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SITUATION AWARENESS REQUIREMENTS ANALYSIS FOR SENSOR ANALYTICS DISPLAY TO FIRST RESPONDERS

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Project C: Situation Awareness Requirements Analysis for Sensor Analytics Display to First Responders

Project Report

Achieving adequate situation awareness (SA) is a difficult and critical challenge during the initial response to any emergency. Situation awareness as applied to emergencies can be described as “the degree that people responding to an emergency (1) are aware of the situation in which they find themselves, (2) understand the meaning of the situation as it reflects their abilities to pursue goals, and (3) accurately anticipate how the situation is likely to change as time passes” (Groner, 2009). Poor situation awareness is present in nearly all sudden-onset emergencies that result in tragic outcomes. The World Trade Center disaster is perhaps the most graphic example, in which commanders literally “on the ground” did not have access to information such as television images (McKinsey, 2002, p.31) and engineering reports that clearly indicated the serious compromise to the towers. Inadequate SA combined with communications deficiencies contributed to numerous excess deaths, particularly to first responders (Lawson and Vettori, 2005). SA is therefore a critical issue in managing emergencies.

The IBM-CUNY-NYU collaboration as part of the *Smarter Cities Research Innovation Project* was conceptualized in late 2009 and began in Spring 2010. An inter-institutional team of researchers drawn from IBM Research, CUNY, and NYU-Poly were selected across several thematic areas: transportation, water, security, and energy. The team members on the security project were from CUNY’s John Jay College of Criminal Justice, City College, NYU-Poly, and IBM. Funding for the project was provided jointly by the participating entities. The CUNY Vice Chancellor of Research provided administrative guidance for this project.

Project C, *Situation Awareness Requirements Analysis for Sensor Analytics Display to First Responders Background* was one of three related security-themed projects. The other projects were A: Access Control Systems for Emergency-Access; and Project B: Conceptualize Multiple Purposing of Sensors. Project A sought to develop a (data) access control model for a simple scenario with ad-hoc connectivity between building sensor systems and emergency responders; explore different policies approximating need-to-know principles; devise effective key-management for the above scenario; and validate the model using an existing testbed at CCNY. Project B sought to develop a review and summary of existing building sensors and capabilities; develop a scenario-based concept model for event detection; and provide a case study of an actual building under emergency conditions. Project A began first, followed by Project C. Project B, led by NYU-Poly, is in progress.

The urban archetype of the high-rise office building was selected as the environment for the security projects. Given the pilot nature of the research, selecting a well-defined yet challenging venue was important. High-rise buildings are also complementary environments for some of the other Smarter Cities research projects.

In addition to investigating the SA problem for emergency responders in its own right, the *Situation Awareness* project described herein was designed to provide insights of value to the other two studies, for example, by eliciting first responder views regarding the need for confidentiality of particular information needed by first responders due to legal (e.g., HIPAA requirements), operational rationale, or potential misuse through disclosure or interception by adversaries such as terrorists. The information needs of first responders has important implications for the utilization of sensor outputs and also suggests paths to development of associated analytics to process sensor outputs into meaningful intelligence for emergency responders. Finally, the findings from this project will help understand ways that required information can best be presented to first responders to enable actionable decisions.

Approach

This study's method is based on a Situation Awareness Requirement Analysis proposed in a Concept Paper published by the Christian Regenhard Center for Emergency Response Studies at John Jay College of Criminal Justice (Groner, 2009). The approach is similar to the analytic method described by Endsley and her colleagues who recommend a goal-directed cognitive task analysis (Endsley, Bolte, & Jones, 2003). Higher level more abstract goals are decomposed to increasingly specific objectives and then into specific decisions. The approach was adapted based upon the roles fulfilled by emergency responder, and focused on the early stages of an incident – the stage in which the initial SA is achieved.

Scenarios

The Endsley *et al* approach is designed to reveal general operational requirements during non-emergencies. Instead, we based this analysis on three emergency scenarios, all of which involved intentionally ambiguous situations. These situations were intentionally ambiguous so that we could discover the information that emergency responders need in their attempts to achieve good situation awareness and respond appropriately. The ambiguity of the scenarios reflects real-world experience; emergency responders must routinely assemble SA from multiple sources of information from the time of notification though the first minutes on the scene of a reported emergency. The ambiguity was intended to force the study participants to critically examine how they make decisions and information they need to make those decisions.

