Combined Systems

Combining more for crisis management

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Please, see http://www.combinedsystems.nl for more information.

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Summary

The Combined Systems project is one of the first integrated crisis management projects in the Netherlands. The project's contributions include: (1) a new model for the development of crisis management support systems: the Combined Systems view (2) new technology in the form of **intelligent building blocks** and (3) a diverse and dedicated **crisis management research community**.

The Combined Systems project has worked on ways to support decision-makers, focusing in particular on problems associated with generating overall situation awareness and maintaining coordinated action in situations in which a large variety of people and organizations must work together.

All phases of crisis management have been examined, using techniques from a range of disciplines. Large-scale crisis management is a complex operation in which many actors and systems need to work together to form an effective organization. The Combined Systems view defines four key system qualities for crisis management organizations: **reliable communication**, **efficient information-sharing**, **good decision-making** and **effective coordination**.

The Combined Systems project has developed **actor-agent crisis communities**. These are networks of interconnected actors (human beings), and software agents (computers running advanced software) that jointly exhibit the key system qualities across organizational boundaries and under highly dynamic circumstances.

The strength of these network-centric solutions provided by the Combined Systems project lies in the organizational and technical mechanisms enabling people to **respond more rapidly** although faced with severe damage to critical infrastructure and insufficient organizational resources.

Preface

At 15:03 on May 13th, 2000, a fire was reported on the premises of a fireworks storage facility (SE Fireworks B.V.) located in a residential area in Enschede, the Netherlands. The location of the fire was quickly identified and firefighters engaged, but the incident escalated. At 15:34 a series of explosions culminated in a major blast that killed 22 people (including four firefighters), wounded 900 and destroyed some 400 houses in the neighborhood. In response to this disaster two crisis centers were opened: one municipal center in Enschede and one regional center in Hengelo. It was unclear for some time who was in control. The mayor of Enschede finally took charge, although the scale of the disaster called for command on a regional level.

Two hijacked planes were deliberately flown into the twin World Trade Center towers in New York City on September 11th, 2001. WTC 1 was struck at 8:46 a.m. and WTC 2 a short while later at 9:03 a.m. The damage caused by the collisions was so severe that both towers collapsed: WTC 2 at 9.59 a.m. and WTC 1 at 10.29 a.m. As a result 2,823 people died, including some 400 emergency personnel. Shortly after the impacts the Fire Department of New York opened two incident command posts in the lobbies of the towers. They attempted to coordinate search and rescue operations in the buildings and to keep track of the locations of their units with magnets on metal boards. This information was lost when the towers collapsed.

The Combined Systems project

The incidents described above are examples of situations in which many people and many different organizations must work together to respond to a crisis of great urgency under chaotic circumstances. The Combined Systems project proposal was developed in the months following 9/11.

The project proposal addressed the questions: *What can be done to improve the decision making capability of large networks of emergency responders under open-world conditions? Where can emergency responders and crisis managers benefit from improved decision support systems? How can multi-agent systems be used to intelligently integrate disparate systems and improve the timeliness and quality of critical information?* The mission of the project can be summarized: to investigate **C**haotic **O**pen world **M**ulti-agent **B**ased **I**ntelligently **NE**tworked **D**ecision support **Systems**. In short: Combined Systems.

The Combined Systems project offers solutions for communication, information, decision-making and coordination that make it possible for people **to respond quickly in the first sixty minutes after a crisis occurs (the golden hour)**. This makes a difference in terms of lives saved. The strength of the solutions lies in the organizational and technical mechanisms enabling people to respond more rapidly even though they are faced with severe damage to critical infrastructures and incomplete organizational resources. The solutions involve a **network-centric approach** to crisis management.

The Combined Systems project consists of researchers from four partner organizations: Thales Nederland Research and Technology, the Delft University of Technology, the Netherlands Organisation for Applied Scientific Research TNO and the Universiteit van Amsterdam. Important contributions were made by Y'All, Inology and Lithp systems. By forming a consortium of industrial and academic partners a multidisciplinary team was established in which about 25 people were involved over a period of 4 years.

The team has **developed a vision** of a new generation of complex systems and created advanced technology necessary to demonstrate essential concepts.

The Combined Systems project was the first project undertaken by the DECIS Lab consortium.

Delft Cooperation on Intelligent Systems (DECIS) Lab

DECIS Lab is the open research partnership of Thales Nederland, the Delft University of Technology, the Netherlands Organisation for Applied Scientific Research TNO and the Universiteit van Amsterdam. The DECIS Lab combines Human Sciences and Information & Communication Technologies in a quest to combine human and artificial intelligence.

The mission of the DECIS Lab is to improve collaborative problem solving capabilities in large actor-agent communities working in chaotic environments. The DECIS Lab advocates a strong demand-driven approach to research and development, where requirements from real world cases present innovative challenges to multidisciplinary teams of scientists, engineers and practioners.

By working together closely the DECIS Lab facilitates the transfer of knowledge to applications. In short: the DECIS Lab performs the role of **transilitator** (knowledge to application transfer facilitator) in the overall innovation process.

The research results are used in a multitude of application areas, such as traffic and transportation management, air traffic control, crisis management, financial transaction management, process management, public safety, etc. Crisis management is the preferred outreach area for the DECIS Lab.

Next to the Combined Systems project, the DECIS Lab is managing several projects, including **Interactive Collaborative Information Systems (ICIS)**. ICIS is a BSIK-funded research project aiming at developing a new generation of information systems that are collaborative, autonomous and intelligent and that enhance human competences. ICIS works towards advances in collaborative decision-making and adaptive interactions between human and artificial actors, enhanced situation awareness and innovative architectures for distributed actor-agent communities.

Thematically the DECIS Lab is focusing on the notion of systems of many human actors interacting with many information systems. The research of the DECIS Lab is concerned with the introduction of multi-agent technologies to mediate among users and information systems. The DECIS Lab is therefore interested in large-scale systems of systems.

Contents

Introduction

Large-scale crisis management is one of the **most complex challenges that modern societies encounter**. When disaster strikes, many organizations need to come together to save lives and limit further losses. Many rescue workers need to start coordinating their actions and communicating their view of the situation, and jointly form themselves into an agile, effective crisis management organization.

Crises are **highly unpredictable and dynamic situations**, and, especially in the early phases of a crisis, developing crisis management organizations have great difficulty controlling the situation. Recent natural disasters and terrorist attacks have shown that chaos usually prevails during the early hours of a response.

The **first sixty minutes** after a victim has sustained an injury is referred to as **the golden hour**. The term highlights the importance of timely treatment of victims. The chances of survival are highest when seriously injured victims are attended to within the first hour.

The same is true for crisis management. **Immediate response** to an incident helps to accelerate situation control, to protect people from harm and to prevent unnecessary escalation of the crisis. Of course, every crisis management organization reacts to incidents straight away. There is, however, room for improvement during the first stages of an incident.

Proper crisis management lies in **rapidly creating an understanding of the situation and its consequences** and in quickly developing an organization that can control the incident, or lessen its effects. In practice, this is a very complex process with many stakeholders, policies and procedures. The process relies heavily on experienced decision-makers and emergency responders getting good information and technological support.

The Combined Systems project

The Combined Systems project began with a study of documentation on recent Dutch crisis cases such as the Enschede fireworks disaster and the Volendam New Years Eve fire. There are several reasons why escalating crises can become difficult to manage.

An important management problem arises when **the crisis management organization needs to be scaled up dramatically** to meet the needs of an escalating crisis. As more organizations become involved, working together becomes more complicated. It is extremely challenging to establish and maintain effective communication between the multiple disciplines in such dynamic circumstances.

The Combined Systems project aims to gather **essential knowledge required for delivering innovative real-world solutions for crisis management**. All phases of the crisis management cycle have been addressed: first making sense of what is going on through observation and orientation. Then, based on this, making decisions and taking action.

The Combined Systems project has developed innovative **building blocks** that can be used in developing such solutions (see page 9). In order to demonstrate the principles of these building blocks a **challenging crisis management scenario** was created. In this imaginary but realistic scenario a large-scale disaster takes place in the Rotterdam Harbor area (see page 29).

The Combined systems project has addressed crisis management as an adaptive **socio-technical system in which many actors must work together**. All actors make intensive use of communication and information systems. A problem is that the required information is often not completely available when it is needed. Therefore the project has addressed research issues concerned with the **timely acquisition and sharing of the relevant information**.

Research themes

The Combined Systems project undertook research that can be broken down into four themes: **Layers of Communication**, **World Modeling**, **Human Computer Symbiosis** and **Escalation**.

Layers of Communication: Within any information system, humans and machines, such as computer programs, have to work together. Every participant within a system (a human or a machine) has a certain information need which is defined by the tasks, role and experience of the participant. The challenge is to deliver information in the right format at the right place to the right participant at the right time. Furthermore, every participant should be able to communicate with other participants.

