Exploring protocols for multidisciplinary disaster response using adaptive workflow simulation

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ABSTRACT

The unique and dynamic changing nature in which a disaster unfolds forces emergency personnel involved with the mitigation process to be greatly flexible in their implementation of protocols. In past disasters the incapability of the disaster organization to swiftly adjust the workflow to the changing circumstances, has resulted in unnecessary delays and errors in mitigation.

Addressing this issue, we propose and demonstrate a method for simulating disasters for work and protocol optimization in disasters response (TAID), based on the BRAHMS multi-agent modeling and simulation language. Our hypothesis is that this low fidelity simulation environment can effectively simulate work practice in dynamic environments to rearrange workflow and protocols. The results from an initial test simulation of the Hercules disaster at Eindhoven airport in the Netherlands look promising for future and broader application of our disaster simulation method.

KEYWORDS

Disaster response and management, adaptive workflow modeling, protocol optimization

INTRODUCTION

Depending on the emergency type, protocols are activated that structure workflow of individual emergency services (such as the fire department, police department, medical services) involved in the mitigation process. In routine situations (such as small accidents, minor collisions) a single protocol per service is able to cover the entire mitigation process, directing the contribution of the individual services in the ad hoc multidisciplinary organization. Collaboration, coordination and competencies are practiced every time these situations occur, leading to an almost automatic synergy of the services and optimization of the workflow and protocols. However, in non-routine or even unique multidisciplinary emergency situations like disasters, a single protocol is not sufficient to guide the entire multidisciplinary organizational response, complicating workflow and protocol optimization. The complex, diverse and dynamic combination of multiple disasters in one disaster area excludes the use of any single, or simple combination of pre anticipated protocols. Decomposition of the situation enables the emergency services to use parts of these protocols to coordinate their work effectively (Basu & Blanning, 2003). In order to adapt to the changing situation quickly, emergency services must be able to break away from established work patterns prescribed in protocols taking snippets from different protocols and relying heavily on the emergency personnel's experience.

Errors in emergency response caused by conflicting or unclear protocols surface when they are least wanted: during the actual emergency response. Strategic decisions have to be made very quickly, by decision makers, who quite often do not have full insight into the tasks that are being performed, who is performing them and what resources are still available. Information shortage (van Someren, Netten, Evers, Kramer, de Hoog & Bruinsma, 2005) and lack of organization and task awareness (Oomes, 2004; Smith & Dowell, 2000) can lead to an unbalanced delegation of tasks; where some emergency personnel are overloaded with work, others are awaiting instructions or are working on tasks that have less urgency; the execution of tasks that are mutually exclusive can delay the overall mitigation process by not using emergency personnel and resources efficiently; and finally, the increase in communication about coordination can endanger the communication infrastructure and increases the probability that liaisons and dispatchers will suffer from the consequences caused by information overload, which can negatively effect the overall mitigation process (Abbink, van Dijk, Dobos, Hoogendoorn, Jonker, Konur, Maanen, Popova, Sharpanskykh, van Tooren, Treur, Valk, Xu & Yolum, 2004; Bruinsma, 2005; Commissie Onderzoek Vuurwerkramp, 2001; Enquête commissie Bijlmerramp, 1999; Raad voor Transportveiligheid, 2002).

Disaster exercises provide opportunities for emergency services to practice multi disciplinary response and protocols in a particular scenario. This offers valuable information about how emergency services react, structure work, communicate, and use resources when confronted with a realistic approximation of a real disaster. Protocols used by the multidisciplinary organization can be tested and afterwards adjusted. Disaster response can be optimized before a real disaster occurs, reducing errors or the impact of errors that occur during actual response (www.minbzk.nl).

Lessons learned from disaster exercises increase experience and competency of the personnel involved, making them aware of possible shortcomings in their capabilities and pitfalls in the protocols. This provides necessary input to structure training and enhance the protocols used. However, from the large number of possible scenario's a disaster can follow, the disaster exercise just follows and practices one, neglecting others. The exercise is thus not able to test protocols exhaustively, since it leaves out all the other scenarios the disaster could have followed. To effectively test the possible combinations, more multidisciplinary disaster exercises have to be conducted, incorporating all possible rational protocol combinations. Staging many disaster scenarios is not practical or possible given the costs, the time investment of the emergency personnel associated with these multidisciplinary disaster exercises, and the inconvenience caused for citizens.

