Shared Situational Awareness in Emergency Management Mitigation and Response

John Harrald
Institute for Crisis, Disaster and Risk Management
The George Washington University
jharrald@gwu.edu

Theresa Jefferson
Institute for Crisis, Disaster and Risk Management
The George Washington University
tjeff@gwu.edu

Abstract

The US is replacing its historical federalist concept of emergency management where primary responsibility resides with state and local governments and their emergency management and first responder resources for coordinating emergency response and recovery, supported by the resources Federal government (coordinated by FEMA) with a Homeland Security National Response system where response to events is controlled by DHS using a military command and control model. This model assumes that those controlling and coordinating the response and recovery will attain and maintain an accurate, shared common operating picture and situational awareness. The objective of this paper is to discuss why the transfer of this concept from its safety and combat origins to the complex, heterogeneous emergency management structure of the United States will be exceedingly difficult, and that short term strategies based on the assumption that shared situational awareness will be easily achieved are doomed to failure.

1. Introduction

Both the definition of situational awareness and the use of the term have evolved considerably. This paper will present a brief history of the term situational awareness, along with its past and current use. It will then explore current assumptions concerning shared situational awareness in response to extreme events. Historically, the United States has relied on state and local governments for coordinating emergency response and recovery to extreme events. The Federal Government has traditionally taken a supporting role. Following the fallout of resent disasters such as Hurricane Katrina, the US is adopting a considerably different approach. This will be one of a Homeland Security National Response system where response to events is controlled by the Department of Homeland Security (DHS) using a military command and control model. This model assumes that those controlling and coordinating the response and recovery will attain and maintain an accurate, shared common operating picture and situational awareness. The objective of this paper is to discuss why the transfer of this concept from its safety and combat origins to the complex, heterogeneous emergency management structure of the United States will be exceedingly difficult, and that short term strategies based on the assumption that shared situational awareness will be easily achieved are doomed to failure.

2. Defining situational awareness

The term "situational awareness" is not present in the Merriam-Webster OnLine dictionary. However, the following definitions are provided for situation and awareness:

<u>Situation:</u> position with respect to conditions and circumstances (the military situation remains obscure), relative position or combination of circumstances at a certain moment [1]

<u>Awareness</u>: having or showing realization, perception, or knowledge [2].

The following definition of "situational awareness" was taken from WIKIPEDIA, the free encyclopedia.

<u>Situational awareness</u> is being aware of everything that is happening around oneself and the relative importance of everything observed — a constantly evolving picture of the state of the environment. Situational awareness can be described broadly as a person's state of

knowledge or mental model of the situation around him or her.

Situational awareness is important for effective decision making and performance in any complex and dynamic environment.

It was originally an aviation term used to describe awareness of tactical situations during aerial warfare. It has now been adopted throughout aviation, and increasingly in other dynamic, complex, situations requiring human control. A general, widely applicable definition describes situational awareness 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" [3]. Endsley discusses three levels of situational awareness.

- **Level 1** situational awareness involves perceiving critical factors in the environment. Often this information will come directly from an individual(s) that is actively sensing the environment. This can include visual perceptions, such as seeing smoke, auditory perceptions, such as hearing an explosion, tactile perceptions, such as feeling the earth rumble, as well as verbal and nonverbal communications with other individuals.
- **Level 2** situational awareness understanding what those factors mean, particularly when integrated together in relation to the decision maker's goals. This requires integrating the somewhat unrelated factors from level one to develop a prioritized list of the combined information's significance and its meaning with respect to the objectives of the decision maker. This implies not only seeing or hearing data but being able to correctly understand the meaning of information. In order to obtain this level of understanding a fairly developed knowledge base or level of experience is required to allow the synthesis of of disparate data nuggets. Therefore, an individual who has limited experience in a given situation may have a difficult time obtaining this level of situational awareness.
- **Level 3** situational awareness is the highest level, an understanding of what will happen with the system in the near future. This means obtaining the data in level 1, understanding its meaning (level 2) and predicting what will happen. This prediction can only be accurate if it is accompanied by a high level of domain expertise. However, domain expertise alone is not enough, it is important there is adequate mental resources, that is to say that the predictor is not overloaded with other information processing tasks [3, 4].

