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GROUP INFORMATION FORAGING IN EMERGENCY RESPONSE: AN ILLUSTRATION INCORPORATING DISCRETE-EVENT SIMULATION

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ABSTRACT

Large-scale emergencies require groups of response personnel to seek and handle information from an evolving range of sources in order to meet an evolving set of goals, often under conditions of high risk. Because emergencies induce time constraint, efforts spent on planning activities reduce the time available for execution activities. This paper discusses the design and implementation of a discrete-event simulation system used for assessing how risk and time constraint can impact group information seeking and handling (i.e., foraging) during emergency response. A demonstration is given of how system parameters may be tuned in order to manipulate risk, time constraint, distribution of information and resources available for response. The results of a pilot test of the implemented system are briefly discussed. Finally, ongoing extensions of this simulation are discussed.

1 INTRODUCTION

Emergency situations create the need for groups of response personnel to seek and handle information from a range of sources, including those in the built and natural environments. Emergencies may sharply change these sources in various ways: emergency operations centers (which are commonly used for collecting and disseminating information) may be disabled or destroyed (Langewiesche 2002), the progress of the disaster may be difficult to discern (Weick 1993), or key response personnel may be incapacitated or otherwise unavailable (Weick 1993; Weick 1995). All of these examples point to the need for effective information seeking and handling in emergency response, and thus to a need for better understanding of these phenomena and the factors that shape them.

Group information seeking refers to “the purposive seeking for information as a consequence of a need to satisfy some goal” (Wilson 2000). Group information handling refers to the physical and mental acts involved in incorporating the information found into the group’s existing knowledge base (Wilson 2000). Collectively, group information seeking and handling are denoted group information foraging (Pirolli and Card 1999).

Contextual factors such as risk, time pressure (Ellis, Cox and Hall 1993; Borgatti and Cross 2003) and distribution of information (Stasser and Titus 1987; Stasser, Taylor and Hanna 1989; Stasser, Vaughan, and Stewart 2000) can influence how information foraging occurs. Risks involve possible threats to life and property. Time pressure arises from the observation that time spent on planning takes away from time available for execution of response activities. Information distribution refers to the distribution of relevant information, either among personnel or in the physical environment.

When individuals form a group, each member typically holds knowledge relevant to the task but not identical to that held by others. Information asymmetry arises when not all group members have access to all relevant information. The proportion of group members who *a priori* hold some information determines the commonality of the information item. Information that is known by all group members is *common* (or *shared*) information. Information known by more than one but less than all group members is *partially shared* information. Information known by only one group member is *unique* (or *unshared*) information. As information is sought and handled by the group, the distribution of common and unique information changes.

Given the rarity of large-scale emergencies, opportunities for observing information foraging behavior during response are severely limited. Moreover, field conditions, while rich in data, are obviously uncontrolled. An alternative is to explore group behavior in synthetic environments (Mendonça et al., forthcoming; Mendonça and Fiedrich, forthcoming). The work presented here is motivated by the question of how to build a synthetic environment that can be used to test theory about how risk and time constraint can shape group information foraging behavior during emergency response. Beyond its benefits as a research tool, such a synthetic environment is likely to be useful for training exercises, since it may offer the opportunity for collecting data that might not otherwise be available from the field. These data may then be analyzed by trainers or trainees in order to gain insight into the effectiveness and efficiency of group information foraging processes.

This paper proceeds as follows. The design (Section 2), implementation and evaluation via pilot study (Section 3) of the simulation that is at the core of this environment are described. Ongoing work, including extensions of the simulation, are discussed in the context of related work (Section 4).

