Multi-agent Systems in Crisis Management: The Combined Systems

A Case Study

1. Introduction

The Combined Systems [1] Chaotic Open world Multi-agent Based Intelligently NEtworked Decision support Systems) project is a research project consisting of several multi disciplinary partners whose aim is to explore and design engineering guidelines for large-scale, open systems in a constantly changing environment.

The purpose of the AgentLink case studies is to give examples of deployed, industry-based applications using agents. While the Combined System is targetted at industry, funding is mainly government provided, and the system needs are not directly industry driven. However, this case study is included into the series because it contributes to the theme of industry projects. The size and complexity of the validation scenarios in the Combined Systems project, combined with the many "off-the-shelf " solutions that are being used in the project, makes it a suitable candidate.

The validation scenario is taken from the field of crisis management, and outlines a use case in which poisonous material has been accidentally released into a city. Early observation of the problems at hand and communication between crisis management experts and people "on the ground" are both crucial, as is alerting the public of the danger, and providing emergency services such as medical support to people affected. The Combined Systems project has provided an intelligent decision support system, using multi-agent technology, that can collaboratively save lives, stabilise the cause of the incident, and conserve the surrounding infrastructure.

In this article, we present an overview of the Combined Demonstration System, discuss the importance of agents within the system, and discuss some of the challenges that were encountered during the development of the system.

2. Project Information

The Combined Systems project is funded by the Dutch government. At a total of 40 person-years (10 person-years each year for 4 years), the Combined Systems project is quite large by research project standards.

Expertise within the project varies, with 9 different partners from various backgrounds. Those areas that are strongly represented in the project include experts from communication, infrastructure, autonomous systems, human factors, and multi-agent systems, with crisis management experts regularly consulted. The project is hosted by the DECIS laboratory [2] in The Netherlands. The DECIS laboratory consists of 4 major partners: Delft University of Technology [3], Thales Research and Technology Netherlands [4], University of Amsterdam [5], and the Netherlands Organisation for Applied Scientific Research [6]. These partners have further invited several other commercial companies to assist on the project: Y'All [7], Inology [8] and Lithp Systems [9].

3. The Validation Scenario

A large-scale validation scenario has been developed that describes a real-world problem, in which many of the aspects of a multi-agent system are useful. The scenario is based on real-world reports from the crisis management domain. It begins with two ships colliding in Rotterdam Harbour, one of which is transporting poisonous material. This material is leaked from the ship, and the wind starts to spread the material over the city of Rotterdam. Evacuation of the affected areas is imperative, and early observation of what is happening in the harbour and in the city is crucial to crisis management experts. Getting medical aid to the affected individuals is also of utmost importance.

The Combined Systems project has developed this case study because it provides a sufficiently non-trivial use case to research the kinds of methods and support needed for large-scale, dynamic systems, is feasible to implement the Combined Demonstration System, and is a good case for demonstration.

3.1 Communication

The Combined Demonstration System uses mobile devices in crisis management tasks. In the 21st century, communication using mobile devices is useful in such cases, because such devices are ubiquitous, and transferring data to and from them is fast and often more reliable than many other means of communication.

For the purpose of observation, mobile devices provides distributed perceptions of the crisis at hand. That is, individuals can perceive their local environment, but the problem would often be more widespread, so different individuals in different areas surrounding the harbour can give crisis management experts a better idea of the overall problem. (Similar effects were seen in the July 2005 attacks on the London underground, in which individuals were able to use their mobile phones to send images and text to police and the media.) Individuals in different areas can be located by the mobile networks, and can be asked to provide information as to what they see, and what the possible causes of any problems may be. Critical Thinking [14] is used to help extract information from the individuals on the ground.

To alert the public, mobile phones can be used to broadcast messages informing the public of the situation, and giving advice and instructions as to what action they should take. In addition, mobile phones can be used by individuals to register information, such as their medical abilities, or people in need of medical assistance. This will help with getting assistance to individuals in need at a faster rate.

The Icon Language [18] is used to communicate in a language-neutral way. Instead of using text, icons are presented, and the meaning of each icon can be inferred from the icon itself. In general, icons bear a resemblance to the concept that they are representing, such as an icon of a car. Icons are used both to present information to people on the ground, as well as for them to construct sentences to be relayed back to the crisis management experts.

Traffic is re-routed away from the crisis scene without causing traffic jams. This is realised by means of dynamic vehicle routing based on indirect communication between vehicles and their environment [17].

Of course, problems arise when using mobile devices for communication. Most notably, connections between mobile devices and the rest of the network can be lost intermittently, which means the data that the people on the ground are trying to send to the crisis management experts can be lost if the system is not designed robustly enough. To ensure robust communication between agents, distributed coding techniques are applied [15].

4.1 Ad hoc Organisations and Dynamic Planning

Information coming from individuals on the ground can be used in many ways. Clearly, crisis management experts can meet at a central meeting point, and use the distributed perceptions to get a clearer idea of what is happening, and what actions need to be taken. However, this information can also be used for other things. For example, after individuals have been registered, the system looks for emergency professionals with certain abilities such as medical skills who are located in an area near to people that require treatment that they can provide. Emergency services can be directed to specific areas based on the information that has been received, and information can be used for collaboration between emergency services.

The formation of organisations to respond to information and needs is managed by the system itself. Such self-managed aspects of the Combined Demonstration System are far more flexible than their static counterparts, as the services provided by the system can change to suit the context of particular problems. Planning and coordinating medical logistics dynamically greatly improves the efficiency of getting services to areas, which is crucial in such crises.