The Navy Aviation Schools Command defines situational awareness as:

> Situational Awareness refers to the degree of accuracy by which one's perception of his current environment mirrors reality [5].

From the above it is obvious that situational awareness, by definition, has an information component, a perception component and a meaning component.

To provide the information component required for situational awareness, the system must be capable of collecting, filtering, analyzing, structuring, and transmitting data. Situational awareness is not only the correct perception of reality, it the correct perception of the relevant elements of the current reality necessary for correct, protective, tactical, and strategic response.

3. Requirements of situational awareness

The information component of situational awareness depends on both the particular domain and the users' dynamic information needs. To determine the information required it is necessary to focus on the basic goals of the decision maker and the major decisions that they need to make to achieve the goals. From the information required it is then possible to determine the individual data nuggets that need to be collected. This emphasizes one of the difficulties with obtaining situational awareness; developing static and anticipated goals. A few general characteristics can be stated about data requirements.

- Collect the data required to satisfy the decision makers goal. The data collected needs to directly support the decision maker in arriving at their objective. While there is often more data collected that is actually required it is important to group and present the data as information that can be directly used to achieve a desired result. Fore example, if the users goal is determine an appropriate evacuation route, some of the data to support this goal could be damage reports for bridges. While the detailed data would present types of damage, severity, etc., the information presented to the user should be focused on bridge usability.

- Data collected should be the attributes necessary to sufficiently describe a required piece of information. For example if an information requirement was a damage report, data collected might be current condition, location, and circumstance (or type).
- Data must provide the ability to describe relationships between things. In the above example, instead of simply a damage report the information needed could be evacuation destinations (relative positions, combinations of circumstances).
- Data must provide the ability to link the attributes for any given piece of information to time. It is important to maintain a timeline of what changes occurred in data values. This will allow the user to obtain Level 3 situational awareness by being able to predict future states.
- Data must be of sufficient quality to meet the decision making and action needs of the moment—completeness, timeliness, accuracy, consistency.

To provide the meaning component of situational awareness, the recipient of the information must be able to accurately perceive the situation described. The act of perception is a function of contextual information, experience, and cognition of the receiver. (In an emergency situation all data is incomplete, therefore the receiver must have the ability to perceive reality based on limited information.) The recipient must also have the ability to understand, integrate, and structure the information provided so that they can transform it into knowledge that represents an accurate picture of the situation and its meaning and allows for the appropriate action. Figure 1, adapted from Ntuen, 2005, details this process[6].

The knowledge acquired from the raw data should allow the decision maker to answer questions such as:

- What are the future implications of the current state?
- What interventions are necessary?
- What are the implied decisions to be made? And finally, what actions are to be taken?

The production of knowledge, along with the imputing of meaning, require trained, experienced receivers.

The terms "common operating picture" and "shared situational awareness" imply that (1) technology can provide adequate information to enable decision makers in a geographically distributed environment to act as though they were receiving and perceiving the same information, (2) common methods are available to integrate, structure, and understand the information, and (3) critical decision nodes share institutional, cultural, and experiential bases for imputing meaning to this knowledge. The first two steps are necessary for the common operating picture, all three are required for shared situational awareness.

