A CASE STUDY OF COMMUNICATION IN A DISTRIBUTED MULTI-AGENT SYSTEM IN A FACTORY PRODUCTION ENVIRONMENT

Erik Olsson, Mobyen Ahmed, Peter Funk and Ning Xiong

Department of Computer Science and Electronics,
Mälardalen University, P.O. Box 883, SE-721 23 Västerås, Sweden,
phone +46 21 10 73 35, fax +46 21 10 14 60

ABSTRACT

A Distributed Multi-Agent System representing the behaviour of a machine maintenance procedure in a factory production environment is modelled using the BRIC language. The model provides an overview and simplification of the communication in the maintenance procedure. The model involves two distributed factory environments, each equipped with a Maintenance Agent and an Experience Sharing Agent. Maintenance agents can be seen as experts in interpreting local sensor data from the machine being observed. They have some basic domain knowledge about when to bring the findings to the attention of an agent, human or system. An agent is also autonomous and may have the trust to shut down a process. The maintenance agent will ask other agents or humans for assistance if bringing the macine ito working order is beyond the agent’s ability. Necessary information about what maintenance actions to perform is provided by an Experience Sharing Agent which has the ability to identify past experience relevant for the current situation and thus beeing able to help the human to make a better and more informed decision avoiding previously, sometimes very costly mistakes.

KEYWORDS

Experience Reuse, Decision Support Systems, Condition Monitoring, Intelligent Agents, Case-Based Reasoning

INTRODUCTION

Running a modern factory assembly line makes high demands for fast production rates without unesasarry hold-ups. E.g. the failure of an industrial robot can cause a hold-up of an entire assembly line costing the affected company large amounts of money each minute on hold. These kinds of situations can be prevented by equipping machines with maintenance agents that continuously monitor the condition of the machine and instantly reports if a failure is detected or foreseen to happen in a near future. According to the MIMOSA standard an agent can perform diagnostic analysis, prognostic analysis, remaining useful life estimates and future failure mode probabilities (MIMOSA, 2004). Maintenance agents can be seen as experts in interpreting local sensor data from the machine being observed. The agent may have some basic domain knowledge about when to bring the findings to the attention of a human and when to shut down a process. Responsibility is delegated to humans in the machine environment performing the necessary actions to e.g. restore the machine into working order. Necessary information about what maintenance actions to perform is provided by an Experience Sharing Agent which has the ability to identify past experience relevant for the current situation and thus beeing able to help the human to make a better and more informed decision avoiding previously, sometimes very costly mistakes. The need for a domain dependent experience sharing system where experience can be gathered, stored and reused is obvious in this situation. This kind of experience sharing could be done within a company or amongst remote collaborating companies (Mobyen et al., 2007). By modelling the task of machine maintenance into a Distributed Multi-Agent System and delegate the monitoring task to a monitoring agent, the repair/remedy action to the human technicians and the task of experience sharing to the Experience Sharing Agent, a reduction in complexity in communication during the maintenance procedure can be achieved. In this paper we present a case study of communication in a Distributed Multi-Agent System in a factory production environment. The paper is structured as follows: Section 2 presents the basic the model entities; the Maintenance Agent, the Experience Sharing Agent and the factory Environment. Section 3 presents the complete Distributed Multi-Agent System model. Section 4 presents two real-world communication examples translated into the model and section 5 gives a brief conclusion of the paper.

BASIC MODEL ENTITIES

In this section we describe a Distributed Multi-Agent System (DMAS) model incorporating two environments. Each environment is equipped with a Maintenance Agent (MA) and a local Experience Sharing Agent (ESA). Experience sharing between the environments is facilitated by a network interface connecting the local ESA's in each environment to each other. To show how communication and interaction between the agents and their environments is performed, a model for communication is presented. It defines a set of speech acts and a finite state automaton defining the resulting state transitions for each speech act. Two scenarios will be presented in the end of this paper to exemplify how the MAS model and the communication model would behave in a real-world application. The components used in the model is influenced by BRIC (Ferber, 1999) which is a simple high level graphics language for describing modular structures such as agents and their environments.

