BULGARIAN ACADEMY OF SCIENCES

CYBERNETICS AND INFORMATION TECHNOLOGIES • Volume **8**, No 4

Sofia • 2008

Software Architecture for Implementation of Complex Simulation Systems

Georgi Kirov, Valentin Stoyanov

Institute of Control and System Research, 1113 Sofia
E-mail: kirov@icsr.bas.bg

Abstract: *The publication presents the simulation technology and software architecture used for development of Computer Assisted eXercises (CAX) in the field of the civil protection. The whole lifecycle of a complex simulation system – from the early stages of system specification to the implementation and exploitation of the system are described. A case study on an integrated simulation of critical infrastructure interdependencies is done.*

Keywords: *Computer Assisted Exercises, complex simulation system, disaster management.*

1. Introduction

With advent of the new technologies a lot of basic facilities, services, information systems, and communication networks needed for the functioning of a community or society are created [3]. The people in developed countries are becoming more and more dependant from these resources and assets due to the critical operations and infrastructures they support. More important, they are vital to the well-being, operations and continuity of the country. However, this dependency widespread poses significant risks to national economy and security because they are vulnerable to a wide variety of disruption, caused by different sources such as natural disasters and terrorist actions. It raises the question for effective emergency management that encompasses a broad range of activities to identify threats and vulnerability so that the appropriate control can be put into place to either prevent incidents from happenings or to limit the effect of an incident [9]. Taking into account that the disaster response and recovery efforts require timely interaction and coordination of public emergency services in order to save lives and property the scientists involve the computer simulation technologies to address many of the challenges brought forth by the need for emergency response preparedness.

The purpose of the paper is to present the experience from a practical implementation and scientific support of EU TACOM-SEE 2006 (European Union Terrorist Act Consequences Management in South-East Europe 2006), which was the first Bulgarian Computer Assisted eXercises (CAX) in the field of the civil protection. In this domain CAX is used to understand and evaluate the impact of a natural disaster or terrorist incident, to test the effectiveness of the emergency response plans, for helping train response personnel, and for vulnerability analysis. Use of such simulation technology allows training of responders and emergency managers at a fraction of cost of the live training exercises. The major difference between traditional simulation systems and CAX is certainly that simulation applications not only require the exchange of data during their runtime but also require the exchange of synchronization information regarding their advancement of simulation time.

In addition, this paper describes the structure and responsibilities of the teams, which have been involved in the preparation and scientific support of the CAX implementation. The teams' work comprises the whole lifecycle of a complex simulation system – from the early stages of system specification to the implementation and exploitation of the system (Fig.1).

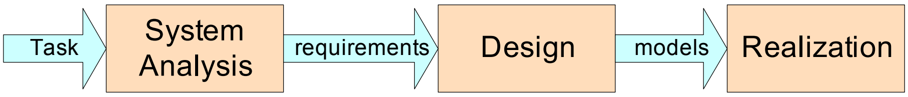

Fig. 1. Lifecycle of the CAX

The rest of the paper is structured as follow. Section 2 presents the state of the art of the distributed simulation technologies, Section 3 outlines the work of the system analyze experts to define the main problems and requirements to support a CAX for emergency management. Section 4 presents the simulation technology and communication infrastructure used for a development of the CAX. Section 5 describes the teams involved in scientific support, preparation, implementation, and evaluation of the CAX. Section 6 presents a case study of a distributed simulation. The last section briefly summarizes the results and recommendations from the CAX.

2. Distributed simulation technologies

The design and execution of distributed simulations has become increasingly important for the analysis of complex systems. In recent years, the Department Of Defense (DOD) has invested considerable resources in infrastructures for distributed simulation modeling. The main simulation technologies are Distributed Interactive Simulation (DIS) protocol, the Aggregate Level Simulation Protocol (ALSP), and High Level Architecture (HLA) (Fig. 2). While the fundamental structure of each is similar, there are differences that can impact an application developer or the administrator of a distributed simulation exercise.