In contrast to real world disaster exercises, computer simulations of disaster response are able to repeat a particular scenario, changing the timing and occurrence of particular events or adding restrictions to the use of personnel and resources. Like other methods, simulations are not capable to exhaustively cover all dynamic aspects of disasters and disaster response such as unpredictable human or environmental behavior. However the simulation makes it possible to test protocols in multiple plausible situations, fine-tuning existing protocols to structure disaster response efficiently in every simulated disaster situation, without the costs, time investments or the inconvenience for citizens. Simulation can therefore be a valuable addition for disaster response (Boin, Kofman-Bos & Overdijk, 2004), for it is able to aid planners and on-scene commanders structure the disaster organizations' tasks, and anticipate on a greater range of possible states of the world.

Although modern techniques and computers are able to produce high fidelity simulations[1] of disaster management situations, we propose a simulation method that has a relative low fidelity. By doing this we are able to create a flexible, dynamic simulation of disaster response that focuses on the aspects that significantly differentiate disaster response from normal emergency response: workflow complexity, communication and information. By describing these reoccurring aspects in detail, and simplifying others, the simulations' applicability to other disasters types significantly increases.

In this paper we propose and demonstrate our method for simulating disasters for work and protocol optimization in disasters response (TAID), based on the BRAHMS multi agent modeling and simulation language (Sierhuis, 2001), which consists of a separate modeling and simulation environment. Our hypothesis is that this low fidelity modeling and simulation environment can effectively simulate work practice in dynamic disaster environments and is able to rearrange workflow and protocols adaptively, without the added effort needed for advanced visualizations (such as rebuilding tailor-made graphic simulation environments).

REQUIREMENTS

Based on the results of a literature review of actual disasters (Bruinsma, 2005), in our view for BRAHMS to be able to validly simulate disaster response the modeling tool should be able to model the dynamics of the disaster setting, the actors, communication, the protocols and tasks. The modeling environment should therefore meet the following requirements.

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[1] Fidelity refers to the degree of similarity between the simulation and the operational situation (Hays & Singer, 1988). High fidelity simulations represent the operational situation and all its aspects as close as possible, whereas low fidelity simulations simplify certain aspects of the operational situation, in order to focus more on others describing them as accurate as possible.

Setting

1.) Since every disaster occurs in a particular *environment*, basic elements such as buildings, roads and distances between them must be available in the simulation. However, these elements may change due to particular events (such as explosions). Another basic element that should be included in the simulation is time, since this is the measurement for the duration of occurrences and tasks.

2.) The tool must be able to model *objects*. Both durable (such as phones, cars, fire-hoses) and non-durable objects (such as water, foam, oxygen) should be included. These objects must be placed in the environment in a particular location, where they can be used by every agent who has the capabilities to use it. Objects must be able to move from one location to another by a certain event (for example an explosion) or person (for example transport). Non-durable objects furthermore must be able to decrease or increase in quantity.

Actors

3.) The actors involved with the mitigation process and the disaster as a whole are the *emergency personnel*, *victims* and *bystanders*. They must be equipped with basic life characteristics that can change due to the disaster situation. The simulation for example must be able to model fatigue, injury and death. Furthermore, knowledge, competencies and information the actors posses about certain things concerning the disaster (disaster information), or response (protocol information), must be incorporated in order for them to react to them.

Communication

4.) Communication *between actors, between objects and actors* and the use of communication devices must be incorporated. In actor – actor communication both verbal and non-verbal communication play an important role. Actor - object communication involves, for example, entering a report sheet into a computer. Object – actor communication can be seen as a warning signal from a monitoring device that can be interpreted by the actor. Finally, object – object communication can be seen as the linkage of two computers in a network.

Tasks

5.) The tasks embedded in the different *protocols*, and *primitive tasks* (such as breathing, walking) must be specified. The tasks should be able to be performed in any particular order, keeping in mind task dependencies. The existence of a task should not, however, be a reason for triggering it, for knowledge and information or the availability of resources mostly determine that. Protocols and tasks should be able to change order given new information about the situation.

Events

6.) Events cause changes in the course of a disaster, and the response to it by emergency services. In a disaster the first event often triggers the initial protocol. Additional events, manipulations of the environment, information, resources or personnel are essential to determine how disaster response is affected by these factors. Events thus are fundamental for the simulation, since they initiate it, and introduce complications for the mitigation organization.