2 DESIGN OF THE SIMULATION

Extreme events may be regarded as events which are rare, uncertain and having potentially high and broad consequences (Stewart and Bostrom 2002). Responding to them requires timely action, which must often be coordinated among multiple organizations (Mendonça and Wallace, forthcoming). Emergency response organizations are groups consisting of personnel who represent these organizations and who are responsible for strategic decision making to address response goals (Mendonça and Wallace, forthcoming). Feedback from the field on the results of their decisions helps shape future decisions. This section describes how salient features of the emergency response situation are accommodated in the simulated system. These are risk, time pressure, uneven distribution of information, and feedback on how well goals are being addressed. Group members specify courses of action and corresponding goals, which are taken as input to the simulator. The outputs of the system are current degree of goal attainment, status on actions previously taken and the level of severity of the event. Interaction between the study group and the simulator is handled by a human-computer interface, as shown in Figure 1.

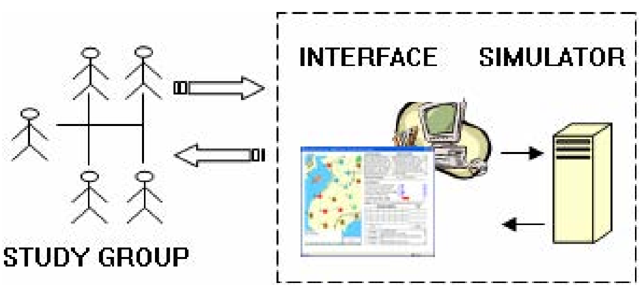

Figure 1: Research Diagram

2.1 Event behavior

Event behavior is characterized by the properties of the emergency (including risk level and distribution of information). Time constraint may be used to induce time pressure.

2.1.1 Risk

Risk is reflected in the level of severity in the simulation. The higher the level of severity, the higher the level of risk. Level of Severity (*LoS*) is a function of the remaining time and the goals unattained; it summarizes the emergency situation and the implementation outcomes of courses of action taken. LoS_t is the level of severity at time , which increases with elapsed time and decreases with goal attainment, as follows:

$$LoS_t = \frac{1-\frac{1}{n}\sum_{i=1}^{n} GoalAttainment_i}{2-t} + \varepsilon, \qquad (1)$$

where $t = time\ elasped / total\ time$ is the current simulation time, expressed as maximum of total time available for responding to the event; n is the number of goals that need to be attained; $GoalAttainment_i$ represents the extent to which goal i has been attained as of time t, as defined in equation (2), below; ε is a normally distributed random variable with mean 0 and variance 0.05, introduced to account for the unexpected positive or negative events that could occur during the event.

2.1.2 Time pressure

Time pressure is the "subjective perception of stress or of being rushed" (Benson, Groth, and Beach 1998). When there is a time limit for a task, time constraint exists; when a person feels stress associated with time constraint, time pressure exists (Ordonez and Benson 1997). In order to achieve time pressure, it is therefore necessary to be able to manipulate time constraint. This is accomplished by manipulating the simulation clock, as discussed below in the section on implementation.

2.1.3 Information distribution and content

As discussed previously, information can be categorized as common or unique according to the number of group members who originally hold it. Common information is information known to all group members; unique information is information known only to one group member. Common information may include such items as meteorological readings. As an example of unique information, the fire department may have access information about firefighting equipment, but not about sites that had medical equipment. Messages containing information about the event may also be tailored and be made accessible only to certain personnel. Other information may be common. For example, all members may have access to a description of the incident and of certain other resources (e.g., about gymnasiums and supermarkets). In this way, personnel may have incomplete information locally but complete information globally, requiring them to forage for information in order to meet response goals.

Information about the resources in the environment is stored in an ontology. The ontology is a hierarchical structure with goals at the top level, followed by functions, object groups, objects and properties. A goal is associated with various functions that contribute to its level of accomplishment. A function is an allocation of resources that may help to achieve one or more goals. A function is associated with one or more object groups. An object group is a set of objects (here, resources such as ambulances) that can be used to execute a function. Properties are atomic-level components of objects (e.g., the number of passengers that can be carried in a particular ambulance). Further details on this ontology are given elsewhere (Mendonça and Wallace, forthcoming). The use of the ontology in the simulation is discussed in the next section.

