INTERNATIONAL JOURNAL OF INTELLIGENT CONTROL AND SYSTEMS
VOL.11, NO. 4, DECEMBER 2006，218-228

Role-Playing Exercise – A Real-Time Approach to Study Collaborative Command and Control

Jiri TRNKA and Johan JENVALD

Abstract- **During emergency response, emergency management and its command and control system are particularly challenged as the responding taskforce puts countermeasures in place intensively and dynamically. To respond effectively these countermeasures are typically coordinated through collaborative work of commanding staff. Information seeking, communication, and data sharing are essential elements of this collaborative command and control work. The traditional research methods used in command and control research do not always allow researchers to fully investigate these elements of collaborative work. In this paper, we describe the role-playing exercise, a real-time approach combining role-playing games and emergency management exercises, for studying collaborative command and control, particularly during improvisation and adaptation work. We also describe the practical application of the role-playing exercise approach in the ALFA-05 research study. This is followed by a discussion on methodological lessons learned from this study. This includes simulation realism and control, ecological and communication settings, and data collection. Our experience suggests that the role-playing exercise approach can be considered as a feasible method for research studies, where interaction and communication of commanding staff are in focus.**

***Index Terms*—Emergency response, command and control, collaboration, simulation, real-time approach, role-playing exercise**

1. INTRODUCTION

Emergency management (EM) is a system with the aim to produce countermeasures to various harmful events, such as accidents, emergencies, crisis or disasters, which can be complex and dynamic. Present EM is in its nature multidisciplinary and complex. The increasing number and variety of involved cooperating organizations in EM requires coordination, which is a complex task itself. The EM system is particularly challenged during emergency response, a period immediately after a harmful event occurs when countermeasures are put in place intensively and dynamically. The part of the EM system actively involved in the emergency response is recognized as a taskforce. A taskforce performs specific and common tasks to execute the desired response. To achieve its goals, the taskforce carries out a multitude of different activities of varying complexity.

The coordination in the EM system is typically realized by means of a command and control (C^2) system. The core of a C^2 system is the commanding staff, formed by one or more commanding officers. Each commanding staff in the C^2 system can be described in terms of its attributes, for example, its goals, allocated authority, command level, and responsibility [45]. In other words, the conditions for the work of the commanding staff are defined by organizational settings within the C^2 system and the EM organizations, which the commanding staff are embedded in. The C^2 system may have multiple commanding staff, usually organized in hierarchical and quasi-hierarchical command structures, to be able to consider different time scales [6]. Commanding staff in the C^2 system can thus reach different levels of interdependence. Consequently, the C^2 system is also complex and dynamic to meet the demands of the EM system itself [31, 27, 3].

In emergency response, one or several commanding staff are involved depending on the extent of the harmful event, size and type of the taskforce, and organizational arrangements of the C^2 system. The commanding staff make decisions to gain and keep control over the event and to effectively deploy the taskforce. The task is characterized by the fact that it requires coordination of several geographically separated units of the taskforce with various capabilities and available resources. Management of internal resources but also sharing of joint resources with other distributed commanding staff, multiple goals of these staff, as well as diverse operational procedures constitute extra challenges specific for C^2 in emergency response [56, 13].

In our research, we particularly focus on information seeking, communication, and data [1] sharing, essential elements of collaborative C^2 work. If two or several commanding staff are to function as a system that strives towards a goal originating from a decision, this goal, or intention, has to be shared among the commanding staff. When many commanding staff are involved in an effort to control a dynamic situation, multiple, conflicting goals are bound to emerge, eventually leading to a need for negotiation about which goals to select and pursue. Information and the way it is communicated are therefore of uttermost importance for successful joint emergency response operations.

1.1 Methods in C^2 Research

Researchers focusing on commanding staff working in high-risk areas acknowledge the importance of having good social, organizational and technological conditions to

This work was supported by the Swedish Emergency Management Agency. This paper is extended from "A real-time role-playing exercise as a methodology to support command and control research" presented at the *3rd International ISCRAM Conference*, Newark, NJ, USA, May 2006.

J. Trnka is with the Dept. of Computer and Information Science, Linköping University, Linköping, SE-581 83, Sweden (e-mail: jirtr@ida.liu.se); J. Jenvald is with VSL Research Labs, P.O. Box 15012, Linköping, SE-580 12, Sweden (e-mail: johan.jenvald@vsl.se).

[1] According to the Shannon-Weaver's general model of communication, messages in the form of data are transmitted as signals between the information source and the destination. The transmitted data have only information value if the receiver has knowledge to receive these data and interpret the message [55]. We therefore refer to all content in the communication as data.

support communication and data sharing between the involved commanding staff [30] in order to tackle disturbances on performance and to uphold high reliability [50, 49, 51].

The traditional research methods used in the C^2 research do not always allow the researchers to fully exploit the issues of information seeking, communication, and data sharing in collaborative C^2 work, particularly during improvisation or adaptation work. In the case of microworld (scaled world) simulations, real-time management, realism (validity), complexity, and overfitting (adjustment to the specific features of a simulation and scenario) are issues of concern [22]. Realism (dynamics of decision making) is also a problem in emergency management exercises [12, 13], where participants often act and describe their actions in accordance with operational procedures instead of rapid decision making. Another example is ethnographical studies that may put observers at risk, are time consuming, and may require many observers [37]. It is also not possible to control the studied events in ethnographical studies. At the same time, by combining advantages and good experience from the different traditional methods the possibilities to study collaborative C^2 work may further advance.

1.2 Aim of this Paper

The goal of this paper is to describe the real-time role-playing exercise (RPE) approach, a method for studying collaborative C^2 work, in particular information seeking, communication, and data sharing. The paper also aims to discuss methodological advantages and disadvantages of the RPE approach, based on its practical application in the ALFA-05 research study.

2. REAL-TIME APPROACHES IN C^2 STUDIES

Real-time approaches, as described in this paper, refer to methods where the participants in a study face tasks conducted in actual time, where the development of the tasks can be described as dynamic [5]. The interest thus primarily lays in understanding how participants act under uncertainty and time pressure when only having access to limited resources. The examples provided below are far from the only ones that utilize this approach. Rather, it is the feature of such studies – scenario-based real-time situation and procedure simulations – that is of interest in the context of this paper.