World Modeling: A world model contains views on the current situation. Every view looks at the situation from a different angle, such as a medical casualty view, an evacuation view, an environmental view, etc. In order to construct a world model, information needs to be gathered, analyzed and distributed.

Human Computer Symbiosis: Symbiosis (interaction) between human and machine helps users to build up an adequate world model for their task given the information in the computer. In the end humans make the decision, but software agents provide situation-awareness and decision support. Computers support humans, but the reverse is also true, as humans can also supply sensor information to agents by making observations and generating information.

Escalation: Escalation may be needed if an organization is no longer capable of controlling a certain situation, and thus needs to adjust itself to regain control. Escalation management is, in that sense, the process of monitoring the situation, assessing the capability of the current organization to control the situation and, if required, altering the organization to regain control. In practice, escalation is about scaling up or scaling down the organization, and making sure that resources are properly deployed.

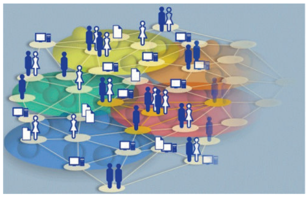
Actor-agent crisis communities

In the Combined Systems view crisis management organizations are **collections of humans and machines** that are linked together in a network. Humans within crisis management organizations (police officers, firefighters, etc) play roles and will be referred to them as **actors**. Machines can be any man-made device capable of specific functions such as sensing, information processing, communication or physical action. Examples of machines are: cameras, mobile communication devices (PDAs), traditional databases, traffic lights and water sprinkler installations. All such machines are represented by **software agents**.

Software agents are advanced programs that have an adjustable degree of autonomy in pursuing a set of goals set by human clients. When goals are in conflict, software agents can facilitate negotiation processes to settle issues. With the use of such machines agents are able to perceive their environment and respond to changes by adjusting themselves or by influencing their environment. These actions are either reactive or proactive.

Software agents interact with other agents, humans and non-agent systems to offer their services, represent others (agency) and cooperate to achieve a set of goals. These goals can be common or conflicting. The term multi-agent system denotes **a network of interacting agents**. Such hybrid networks of humans and agents are **actor-agent communities**. Social and technical components are treated as inseparable and any member, whether human, computer, or organization, is equally important to the social network.

Flexible crisis management organizations can be seen as actor-agent crisis communities in which **humans and software agents collaborate as peers**. Agents manage the available resources and their accessibility to humans. By standardizing the way that all community members communicate, the agents avoid unnecessary technical and behavioral complications.



The Combined Systems project advocates the use of networks of sensors, ad hoc team formation strategies, management of traffic and communication networks and other forms of decentralized, crisis management activities. Future crisis management organizations will consist of both actors and software agents that work together to achieve their common goals in sometimes chaotic circumstances.

Key qualities for crisis management systems

Large-scale crisis management is a complex operation, in which many actors and software agents need to work together to form an effective organization. The type of crisis cannot be predicted; neither can the shape of the crisis management organization. Supporting technology, therefore, used in **crisis management decision support** should be able to handle novel and dynamic situations.

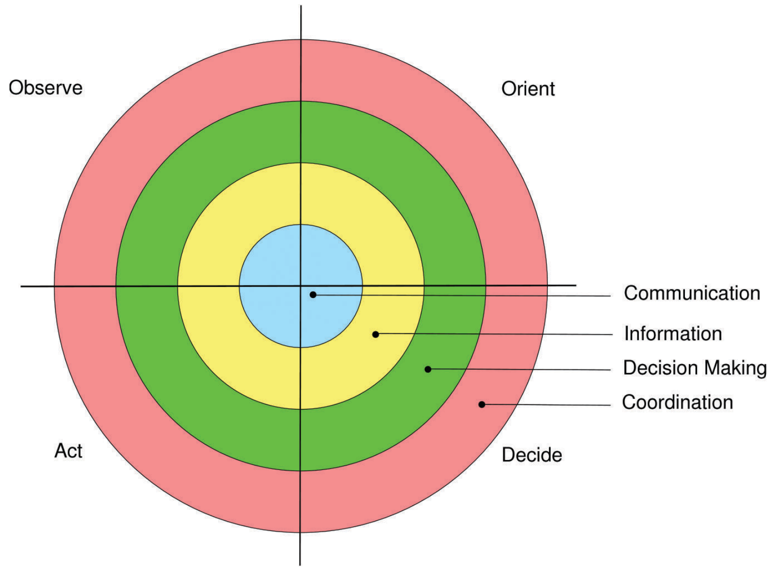
Four system qualities are important for crisis management: **communication**, **information-sharing**, **decision-making** and **coordination**.

The Combined Systems project has addressed the four key qualities from an integrated point of view. **Information-sharing** depends on reliable **communication** networks. Good **decision-making** can only occur if information is shared well. Effective **coordination** can only happen when the right decisions have been made.

A common model for proper decision-making is the **Observe-Orient-Decide-Act loop**. This is a model for decision-making that originated in the military domain, but which is now frequently used to describe operations in all kinds of domains. The phases in the OODA loop are:

- The **Observe** phase takes in information about the environment, the status, and the threat.
- The **Orient** phase makes estimates, assumptions, analyses, and judgments about the situation to create a cohesive situation awareness.
- The **Decide** phase determines what needs to be achieved, whether it is an immediate reaction or a complex plan.
- The **Act** phase executes the strategic decision. While doing so, it continually adjusts operational plans to specific and changing circumstances that are encountered.

The OODA loop combined with the four key qualities for crisis management systems form the Combined Systems view which is illustrated here.



The Combined Systems view

There are two dimensions: (1) the OODA loop and (2) the key qualities represented as layers.

Every quadrant represents a decision-making phase: Observe, Orient, Decide and Act. The four colored layers represent the four key qualities. In the middle of the picture the blue circle represents communication. When communication is reliable, information (represented by the yellow circle) can be shared. Good decision-making (green)is possible given the right information, and coordination (red) ensures that the decision is carried out as planned.

The four key qualities are now discussed in detail.

Reliable communication facilities

Communication facilities, such as wireless communication devices, data networks and communication protocols, make it possible to exchange data and interact in a distributed, dynamic organization. The ability to communicate is the backbone of any mission. Studies of major crises have shown that communication still is a key concern in crisis management and that many failures are the result of failing or unsuitable communication facilities.

Crisis management organizations cannot afford to lose contact with units in the field. Therefore, **reliability** and **robustness** are crucial. Also, the communication facilities need to be **flexible**. Crisis management organizations are typically formed **on demand**, and so should the communication network. Additionally, communication should be **responsive**, because crises unfold quickly and any crucial news needs to be spread immediately.

Efficient information sharing

Communication networks make it possible to share information. Information-sharing is about getting the right information to the right people, at the right time. Efficient information-sharing requires an understanding of the information needs of those involved, access to information sources, and the availability of systems that can process and store information, as well as share it with those who need it.

In crisis management, sharing information is crucial. Everybody involved needs to know what the nature of the situation is, what they can expect and who is at risk. Therefore, information needs to be **accessible**, **comprehensible** and **relevant**. In practice many social and technical circumstances can impede efficient information-sharing. If information is not stored or shared, it will be difficult to access that information when actually needed. For instance, actors possessing certain pieces of information may not be available when needed or may be unknown to the organization altogether.

Another complication may be compatibility issues between information systems and information sources and problems with translating information from one medium to another. Also, especially in the early phases of a crisis, there will be huge amounts of information entering the organization. Not all information will be **relevant** to everyone, so information must be filtered and clustered somewhere along the line. Most of these complications have been analyzed from a technical point of view, while recognizing that organizational and cultural issues are also of concern.

Sensible decision-making

Having the right information is essential to proper decision-making. Even with the right information, making decisions can be very hard, especially when human lives are at stake. Decision must be both **appropriate** and **sensible**.

A crisis organization is different from a normal organization. It is assembled for the crisis at hand and evolves during the crisis. At any time, the scale of the organization needs to be in line with that of the incident. It is important for decision-makers to know the state and structure of the organization and the roles and responsibilities of those that are part of it. That way, decision-makers can make **appropriate** decisions that are in line with the state of affairs on the scene.

However, decision-making under stressful and pressing circumstances is difficult because of the lack of a complete overview of the situation. In such situations, there is a danger of being biased towards a certain conclusion, even though contradictory information might be available. Decision-makers under stress need to keep an open mind so they can make **sensible** decisions about what is going on.

Effective coordination

Good decision-making should be followed by good coordination strategies. Coordination deals with translating general decisions into more specific goals and tasks for everyone involved. Coordination defines who is in charge of which part of the operation. Each crisis demands a different strategy and the crisis management organization should be able to attune coordination strategies to the situation at hand. Predictable incidents can be handled by defining roles and tasks in advance, but such static coordination can fail when incidents are more complex and chaotic. Being capable of adapting the coordination strategy to the situation is what makes an organization **agile** and **effective**.

