COMBINED SYSTEMS

The Combined Systems Point of View

Paul Burghardt
Delft Cooperation on Intelligent Systems (DECIS)
Delftechpark 24, 2628 XH Delft, The Netherlands
Email: paul.burghardt@decis.nl

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Abstract: Crisis Management Systems are evolving from human organizations making use of information systems towards three-layered networks of human actors, artificial agents and traditional information systems. In order to understand the qualities of such complex "COMBINED" systems a joint effort of the sciences of human and artificial systems is required. To ensure practical results, research efforts should anticipate engineering efforts by providing architectural mechanisms and patterns associated with the qualities and capabilities of Combined Systems as a whole.

1. INTRODUCTION

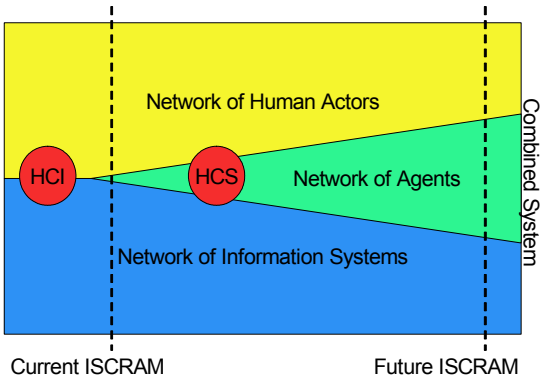
This presentation will generally introduce the Combined Systems Research Project and will emphasize the particular point of view the project has taken on Crisis Management Systems. The functional architecture of the prototype system that is being developed will be presented separately [Storms 2004] as well as more specific research on the theme of self-awareness [Oomes 2004].

1.1 The Combined Systems Project

The term "COMBINED" was originally a creative acronym for the project proposal. It stands for Chaotic Open world Multi-agent Based Intelligent NEtworked Decision support systems. As one can imagine, this general notion requires some interpretation and refinement to relate it to real world practices. During the first year of this four year (4x10 man year) project, considerable time was taken to develop a conceptual point of view on Crisis Management Systems. By studying the documentation on recent Dutch crisis cases such as the Enschede Fire Works disaster and the Volendam New Years Eve Fire we learned a lot about the way a crisis can escalate become difficult to manage.

We focused our attention on the problems that are encountered when a crisis management organization must be scaled up dramatically to meet the needs of an escalating crisis. Because many organizations are involved in such situations it beco mes a complex matter to work together well. It is extremely challenging to communicate effectively between multiple practical disciplines in the context of a continuously changing configuration of distributed systems and teams. The main purpose of the Combined Systems project is to develop the essential knowledge necessary for the realization of of innovative real world solutions.

The scenario we have chosen to illustrate results is a large scale disaster in the Rotterdam Harbour which potentially threatens thousands of lives. The prototype system integrates distributed perception networks (DPNs), virtual control rooms and networks of personal digital assistants (PDA's). Together this forms a system of stationary and mobile devices in ad hoc wireless and wired networks. Throughout this system of systems a multi-agent systems (MAS) layer intelligently facilitates the world modeling to maintain self and situation awareness. It also support collaborative decisionmaking and action in the are of crisis detection, response and management.



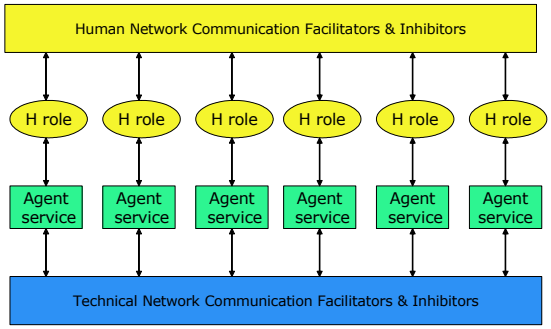
1.2 Point of view

We do not expect that the Combined Project is unique in its ambition. Therefore ample time was taken to find a promising point of view. We will stress three points.