The Maintenance Agent

A MA is specialized in interpreting data from the device it is connected to. The agent observes its environment through one or more sensors. Additional information about the environment may also be acquired through communication with other agents or systems. The agent may have some basic domain knowledge about when to bring the findings to the attention of a human and when to shut down a process. The agent also has social skills to communicate its findings. It may also ask for additional information to make a final decision and it has facilities to receive appropriate feedback (Funk et al., 2006). Handling groups of sensors with a dependency between measurements enabling sensor agents to collaborate and learn from experience, resulting in more reliable performance. Sensors agents may also improve their performance, e.g. recalibrate sensors if needed, or determine if sensors are faulty. Similar sensors may also share experience enabling them to avoid repetition of similar failures or make estimates on their reliability. Figure 1 outlines a Maintenance Agent in its environment.

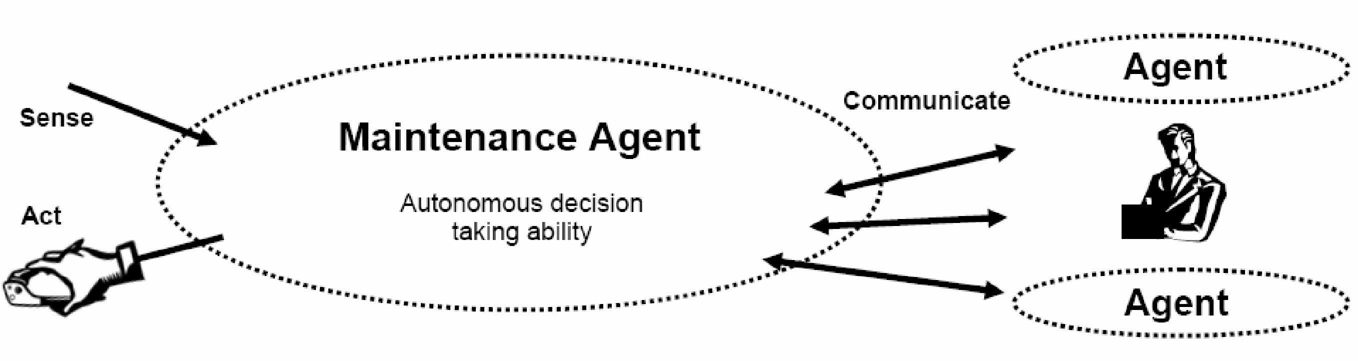


Figure 1. Outline of a Maintenance Agent in its environment (Funk et al., 2006).

The agent has a perception module containing necessary information for basic pre-processing and abstraction of the sensor data. It is a learning agent (Russell and Norvig, 2002) with a deliberation module containing a memory that stores basic domain knowledge and capabilities to make a decision using e.g. Case-Based Reasoning, Rule-Based Reasoning etc. A general BRIC model of an agent is depicted in Figure 2.

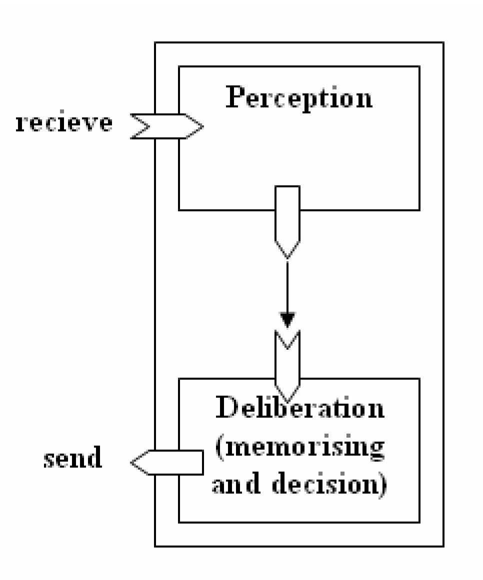


Figure 2. A general BRIC model of an agent.