It takes time to find the optimal coordination strategy, to inform and instruct all teams and systems and to assess effects. The coordination strategy should anticipate things to come. If it takes too long to change the coordination strategy then the desired effect might not be achieved. An agile organization changes strategies at the right time and continuously assesses their effectiveness. In modern crisis management, this flexibility has proven to be difficult to achieve, due to the fact that many organizations with rigid and incompatible coordination procedures are involved.

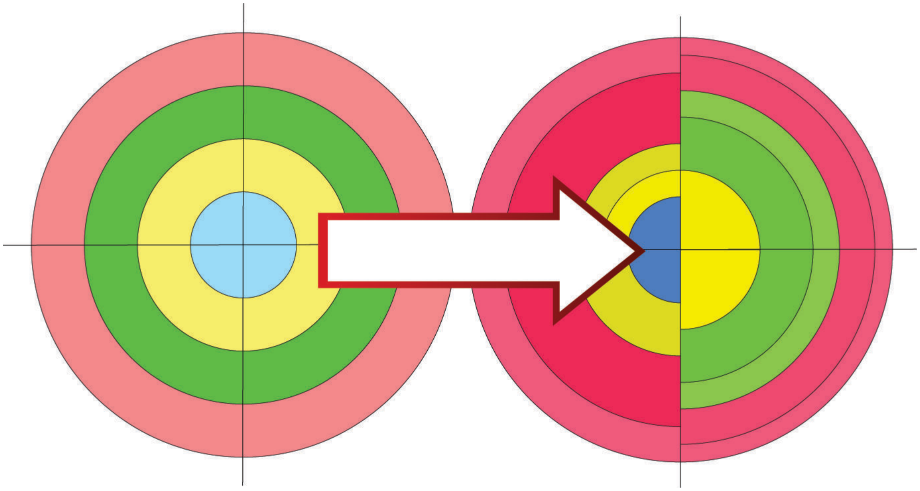
Intelligent building blocks

The Combined Systems project has developed innovative technology to support crisis management and contribute to the system qualities mentioned in the previous chapter. Since there are various way to construct crisis management system, a number of **intelligent building blocks** have been developed that can be used in various combinations:

- **Distributed Workflow Execution Architecture for Mobile (DWEAM)** enables information sharing and workflow execution in ad hoc networks.
- **Semantic Network Engine (SNE)** is a distributed knowledge base for managing static and dynamic crisis management information.
- **Icon Language** is a visual language composed of various icons, which can quickly be assembled into messages.
- **Distributed Perception Networks (DPNs)** are distributed sensors that can be used for hypothesis testing both before an incident (early warning) and after.
- **Critical Thinking Tool** prevents tunnel vision and information bias by encouraging decision-makers to keep an open mind to other explanations.
- **Organizational Awareness** is knowing how to use knowledge of the organization to minimize the number of casualties and damage.
- **Self-Managing Distributed Systems (SMDS)** coordinate, configure and manage hardware and software resources in a mission-oriented dynamic collaboration system.
- **Market-based agent negotiation** is a decision-making technique inspired by markets for goods and services, in which participants can bargain about possible solutions.
- **Ant-based routing**, inspired by the behavior of real ants, is an approach to finding short paths and to solving routing problems.

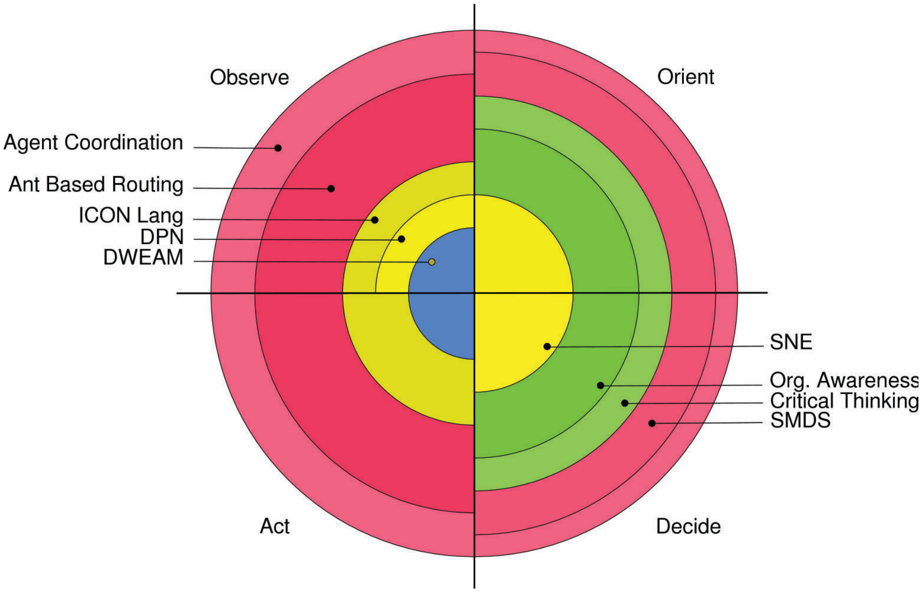
Each building block supports one or more phases of the OODA loop: Observe, Orient, Decide and Act. Furthermore, each building block supports one or more key system qualities: reliable communication, information-sharing, sensible decision-making and effective coordination.

Mapping these building blocks onto the Combined Systems view yields:

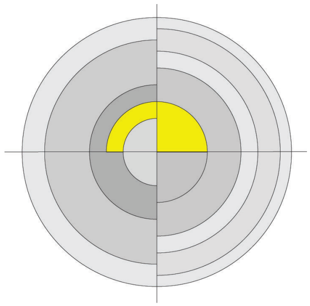


Transition from the “Combined Systems view” to the “technical Combined Systems view”

This results in the technical Combined Systems view :



The technical Combined Systems view



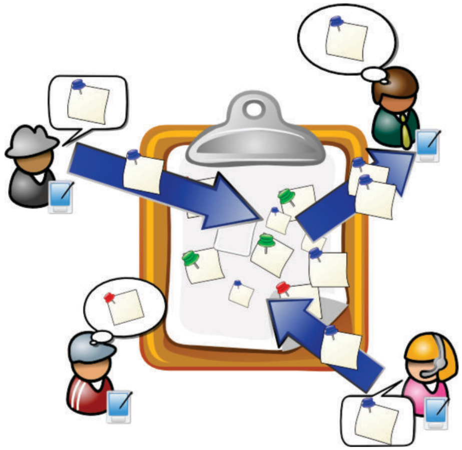
Each intelligent building block has its place in the Combined Systems view. For example, DPNs (Distributed Perception Networks) are specialized for the observe and orient phases. Furthermore, DPNs support the key system quality: information-sharing.

The intelligent building blocks are now discussed in detail. To show the location in the technical Combined Systems view, small versions of the picture are placed next to the description of each building block. As an example, the small version for DPN is given here to the right.

Enabling reliable communication with *Distributed Workflow Execution Architecture for Mobile (DWEAM)*

Distributed Workflow Execution Architecture for Mobile (DWEAM) enables information-sharing and workflow execution in ad hoc networks and is designed for use by crisis management organizations. DWEAM builds and **maintains a communication network** among Personal Digital Assistants (PDAs) and ensures reliable data throughput. It is **independent of infrastructure**, as the messages are only exchanged and forwarded by wireless connections between neighboring PDAs.

Information technology improves crisis management support by allowing **timely data processing and delivery**. Timely access to data is crucial for informed decision-making and as a result information technology has quickly been adopted in the crisis management centers. Computers are becoming smaller and more powerful and will soon be used routinely by the members of operational teams, just as they are used in control centers today. Every team member will be using a PDA, just as radios and cellular phones are used today. The PDA will support old-style voice communication, but can also **connect to supporting IT services** by a wireless network.



PDAs communicating via a blackboard

DWEAM uses a **distributed blackboard model** for sharing information. The blackboard is a facility that stores all the data gathered during system runtime. A client PDA can access the blackboard to review and change its contents and can narrow its view to only a part of the blackboard that it is interested in. DWEAM requires the blackboard clients to describe the data that they produce and the data that they consume.

DWEAM processes the descriptions so that the consumers of a certain class of data are connected to the producers of that data. When a producer changes the blackboard contents by adding, changing or removing data, all the consumers interested in the changed contents are notified.

