Resilience of Emergency Response Systems

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Abstract. An emergency response system (ERS) is an example of resilience engineering, even though it is neither a single entity or technological system nor an organization with operational activities. This paper presents preliminary efforts to model an ERS and evaluate its efficiency, reliability, and resilience/brittleness. Typical organizational behaviors during emergency responses were also examined and the findings incorporated into a previously developed computational model of normative organizational behavior.

1 INTRODUCTION

Emergency response systems (ERS) and incident management systems (IMS) are the last line of social defense against natural disasters, major industrial accidents, and malicious acts of terrorism. ERS can be regarded as one method of organizational resilience, meaning that organizations should be ready to respond to and recover from sudden unanticipated events or disasters (Hollnagel et al., 2006). An ERS can also be viewed as an example of resilience engineering, even though it is neither a single entity or technological system nor an organization with operational activities. This paper focuses presents preliminary efforts to model an ERS and evaluate its efficiency, reliability, and resilience/brittleness.

ERS provide a consistent, integrated framework for an efficient and effective response to disasters. In Japan, for example, the ERS is based on the Disaster Measures Basic Law, except in the case of disasters caused by malicious acts (in this case, the ERS is based on the Protection of Lives and Assets Bill enforced in 2004). It consists of various emergency response plans and manuals distributed among various sectors of national and local governments, governmental agencies, public institutions, and private companies. In the case of an actual emergency, multi-organizational cooperation and coordination based on the ERS is expected. The ERS has various unique and common features of resilience engineering, for example:

1) Standardization of organizational structure, and necessary processes and procedures is a core component of the ERS; however, adaptive and flexible responses are also important in actual emergencies and have significant mitigating effects on the negative consequences of disasters.

2) The negative effects of natural, adaptive, and flexible responses, as well as inappropriate responses, are sometimes amplified during intra- and inter-agency coordination, and can lead to confusion.

3) It is difficult to monitor the current status of the system in everyday activities because the ERS is activated only in actual emergencies.

4) At present, there is no established methodology or criteria for assessing ERS, which makes it difficult to make improvements.

We previously developed a prototype simulator of inter- and intra-agency communication and coordination in an emergency setting using a normative model of organizational behaviors during emergency responses (Kanno et al., 2006). Various rules, protocols, and procedures were subsequently identified through task analyses, observations, and records of emergency exercises in addition to interviews with emergency responders of various organizations. We then constructed a normative model of organization with a conventional human model incorporating the input-decision-action cycle, and developed a multi-agent simulator of ERS.

We also investigated typical responses to problematic situations (typical errors and error handling, and typical natural, adaptive, and flexible responses), with the intention of incorporating the findings into the normative model. With such a model and simulation, assessment of the influence of non-standardized responses in multi-organizational emergency responses is then possible. In this paper, we present initial efforts regarding investigation and implementation of the above behaviors and conclude by discussing preliminary test results obtained with the model.

The following section describes the normative organization model developed in our previous study. In Section 3, preliminary results of the investigation of typical behaviors (natural responses, errors, and error handling) in emergency situations and implementation of these behaviors into the model are described. Finally, discussion and conclusions are given in Section 4.

2 The Organization Model

In our previous study, we proposed a normative organization model for emergency responses and developed a simulator that simulates the response activities of various organizations in an emergency situation (Kanno et al., 2006). The model covers the various granularities of organizations, from small task groups to local government offices, and integrates them into the simulations. At this stage in our research, the agents included in the simulation were implemented as normative agents that do not make inappropriate or emergent responses. As pointed out previously, it is also necessary to take into account the influence of erroneous behaviors and the adaptability of organizations to simulate real-life emergency responses, because coordination and communication mechanisms could also change in response to unforeseen emergency situations.

2.1 Model Architecture

We applied a human modeling approach to model organizational behavior in an emergency response. Single organizations and groups were seen as a single entity processing in an input-decision-execution cycle; that is, each organization and group obtains information or resources from the disaster environment or other agents, decides appropriate actions based on established rules formed with reference to their knowledge base and message storage, and then executes these actions. The number of participants and granularity of each organization can be configured by designing appropriate knowledge bases for each organization. In the following subsections, we provide a brief explanation of the major components of the model.

Input. Organization agents exchange various messages (e.g. information, queries, requests, resources, etc.) with each other (these messages are described in detail in the next subsection). During input, messages (XML) are parsed whenever a new message is received from another agent or the environment, and the content of the message is then processed during the decision-making step. Information messages are stored in message storage and can be referred to by an agent during subsequent decision-making. The number of resources increases each time a new message is obtained.

