APPLYING MULTI-AGENT SYSTEMS TO ORGANIZATIONAL MODELLING IN INDUSTRIAL ENVIRONMENTS

M. C. Romero[1], R. M. Crowder[2], Y. W. Sim[2] and T. R. Payne[2]
[1]Departamento de Tecnología Electrónica, University of Seville, Spain

[2]School of Electronic and Computer Science, University of Southampton, U.K.

Keywords: Simulation, multi-agent systems, artificial social systems, engineering design, integrated product teams.

Abstract: This paper considers an agent-based approach to organizational modelling within the engineering design domain. The interactions between individual designers within a design teams has a significant impact upon how well a task can be performed, and hence the quality of the resultant product, hence many organisations wish to model, and hence fully understand the process. Using multi-agent social modelling, designers and the design task attributes can be the subject of rules implying how well tasks can be performed given different levels of these attributes. In this paper we discuss the background to the work and the identifications of individual, and team variables.

1 INTRODUCTION

This paper reports an approach to organisational modelling within the engineering design domain. While the use of software to undertake simulations within the engineering design process, for example computational fluid dynamics or finite element analysis, is well known, modelling of the process itself is less well understood. Our current research objectives are:

- To model the organisational processes as applied to engineering design, by bringing together expertise in organizational practice, agent modelling and organisational or work psychology.
- Undertake simulations to address specific problems within a design organisation.

In order to achieve these aims we need to address two fundamental questions, firstly the integration and application of a number of disparate technologies to a demanding real world problem. The second is extending simulation and modelling to organisational systems, by exploiting intelligent agent technology and the work psychologists' understanding of the operation of individuals and organisations. This work adopts a socio-technical approach, combining expertise in technical and social issues

It is widely understood that when a new design problem emerges, the designer's knowledge related to their previous experiences of similar problems is applied. (Adler, Davis et al. 1989) comments that more experienced designers are able to connect a resolved design problem to a new problem quicker and easier than less experienced designers. Central to effective knowledge management is the integrated product team or design team, where the characteristics of the participants and their relationships are critical. This includes their informal network of contacts, personal experiences and the designer's own memory. It has been shown that approximately 20% of the engineers time is spent searching for and absorbing information, of which 40% will be from personal resources, even when information is available elsewhere in the organization (McMahon, Lowe et al. 2004) (Shadbolt and Milton 1999).

In this work we consider the engineering design environment, where both designers and tasks have particular attributes. A large body of psychological research has demonstrated that interactions between humans and tasks have a large impact upon how well a task can be performed. Within a computer modelling environment, designers and task attributes (e.g. task complexity, expertise, trust) can be the subject of rules implying how well tasks can be performed given different levels of these attributes

C. Romero M., M. Crowder R., W. Sim Y. and R. Payne T. (2008).
APPLYING MULTI-AGENT SYSTEMS TO ORGANIZATIONAL MODELLING IN INDUSTRIAL ENVIRONMENTS.
In *Proceedings of the Tenth International Conference on Enterprise Information Systems - AIDSS*, pages 181-186
DOI: 10.5220/0001683101810186

(Martinez-Miranda, Aldea et al. 2003). For instance, if a particular task is complex, then the designer may need additional knowledge or expertise to complete the task.

2 RELATED WORK

Several approaches to modelling engineering design teams and IPTs have been reported in the literature to date. The GRAI-Engineering approach models the structure of the co-ordinated decision and design activities, and is based on systems, hierarchy and activity theory, but does not consider social behaviour within teams (Girard and Doumeingts 2004). TEAKS (Martínez-Miranda, Aldea et al. 2006) is reported to take a multi-agent systems approach for modelling the performance of a design team, and hence facilitates optimization. The variables with TEAKS are based on the PECS (*Physical condition, Emotive state, Cognitive capabilities and Social status*) reference model of human behaviour (Schmidt 2002)

Given the characteristics of multi-Agent Systems (Wooldridge and Jennings 1995), they can be seen as a very useful tool for modelling human behaviour, and in particular, social behaviour. The use of multi-agent systems has been explored to support human teams (Payne, Sycara et al. 2000), where agents were used to provide support to team members given a time-critical task, by aggregating relevant information from their peers about other member actions. Likewise, social dynamics have been studied through modelling human and group behaviour using multi-agent simulation methods (Tsvetovat and K.Carley 2004). The agent-based approach can enhance the potential of decentralised computer simulation as a tool for theorizing about social scientific issues, since it facilitates the modelling of artificial societies of autonomous intelligent agent.