The touch screen of a Zaurus PDA

The Zaurus PDA

Zaurus is the first PDA to be closer in performance to that of desktop computers than to that of embedded devices. It first appeared on the market in 2004. It is also the first PDA to have a screen large enough for comfortable user interaction and yet compact enough to be portable. The Zaurus has been used to demonstrate several Combined Systems building blocks.
The Zaurus PDA conveys observational information which is processed by agents. Icon Language (see page 16) can be used to enter information. The PDA also gives feedback to the user. The PDA is equipped with networking devices to connect to external IT infrastructure if available, but can also communicate without infrastructure. The basic interface consists of a touch screen, a keyboard and audio input and output.

Improving communication interoperability with the *Semantic Network Engine (SNE)*

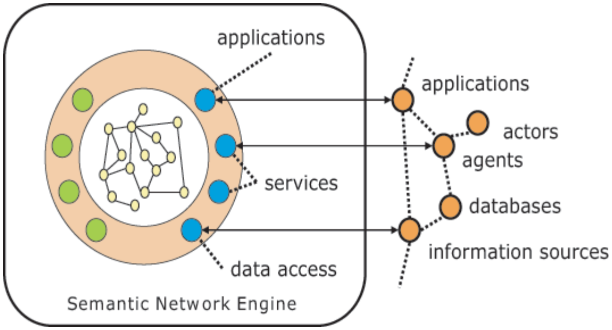
The **Semantic Network Engine (SNE) is a distributed knowledge base**. It stores and allows retrieval of static and dynamic information at various levels of detail. The semantic network itself is composed of nodes that represent specific concepts (a person, a place, etc.) and edges that represent meaningful (semantic) relationships between these concepts. Furthermore, nodes and relationships can have specific properties.

The Semantic Network allows the storage of all (more or less) **static information that might be important for crisis managers**. This might include the contents of ships, descriptions of chemicals, symptoms of diseases or phenomena related to the various kinds of incidents.

With the same ease the Semantic Network can store **dynamic information**, such as analyzed content of the emergency messages arriving at the emergency call center. On one side an information provider stores his information in the network without necessarily knowing what purpose it is to be used for. On the other side information consumers will retrieve whatever information might be relevant for the situations they have to face. Intelligent services will try to match the information provided to the information requested with as few pre-defined mappings as possible.

In a crisis scenario, **all emergency messages are stored in the Semantic Network**, whether provided by PDAs, SMS or phone calls. These text-based messages are analyzed and extracted information is added to the messages with the help of Information Extraction Services/Agents. Message surveillance agents supply the messages to the Critical Thinking Tool (see page 20). When there are too many messages, these agents will first request a smart clustering of messages and deliver the clusters generated instead (information reduction). Depending on the phenomena signaled in the messages an SNE service might also propose possible (or plausible) hypotheses to the Critical Thinking Tool.

The SNE has an extremely flexible multilingual information architecture, comparable to that of a database. Associated services perform intelligent analysis with available information. Each analysis service is configurable and in most cases its configuration parameters are also nodes in the network.

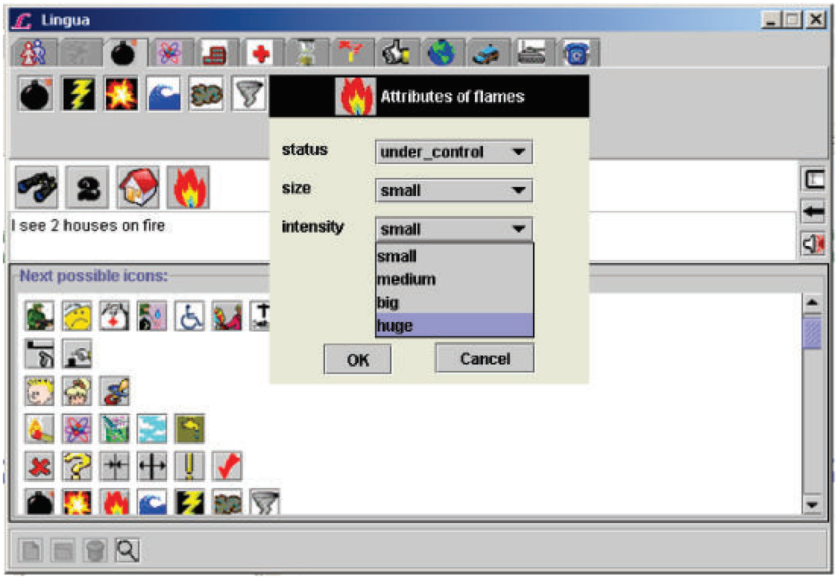


The conceptual architecture of the Semantic Network Engine

Services are in most cases highly specialized and have, through their configuration, knowledge about a specific domain, such as crisis management. As shown in the picture, there are several services, such as services for clustering, image meta-data analysis, HTML analysis, information extraction, semantic and network distance and a reasoning engine. Other services are dedicated to displaying the information (HTML) or to transforming it into XML or RDF. XML and RDF are machine-readable information and knowledge representation languages. The services function on a best-effort basis, based upon what is known.

Sharing information by *Icon tools*

Icon Language is a visual language composed of graphic symbols (icons). The language includes a formal grammar that is used to **make sentences** from icons that are given as input by the user. Icons can be used for communication across language barriers. The meaning of an icon is derived from the icon itself, which is pictorial, from the particular context the icon is used in and from the interpretation of the viewer of the icon. Icon Language can be used as a translation tool, from one language to another, or even from one modality to another.



The Icon Tool interface, showing how to select attributes for the “flames” icon

Icon Map is a tool that allows a user to report about crisis situations by placing icons on a map at the point where the event occurs. The tool makes use of Icon Language and a geographical map to describe situations. Icon Map makes use of a world model with a pre-defined set of icons and relations between them. This information is forwarded to other building blocks for further processing.

The Icon Map tool collects observations from multiple users who are separated in space and time and fuses them in the current world model. The current world model is used to provide feedback to the user. The meaning of each individual icon in the Icon Map tool represents a word or a phrase.

The Icon Map Interface, showing how icons are placed on a geographical map

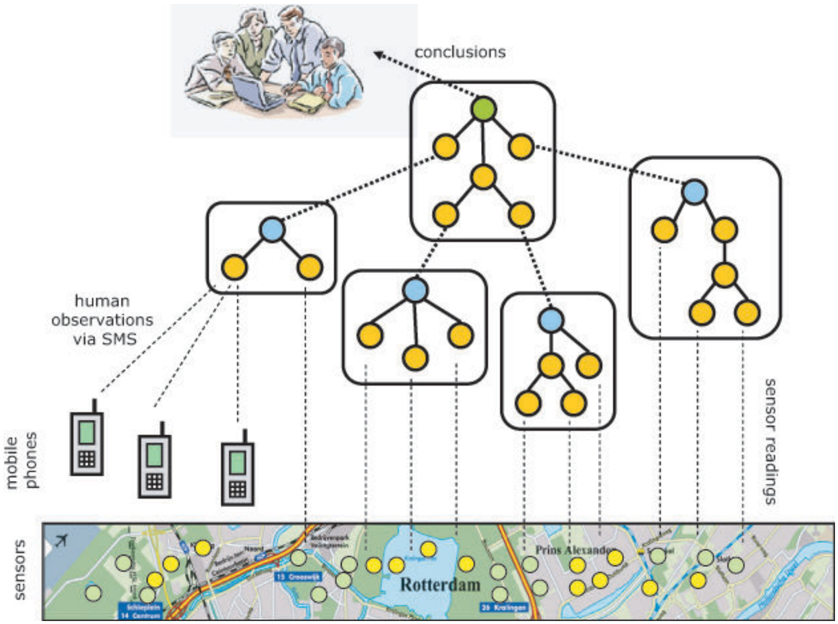
Icon Map for Managing Emergencies

Icon Map provides people in the field with an efficient way of communicating in a crisis area. The tool is language-independent, intuitive and easy to use. The graphical user interface is made to fit on PDAs. The PDA can be used in noisy places where speech communication is not possible.
Every icon, such as for fire, has the attributes of status, size and intensity (for example: under control, big, high). Scenarios for different types of disasters have been defined, including a building on fire, a traffic accident, a bomb or a gas explosion.
Information from the Icon Map tool is collected and can be reported to stakeholders. The tool checks the reports for correctness, completeness and consistency. For example, if a user only reports a fire, the tool asks the user about its size and intensity.

Combining information with *Distributed Perception Networks (DPN)*

Distributed Perception Networks (DPN) supports quick and reliable situation assessment in crisis management by merging information from numerous diverse sources. In a crisis a decision-maker often has to draw conclusions about events (facts) that cannot be observed directly but do have observable effects. The hidden events must be inferred by interpreting observations obtained from people and sensors. While large quantities of data relevant for crisis management can be accessed via existing sensors and communication infrastructure, such as mobile phone networks, the Internet, etc, its interpretation requires substantial processing capabilities and domain expertise. With the help of DPNs such valuable information resources can be exploited efficiently.