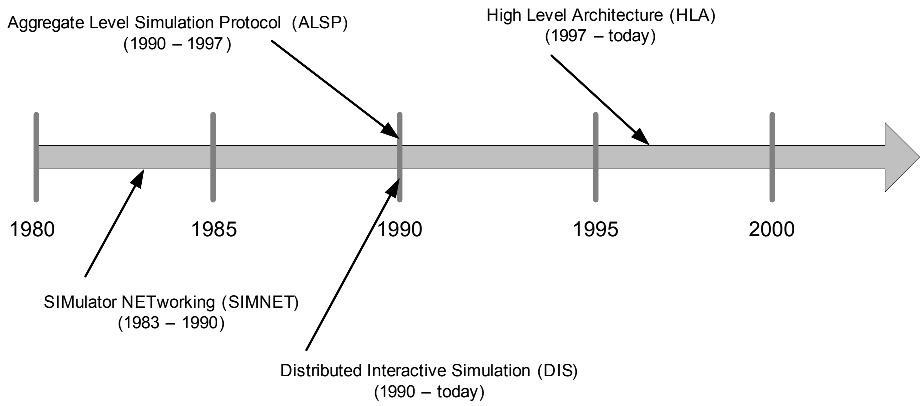

Fig. 2. Historical perspective

In 1983 the Defense Advanced Research Projects Agency (DARPA) sponsored the SIMNET (SIMulation NETworking) program to create a new technology to expand the current single task trainers into networked team trainers. SIMNET was tremendously successful, producing over 300 networked simulators.

The first standard for interactive distributed simulation was IEEE 1278.1, also known as the Distributed Interactive Simulation (DIS) protocol. Although DIS was originally developed for military applications, the technology is well suited as a simulator interoperability standard for civil application areas. It was based on the use of standard formatted packets, designed for the data required by these specific applications. DIS allows geographically separated simulators to work together, interacting in real-time, to provide predictions just like a single integrated simulator. The technology also allows real entities to be included in the simulation loop. The foundation of DIS is a standard set of messages and rules, called Protocol Data Units (PDUs), used for sending and receiving information across a computer network. The most common message is the Entity State PDU which represents all of the state information about a simulated entity that another simulator needs to know. The fact that there is no central server is perhaps the most surprising DIS characteristic. DIS used broadcast architecture, in which all data is transmitted to all simulators where it can be rejected or accepted depending on the receivers' needs. By eliminating a central server through which all messages pass, DIS dramatically reduces the time needed for a simulator to send important information to another simulator [1].

However, DIS has some drawbacks. Three features in the underlying data transport mechanism cause problems. Firstly, messages can get lost or arrive in the wrong order due to the use of the UDP/IP protocol. Secondly, the messages sent are part of standardised, fixed-sized Protocol Data Units (PDUs), although generic PDUs exist to communicate any type of data. Finally, due to the broadcast mechanism, the scaleability is rather limited. In the case that simulation experiments have to be repeatable, reliable data transfer is crucial [6].

Problems due to the inflexibility and lack of scalability of DIS approach have led to a different approach, the High Level Architecture (HLA), which becomes IEEE 1516 Standard. The HLA defines a set of rules governing how simulations, now referred to as federates, interact with one another. The federates communicate via a communication environment called the Runtime Infrastructure (RTI) and use an Object Model Template (OMT) which describes the format of the data. The HLA does not specify what constitutes an object, nor the rules of how objects interact. This is a key difference between DIS and the HLA.

Besides facilitating interoperability between simulations, the HLA provides the federates a more flexible simulation framework. Unlike DIS where all simulations receive every piece of data broadcast, the HLA federates use data management mechanism based on publishing and subscribing. These facts make it possible to have more simulations on a network at one time because the amount of data being sent is reduced. The simulation software is also simplified because it does not need to process extraneous information.