1) Information systems for crisis prevention, response and management should be conceptualized as an integral part of crisis management organizations. We have labeled this class of organizations that features intensive use of information and communication systems "Combined Systems". A consequence of this conception is that system and software engineers should devote considerable attention to business process and domain modeling before delving into more specific work on requirements, analysis and design. Close cooperation with the human sciences and management disciplines is required. Ultimately the aim of Combined Systems engineering is to improve the qualities of the crisis management organizations as a whole. Excellent qualities of the information systems as such are not enough.

2) Combined Systems of the future can be conceptualized as widespread collaborative networks of many human actors and artificial agents operating in a chaotic open environment. These emerging systems of autonomous cognitive systems form an intriguing field of research and development. A consequence of this is that system and software developers should adopt and develop multi-agent systems (MAS) technology. In these hybrid organizations where tasks are reallocated between humans and agents, qualities such as transparency and trust will be of major concern.

·3) Combined Systems form a new kind of phenomena that justify a new interdisciplinary field of research and development. A collaborative effort of many scientific and engineering disciplines is required in both the human and artificial systems domain. This has consequences for the organization and culture of cross-disciplinary research and development projects. Simply dividing loosely coupled tasks between consortium partners from traditional disciplines may not be an adequate response to pressings societal needs.



In the following paragraphs we will expand this point of view by describing the research topics and applications the project is currently working on.

2. RESEARCH TOPICS

2.1 Network Oriented Perspective

In the evaluation of crises it is not uncommon to conclude that further efforts should be made to improve the collaboration between organizations involved in crisis detection, response and management. More information should be shared; communication should be improved.

The Combined Systems project also assumes that improving communication will support better collaboration. Utilizing information from various sources could improve situation awareness, critical collaborative decision-making and well synchronized action.

The emphasis on collaboration and communication makes clear that we are often dealing with networks of many actors and distributed information systems. We have therefore taken the point of view that Combined Crisis Management Systems should be conceptualized as strongly networked organizations and have thus adopted a network oriented perspective. All topics and applications assume that processes involve distributed actors and agents that form virtual work organizations. Managing knowledge and information in a real time context is the key challenge.

Given the fact that large numbers of actors and agents may be involved in crises it becomes interesting to view the structure and dynamics of these networks from different perspectives. Recent viewpoints on networks [Buchanen 2002], smart mobs [Rheingold 2003] and emergence [Johnson 2001] offer inspiring points of view.

2.2 Architectural policies

The conception of crisis management organizations as networks directly brings communication and management concerns to mind. Which information could be exchanged? Will this improve the quality of situation and self awareness? How can information from various sources be combined? How do we judge the quality of such information? Who manages what? How should collaborative decision making be organized? Which decisions should be taken more locally, which ones more centrally? How can information systems be tuned to support the control structures? How can actions be synchronized? How should roles and tasks be distributed? How should resources be allocated and configured?

For the planning of the project it is important to understand the key decisions that can be made with regard to the structure and dynamics of a Combined System. Three high-level decisions have shaped the project. We aim to improve Combined System qualities by:

- Actor to Agent delegation of tasks
- Usage of decentralized mechanisms
- Support for Communicative Action

2.3 Actor to agent delegation

In the combined project we expect that future crisis management systems can make good use of intelligent multi-agent systems. We expect that many well-structured tasks can be delegated to artificial agents [Wooldridge 2002]. This gives human actors more time to work on ill-structured problems that require higher level human faculties to solve.

To pick up where major projects such as ARCHON [Wittig 1992] left off, major investments are required to work on the challenges so excellently described in the Agentlink Roadmap [Luck 2003].

Crisis management systems will consequently evolve from two-layered systems of humans using traditional information systems towards hybrid networks of human actors and artificial agents making use of lower level information systems that supply basic information services (see figure above). The initiative in processes will alternately be taken by actors and agents, thus giving rise to mixed initiative systems.