DPNs **assist human decision-makers** by gathering and combining this information. This reduces the workload on decision-makers, while at the same time improving the quality and the response time of situation assessment processes.



The Conceptual architecture of Distributed Perception Networks

DPNs can be used as flexible early warning systems or systems for automated hypothesis verification based on large amounts of information. From the OODA loop perspective, the DPNs contribute to the Observe and Orient phases, thus improving the overall performance and robustness of crisis management processes.

The DPN architecture supports a **plug-and-play approach** to the construction and maintenance of complex distributed fusion systems. In general, DPNs are systems of cooperating agents, processing nodes that implement a logical layer on top of existing sensors, communication and processing infrastructure. DPN agents are basic building blocks that can autonomously organize themselves into useful distributed information fusion systems.

The DPN agents implement communication protocols which support (1) quick discovery of the information sources that are relevant for a particular situation assessment process, (2) self-configuration of meaningful fusion systems and (3) easy integration of new information sources as they become available at runtime.

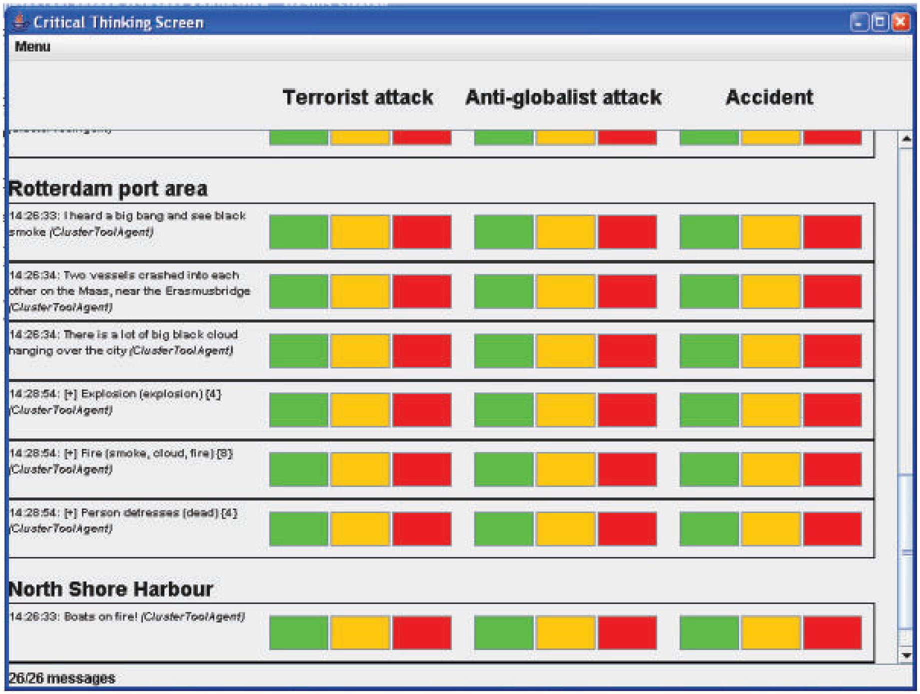
Cooperating DPN agents use theoretically sound and robust algorithms to distill relevant information from large amounts of noisy and heterogeneous data in an efficient way. DPN agents can efficiently map observed symptoms to different hypotheses of interest by using distributed probabilistic models, which capture causal relations between the hidden phenomena of interest and observable events. Causal probabilistic models can support very robust fusion systems and rigorous techniques for runtime analysis that allows detection of potentially misleading fusion results. In addition, probabilistic models that explicitly describe causal relations support the systematic acquisition of relevant information.

By using probabilistic models DPN agents can formulate simple queries, which are communicated to the people in the affected area via the existing communication infrastructure. For example, a DPN system might use GSM networks to send SMS messages, such as: "Do you smell ammonia? Reply with 0 for NO or 1 for YES". Each reply to this SMS is sent back to the DPN agents, which use it as evidence. In this manner, the DPN agents guide the acquisition process such that ambiguity in communication is reduced and humans provide only information about facts relevant to a particular situation assessment task. Note that via the existing communication infrastructure, such as phone lines and GSM networks, many people in the area can provide large amounts of relevant information, which can result in very robust situation assessment, even if no reliable sensors are available.

The ability of DPNs to **combine heterogeneous information** is of great relevance to crisis management, which often requires interpretation of **large numbers** of reports from human observers and readings from various sensors.

Overcome information bias using the *Critical Thinking Tool*

The **Critical Thinking Tool helps to prevent tunnel vision and information bias**. It encourages decision-makers to formulate more than one hypothesis in order to keep an open mind to other explanations. Furthermore, it allows the user to color-code information for each hypothesis. Green is used for information that supports a hypothesis, red for non-supporting information and orange for neutral information. All coded information is displayed on a computer screen.



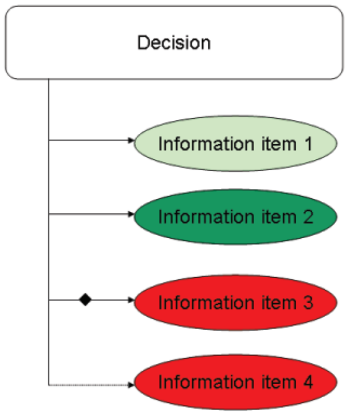
Screenshot of critical thinking tool interface

Displaying all the information in this manner has two advantages: (1) it offloads the user's memory and (2) it can easily be consulted by a colleague or software agent.

Decision-makers in a crisis situation base their decisions on information received regarding the crisis. They are usually not at the location of the incident themselves and thus have to relate to other people's observations.

During the sense-making process the decision-maker faces several pitfalls, such as **tunnel vision** (focus on one explanation to the exclusion of other possibilities) and **information bias** (focus only on supporting information), to name but two. One can overcome these pitfalls by thinking critically, that is, asking questions, such as "Have I looked at other possibilities?" and "How likely are these possibilities?".

An improved Critical Thinking System has been developed to promote critical thinking throughout crisis management process. To overcome tunnel vision and information bias the system supports the visualization of meta-information, such as reliability and status. This is achieved by visually separating validated from unvalidated information, and the decisions from the hypotheses (planned decisions).



Relations between information and hypotheses represented in an argument map

Relations between information and hypotheses can be viewed in several ways, for example, in an argument map (see the figure above). When the user decides which hypothesis is the most likely, this hypothesis is promoted to a decision. A report can be generated to inform the stakeholders. The report shows, using the argument structure, how the information supports the decision.

Decision support by *Organization Awareness*

Organizational Awareness is knowing how to use the knowledge of the organization. Crisis management organizations are ad hoc assemblies of multiple emergency services that need to **work together to minimize the number of casualties and the damage level**. In order to be efficient, emergency personnel not only need shared awareness of the situation, but also awareness of the organization.

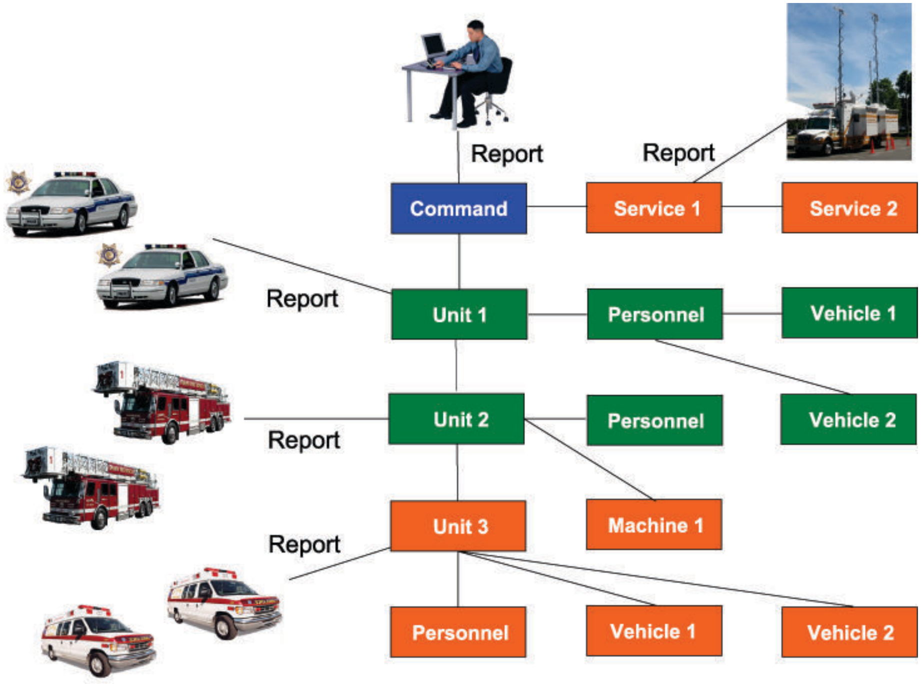
The Combined Systems project emphasizes the role that emergent and self-organizing groups of civilians can play in the phases immediately after an incident. People who are willing to join in the crisis management organization could identify themselves and their capabilities to the ad hoc organization using personal network devices. This knowledge may be publicized within the group, which would enable those involved to get a view of the group. This would, for instance, make it possible for bystanders with medical skills to quickly join in and provide aid to those who need it first.

