Sobah Abbas Petersen

An Agent-based Approach to Support the Formation of Virtual Enterprises

Dr.ing.-thesis 2003:70

Faculty of Information Technology, Mathematics and Electrical Engineering
Department of Computer and Information Sciences

NTNU

Norwegian University of Science and Technology
Faculty of Information Technology, Mathematics and Electrical Engineering
Department of Computer and Information Sciences
N-7491 Trondheim
Norway

Dr.Ing. Thesis 2003:70

IDI Report: 07/03

ISBN 82-471-5622-9
ISSN 1503-416X

Abstract

This thesis presents an agent-based approach to support the formation of Virtual Enterpises. Virtual Enterprises are formed by individual entities that come together as a team of partners that collaborate to achieve a specific goal. The dynamic nature of Virtual Enterprises imposes strong demands on its formation. Thus, the capability of effectively assembling the best team of partners is key to its success.

The aim of this work is to consider a Virtual Enterprise from the point of view of Enterprise Modelling and Enterprise Integration and to propose an agent-based approach for supporting the formation of VEs quickly and efficiently. The agent-based support is aimed at providing decision-making support for human beings by using software agents in the evaluation and selection of partners for a Virtual Enterprise.

The agent-based approach uses software agents to represent the partners of a Virtual Enterprise and consists of an agent-based model, the Virtual Enterprise formation process and a multi-agent architecture to support the formation process. The agent-based model proposes a means of defining the main concepts of a Virtual Enterprise: goals, activities, roles, requirements and agents, and the relationships among them. The Virtual Enterprise formation process is analysed as an Agent Interaction Protocol to identify the interactions among the agents and the information that is exchanged. The AGORA multi-agent architecture has been adapted to support the formation process.

The work presented in this thesis is based on both theoretical and empirical work. The initial ideas were based on the literature and experiences from industry and two research projects CAGIS and Globeman 21. The agent-based approach was validated using several industrial case studies.

The agent-based approach, which considers the concept of a Virtual Enterprise and its formation process in terms of agents is the main result of this work. The main contributions are an agent-based definition of a Virtual Enterprise, an agent-based model of a Virtual Enterprise, Agent Interaction Protocols for the formation processes and a multi-agent architecture to support the formation of Virtual Enterprises. The case studies provided an evaluation framework for the applicability of this agent-based approach and a set of requirements to improve it.

Preface

This thesis is submitted to the Norwegian University of Technology and Science in partial fulfillment of the requirements for the degree *Doktor Ingeniør*. This work has been conducted at the Department of Computer and Information Sciences, NTNU, Trondheim. Part of this work was conducted while I was a visiting researcher at the Enterprise Integration Laboratory, University of Toronto, Canada.

Acknowledgments

The work presented in this thesis has been financed by the Norwegian University of Science and Technology, first within the CAGIS project and later through the ADIS project, both funded by the Norwegian Research Council.

First, I would like to thank my supervisor Professor Mihhail Matskin for his advice and support during the last six years. I also appreciate the freedom that he has given me in pursuing research in a direction where I could use my industrial experience.

My sincere thanks go to Professor Monica Divitini for her continued support and friendship during this period. Monica has been a great source of help in formulating and structuring my thoughts and her constructive criticisms of my work has been a learning ground. I would also like to thank her for her willingness to babysit my daughter.

Part of this work was carried out at the Enterprise Integration Laboratory, University of Toronto. I would like to thank Professor Mark Fox for inviting me to work with his group and Mihai Barbuceanu for his support. A special thanks goes to Michael Gruninger for his help in developing the model presented in this thesis and for the interesting discussions. I would like to thank Det Norsk Veritas and Professor Reidar Conradi (and the CAGIS project) for the financial support for visiting Toronto.

I would like to thank Orsolya Szegheo for our wonderful cooperation and all the interesting discussions during the early stages of this work. The different views that we shared about the concept of a Virtual Enterprise was indeed fruitful for the work in this thesis.

This work was conducted within two research projects, Globeman 21 and CAGIS. A lot of ideas for this project were inspired from the Globeman 21 project. I would like to thank Frank Lillehagen and Paul Fosland, NCR METIS, for their support and for giving me the opportunity to work on the Globeman 21 project. A special thanks goes to the members of the Globeman 21 consortium and CAGIS for the fruitful cooperation.

I would like to thank my colleague Jinghai Rao for helping me with the implementation of some of my ideas using AGORA. I am grateful to Sari Hakkarainen for her guidance and help in developing a modelling notation for my agent-based model.

I am grateful for the case providers for giving me access to information from their companies as well as spending the time to discuss it with me. They are Rifaath Jaleel from BFS, Dag Sjong from Statoil, Tore Christiansen from DNVS, Ole Jonny Klakegg from PTL and Edgar Karlsen from ODA. Validating this work would have been harder without their help. I would like to thank Tore Christiansen specially for his comments on my work.