4. Agents in the Combined Project

While the Combined Systems project is not aimed solely at autonomous agents and multi-agent systems, agents play some of the most central roles in the system, particularly for information logistics and coordination. Traditional software development strategies would not be effective in handling the vast amounts of dynamic data and decision making in the system. This is the primary reason for choosing the validation scenario discussed in Section 3.

4.1 Agents in Communication

Agents provide three important capabilities in the Combined System communication. Firstly, information-agents help to organise data as it is sent in from the people on the ground; secondly, network-agents help to alleviate some of the problems with the volatile network connection encountered with mobile devices; and thirdly, coordination-agents are responsible for coordination the overall operation.

The agents are responsible for performing initial analysis on the data that is received from individuals on the ground. Upon receiving new information, specialised agents assess this information and aggregate it in order to give crisis management experts a better view of the overall situation. For example, the data can be organised based on the time and location of the individual that sent the data, so the managers can judge if and how fast the gas is spreading. Semantic engines are used to group messages into categories based on their content, as well as to filter out messages with duplicate meanings.

To help alleviate some of the network communication problems, agents monitor network connections and send information at appropriate times. For example, if an individual on the ground enters information into their mobile device, and then attempts to send the information, rather than report to the individual that the information cannot be sent because a connection to the recipient is not available, the agent with the responsibility of sending the information will keep it until a connection becomes available.

Flexibility is important in the system, because in a time of crisis, it is likely that networks will be overloaded, and that the individuals on the ground be distracted by other events and activities, and may not be able to continue checking to see if their device has connectivity.

4.2 Agents in Organisation and Planning

Dynamic organisation and planning is a major contribution of the Combined Demonstration System. Agent-based mobile devices are applied to automatically construct ad-hoc wireless networks. Communication between the mobile devices and centralised servers may not be

possible at certain times, but local communication may still be a possibility. This will give the advantage that individuals on the ground can browse lists of people that are in their area, and receive information about the type of emergency or specialist service they can provide or receive from each other. Matching individuals with medical and specialist capabilities with individuals requiring medical attention can significantly decrease the time taken to provide first aid, which increases the likelihood of patient survival.

Such organisational awareness is a major step up from coordinating these services centrally, either automatically or manually [16]. Global connectivity is not required, and information can be gathered, collated, and sent to individuals at a much faster rate. The inclusion of last-minute information is such planning also allows for more services to deployed in more efficient manner. Again, semantic engines are used to filter out messages containing the same content.

Performing tasks such as matching medical professionals on the ground with individuals in need is a straightforward task once the necessary information is available. The concept of agents and roles provides an excellent metaphor for specifying, designing, and implementing this behaviour, as the system structure can be mapped to the real-world, human-based structure that would otherwise be used to fulfil this behaviour.

4.2 Agents and Other Technologies

Another positive aspect of the implementation of the demonstration system is the use of agent technology within the system. The implementation-level technology that is used is quite standard and largely based on open-source software.

While the agent system is highly collaborative and handles dynamic data well, the agents themselves are not "super-intelligent". The open-source Cougaar Agent Architecture [10] is being used to develop agents.

The 5 Capabilities (5C) model is used for analysing the capabilities of the agents in the system [19]. In this model, each agent has a small set of specialised capabilities, with each capability

divided into 5 categories: communication, competence, self, planner, and environment. The communication model handles the interactions between other entities in the system; the competence model contains the knowledge and procedures for carrying out tasks for which the agent is designed; the self model gives the agent an idea of what it is designed for; the planner model handles the decisions of what an agent should be doing; and the environment model handles the interpretation of the environment from the percepts of the agent.

In the Combined Demonstration System, important entities in the real-world are represented by an agent. For example, a patient in need of medical assistance, or an ambulance travelling to the effected area. Some agents work as a sensors, whether it be via hardware or via human input. Additional agents are also engaged in running the system, such as agents to manage deployment of emergency services.

OpenMap [11] is used for handling geo-spatial information. OpenMap is an open-source toolkit for building applications that require the mapping and handling of geographical information. Combining the agent metaphor with OpenMap allows the system to "see through the eyes of the victim", thus giving the system a way to view data in a distributed and localised way, and to help management agents understand the local perspective of individuals in the system.

Other development technologies are also quite standard. CVS [12] and Eclipse [13] are used for version control and source editing respectively.

5. Discussion

The dynamic nature of the system requires autonomous and flexible entities that can be modelled using the agent metaphor. As with many other large-scale systems, agents make up only small percentage of the overall system; yet they provide some of the most important parts of the system. In particular, they provide a suitable abstraction for the system's functions and dynamics.

The current state art of open-source support for agent-based systems, such as the JADE and Cougaar development platforms are mature enough for industrial agent development. Although taking time to understand the agent frameworks was valuable, it was costly in terms of time and funds. It is also clear that the use of current agent standards are somewhat limited in the project. The choice not to use many standards reflects the closed nature of the system. That is, the agents in the system are designed and developed within the project only, and the system does not inter-operate with other agent from other crisis management systems.

The Combined Demonstration System has already been demonstrated at several roadshows, and the feedback from the invited guests was positive. At each iteration, the integration of new aspects of the system is working well, a common theme found in development of agent-based systems. The Combined Systems project has used real use cases to construct a large-scale validation scenario, which will help to further improve the state-of-the-art in several research fields, including autonomous agents and multi-agent systems.

Further information on the Combined Systems project can be found at: http://combined.decis.nl/. In addition to more information on the topics discussed in this paper, the page contains information about the other research topics in the project, information about the validation scenarios used in the project, the partners participating in the project, and publications available for the public to download.

References

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