As stated, all of the scenarios involved high-rise commercial buildings, a setting of general interest to IBM's Smarter Cities Initiative. The scenarios used were: (1) a reported fire; (2) a reported person who is hostile and potentially armed; and (3) the apparent release of a potentially hazardous airborne contaminant somewhere inside or nearby the building. These scenarios were limited by resource constraints, but were reflective of the most high-consequence emergencies that typically face these environments.

Roles

The project investigated the information requirements for three primary public safety agency roles during an *initial response* to the three emergency scenarios in a high-rise building: (1) firefighters, (2) police officers, and (3) emergency medical technicians. We wanted to collect information about SA processes from mid-level commanders who are dispatched in response to the initial report of an emergency as defined by our scenarios. These personnel typically assume command in the initial stages of an incident. It is these personnel who are responsible for developing SA that will determine the trajectory of the incident. (Given resource limitations, we omitted many vital roles assumed by building and tenant management and staff. For a more complete explanation of these roles in a fire emergency, see Jennings, 1995).

Goal hierarchy

For this project, data was collected and represented in the form of a goal or abstraction hierarchy. Higher level goals are relatively abstract, and can then be broken down or decomposed into increasingly specific and concrete enabling goals. In an abstraction hierarchy the forms of the goals change along with the level of abstraction. Rasmussen and colleagues (1994) describe an abstraction hierarchy as a map of the cognitive territory that a decision maker has to navigate in order to comply with work requirements. In the scheme used in this study, the hierarchy is ranked by increasing levels of specificity as follows: (1) responder role, (2) goal, (2) objective, (3) actionable decision, and (4) required information.

Figure 1 shows the decomposed elements of the goal hierarchy, along with a tree diagram that illustrates the increase in detail as responder needs become increasingly specific. In the results section of this report, the tree structure is used to provide an easily understood format for the findings.

For example, for a police officer responding to a reported hostile person, a goal may be "apprehend hostile person," while objectives might include "determine location in building." Actionable decisions might be "Do I walk up stairs or can I take elevator?" while information needed to make the decisions includes such information sources as "verbal reports from occupants in the building lobby" or "video images from surveillance cameras."

To further inform Project B, we wanted to also collect information about the potential uses of sensors to augment current practice.