An example of a local Case-Based MA is given in (Olsson et al., 2004). The agent uses a Case-Based Reasoning method and a nearest neighbour approach for a light weight solution of recognizing and diagnosing audible faults on industrial robots. Sensor signals such as sound is recorded and compared with previous recordings, although also currents (Olsson, 2007) and other input signals have been explored and works appropriate.

The Experience Sharing Agent

The ESA operates in collaboration with the local sensor agent. It is a Case-Based experience sharing solution that enables reuse of experience in a more efficient way compared with what common practice in industry today. The ESA identifies and presents the most significant experiences to assess from the collaborative space where experiences from various companies may have been stored under many years. It may work globally through the internet and gather and share textual experiences but it can also use structured experience and mixed representations with both textual and non-textual features (Mobyen et al., 2007). The general BRIC model of an ESA is depicted in Figure 3.

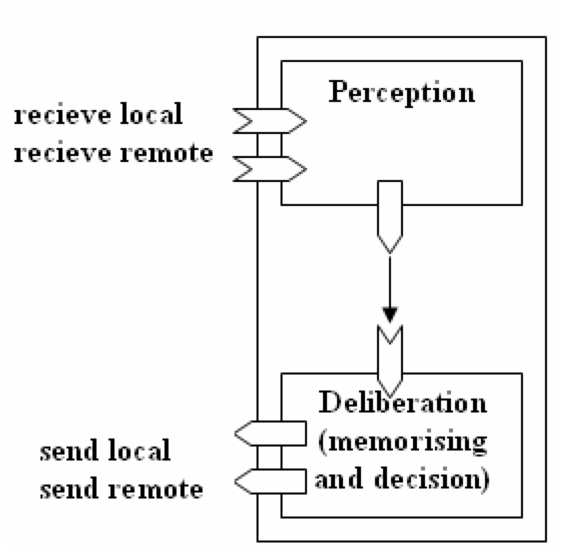


Figure 3. The general BRIC model of an Experience Sharing Agent.

The general BRIC model of an ESA in Figure 3 is depicted with two perception modules enabling connections to a local computer terminal and to a network interface. It has necessary pre-processing elements for removal of noise and extraction of relevant features and it has a deliberation module with a memory storing knowledge and experience. It has capabilities to make a decision based on its locally stored knowledge or via remote communication with other agents using e.g. Case-Based Reasoning. For human interaction a specific problem description can be given into the system through the user interface in a natural language. A text tokenizer algorithm decomposes the whole textual information into sentences, and then into individual words enabling a Case-Based Reasoning algorithm to retrieve closely related cases for decision support.

The Environment

We model the environment as an agent with input and output terminals. The environment perceives and sends messages from/to the agents acting in it. Inside the environment there are facilities to enable communication. The communication facilities can be e.g. a computer terminal for manual input/output to the agents. The environment is divided into two parts; the MA part and the ESA part as depicted in Figure 4.

