their different professional languages via scientific contestation achieving collective sense-making [121]. However, during complex emergencies, responders should make rapid coordination decisions in order to support fast response [122]. Achieving a shared goal among the emergency responders in a limited amount of time, it is extremely challenging due to the dynamic nature of the emergencies where the situation continuously changes and the goal becomes outdated. As a result, the responders frequently do not share information because from their perspective, they consider this information no longer significant or even outdated. This can lead to a dynamic information sharing situation constantly in flux, but dependent on the perceived by the response actors' information relevance [17].

An extensive literature survey demonstrates that emergency response organizations struggle with information sharing, communication and coordination [10, 17, 21-23]. Furthermore, Wolbers and Boersma [17] based on empirical research mention that despite the fact that emergency response organizations rely upon each other's information to align work processes, they do not share information tending to operate within their own professional boundaries.

Information management can play a critical role in addressing the coordination and information sharing problems between the involved organizations' boundaries [123, 124]. Information management can also be seen as both the problem and the solution for adequate SA to support coordination [17]. However, emergency response organizations may attempt to solve the information management problems through information systems which support its users to reach shared SA by deploying a COP [20, 21]. Such systems can be derived from the logic of Network Enabled Capabilities (see section 3) [18].

6.3. The Added Value Service of a COP in Emergency Response

The familiar three Cs (Communication, Coordination and Control) of emergency response necessitate an interdependent, evolving process of organizational management. In the language of practice, creating a COP is crucial for clear communication and coordination of actions as it enables the achievement of a sufficient level of shared information among the different organizations participating in emergency operations. In particular, a COP enables data fusion providing a collection of correlated recognized pictures which facilitate a shared picture of operations [125, 126]. In this way, all the involved actors can understand each other's constraints as well as the potential combinations of collaboration and support among them under a given set of conditions [21].

SA is about how individuals and teams know and comprehend what is going on around them [127]. Furthermore, good SA provides a firm ground for effective decision making. The development of this good SA is facilitated through the deployment of an effective COP which visualizes the relevant information [128]. Furthermore, a COP can ease collaborative planning and it can support several levels of command across the various agencies involved in an operation to achieve shared SA [118]. On the contrary, Comfort [21] stress that the lack of a COP tend to drive the emergency response operations to a hierarchical structure of control, fact that creates asymmetry in the information processes. This asymmetry results from the fact that organizations with higher level of responsibility and authority transmit their orders to lower levels without having any operational feedback from the ground of field operations outside the formal chain of command. Thus, a COP tends to support the development of a shared perspective on priorities for emergency operations.

For achieving shared SA based on a COP between different emergency response organizations, systems underpinned by the network centric working logic must be employed. The relation between the NEC value chain components and the emergency response process phases (adapted from Zwaneveld, et al. [129]) is attempted to be demonstrated in table 5. The basic idea is that better networks can lead to better information which feeds detection,

warning and verification processes, which in turn can contribute to the development of better situational interface. Better information leads to improved response by the emergency organizations which in turn it contributes to the more efficient utilization of resources and assets so that better actions can take place in the field of operations. Better actions lead to better outcomes i.e. faster normalization of the situation and hence minimization of the incident's or disaster's consequences (socioeconomic and environmental losses).

Table-5. The NEC value chain components and the emergency response process phases.

NEC value chain		Emergency response phases	Benefits
BETTER	Networks	Technical infrastructure	Emergency organizations and responders
	Information sharing	Detection, warning	Better situation interface
	Shared understanding	Verification	Based on better situation interface
	Decisions	Respond, driving and arrival	Optimal use of resources and assets
	Actions	Site management operations	More efficient response operations
	Effects	Normalization	Faster treatment of the situation and minimization of socioeconomic and environmental consequences

Source: (Adapted from Steenbruggen, et al. [76])

For measuring the added value service of SA for emergency response, a 3D cube (see figure 7) is introduced which bases on: 1) SA levels derived from Endsley's definition (see Hone, et al. [130]) SA components of emergency response; 3) emergency response process phases (adapted from Zwaneveld, et al. [129]).

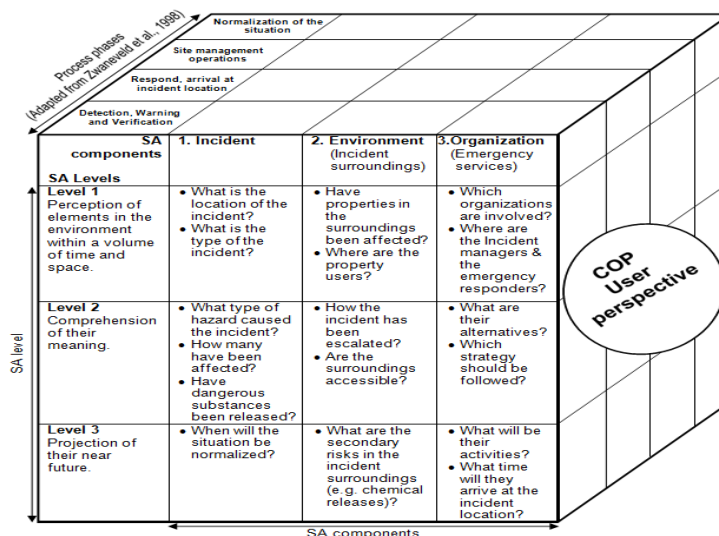


Figure-7. 3D cube for measuring Situational Awareness for emergency response
Source: (Adapted from Steenbruggen, et al. [76])

The proposed 3D cube can form the basis for quantitative and qualitative measurement of the value added service of a COP in supporting emergency response processes between the involved organizations. The qualitative aspects focus on the economic effects in the sense of reduction of losses and casualties which may result from a false detection of an incident or disaster. The quantitative aspects focus more on cooperation, system and information quality [76, 131-134].