2.2 Response task

The task of the responding organization is to allocate resources to the incident location (upon arrival, the resources are managed by commanders at the scene). Groups are given a time limit to plan and execute courses of action to accomplish the goals of the response. In other words, every minute spent on planning is one less minute available for execution. As time passes, certain resources therefore become infeasible. Simultaneously, the situation may be escalating, so that risk increases due to increasing severity of the situation and decreased capability of response.

2.2.1 Goals

Goals are assumed to be provided to the responding organization (e.g., by policy makers). Goals reside at the top level of the ontology. The variable *GoalAttainment* represents the degree to which allocated resources can achieve the goal which the group associates with them (e.g., using an ambulance to treat injured persons). *GoalAttainment* can take on any value from 0 to 1, as defined in equation (2):

$$GoalAttainment_i = \frac{\sum_{j=1}^{m} ActionScore_{ij}}{TotalScore_i} - Penalty_i, \qquad (2)$$

where i is the index of the goal; j=1,...,m is the index of course of action submitted; $ActionScore_{ij}$ is the score of goal i that can be achieved by submitting the jth course of action, defined as follows:

$$ActionScore_{ij} = \sum_{k=1}^{r} V_{ik} + \varepsilon. \qquad (3)$$

where k is the index of the resource in course of action j, k=1,...,r; and V_{ki} is a constant indicating whether resource k can fully achieve goal i as identified in the ontology (i.e., V_{ki}=1 the resource k is identified with goal i via at least one parent object group and function, otherwise V_{ki}=0) (Mendonça and Wallace, forthcoming). *TotalScore(i)* is the score for goal i that can be achieved by group with optimal performance. The optimal score may be determined by expert evaluation (e.g., by considering a number of previous solutions to the response task). An example of how to determine the optimal score is given in Section 3. If more resources are sent than are needed, $GoalAttainment_i$ is decreased based on a *Penalty* function. This variable is included since it is common practice in emergency response to hold some resources in reserve in case additional events occur. The *Penalty* function takes a marginally decreasing deduction from the previous goal score, as follows:

$$Penalty_i = \begin{cases} 0, \text{ if } \sum_{j=1}^{m} ActionScore_{ij} \le TotalScore_i \\ 1 \Big/ \exp\left(\sum_{j=1}^{m} ActionScore_{ij} - TotalScore_i \right), \text{ otherwise} \end{cases} \qquad (4)$$

Finally, the variable ε is a normally distributed random variable with mean 0 and variance 0.1, and is included to account for random variation in the degree to which the course of action meets the goal.

2.2.2 Feedback

The values of *GoalAttainment* and *LoS* are passed back to the group, along with other ancillary information, such as start time plus the time of execution for each inputted course of action. It is assumed that a course of action is completed once a resource has arrived on the scene. The corresponding goal attainments and level of severity are then updated and displayed to group members. The leader of the group can also view the history of the level of severity, all submitted courses of action (pending and executed), and the messages other group members sent.

2.3 Group configuration and system interaction

Each group is assumed to consist of individuals occupying roles. Different roles have different access to the information, and take different responsibilities. It is further assumed that the group leader communicates group decisions to the simulator, though this assumption could certainly be relaxed.

Inputs from the group leader are stored in a data structure, with one structure for each course of action taken by the group. Every course of action is assigned a unique identifier and time coded for time of onset (assumed to take place the moment the action is submitted by the leader). A resulting record in the database includes all courses of action, with start time, the average goal attainment at current time, course identifier, one string with the course of action, and goals with which the resources are associated. Other group members choose resources to be used and the goal(s) relevant to these uses. These are then communicated to the leader and assembled by the group into courses of action.