The MAS systems can help crisis management organizations to scale up effectively in response to escalating crisis situations. Agents can help to rapidly reorganize and reconfigure the system as the situation changes and thus support the realization of self-managing distributed systems (SMDS).

From the human factors point of view traditional human-computer interaction (HCI) will evolve towards what the Combined project now calls human computer symbiosis (HCS).

2.4 Decentralization mechanisms

Self-management of distributed systems (SMDS) has become an important theme in the project. This notion can be applied to low level technical configurations in information systems, but also to higher level processes where multi agent systems and people dynamically reorganize themselves as the situation in a crisis changes.

The general idea behind this notion is to delegate some control to lower level systems, that can autonomously reconfigure themselves to provide certain services as needed. Interestingly there are at least three complementary approaches to self-management. These are: a) the generation of local master plans, b) explicit planning negotiations between autonomous agents and c) the use of ant based control (ABC) algorithms that make use of emergent phenomena. The first style is generally considered most “centralistic” and the last more “decentralized”.

Within the project we will explore all three mechanisms and use them in conjunction with each other. We aim to learn under which conditions to apply which type of mechanism. Below we will briefly mention some of the specific topics and applications the project is working on.

In the area of virtual control rooms we will make use of a SMDS-realizations that work in conjunction with service agents to solve specific problems that have been delegated to the crisis management system. Based on descriptions of the capabilities of the service agents and on the availability of these resources a specific master plan will be made to solve a well structured problem. Early prototypes will for example be concerned with the recognition of and response to chemical disasters. The SMDS application initially configures resources to focus on an assessment of the situation. It will then shift attention to the configuration of alert and response processes.

Out in the field a network of personal digital assistants (PDA’s) will be used to gather specific information in the crisis scene and to help provide real time local situation awareness. To avoid dependency on central infrastructures and databases use will be made of WiFi and distributed encoding techniques. All local information will be available to all mobile devices in this ad hoc network as if there is a central database. In fact the information will be distributed and redundant. When certain

devices or links fail no data should be lost. The aim of the research is to do this efficiently and effectively.

The first application of this technique is concerned with positioning of people and events on the crisis scene by making use local observations. Such information can of course also be uploaded to other networks and become available to control rooms.

Decentralization by making use of the Ant Based Control will be applied to routing problems to aid evacuations by car from a city and by foot from large damaged buildings.

These specific ABC applications have drawn our attention to the nonlinear dynamics in crisis management work organizations and to the necessity to consciously consider and manage emergent phenomena [Guastello 2001].

In yet another segment of the prototype system a network of autonomous sensor suites will be developed that aims to decentralize the multi-sensor data-fusion processing by using a mix of SMDS and agent based techniques.

From an organizational point of view the project is investigating possibilities to make complex information systems more manageable by implementing the classical organizational design patterns [Galbraith 1976]. These are: a) Reduction of the need for information exchange and communication by creating autonomous tasks, b) enlargement of the information exchange capacity by rationalization of hierarchical information systems and the creation of decentralized lateral relationships.

2.5 Communicative Action Support

Communication can have many meanings. Simply having the technical facilities to send and receive messages does not necessarily guarantee that communication between human participants will have the desired results. Even when ergonomic aspects of human computer interaction have been dealt with properly there is still no guarantee that the participants will arrive at a common understanding of the crisis situation.

When we define communicative action as the human interaction process through which actors develop their perception, plans and actions with regard to a crisis situation it is clear that this is much more than just a technical process. Ideally an argumentative process should take place in which actors provide good reasons for the conclusions they propose to agree on collectively. Due to time constraints and human factors the situation will often be far from this ideal. Even when the information systems for crisis response and management are excellent, human factors of a psychological, sociological, economical, political and cultural nature will have a pervasive influence. The ideal communicative action that is facilitated by information technology can be severely inhibited this broad array of human factors. In networks of human actors all communication also has strategic and instrumental aspects that are not primarily aimed at collaboration on shared awareness, common goals or collective action.