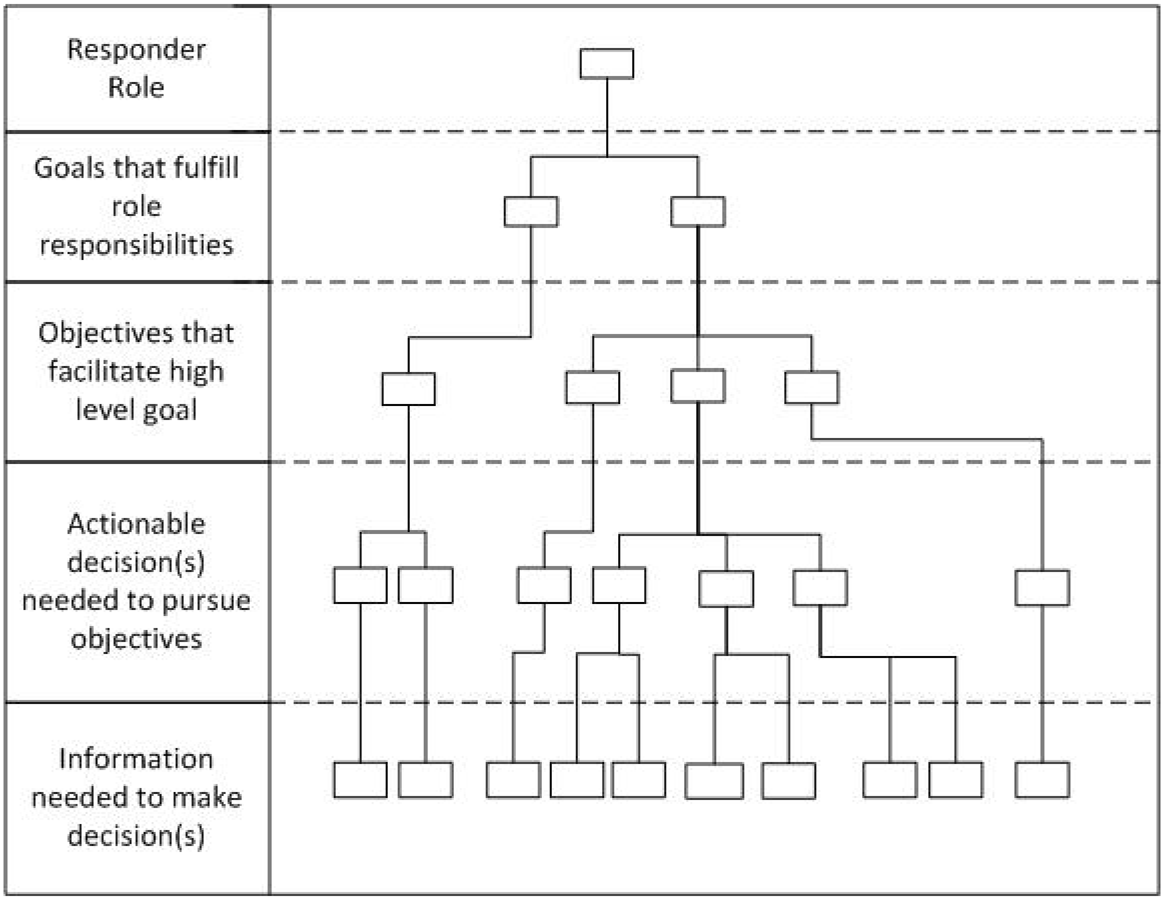

Figure 1. **Tree Diagram Showing the Abstraction Hierarchy used in this Project**

Methodology

Sampling

The project sought information from three types of first responder professionals: firefighters, police officers, and emergency medical technicians. All of the interviewed persons were senior emergency responders with hands-on experience and expertise related to the selected scenarios in high-rise buildings. In each case, a high ranking officer was approached and asked to select persons who could provide such information. Firefighters and emergency medical technicians were contacted with help from the New York City Fire Department.

The research team had also sought contacts through the New York City Police Department, but permission was not secured within the required time frame. As a result, the project sought and received interviews from the Police Department in Irving, Texas and other local law enforcement officers in the New York area. After receiving a list of qualified informants, the project team contacted the suggested persons with assurances that their participation was anonymous and entirely voluntary, along with other requirements following approval by the John Jay College

Institutional Review Board's authorization for research using human subjects. A total of 16 informants were interviewed.

Interviews

Interviews were conducted using a semi-structured "negotiated text" approach (Fontana & Frey, 2000). In a structured interview, all informants are asked the exact same questions without any variation in the wording. In an unstructured approach, interviewers are free to pursue whatever paths of inquiry lead to a greater understanding of the informants' views. The method employed here used a semi-structured approach in an effort to focus on a clearly defined scope of inquiry while still allowing interviewers to make unscripted inquiries that would yield a deeper understanding of the topic of research.

In a negotiated text approach, interview data are viewed as a collaboration between the interviewer and the informant for the purpose of minimizing the amount of interpretation required by the interviewer. This approach evolved as a way of coping with hierarchical, gender and cultural differences between interviewers and informants. While the current context creates much less difficulty than many inquiries in the social science disciplines, the problem is not wholly avoided. Emergency responders belong to strong cultures and members may believe that outsiders are unable to fully understand their roles. This division may reduce trust and inhibit the possibility of a shared understanding between interviewer and informant.

Interviewers had varying expertise, ranging from scholarly work on emergency response and considerable experience as emergency responders to general familiarity resulting from academic training as graduate students in a protection management (security, emergency management, fire safety) program. While some familiarity with the domain and professional terminology is necessary, interviewers were instructed to respect their roles as recorders of information and to assure that the interview subjects were not being led or that the interviewer was not making assumptions about actions or information needs of the participants.

For the purpose of developing a method that minimizes the problems of interpreting data, interviewers filled out a table (as shown below in Figure 2) on a display shared by both interviewer and informant. The informant was explicitly asked to review the data recorded by the interviewer being shown on the shared display. Suggestions for any changes that more accurately reflected his or her views were requested as well. Interviewers added rows and divided and merged cells to capture the interview data.

Goal	Objectives	Actionable Decisions	Information needed to make decision	Sensitivity of information	Sources of Information	Sensor Technology	Comments

Figure 2. Operationalized Table for Collection of Data

Given the speed at which interviewers recorded responses, the meaning of entries were not always clear. Once the data were recorded, the project team reviewed the data tables with the interviewer for the purpose of clarifying ambiguous entries, while trying to leave the the intent of the informant unaltered. Efforts were also made to reduce and interpret the use of jargon and technical terms.