3 IMPLEMENTATION AND EVALUATION

The simulation has been implemented and calibrated using data drawn from an actual case of emergency response. The case concerns a cargo ship fire with an oil spill, drawn from an actual incident (Harrald, Marcus and Wallace 1990). In the simulation, four goals are defined: (1) control of access to incident location, (2) control of fire at incident location, (3) removal of trapped persons from danger, and (4) treatment of injured persons. For the scenario used in this system, the total scores corresponding to Goals 1, 2, 3 and 4 are 4, 2, 1 and 2 respectively. The total scores are determined in the following way: the solutions produced by six expert groups from previously experiments using the same emergency scenario were reviewed by four expert judges; the judges evaluated the group performance by answering a set of 7-point Likert-scale questions; the score of the performance for each solution was calculated by summing the scores of each question, and the optimal solution was the one with the highest score; the resources used in the optimal solution was then categorized according to the object group(s) they belong to, and summed for total scores for each goal. Each group has five participants: one group coordinator (CO) acts as a facilitator and principal communicator with the simulated system; the other four act as the representatives of four particular emergency services: Police Department (PD), Fire Department (FD), Medical Officer (MO), and Chemical Advisor (CA). There is a maximum of seven resources which can be used in each course of action.

3.1 Implementation of the system

An object-oriented programming paradigm was chosen for implementing the system. Objects enable simulation components (including graphics and sounds) to be changed or replaced without having to make extensive changes to other parts of the system. In other words, an object-oriented implementation platform enables a modular approach to building and modifying the simulation.

The simulation functions embedded in the system are written in Visual C++ 6.0, and converted to Xtras using Macromedia® Director® Xtra Development Kit as a "plug-in" that extends the functionality of system. Two Xtras are developed to calculate the goal attainment and level of severity respectively. The front-end interfaces for the CO and the other four roles are developed in Macromedia® Director® MX 2004. The system is compiled for use over the world-wide web. The system is embedded within a virtual workspace (http://emprov.njit.edu) being used for a variety of research and education activities under National Science Foundation grant CMS-0449582. The workspace is implemented in phpBB (an open source software), with a link to a mySQL database management system (DBMS). All system logs, group communications, and individual click streams are captured and stored in a database maintained by the DBMS, and are accessible for visualization and analysis through the workspace.

3.1.1 Manipulation of simulation properties

Risk is manipulated by updating the content of messages passed to the group members Time pressure is manipulated by changing the speed of the simulation. A variable *Speed* is defined in the simulator to control how fast the system runs. When *Speed* is equal to 1, it runs at real (i.e., clock) time. If *Speed* is set to 2, the system runs twice as fast as real time. It is assumed that time pressure increases as *Speed* increases, though this may be empirically verified via a post-session survey. Finally, each group has two ways to seek information: (1) query the information from the system or (2) acquire information from group members via conversation. The CO has access to all information. However, via conversation non-CO participants can seek unique information from other group members.

3.1.2 Human-computer interface

Interaction between the members of the group and the simulator is handled by a human-computer interface. Figure 2 shows the interface used by the CO. The map displays the locations of resources and the incident location. Group members obtain information on a site by clicking on its icon. A list of the equipment available at the site is displayed in the lower left. Once a resource is allocated by CO, it is marked as "used." The CO inputs the courses of action in the middle right area. Above the input area is display of goal attainments and level of severity. Below the input area are "Messages" showing what the other four roles sent to CO, "LoS History" updating the levels of severity every 30 seconds, and "Actions" showing both pending and executed courses of action submitted by CO.

Figure 3 shows the interface used by one of the non-CO roles - the fire department (FD). The difference between the CO and the non-CO interfaces is that the non-CO interface only allows the user to check the items that are authorized to be used, along with the corresponding goal(s), and then to send this information to the CO. In other words, decisions about the use of the resources must be entered by the CO. All information about sent messages is displayed in the textbox at the lower right.