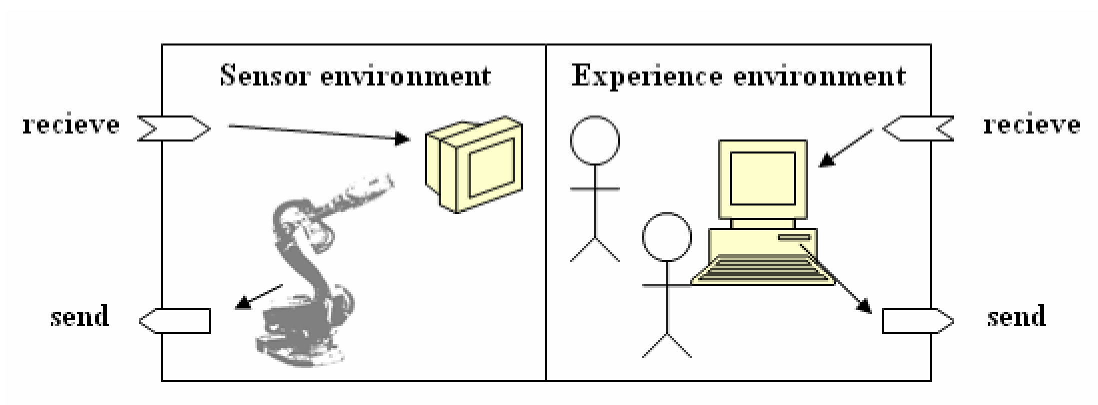
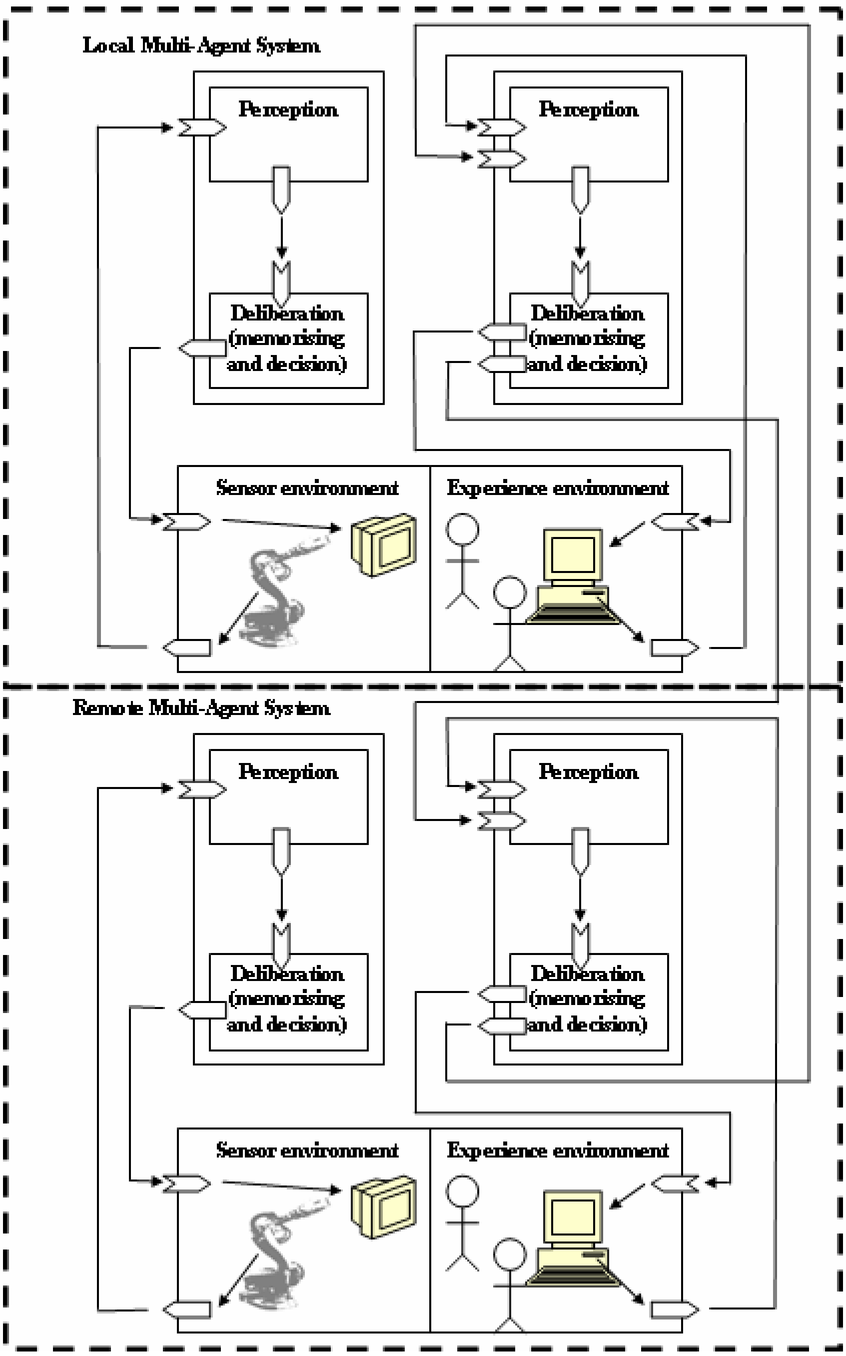


