Using Simulation, Modeling and Visualization to Prepare First Responders for Homeland Defense

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Abstract
Terrorism with weapons of mass destruction presents numerous challenges to authorities and responders in the public safety area. Training is extremely important to establish and tune an effective and efficient response system capable of handling chemical, biological, radiological and nuclear events. The paper characterizes the unique conditions for training responders from multiple agencies within separate jurisdictions. Examples from four full-scale emergency response exercises cover weapons of mass-destruction, urban environments, and political violence. In each such live simulation exercise, computer support based on modeling and visualization supported feedback and evaluation to promote effective cross-organizational learning.

Introduction
The way we look at public safety has changed in the light of recent world events. Asymmetric warfare is a reality that not only concerns military forces in war zones, but also has the potential to affect the everyday life of millions of people. New types of carriers can deliver weapons of mass destruction in non-traditional ways to inflict casualties and create havoc in civilian communities. Responding to this challenge requires new approaches to crises management and preparedness. Interoperability and integration of services are fundamental to leverage the resources available across both military and civilian organizations in multiple jurisdictions.

In the United States, the federal government has established the Department of Homeland Security. The Department of Homeland Security has the mission to develop a comprehensive national strategy to secure the United States from terrorist threats and attacks and to coordinate its implementation. This strategy identifies emergency preparedness and response as one of six critical mission areas (Office of Homeland Security, 2002). A cornerstone in this area is training. A national training and evaluation system, including a national exercise program, will be established to ensure that civilian personnel at all levels of government are prepared. Training challenges include response to chemical, biological, radiological and nuclear events, military support to civil authorities, multi-agency cooperation, and integrated command and control.

In this paper, we analyze the specific problems involved in training first responders for large-scale operations in response to events involving weapons of mass destruction. Our emphasis is on live simulation exercises. We examine how methods and tools developed around simulation, modeling, and visualization can facilitate this type of training. In particular, we consider how the taskforce training approach by Jenvald (1999) and methods for multimedia representation of tactical operations by Morin (2002) combine to address crucial training issues. A series of examples from previous exercises provide an illustration of difficulties and possibilities identified. Finally, we discuss some future directions for research and development.

Learning from experience
When people train in a live simulation, they take part in experience-based learning. However, participants in complex, dynamic situations are thrown into action with
limited possibility to step back and reflect on actions as the situation unfolds (Winograd & Flores, 1986). After the action, on the other hand, it is essential that they reflect on the exercise as a basis for sustaining strengths and remedying weaknesses. Kolb (1984) emphasized the combination of concrete here-and-now experience with the use of feedback to change practices and theories. Norman (1993) noted that reflection on performance makes it possible to better know what to change and what to keep. Effective processing requires accurate feedback on the actions taken, which is often a problem in dynamic and distributed environments, such as rescue operations, where the people may not see the effects of their actions (Hoffman, Crandall & Shadbolt, 1998) and where the environment may change spontaneously, without deliberate intervention (Wærn, 1998). Debriefing provides an opportunity to engage in structured reflection on an experience in order to modify behavior based on that experience (Pearson & Smith, 1986; Raths, 1987; Lederman, 1992). In training, debriefing is commonly referred to as after-action review (Morrison & Meliza, 1999). Rankin and associates (Rankin, Gentner & Crissey, 1995) described an after-action review as a professional discussion of an exercise, which concentrates on performance standards. To provide effective feedback, methods and tools to present representations of operations have been developed and used to support after-action reviews in military settings as well as in emergency management and response (Jenvald, 1999). Morin and colleagues (Morin, Jenvald & Thorstensson, 2000) described how models of rescue operations built from multiple sources of data could support analysis and feedback. Applications of this method include training (Crissey, Morin & Jenvald, 2001) and real operations (Morin, 2002; Thorstensson, 2002). It has also been used to investigate communication in command and control (Thorstensson, Axelsson, Morin & Jenvald, 2001; Albínsson & Morin, 2002; Albínsson, Morin & Fransson, 2003).