Adaptability

7.) The setting, tasks, actors, and communication must be able to change according to the situation the emergency response is faced with. The output from the simulation should vary as the elements in the modeling environment are changed.

In the following sections we will present our method to simulate dynamic adaptive disaster response. First, we will show if, and how this method satisfies the requirements presented above. Second, we will present a test simulation in the form of a dynamic reconstruction of the emergency response to the Hercules disaster at Eindhoven airport the Netherlands in 1996. Based on this case we will test if the TAID method combined with the BRAHMS simulation language can simulate work practice in dynamic environments, so protocols and workflows can be restructured to adapt to the changing circumstances of the disaster. Although adaptability is not fully represented in the simulation of the Hercules disaster response, the results from this initial simulation are promising for future application of our disaster simulation method in dynamic changing environments.

TAID METHOD OF MODELING DISASTER RESPONSE USING BRAHMS

BRAHMS was developed to support the design of work by illuminating not the formal elements of how work should be done, but by focusing on how work actually is done (Sierhuis, 2001). BRAHMS can be described as: '… a multi agent simulation tool for modeling the activities of groups in different locations and the physical environment … A BRAHMS model reveals circumstantial, interactional influences on how work actually gets done, especially how people involve each other in their work.' (Clancey, Sachs, Sierhuis, & van Hoof, 1998) The tool has its roots in object oriented and other agent based languages, which shows in the tools' use of an ontology-like, hierarchical structure, which can both describe the common characteristics and the individual differences in an efficient way. For example, tasks that are performed by the emergency services are hierarchically structured in such a way that people in subgroups inherit these from the parent group (figure 1). As a result, the tasks of the main disaster organization apply to all services into which it branches. The further the branch reaches, the more specific the task becomes.

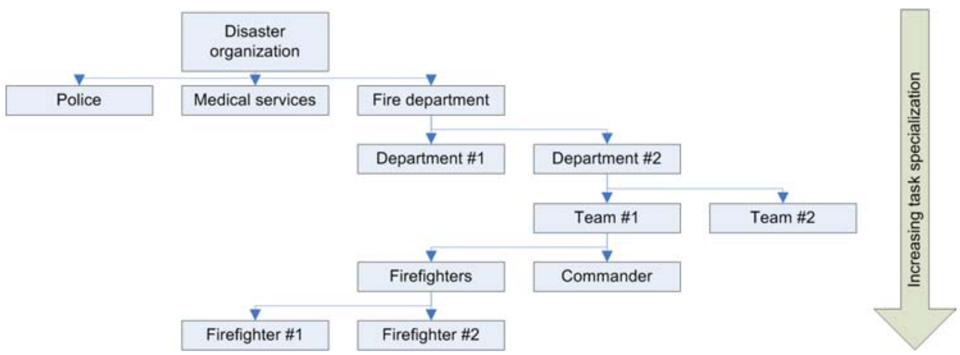

Figure 1. Snippet from a generic hierarchical structure of a disaster organization.

This hierarchical approach enables the modeler to simply and quickly apply changes to the model, affecting all subgroups. It further resolves the problem of defining all characteristics for a new group that enters the organization. It provides the opportunity to make a disaster response 'template' where general disaster response is pre specified high in the hierarchy, and minor adjustments at a lower level, making the model easily applicable to completely different disaster situations. Using the consist-of taxonomy shown in figure 2, a world is created consisting of a hierarchically structured modeling formalism consisting of agents, objects, beliefs and facts, activities, and geography. In the simulation environment these concepts interact based on the beliefs agents hold (representation of information).

Groups contain
- agents who are located and have
- beliefs that lead them to engage in
- activities that are specified by
  - workframes that consist of
  - preconditions of beliefs that lead to
  - actions, consisting of
  - communication actions
  - movement actions
  - primitive actions
  - other composite activities
  - consequences of new beliefs and world facts
  - thoughtframes that consist of
    - preconditions and
    - consequences