Figure 4. The environment model. It is divided into two parts; the MA part and the ESA.

The MA constantly perceives input from its sensor and is constantly occupied with analysis of its perceived sensor data searching for anomalies. On the other hand, the ESA is only operating when certain environmental state transitions occurs. A state transition can be e.g. initialized by either a sensor agent reporting an anomaly or by some other stimuli e.g. a technician entering a question or some information on the computer terminal.

MODEL OF A DISTRIBUTED MULTI-AGENT SYSTEM IN A FACTORY ENVIRONMENT

The example model shows two distributed environments, each equipped with their local MA and ESA. They are connected to each other via the ESA network interfaces enabling experience sharing between the environments.



Figur 5. BRIC Model of two distributed Multi-Agent System environments.

Figure 5 depicts the layout of the model. The environments represent e.g. distributed factories with local machines and local MA's connected to the machines. The local MA's are mainly autonomous entities perceiving and reacting upon the sensor data. They are equipped with a simple communications interface connected to the environment via e.g. a computer terminal. A local ESA enables local, as well as remote experience sharing between the distributed environments. It receives routes and retains information while continuously expanding its experience database. The model reacts upon states in the environment e.g. an event initiated by a sensor agent or a manual query entered by a technician on a terminal.

Communication and Interaction Model

In this chapter we define a model for communication between MA's, ESA's and their environments. It defines a set of speech acts and a finite state automata (Aho and Ullman, 1994) (Salling, 1997) defining the resulting state transitions for each speech act. The model is not intended to be complete but merely an example of useful speech acts for communication between MA's, ESA's and their environments for effective communication in a machine failure situation.

Each agent possesses a set of speech acts that enables communication between them. A speech act is defined by a message

A : B << Request(P)

where sender agent *A* sends a message containing a request *P* to agent . A speech act initiates a series of subsequent actions defined by the behaviour of agent B when responding to request P.
Table 1, Table 2 and Table 3 defines speech acts for the SA, ESA and the environment respectively.

Input/Output	**Syntax**	**Semantic**
Output	*Report(Fault(x))*	Report fault x
Input	*Feedback(Fault(x))*	Receive feedback for fault x

Table 1. Maintenance Agent speech acts. The Maintenance Agent is responsible for reporting the faults it finds to the environment. It also has some ability to receive feedback from the environment.