Training first responders

In the military domain, many simulation-based tools have been developed to enhance the realism of training and to provide effective feedback to the participants (Morrison & Meliza, 1999, Jenvald, 1999). Thorstensson and associates (Thorstensson, Morin & Jenvald, 1999) analyzed the differences between military training and training for emergency management and response and found significant differences, but also many similarities. Large-scale emergency response operations resemble military operations in many respects. Both involve numerous individuals and teams working together in a geographically distributed area of operations. The outcome of an operation depends on the cooperation between individuals and teams and the careful coordination of their efforts. As a consequence, the training issues involved in large-scale emergency response operations are similar to those encountered in the military domain. It is, therefore, important to investigate to what extent existing methods and systems for military training are applicable to the training of first responders in public safety. Table 1 lists some of the differences between the military and public safety domain. Morin and colleagues (Morin, Jenvald & Crissey, 2000) analyzed training needs and training opportunities for emergency response to mass-casualty incidents. They identified training audiences and classified training on the individual, team, command post, and taskforce level. In this framework, taskforce training corresponds to full-scale, live exercises with people and equipment in the field. This type of training enables all personnel to engage in a common exercise, where they can apply their skills in a realistic scenario. Such training can produce learning situations at the level of complexity that do not occur in individual training or team training. However, effective taskforce training requires that individuals and teams have attained proficiency in their roles.

Public safety agencies spend most of their time on watch or responding to calls. The time available for training is limited. Furthermore, the public safety community has primarily been organized to handle the everyday accidents that constitute the vast majority of emergencies. Major incidents occur infrequently. Also, the community is heterogeneous in the sense that it includes many different agencies at various levels of government. Major exercises thus must incorporate public safety assets both vertically across levels of government and horizontally across multiple professions and specialties. They are complex, as they require cooperative planning and orchestration.

<table>
<thead>
<tr>
<th>Training issues</th>
<th>Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main purpose of the training</td>
<td>Improve the ability to solve common tasks</td>
</tr>
<tr>
<td>Training organisation</td>
<td>Designated training organisation</td>
</tr>
<tr>
<td>Sequence of exercises</td>
<td>Single exercise</td>
</tr>
</tbody>
</table>

Table 1: Characterization of training conditions in the military domain and the emergency response domain, respectively.
A primary challenge in training responders for homeland defense is to overcome organizational and jurisdictional barriers. Flin (1996) observed that there seemed to be limited cross-transfer between public safety organizations despite their having similar goals and employing similar means to achieve those goals. Training together and debriefing together may be one way to promote the interaction between agencies.

Training is crucial for preparing first responders for homeland defense. Taskforce training involves teams from multiple agencies and levels of government in a realistic learning situation. To create a realistic training environment and to provide effective feedback, methods and tools originally developed for military training can be adapted to the needs of the civil sector.

**Computer-supported taskforce training**

To conduct a major exercise that includes an effective after-action review requires a systematic approach to training. Jenvald (1999) presented a method for computer-supported taskforce training, which incorporates steps to ensure that the course of events of the exercise is documented and accessible for after-action review and analysis. Figure 1 gives an overview of the method, which includes the following five steps:

- **Planning.** The planning step defines the goals of the exercise, identifies particular topics or themes that should be highlighted, and creates the exercise scenario accordingly. Evaluation criteria are established relative to the goals and an instrumentation plan is developed. This plan links the goals of the exercise to evaluation criteria by defining observable measures of performance and prescribing means of data collection.

- **Preparation.** Before the exercise, it is necessary to inform participants about the exercise. Instructors and observers need guidelines and instructions regarding what to pay attention to and how to report observations. Automatic instruments for data collection must be installed, configured, and started.

- **Exercise.** During the exercise, the participants act in their roles in the unfolding scenario. Data are captured by the instrumentation system to document the course of events. The result of data collection is a mission history, which is an event-based, time-ordered multimedia model of the mission.

- **After-action review.** Participants, observers, and trainers assemble to conduct an after-action review of the exercise. In a process of critical reflection, the participants explore the exercise using the mission history as a cognitive aid. Instructors and observers may pose questions or offer comments and guidance to facilitate debriefing.

- **Analysis.** Reflections, comments, and remaining questions may serve as starting points for a deeper analysis of the exercise. Evaluation results and observations may lead to new training needs and modified tactics, organization, and equipment.

Both the after-action review and the post-mission analysis are exploratory tasks. Observations during the exercise and findings from examining the mission history lead to new questions that can be explored. To support this mode of analysis, the MiND presentation tool includes an exploratory multimedia interface. This interface enables a user to browse the mission history and to replay sequences of the mission (Morin, 2002).