Within the scope of the Combined Systems Project as it was defined there are limited opportunities to investigate human factors. We have however identified a set of topics and applications that can provide some facilitators for communicative action.

When actors are involved in collaborative decision-making it is important to openly and critically manage hypotheses. We aim to provide a color coded visualization of multiple hypotheses and information elements that make it easier for humans to keep several hypotheses open and to collaboratively judge which hypotheses is best supported by the evidence. These interface will be made available for both stationary and mobile devices.

The purpose of this technique is to help humans to collaboratively provide good reasons for important conclusions, rather than jumping to conclusions too soon. Especially under stress and time constraints we expect that this technique will help to keep an open mind things and to make a better judgment of the situation. In the example case we are working on actors must decide what the exact nature of the Rotterdam Harbor Crisis is, and if the consequences are dangerous enough to justify large scale evacuations.

While the visualization mainly focuses on rationalizing the relationship between evidence and hypotheses, another research topic focuses on the quality of the evidence provided. Especially when evidence is based on several data elements in which there is a degree of uncertainty, it is difficult to judge it's reliability. In the decision-making process it could be of help to have some kind of measure of the reliability of the evidence. For this reason work is being done on the application of Bayesian belief networks. Possibly the measures this provides will be used in the critical thinking visualizations.

On a bit deeper level communicative action may be disturbed by misunderstandings on a semantic level. Information may be misinterpreted, misused or not used due to differences in terminology or ontology. The project is therefore making a substantial effort to integrate semantic based technologies to cope with these kinds of problems. A

semantic network engine (SNE) will be used to collect, interpret and integrate evidence, that at some point will be made available via the critical thinking interfaces.

Whn used in conjunction with each other the techniques for hypothesis management, reliability measurement and ontology mapping may help human actors to communicate rationally about the situation at hand, despite many complicating factors.

2.6 Organization Images & qualities

When developing information systems it is customary to develop an idealized model of the processes taking place in the domain. While it is extremely important to provide ample attention to such context modeling before specifying a supportive information system, there is also a danger that the model abstracts away from the complications introduced by human factors. The result is that the process models come go suggest a relatively rational and mechanical image of the crisis management organization. This may lead to disappointments when processes in reality prove to work less efficiently and effectively, despite the fact that the information system was constructed correctly.

While traditional designs of information systems may encourage the adoption of a rather mechanical image of organizations, the conception of Combined Systems now suggests a more organic image. Neither are necessarily adequate to capture the nature of crisis management organizations. Cultural and political aspects require further attention. When designing a system of any sort it is however necessary to critically evaluate the organizational image [Morgan 1986] that the domain and process models suggest. Reconsideration may lead to other specifications and expectations.

The point we have come to realize at DECIS in general and in the Combined Systems project in particular, is that the qualities of systems for collaborative decision-making are not only qualities of technical systems or qualities of human networks, but qualities of the complete configuration of human and artificial systems.

The consequence of this insight is that quality terms such as adaptability, flexibility, scalability, trustworthiness, efficiency etcetera take on a different meaning. They are qualities of hybrid systems and need to be developed and assessed with that perspective in mind.

This does not necessarily invalidate traditional systems and software engineering methodologies. It does however emphasize the importance of business modeling, user oriented developed and human factors.

The quality of a Combined crisis management system should not be confused with the quality of its information system or of its human organization. Research and development that considers these parts separately is necessary but not sufficient to achieve qualities on the Combined Systems level.

2.7 Accelerator Cases

The combined project is not without ambition. It is therefore important to find an approach to make the research and development work feasible.