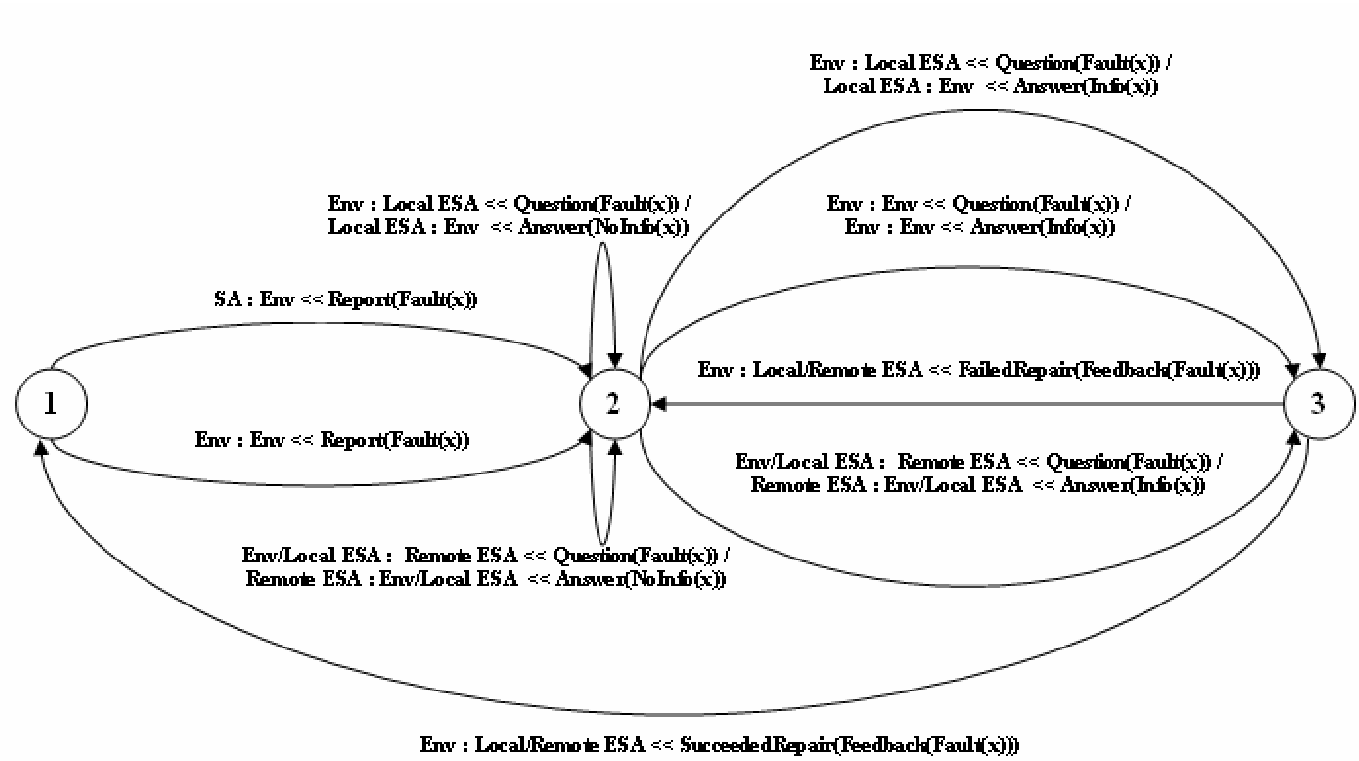
Input/Output	**Syntax**	**Semantic**
Input	*Question(Fault(x))*	Receive question x
Output	*Answer(Info(Fault(x)))*	Answer providing information about fault x
Input	*Feedback(Fault(x))*	Receive feedback on x

Table 2. Experience Sharing Agent speech acts. The Experience Sharing Agent speech acts responds to *Question(Fault(x))* providing information about what action should be taken and what results to be expected in *Info(Fault(x))*. Feedback can also be arbitrary provided.

Input/Output	**Syntax**	**Semantic**
Output	*Report(Fault(x))*	Report fault x
Input	*Question(Fault(x))*	Receive question x
Output	*Answer(Info(Fault(x)))*	Answer providing information about fault x
Output	*SucceededRepair(Feedback(Fault(x)))*	Provide positive feedback in repairing fault x
Output	*FailedRepair(Feedback(Fault(x)))*	Provide negative feedback in repairing fault x

Table 3. Environment Speech Acts. The environment uses a combination of speech acts from the SA and the ESA. It has the ability to report faults that may have been missed by the sensor agent and it

has the ability to ask and answer questions. It also has the the ability to provide new feedback to the ESA whether an answer resulted in success or failure. Feedback to the MA can also be given.



Figur 6. A finite state automaton representing the environmental states and their according speech acts. State 1 represents "normal operation", state two represents "machine failure mode, waiting for information" and state 3 represents "remedy in progress".