The Aggregate Level Simulation Protocol (ALSP) is a protocol and supporting software that enables simulations to interoperate with one another. Replaced by the HLA, it was used by the US military to link analytic and training simulations.

The potential advantages of distributed simulation technologies are evident: increased flexibility, building on existing software and communications standards, maximisation of the use of existing simulation assets, and thus reduced costs.

3. System analysis

The purpose of system analysis is a representation, as of a current or future point in time, of a CAX in “civil protection domain” in terms of its component parts, what those parts do, how the parts relate to each other, and the rules and constraints under which the parts function. System specialists use C4ISR Architecture Framework [2] known as a structured approach for the development and presentation of the CAX architecture. The C4ISR provides guidance on describing architectures.

There are three major perspectives, i.e., views that logically combine to describe the CAX system architecture. These three architecture views are the operational (Fig. 3), systems (Fig. 4), and technical views.

Each of the three architecture views has implications on which architecture characteristics are to be considered and displayed, though there is often some degree of redundancy in displaying certain characteristics from one view to another. C4ISR provides architecture products that constitute the minimal set of products required to develop architectures that can be commonly understood and integrated within and across experts responsible for CAX implementation and support.

The operational architecture view is a description of the tasks and activities (Fig. 3), operational elements, and information flows required to accomplish or support a CAX operation. It contains descriptions of the operational elements, assigned tasks and activities, structure and information flows required supporting of the CAX. It defines the types of information exchanged, the frequency of exchange, which tasks and activities are supported by the information exchanges, and the nature of information exchanges in detail sufficient to ascertain specific interoperability requirements.

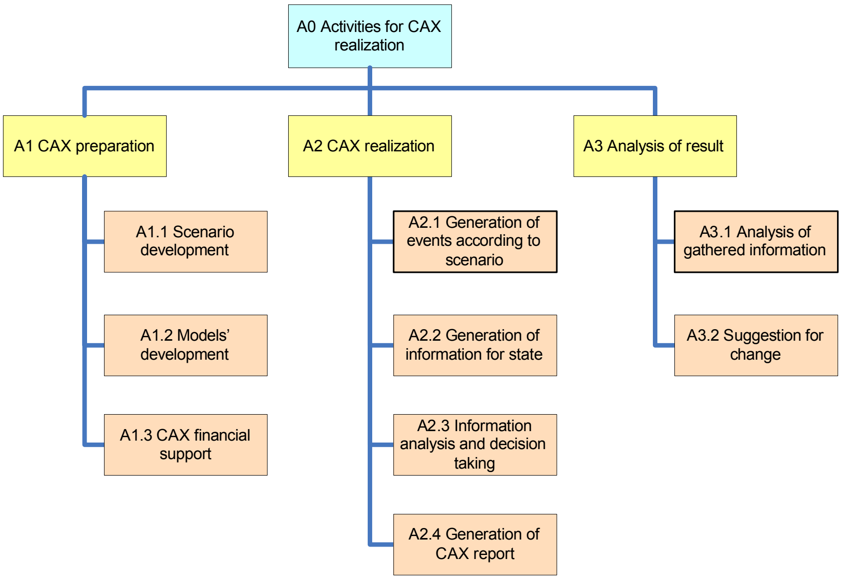

Fig. 3. CAX activity model

The systems architecture view is a description, including graphics, of systems and interconnections providing for, or supporting, CAX functions (Fig. 4). It identifies which required systems support the operational view requirements. It translates the required degree of interoperability into a set of needed system capabilities and compares current implementations with needed capabilities.