2.1 Role-Playing Games

A role-playing game (RPG) is an interactive multi-person setting, where participants (humans) try to solve a problem or overcome various obstacles in a collaborative manner. In the RPG, participants assume roles of various characters as well as their duties and tasks according to a scenario. The RPG executes via dialog between participants and a game-master, where the participants describe their actions as well as reactions to the conditions they obtain from the game-master. The game-master (in the literature sometimes also referred as facilitator, coordinator, umpire, or controller) provides participants with feedback on effects of their actions, but also describes surroundings, sense impressions, etc. according to the scenario. This procedure is repeated during the entire game.

RPGs can be abstractions of the real world, or its parts. These RPGs reproduce reality, and are thus considered as simulations [15]. If RPGs include settings, which have different characteristics and behaviour than in the real world, they are considered as games [15].

In the context of this paper, we focus on the first type of RPGs. Moreover, we concentrate on a special case of RPGs, where real decision makers operate in simulated systems involving decision making in critical situations [58]. In other words, real decision makers make decisions on hypothetical conditions [58] and have access to simulated resources (also referred to as computer generated forces) [29].

In the military and EM domain, two types of RPGs simulating real world systems can be found, tactical decision game (TDC) and operational game.

TDC is a low-fidelity RPG using mental, or mental and visual simulation [36], focusing on non-technical skills of decision makers [13] such as time and uncertainty management [35]. Due to its settings (using written scenarios, single person tasks or small group discussions) information gathering, technology employment, communications, and computers are eliminated (excluded) from these RPGs [24]. TDCs often involve only one interaction between the participants and the game-master (in the beginning of the TDC when the scenario is presented to the participants) and have duration from several minutes to one hour per session. According to Crano & Brewer, participants do passive role-playing, i.e., only predict how they would act or behave in the context of the given scenario [11]. TDCs have been used both in C^2 training and research. Crichton & Flin, and Crichton, Flin & Rattray describe short duration TDCs in training for intuitive decision making and pattern recognition skills [14, 13]. Lewis & Barlow use computer-based TDCs to study crucial decision making in close combat [38].

Operational games are of explorative nature, providing insights of decision making in complex situations [59, 53]. As Shubik points out, operational games are intended for situations where we need to know "what is going on" [57]. Thus, unlike TDCs, operational games are supposed to be as near to reality as feasible [59]. An operational game can thus be a combination of mental, visual and physical simulation. Operational games have much longer duration than TDCs and utilize interaction among the participants, as well as between the participants and the game-master continuously during the entire RPG. In other words, the participants do active role-playing as their actions and behavior are influenced as well as dependent on other participants [11]. Active role-playing by the participants

represents therefore internal parameters governing the simulation [20]. This makes operational games more difficult to control compared to traditional research experiments [9] since they contain both planned and unplanned variations [11], which may be difficult to predict [53]. Further, the speed of the operational games is normally four to six times faster than normal time [53]. Cooper, Cooper et al., and Klein & Cooper mention two examples of operational games used in C^2 research and training, the so-called three-room war game and the superior commander system, both focusing on behavior and decision making [9, 10, 34].

2.2 Emergency Management Exercises

Emergency management exercises can be seen as training events but also as methodological tools of evaluation research, providing the exercise managers and researchers with the opportunity to test effectiveness of emergency plans, training, as well as abilities of personnel to execute these plans [46].

There are principally three types of emergency management exercises: tabletop, functional and full-scale. Furthermore, emergency management exercises can also be categorized in a variety of ways. For example Payne mentions some of these categories, such as indoor vs. outdoor, individual (only one organization participates in an exercise) vs. combined (an exercise with several organizations involved) and on-site vs. off-site exercises [43].

Tabletop exercises have the form of brainstorming or group discussion when the participants go through their actions step-by-step [4]. They are commonly organized indoor at a single location [44] and use written scenarios and other visual means (for example maps). Tabletop exercises are rather informal and do not achieve realism of simulated executions [44].

In contrast to the tabletop exercises, functional and full-scale exercises are real-time mental, visual and physical simulations. Functional exercises focus on one or few specific operational activities or command posts [46]. They are executed in real-time, involve operational personnel, and can be executed both indoor and in the field. Perry, and Peterson & Perry examine effects of functional exercises on the participants and their perception of teamwork and response network effectives [44, 46]. Payne mentions in this context a special type of functional exercise – so-called communications simulated exercise – considered for exercises focusing on call-out, command and control, and communication [43]. Communications simulated exercises are conducted indoor, use progressively unfolding scenarios, involve several organizations (combined exercises) and command posts, and can be design as simple but also as complex [43].

Full-scale (or also live) exercises test most or all the functions, which would be involved in a real event [46]. For this reason, full-scale exercises are always at least partly located outdoor to achieve high realism [44]. See Helsloot and Carrel for examples of full-scale exercises [25, 8].

3. (COMPUTER-ASSISTED) ROLE-PLAYING EXERCISE

The role-playing exercise (RPE) is a real-time, scenario-based approach, combining RPG and emergency management exercise methodology with thorough data collection from microworld (scaled world) simulations. We suggest the RPE approach as a method, which can be used in a systematic way to perform research on collaborative C^2 and its structures, functions and modalities. This includes decision making and communication by individual commanders, commanding staff as well as at particular command posts.

The RPE approach builds on the RPG philosophy, where real world systems are simulated, such as in TDCs and operational games. Thus the participants in the RPE are real decision makers, who act in their professional roles. The management of the RPE and the interaction among the participants and between the participants and the game-master are comparable with operational games (see Fig. 1).

The simulation settings in the RPE approach are different than in TDCs and operational games. The settings are strictly steered by realism in order to achieve high validity of the RPE. All activities are continuous and changing as in reality. Time is at the same speed as in reality. Temporal behavior and functionality of resources in the simulation corresponds to reality. In principle, the RPE approach utilizes four of the five dimensions of realism, described by Drabek & Haas – real groups, tasks, ecological settings, and social system – in the simulation content [18].

- Real groups mean that meaningful units of analysis containing real decision makers with shared experience are utilized [18].
- Type of task, activity and demand, which the participants carry out in the simulation, is identical with the participants' sphere of tasks in reality [18, 20].
- Ecological settings in which the participants act are same or very similar to reality [18].
- Social system is utilized so the interaction and relations between the participants correspond to reality [20, 18].

The fifth dimension of Drabek & Haas's realism – knowledge of participating – suggesting the use of study subjects unaware of their participation, cannot be fulfilled since all the participants in RPEs are aware of their participation [18].

