Consolidating Requirements Analysis Models for a Crisis Management Training Simulator

Jan Rudinsky
University of Iceland
janr@hi.is

Ebba Thora Hvannberg
University of Iceland
ebba@hi.is

ABSTRACT

This paper presents a requirements model of the activities of the response phase of a crisis management simulator. The model was constructed based on three types of incidents in three different countries, and it derives from extensive requirements elicitations in meetings, field visits and workshops with a broad range of stakeholders from multiple agencies. A second contribution of the paper is the application of work model consolidation and lessons learned therefrom. A third contribution of the paper is an analysis of the similarities and differences of three different crisis management systems in the transport sector in three different European countries.

Keywords

Consolidation, crisis incident types, requirements, simulator, crisis management, contextual design.

INTRODUCTION

Crisis management resolves and prepares for events such as natural disasters, accidents and intentional incidents. Crisis management is a complex task that requires activities to be synchronised across a number of responding organisations at many locations. To provide fast and effective joint responses, standardised systems (Lindell, Perry and Prater, 2005) that encompass emergency response command, coordination and training should replace improvised mechanisms.

As characterised in the Incident Command System, the management of a major or critical incident extends over four phases: preparedness, response, recovery and mitigation (Irwin, 1989). As pointed out in a study of emergency management information systems (Onorati, Malizia, Díaz and Aedo, 2010), emergency phases have been classified in different ways. Emergency management can be divided into three phases: prevention and mitigation, planning and training, response and recuperation (Waugh and Streib, 2006); or it can presented as a lifecycle divided into three stages: pre-incident, during-incident and post-incident (Chen, Sharman, Rao and Upadhyaya, 2008). The primary focus of our study is the response phase of a major incident. Hopefully, the results will be used by a variety of emergency agencies in the early phase of training to improve preparedness.

The deployment of a crisis management system and the training of its personnel is paramount. Knowledge and skills of the emergency response have to be trained initially and then regularly refreshed. The training should be used to expose responders to a range of situations based on potential scenarios that may occur in their jurisdiction. An important training method for emergency preparedness in the aviation sector is a large-scale, multi-agency, real-life exercise that improves crisis coordination and communication in a close-to-real environment training conditions. Because the training is expensive but needs to take place regularly, a computer simulator is an effective solution. The motivation of the research reported in this paper is to develop such a simulator for training the first responders and commanders of crisis management systems.

RELATED WORK AND OBJECTIVES OF THE RESEARCH

The literature reports several problems affecting current crisis management systems and provides the latest data about crisis management in a number of analyses, case studies and data models. An analysis of collaboration in

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aviation security (Drury, Henriques, Beaton, Boiney, GreenPope, Howland, and Klein, 2010) identified current problems in the aviation sector as a voice-only coordination and missing standards in crisis management. The solution proposed to the former was to use speech-to-text transcription, which provides information retention and increases situational awareness. To avoid mistrust in the second case, an operational framework with standardised procedures should be in place to allocate the activities and responsibilities.

A case study addressed the response to a railway accident in the UK (Smith and Dowell, 2000). It investigated possible sources of inter-agency miscoordination. Two findings were noted: poorly shared mental models and a possible conflict between the requirements of distributed decision-making and the nature of individual decision-making. The analysis focused on a single task of crisis management, i.e. transport casualties from an isolated location to hospital. Second study carried out in the Dutch crisis management domain (van de Ven, van Rijk, Essens, and Frinking, 2008) suggested implementation of Network Centric Operations (NCO) to resolve the shortcomings of information flow in current verbal communication-based crisis management. The results showed that the NCO improves decision making and planning for complex situations. Alternative solution to performance barriers in inter-organizational data exchange was offered by the case study focusing on the time-critical information services (TCIS) (Schooley, Marich and Horan, 2007) in the Emergency Medical Service domain.