The system researches show that the main problem in the CAX implementation for the purpose of civil protection is associated with an operational environment that is uncertain, fast moving, and flooded with information [8]. The systems analyze "civil protection domain" takes into account that the sources of threats are becoming more complex. From one hand the number of the natural disasters increases. From the other hand, man-made disasters are bewildering due to multipolar conflicts with new and potentially shifting alliances. Therefore, just maintaining situational awareness in CAX is a significant challenge for the architecture specialists. The most critical for the CAX are information fusion and management at different levels, communication, planning and monitoring. Add to this, the new requirements for rapid deployments, joint rescue operations, and an information infrastructure that must be fast realized in hostile environments, the current technologies are no very effective. The traditional distributed simulation mechanisms do not manage with the integration of different simulation models and overloaded network traffic. For example, in the last several decades a great number of simulation and training systems have been developed by different vendors. These systems are adept at the training users to do their jobs as individuals. However, it does not provide the ability to function as a member of a coordinated team. Especially in security and civil protection sectors, team training is very important.

Therefore, if these systems can be connected together in such a manner that they may participate in the same simulation exercise, team training can take place using these simulation systems. There is a critical need within the simulation and modeling community to integrate realistic models into existing behavioral simulations.

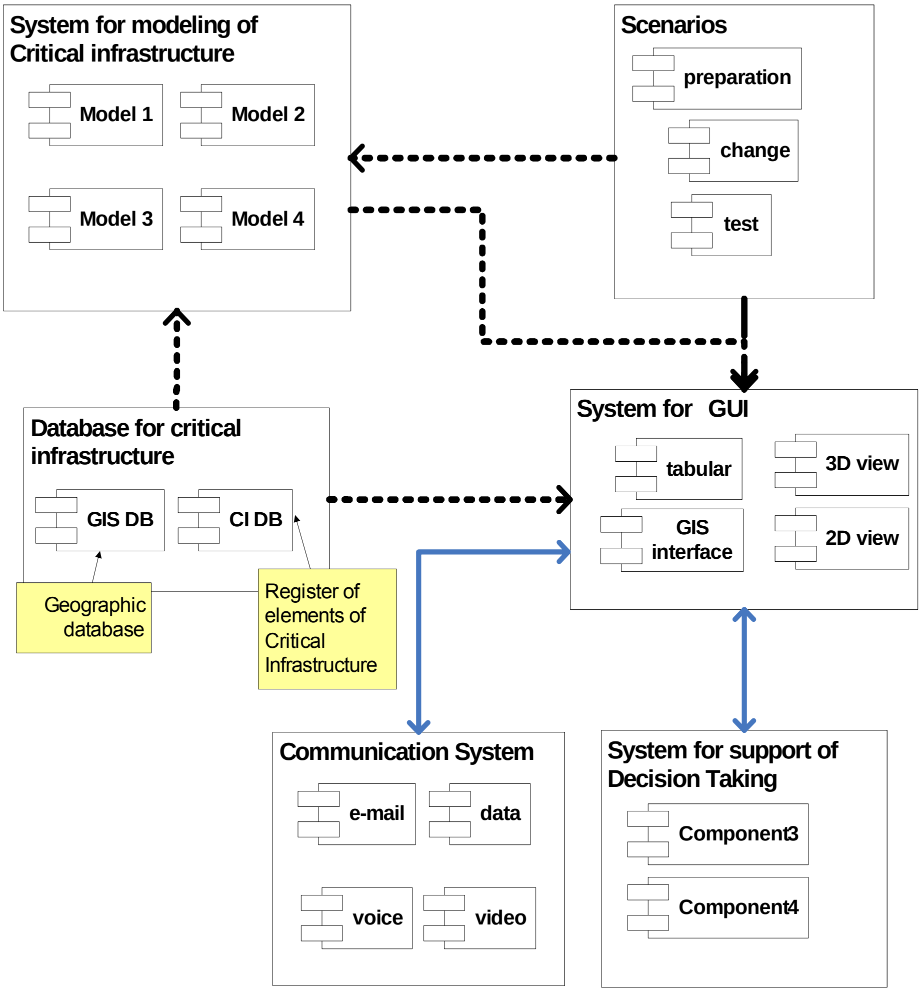

Fig. 4. Components of the CAX system

The requirements for a distributed simulation appropriate for human factors research motivated the development of a custom simulation architecture that could be implemented and tailored more easily than existing distributed simulation architectures, such as DIS. CAX distributed simulation was needed to place human experimental subjects operating separate disasters and infrastructure objects simulators in a common simulation environment. Experiments designed to study the impact of a natural disaster or terrorist incident require a real-time simulation facility capable of modeling and coordinating representations of weather and critical infrastructure objects.