The RPE approach distinguishes two groups of ecological settings and their fidelity, simulation content (high-fidelity) and physical arrangements of participants' workplaces (low-fidelity). The RPE has thus primarily the form of mental or, mental and visual simulation. Depending on the research questions, the physical arrangements of participants' workplaces may range from

paper-and-pen to low-fidelity decision support systems (DSS) with limited functionality. This allows researchers to have control over various technological artifacts and their use. Moreover, the participants can be co-localized at one site, which is essential for briefing, debriefing, and simulation control.

Due to the nature of the RPE – dynamic, utilizing active role-paying and steered by internal parameters – the game-master is supported by a RPE staff, a team of researchers and exercise managers with expertise in various areas. Moreover, the possible complexity of the scenarios calls for further support in planning, management, data collection and visualisation of the RPE so the researchers, emergency managers and participants can examine the course of events of an emergency operation. It is of great value to establish an overall view of the RPE to provide a common frame of reference and to facilitate subsequent analysis and evaluation of complex situations, such as emergency response by a geographically distributed commanding staff and taskforce [29, 42]. Visual models of minutely documented simulations make it possible to analyze similar scenarios to systematically identify cause-effect relationships that influence the outcome of emergency operations [48]. This support can help researchers and exercise managers in their decisions on the outcomes in complex and extensive RPEs [53], to grasp the big picture [39] and to explore the interaction between critical factors in great detail. It also plays important role in assessment of process reliability of the RPEs (see Gestrelius [20]).

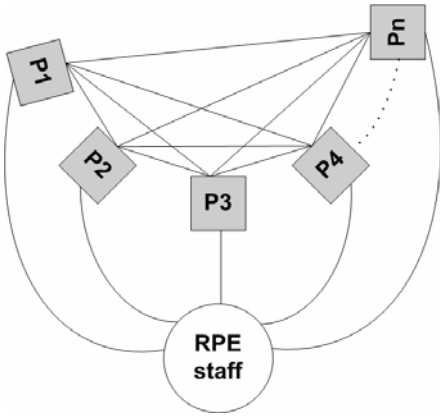


Fig. 1. A schematic example how a RPE is organized: n participants, which interact with each other and with the RPE staff.

Various information and communication technologies (ICT), such as geographical information systems (GIS), simulation and modelling tools, advanced databases, communication, and surveillance systems are some of the technologies, which are highly relevant in the context of the RPEs. However, fully computer-based simulators may have problems to cover all the possible options, which rise from the participants' actions and the interaction between the participants. Instead, ICT are used to support the RPE staff in generating responses during the execution of RPEs, but also as during the planning and evaluation. Thus we talk about computer-assisted RPEs. ICT have been successfully used in various computer-assisted full-scale and functional exercises ranging from emergency response to mass-casualty incidents [40, 26] to training of critical incidents management in the power production industry [41]. As Morin highlights, they are also highly relevant in the context of research applications, such as the discussed RPE approach [42]. Nevertheless, the usefulness of ICT is determined by the models devised to represent the scenario, the means of data acquisition employed and the data collected from the actual RPEs.

4. CASE: ALFA-05 RESEARCH STUDY

In this chapter we describe the practical application of the RPE approach, made in the ALFA-05 research study.

The practical application of the RPE approach builds on methodology for planning and management of functional and full-scale exercises (see for example [29, 39, 40]), which is suitable for complex simulations with longer periods of planning process (from months to years). The planning and management of the ALFA-05 study utilized the following steps:

- Definition of methods and research focus
- Scenario modeling
- Scenario structure analysis
- Execution
- Data collection
- Visualization
- Documentation

4.1 Definition of Methods and Research Focus

The definition of methods & research focus is an assessment process to establish if the RPE approach is a feasible method with respect to the research questions and available technical, financial, and human resources. During this process questions on what factors to prioritize in order to make data collection, visualization and analysis are discussed.

The research question in the ALFA-05 research study was to study collaborative C^2 work of distributed commanding staff from different EM organizations. In particular, the attention was given to the following three areas of collaborative C^2 work:

- Information seeking at different command posts.
- Data sharing between these command posts.
- Selection of information sources by particular commanders.

Due to the relative high complexity of the real-time RPE, it was decided by the research team to use additional methods for the purposes of methodological triangulation [16]. The decision was based on previous experience from microworld (scaled world) simulations [21, 23] and other experimental studies [30]. The selected methods were after action review and observation.

During the RPE interaction among the commanding staff, and between the commanding staff and their taskforce is present extensively. In order to be able identify and interpret important factors pertaining to the interaction the research team decided to carry out after action review (AAR) directly after the RPE. AAR is a professional discussion of an event (e.g. accident, training session), which focuses on performance standards [47]. The AAR is particularly important, when commanding staff and units from different EM organizations work together [19]. The goal of the AAR is to give participants feedback on mission and task performance and to support the reflection phase [54, 17]. AARs have also been used widely in the context of emergency management exercises and RPGs.

In the context of the ALFA-05 study, the AAR was designed to start one hour after the RPE and continued for two hours. First, the participants were given a short debrief of the RPE and the incidents in the simulation as they were planned and actually occurred. In the following reflection phase, the participants were motivated to recapitulate their actions to clarify for the researchers and themselves what happened and why it happened. Led by an AAR facilitator, six topics were debated in a moderated discussion. In the discussion all the participants wrote down notes related to a topic. Selected key participants were asked to read their notes aloud. Then all the participants were allowed to take part in the discussion on the topic. This procedure was repeated for all six topics. The topics were prepared by the AAR facilitator, observers, game-master and RPE staff members, and concerned the areas of real-time RPE as a method, information seeking, communication, and data sharing.

The observations were designed as open semi-structured observations, where observers act as complete observers [7]. Complete observers do not participate or interact with the observed subjects. This definition of observers was important with respect to the task realism, so the participants are not disturbed during the RPE. The observations were made directly as well as indirectly (via video surveillance and communication monitoring system). The observers were allowed to move freely during the RPE. The observers were also present during the AAR. Four different observers were in place as a part of investigator triangulation [16]. These observers were senior researchers from the areas of C^2, informatics, communication, and simulation. The observers were motivated to particularly address the following areas – information seeking, communication, data sharing and methodological issues – with respect to the research questions.

4.2 Scenario Modeling and Structure Analysis

Scenario modeling is the process of defining objects and events that make up the base of the simulation content [33]. It is followed by scenario structure analysis, a process assessing contextual consistency, which aims at checking internal and external validity [52], and identifying critical phases in the RPE, which are likely to require careful coordination [40]. These two processes are iterative and are one of the essential factors influencing validity of the simulation [53].