These case studies have identified crisis management problems and solutions by investigating one type of incident, a part thereof or a single area of incident response. Our premise is that when building a computer simulator for crisis training, it will be more efficient to provide functionality for different types of incidents and response areas, thus serving a broader market. Hence, this work looks at crisis management across different response systems and incidents to identify typical tasks that occur in accidental and/or intentional incidents.

As alternative to the case studies, crisis management modelling provides findings where it can be difficult to run controlled experiments. Several examples are mentioned here. A multi-agent system for crisis response simulation was developed (Gonzales, 2009) to evaluate different coordination mechanisms for crisis response organisations. A Disaster Management Metamodel was developed to create a decision support system to unify, facilitate and expedite access to disaster management expertise (Othman and Beydoun, 2010). The Dynamic Emergency Response Management Information System (DERMIS) (Turoff, Chumer, van de Walle and Yao, 2004) includes design principles and specifications resulting in Requirements for Emergency Response and Conceptual Design Specifics including metaphors of the system, human roles, contexts, notifications and links among them. Other models, such as a conceptual model for crises affecting critical infrastructures such as water, power and transport (Kruchten, Woo, Monu and Sotoodeh, 2007) have focused on a specific domain in crisis management.

The above brief discussion of the literature indicates that there is a need to develop an advanced training system. The current literature shows that there is a need to model crisis management, but some of the work on modelling has been done from data in the literature and not directly on real cases. Furthermore, the real case studies have typically described only a single crisis management system. These considerations motivated the research reported in this paper, which is carried out as part of a larger project developing a training simulator for crisis managers. To mitigate the problems in crisis training, which are that it occurs infrequently and is significantly expensive, the idea is to create a virtual environment that allows managers and first responders to train often and on-demand and thus bring the cost down. Additionally, the system should allow trainees to learn, observe, and try other roles in crisis management to achieve a better understanding of the process, increase shared situational awareness and improve decision making. So that the simulator can serve a variety of crisis management situations not only within a sector but also between sectors, our goal was to obtain insight into crisis management activities in various organisations in the transportation domains of aviation and rail services in multiple European countries.

On the basis of thorough data collection from site visits and end-user workshops, we aimed to model the work of first responders, coordinators, crisis managers and instructors in these organisations and to consolidate those models by using reasoning from the particular to the general. Using a user-centred design method with a focus on user interactions and interface design, we sought to comprehend how crisis managers and first responders structure their work and to analyse the commonalities and differences across the systems.

GATHERING DATA

Crisis management data were collected from three European incident response systems in three different countries over a period of six months. Crisis management training representatives of each system initially introduced a command and coordination system and provided examples of major or critical incidents. Four cases of major incidents are described in Table 1.

Id	Location	Incident	Description
AI1	Country 1	Aircraft incident	An aircraft accident when engine failure caused crash landing
AI2	Country 2	Aircraft incident	An aircraft accident when engine failure caused crash landing
BT3	Country 2	Bomb threat	A man-made incident of a bomb located in an airport building
TC4	Country 3	Train crash	A train and vehicle collision at a crossing due to signal damage

Table 1. Major Incident Cases

The data were elicited during site visits to airports and train stations and at meetings with various stakeholders such as the personnel of incident response agencies. The purpose of this first round of meetings was to learn about the incidents, roles, tasks, artifacts, procedures and contexts at the three sites. The data elicitation during the first round was unstructured and relied on presentations given by the respective crisis management teams. These meetings lasted two days at each site.

Two types of training sessions were observed. A table-top exercise used a simulated scenario (e.g., an aircraft incident) that allowed crisis managers to train through real-life communication and coordination in a modelled environment. The table-top exercise lasted one hour. The second type of training session was a live action role play, which is a multi-agency, large-scale training exercise wherein people accomplish their tasks in a real-life environment and are supervised and evaluated by a training manager. Observations during these exercises, which lasted one and a half days with informational meetings and post-action reviews, provided further detail on crisis coordination and communication. Information on the context and the artefact was collected by taking photos and videos on the scene.