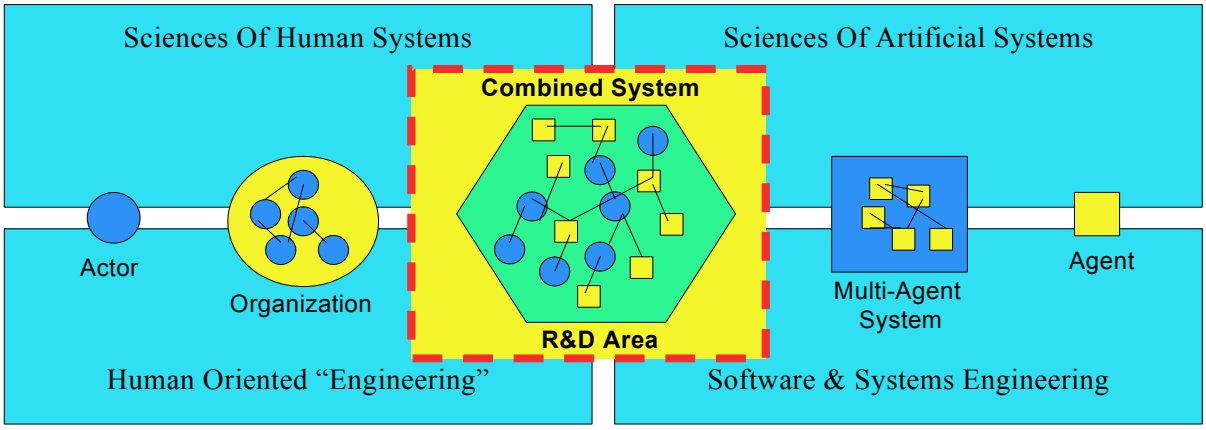
Inspired by examples of control rooms that have the intent to accelerate collaborative decision making processes by providing excellent information systems support we have come up with the notion of “virtual accelerator room cases” (VARs). In style with the Unified Process [Kroll 2003] we are developing complete use cases that cut through all layers and segments the Combined System Prototype. Such cases focus on a specific decision or action to be taken, and aims to accelerate the communicative action by making use of the architectural policies described above.

3. CONCLUSIONS

While developing our point of view on Combined Systems our situation and self awareness as a project has developed. When we compare our area of concern with the topics called for by National and European research and development projects we find it difficult to find call topics that recognize the need to research and develop Combined Systems as a whole.

It is also our impression that many recognized academic disciplines cover either the human side or the artificial side but not both. Furthermore disciplines tend to favor either the practical engineering of systems while others are concerned with scientific theory. Disciplinary specialization is required to meet academic expectations and business needs. Given this disposition it is not surprising when contributions to the combined crisis management systems tend to have an analytic character. Concern for the synthesis of the required systems of systems becomes a matter of practical business and politics.

Based on accounts of practical experience in research and development consortia where many disciplines are involved it is evidently difficult collaborate between scientists and engineers in one project. Sensibly combining a human factors and multi-agent perspective also proves to be a



challenge. Throughout all disciplines it is clear that dealing with networks of systems is almost by definition more complex that dealing with singular systems. Given the complexity of either social systems or multi-agent information systems on their own, it seems ill-advised to conceive projects that mix in both. In practice however such a mix will be unavoidable. Experiments with virtual accelerator room cases as suggested above are therefore quite relevant.

Within the Combined project we have recognized the need to experiment with new ways to work together across disciplines and partners. By working as a distributed team [Haywood 1998] and making use of collaborative tools and knowledge management methods we aim to achieve interdisciplinary results, rather than output from multiple disciplines. We are further intrigued by the open source and open content approach. The tool developed by the Tiki community deserves honorable mention for its very valuable facilitation of work in open minded projects [www.tikiwiki.org].

On the whole it is important to realize that the introduction of new information technologies in Crisis Management and Response organizations is an innovation process that will require organizational, legal and cultural changes. Coping with this cultural lag should be a major consideration in the dissemination of research and development results.

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