7. CONCLUDING REMARKS

Emergencies are unique, dynamic and complex situations where it is virtually impossible to forecast their evolution. Furthermore, during the emergency response operations several teams coming from different safety

organizations with different backgrounds, cultures and goals have to cooperate in order to minimize the negative impacts of an emergency in terms of human injuries and casualties, environmental disruption and economic losses. Nowadays, information systems have become increasingly important in supporting emergency response tasks which can range from management of routine and small scale incidents to the more severe and large scale disasters. Nevertheless, information sharing between different emergency response organizations is still in its infancy. Noteworthy is that one of the primary factors in accidents attributed to human error is the lack or inadequate information which limits situational awareness [125].

For effective response, flexible information and communication systems which facilitate communication and coordination not only within but also among the multiple teams involved are required. In this context, the concept of network centrality which is rooted in the military domain, it can be seen as a vehicle towards better information sharing which in turn can support faster decision making and enhanced spatiotemporal organization of resources and assets in the increasingly fluid environment of the emergency response. In particular, by working in a network centric way, information sharing advantage can be gained through technology and effective network mechanisms delivered for geographically dispersed resources and assets. Military battlefield situations can be as chaotic as emergency response operations and they may require even faster response times. Therefore, the concept of network centrality can be adapted from the military field and it can be applied for emergency situations tailored to their specific conditions towards creating a surplus value for the response operations. However, the successful adoption of such a concept requires its careful introduction in different stages based on a maturity model. In addition, it requires training of the emergency response stakeholders in order to overcome potential lack of knowledge.

Network centric information systems facilitate networking of emergency response stakeholders towards achieving operational effectiveness as well as integration of new information derived from multiple sources with other knowledge. Furthermore, they enable unobstructed flow of information and knowledge among the entirety of the emergency response administrative structure. Instead of information passed vertically within the command chain where it may be lost or even discarded, it is circulated freely among all the involved emergency response actors. In essence, the information shared for developing a common operational picture is conveyed to all the parties involved in the operation, the field team and people in the command post. As a consequence, while officers at the uppermost levels of the involved safety agencies are aware of the real time conditions at the emergency response site through a common operational picture, the field personnel can have readily access to tactically relevant information if needed as much as to this common operational picture, if such may affect their operations. In general, by incorporating the network enabled capabilities in emergency response, the attributes and flexibility needed by adaptive management can be facilitated, which as suggested by Wiese [51] it can be the most effective management approach to potential disasters.

Data acquisition from multiple sources and dissemination of the collaborative information through network centric systems contribute to the development of a common operational picture which can support all the responding units to have the same understanding and awareness (shared situational awareness) of information and emergency status when conducting operations. Thus, network centric systems and a common operational picture are basic components to achieve improved situational awareness. Developing shared situational awareness in the complex and dynamic environment of an emergency, it can drive to self-synchronization and better coordination of the emergency response stakeholders. As a consequence, operational risk can be reduced and at the same time the total performance of decision-makers as well as the speed of operations and responsiveness in the physical domain can be increased towards improving mission effectiveness.

In the context of emergency response, the criteria which should drive the design of information systems in order to meet the requirements of the end-users, they go beyond the technological capabilities. Such information systems must satisfy the information requirements of the emergency response agencies but also they should support cognitive and psychological capabilities in the information-rich and complex dynamic environment of emergency

situations. In particular, special attention needs to be paid to the cognitive domain. Humans are limited by working memory and attention. New information from multiple sources must be integrated with other knowledge. How people direct their attention when acquiring new information has a fundamental impact on which elements are incorporated in their situational awareness. Therefore, network centric information systems should be designed to support working memory and attention which in turn they can assist in addressing information overload. Otherwise, the limits of working memory can cause constraints on situational awareness [92]. Furthermore, as not all the information is relevant to the tasks of all the safety agencies, a comprehensive inventory of which information is relevant for each safety organization needs to be done towards preventing information overload.

In short, a common operational picture achieved through network centric systems, it can contribute to create shared situational awareness towards faster normalization of an emergency situation. Hence, it can be seen as an emergency response tool with an added value not only in effective sharing of information but also in understanding the real meaning and the temporal value of the required and used information for the operation, communication and coordination processes. In the cognitive domain, technology combined with organization, processes and people can provide efficient decision making behaviors with better actions and effects in the physical domain. This article has shown through an extensive literature survey from different domains and perspectives that the utilization of a common operational picture is a promising instrument for smart emergency response. However, more work still needs to be done towards empirically measuring in a statistical consistent way the added value of incorporating such systems in emergency response operations. Furthermore, not only training of the emergency response professionals in a network centric way of thinking and handling of information is required, but also the institutional and legal implications of utilizing such networks for sharing and exchanging information between the involved safety organizations have to be addressed.

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