Source	**Material collected**	**AI1**	**AI2**	**BT3**	**TC4**
Site visit with crisis managers	Presentation and unstructured interview	x	x	x	
	Meeting notes	x	x	x	x
	Photos	x	x		
End-user workshop	Meeting notes and transcription from semi-structured interviews	x		x	x
Written description about work and systems	Manuals and emergency procedures		x	x	x
Table-top exercise	Photos and videos	x			
Large-scale exercise	Photos and videos	x			

Table 2. Material Collected from Stakeholders for Each Incident Case

After the site visits, workshops were held at each site. Before the workshops, each group of stakeholders received a scenario description of one of the incidents (except for case AI2). The participants were asked to read the scenarios and comment on them during the workshops. The workshops allowed us to gather crisis management details such as the system's structure, the specific roles agencies and personnel, and key tasks in the training exercise. The participants took part in semi-structured interviews, either individually or in groups, and they provided information on their roles, competencies, current training and their expectations regarding the proposed system. The interviews were audio-taped and transcribed or summarised.

To better understand the roles of agencies during crisis management, a set of procedures and manuals about the incident command systems was collected during the workshops. The documents provided additional information about the command structure and agency roles and responsibilities. Table 2 gives an overview of the instruments and material collected at each event and incident type.

DATA ANALYSIS

A user-centred design method with a focus on user interactions and interface design was sought to analyse the collected data with the aim of describing the requirements of a crisis management training system. The Contextual Design method was selected.

> *"Contextual Design is an approach to defining software and hardware systems that collects multiple customer-centered techniques into an integrated design process.*

Contextual Design makes data gathered from customers the base criteria for deciding what the system should do and how it should be structured." (Beyer and Holtzblatt, 1998)

The data gathered during the interviews, observations and document review was organised into Contextual Design Work Models. There are five distinct models that describe work practices:

- **A flow model** represents how work is divided between people. It includes roles and responsibilities and it describes the communication and coordination necessary for people to do the work. A flow model includes all instances of passing an artefact, information exchange and coordination.
- **A sequence model** captures the steps that people take to achieve work goals. The steps are organised in a detailed sequence that includes information such as the trigger that initiated the work, the goals to be accomplished and the steps to be performed.
- **An artefact model** shows the things that support the work process. The artefacts created, used or modified during the work are described with their structure, usage and intent.
- **A cultural model** integrates a cultural view of the work process. It may include policies, expectations, desires or values of the people to accommodate the work.
- **A physical model** describes the user's environment and the physical infrastructure. The model provides information on how the environment affects the work, specifically that which supports the goal and that which constrains it.

The data for the models was acquired with the Contextual Inquiry technique. This technique defines the work models from the point of view of an individual role. The person being interviewed describes the tasks relevant to his/her role while performing them, and the person in charge of the interview can ask questions. Because the nature of incident response requires maximum concentration and minimal unnecessary disturbance, it would have been difficult to follow the technique strictly. Instead, the data were collected through the method described in the previous section and organised into the work models according to the tasks performed. Thus, the models reflect the work of a group of roles instead of individual roles. Other methods could have been selected for work analysis instead of Contextual Design. Most popular are the Cognitive Work Analysis method and the Hierarchical Task Analysis (Salmon, Jenkins, Stanton, and Walker, 2011). While these methods have proved beneficial each with its own strengths, we chose CD because of its detailed guidelines for application.

Although the above five models were created for the incidents, sequence work models became the key models in the process of data consolidation across the incidents. They allow the activities performed by personnel or agencies within a crisis management system to be analysed. The data gathered from stakeholders provided enough information to create a sequence model for each system. The sequence model is composed of users' work activities ordered as a sequence of *steps* that the user performs to accomplish a task. In addition, the model includes meta-information such as *triggers* that prompt users to initiate the activity, *intents* that explain why the user is doing the task and *breakdowns* describing problems encountered while performing the activity. Examples of communication during task execution were also included where available to provide additional information.