In the ALFA-05 study, to achieve high realism in the four dimensions of realism – real groups, tasks, ecological settings (simulation content) and social system – both domain experts and modeling experts were actively involved. The domain experts were senior exercise managers and fire & rescue incident commanders. The simulation experts were senior researchers with experience from microworld (scaled world) simulations, functional exercises and other experiments.

The process of the scenario modeling went through the following four areas, commonly recognized in the scenario planning [1]:

- Size and complexity of concerned geographical area.
- Number and range of objectives, controlled through number and severity of simulated incidents.
- Scenario duration.
- Nature of required response, from passive to active involvement.
- Number of roles, affecting the degree of interaction between the participants.

The scenario type and size were designed to involve EM organizations from two neighbouring counties (taskforce) in a joint emergency operation (task). The task was a response to an incident located at the border of two different counties. The reason for locating the scenario at the border of two counties was unclear operational procedures with regard to C^2 responsibilities and thus initiating negotiation, adaptation and improvisation of the participants.

To achieve a realistic scenario and to simulate a plausible situation a single, self contained event – a middle-size forest fire during summertime in Sweden – was selected as the main incident. Forrest fires commonly involve a relatively larger taskforce with a number of geographically distributed units and have proven to be suitable for simulations [22, 30]. Further, a number of additional incidents were carefully selected by the domain experts, based on their experience from historical forest fires. These incidents are launched during the RPE and are used to control the tempo of the RPE as well as to establish certain context with regard to the objectives. The additional incidents are:

- Traffic disturbances on surrounding roads.
- Threat from the fire to a neighboring zoo with several thousands of visitors.
- Search and rescue of a group with small children on a picnic.
- Life threatening allergic reaction for one of the responding fire-fighters.
- Traffic accident on the nearby highway.
- Pressure from media requiring incident information.

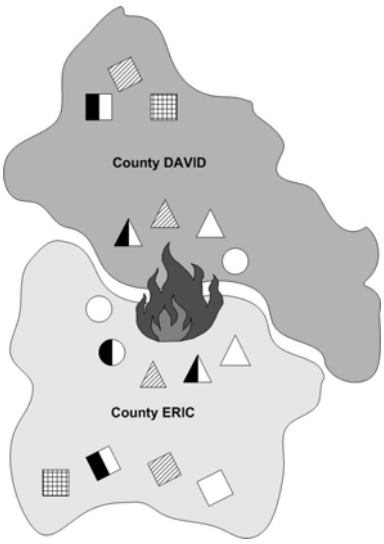
In accordance with the RPE approach, the scenario was planned as a real-time scenario, where scenario time is equal to reality. In other words, the scenario was proposed

as continuous with the simulation start time 00:00 and stop time 02:00. The scenario takes place on Saturday, July 2, 2005, starting at 10:30 and continuing for two hours.

Based on the size of the geographical area, incident locations, and simulation duration relevant EM organizations were selected. This was followed by mapping of their C^2 structures, resources, etc. From the collected data, incident commanders and dispatch officers were chosen as the most relevant command posts to focus on in the RPE in order to obtain meaningful and analyzable group of commanding staff. At the end, the following command posts were selected to participate in the RPE:

- County 112/911 emergency operator (2x).
- Municipal fire & rescue on-site incident commander (2x).
- Municipal fire & rescue dispatch officer (1x).
- County police on-site incident commander (1x).
- County police dispatch officer (1x).

The overview of the EM organizations in the RPE and the involved command posts are shown in the Fig. 2. The other command posts were also invited from the concerned EM organizations and were allocated as a part of the RPE staff. The RPE staff contained six researchers, one researcher with fire-fighter training, county medical team leader, county emergency management officer, and one technician. The game-master was a senior fire & rescue incident commander / a senior exercise manager with experience from RPGs and functional / full-scale exercises.



Legend: ○, ◇, △ - fire & rescue service; ◐, ◭, ◧ - county police administration; ◬ - emergency medical service; ◈ - 112/911 emergency call-center; ◱ other (municipal crisis committee & county emergency management office, etc.)

Fig. 2. Command posts involved in the RPE and their distribution between participants (◇ and ○ shape) and RPE staff (□ and △ shapes).

To provide the participants with as realistic ecological settings in the simulation as possible the available resources and their behaviour in the operational environment were fully corresponding to reality. For example, the police dispatch officer was provided with a list of available resources – police patrol vehicles, including pictures and call signs – in the RPE, which were corresponding to police resources of that day in reality (July 2, 2005). During this process GIS modelling was used extensively.

4.3 Execution

The ALFA-05 study took place at the Linköping University in Linköping on December 1, 2005. The day started with briefing and RPE introduction to the participants, observers and RPE staff. It was followed by a short introduction to the RPE area.

Fig. 3. A participant's workplace – paper map, overview of available resources, notes and computer-based communication tool C3Fire (Photo: Björn Johansson).

The RPE took place in a closed room, which was divided into two sections. The first section comprised RPE staff. Conceptually a complete C^2 room was established. The game-master and the members of the RPE staff had information about all recourses (e.g., officers on duty, all vehicles in the scenario areas, including pictures of units, call signs, equipment, size of water tanks, etc.) available. Their task was to launch incidents, simulate responding units and other command posts outside the scenario area, and to answer all different questions from the participants. For this reason, the Internet, phones, various maps, and resource sheets were available for the RPE staff. The game-master and the RPE staff had also communication and video surveillance systems available, allowing them to monitor participants' communication and workplaces in real-time.

In the second section seven participants' workplaces were organized. Each station was customized to the concerned command post, including relevant maps, a list of available resources and a short brief of the situation at the start of the RPE (see Fig. 3). Since the RPE approach was practically used for its first time, the research team decided to use the simplest workplace.

The RPE started at 10:30 when multiple emergency calls were made to the 112/911 emergency call-centers by the RPE staff. From this moment the participants carried out actions to handle the incidents launched in the RPE. The RPE continued for two hours until it was stopped by the game-master. After a one hour break the AAR was carried out for two hours.

4.4 Data Collection

Communication during the RPE represented the main data source. The participants were allowed to communicate between each other and with the RPE staff only through text messages. For this purpose a network comprising twenty computers and one server was set up. A research environment for collaborative team work called C3Fire [23] was used to support the computer-mediated communication (see Fig. 4). All communication was stored in log-files.