When the project team was sought to interview police officers from outside the New York City, internet-based communications applications Skype® and GotoMeeting® were used. These programs enable users to share a common computer display. The interviewer and informant interacted verbally while both viewed the live data collection table. The use of these technologies was effective in this interview methodology.

Data analysis

Once the interviews were completed, the project team consolidated the interviews by role and scenarios to yield a master table* (see Figure 3) for each of the following nine areas:

	Firefighter	Police officer	Emergency medical technician
Fire	A1-fire-FD	A2-fire-PD	A3-fire-EMS
Hostile intruder	A4-hostile-FD	A5-hostile-PD	A6-hostile-EMS
Airborne toxic release	A7-contaminant-FD	A8-contaminant-PD	A9-contaminant-EMS

*Entries in the matrix refer the appendix where the report analyses are shown.

Figure 3. Summary of Interviews Consolidated by Role and Scenario

Consolidation involved finding themes across interviews within each of the nine scenario-role pairings to avoid needless repetition and to ease interpretation of results.

Results

The results from this study are presented in Appendix A using the hierarchical tree structure presented in the methodology section of this report. As noted earlier, in addition to collecting information that fits within the abstraction hierarchy, interviewers also queried informants about the sensitivity of required information and actual and potential sensor-based information sources. This information is represented using special symbols that are attached to the associated entries in the hierarchy.

The collected sensor and information sensitivity information is also presented in Tables 1 and 2. The reader can explore the informational sources and context for these entries by studying the analyses in Appendix A.

Table 1: Sensor-relevant Comments	Location in Appendix
Most current buildings have failsafe door systems.	A-fire-FD
Traffic cameras and GPS may be helpful.	A1-fire-FD
Remote controls to read pressure and control shutoff would be useful.	A1-fire-FD
Encapsulated thermometers and heat level sensors can confirm safe entry. All company officers carry carbon monoxide detectors when breathing air masks are not worn.	A1-fire-FD
Standalone pipe systems should have alarms to transmit an alert when damaged.	A1-fire-FD
Automated check-in/out systems and emergency roll-calls can help track all responders on site.	A1-fire-FD
Any visibility in a building – cameras, closed circuit television, etc. – will improve the overall response.	A1-fire-FD
Accounting for all occupants could occur through electronic displays or check-in systems.	A2-fire-PD
Radios do not always have the best reception indoors. Other ways to track responders would be beneficial.	A2-fire-PD
Some agencies currently have handheld cameras that can be carried; having a live feed to staging areas would beneficial.	A3-fire-EMS
Secure electronic data terminals would allow for open communication regarding patient needs.	A3-fire-EMS
Automated vital sign machines for the field would expedite triage and treatment.	A3-fire-EMS
Chemical monitors would help to protect all on scene.	A3-fire-EMS
One standard frequency for multi-agency use would allow for clear communication.	A4-hostile-FD
Overriding elevator function may be necessary.	A4-hostile-FD
Any visual aide would be beneficial to determine safety of area.	A4-hostile-FD
Consider ways to override building security when access cards are required.	A5-hostile-PD
Closed-circuit television within buildings may provide a safe view.	A5-hostile-PD
Multipath talkgroup technology can find available open radio frequencies.	A5-hostile-PD
It is absolutely necessary to get a visual, possibly through throw phones or security cameras.	A5-hostile-PD
Some responders may require tactical suits for prolonged operations.	A6-hostile-EMS
Closed circuit television or other visual input will be necessary to effectively gauge the situation.	A6-hostile-EMS
Scannable triage tags would decrease communication times.	A6-hostile-EMS
An interagency communications system should not interfere with responder-specific transmissions.	A6-hostile-EMS
It may be necessary to provide instructional assistance to those who cannot be	A6-hostile-EMS