A single sequence work model was created for each of the four major incidents (AI1, AI2, BT3 and TC4) describing the structure of the major crisis management tasks for the three different types of incidents (aircraft incident, bomb threat and train crash). Figure 1 shows a sequence work model of a representative task from incident AI1.

↓ **Put out the fire**

- *Trigger*
    - Arrival on the scene and fire spotted
- *Intent*
    - Being able to approach the wreckage
- *Steps*
    - Decide where to send vehicles
        - Coordinator observes the scene from a distance
    - Coordinator allocates responding units
    - Coordinator keeps away and does not manage the fire
    - To extinguish fire use roof-mounted monitor to deploy water and foam first
        - Joystick controlled device operated from the cabin
    - Coordinator can split fire fighters into groups in case of several fires
    - Fire fighters then take fire hoses from sides of the truck
    - Continue firefighting until the fire is extinguished

Figure 1. A Sequence Model from a Representative Task from Incident AI1

CONSOLIDATED SEQUENCE MODELS

The work models describing the incident cases AI1, AI2, BT3 and TC4 were consolidated according to the Contextual Design method. Two or more sequence models are consolidated to reveal the structure of a task, its strategies and activities. The criteria for matching the models include triggers, intents and steps. When one or more criteria are identical in both sequence models, the sequence is moved into the consolidated model. An abstract step is created for where an exact match is not possible, and it represents a number of tasks from both consolidated models. The consolidated work model should include all actions users take and not only common actions that most users take. The consolidation helps to create a single coherent view of the work practices across different incident response systems. Once consolidated, the models reveal typical work structures, orders of actions and task strategies. For the case study presented in this paper, each sequence model was consolidated in a three-stage process (see Figure 2).

AI1 and **AI2** → Consolidated Model 1 (**CM1**)

CM1 and **BT3** → Consolidated Model 2 (**CM2**)

CM2 and **TC4** → Consolidated Model 3 (**CM3**)

Figure 2. Three Stage Consolidation Process

The two aircraft incident models AI1 and AI2 were first consolidated into CM1. That model was compared with the bomb threat incident model BT3 to produce CM2. Finally, CM2 was consolidated with a model for the train crash incident TC4 into the final model, CM3.

An example of task consolidation is shown in Figure 3. The task of initial response is consolidated for the aircraft incidents AI1 and AI2. The triggers are identical: even though different names apply (ATS=ATC and SSLCI=ARFF) and the intents do not match, they share a common purpose. Finally, some of the steps are identical, some are similar and others are unique.