Jennings (Jennings 2000) proposed the typical structure of a multi-agent system (Figure 1). The system contains a numbers of agents, which interact with one another through communication. The agents are able to act in an environment; different agents have different "spheres of influence", in the sense that they will have control over different parts of the environment. These spheres of influence may coincide in some cases. The fact that these spheres of influence may coincide may give rise to dependency relationships between agents. When faced with what appears to be a multi-agent domain, it is critically important to understand the type of interaction that takes place between the agents. In order to clarify the interaction between

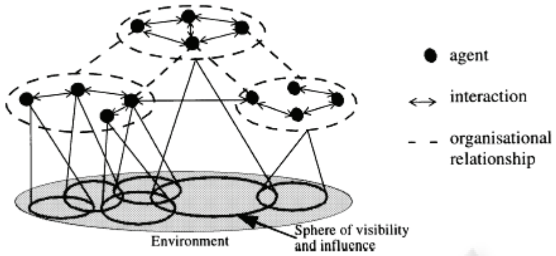

Figure 1: Canonical view of an agent-based system (Jennings, 2000).

agents, (Jennings et al, 1998) distinguish between cooperative models and self-interested models. In the first type, agents cooperate to achieve a common goal and in the second one agents negotiate in order to achieve its own goal as best as possible.

Negotiation is seen as a method for coordination and conflict resolution (e.g., resolving goal disparities in planning, resolving constraints in resource allocation, resolving task inconsistencies in determining organizational structure). Negotiation has also been used as a metaphor for communication of plan changes, task allocation, or centralized resolution of constraint violations. Hence, negotiation is almost as ill-defined as the notion of *agent*. (Jennings, Sycara et al. 1998) give what we consider to be the main characteristics of negotiation, which are necessary for developing applications in the real world. These are: (a) the presence of some form of conflict that must be resolved in a decentralized manner, by (b) self-interested agents, under conditions of (c) bounded rationality, and (d) incomplete information. Furthermore, the agents communicate and iteratively exchange proposals and counter-proposals.

Team working processes has been extensively studied by psychologists (Guzzo and Dickinson 1996). In a review of the research literature (Applebaum and Blatt 1994), team working was shown to offer organizations many advantages over individual working and was associated with organizational efficiency and improved quality. However, there is widespread acceptance that effective team-working does not result from management; for example simply putting a group of individuals together and expecting them to function well as a team is rarely effective (Guzzo and Dickinson 1996). The team's performance depends on a variety of factors and processes concerning the characteristics of the individual team members (e.g. motivations, ability) and also the way the team interacts and works together to achieve the team's goals (e.g. communication processes, trust, shared understanding). As organisations continue to recognise the benefits that teams bring to their business, researchers are becoming increasingly in team processes such as decision making, social loafing, minority influence, polarization of views, leadership, and the stages of team development.

3 DESIGN TEAM SIMULATION

When a new design problem appears, the designers' knowledge related to previous experiences in similar problem is readily applied. That is, the process begins by using the designers' knowledge of a similar or related problem, if this approach is possible; undertake the correct process to resolve the new problem. Adler (Adler, Davis et al. 1989) states that more experienced designers are able to connect a resolved design problem to another new problem quicker and easier. Information about how the problems are resolved forms part of the captured design rationale which in general, is available to others designers who are working in related areas (Shadbolt and Milton 1999). The process is shown in the Figure 2.

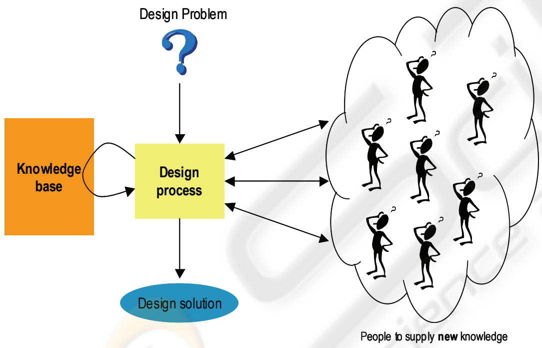

Figure 2: Generic design process.

Generally, a designer follows a numbers of steps in order to resolve the design problem. We have to undertake detailed studies on any design process in order to extract the rules in a design process.