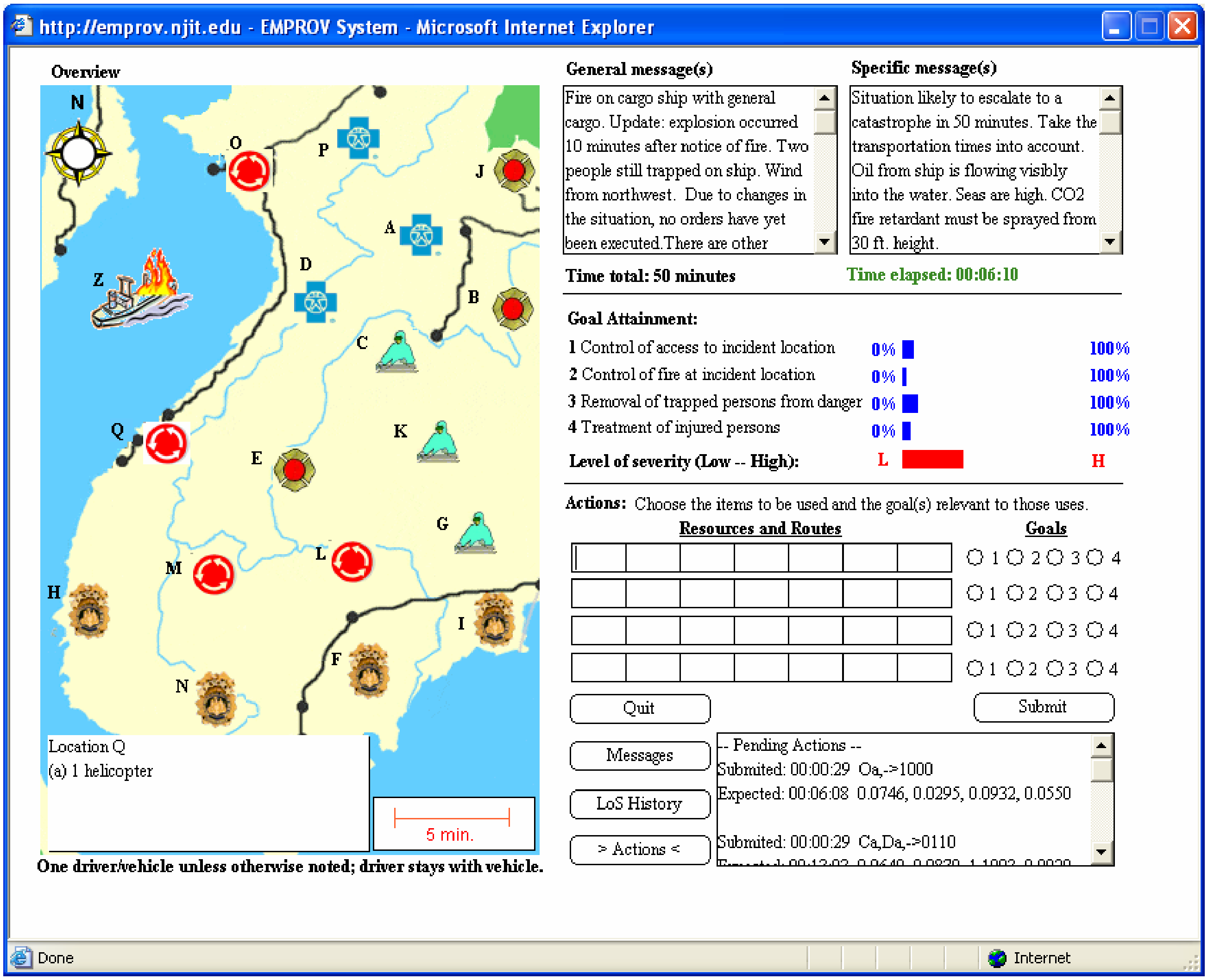

Figure 2: Interface for CO

3.1.3 Feedback

Two outcome variables—risk and level of severity—are provided by the simulator via the interface as feedback. The timing of the updates to the values of these two variables is determined as follows: when a course of action is submitted by the CO, a time stamp is attached to indicate the time of onset of the course of action (assumed to be instantaneous). The simulator then calculates the time at which resources will arrive at the incident location, and this value is added as an attribute of the course of action. The system checks the status of all courses of action—and thus updates the values of the two variables—every 30 seconds.