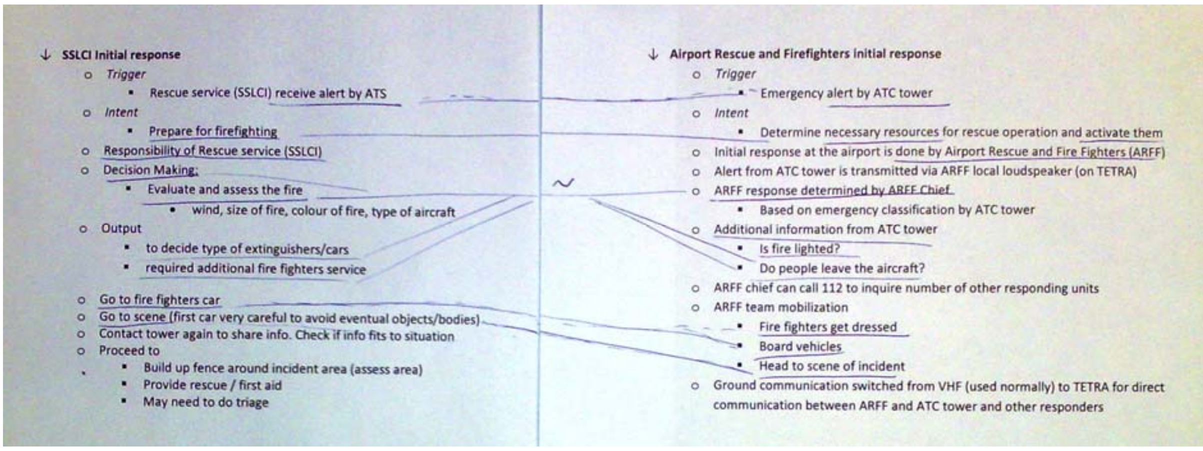

Figure 3. Consolidation of the Initial Response Task for Two Aircraft Incident Cases (AI1-AI2)

The models derived from cases AI1 and AI2 describing aircraft incidents were consolidated first. Abstract tasks were created by matching individual tasks from the two work models to produce an initial consolidated sequence model (CM1) with 17 abstract tasks. Fifteen out of the abstract tasks were common to both sequence models (see Table 3). Where more than one criterion could be used to match a single task, the tasks were matched by individual steps (11 cases), by intents (10 cases) and by triggers (five cases). The two remaining tasks were unique for case AI1 (Casualty counting and Investigation).

The result of the first consolidation (CM1) was merged with the sequence model describing a bomb threat incident (BT3). A seventeen-task model again emerged, wherein a resemblance was identified in 13 of the tasks. The tasks were matched by steps (eight cases), intents (five cases) and triggers (two cases). Differences between some of the matched tasks and a lower number of matches indicate fewer similarities between the consolidated model of aircraft incidents and the model of a bomb threat.

The consolidation process was repeated with the last data set describing a train crash incident (TC4). The consolidated model CM2 matched with the TC4 model in 14 tasks on steps (nine cases), intents (three cases) and triggers (one case). The number of consolidated and matched tasks and details about the matching criteria are summarised in Table 3.

Source	Result	Total number of tasks	Matched tasks	Number of matches		
				Steps	Intents	Triggers
AI1, AI2	CM1	17	15	11	10	5
CM1, BT3	CM2	17	13	8	5	2
CM2, TC4	CM3	17	14	9	3	1

Table 3. Material Collected from the End Users and Managers

The final consolidated sequence model (CM3) has 17 tasks and is shown in Figure 4. The tasks form a time sequence indicating their order and which tasks run in parallel. However, we do not specify when exactly each task starts or ends. The consolidated model starts when an emergency response agency is notified of an incident. The incident is classified and corresponding emergency services are alerted. Each agency determines the necessary resources and activates them. Responding personnel meet at a rendezvous point and the first responders to arrive provide detailed information about the incident. Gradually, the scene becomes organised according to an emergency plan and each agency executes its role. A command structure is set up to provide fast and effective joint responses. The primary goal of the rescue operation is to mitigate life-threatening situations and evacuate casualties. Parallel goals are to care for relatives, deal with the media and investigate the incident. To determine the size of the incident and maintain awareness of the operation's progress, each casualty is registered and counted. Once discovered, each casualty is assigned a transport priority during a triage task. Each casualty is then transported to a collection point to receive medical treatment, check for status changes and collect detailed information. Finally, the casualty is transported out of the scene either to a hospital or another appropriate place.