3.1 Defining the Model

We have seen also there exist a number of technologies in industrial design sector to undertake design projects with different complexity. Some of those methodologies have been matured along many years and they are defined perfectly. Although these methodologies aren't used to model behaviour designer in a specific design but themselves designs, they can help to profile how designers operate from a general viewpoint. In order to know this behaviour from an organisational viewpoint it's necessary to acquire information directly from working designers. It is anticipated that a considerable proportion of work will involve interviewing designers to obtain a range of metrics.

The necessary information not only includes the steps that designers carry out during design process, even the interactions between different designers. It's in this point where social sciences come into play. Social sciences can be applied in multi-agent based systems modelling and simulation. (Davidsson 2002) describes a Computer Science view of agent based social simulation (ABSS) whose intersections are shown in Figure 3.

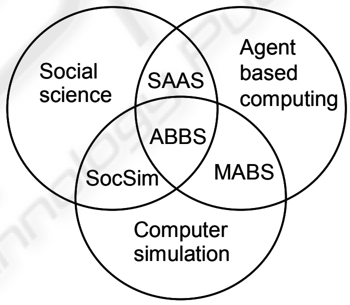

Figure 3: The intersections of the three areas defining ABSS (Davidsson 2002).

In hierarchical model of information systems, each information agent is responsible for providing information about a specific domain. Information agents further down the hierarchy provide more specialized information about a domain. In response to a query, an information agent may cooperate with information agents in other domains or sub-domains, in order to generate a response. Communication network solutions are based on a hierarchy of autonomous intelligent agents, which have local decision making capabilities, but cooperate to resolve conflicts. Higher level agents arbitrate unresolved disputes between peer agents.

The methodology for the development of agent societies based on this framework consists of several levels:

- Designing coordination model.
- Defining environment in terms of global requirements and domains

- Describing behaviour in terms of agent roles and interaction patterns.
- Defining internal structure of agents in terms of requirements for communication, action, interface, and reasoning behaviour.

On the other hand (Norman, Jennings et al. 1997) propose an architecture for the business process management that can be applied to any hierarchical social architecture in which interaction between different agents organized in a specific way is necessary Figure 4)

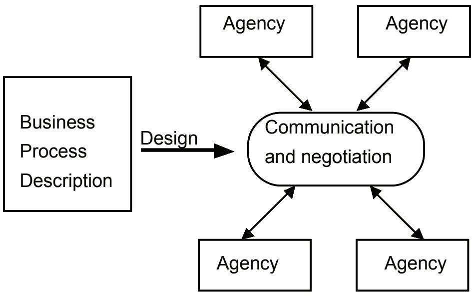

Figure 4: Designing an agent-based business process management system (Norman, Jennings et al. 1997).

A logical hierarchy of agencies to represent the hierarchical interactions between human in a business environment, consisting of:

- Agency
- Responsible agents
- Tasks
- Sub-agencies

An Agency is recursively defined: an agency consists of a single responsible (or controlling) agent, a –possible empty– set of tasks that the responsible agent can perform, and a –possible empty– set of sub-agencies (see Figure 5). The responsible agent represents the interests of the agency to its peers. Any communication with an agency must go through the responsible agent. A sub-agency typically behaves in a cooperative manner towards its responsible agent, this agent being responsible for representing the interests of the agency in the wider community. This relationship between sub-agency and responsible agent can be viewed as a type of social commitment, and provides a mechanism for the encapsulation and abstraction of services.

However, in these communications, trust, influences the relationship that exists between them. Trust is a fundamental concern in large-scale open distributed systems and has resulted in a considerable amount of research and hence models as discussed in (Huynh, Jennings et al. 2004). Trust lies at the core of all interactions between the entities that have to operate in such uncertain and constantly changing environments. Trust can be defined as a belief an agent has that the other party will do what it says it will (being honest and reliable) or reciprocate (being reciprocative for the common good of both), given an opportunity to defect to get higher payoffs.

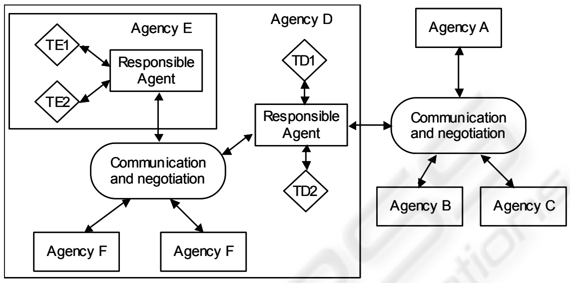

Figure 5: The logical hierarchy of agencies (Norman, Jennings et al. 1997).