Decision Making. In this step, based on the contents of the messages obtained, appropriate responses are determined. In our previous study, we identified and categorized response rules into two types: protocols and situation-oriented rules. Protocols include both explicit and implicit codes for correct conduct and are embedded in the structure of the system (organizational structure, role allocation, etc.). Other kinds of typical responses were also observed during emergency exercises, such as re-queries, re-requests and reconfirmations, and initiated depending on the situation. In this paper, these responses are referred to as situation-oriented responses and the initiating rules as situation-oriented rules. Details regarding the implementation of these rules are given in Section 3.

Execution. In this step, actions, tasks and procedures are executed. An action is a primitive activity during an emergency response, such as making a phone call or dispatching personnel, and is defined as a set of required resources with an expected duration and effect. A task is a typical structured activity implemented as part of the emergency response plan such as emergency transport and emergency monitoring, and includes several actions. A procedure is a single or series of actions predefined in the emergency response plan or manual. It also contains preconditions and is automatically initiated when these preconditions are satisfied.

Knowledge Base. Each agent has its own knowledge base that stores knowledge about points of contact, necessary procedures, the structure of the organization it belongs to, and role and task allocation. By editing the content of the knowledge base, different emergency response systems for various types of organization can be developed. In decision making and action execution, each agent refers to the content of its own knowledge base. All received information is stored in message storage, and can also be accessed by the agent in deciding a response.

2.2 Ontology and Messages

We constructed ontology to describe the context of emergency situations and response activities by analyzing various emergency response plans and manuals, emergency exercise scenarios, and emergency response activities. This ontology was used to represent both the contents of messages exchanged during multi-agent simulation and knowledge entities stored in each agent's knowledge base. Fig. 1 shows the XML schema of a message based on this ontology. An XML schema describes the structure and constraints of a XML document.

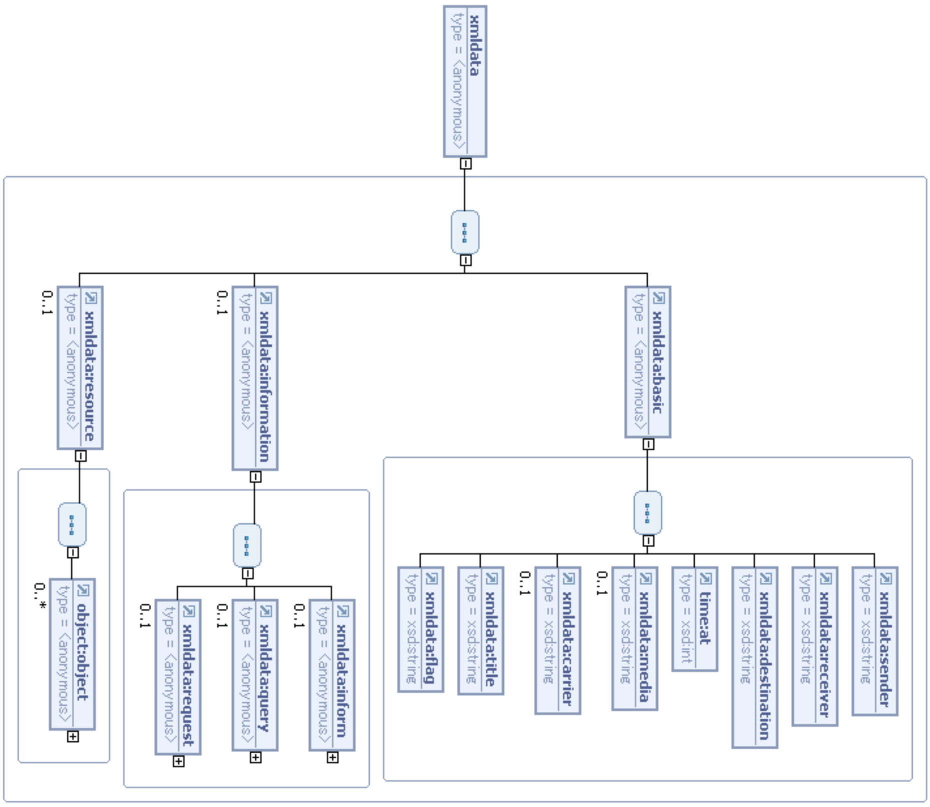

Fig. 1. XML schema of a message

Message Content. Communication and resource exchanges between different organizations are realized by transfer of a structured message (XML) like that shown in Fig. 1. A message contains basic information accompanied by information on, for example, the sender, the media used, and so on. Parts marked with an extension mark in Fig. 1 such as "xmldata: inform" have subsequent structures that enable more detailed description.

We used three basic types of information (inform, query and request) also structured by an XML schema. Fig. 2 shows the detailed structure of a "request" (part of the entire message). The other types of information are also based on a hierarchical structure and described by XML.