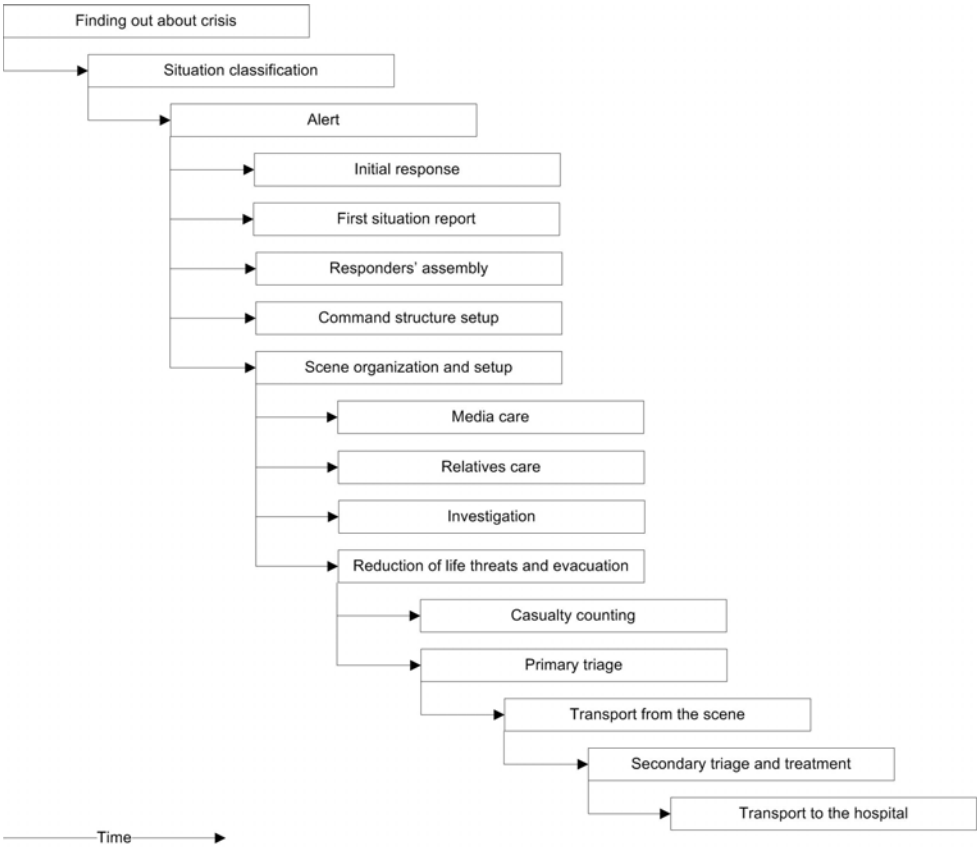

Figure 4. Tasks of Consolidated Sequence Work Model CM3

LESSONS LEARNED ABOUT MODELLING AND CONSOLIDATION

From the collected data, it was not always possible to derive action triggers or intents. Therefore, the consolidation was mostly performed by matching the tasks and less by matching intents or triggers. Examples of communication included in the work models provided a better understanding of the tasks. However, this information was only of limited value for the purposes of consolidation and could have been omitted.

Crisis management is a serious process that requires full concentration and a minimum of unnecessary disturbances. The possibility of making a Contextual inquiry as suggested in Contextual Design was unlikely with crisis personnel because it requires either unobtrusively observing how they perform their task and letting them describe it or directly asking them about the task as they perform it. Opportunities to observe live emergency responses during an incident or an exercise are rare. We did not find that these methodological deviations seriously lessened the accuracy of the models. Overall, the sequence models proved helpful in capturing work practices during crisis management.

During the crisis management process, activities are running in parallel that are usually the responsibility of different agencies. It appears to be better to include such activities in separate sequence models than to describe them in a single sequence. When consolidating sequence models organised next to each other (as shown in Figure 5, right), it is easier to follow a time line. This organization eliminates confusion from going back and forth in the consolidated material (shown in Figure 5, left).