Figure 2. The BRAHMS consist-of taxonomy

In the disaster domain, agents, and groups of agents represent the people and the organizations involved in the mitigation process. Agents are structured in groups based on similar tasks, organizational type or competencies. Figure 1 shows that firefighter #1 and #2 belong to the similar group of firefighters, and to team #1. This implies that, in absence of differentiating characteristics, they normally work on the same type of tasks defined in their organizations protocol. Objects and groups of objects (classes) represent all objects that emergency personnel can use during the mitigation process (such as fire trucks, stretchers), but also all objects located in the disaster environment (such as obstacles, fire). It can consist of objects that can be used once and objects that can be used repeatedly. Beliefs and facts are representations of respectively subjective and objective representations of the world by agents and objects. Facts are pieces of information that are not private to the owner of the information and can be 'seen' by everyone who is in the same location as the agent or the object. An example of a fact is organizational membership of a particular agent. An agent can communicate this by wearing a particular uniform, without actively communicating it. Beliefs form the inner thoughts of agents and objects, which can only be extracted by interacting with them. Agents and objects can have beliefs about anything in the world and these can be inconsistent with the facts in the world. An agent, for example, can posses the belief that the color of the car causing an accident is red (belief of the agent), while in fact it is grey (fact of the object). Beliefs thus are subjective representation of the world, and can under certain circumstances be biased. Beliefs are the trigger for the activities performed by an agent. Activities and work frames respectively represent tasks and series of tasks performed by an agent. People engage in activities based on beliefs that they have about the world. Individual differences caused by the absence of information or presence of faulty information can thus have an effect on the tasks performed by the agent. Information processing biases -caused by information overload- can also be modeled this way, filtering the information that becomes a belief triggering a task or a series of tasks. Geography represents the spatial relation between agents and objects. It provides locations where agents and objects can be placed and moved around in (such as a country, office, car). Geographical relations between locations are expressed in the variable time it takes to move from one location to another. The relative distance can be defined by, for example, the mode of transport or obstacles on the road and can differ for all agents or objects.

Figure 3 shows BRAHMS' main window with the sub-models, defining geography, agents and object. The hierarchical structuring of these concepts is clearly shown. For example, the Netherlands contain the town of Enschede, which in turn contains several fire departments, and a disaster area.

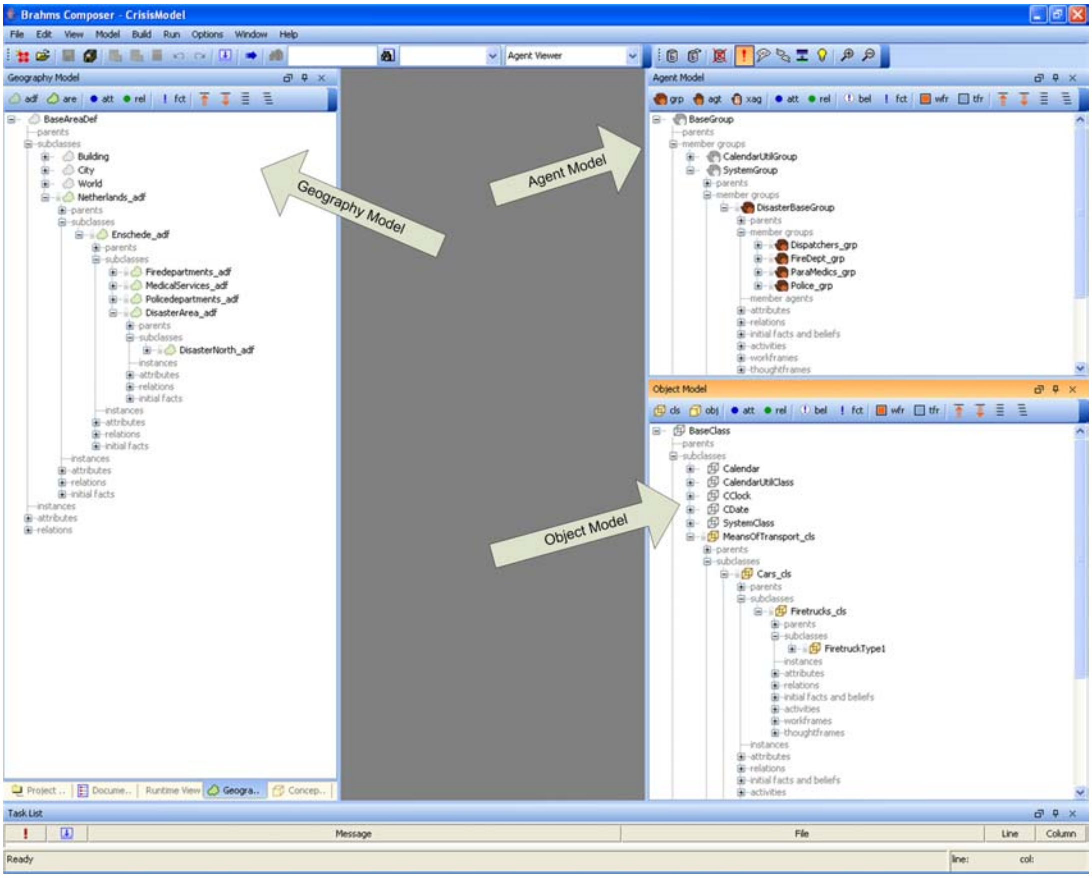

Figure 3. The BRAHMS modeling environment

It can be concluded that the BRAHMS environment in combination which the TAID method has the potential to fulfill the requirements.