The above mentioned considerations raise questions about the problems with team training and interoperability between simulation applications. This is a very interesting area of research with many technical and economic implications. The result from the system analysis is a definition of structure and requirements, which CAX has to meet to allow the use of modeling and simulation across the incident management lifecycle - prevention, preparedness, response, recovery and mitigation. To realize and support the requirements for CAX many scientific, technical and technological challenges must be addressed.

4. CAX architecture

The CAX simulation architecture is based on a distributed framework that can be rapidly implemented with the development of interoperability standards for the modeling and simulation. Together, the framework and interoperability standards can significantly increase the use of modeling and simulation for disaster management. In turn, it will help improve the incident management capabilities.

The CAX for UE TACOM-2006 uses a distributed simulation environment that provides integration of different simulation models. It is intended to provide a generic platform that allows communication between simulation models based on HLA/RTI standard for information exchange. This approach addresses the multiple independent aspects of emergency situation and simulates the overall effect on the vital infrastructure objects [4]. Fig. 5 presents an architecture for distributed simulation that provides communication infrastructure for the models' coordination and time synchronization. The benefit of this approach is a possibility of doing an assessment of the elements of the Critical Infrastructure affected by an emergency situation. It will help all organization take the right response actions. The CAX simulation environment includes the following more important elements.

Simulators – Different simulators are integrated in CAX simulation environment to simulate the disaster. These modules are used to model a wide range of activities concerning disaster and its impact on the critical infrastructure. For example, simulators model the first and secondary impact of the disaster, the action of response services such government agencies, fire, police, medical personal and other services and organization responsible for rescue activities. The simulators allow evaluating the complex impact of environmental factors on the disaster impact.

Distributed simulation environment – Models developed with different simulators can be integrated and communicate through common communication environment based on the HLA/RTI (High Level Architecture/Run Time Infrastructure) standard. It provides the communication functions and services that define a simulation *Interface Specification*, which permits a set of independently-developed simulations, to be brought together into a coordinated complex system. It means that different models can communicate using HLA/RTI services [7].