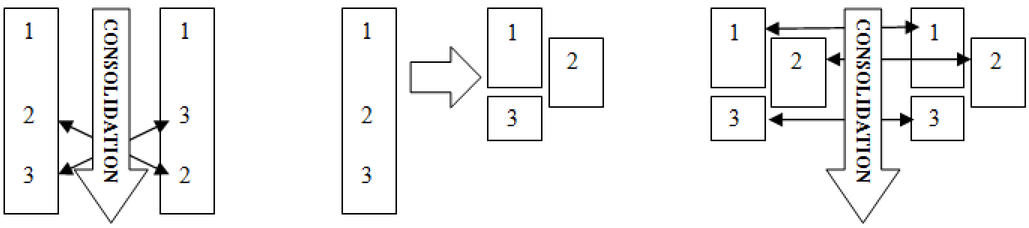

Figure 5. Consolidation of Sequentially Ordered Tasks (left) and Tasks Ordered in Parallel (right)

DIFFERENCES IN CRISIS MANAGEMENT

A major difference observed across the incident response systems was the names of roles and places. Places at an incident scene have different names in the different systems, but their locations and their use reveal a purpose that is identical across the systems. Similarly, identical crisis management roles may have different names in the different systems. Unlike places and roles, activities and crisis management organisation bear a higher level of similarity between the systems. The following sections describe the differences identified during the consolidation process.

Consolidation of Aircraft Incidents

During the consolidation, a difference in the structure of crisis management was noticed between the aircraft incident cases AI1 and AI2. The first incident response system of AI1 appears to be centralised with alert information being distributed by a national emergency system, whereas in the case of AI2 the aviation agency is responsible for alerting and thus the national emergency level is not involved. The reason behind this difference is believed to be the scale of each system. An aircraft incident reaches the national level in a smaller country, whereas it is kept at the local level in a larger country with a complex emergency response system.

A volunteer organisation has an important role in the crisis management system in the case of AI1. Not only does it serve as a source of personnel and other resources, but it can also provide the skills to replace the professional emergency services if necessary. The flexibility for people to change roles is an important attribute of the system in AI1 that affects all the first responders but not the coordinators or commanders. For example, a firefighter can become an emergency medical team member when firefighting tasks are finished. This flexibility to change roles makes effective use of resources during crisis management, especially with limited resources.

Three differences were observed in casualty management. Decisions regarding casualty placement at the incident scene are the responsibility of a coordinator in system AI1, but they are the responsibility of an on-scene commander (one level higher) in AI2. Whereas in the case of AI1 all casualties are transported to a safe location that is sheltered and heated, and from there to a hospital when transport is available, in AI2, the lightly injured are transported to a shelter, while serious injuries stay near the scene and are directly transported to the hospital. The reason for the additional transport in the case of AI1 is believed to be a greater possibility of bad or serious weather conditions.

An important difference was observed in the monitoring of casualty flow. Whereas in AI1 it is the police's responsibility to count and register all casualties leaving the scene of the accident, in the data describing AI2 a similar activity was not identified. Similarly, investigation and scene recovery were found only in AI1.

Consolidation with a Bomb Threat

There are several differences between the consolidated aircraft incident model (CM1) and the bomb threat case (BT3). An incident warning is a unique action that starts the crisis management process in the BT3 case. Compared with an accident (e.g., an airplane crash), an incident such as a bomb threat is intentional and therefore a warning carrying information of a possible attack may be received in advance. It is then confirmed by a threat message (e.g., a threat call). In this case, the Situation classification phase is extended to include threat evaluation. The threat is either validated or dismissed by the airport and police officials based on the available information.

The alert and initial response phases of a bomb threat include cooperation with non-emergency response services such as airline operators and facility managers. Therefore, these organisations must be a part of the crisis management training team.

In the case of an aircraft incident, a reduction of the threat to life and an evacuation follow each other after the incident occurs. However, in the case of a bomb threat, the evacuation is triggered before the incident happens (i.e., before the bomb has exploded). When a suspicious luggage item is found it must be checked and evaluated for possible explosives. At that point, an evacuation is triggered. When an explosion has taken place, the processes of life threat reduction and evacuation are similar to those in an aircraft incident but with an additional step in which specialists determine the type of bomb to select a proper fire extinguishing method.