**Application examples**

We describe four examples of how computer-supported taskforce training applied to emergency management and response in scenarios addressing weapons of mass-destruction in multi-agency settings. The examples come from exercises: *Alvesta, Orlando, Cornelia, and Daniela.*
Alvesta. The first field exercise took place in Alvesta, Sweden, in October 1997 as a part of a project sponsored by the Swedish Rescue Services Agency. The goal of this project was to develop methods and tools for assessing emergency planning for incidents involving chemical warfare agents (see Figure 2). An important activity in this project was to conduct operations based on realistic scenarios according to existing plans and study the outcome (Rejnus, Jenvald & Morin, 1998). The exercise involved emergency response to a simulated chemical attack on the town Alvesta. Approximately 180 first responders from different agencies participated and 49 extras acted as casualties. For this exercise, methods and tools were transferred from the military domain to civilian emergency response (Thorstensson et al., 1999). Data collected included:

- Position tracks from GPS locators
- Deployment of special resources (decontamination station and medical aid station)
- Deployment of units in clean and contaminated areas
- Reports from chemical detection
- Casualty flow and treatment data using timed checkpoints
- Tactical radio communication
- Digital photographs
- Video footage

The mission history from Alvesta was used to explore the exercise at an after-action review for all 230 participants 90 minutes after it ended. The exercise commander from the Swedish Rescue Services Agency acted as a tour guide and conducted a walkthrough of the exercise with frequent stops at critical situations. Key participants commented on situation assessment and decisions, using the mission history both to identify and recall situations and to illustrate their line of thought. Two weeks later the model was used in a similar manner to support an in-depth analysis of the different functions in the operation as a basis for assessing the emergency plans. Finally, the mission history was included in a multimedia CD-ROM addressing chemical warfare hazards and used in a curriculum covering nuclear, biological, and chemical hazards at Umeå University, Sweden (Jenvald, Morin & Rejnus, 2000).

Orlando. In May 2000 a joint Swedish-American team organized a field study in Orlando, Florida (Crissey, Morin, & Jenvald, 2001). The purpose was to explore the effects of transferring the methods and tools used in the Alvesta exercise to a different country, organization, and culture. To this end the team participated in an emergency-response exercise to a chemical incident. In the operation fire–rescue units from two counties and three police forces, drawn from a 25- by 25-kilometer area, responded to a simulated chlorine gas leak in a suburban location (see Figure 3). There, they rescued and treated two victims and contained the leak. The operation took place in the morning and after a lunch-break the participants assembled for an after-action review. The Director of Training of the Orange County Fire Rescue Department facilitated a walkthrough of the operation using the mission model along the same lines as in the Alvesta study. The Orlando exercise in many respects was a replication of the Alvesta exercise. The same methods and tools were used. Models and views could be reused once the geodetic differences were settled. Reconstruction and exploration supported an after-action review similar to that in Alvesta. In spite of differences in legislation,
doctrine, organization, culture, and language, we found nothing in the study that contradicted the assumption that the methods and tools for reconstruction and exploration could indeed be transferred to different environments.

**Cornelia.** On November 22, 2000, some 200 first responders and command staff from the local fire department, the county medical services, and county police joined forces with personnel from the urban transport authorities and train operators to practice emergency response to a subterranean train derailment. The scenario centered on a train derailment in the Stockholm subway system, caused by sabotage. In a tunnel, 150 meters from the platform of a downtown subway station, an object on the track caused a train to derail, hit the tunnel wall, and come to an abrupt stop. The impact left 86 people on the scene with various injuries, including five fatalities represented by mannequins. The train driver, who had sustained only slight injuries, used the train’s radio to notify the traffic control center about the incident. From that point, personnel in the traffic control center initiated emergency activities according to their standard procedures. All victims were removed from the train, stabilized on scene, and transported to three trauma hospitals in the Stockholm area.

Using similar data collection procedures as in the previous two cases a mission history was constructed from the exercise. The mission history supported an after-action review three hours after the exercise ended. Furthermore, it was crucial in the analysis of coordination and collaboration among responders from different agencies. The starting point of the analysis was questions raised by participants and observers at the after-action review. However, several new issues were discovered in the course of analysis. For example, why did it take so long to get the victims to the hospitals? The estimated time was 90 minutes, but in reality it took 2 hours and 43 minutes. The analysis leading to a tentative answer to this question provides an illustrative example of how the mission history can support exploration of inter-agency coordination. Table 2 summarizes the information used in this process.

- Items 1 and 2 define the scope of the analysis by identifying the start of the exercise and the time of arrival of the last patient.
- Items 3 and 4 identify when the first patient left the incident scene and arrived at the hospital.

Was there a plausible explanation for the 67-minute period that elapsed before the first patient left the subway station? To answer this question, we examined how the chain of medical aid was organized. A critical strategic decision is whether to establish a casualty collection point (CCP), or to rush patients to hospitals with only minimal on-scene prioritization and stabilization. The medical commander is responsible for this decision, but needs to consult the fire commander regarding a suitable location for a CCP. In either case, the police are responsible for registering the casualties.