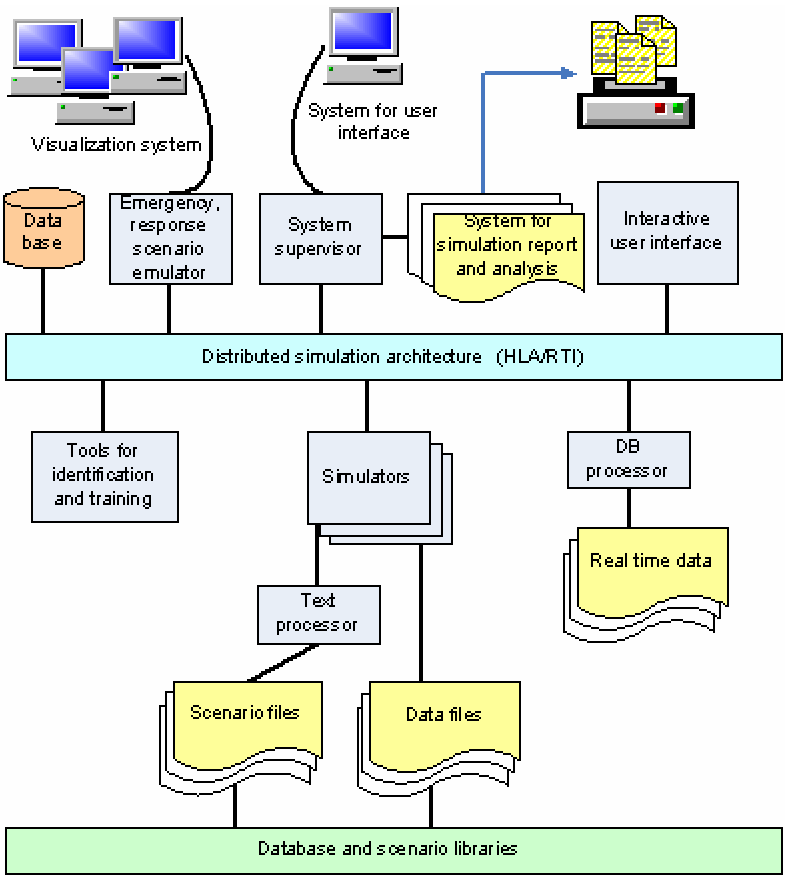

Fig. 5. Simulation architecture for CAX

Scenario emulator – This module provides the communication medium between simulators and visualization systems. It gathers the information from simulators and evaluates the status of all simulated objects. In the next step it sends the information as an input of the visualization.

Database – It supports all information for a normal operation of the CAX. For example, terrain and city maps, GIS data, and information about the buildings and objects of the critical infrastructure. In addition, the database contains a great number of files required by different simulators such as disaster scenario files.

Interactive user interface – This module is very important element from the CAX architecture. The software engineers use them for the synchronization and system settings of the complex simulation environment. Interactive user interface can be used to generate and modify different disaster scenarios. Furthermore, this tool is used for visualization of the scenario taking into account the results from the emulators [9].

Tools for identification and training – The main purpose of this module is a training of the employees that are responsible for rescue activities and emergency management. They can test their degree of preparation and qualification using interaction with the simulation.

The proposed distributed simulation architecture for support of CAX can integrate the different simulation models in a common distributed framework. More important, this technology provides information exchange between them. It allows simulation of many aspects of the disaster and evaluating the overall effect on the critical infrastructure.

5. Groups for scientific support and implementation of CAX system

The scientific support and organization of CAX for emergency management is an inter-disciplinary process, which has to address many technical and organization challenges. In order to cope with a disaster management, all organizations involved in CAX need to interact closely at various levels. These hierarchy levels correspond to different expert groups, which analyze gathered data, put in context, and transform in reports and instructions. Because of these considerations, the participants in a CAX are divided in groups as follows:

Group of peoples that are being trained **–** Those are peoples from the integrated security sector and civil protection agencies and organizations. They participate in subgroups according to their specialties and responsibilities. For them any information needed for decision making in crises situations is available (graphical, textual, any tools that might help their decision making process etc.). The purpose of CAX for this group is to be educated to act in crises, improving collaboration with each other, maximum usage of communication – informational resources.

Group for preparation of CAX – They assure the preparation of CAX and monitor the imlementation of the exercise itself. This group has to prepare the operational plan individually for each exercise, the scenario which will be "played" during the course of CAX. The group for preparation looks after the complicity of database of the system with actual data for each exercise; they are preparing the working places for the participants with all the documents, and software tools necessary for conducting the exercise.

Group controlling the course of the exercise **–** They are monitoring the work of the peoples that are being educated, they start, change the scenarios during CAX, and they control the time scale of CAX. The group consists of specialists who are well prepared for these tasks.

Group for analysis **–** The group is formed of specialists out of integrated security sector. They analyze and evaluate the actions and decisions of peoples from the first group, they develop proposals for optimizing the patterns for action in crises situations. Besides, group for analysis also consults the specialists for improvement of the CAX system.

The experience shows the implementation and support of a CAX for disaster management requires a number of different groups, each with their own responsibilities, objectives, and resources.