With regard to the intensity of the RPE, the participants' workplaces and the RPE staff were monitored via nine video cameras connected into a video surveillance system. The video cameras recorded all the activities during the RPE, as well as the AAR.

All the material used in the study was archived. This includes notes made by participants, RPE staff, and observers on paper and maps used during the RPE and AAR.

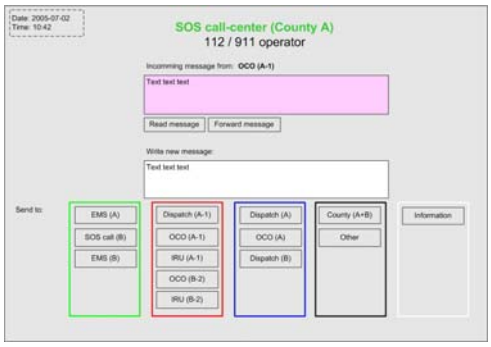


Fig. 4. C3Fire communication environment – 112/911 emergency call-center operator user interface.

4.5 Visualization and Documentation

Visualization is the means of making events, circumstances, and relationships visible to the participants during the AAR and after the RPE as well as to the researchers carrying out analysis. During the visualization the collected data are formatted and organized according to the objectives of the visualization and the needs of the researchers and target audience. It is followed by documentation, a final step of organizing and packaging models, data, and procedures in a form that is comprehensible to a research and professional audience and easy to access and distribute [28].

4.6 Results and Findings

The RPE approach combined with the AAR and observations in the ALFA-05 research study provided the research team with answers to the research questions. In particular, AAR proved to be an important tool for the interpretation of data collected during the RPE.

The data analysis of the ALFA-05 study contributed to a range of findings providing new insights on collaborative C^2 work in distributed C^2 structures. From the findings made in the ALFA-05 study, several can be emphasized:

- Distribution of communication density between the different commanding posts was not directly related to the scenario and its incidents, but rather to the availability of resources to the particular commanding officers. Resource availability and allocation had impacts on communication volume.
- The way that information was searched, where and how was dependent on the dynamics and task load during the emergency response. Information seeking is dependent on local knowledge, experience and task load.
- Differences between planned and actual C^2 work were found. Tasks were distributed differently based on the situation than according to the organizational arrangements.
- Commanding officers communicated pro-actively, distributing information on push-basis.

For further reading on the analysis of the data collected in the ALFA-05 study, please, see Trnka, Johansson and Granlund [60], and Woltjer, Trnka, Lundberg and Johansson [61].

5. METHODOLOGICAL LESSONS LEARNED

In the following discussion we go through the main methodological lessons learned from the application of the RPE approach in the ALFA-05 research study. The discussion is based on the following data:

- Participants' reflections on the RPE as a method collected during the AAR.
- Observations made by the observer for methodological issues (a senior researcher in the area of simulations) during the entire ALFA-05 study, from the initial planning to the analysis of the collected data (a period of fourteen months). This included attending meetings, studying documents, and examining the execution of the RPE and AAR.
- Informal debriefing with the game-master and the RPE staff directly after the execution of the RPE and AAR.
- Informal interviews with the observers carried out in a period of several weeks after the RPE execution.

5.1 Simulation Realism and Control

The scenario obtained high user acceptance. During the AAR, the participants described the scenario with its incidents as authentic. In particular, the strict use of real resources was acknowledged. Moreover, the tempo in the RPE was also experienced as realistic by the participants. The observers reported signs of high task load of several of the participants. The level of realism is also supported by the fact that problems occurring during real emergency response operations also occurred in this RPE. For example, the concerned fire & rescue on-site incident commander was called to the incident site later than the other EM organizations. This commander faced difficulties with command hand-over and missing information from previous response phases, like in situations often occurring during middle-size and large fires. Thus it is possible to achieve highly realistic simulations in the form of RPEs.

The RPE in the ALFA-05 study was self-going since sufficient complexity was at place as an effect of the scenario and the interaction between the participants. The participants in the RPE were experienced commanding officers capable of doing mental simulation. Though, our experience suggests that it is important to explain to the participants that they may become involved in the scenario at later stages, or on a very limited scale. It is a question to what extent the participants should be aware that the involvement of each participant is strongly dependent on how the incidents in the RPE are managed by other participants. It happened once in the ALFA-05 study that a participant was repeatedly contacting the RPE staff regarding non-involvement in the RPE. Due to the nature of the RPE, the discussed case was efficiently handled by adding an extra incident to the scenario by the game-master and the RPE staff. In this context, it should also be highlighted how important it was to use experienced personnel and domain experts in the RPE staff.

The RPE was two hours long and during the entire time the RPE staff faced high workload. The experience from the ALFA-05 study suggests to extend the RPE staff with several persons for RPEs of similar nature.

5.2 Communication Settings

The communication was designed so the participants were only allowed to communicate via text messages. The research team was aware of the implications from this choice. Nevertheless, due to the fact that the RPE was executed in one closed room as well as the experience from using text communication in microworld (scaled world) simulations it was decided to use only text communication.

The use of text communication allowed the game-master and the RPE staff to follow all communication, involving in total fifteen persons (seven participants and eight members of the RPE staff), in real-time. Moreover, full transcript of the communication was available within hours after the RPE. The delay caused by the actual writing of the messages also allowed the game-master and the RPE staff to easier manage the incidents and tempo in the RPE. From this perspective, the text communication had a clear advantage.

The text communication was also accepted as a mean of communication by the participants, where communication one-to-one normally occurs. The participants saw their communication in the RPE as very similar to their communication in reality. The participants identified two areas during the AAR where the use of text communication was seen as problematic.

First, a narrow number of emergency calls was possible due to the use of text communication. The 112/911 emergency operators found it limiting when it was possible to communicate only with a certain narrow number of persons calling 112-number. This caused problems since they are making their judgements about certain events, such as forest fires, partially on the volume of received emergency calls. A solution to this problem is the use of another scenario, where normally a rather small number of emergency calls occur. Another way of approaching this issue is a combination of voice communication and a higher number of callers. A similar approach has been already applied in functional and full-scale exercises with the help of specialized tools, such as CITE® and MIND [42, 29].