The core to the Trust model is the development of ratings upon which a decision regarding trustworthiness is based. The ratings are normally based on a number of metrics, for example interaction trust, role-based trust, witness reputation, and certified reputation. It is therefore clear that one of the key activities within modelling the engineering design process is to identify the individual metrics within the concept of engineering design, and they determine the trust rating.

3.2 Variable

A large number of variables that characterise an engineering design environment should be considered, including:

- The task's complexity;
- The designer's ability;
- The frequency and content of the communication to and from designers.
- Psychological variables, including shared understanding, trust, and motivation.

Balancing the relative importance of these variables used within the model is fundamental to developing a realistic simulation of design teams. Given the difficulty of accurately quantifying such variables, our initial approach assumes a finite, qualitative set of descriptors (e.g. *high...medium…low*). The weightings for each of the variables are adjusted on the basis of the information collected during interviews within actual design teams.

3.3 A Model of a Design Team

The design activity model used is shown in Figure 6. The model for the individual design activity is based on the IDED0 approach. (O'Donnell and Duffy 2002), where a number of knowledge sources are used to provide the knowledge necessary to satisfy the design requirements, which in this model is defined by a goal, K_O.

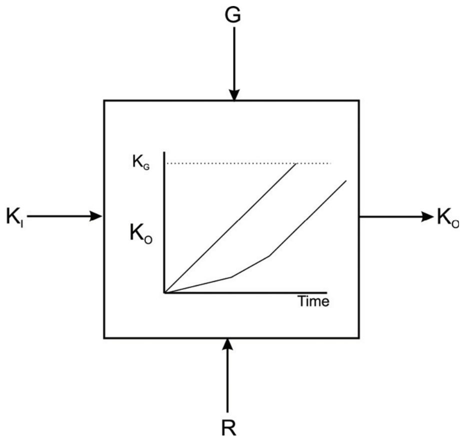

Figure 6: The design activity model.

As the teams are multi-disciplinary, it is proposed that the task, resource, input and output knowledge are held as vector of core competencies also as a finite, qualitative set of descriptors. In order for the individual activity to proceed, it operates under a set of knowledge constraints, namely:

- K_I is the internal knowledge of the designer and can either be explicit or tacit, remain either constant during the task.
- K_O, knowledge generated as the design task proceeds, equal K_G at the completion..
- $G = \{G_T, G_S\}$ is the constraints either technical G_T or social G_S that directs and determines the design activity.
- R, the external knowledge resources available to the designer

Within the model a set of algorithms are used to relate the knowledge input to the knowledge output as a function of time. In order to simulate the interaction between designer and a second designer or a resources the communication paths variables are dependant on a number of parameters including the *communication medium* and *context*, which in term determines the trust that the designer places on the knowledge received. The current implementation assumes that all requests are responded to immediately without question.

Currently, the design activity function is linear, but will be modified as we complete a number of interviews with members of design teams within manufacturing companies.

As a minimum, a team (by definition) must consist of at least two people (with a maximum of around 20 people), Figure 7 illustrates a two member simplified integrated product team (IPT), working on a single task.

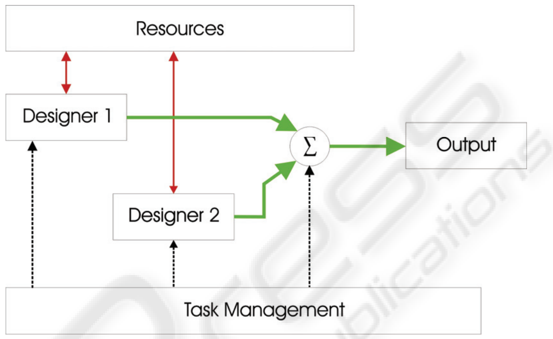

Figure 7: A simplified integrated product team, showing two designers working on a single task.

4 IMPLEMENTATION

A multi-agent system (MAS) simulation of a number of designers has been developed using the JADE platform. Currently, there are six designer agents, two resource agents and a single task manager living in the MAS, the required states and behaviours are defined in Table 1.

Table 1: Agents' state and behaviour.