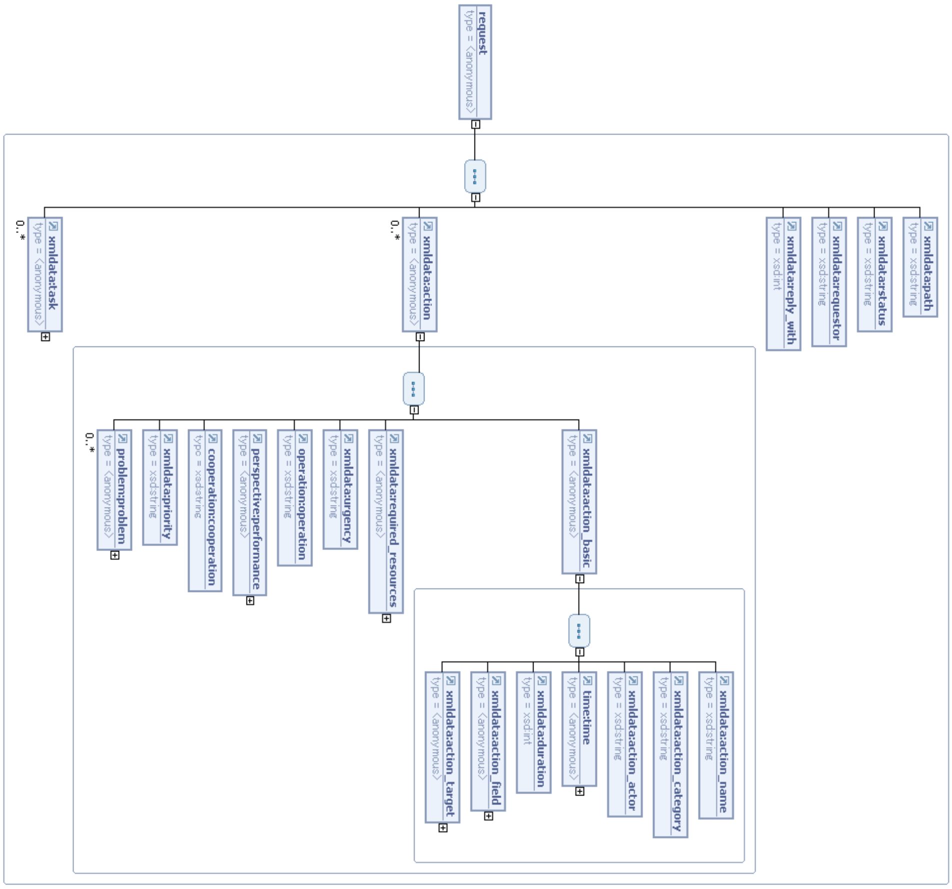

Fig. 2. XML schema of a "Request"

3 Typical Behaviors during Inter- and Intra-Organizational Coordination

To investigate typical organizational behaviors implemented during problematic situations in an emergency response we conducted interviews and questionnaire surveys of emergency responders, such as local government officials, police, and nuclear experts, as well as observing emergency exercises during various disasters; for example, an accident in a nuclear facility, an earthquake in an urban area, and a terrorist attack of a nuclear facility. In the interviews and questionnaire surveys, respondents were asked to describe both experienced and expected problems in actual emergencies or emergency exercises and how they coped or would cope. They were also asked how they would respond to problematic situations observed during the above emergency exercises as well as emergency situations obtained in preceding surveys. Table 1 shows an example section of the questionnaire.

Table 1. An example section of the questionnaire

	Question
Problematic Situation	• When did/could the problem occur? (Information gathering, situation assessment, decision making, coordination, execution, etc.) • Where did/could you experience the problem? (Location, section, organization, sections and organizations involved etc.)

	• Describe the situation in detail
Response	• What did/would you do or not do in response?
Normative Response	• What should you have/should you do in this situation?
What-if question	• How would you respond to the following situation?

3.1 Problematic Situations and Typical Responses

Table 2 gives examples of the results of the survey. The left column shows the problematic situations presented and the right shows typical responses. Respondents did not necessarily choose only one response, but rather often implicated several simultaneous responses or multiple options one after the other until they achieved their goal. Some responses are defined in agency manuals, but most are not and, in such situations, the responses were based on experience or common sense. These various options could cause confusion especially during inter-organizational communication and coordination.