4. History of Situational Awareness

The term situational awareness was first used in aviation safety. Most of the related research has been conducted in military aviation [7][8]. The majority of aviation accidents have a human error causal component. Many accidents due to "pilot error" can be attributed to a loss of situational awareness, the pilot loses the ability to accurately perceive reality using information sources available (e.g. Tenerife

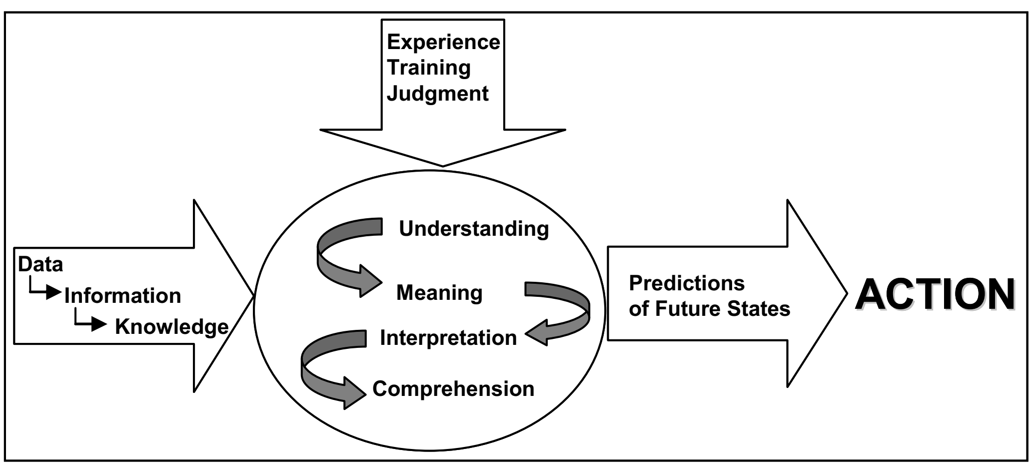

Figure 1. Transformation of data into action

accident). There has been a great deal of effort put into designing instruments that improve the information provided and training programs aimed at improving the ability to process information and to utilize the entire cockpit team in order to improve perception. These concepts are embedded in aviation cockpit management as well as maritime bridge team management.

The concepts of shared situational awareness and common operating picture have been adopted by the military as a whole as a guiding principal for combat operations [9]. This concept has also been adopted as a goal for law enforcement, firefighters and other first responders.

In the US, emergency management is absorbing military concepts and constructs as a consequence of its placement in the context of homeland. Shared situational awareness is one such construct. The terms are being used in planning documents and tool development for emergency management projects which are being funded by DHS. An example of one such project being conducted by ITR-Rescue at California Institute for Telecommunications and Information technology is SAMI (the Situational Awareness from Multimodal Input) [8].

The DHS Concept of Operations Plan for the 2006 Hurricane Season assumes an ability to create a "single Federal information sharing and management portal to ensure situational awareness of the common domestic operating picture", and states that DHS will "emphasize maintaining situational awareness of the common operating picture and total asset availability" and it will "maintain comprehensive, near real time situational awareness of the common operating picture". The plan describes the common operating picture, relying heavily on terminology more common to military doctrine than to emergency management plans, as follows:

> "The cornerstone of information superiority, at all tactical levels of an Incident and/or Unified Command, is a robust, continuous, common operating picture of the in-theater operational environment. The resulting heightened situational awareness vastly improves the effectiveness with which Incident Commanders at all levels can pursue, and accomplish, a mission. The common operating picture can allow tactical decision making at the lowest levels of command consistent with the higher level commander's operational objectives and the decentralized tactical execution can enhance the ability of lower level tactical units to react quickly to changing circumstances. One of the most significant challenges facing incident commanders is the ability to predict the escalation of an incident from a low level to a high level, and the point at which various types of multi agency and/or multi jurisdiction coordination would be required. As the response level of an incident increases, additional operational agencies become involved, requiring agency to agency communication in addition to person to person communication. Interagency communication and coordination, augmented by situational awareness provided by a common operation picture are critically important in the management of an event [10]."

Figure 2 shows the evolution and adoption of the concept of situational awareness.