Locations can be entered in the geography model. Distances between these locations can be modeled by either constructing direct paths using time as a measure for distance, or by variable traveling time indicators that influence traveling time. The latter enables modeling of relative distance between two locations. The locations can adapt to changes in the environment by, for example, becoming off limits to everyone, and sending out information that is has collapsed.

The object model enables it to model, both durable and non durable, objects by embedding an adaptive belief about quantity to the object. Furthermore, objects can be modeled in such a way that only agents with a belief containing 'knowledge' about the use of the object are able to use it or move it.

By using beliefs, modeling of basic life characteristics (such as breathing, walking), is made possible, and are able to change according to circumstances. However more research is necessary concerning which physiological and psychological states mainly influence the work in disaster response. The use of knowledge and competencies, and particularly how it is applied should also be examined further.

Concerning the communication aspects of the model, all types of communication are possible, using all types of communication equipment. For example, a restriction to the number of active communication devices at one time makes it possible to limit the communication infrastructures capabilities, leading to loss of information or faulty messages. Communication errors during the transmission and acceptance of the message can be incorporated by equipping the receiver with certain information processing biases, or by not incorporating certain beliefs (and thus not triggering a particular task).

The hierarchical modeling structure enables protocols to be divided into subtasks and series of tasks. These parts can be addressed by the emergency personnel without having to use the entire protocol, resulting in efficient restructuring of the workflow depending on the needs of that particular moment. This way of organizing tasks, furthermore, enables normal tasks (basic life tasks) such as breathing to be easily modeled high in the hierarchy, applying to all people in the simulation. The simulation environment however, is not able to create new tasks for the agents or objects. As long as tasks are defined at the proper level of granularity fitting the needed detail, tasks can be seen as generic and re-occurring in most disasters. As a consequence task execution sequence is more likely to change than the generic tasks themselves.

The remaining requirements (using events and adaptability), are also met by the modeling environment. Events can be initiated by an 'event agent' that at a certain moment in the simulation fires a belief, changing the environment, which in turn fires certain tasks with agents. Events can occur randomly or at specified times, thus testing the rescheduling abilities of the agents and the protocols.

APPLICATION: THE HERCULES DISASTER

During its landing, a Belgian Hercules military aircraft crashed at an army airbase in Eindhoven, the Netherlands, while carrying 37 members of the Royal Dutch Army brass band and a crew of four. The initial crash caused the passengers or crew no serious harm. However, due to the kerosene fire that followed in combination with errors made during the disaster response 34 persons died and the remaining 7 were seriously wounded. The 27 investigation reports that followed showed that the disaster organization failed on several points:

- lack of clarity about protocols and task delegation;
- inefficient collaboration between the airbase fire department and the Eindhoven fire department;
- insufficient resources (human and material) to cope with the rescue;
- suboptimal use of available information.

Furthermore, the mitigation during the Hercules disaster faced difficulties due to:

- discrepancies between beliefs and facts;
- multiple protocol activation;
- multiple organization collaboration;
- delay caused by misinterpretation of non verbal signals;
- inefficient collaboration;
- communication errors.

Modeling

Based on the minute to minute transcriptions from the actual disaster (Raad voor Transportveiligheid, 2002), the Hercules disaster was reconstructed using BRAHMS. Figure 4 shows a sample of the initial beliefs and facts of the airbase fire department. 'Initial' refers to the simulations start state. These facts and beliefs refer to:

- knowledge about who uses certain radio frequencies ([…]GebruiktPortofoonKanaal[…])
- knowledge about own membership (current.ismemberof[…])
- knowledge about others and their membership of organizations ([…]isMemberOf[…])
- knowledge about the organizational structure ([…]hasBevelvoerder[…], […]hasOSC[…])