Second, all the participants missed the opportunity to listen in ongoing radio traffic between responding units. In reality, as highlighted during the AAR, this is commonly used by the participants as one of the main information sources to create an operational picture. These comments disclosed unintended use of the radio communication systems: passive participation in communication. In this RPE, to simulate such communication would have been too demanding from organizational as well as technical perspective due to the high number of incident response units involved. However, future RPE may use live radio communication, if relevant to the research questions. Such simulated radio communication has been used in research experiments [2] as well as in training operational games and functional exercises [21]. At the same time, besides the technological requirements, using live radio communication brings higher demands on the RPE staff in terms of number and skills of the personnel.

5.3 Ecological Dimension - Workspace

The RPE approach utilizes low-fidelity of physical ecological settings, meaning participants' workplaces. In the ALFA-05 study, with respect to the research questions, simplified workplaces were built with the use of paper, pencils and maps. It turned out to be restricting for some of the participants used to work with advanced computer-based DSS incorporating digital maps. The participants found it difficult to work without this support. They felt that they could not perform at the level of speed and quality they normally do, as revealed during the AAR. The way they executed certain tasks, especially those involving localization and navigation, in the RPE was not fully matching with the way the tasks are carried out in reality.

In other words, these command posts have already extensive technological support, which the commanding officers are dependent on in execution of their tasks. A question, which is relevant for RPEs in general, is how to simulate these technologically dependent command posts at low-fidelity and at the same time keeping high realism of the tasks. A solution would be replication of the participants' DSS. By doing that, we would achieve high ecological fidelity of the participants' working stations. On the other hand, this would significantly increase the complexity of such simulations. Namely, the complexity is influenced by the increased number of participants' tasks, and the decreased control over the use of the technology. Thus, the impacts of including technologically dependent command posts in RPEs require attention in the planning process.

An issue the research team was aware of was a co-localized action. This situation occurred when fire & rescue and police on-site incident commanders met at the incident site. Instead of having face-to-face dialogue and eye contact, they were forced to communicate only through text messages. This was caused by the organizational settings in which the RPE took place, i.e., participants co-localized in a single room. This issue needs to be addressed in future RPEs, for example by using more rooms and modes of communication.

A topic related to the workspace is the social context of a workplace, in this case dispatch rooms and emergency call-centers. Response to an emergency event is commonly joint effort work of several commanding staff. This part of the social system was corresponding to the reality in the RPE. However, the teamwork is common between operators and dispatchers at a single commanding staff (e.g. a single dispatch room). In reality these participants share the task load with their colleagues. In the discussed RPE, the participants were sitting alone. This influenced the number and selection of tasks the participants did in the RPE. This is, of course, an important methodological issue since such social context is difficult to establish in the context of RPEs in general. However, this factor is very much dependent on the objectives of particular simulations. In the ALFA-05 research study, the attention was given to particular commanders concerning how they conduct information search and data sharing. It was concluded by the research team, that AAR sufficiently documented this factor. Nevertheless, particular attention has to be given to this issue in future RPEs.

5.4 Data Collection

The research questions in the ALFA-05 research were covered by the collected data. Furthermore, a number of findings overreaching the research questions were made. An example of such finding is the differences between planned (according to the organizational arrangements) and actual C^2 work. To be able to generalize such findings, it turned out to be necessary to use additional methods. We suggest adding interviews as an additional method to utilize in the context of the RPE. By interviewing the participants after a certain reflection period they can explain and reflect on their individual actions and behaviour in a RPE. Though, it is more problematic to use post interviews to study the participants as a group due to the risk of bias. Since the real groups are used, the participants most likely meet in their professional life and potentially discuss their participation in the RPE. As Hudson (cited in Killian [32]) describes, the participants may develop a so called group version, a standardized interpretation of the simulation. From this perspective, AAR can particularly focus on the group as a whole and interviews on individual participants.

6. CONCLUSIONS

This paper describes RPE, a real-time approach combining RPGs and emergency management exercises, for studying collaborative C^2 work. The essential features of the RPE approach are:

- High realism of the simulation content.
- Low-fidelity ecological settings.
- Co-localization of the participants.
- Involvement of both domain and simulation experts.
- Using domain and modelling experts in planning and execution.

Advantages of this approach are the opportunity to create complexity, to design own scenarios, and to carry out joint AAR immediately after the RPE. At the same time, the RPE approach can be used to create situations with advanced realistic scenarios without putting participants, game-master and RPE staff at risk, something that would be very difficult in reality.

The ALFA-05 research study provided the research team with answers to the research questions. The RPE approach with the AAR and observations thus proved to be suitable method to study information seeking, communication and data sharing in distributed C^2 structures. It was possible to study the actual interaction between commanding staff as well as individual commanders in controlled settings. Moreover, the AAR revealed high acceptance of the simulation by the participants.

At the same time, several methodological lessons learned were made during the ALFA-05 study. This includes particularly following three findings:

- Communication settings – the way how and by what means (text, voice or both) participants communicate in a RPE is dependent on scenario and research questions.
- Ecological fidelity – the level of ecological fidelity (participants' workplaces) needs attention if technologically dependent command posts are included in a RPE, since it is more difficult to achieve realism in the task fidelity for such posts.
- Co-localized action – the activities where participants meet face-to-face in reality need to be planned so the participants can meet similar way in the simulation

(available space) and this meeting is sufficiently documented (data collection).

The methodological lessons learned need to be considered in future RPEs. An attention is particularly required with respect to the simulation complexity and the balance between research questions and fidelity of ecological settings. In this sense, the RPE approach represents a demanding method, requiring extensive technological, organizational and human resources. At the same time the RPE approach allows studying collaborative C^2 in a way, which is not possible with the traditional research methods.

ACKNOWLEDGEMENT

The authors would like to thank Jonas Landgren (Viktoria Institute), Björn Johansson (Linköping University), Jonas Lundberg (Linköping University), Erland Jungert (Swedish Defence Research Agency), Rego Granlund (C3Fire), Magnus Morin (VSL Research Labs), and Åke Sivertun (Linköping University) for their comments, observations, and reflections of the ALFA-05 study.

REFERENCES

[1] Alexander, D., "Scenario methodology for teaching principles of emergency management", *Disaster Prevention and Management*, Vol 9, No 2, pp. 89-97, 2000.

[2] Artman, H., "Team situation assessment and information distribution", *Ergonomics*, Vol. 43, No. 8, pp.1111-1128, 2000.

[3] Ashby, W.R., *An Introduction to Cybernetics*, Methuen, England, 1956.

[4] Baldwin, R., "Training for the Management of Major Emergencies", *Disaster Prevention and Management*, Vol. 3, No. 1, pp. 16-23, 1994.