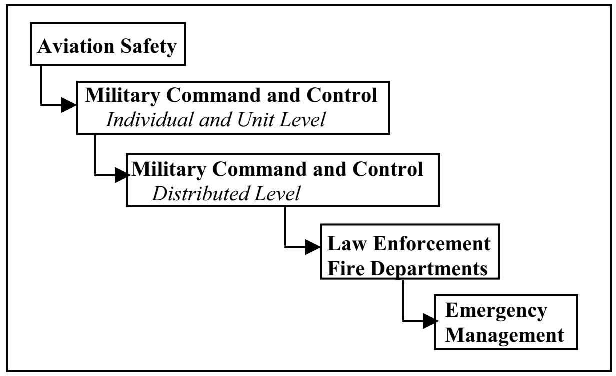

Figure 2. Evolution and adoption of Situational Awareness

5. Implications

A number of problems concerning the interpretation of data are encountered when moving decision making from (1) individuals in homogeneous groups at the same location to (2) distributed homogeneous groups and finally to (3) dispersed non-homogeneous groups.

- Disparate semantic meaning of the data collected
- Inadequate ability to ensure or even know data quality (particularly the timeliness and completeness components)
- Even when given the same data, non-homogeneous decision nodes will perceive the information differently
- Even when given the same data, and similar perceptions, different nodes will imply different meaning and requirements for future action

5.1. An example: Dealing with situational awareness during a catastrophic

At 4:03 am on a Monday morning in March, a magnitude 7.3 earthquake occurs on the Hayward fault with an epicenter very near the University of California, Berkeley. The Hayward fault event is not unanticipated, and has been studied by scientists and emergency managers for years. However, in the darkness and confusion surrounding the early morning hours it is difficult to get an accurate picture concerning the event that has just occurred.

Officials from the State Office of Emergency Management in Sacramento, CA as well as those from FEMA and DHS in Washington, DC get their initial situational awareness from prior modeling results: the Association of Bay Area Governments, FEMA, and the State of California have developed loss estimation models for this scenario. Initial estimates are that over 100,000 dwelling units are severely damaged in the bay area, primarily in Alameda and San Francisco county. The models predict that almost 400,000 people will be displaced and will need food and water and 110,000 will need emergency shelter. Oakland and San Francisco airports and the Port of Oakland are expected to be closed as are major interstate highways (I-80, I-580, I-880, Highway 13, Highway 101) and bridges (Bay Bridge, Dumbarton Bridge, Richmond—San Rafael Bridge). Models developed by the University of California, Berkeley predict severe damage to that institution. Significant casualties are also expected.

The information generated from the models enables the DHS Secretary to declare an Incident of National Significance and to activate the Catastrophic Incident Annex of the National Response Plan and to deploy specialized resources (e.g. Rapid Needs Assessment Teams, FEMA advance teams, Urban Search and Rescue Teams, NDMS teams, Disaster Mortuary Teams) and to begin the mobilization of both government and Red Cross resources. The problems associated with a "common operating picture" and "situational awareness" begin almost immediately. Due to bridge and highway failures and communications problems, the Bay area has been transformed into four or five disconnected and isolated islands. Initial communications with FEMA Region Nine are restricted to satellite phone. Although Travis Air Force Base is open, emergency managers are unable to get a clear picture concerning where the greatest needs are, and how to get there. Rain and fog impede overflights and satellite imagery during the first morning and scattered reports from citizens, media and responders from the area are conflicting and vague. For example, reports have been received that the Bay Bridge is "down" but no one in Washington or Sacramento knows if that means the bridge has collapsed, a section has collapsed as occurred during the Loma Prieta earthquake, or if an on ramp is closed. Similarly, unconfirmed reports have been received from the media that there are "thousands" of casualties at UC Berkeley, and that people are trapped in collapsed buildings in Oakland. In Washington, the Homeland Security Operations Center (HSOC), the FEMA National Response Coordination Center (NRCC), and the White House Homeland Security Council have delivered conflicting initial assessments to the President (FEMA's assessment based on HAZUS model output, DHS based on initial reports from the media, NORTHCOM, and the state of California OEM, the HSC based on conversations with the Governor of California). The HSOC and the NRCC were operationally, but not physically, combined after Hurricane Katrina into the National Operations Center (NOC). The Berkeley earthquake is demonstrating that the two operations centers are still operating independently. The DHS Secretary has convened his interagency Incident Advisory Council and is receiving information directly from senior officials and from other cabinet officials (e.g. health and medical information including status of medical assets in the region processed through the DHHS EOC). The President's Homeland Security Advisor has convened the Domestic Readiness Group (DRG) to provide policy advice to the President and to the DHS Secretary.