reached; consider CCTV or throw phones.	
Any visual or audio data would be helpful.	A6-hostile-EMS
This will require the use of chemical detectors.	A7-contaminant-FD
Aside from carbon monoxide, buildings do not have specialized chemical detection systems. This delays notification until actual symptoms are reported.	A7-contaminant-FD
All sensors should be cleaned and maintained for future use	A7-contaminant-FD
Radiation monitors should be small enough to carry.	A7-contaminant-FD
Current air monitoring sensors must be continuously improved upon.	A7-contaminant-FD
Chemical identification technology for on-scene officers would allow Police to immediately understand their situation.	A8-contaminant-PD
A county-wide hotline would allow for covert communication.	A8-contaminant-PD
Some areas may also have phone-based mass notification systems.	A8-contaminant-PD
Mobile Command Vehicles are equipped with chemical/biological sensors, plume modeling capabilities and a siren notification system.	A8-contaminant-PD
Radiation and carbon monoxide detectors can currently be carried.	A9-contaminant-EMS
The current HAZMAT guide is not in electronic form.	A9-contaminant-EMS
Other chemical detectors would be beneficial, but are currently bulky, expensive, and unavailable to first responders.	A9-contaminant-EMS
Pager communications are often delayed. Consider radio-encrypted texting to LED screens.	A9-contaminant-EMS
Satellite mapping and weather conditions are best when all responders have constant updates – cell phone screens are often too small to provide this information.	A9-contaminant-EMS
Triage tags that can be scanned are currently being developed.	A9-contaminant-EMS

Table 2: Information Security Comments	Location in Appendix
Information should be shared as quickly as possible to ensure everyone's safety.	A1-fire-FD
In the event that the fire may have been purposeful, information regarding personnel safety should be kept private.	A1-fire-FD
Public address systems can help to notify everyone.	A1-fire-FD
Information must be public for people to comply with evacuation orders.	A2-fire-PD
Personal information is protected. Only information regarding the number and severity of patients can be transmitted.	A3-fire-EMS
Continuous concern regarding public panic or media exposing response tactics.	A4-hostile-FD
If a responder is hurt, they may be referred to using a "code word" during medical communications.	A4-hostile-FD
Any information on the suspect will be released immediately.	A5-hostile-PD
Media must not give away tactics to suspect.	A5-hostile-PD
Responders must be aware of public panic.	A5-hostile-PD
A well-controlled radio system will be necessary during all decision-making.	A5-hostile-PD
Live news coverage may be restricted.	A5-hostile-PD
Response has priority over information control, but all media inquiries must be addressed.	A5-hostile-PD
To avoid public panic, injuries to responders will be considered highly sensitive.	A6-hostile-EMS
The whereabouts of the staging area may be kept private to protect those on scene.	A6-hostile-EMS
Safety is the number one priority during all decision making.	A6-hostile-EMS
This information must be protected to ensure a safe location.	A6-hostile-EMS
Transmissions not sensitive, but must be HIPAA compliant.	A6-hostile-EMS
Notifying the public is necessary, but must be done delicately to avoid public panic.	A7-contaminant-FD
The public must be continually updated.	A7-contaminant-FD
The cause, location, or nature of the chemical may be of a sensitive nature.	A8-contaminant-PD
This (the safety of responders) takes priority over the control of information.	A8-contaminant-PD
Initially, information (regarding the cause of a chemical release) should be made public.	A8-contaminant-PD
Information will be provided through a Public Information Officer to avoid public hysteria.	A8-contaminant-PD
Consider sending confidential information digitally.	A9-contaminant-EMS
Personal information is protected; only triage "color" can be shared.	A9-contaminant-EMS

Conclusions

The collaborative interview method employing negotiated text was very successful. Interviewers reported that informants rarely suggested ways that the data entries could more accurately reflect their views, even when informants were specifically asked if they wanted to suggest changes. Interestingly, interviews conducted over the internet provided more successful collaborations, presumably because the informants were primarily focused on the tabular input displayed before them. In face-to-face interviews, informants were more focused on the interviewer rather the shared display on a laptop computer or projected image.

We recommend that expert representatives of the roles participate in the consolidation process in an attempt to eliminate potential errors, followed by additional interviews as necessary to correct such errors. For example, an essential goal missing from the analysis involves moving of building occupants to locations of relative safety. This omission may have resulted from informants simply overlooking the goal, from a real underlying neglect of the goal in planning for emergencies or from the objective being routinely assigned to building management instead of emergency responders. We feel that errors are best avoided by having subject matter experts review the results, followed by additional data collection and analysis as necessary.