[5] Brehmer, B., "System Design and the Psychology of Complex Systems", in *Empirical Foundations of Information and Software Science*, J. Rasmussen and P. Zunde (Eds.), Plenum Publishing Cooperation, New York, 1987.

[6] Brehmer, B., "Organization for decision making in complex systems", in *Distributed Decision Making: Cognitive Models for Cooperative Work*, J. Rasmussen, B. Brehmer, and L. Leplat (Eds.), John Wiley & Sons, pp. 335-347, 1991.

[7] Burgess, R.G., *In the Field: An Introduction to Field Research*, Routlege, 1984.

[8] Carrel, L.F., "Epidemic in Switzerland: Description of a Strategic Leadership Exercise by the Swiss Government", *Journal of Contingencies and Crisis Management*, Vol. 13, No. 4, pp. 170-175, 2005.

[9] Cooper, D.F., "The Superior Commander: A Methodology for the Control of Crisis Games", *Journal of the Operational Research Society*, Vol. 30, No. 6, pp. 529-537, 1979.

[10] Cooper, D.F., Klein, J., McDowell, M.R.C. and Johnson, P.V., "The Development of a Research Game", *Journal of the Operational research Society*, Vol. 31, No. 2, pp. 191-193, 1980.

[11] Crano, W.D. and Brewer, M.B., *Principles and Methods of Social Research*, Lawrence Erlbaum Associates, 2002.

[12] Crichton, M.T., "Decision making in emergencies", *Horizons of Psychology*, Vol. 10, No. 4, pp. 7-22, 2001.

[13] Crichton, M.T., Flin, R. and Rattray, W.A.R., "Training Decision Makers – Tactical Decision Games", *Journal of Contingencies and Crisis Management*, Vol. 8, No. 4, pp. 208-217, 2000.

[14] Crichton, M. and Flin, R., "Training for emergency management", *Journal of Hazardous Materials*, Vol. 88, No. 2-3, pp. 255-266, 2001.

[15] Crookall, D. and Saunders, D., "Towards an Integration of Communication and Simulation", in *Communication and Simulation*, D. Crookall (Ed.), Multilingual Matters, pp. 3-32, 1998.

[16] Denzin, N.K., *Sociological methods*, McGraw-Hill, New York, 1978.

[17] Downs, C.W., Johnson, K.M. and Fallesen, J.J., *Analysis of feedback in after action reviews* (ARI Technical Report 745), U. S. Army Research Institute for Behavioural and Social Sciences, Alexandria, VA, USA, 1987.

[18] Drabek, T.E. and Haas, J.E., "Realism in Laboratory Simulation: Myth or Method?", *Social Forces*, Vol. 45, No. 3, pp. 337-346, 1967.

[19] Gentner, F.C., Cameron, J.A. and Crissey, M.J., "Essential Training Needs and Resources for Simulation Observer/ Controllers", *Proc. of the 19th Interservice/Industry Training Systems and Education Conference*, Orlando, FL, USA, 1997.

[20] Gestrelius, K., *Simulation and training games: Experiential learning*, SAAB Training Systems, AB, 1998.

[21] Granlund, R., "Micro-world Systems for Emergency Management Training", in *Co-operative process Management: Cognition and Information Technology*, Y. Waern (Ed.), Taylor & Francis, pp. 159-184, 1997.

[22] Granlund, R., *C3Fire – A Microworld Supporting Emergency Management Training* (Thesis No. 598), Linköping Studies in Science and Technology, Linköping University, Linköping, Sweden, 1997.

[23] Granlund, R., *Monitoring Distributed Teamwork Training* (Diss. No. 746), Linköping Studies in Science and Technology, Linköping University, Linköping, Sweden, 2002.

[24] Green, W.G., *Exercise Alternatives for Training Emergency Management Command Center Staffs*, Universal Publishers, 2000.

[25] Helsloot, I., "Bordering on Reality: Findings on the Bonfire Crisis Management Simulation", *Journal of Contingencies and Crisis Management*, Vol. 13, No. 4, pp. 159-169, 2005.

[26] Ingrassia, P.L., Geddo, A., Lombardi, F., Calligaro, S., Prato, F., Tengattini, M., Morin, M., Jenvald, J. and Della Corte, F., "Objective evaluation in a disaster drill: accuracy of triage operations", *Proc. of the 3rd Mediterranean Emergency Medicine Congress*, Nice, France, 2005.

[27] Jansen, E., Jones, C.R. and Sovereign, M.G., "The Command and Control – Emerging Effects Framework: An Overview", *Proc. of the 7th ICCRTS Command and Control Research and Technology Symposium*, Monterey, CA, 2000.

[28] Jenvald, J., Morin, M. and Kincaid, P., "A Framework for Web-Based Dissemination of Models and Lessons Learned from Emergency-Response Operations". *International Journal of Emergency Management*, Vol. 1, No. 1, pp. 82-94, 2001.

[29] Jenvald, J., *Methods and Tools in Computer-Supported Taskforce Training* (Diss. No. 598), Linköping Studies in Science and Technology, Linköping University, Linköping, Sweden, 1999.

[30] Johansson, B., *Joint control in dynamic situations* (Diss. No. 972), Linköping Studies in Science and Technology, Linköping University, Linköping, Sweden, 2005.

[31] Jungert, E., Derefeldt, G., Hallberg, J., Hallberg, N., Hunstad, A. and Thurén, R., "Architecture-based Model for Preventive and Operative Crisis Management", *Proc. of the NATO SCI-158 Symposium on Systems, Concepts and Integration Methods and Technologies for Defense against Terrorism*, London, UK, 2004.

[32] Killian, L.M., "An Introduction to Methodological Problems of Field Studies in Disasters", in *Methods of Disaster Research*, R.A. Stallings (Ed.), Xlibris Corp., pp. 49-93, 2002.

[33] Kleiboer, M., "Simulation Methodology for Crisis Management Support", *Journal of Contingencies and Crisis Management*, Vol. 5, No. 4, pp. 198-206, 1997.

[34] Klein, J.H. and Cooper, D.F., "Cognitive Maps of Decision-Makers in a Complex Game", *Journal of the Operational Research Society*, Vol. 33, No. 1, pp. 63-71, 1982.

[35] Klein, G.A., "An Overview of Naturalistic Decision Making Applications", in *Naturalistic Decision Making*, C.E. Zsambok and G.A. Klein (Eds.), pp. 49-60, Lawrence Erlbaum Associates, 1996.