Minor differences were found in casualty collection and care for relatives in the bomb threat case. The on-site organisation does not include centres for casualties and relative care when the bomb is outside of airport structures. The process of casualty registration focuses on the bodily evidence only, and the investigation gathers evidence as in the aircraft incident case, which also focuses on victim identification, namely, survivors and deceased.

Consolidation with a Train Crash

Differences were observed in naming in the command structures of TC4 and CM2. A system of three labels, gold, silver and bronze, is used by the police and other emergency services. The labels indicate responsibility for strategy (gold), tactics (silver) and operations (bronze). The command structure is role-specific and not rank-specific. If compared with the AI1 case, the command structure is more complex and the officers change their role based on the scale of the incident and the incident response phase.

The first situation report of a train crash provided by the police in TC4 is preceded by a thorough situation assessment, in contrast to case CM2. Information such as the number of casualties, hazards, the type of incident, its location and access to the scene is logged and the information is shared with a control room.

The complexity of the TC4 system is evident during the investigation phase. Several investigative bodies work on the scene in parallel and they need to agree on on-scene primacy and information sharing procedures. These are dependent on the cause and scale of the incident.

In the case of a railroad incident, safety must be ensured for all the emergency services in the area. The police are therefore responsible for liaising with the rail network and requesting “power-off” and “trains stopped” signals during the Reduction of life threats and evacuation phase.

The triage procedure in the TC4 case introduced an additional casualty category. An expectant blue is used in situations where there are such large numbers of patients that to respond to the clinical needs of every individual and to injuries that are potentially not survivable would be detrimental to other patients. Thus, primary triage (triage sieve) and secondary triage (triage sort) were identified, although the activity and the types of locations remain similar to those in case AI1. Casualty counts and records of casualty movements are kept by police together with ambulance crews, including information on where casualties are sent away from the scene.

CONCLUSION

We have consolidated models describing four cases of major incidents. The cases include the structures of major crisis management tasks for three types of incidents in three European countries. The work can be considered as an initial contribution to activity consolidation across different incident response systems.

The contributions of the paper are threefold. A requirements model has been created based on extensive requirement elicitation in meetings, field visits and workshops with a broad range of stakeholders from multiple agencies. A second contribution of the paper is the application of work model consolidation and lessons learned therefrom. A third contribution of the paper is an analysis of similarities and differences of three different crisis management systems in the transport sector in three different European countries.

As in any study, there are potential limitations and threats to validity. We have applied Contextual design methods to describe and to consolidate data about crisis management across different systems. The nature of incident response and time constraints make it difficult to collect data with the level of detail required to create Contextual design models. A sequence work model was therefore selected as the key model for data consolidation, and this model allowed the activities performed by personnel or agencies in the crisis management system to be analysed. The consolidation results in a task sequence suggesting the order and the concurrence of the task. However, it does not show exactly when each task starts or ends.

We have found a number of differences between crisis management systems and between the incident cases. The system differences are caused by the size of the country, the amount of resources available or local weather conditions. Incidents of different types require distinct tasks to be accomplished or the same tasks to be carried out in different ways. The process of consolidation has shown that similarities are more evident at the level of crisis management organization and command, while differences are prevailing in procedure details.

Finally, we summarise a few lessons learned. Crisis management is a serious process and requires full concentration. Instead of live observation and direct enquiry of participants doing the work, we have used unobtrusive methods including interviews, discussions and observation of training exercises. This approach brings certain limitations to the data collected and makes the consolidation process focus more on actual steps performed rather than on action triggers or intents. The data collected about information exchange provided a better understanding of the tasks but only limited help for the consolidation. As a part of future work, it will be interesting to compare Contextual design methods to others with respect to ease of consolidation. This could fit well into forming the landscape of methods for designing socio-technical systems (Baxter and Sommerville, 2011). The consolidation process is easier when parallel tasks are placed next to each other. In this way, the consolidation can follow a time line and eliminate confusion from moving back and forth between the consolidated models.

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