The scope of the current study is limited not only by the scenarios, but also by the roles that were investigated. Building emergencies involve complex social and technological interactions, and emergency responders do not act independently from building and facilities managers, facility engineers, tenant managers and staff, and in-building emergency response teams (e.g., fire safety and security directors, floor wardens) (Jennings, 1995). People in these roles rely on shared information to achieve a common understanding of the situations that they face. A more complete representation of information requirements awaits an extension of this research to include informants in these important roles.

The line of inquiry represented in this project has considerable value in the design and evaluation of visual and audible interfaces. There is reason to believe that people best understand information when it is formatted in a manner consistent with the goals they are trying to pursue. Informational requirements are organized according to responders' goals, so these findings can also provide guidance to the design and evaluation of system visual and auditory interfaces. (Bennett, Nagy, & Flach, 2006)

The specific findings for each scenario also provide the basis for identifying possible use of existing sensors to enhance information flows; conceptualization of modification to or repurposing of existing building sensors; and design of conceptual approaches to development of analytics for improving the detection and management of emergencies in high-rise buildings utilizing outputs of multiple building sensors.

Further Research

This project has demonstrated a methodology for understanding the information needs of first responders and the role played by existing sensor technologies in incident detection and management. Based on the three scenarios examined, additional research building on these findings should be undertaken to include building management personnel. In addition, the role of specific extant sensors and adaptations to sensors to perform in emergency detection and management roles is necessary. A high-level expert conceptual analysis of sensor applicability to building emergency support should be pursued following findings of Project B. Finally, a program of data collection from field observations and experiments is necessary around a defined case to validate analytics for sensor outputs and their display for use by those responding to emergencies in buildings.

The value of the Situation Awareness Information Requirements Analysis used in this study would be greatly augmented by a subsequent analysis analyzing the current and potential sources of required information and the associated flow of information among key roles during an emergency response. Such an "information flow" analysis, coupled with the type of study described in this report, would provide a complete picture of the procedures and technologies that can be used to provide the information essential to achieving a level of situation awareness needed to make timely and effective decisions. An information flow analysis would also more clearly reveal goal conflicts. An example might be the conflict between providing information to the public while not revealing information of potential value to adversaries.

A prosaic but potentially powerful aspect of this approach is the augmentation of conventional security/safety sensors such as smoke detectors with information from building sensors to reduce the problem of false alarms and their attendant costs in terms of lost productivity for building occupants and added costs to local governments for emergency response and reduced availability of emergency services.

Finally, the findings of this research should be extended in scale to the neighborhood or city level, where challenges of aggregating information from multiple buildings and the implications of access to such information can be understood. The threat of seriously negative outcomes often results from larger scale emergencies that encompass multiple buildings and can be realistically examined using a set of more severe scenarios. This implies a repeat of this process taking place at the level of several buildings simultaneously, which is considerably more complex.

References

Bennett, K. B., Nagy, A. L., & Flach, J. M. (2006). Visual Displays. In G. Salvendy, *Handbook of Human Factors and Ergonomics (Third Edition)* (pp. 1191-1221). Hoboken, NJ: Wiley.

Endsley, M. R., Bolte, B., & Jones, D. G. (2003). *Designing for situation Awareness: An Approach to User-Centered Design.* Boca Raton, FL: CRC Press.

Fontana, A., & Frey, J. H. (2000). The Interview from Structured Questions to Negotiated Text. In N. K. Denzin, & Y. S. Lincoln, *Handbook of Qualitative Research, Second Edition* (pp. 645-672). Thousand Oaks, CA: Sage.

Groner, N. (2009). *Situation Awareness Requirements for Emergency Planning: Working Paper 09-02.* Retrieved June 2011, from Regenhard Center for Emergency Response Studies: http://christianregenhardcenter.org/

Jennings, C. (1995) "High-Rise Office Building Evacuation Planning: Human Factors versus "Cutting Edge" Technologies." *Journal of Applied Fire Science*, Volume 4, Number 4. (pp. 289-302).

Lawson, J. R. & Vettori, R. L. (September 2005) *Federal Building and Fire Safety Investigation of the World Trade Center Disaster*. NIST NCSTAR 1-8. Building Fire and Research Laboratory, National Institute of Standards and Technology.

McKinsey and Company (2002) *Increasing the FDNY's Preparedness.* p. 31. Retrieved from http://www.nyc.gov/html/fdny/html/mck_report/toc.shtml.

Rasmussen, J., Pejterson, A. L., & Goodstein, L. P. (1994). *Cognitive Systems Engineering.* New York: Wiley Interscience.

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