3.2 Pilot test

A pilot test of the complete system was run with five response personnel from the Port of Rotterdam in The Netherlands as part of a one-day training program. The task was completed, and computer logs collected for data analysis. Informal discussions with participants suggest that they were satisfied with the realism of the simulation, that it induced time pressure and that it enabled them to employ their expertise to reach decisions. Table 1 shows an excerpt of the data stream produced during the session. For example, the first row indicates that the medical officer (MO) in group 3 clicked site *D* at 5:44:02 AM to access the resource information.

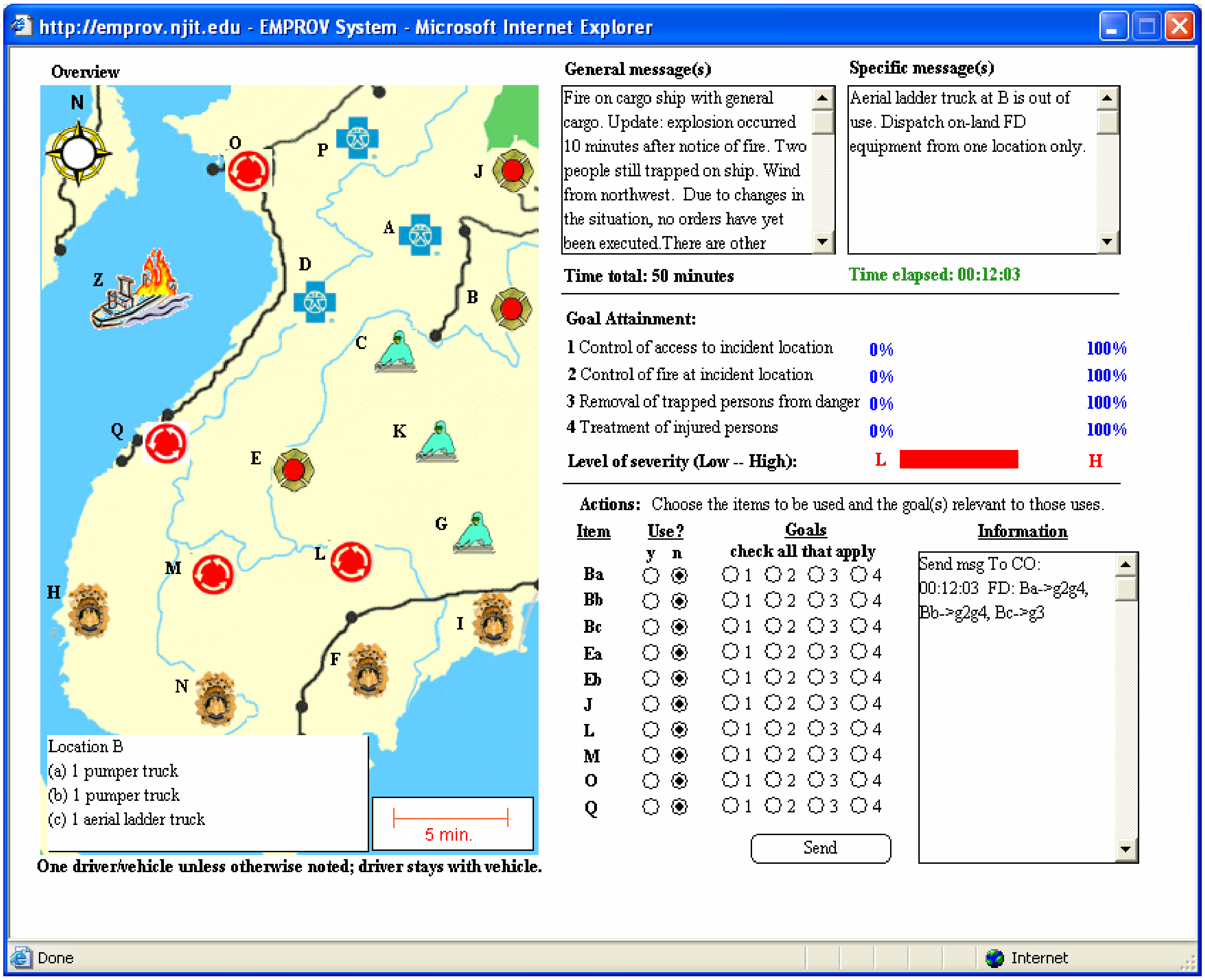

Figure 3: Interface for One of the Non-CO Roles (FD)

Table 1: Data Stream Excerpt

Group No.	Time	Role	Site
3	05:44:02	MO	D
3	05:44:06	FD	E
3	05:44:09	MO	P
3	05:44:43	CO	B

The complete data stream can be analyzed to determine the extent of search (via the computer interface) for common versus unique information over time. Figure 4 shows the number of clicks on common versus unique information over time. In the early stages of the task, search for unique information using the interface happened more frequency than search for common information. A tabular summary is given in Table 2, which shows the frequency and percentage of clicks by role. In this task, the chemical advisor (CA) and coordinator (CO) did more information seeking than the other roles, since their information seeking activities account for 66% of the total amount of information seeking by the group.

To yield further insights, computer logs such as these could be supplemented with video and audio recordings of the group, which would indicate how common and unique information are being sought and handled via conversation.

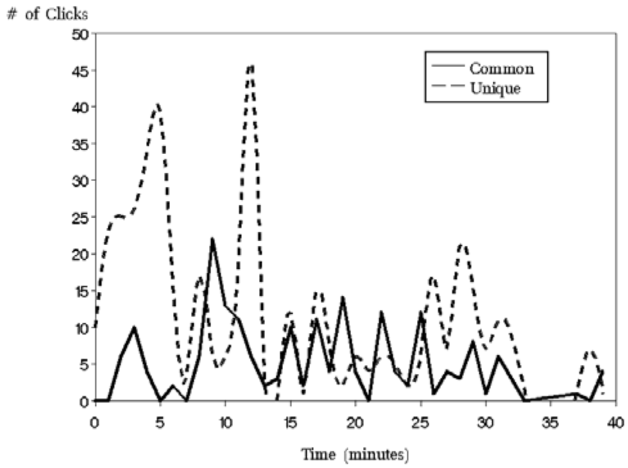