6. A case study: An example of integrated simulation system

To verify the effectiveness of the new simulation technology, a case study was done on an integrated simulation of critical infrastructure interdependencies and their control mechanisms. The purpose of the integrated simulation is to observe how the critical infrastructure objects behave when unordinary events occur. The integrated simulation system is created from a set of models that are interconnected with each other. The proposed simulation system consists of several functional components [7]:

Simulation models: All simulated entities, such as different infrastructure elements or threats, are referred to as *simulation models.* It includes models of infrastructure objects, data collectors, and disasters. The simulation models consist of C++ code that access communication services provided by the RTI communication environment. This mechanism allows communication between simulation models based on HLA standard through RTI infrastructure. The communication between infrastructure objects in the integrated simulation is based on a common object model. It contains exchange data created by the developer that shows the relationships between models. Therefore, the common object model defines object classes, their attributes and interaction classes that are commonly used and exchanged among models in the simulation.

Viewer application: The viewer is developed to provide an integrated display environment [Fig. 6]. It can act as a passive recipient and display simulation data from the rest of simulation system. The viewer is an important part of the simulation system because it provides analysis tools and playback capabilities. The viewer communicates with the simulation models over TCP/IP protocol that allows different models to reside on separate computers [5].

The scenario for this case study attempts to incorporate realism and flexibility. The aim of the example is to evaluate the impact of a hurricane and potentially cascading effects, to test the effectiveness of the emergency response plans, for helping train response personnel, and for vulnerability analysis. As a result of repeated execution of simulation, data is collected and analyzed, and the results are documented. The simulation results are presented in Table 1. It display simulation time and state variables of the interdependent models exchanged through RTI environment. A row of the table represents the time series of a state variable. A column represents the set of the simulated variables. The state of the variables at time *t* depends only on the states before *t*. The simulation results can be used for an analysis and assessment of the cascading effects and improving critical infrastructure protection.

The presented simulation system is used for implementation and scientific support of EU TACOM-SEE 2006, which was the first Bulgarian Computer Assisted Exercises (CAX) in the field of the civil protection [9].