EXAMPLES

To exemplify how the MAS model and the communication model would behave in a real-world application we here give examples of two possible events of machine failures in an application containing two distributed factory environments as depicted in Figure 5. Each factory environment contains an industrial robot, an MA monitoring the robot, an ESA and a technician managing the environment responsible for keeping it in a state of normal operation and thus to repair and report any occurrence of anomalies that may inhibit the normal operation of the factory.

Example 1: Machine Breakdown Reported by Maintenance Agent

In this example, a fault in a gearbox on the robot is perceived by the MA who immediately reports it to the environment via a computer terminal. The technician managing the environment notices the report and shuts down the robot and halts the affected production line. The technician uses the information about the state of the robot provided by the MA and makes a query to the ESA by entering the reported state on the terminal connected to it. The ESA performs a search in order to find information about a similar case of machine breakdown. In this example, the local ESA has no such information and asks a remote ESA. The Remote ESA luckily has a similar case and answers the local ESA who provides information about what action should be taken and what results to expect to the technician. The technician fixes the robot using the provided information and starts the production line again. Some revisions had to be made to the recommended actions in the case and the technician provides this as feedback to the ESA which saves this as a new case in the ESA database. The factory is now in the normal running state again and new knowledge has been acquired by the ESA. In Table 4 the speech acts of the above scenario are noted.

State of Factory	**Speech Act**
Normal Operation	*SA : Env << Report(Fault(x))*
Failure Mode	*Env : Local ESA << Question(Fault(x))*
Failure Mode	*Local ESA : Remote ESA << Question(Fault(x))*
Failure Mode	*Remote ESA : Local ESA << Answer(Info(Fault(x)))*
Failure Mode	*Local ESA : Env << Answer(Info(Fault(x)))*
Remedy in Progress	*Env : Local ESA << SucceededRepair(Feedback(Fault(x)))*
Normal Operation	

Table 4. Machine failure speech acts and state transitions.

Example 2: Machine Anomaly Reported by Environment

In this example, an anomaly in the robot (e.g. its fails to pick up an object) is perceived by the technician but the maintenance agent has not perceived or reported any fault. The technician shuts down the robot and halts the affected production line. The technician makes her own diagnosis and enters a query to the ESA which after a local and a remote database search still has no feasible answer to provide. Luckily, it is an experienced technician and she manages to use her own experience to repair the fault. She also in the meantime, manages to acquire some new knowledge. She starts the production line again and provides feedback appropriate feedback both to the maintenance agent and to the ESA. In Table 5 the speech acts of this scenario are noted.

State of Factory	**Speech Act**
Normal Operation	*Env : Env << Report(Anomaly(z))*
Failure Mode	*Env : Local ESA << Question(Anomaly(z))*
Failure Mode	*Local ESA : Remote ESA << Question(Anomaly(z))*
Failure Mode	*Remote ESA : Local ESA << Answer(NoInfo(Anomaly(z)))*
Failure Mode	*Local ESA : Env << Answer(NoInfo(Anomaly(y)))*
Failure Mode	*Env : Env << Question(Anomaly(z))*
Failure Mode	*Env : Env << Answer(Info(Anomaly(z)))*
Remedy in Progress	*Env : ESA/MA << SucceededRepair(Feedback(Anomaly(z))))*
Normal Operation	

Table 5. Machine failure speech acts and state transitions.

CONCLUSIONS

This paper presents a case study of communication between agents in a distributed multi-agent system in a Factory Production Environment. The paper is aimed to provide an overview and a reduction in complexity of the communication procedure during the maintenance of a machine. The system is modelled using the BRIC language. The model is not intended to be complete but merely an example of useful speech acts for communication between agents and their environments in critical maintenance situations. Two real-world examples are given and translated into the model. State transitions in a finite automaton represent the maintenance procedures and their outcomes. The communication model can easily be expanded to describe new environments and situations.

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