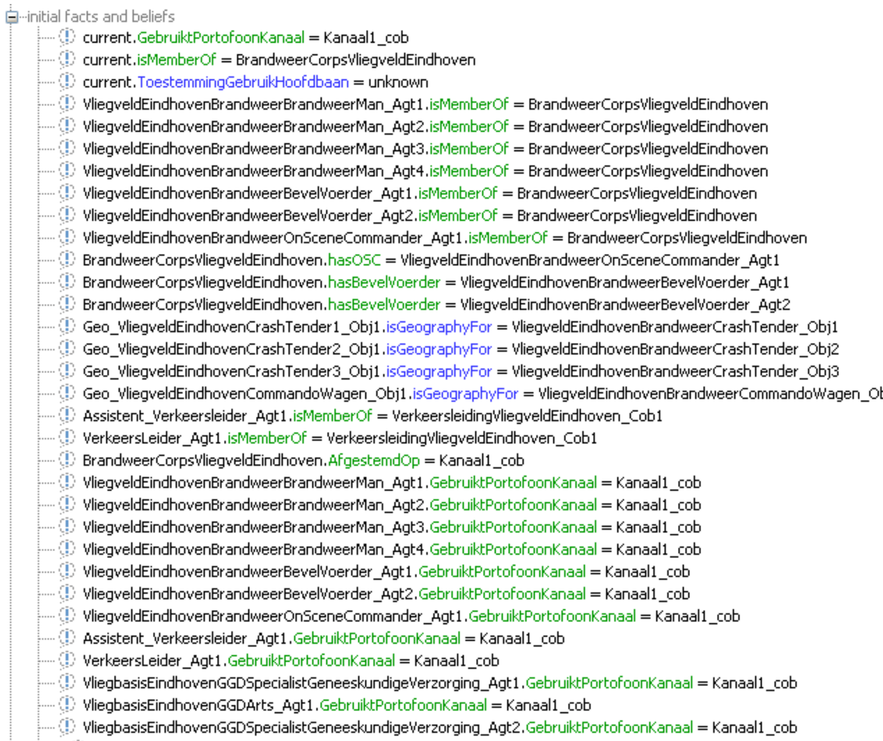

Figure 4. Sample from the airbase firefighters' initial beliefs and facts

Tasks involved with the Initial response by the firefighters are shown in figure 5. Since these tasks are shared by all airbase firefighters they are quite general. For example the task 'GaNaarAccidentLocation' (move to accident location) consists of: 1.)'Instappen' (getting into car); 2.)'WegRijden' (drive); 3.)'Uitstappen' (getting out of car); 4.)'WerkenTijdensRijden'(working while driving). The latter includes multitasking activities such as 'getting in gear' or calling. The preconditions for initiating the task of going to an accident location are:

- the On-scene Commander must have clearance from the tower to use the runway;
- the firefighters must be aware of an accident;
- the accident must occur in their district;
- the accident location must be known;
- the firefighters must know what car to take, and their role in the organization.

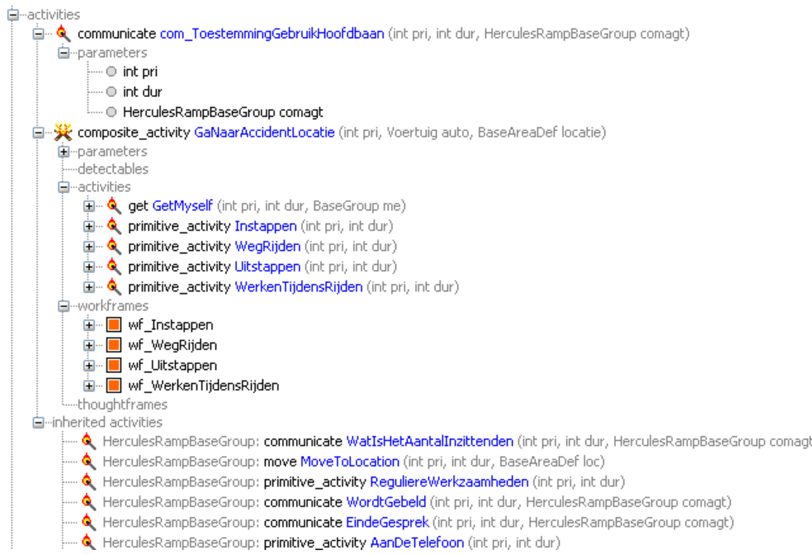

Figure 5. Tasks concerning initial response by the airbase fire department

Simulation

After having entered the characteristics of the Hercules disaster into the BRAHMS modeling environment, it is entered in the BRAHMS simulation environment. This runs the simulation and returns a bar like workflow diagram for all agents and objects in the model where tasks are structured on a horizontal timeline. As is shown in figure 6, the simulation results include information about the name of the agent or object, the location and agents' thoughts.