Even after communications are established, the situational awareness problems persist. The Homeland Security Information Network (HSIN), developed to provide uniform, richer, information sharing capabilities and collaborative tools has been overwhelmed. Information available through HSIN is not quality checked and is inconsistent, inaccurate, and incomplete. The information available is changing rapidly and it is difficult to determine the source or timeliness of the information. In particular, GIS imagery is available on HSIN from several sources (State of California, USGS, FEMA), and different images convey different information. There is no process for updating and date stamping situational information as reports from the field, ground truth, initial estimates produced by models, media, and rapid needs assessment teams. In particular, status of critical infrastructure (e.g. road closures, water availability, sanitation) is difficult to determine since reports are using non standard, non technical, and inconsistent language. First responders and infrastructure managers, engaged in critical life safety and lifeline repair tasks cannot provide consistent or complete information. Managers in the NOC are suffering from information overload and are beginning to narrow their focus to one or two sources of situational information, a typical human response (typically CNN and one source from the field…HSOC is relying on reports from the state OEM, the NRCC is relying on the FEMA advance Emergency Response Team. The pre-designated Federal Coordinating Officer has been briefed by the NRCC and has been deployed to Travis as has the pre-designated Primary Federal Official (after briefings from DHS HSOC) and the pre-designated Defense Coordinating Officer (after briefings from NORTHCOM)).

The White House DRG is collecting information from all available sources. On day 2, as a Joint Field Office and unified Federal/State command is established in Sacramento it is apparent that the operating picture of the President, the DHS Secretary, the Governor, the PFO, the FCO, and responders on the ground in the bay area do not have a is not yet a common one. It is also clear, that even where there is common understanding of situational information, substantial differences exist in meaning attributed to that information depending upon the background, experience, and organizational responsibilities of the manager/decision maker.

The above example illustrates several problems in trying to achieve a common operating picture and shared situational awareness among the heterogeneous responders to a complex, catastrophic event.

5.2. Problems achieving a common operating picture and shared situational awareness

Endsley, et al define 8 common pitfalls that often occur when attempting to obtain situational awareness on an individual level.

- Attentional Tunneling - the user locks in on certain aspects/features of the environment they are trying to process and begin to exclude other information sets
- Requisite Memory Trap - the user reaches their limit in working memory
- Workload, Anxiety, Fatigue, and Other Stressors – these factors will decrease the user's limited working memory, diminishing their ability to collect and filter information, resulting in erroneous decision making
- Data Overload – the users ability to process information becomes saturated
- Misplaced Salience - false alarms, less important information, etc,, distract from vital information
- Complexity Creep - as systems become more and more complex the users ability to understand the information offered prevents them from forming appropriate mental models
- Errant Mental Models - errant mental models result in limited comprehension and the inability to anticipate future events
- Out-of -the-loop Syndrome – as the system become more automated individuals are left out of loop, thereby reducing the overall situational awareness [14].

As we move from an individual or narrowly focused operating picture to that of a common operating picture with shared situational awareness the pitfalls/problems increase. The environment changes from one where decision makers are operating on a level playing field, with shared backgrounds, organizational culture, goals, and training to one where the decision makers have very diverse backgrounds, training, goals, etc.

Problem 1: Semantic meaning of data concerning impacts that are collected from multiple sources—e.g. local jurisdictions, press, citizens' reports:

- Damage reports to structures
- Power, communications infrastructure reports (outages)
- Physical infrastructure reports (bridges, roads, levees, ports)
- Secondary incidents (fires, toxic releases, oil spills)
- Casualties (injuries, deaths)
- Displaced people

What are the semantic meanings people use when reporting….e.g. is there a shared meaning of a "damaged house" or "displaced person"? What does it mean to report that a bridge or road is "out"?