[36] Klein, G.A., *Sources of Power: How People Make Decisions*, MIT Press, 1999.

[37] Landgren, J., "Fire Crew Enroute Sensemaking in Emergency Response", *Proc. of the 1st ISCRAM conference*, Brussels, Belgium, pp. 87-92, 2004.
[38] Lewis, E. and Barlow, M., "The Use of Games to Investigate Tactical Decision-Making", *Proc. of the SimTecT 05*, Sydney, Australia, 2005.
[39] Morin, M., Jenvald, J., and Thorstensson, M., "Computer-Supported Visualization of Rescue Operations", *Safety Science*, Vol. 35, No. 1–3, pp. 3–27, 2000.
[40] Morin, M., Jenvald, J. and Crissey, M.J., "Training Needs and Training Opportunities for Emergency Response to Mass-Casualty Incidents", *Proc. of the 11th International Training and Education Conference (ITEC'2000)*, The Hague, Netherlands, 2000.
[41] Morin, M., Jansson, L.D. and Jenvald, J., "Training and Evaluation of Crisis Information Management", *Proc. of the Modeling and Simulation for Public Safety Conference (SIMSafe2005)*, Linköping, Sweden, 2005.
[42] Morin, M., *Multimedia Representations of Distributed Tactical Operations* (Diss. No. 771), Linköping Studies in Science and Technology, Linköping University, Linköping, Sweden, 2002.
[43] Payne, C.F., "Contingency plan exercises", *Disaster Prevention and Management*, Vol. 8, No. 2, pp. 111-117, 1999.
[44] Perry, R.W., "Disaster Exercise Outcomes for Professional Emergency Personnel and Citizen Volunteers", *Journal of Contingencies and Crisis Management*, Vol. 12, No. 2, pp. 64-75, 2004.
[45] Persson, P-A., "Toward an Understanding of the Service-Based Command System", *Proc. of the 9th ICCRTS Command and Control Research and Technology Symposium*, Monterey, CA, 2004.
[46] Peterson, D.M. and Perry, R.W., "The impact of disaster exercise on participants", *Disaster Prevention and Management*, Vol. 8, No. 4, pp. 241-254, 1999.
[47] Rankin, W.J., Gentner, F.C., and Crissey, M.J., "After Action Review and Debriefing Methods: Technique and Technology", *Proc. of The 17th Interservice/ Industry Training Systems and Education Conference*, Albuquerque, New Mexico, USA, 1995.
[48] Rejnus, L., Jenvald, J. and Morin, M., "Assessment of Emergency Planning Based on Analysis of Empirical Data", *Proc. of the 6th International Symposium on Protection against Chemical and Biological Warfare Agents (CBWPS)*, Stockholm, Sweden, 1998.
[49] Rochlin, G., "Safe operations as a social construct", *Ergonomics*, Vol. 42, No. 11, pp. 1549-1560, 1999.
[50] Rochlin, G., "A Rational Choice of Error: Comments on the JCO Accident Report", *Cognition, Technology & Work*, Vol. 2, No. 4, pp. 232-234, 2000.
[51] Rochlin, G. and Demchak, C.C., "The Gulf War: Technological and Organizational Implications", *Survival*, Vol. 33, No. 3, pp. 260-273, 1991.
[52] Rolfe, J., "SAGSET 1990 – The proof of the pudding: The effectiveness of games and simulations", *Simulations/Games for Leaning*, Vol. 21, No. 2, pp. 99-117, 1991.
[53] Rubel, R.C., "War-gaming network-centric warfare", *Naval War College Review*, Vol. 54, No. 2, pp. 61-74, 2001.
[54] Scott, T.D., *Tactical engagement simulation after action review guidebook* (ARI Research Product 83-13), U. S. Army Research Institute for Behavioural and Social Sciences, Alexandria, VA, USA, 1983.
[55] Shannon, C. and Weaver, W., *The mathematical theory of communication*, University of Illinois Press, 1949.
[56] Shen, S.Y. and Shaw, M.J., "Managing Coordination in Emergency Response Systems with Information Technologies", *Proc. of the 10th Americas Conference on Information Systems*, New York, NY, USA, 2004.
[57] Shubik, M., "On the Scope Gaming", *Management Science*, Vol. 18, No. 5, pp. 20-36, 1972.
[58] Skyttner, L., *General Systems Theory*, World Scientific, 2001.
[59] Thomas, L.C., *Games, Theory and Applications*, Courier Dover Publications, 1984.
[60] Trnka, J., Johansson, B. and Granlund, R., "Information support in collaborative command and control work – An empirical research using a role-playing exercise approach", *Proc. of the 11th ICCRTS – Int. Command and Control Research and Technology Symposium*, Cambridge, UK, 2006.
[61] Woltjer, R., Trnka, J., Lundberg, J and Johansson, B., "Role-Playing Exercises to Strengthen the Resilience of Command and Control Systems", *Proc. of the 13th ECCE – European Conference on Cognitive Ergonomics*, Zurich, Switzerland, pp.71-78, 2006.

Jiri Trnka received M.Sc. degree in Transport System and Engineering in 2002 from the Linköping University, Sweden, and M.Sc. degree in Geoinformatics in 2003 from the Linköping University, Sweden.

He is a Ph.D. Student at the Department of Computer and Information Science, Linköping University, Sweden. He is a member of the Swedish National Network for Command and Control Research.

Johan Jenvald received his M.Sc. degree in Computer Science and Technology in 1992, and his Ph.D. degree in Computer Science in 1999 from Linköping University, Sweden.

He is an Associate Professor of the Department of Computer and Information Science, Linköping University, Sweden, and the president and research associate of VSL Research Labs AB, Sweden. He was a chief scientist at the Swedish Armed Forces Naval Centre, and the head of the Modeling and Simulation Section at the Swedish Armed Forces Headquarters from 1999 to 2002. He has published more than 20 papers on simulation, modeling, command and control, and taskforce training.

He served as a program committee member for the 2002, 2001, 2000 and 1999 Int'l Medical Simulation and Education Conference (MSEC), co-chairman of a program committee for the 2004 and 2002 Swedish – American Workshop on Modelling and Simulation and chairman of the program committee for VR-Forum 2003.

Dr. Jenvald is a fellow of the Royal Swedish Society of Naval Sciences, a fellow of the Swedish Defence Research Society and a member of the International Emergency Management Society.