- A photograph from the ticketing area at 10:14 shows police officers preparing a CCP (Item 5). Browsing police communication around 10:14 revealed Item 6, an audio link that suggests that fire commander was involved in the decision. Items 7 and 8 illustrate the growing confusion regarding the CCP in the police organization. The police commander 1050, at the joint incident command post, and officer 1710, in the ticketing area, clearly had diverging views.
- Going back to the first minutes of the operation revealed that the police were first on scene (Item 9) and started organizing their activities. The first medical units arrived 7 minutes later followed by the first fire–rescue units (Items 10 and 11). The senior fire commander arrived at 10:16 (Item 12). A shift of command took place in the fire–rescue organization when the senior fire commander arrived around 10:16. The first commander (from unit 123) may have failed to report the crucial decision about the CCP to the senior commander. Alternatively, he may have regarded the CCP in the ticketing area as a temporary assembly point. The latter hypothesis is supported by data from the mission history.
- An audio clip (Item 13) contains an order to deploy tents for a CCP in a park outside the subway station. A video clip from 10:40 shows the incident commander discussing the CCP with his deputy. In this conversation, they mention three CCPs, two of which are regarded as temporary (on the platform and in the ticketing area).
Table 2: Exploration of the ambiguous casualty collection point using the Cornelia mission history.

<table>
<thead>
<tr>
<th>Item</th>
<th>Time</th>
<th>Medium</th>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10:00</td>
<td>Audio</td>
<td>Traffic control network</td>
<td>The train driver reports the incident to the traffic control center</td>
</tr>
<tr>
<td>2</td>
<td>12:43</td>
<td>Report card</td>
<td>Casualty registration</td>
<td>The last two victims arrive at Danderyd Hospital.</td>
</tr>
<tr>
<td>3</td>
<td>11:07</td>
<td>Photo</td>
<td>Medical observer</td>
<td>Ambulance crew bring the first patient out from the station</td>
</tr>
<tr>
<td>4</td>
<td>11:13–11:25</td>
<td>Position track</td>
<td>GPS</td>
<td>Ambulance B887 takes the first patient to the hospital</td>
</tr>
<tr>
<td>5</td>
<td>10:14</td>
<td>Photo</td>
<td>Police observer</td>
<td>Police officers prepare a CCP in the ticketing area</td>
</tr>
<tr>
<td>6</td>
<td>10:15</td>
<td>Audio</td>
<td>Police network</td>
<td>The officer in charge of casualty registration (1710) reports to the police commander (1050) that the fire commander has ordered the CCP to be in the ticketing area. This decision has been communicated to the medical personnel on scene.</td>
</tr>
<tr>
<td>7</td>
<td>10:24</td>
<td>Audio</td>
<td>Police network</td>
<td>1050 informs 1710 that the CCP is going to be in tents in the street outside the station</td>
</tr>
<tr>
<td>8</td>
<td>10:30</td>
<td>Audio</td>
<td>Police network</td>
<td>1710 requests from 1050 a clarification of the location of the CCP, because medical personnel are going to remain in the ticketing area</td>
</tr>
<tr>
<td>9</td>
<td>10:03</td>
<td>Position track</td>
<td>GPS</td>
<td>Police unit 9770 arrives, followed by police units 9760, 1710, and police commander 1050</td>
</tr>
<tr>
<td>10</td>
<td>10:10</td>
<td>Position track</td>
<td>GPS</td>
<td>Emergency medical team B880 and ambulance B881 arrive</td>
</tr>
<tr>
<td>11</td>
<td>10:11</td>
<td>Photo</td>
<td>Fire observer</td>
<td>The first fire units arrive. The officer of unit 123 assumes command</td>
</tr>
<tr>
<td>12</td>
<td>10:16</td>
<td>Photo</td>
<td>Fire observer</td>
<td>The ranking fire commander (102) arrives and assumes command</td>
</tr>
<tr>
<td>13</td>
<td>10:23</td>
<td>Audio</td>
<td>Fire command network</td>
<td>102 orders fire unit 435 to deploy tents for the CCP in the street outside the station</td>
</tr>
<tr>
<td>14</td>
<td>10:40</td>
<td>Video</td>
<td>Command post observer</td>
<td>The incident commander discusses the situation with his deputy and summarizes his view of the CCP. Three CCPs are mentioned: platform, ticketing area, and tents outside the station.</td>
</tr>
<tr>
<td>15</td>
<td>10:39</td>
<td>Audio</td>
<td>Fire tunnel network</td>
<td>Fire unit 193 asks the fire commander 102 whether the CCP in the street is ready to receive casualties.</td>
</tr>
<tr>
<td>16</td>
<td>10:49</td>
<td>Photo</td>
<td>Medical observer</td>
<td>Four ambulances idling outside the station with drivers</td>
</tr>
</tbody>
</table>

- Another audio sequence (Item 14) reveals that the fire commander in charge of the platform is waiting for a CCP in the street. He does not mention the CCP in the ticketing area.