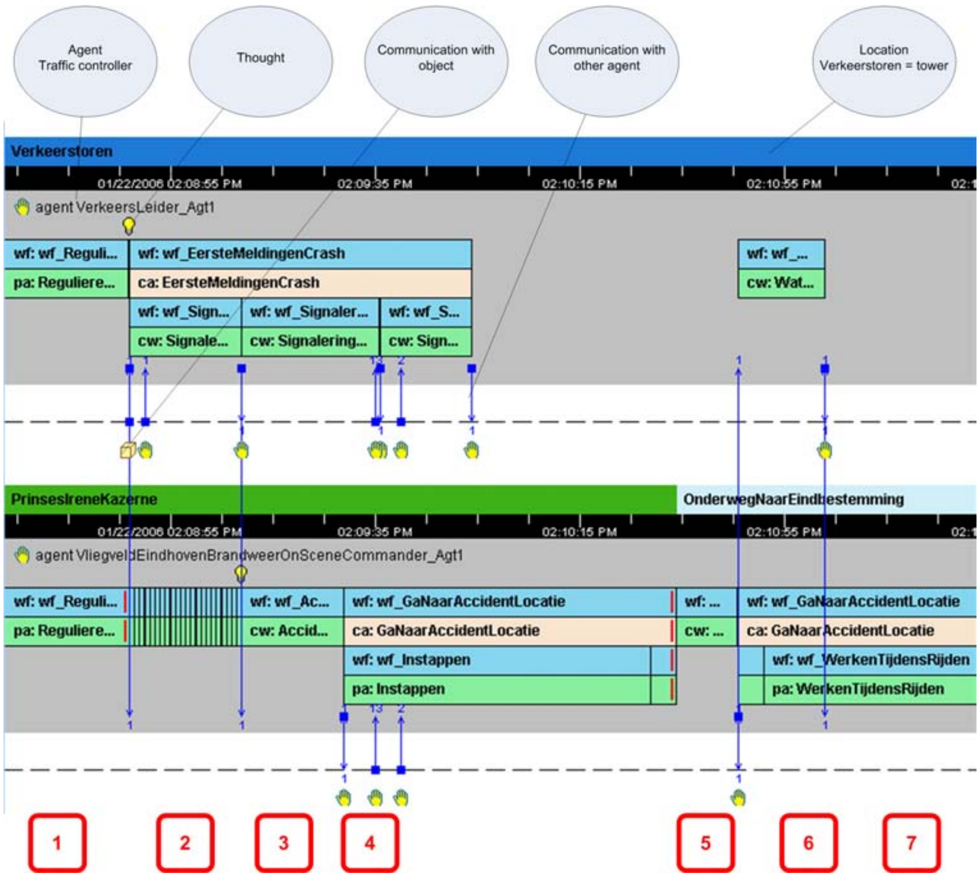

Figure 6. Interaction and workflow of the traffic controller and the on-scene commander

Based on the interaction and workflow between the on-scene commander and the traffic controller, shown in figure 6, this output will be explained using parts 1 to 7 that are shown below in figure 6. In figure 6 agents are shown as, objects are shown as, thoughts are shown as and communication is shown as. To illustrate its use, for the first two parts these symbols are incorporated in the text

1.) At the start of the simulation the on-scene commander and the traffic controller are having a normal working day, doing normal work (Reguliere werkzaamheden).

2.) The traffic controller sees that the Hercules plane ( ) is in trouble, and receives confirmation by the pilot ( ). At that moment he is aware of the accident ( ). He initiates the crash protocol, calling first the on-scene commander( ). At the end of the call, the on-scene commander is aware of the accident ( ).

3.) The traffic controller then calls the airbase medical services. Parallel to this, the on-scene commander informs the air base firefighters, who in turn are aware of the accident.

4.) The traffic controller calls the airbase dispatcher and orders to call the emergency services with a request for ambulances. The on-scene commander gets into his car and awaits an answer from the tower to a question from another firefighter for permission to drive on the runway.