Decision-makers in crisis management organizations need to have proper organizational awareness, i.e. an understanding of the multiple parties that make up the organization and how they relate to each other in terms of roles, responsibilities and tasks. Effective crisis management organizations

Effective crisis management organizations

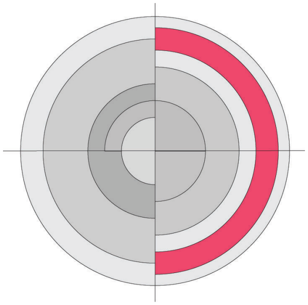
After a major incident, such as a major fire, an explosion, or a chemical spill, it is crucial to build up an effective crisis management organization as quickly as possible. This process of scaling up should result in an organization with the appropriate size and structure, relative to the nature, size, and complexity of the incident. The construction and scaling up of an organization is a complex process: crisis management organizations are multi-disciplinary and have a complex command structure. When a crisis management organization has been created, it is crucial to keep the organization in line with what is happening at the scene, to prevent further escalation of the crisis.

When public services have arrived at the scene and become engaged in the incident, organization awareness analysis can be used to see if there are any organizational flaws. Managers, for instance, could ensure that the formal organization that needs to be in place in the event of a chemical incident in the Rotterdam harbor is fully staffed. Such an effort would involve comparing the real-time, dynamic organization chart to the desired organization. Analysis of such a dynamic organization chart could also serve to reveal issues regarding the chains of command, broken communication lines and absent units.



Schematic overview of Organization Awareness

Organization awareness can be enhanced by making use of future agent-based mobile support systems. Every organizational unit (center, department, unit) could be equipped with a PDA-like system that monitors the buildup of the organization in real-time, provides relevant information on the organization and helps to detect flaws in the organization's structure. Each system acts as a representative of its owner and communicates with other systems in order to obtain a view of the organization from the local perspective. Working in conjunction these systems provide a real-time view of the entire organization that can be used to verify whether the actual state of the organization is in line with plans and current procedures.



Improving resource coordination with *Self-Managing Distributed Systems (SMDS)*

Self-Managing Distributed Systems (SMDS) coordinate, configure and manage hardware and software resources in a mission-centric dynamic collaboration system. Mission-centric means that all resources (human actors, software agents and hardware) are assembled and deployed to achieve a specific common objective. The actors and agents, originating from all kinds of organizations, such as police, fire department, medical, form a dynamic collaboration system to achieve this common objective, which implies that the Combined System will adapt its behavior to the situation at hand.

Within SMDS a number of crisis management facilities are defined that match the demands arising from a crisis management situation (demands regarding information, resources or services) on the capabilities of the participating resources. SMDS establishes a global overview of the current situation - of the crisis management system as a whole - and delegates coordination and management responsibilities to dedicated crisis management resources. These crisis management resources are responsible for creating and implementing an action plan, describing the deployment of resources, their interrelationships and operational constraints.

Maintaining its global overview, SMDS continuously keeps track of the system's behavior and assesses whether the current set of resources is actually capable of achieving the common objective or not; if not, this means the crisis management system requires reinforcement (escalation). Also, SMDS monitors whether the progress and performance of the overall crisis management system is as planned or requires improvement.

SMDS helps crisis management systems to **get organized quickly**, deploys new resources immediately, takes reactive measures when resources fail or disappear. In short, it helps the crisis management system to **run smoothly until the common objective is achieved**.

SMDS in Practice

SMDS divides management responsibilities into four segments. Tasks that need to be performed by a crisis management system are presented to the planning segment. The planning segment creates a global plan for task allocation. The plan is derived from a distributed knowledge-based system with knowledge of all available resources, their capabilities, properties and interoperability. The instantiation segment contracts the right actors and agents that have to perform subtasks in the global plan. Next, the monitoring segment is responsible for guarding plan execution and quality of service management. Finally, the federation segment deals with establishing multi-party collaboration of systems.

An SMDS-based system makes collaboration **more efficient and effective** compared to systems using conventional collaboration strategies. Opportunities for improving the intended course of actions are detected early, and implemented if considered worthwhile.

SMDS will detect early whether the available resources and capabilities in a crisis management system may be insufficient for successful completion of the mission. This characteristic enables the system to generate escalation triggers. The monitoring facilities enable early detection and remedy for undesired behavior or system breakdowns. The federation facilities allow for dynamic seamless integration of services offered by the resources in the system. Groups of resources entering or leaving the Combined System cause the planning facilities to reconsider the intended course of action. These characteristics make the crisis management system **robust** in the event of dwindling or failing resources and yield sufficient **flexibility** to deploy new (types of) resources or adopt new solution strategies.

Improving resource coordination using *Market-based agent negotiation*

Market-based agent negotiation is a decision-making technique inspired by the dynamics of economics and trade. When a decision is difficult to make, participants can bargain about possible solutions. Various negotiation-based mechanisms exist that vary with respect to several dimensions.

Using agent technology, human beings and resources can be represented by software agents, for example sensor agents, company toxic database agents, fire-fighter agents, medical agents, weather prediction agents and evacuation agents. When the evacuation agent has to make an important decision, it will negotiate with other agents about information. The weather prediction agent and the sensor agent could be in competition, because they offer conflicting data assessments.

The competitive behavior of agents is exploited in order to find the best solution. In a virtual market, **buying agents** may request or place bids for a common set of objects, such as services, information or access to resources. **Selling agents** - or auctioneer agents - are responsible for processing bids and determining the winner. Allocation of objects to agents is either facilitated by a central auctioneer agent or a by a sequence of (bilateral) local negotiations between buyers and sellers. First aid market negotiation

First aid market negotiation

An import crisis management task is coordinating resources, such as medics and casualties. Software agents support actors by taking over administrative decisions. Given a crisis situation, every medic is represented by a **medic agent** and every casualty by a **casualty agent**. The medic agent ensures the decision on which casualties to treat.

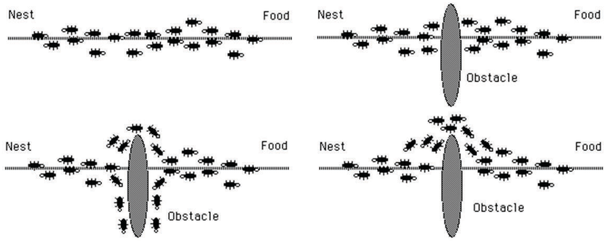
Each medic agent has a job list containing the set of casualties that have to be treated. The agents assign values to their job lists and will try to exchange jobs with other agents in order to arrive at the best deal. Within a **virtual market**, several medic agents will negotiate workload. For example, medic agent A can trade a severe casualty for a number of less severe casualties from medic agent B. Medic agent B can in turn negotiate with medic agent C, etc.

A deal between two medic agents is achieved when both agents benefit from the trade, meaning that the individual value of their job list increases. As part of the negotiation process, preferences for individual casualties are taken into account, when, for instance, treatment of a casualty requires special skills.

Improving resource coordination using *Ant-based routing*

Ant-based routing is inspired by the behavior of real ants in nature. Ants lay pheromones to find the shortest path from their nest to a food source and vice versa. This method can also be used in information systems with several functions. The ant-based routing mechanism is able to offer dynamic routing. It reacts to the changes in chaotic situations and provides the shortest path to a destination.

In case of an accident or disaster close to a highway, the route can get blocked and create a traffic jam. It is usually unclear to drivers stuck in traffic what has happened and what should be done. Routes to the congested highway should be blocked and drivers should choose alternative routes. Ant-based routing offers alternative routes to the drivers. In case of disaster the emergency teams need to go into action as soon as possible. Under crowded traffic conditions, they will be delayed because of the congested roads. **Ant-based routing can divert traffic and provide faster alternative routes for emergency vehicle traffic**.



Schematic overview of the process of laying pheromones

Evacuating ants

Evacuation of people from a dangerous area has a high priority. In case of a building, for example, the default evacuation plan is static and occupants have to rescue themselves following the signs pointing to the exit ways. But, during a crisis, there is a dynamically changing environment: escape routes or exit doors may be blocked. An adapted version of ant-based routing will dynamically point the people to the closest available exit. It will make use of up-to-date information provided by cameras and sensors at the doors or from direct observation of people on the move.

In practice

This chapter illustrates the added value of the technology developed within the Combined Systems project using an imaginary but realistic scenario.