Agents	State	Behaviour
Designer	Ability Motivation	Performs task assigned by TaskManager If ability is less than task complexity, get information from Resource
Resource	Ability Motivation	Ability is high Respond with information
TaskManager	Task progress Task complexity	Assign tasks to agents Keep track of task progress

Each designer and resource agent has two variables (ability and motivation), the values are assigned at the start of the simulation. The task manager agent is responsible for assigning task to the designer agents and monitors their work progress. The design process is assumed to be in sequential at the present stage of development phase, i.e. designer 2 will only start work after designer 1 had completed their task (see Table 2).

Table 2: Results for a six person IPT.

Designer Ability	Designer Motivation	Time to complete
High	High	18
Medium	Medium	28
Low	Low	52
Low	Medium	36
Low	High	28

Table 2 shows the results for a six person IPT where the completion time is in arbitrary units. The task complexity is *high* and the communication rules assume that every request is handled on receipt.

5 CONCLUSIONS

This paper has reported the initial approach to the modelling of IPTs within large engineering organizations. Within this model we have implemented a knowledge-time relationship which is currently considered to be linear, but further work is being carried out to be to optimize the algorithms within the design activity model. The initial feedback from our industrial partners indicates that this is an acceptable approach for modelling.

ACKNOWLEDGEMENTS

The work described in this paper has been funded by the DTI (Department of Trade and Industry) and Rolls Royce under the HIPARSYS grant: TP/3/DSM/6/I/16032. The authors acknowledge the contribution from Mark Robinson and Helen Jackson for the Leeds Business School (University of Leeds) and from the Ministerio de Ciencia y Tecnología (Spain) within I+D+I National Program through the project with reference number TEC2006-08430.

REFERENCES

Adler, M., A. Davis, et al. (1989). Conflict resolution strategies for non-hierarchical distributed agents. Distributed Artificial Intelligence. L. Gasser and M. Huhns, Pitman Publishing. II**:** 139-16.

Davidsson, P. (2002). Agent Based Social Simulation: A Computer Science View. Journal of Artificial Societies and Social Simulation 5(1).

Girard, P. and G. Doumeingts (2004). GRAI-Engineering: a method to model, design and run engineering design departments. International Journal of Computer Integrated Manufacturing 17: 716-732.

Huynh, T. et al. (2004). FIRE: An Integrated Trust and Reputation Model for Open Multi-Agent Systems. *16th European Conference on Artificial Intelligence*.

Jennings, N. (2000). On Agent-Based Software Engineering. Artificial Intelligence 117(2): 277-296.

Jennings, N. et al. (1998). A Roadmap of Agent Research and Development. International Journal of Autonomous Agents and Multi-Agent Systems 1(1): 7-38.

Martínez-Miranda, J. et al. (2003). Simulation of work teams using a multi-agent system. *AAMAS '03*, Melbourne, Australia.

Martínez-Miranda, J. et al. (2006). TEAKS: simulation of human performance at work to support team configuration. *5th international joint conference on Autonomous Agents and Multiagent Systems, AAMAS06,* Hakodate, Japan.

McMahon, C., A. Lowe, et al. (2004). Knowledge mangement in engineering design : personalization and codification. Journal of Engineering Design 15(4): 307--325.

Norman, T. et al. (1997). Designing an Implementing a Multi-Agent Architecture for Business Process Management. *ECAI'96 Workshop Agent Theories, Architectures, and Languages: Intelligent Agents*.

O'Donnell, F. and A. Duffy (2002). Modelling design development performance. International Journal of Operations & Production Management 22(11): 1198-1221.

Payne, T. et al. (2000). Agent-Based Team Aiding in a Time Critical Task. *HICSS '00: Hawaii International Conference on System Science.*

Schmidt, B. (2002). Modelling of Human Behaviour The PECS Reference Model. *14th European Simulations Symposium*.

Shadbolt, N. and N. Milton (1999). From knowledge engineering to knowledge management. British Journal of Management 10: 309-322.

Tsvetovat, M. and K.Carley (2004). Modelling Complex Socio-technical Systems using Multi-Agent SimulationMethods. Kunstliche Intelligenz (Artificial Intelligence Journal) Special Issue on Applications of Intelligent Agents (2).

Wooldridge, M. and N. Jennings (1995). Intelligent Agents: Theory and Practice. The Knowledge Engineering Review 10(2).