5.) After permission is granted, the fire trucks leave the fire station. The on-scene commander asks the traffic controller if he knows if the Hercules was carrying passengers, and if so, how many.

6.) The traffic controller says, using the radio, that the number of passengers is not known to him.

7.) The on-scene commander continues working in the car until he reaches the disaster area.

The power of the simulation lies in the fact that tasks are initiated by information that reaches the agent or object, which allows for what-if simulation. For example, without information, in the form of beliefs incorporated by the receiver, the receiver does not initiate the task which in turn can affect the workflow of others or the state of the world. The on-scene commander will not initiate the protocol if he is not aware of the accident. This affects both the disaster (mitigation does not start, so, for example, fire is able to spread to other locations), and the disaster response (delay of the mitigation, increase in casualties). Furthermore, task duration can be random (between boundaries of a minimum and a maximum specified duration). In practice a task after all, never takes the same time to complete, every time.

CONCLUSION

This paper presented the TAID method to simulate dynamic emergency response to disaster situations, using the BRAHMS modeling and simulating tool. Using a set of requirements that minimally should be met for simulation of disaster response, it can be concluded that the TAID method, combined with the BRAHMS simulation language can simulate work practice in disaster response, and has the potential of exploring its dynamics. Table 1 shows an overview of the requirements that should be met in order to achieve this. All requirements shown in table 1 are, or could be met, and can adapt to the dynamic changing disaster environment. Additionally, protocols and workflows can be restructured to adapt to the changing circumstances of the disaster, which makes it possible to answer the "what if" question, extensively testing protocols and workflows of emergency services in order to resolve counter-productive or mutually exclusive behavior from actors in the field. By doing this it can potentially exclude possible pitfalls in disaster management. The low fidelity of the way disaster response was simulated using BRAHMS, furthermore, does not cause the simulation of work practice to be less accurate. This way, workflow in disaster response can be structured, manipulated and researched in an efficient, cost effective way.

Requirements				
Setting			**Communication**	
Locations (buildings roads)	✓ D		Between actors, between objects	✓ D
Distances	✓ D		Between actors and objects	✓ D
Time	✓ D*		Communication devices	✓ D
Objects	✓ D		Verbal	✓ D
Durable	✓ D		Non verbal	✓ D
Non durable	✓ D			
Knowledge restricted usage	✓ D		**Tasks**	
Moveable	✓ D		Protocols	✓ D
			Primitive tasks	✓ D
Actors			Work Order	✓ D
Basic life characteristics	✓ D F		Task dependencies	✓ D
Physiological states	✓ D F			
Psychological states	✓ D F		**Events**	✓ D
Knowledge	✓ D F			
Competencies	✓ D F		**Adaptability**	✓ D

Legend	
✓	Possible
D	Dynamic elements can be embedded
D*	Can be dynamical, however, unnecessary
F	Further specifications necessary

Table 1. The extent to which the requirements for disaster modeling and simulating are met by BRAHMS

The simulation of the Hercules disaster lets us conclude that with the TAID method of modeling disaster response using the BRAHMS modeling and simulating environment the groundwork is laid for future adaptive simulation of dynamic disaster response. Although this version of the simulation does not yet incorporate the adaptive characteristics, Sierhuis' (2001) space mission simulations demonstrate that adaptability is possible using BRAHMS. Furthermore, the TAID method illustrates that low fidelity tools, such as BRAHMS, can effectively simulate work practice in disaster response, without developing costly visualizations that are not essential for coming to grips with the basic processes.

The results from the simulation of the Hercules disaster response are promising for future application of our disaster simulation method and BRAHMS for protocol and workflow optimization. The hierarchical method of structuring the elements in BRAHMS (such as agents, objects, tasks) greatly simplifies the applicability to other disaster situations without the necessity to build a completely new model from scratch, increasing modeling efficiency. This enlarges the possibility of the simulation tool to run in parallel with real disasters so it can structure the mitigation real time.

FUTURE WORK

In order to improve the validity of our method for simulating disasters it is essential to know which factors mostly influence work, and how they influence work. Table 1 shows that further research is necessary in the field of modeling the actors' work practice. What is the impact of heat, fatigue, and other physiological influences? What is the impact of stress, the use of heuristics and biases or other psychological states? What typical knowledge or shortcuts do emergency personnel use? How can we incorporate competencies or experience within the simulation? Future work will focus on determining the impact of these factors in practice and in the simulation model.

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