In this scenario two ships collide on the Maas River, near the Erasmus Bridge and Erasmus University in the city of Rotterdam, the Netherlands. Below is a description of what happens when this incident takes place and the how the intelligent building blocks can support handling and controlling the situation. In essence the techniques assist observation and situation orientation in the golden hour, thereby leading to faster decision-making and action.

Two ships collide on the Maas river

At the Maas River in Rotterdam two ships collide. The collision happens almost in the center of Rotterdam and is therefore witnessed by a number of people. Some people panic, others stop to watch the show. People call the emergency call center, but also phone their friends to tell them what they see. Some use their PDAs to send messages and to seek information on the incident.

Meanwhile, the Rotterdam Port Authority picks up the collision on their sensing systems and send out a vessel to investigate the situation. The Port Authority has not been able to establish radio contact with any of the vessels and is, therefore, in the dark as to what is going on. Suddenly, one ship catches fire and smoke billows out into the air. This plume of thick smoke alarms drivers on the Maas Boulevard and a traffic jam ensues.

The scene

Spectators are chatting nervously and people are filled sense of panic. They sense that this is not just a harmless accident. The quay floods with people and traffic comes to a halt. The many tourists roaming the area are confused about what is going on, and feel lost. Some use their PDAs to ask about the situation using Icon Language.

Icon Language

Tourists who do not speak Dutch still want to know what is going on. This type of communication goes beyond the typical tourist chat, so a little help is very welcome. Because this information can be life-saving, it is preferable to communicate in one's own language, which is always easier to understand in a critical situation. Icon Language can be of some help. It is easy to form sentences with a few icons and translate them to any target language without having to wait for a translator.

Stationary sensors in the area begin to sense gas. A warning is sent to the control room. Since sensors can be unreliable, additional information should be gathered and interpreted before conclusions can be made and warnings issued. The system assists with situation assessment, using large amounts of relevant information that can be obtained from people and different types of sensory systems.

Distributed Perception Networks (DPNs)

A few sensors detect the gas at an early stage. These sensor reports trigger the activation of DPNs, which look for available information sources that are relevant to the assessment of the current situation. The DPNs can use information on health symptoms obtained through emergency calls and paramedic reports, mobile sensor suites and mobile labs that join the scene at a later stage, etc. The DPN system guides the information acquisition process and automates the interpretation of observations such that reliable situation assessment can be made very quickly, thus improving the efficiency and effectiveness of decision-making processes.

Because the gas has not spread very far yet, authorities are hopeful that they can identify it before it reaches the Boulevard, where many cars are stuck in traffic.

Cars in traffic jams surrounding the harbor area start to exchange information via their routing systems. Further away from the Boulevard, drivers are being warned of the traffic jam and routing systems are directing traffic away from the Maas Boulevard area.

Ant-based routing

The ant-based routing system collects information about the state of traffic directly from the cars during their ride and immediately sends this back into the network. For example, cars on the Maas Boulevard send information into the system that the average speed is 5 km/h. This information becomes available to other cars, which are immediately redirected away from the Maas Boulevard. The traffic jam will not grow, because all the cars using this system will take alternative routes. The cars in the traffic jam also pick another route. Within 20 minutes the Maas Boulevard is open for the fire brigade, the ambulance and the police, without the time-consuming process of asking many individuals to leave the area.

The first officials that arrive at the scene use their network-connected PDAs to take inventory of the incident and place it on a virtual map. This helps their colleagues at the emergency room to understand the situation.

Icon Map

The first officials to arrive take out their PDAs and start to place icons on the map. They observe a fire, a car that hit a lamp post, a person fainting, an unattended briefcase and other events. Each observation is noted and sent to a main map. This map collects all the notes and matches them. When one official puts a fire icon on the corner of two streets and three other officials put it on the opposite corner, for instance, the system assumes that the first official made a mistake and removes the first observation. On the other hand when the three report two fires, one on both corners, the system shows two fires, one on each corner. The first official might not have seen that other fire, because he watched from a different angle and was not able to see the second fire. Very soon, the map shows a reliable picture of the situation.

It does not take long before the first bystanders start coughing and complaining about teary eyes. Some collapse on the floor, gasping for air. People start calling for help, and many flee the area. The policemen on the scene check their PDAs for any medics in the neighborhood, and the whereabouts of their colleagues, so they can warn them.

Organization Awareness

The PDAs that the officials use at the scene are not just for note-taking. As soon as they enter the area, their PDA registers them to the crisis management network, including name, role and capabilities. This information is spread throughout the organization to let everyone know who is taking part in the action. In the field, this would help officials get a better sense of the presence of colleagues on the scene. At the same time, this information can be used by command teams to assess whether the response force is at the requisite scale and to ascertain that all essential departments have been notified. Such a mechanism would improve organizational awareness, which is an essential condition for complex operations such as crisis response.

While the first responders do their work at the scene, the emergency command room starts to fill up with people for the operational and policy team. They are advised by the DPN network that the gas is of a certain toxic type. This means that the team needs to decide how to help the victims in the unsafe area and evacuate people in threatened areas. There are many possible scenarios but there is still too much uncertainty as to what caused the accident for a final decision to be made. Everyone, even those still on the way to the emergency center, is given access to the Critical Thinking Tool to help match the information against possible hypotheses.

Critical Thinking Tool

Under time pressure human decision-makers are susceptible to certain common failings such as not taking into account information that conflicts with an accepted hypothesis. This can be an issue at times when things are not what they seem. By using a critical thinking tool, which makes the connection between evidence and hypothesis explicit, it is possible to avoid such pitfalls. Users of the Critical Thinking Tool find it easier to locate missing and ambiguous information during the decision-making process, leading to better decisions in managing the crisis.

Messages are often generated in clusters. The initial collision of the two ships was noticed by a lot of people who then generated similar messages. The semantic network engine in place clustered all messages about the collision itself and delivered one single report to the command team.

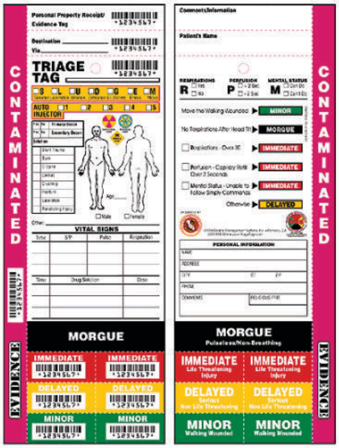
Semantic Network Engine (SNE)

Incoming messages are of vital importance for situation assessment. However, in any situation, there will be many messages with almost the same content. High volumes of similar messages hinder the recognition of important new information and may even convey the impression that a certain event is more important than it actually is. The SNE uses semantic network technology to process incoming messages on the basis of their meaning and dynamically creates clusters of messages that make it easier to keep track of new and unusual events. The SNE, moreover, makes it possible to annotate and work with information on a semantic basis.

Unexpectedly, the communication network collapses and no new information comes in. But the team in the emergency room keeps its focus on the problem. They do not panic about the possible loss of information. And they are proven right - when the communication network becomes available a few minutes later all the information that first responders reported during the communication network's downtime is now available for the emergency room. First responders did not have to worry about the information either, because a local communication network was rapidly set up that gave them an opportunity for later dissemination.

DWEAM

It is possible that during a calamity service networks lose power or are overloaded. This implies that services, such as mobile telephony network connections, stop working. This presents an obstacle to information delivery, a critical problem in situations in which responders depend on timely information flow. DWEAM is a system that sets up a network on the fly, with only the mobile devices which are carried by the people on site. It also sets up a local data distribution network, using the transceivers present in mobile computers and without the need for any external infrastructure. A DWEAM-powered network can then be used as an additional communication facility.



Only 10 minutes after the gas reaches the first streets next to the Maas, wind carries toxic gasses away from part of the incident area. The operational team decides that a medical team should help as many people in that area as possible. Ambulances are sent (with gas masks) to transport people out of the threatened area. Once again, the dynamic routing system helps them to find their way in the chaos.

The medical team starts with a few people that live near the area, but the number of people quickly increases during the next 15 minutes. The medics have to decide which people to treat first in order to save as many lives as possible. The medical staff is supported in this difficult situation by a triage support system advising them on which patient to treat next.

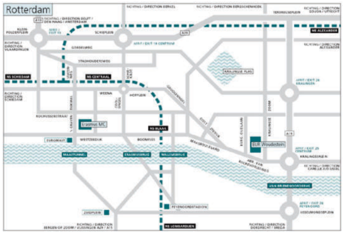
First Aid Coordination

Each casualty has a specific injury type and a triage state indicating the severity of the injury. Based on this color code the medics can easily judge how quickly someone needs medical treatment. The planning system allocates medics to casualties based on this information in such a way that the maximum number of lives is saved.