Problem 2: The quality of the incoming data.

- How complete is the data? If it is only partial data, is it comprehensive partial data or complete data on a portion of the area? In the early stages of a disaster, a comprehensive picture of the situation is required. Detailed local information is less useful that coarser, global reports.
- What is the timeliness of the report? Is the data time stamped, can data be compiled to get an accurate picture of the event at any point it time?

- What is the consistency of the data? Are the same entities being reported from all sources?
- What is the accuracy of the data? What sources should be trusted? How is contradictory data reconciled?

Problem 3: Selecting relevant meaningful data and integrating the information given the semantic and quality concerns addressed in problems 1 and 2.

- What criteria is used to select "meaningful" data?
- Who determines this criteria?
- If it is possible to determine such a criteria, what is the role of intelligent agents in this process and can they be seamlessly and appropriately integrated?

Problem 4: Ensuring consistency concerning the perceptions of information.

- Taking advantage of the various methods for displaying information
- Taking into consideration context, bias, experience, etc.
- Taking into considering, stress level of individual and group decision makers
- Compensating for organizational culture and individual experience.

Problem 5: Ensuring that decision makers infer a consistent meaning and implications for required action. The construct of meaning must compensate for non-homogeneous institutions required to make decisions and take actions. The organizational cultures of Federal agencies (FEMA, DHHS, DOJ, DOD) are markedly different as are the cultures of other organizations involved, i.e., the Red Cross, State agencies, other not for profits and private sector organizations.

6. Implications and conclusions

Current practices assume that the solution to emergency management is to collect and transmit as much data as possible and then combine the data into summary reports, thereby enabling decision makers to have the information that they need to take appropriate actions. The assumption is that data is the only barrier to appropriate action. As a result of the devastation associated with Hurricane Katrina, the Federal government is focusing on collecting an ever increasing amount of data. The idea is that once the numerous information systems are operational the only thing necessary to obtain the information needed to make an accurate decision is the interoperability of these systems. "Data interoperability" is assumed to be the path that leads to a "common operating picture" and "situational awareness".

As this paper points out this view completely ignores the semantic meaning of data. It does not consider the way that information needs change during an extreme event and that the emphasis on quality, timeliness, and accuracy will also change at various points along the disaster timeline.

An example was presented that illustrates the problems that will arise when too much emphasis is put on the data transformation process and not enough is put on the sensemaking process. It illustrates that a strategy that ignores the heterogeneous organizational and cultural dimensions of emergency management is more likely to result in information overload than situational awareness. Another question that emerges is, what is the actual role of shared situational awareness. It must be recognized that not all actors involved in the response and mitigation to an extreme event will require the same information. When attempting to consolidate information to obtain a shared situational awareness there is a very real possibility that information that is relevant to one or more parties will be inadvertently left out.

The complexity of a National organizational system precludes tactical control from a centralized emergency operation center. Transferring military command and control concepts and protocols to heterogeneous organizations, faced with complex civil problems, without the training, culture, and resources of the military is a difficult if not impossible process. More importantly, the effort to make emergency management technology and structure mirror the military is unnecessary and potentially misguided Emergency managers need an information and communication technology structure that will support creative, adaptive behavior throughout a distributed decision making network. This technology should enhance the ability to transfer, analyze, verify, and display information to enhance collaboration and coordination, not to support organizational control. Problems encountered during the response to extreme events are unique and often unanticipated and the appropriate behavior is often improvised on scene [15].

The inevitable failure to obtain and maintain a common operating picture will impede a response in rigid command and control system. However, shared situational awareness is not a necessary precondition for enabling and supporting the decisions and behaviors necessary for successful reaction to and management of the unexpected.. The technological systems we create must enhance, not impede this organizational agility.

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