Table 2. Preliminary Results of the Questionnaire Survey

Situation	Response
You receive information, the source of which is unknown	1. Ask the provider and/or confirm its reliability with other agencies 2. Compare it with the information at hand, but do so urgently
You receive conflicting information	1. Verify with both sources and/or another outside organization 2. Verify with a reliable agency or organization such as the police or fire department 3. Gather primary information
You receive a request that is not appropriately processed (e.g. without authorization)	1. Confirm with the authority section/organization 2. Return to the requesting section/organization 3. Respond, but only if it is urgent
You cannot contact an organization	1. Try other communication tools 2. Send a contact 3. Ask another organization that seems to have similar information 4. Give up making contact, and try to make a decision using the information at hand
You receive a request out with your role and responsibility	1. Transfer to an appropriate section/organization 2. Transfer to an appropriate section/organization and report to the requestor 3. Confirm with the requestor and/or transfer it to a higher level section/organization
A request or query is left unanswered	1. Re-request/re-query 2. Send a contact 3. Send a request/query to another appropriate organization

3.3 Implementation of the Organization Model

Using the above situation-oriented response rules, the previously developed organization model could then be implemented. The problematic situations obtained in the survey could be described with the ontology in Section 2 and implemented as what-if rules. Fig. 3 shows the response behaviors of two situation-oriented (error-handling) rules: “return” and “retry”. The “return” rule refers to a situation when the agent returns an unauthorized request to the appropriate section or organization, and “retry” is when the agent tries to send a message via a different organization when communication blackout is experienced.

Fig. 3 shows task and communication flows related to a normal request for self-defense force (SDF) dispatch by a municipal government; in this figure, time flows from left to right. Horizontal lines represent an agent or agent group. Information and resource exchanges are represented by arrows and commitments to non-communicative actions by colored lines on the time axis. The leftmost arrow represents a script provided by Scenario Manager. Triggered by the script, the municipal government sent an inadequate request for SDF dispatch (without approval by the local government) and, in addition, the communication line between the local and municipal governments was disabled. The SDF office returned the request to the municipal government because of the lack of authorization. The municipal government then tried to send the returned request to the local government for approval, but the communication line was found to be disabled. They therefore sent it to the local government via a different municipal government.

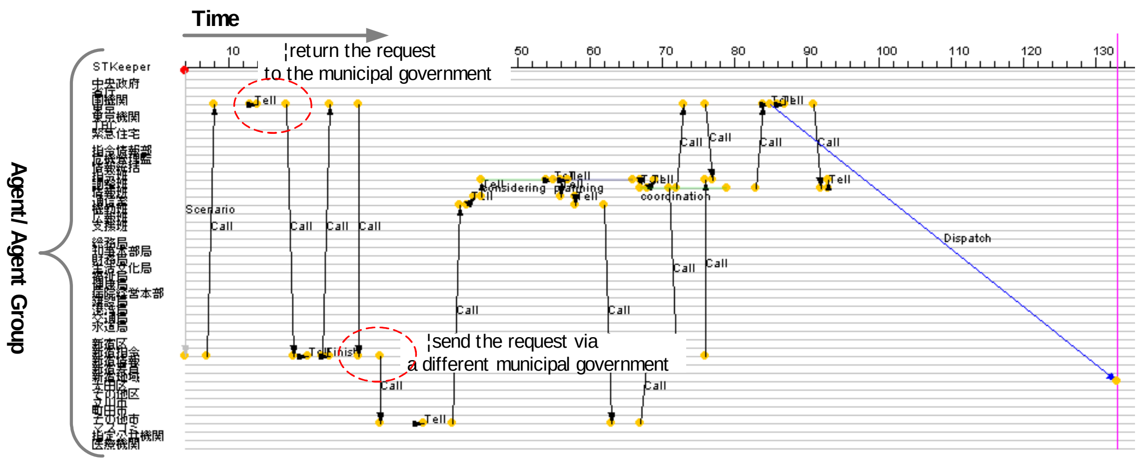

Fig. 3. Response behaviors of two situation-oriented rules

4 Conclusions

The present study investigated how off-site individuals involved in emergency response activities behave in response to typical problematic situations. The preliminary results presented here indicate that non-standardized responses differ among individuals and organizations, and are mostly based on previous experience and tact.

We also developed ontology to describe emergency situations and activities and, along with the situation-oriented rules obtained through the survey, included it in the simulation. Using such a model, it is possible to analyze the resilience or stability of emergency response systems under the influence of non-standardized responses during problematic situations.

At this stage in our work, we implemented only a few rules and confirmed agent behaviors using a simple test simulation. As a next step, we intend to include additional rules and conduct further simulations to analyze the performance of emergency response systems in more detail. Despite the limitations of this rule-based approach, our simulation could help analyze the resilience of ERS, which is difficult to do using other existing methods such as emergency drills and exercises.

Acknowledgement

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