Personnel from the different agencies did not have a common view of how the chain of medical attendance was going to be organized. Item 8 clearly illustrates this confusion from the point of view of the police. Also, Item 8 indicates that the medical personnel had no intention to relocate to tents in the street.

Although sometimes confusing and contradictory, Items 5 to 15 suggest that the operation was going to include a CCP. However, Item 16 indicates that the medical services did not share this view. It shows ambulances idling with drivers ready to pull up to the station entrance to load patients. Unfortunately, there was no evidence in the mission history about who made the decision to keep ambulance crews waiting in the street.

The example is representative for the typical course of analysis in an explorative setting. A piece of data triggered a question. Another piece provided a clue and a time point. Browsing communication data around that time point revealed additional relevant data. Multiple sources made it possible to corroborate findings and construct a chain of evidence to formulate hypotheses and support conclusions. The mission history was a crucial element in this analysis by presenting the basic facts of the tactical operation. MIND facilitated exploration by supporting access and navigation in the mission history. In particular, it helped analysts link communication data to contextual information and vice versa.
Daniela. In December 2002, first responders from various agencies in Linköping, Sweden, trained together in a scenario that involved politically motivated violence. A covert political meeting turned into a blazing fire, when militant members of an opposing fraction appeared on the scene (see Figure 5). This scenario was constructed to force commanders from various agencies to integrate command and control, while the focus of the incident shifted from law enforcement, to fire suppression and rescue, and to medical aid.

During the exercise in the morning, observers and technical systems collected data. In the afternoon, participants and observers conducted an after-action review facilitated by the mission history. Later, the agencies involved used the mission history to analyze incident command, coordination, and communication. This use of computer-supported taskforce training supported the conclusion from the previous exercises: Exploration and context are crucial for reconstructing the events of a complex scenario to facilitate reflection and analysis.

**Discussion**

Although complex and resource intensive, live simulation exercises are essential for developing and sustaining the preparedness and responsiveness of our first responders. They provide an opportunity for managers and responders to gain an insight into the processes involved in a major operation and their interactions. With appropriate performance measures, live simulation can be used to validate the incident response system (Rejnus et al., 1998). However, Jenvald (1999) cautioned us not to confuse training and system validation, because they have different ends and means.

Feedback is a critical component in experience-based learning. In a distributed environment, people have problems relating actions to outcomes (Hoffman et al., 1998). Computer-supported taskforce training operates under the assumption that providing a coherent view of the course of events is a crucial step toward overcoming this difficulty. Modeling and visualization are key techniques in constructing a mission history and exploring it in an after-action review as well as in subsequent analyses (Morin, 2002). A mission history is a tangible and visible representation of an operation that can be examined and disseminated. As such, it can convey lessons learned from operations to responders who did not participate.

The examples included in this paper indicate how the methods and tools of computer-supported taskforce training apply to training of first responders for homeland defense. Dealing with weapons of mass-destruction in urban environments is a nightmare scenario that must be seriously considered. Such events never entail just a fire-rescue mission or a law enforcement operation. Instead, multiple agencies must join forces within their jurisdictions to handle the situation. The Cornelia example demonstrates some of the difficulties involved in inter-agency coordination. It also gives ideas for future research on how explorative analysis can be conducted using process data and multiple levels of representations (see also Woods, 1993; Xiao & Vicente, 1999).

The need for training is perpetual. Acquiring new skills and new knowledge, sustaining proficiency, and practicing to achieve higher levels of competence must be inherent activities in any response organization. To this end, public safety agencies must analyze training needs and identify training opportunities to devise appropriate training programs (Morin et al., 2000). Taskforce training is one crucial element in a training approach for homeland security. In our field exercises, we have observed that the after-action review process is greatly facilitated by the use of a mission history. The trainees were able to relate their own performance to the activities of other teams and individuals. Usually, the trainees accepted the mission history presented as a fair and unbiased description of the course of events. As a result, the discussions at the after-action reviews tended to be very open-minded and focused on facts. We have found that this positive environment promotes rapid learning by facilitating the process of identifying strengths and shortcomings in individual, team and management procedures.

**References**