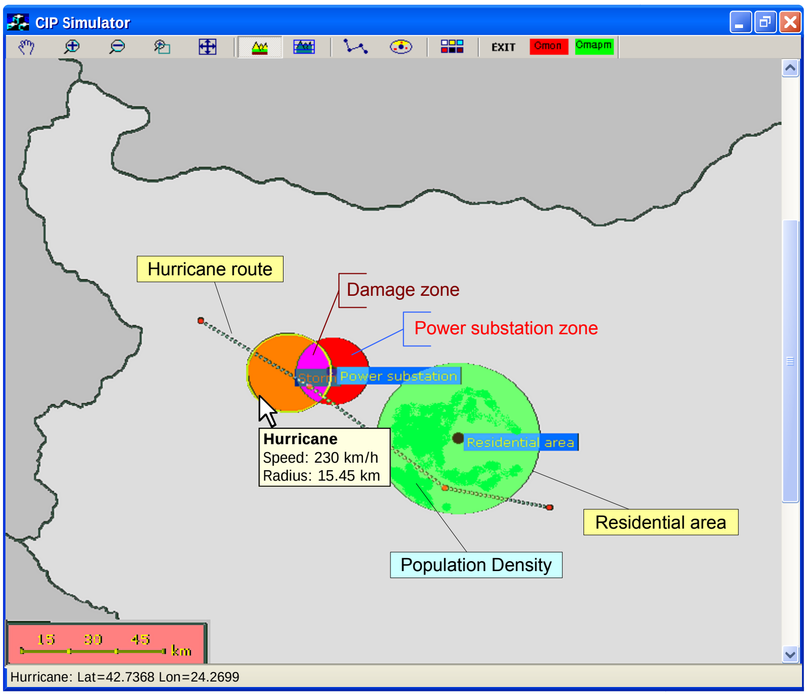

Fig. 6. Viewer application for hurricane simulation

Table 1. Simulation results for hurricane and potentially cascading effects

Space-time graph for disaster simulation							
Hurricane	Latitude	43.2299	43.2269	43.0365	43.9603	42.7368	42.5868
	Longitude	23.3271	23.3336	23.7375	23.8540	24.2699	24.5196
	Speed, km/h	190	190	220	220	220	220
Power substation	Latitude	43.0295	43.0295	43.0295	43.0295	43.0295	43.0295
	Longitude	24.0012	24.0012	24.0012	24.0012	24.0012	24.0012
	Damages, %	-	-	15	30	35	35
Residential area	Latitude	42.7514	42.7514	42.7514	42.7514	42.7514	42.7514
	Longitude	24.6549	24.6549	24.6549	24.6549	24.6549	24.6549
	People in disaster	-	-	-	2	23	58
	Electricity	-	-	-	32	43	56
	Damaged buildings, %	-	-	-	-	16	23
Simulation time, s		300	310	880	1120	1750	2160

7. Conclusions

The paper presents the experience from the practical implementation and scientific support of Computer Assisted Exercise (CAX) EU TACOM-SEE 2006, which an overall objective is the improved response capacity and co-ordination of civil protection structures, experts and intervention teams by ensuring compatibility and complementary in their assistance to a requesting country in the context of the Civil Protection Community Mechanism [10].

The experience EU TACOM-SEE 2006 shows that the CAX is one of the most complex simulation systems that provide a comprehensive development environment for simulation and analysis of disaster management. The main advantages of the CAX can be briefly summarized in the following points:

- CAX provides integration of the different simulation models in a common distributed framework. It allows simulation of many aspects of the disaster and evaluating the overall effect on the critical infrastructure.
- CAX supports different time scales of integrated simulators and reuse of the simulation models.
- The effects of information and environmental changes on the disaster model's behavior can be analyzed.
- CAX is appropriate to verify emergency management plans.
- CAX can be used with pedagogical purposes for training the experts that can experiment in a simulated environment knowing that their mistakes couldn't cause any problems.

References

1. Argüello, L., J. Miró. Distributed Interactive Simulation for space projects. ESA Bulletin 102, 2000.
2. C4ISR Architectures Working Group. Department of Defense, C4ISR Architecture Framework Version 2.0, 1997.
3. Edwards, P. Millennial Reflections on Computers as Infrastructure. – History & Technology, Vol. **15**, 1998, 7-29.
4. Jain, S., R. McLean. A Framework for Modeling and Simulation of Emergency Response. – In: Proc. of the 2003 Winter Simulation Conference, New Orleans, Louisiana, 2003, 1068-1076.
5. Jain, S., R. McLean. Modeling and Simulation of Emergency Response: Workshop Report. Relevant Standards and Tools, National Institute of Standards and Technology Internal Report, NISTIR-7071, 2003.
6. Jense, G., H. Kuijpers, A. Dumay. DIS and HLA: Connecting People, Simulations and Simulators in the Military, Space and Civil Domains. **http://wwwpa.win.tue.nl/kuijpers/publications/iaf97.pdf**
7. Kirov, G. Integration of Simulation Models of the Elements of the Critical Infrastructure in Common Simulation Environment. – In: Proc. Scientific Support of the Transformation in Security Sector-2006, Center for National Security and Defense Research – Bulgarian Academy of Sciences, ISBN-10: 954-322-175-8, ISBN-13: 978-954-322-175-2, 2006, 143-159.
8. Kirov, G., V. Stoyanov. Architecture Approach in the Analysis of the Requirements and Design of Simulation Systems, I&S INFORMATION & SECURITY. – An International Journal, Vol. **16**, 2005, 104-114.
9. Swanson, M., A. Wohl, L. Pope, T. Grance, J. Hash, R. Thomas. Contingency Planning Guide for Information Technology Systems. NIST Special Publication, 2002, 800-834.