The gas is also threatening another area. In the emergency command room the command team is busy assessing new risks. They call in the help of the SMDS, the service-planning and scheduling tool. The SMDS generates a plan first, to consult service agents able to classify the gas (toxic, non-toxic) based on the observations (emergency calls and sensor readings) and, second, to consult service agents that can predict the spread of the gas cloud (using weather forecasts and dispersion models).

SMDS

SMDS is a tool that, based on the knowledge of different services, formulates an optimal combination of services that guarantees a solution with a certain level of quality. Because all services and their properties are known within SMDS, it is very easy to calculate an optimal combination of services, for example, one can calculate within three minutes how the gas is spreading. And of course SMDS takes far less than three minutes to come up with the list of services to use!



Every piece of information comes directly from the SNE, where all information is stored and tracked. Based on these results, the decision is made to evacuate Erasmus University. Again the PDAs with DWEAM are of great importance; they show a map of the University grounds and the place where transportation buses are located.

In the end, the university is evacuated before the gas reaches the campus and all those individuals who have been exposed to toxic gas make a quick recovery, thanks to well-coordinated medical attention.

A more detailed technical discussion of this scenario can be found on the Combined Systems project website: http://www.combinedsystems.nl.

Combining more

The Combined Systems project is one of the first integrated crisis management projects in the Netherlands. Its main contributions are: (1) a new model for the development of crisis management support systems: the Combined Systems view (2) new technology in the form of **intelligent building blocks** and (3) a diverse and dedicated **crisis management research community**.

The Combined Systems view

Within the **The Combined Systems view**, the Combined Systems project has addressed crisis management as an adaptive **socio-technical system in which many actors must work together**. All actors make intensive use of communication and information systems. The Combined Systems project has addressed four key qualities: **making communication reliable**, **sharing information**, **good decision-making** and **effective coordination** for crisis management by using local, emergent information sharing and reasoning methods and techniques that help people to efficiently interact and share information. This resulted in the Combined Systems view.

Traditionally, crisis management research is dominated by the perspective of top-down control from central control rooms. The way to make a difference is to **take a bottom-up perspective** that stresses rapid improvisation and self-organization processes in chaotic field situations as can be witnessed in the early hours of major disasters. The strength of the solutions developed with in the Combined Systems project are the organizational and technical mechanisms enabling people to **respond more rapidly** even though they are faced with severe damage to critical infrastructure and incomplete organizational resources.

Intelligent building blocks for crisis management systems

The Combined Systems project has worked on technologies to build robust and reliable communication networks on the fly, particularly aimed at data exchange in networks of wireless devices. This resulted in **intelligent building blocks** for better crisis management decision-making, where **communication is reliable**, **information is shared**, **decision-making is well supported** and **coordination is most effective** for crisis management organizations.

When dealing with concrete communication systems, information systems, decision support systems and action coordination systems, innovative extensions and alternatives to current practices are needed. The outcome of the Combined Systems project supports the incremental evolution of the current baseline of assets toward a more network-centric one that fosters ad hoc solutions, i.e. improvisation. **By definition improvisation is one of the most appealing answers to chaos**.

Breakthroughs should be sought in a **network-centric crisis management approach** that makes use of advanced organizational and technical enablers for self-organizing mechanisms. This does not replace centralized mechanisms, but complements them with empowered decentralized mechanisms.

Crisis management community

Part of the Combined Systems project's success has been to establish a **dedicated crisis management community**, centered around the DECIS Lab. This community will continue development of the project's result, further deepen its insights, and facilitate the transfer of knowledge from the theoretical and experimental to the practical domain.

Focusing on the Rotterdam harbor scenario has helped the Combined Systems project to better position the intelligent building blocks. It also led to fruitful contacts with practitioners in the field. Project participants became deeply involved in the conferences and communities of research and practice in the field of crisis management.

Via the Combined Systems project , the **DECIS Lab** has become a major supporter of and contributor to The International Emergency Management Society (TIEMS, see http://www.tiems.org) and the network on Information Systems for Crisis Respone and Management (ISCRAM, see http://www.iscram.org).

Selected project publications

The following is a partial list of academic publications representing the results of the Combined Systems project. For a comple overview of project deliverables, please visit http://www.combinedsystems.nl.

Combined Systems Architecture and Crisis Management Domain

Appelman, J., van de Kar, E., den Hengst-Bruggeling, M., van de Ven, J., and Burghardt, P. (2006). A Service Elicitation Process for Crisis Management Technologies. In *Proceedings of the Third International Conference on Information Systems for Crisis Response and Management (ISCRAM 2006), New Jersey, USA*.

Burghardt, P. (2004). The Combined Point of View. In *Proceedings of the First International Conference on Information Systems for Crisis Response and Management (ISCRAM 2004), Brussels, Belgium*.

Klapwijk, P. and Rothkrantz, L. J. M. (2006). Topology based infrastructure for crisis situations. In *Proceedings of the 3rd International Workshop on Information Systems for Crisis Response and Management (ISCRAM 2006), Newark, USA*.

Storms, P. (2004). System of Systems Architecture. In *Proceedings of the First International Conference on Information Systems for Crisis Response and Management (ISCRAM 2004), Brussels, Belgium*.

Distributed Coding and Ad-Hoc Networks

Miletić, F. and Dewilde, P. (2004). Distributed Coding in Multiagent Systems. In *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics (SMC 2004), The Hague, The Netherlands*.

Miletić, F. and Dewilde, P. (2005a). Coding Approach for Fault Tolerance in Multi-agent Systems. In *Proceedings of the IEEE Conference on Knowledge Intensive Multi-agent Systems (KIMAS 2005), Boston, USA*.

Miletić, F. and Dewilde, P. (2005b). Data Storage in Unreliable Multi Agent Networks. In *Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multi Agent Systems (AAMAS'05), Utrecht, The Netherlands*.

Miletić, F. and Dewilde, P. (2005c). Design Considerations for Infrastructure-less Mobile Middleware Platform. In *Proceedings of the Belgium-Netherlands Artificial Intelligence Conference (BNAIC 2005), Brussels, Belgium*.

Miletic, F. and Dewilde, P. (2006). A distributed structure for service description forwarding in mobile multi-agent systems. *Intl. Tran. Systems Science and Applications*, **2**(3). To appear.

Icon Language

Tatomir, B. and Rothkrantz, L. (2005). Crisis Management using Mobile ad-hoc Wireless Networks. In *Proceedings of the Second International Conference on Information Systems for Crisis Response and Management (ISCRAM 2005), Brussels, Belgium*, pages 147–149.

Tatomir, B., Rothkrantz, L., and Popa, M. (2006). Intelligent system for exploring dynamic crisis environments. In *Proceedings of the Third International Conference on Information Systems for Crisis Response and Management (ISCRAM 2006), New Jersey, USA*, pages 288–297.

Distributed Perception Networks and Information Fusion

de Jong, J. and van Norden, W. (2006). Application of hybrid metaheuristics in sensor management. In *Aerospace Science and Technology*. In press.

de Oude, P., Nunnink, J., and Pavlin, G. (2005a). Distributed Bayesian Networks in Highly Dynamic Agent Organizations. In *Proceedings of the Belgium-Netherlands Artificial Intelligence Conference (BNAIC 2005), Brussels, Belgium, 17-18*.

de Oude, P., Nunnink, J., and Pavlin, G. (2005b). Distributed Bayesian Networks in Highly Dynamic Agent Organizations. In *Proceedings of 17th Belgian-Dutch Conference on AI (BNAIC), Brussels, Belgium*.

de Oude, P., Ottens, B., and Pavlin, G. (2005c). Information Fusion with Distributed Probabilistic Networks. In *Proceedings of the IASTED International Conference on Artificial Intelligence and Applications, Inssbruck, Austria*.

Maris, M. and Pavlin, G. (2006). Distributed Perception Networks for Crisis Management. In *Proceedings of the Third International Conference on Information Systems for Crisis Response and Management (ISCRAM 2006), New Jersey, USA*.

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More information

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Senter/Novem, see http://www.senternovem.nl/senternovem
Crisis management at the Dutch ministry of the Interior, see http://www.minbzk.nl/veiligheid/crisisbeheersing, http://www.handboekrampenbestrijding.nl en http://www.rampenbeheersing.nl
Port of Rotterdam, see http://www.portofrotterdam.com

Research and communities

DECIS Lab, see http://www.decis.nl
Combined Systems project, see http://www.combinedsystems.nl
ICIS project, see http://icis.decis.nl
Crisis Domain Wiki, see http://wiki.decis.nl/crisisdomain
ISCRAM, see http://www.iscram.org
The International Emergency Management Society (TIEMS), see http://www.tiems.org

Agentlink (agent research community), see http://www.agentlink.org
Cougaar (Combined Systems project's adopted agent plaform), see http://www.cougaar.org
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