Figure 4: Number of Clicks on Common Information vs. Number of Clicks on Unique Information over Time

Table 2: Clicks by Role

Role	# of Clicks	% of Clicks
CA	260	43
CO	138	23
FD	41	7
MO	55	9
PD	117	19

4 CONCLUSION

Emergencies require responding personnel to seek and handle information from a range of sources, usually under conditions of risk and time constraint. Yet there are few opportunities for collecting data associated with information seeking and handling activities under actual field conditions. Simulation environments may be used both to collect data on information foraging in emergencies, and also to provide training (Mendonça et al., forthcoming). For example, analysis of data from training sessions using such simulations may enable trainers and researchers to study human responses in emergencies to a deeper extent, and develop more accurate emergency training programs for specific high-risk events (Mendonça, Beroggi and Wallace 2001).

This paper presents the design, implementation and preliminary evaluation of a simulated emergency environment. It also provides an illustrative example of how to manipulate the contextual factors in the simulated system in order to investigate the impacts of these factors on group information foraging behavior. The simulated system has been favorably evaluated via a pilot test.

Future work based on the current simulation system includes using the simulation engine and associated software for developing and testing other theories, such as those which explain how decision makers respond to highly non-routine events (Mendonça and Wallace, forthcoming; Mendonça, forthcoming). Future work also includes incorporating computer-based support system for group information foraging and decision making processes.

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