I would like to thank the administrative and technical staff in the department for their help at all times. My colleagues at IDI, past and present, have helped to provide a nice working environment. I would like to thank them for their willingness to help and the ocassional laughs. Special thanks goes to Jörg, Amund, Diego, Wacek and Zoran.

I would like to thank my friend Helen de Wagt for editing this thesis as well as being a wonderful friend. My friends, in the Maldives and elsewhere have been a great source of strength and support and I would like to thank them for all the emails, jokes and the laughs that has kept me going over the years; Hajja, Sousun, Aindhy, Laila, Sadna and Gul. My sincere thanks to Tor and Anne for giving us a warm welcome in Trondheim.

Finally, I would like to thank my family for their love, encouragement and support, even when I moved to the freezing north. My warmest thanks goes to Idar for his love and patience and to Hannah for her smiles and just for being there.

Sobah Abbas Petersen
Trondheim, October 10, 2003

Contents

List of Figures

List of Tables

Abbreviations

ACL	Agent Communication Language
AI	Artificial Intelligence
AIP	Agent Interaction Protocol
AOR	Agent-Object-Relationship
AUML	Agent Unified Modelling Language
BDI	Belief, Desire, Intentions
BFS	Business and Financial Consulting Group
DAI	Distributed Artificial Intelligence
DAML	DARPA Agent Markup Language
DNVS	Det Norske Veritas Software
EE	Extended Enterprise
EEE	Extended Enterprise Engineering
FIPA	Foundation for Intelligent Physical Agents
GERA	Generic Enterprise Reference Architecture
GERAM	Generic Enterprise Reference Architecture and Model
KIF	Knowledge Interchange Format
KQML	Knowledge Query and Manipulation Language
MAS	Multi-agent Systems
MAUT	Multi-attribute Utility Theory
ODA	Organization Development Alliance AS
OIL	Ontology Interface Layer
PTL	Prosjekt og Teknologiledelse AS
RDFS	Resource Description Framework Schema
TOVE	TOronto Virtual Enterprise
UEML	Unified Enterprise Modelling Language
UML	Unified Modelling Language
VE	Virtual Enterprise
VERAM	Virtual Enterprise Reference Architecture and Methodology
VERA	Virtual Enterprise Reference Architecture
VO	Virtual Organisation

Part I

SETTING

Chapter 1

Introduction

1.1 Problem Definition

Advances in communication and distributed information technologies have changed the way that business is conducted. Enabled by technologies such as software agents and Electronic Commerce, enterprises have gone beyond the geographical and socio-cultural boundaries and have become entities that not only compete in the global market, but also draw their resources from an international market. The trend of outsourcing seems to be replaced by strategic alliances, where enterprises or individuals work together towards a common goal and share their responsibilities as well as their profits. The concept of a Virtual Enterprise (VE) has emerged as a means of dealing with this new type of alliance.

VEs are a means of meeting the requirements of dynamism and agility that an organization must have to be able to survive in today's dynamic business environment. This calls for new ways of organizing work and requires technological support that allows flexibility. Software agents have been proposed as a suitable solution technology to support VEs, e.g. [Bernus and Nemes, 1999].

One of the most important stages in the lifecycle of the VE is the formation of the VE. An important part of the formation of the VE is the selection of its partners, [Camarinha-Matos and Afsarmanesh, 2001]. They are selected on the basis of their ability to fulfil the requirements of the VE. Thus, the success of the VE is strongly dependent on the commitment, performance and delivery capabilities of its partners.

In this thesis, we consider the formation of VEs, in particular, the selection of partners for a VE. We describe an agent-based approach which consists of an agent-based model of a VE, the VE formation process and a multi-agent architecture to support the formation of VEs.

1.2 Motivation and Aim

There is a need to be able to model a VE as modelling allows a VE to analyse, prepare and (re)design the VEs business process, partner roles, contracts, etc., [Zweger et al., 2002]. Similarly, there is a need for supporting the formation of VEs. A crucial competitive factor of a VE is its ability to form a customer-focused team, [Vesterager et al., 2002]. The competitive advantage of a VE is often jeopardized by the time it takes to set it up, specially if it is composed of partners that are unknown to one another before the formation of the VE, [Tølle and Vesterager, 2002].

Several agent-based approaches and systems have been described in the literature (an overview of which is given in Chapter 5). While these address a wide aspect of multi-agent systems, they do not address a holistic model of a VE. They simplify the concept of a VE and focus on a single aspect or a single phase in the lifecycle of a VE.

In this thesis, we focus on the formation phase of the lifecycle of a VE. However, we believe that it is important to have a holistic view of the VE and take into account its complete lifecycle.

The aim of this work is to consider a VE from the point of view of Enterprise Modelling and Enterprise Integration, [Vernadat, 1996], and to propose an agent-based approach for supporting the formation of VEs quickly and efficiently. We aim to support the VE formation process by providing decision-making support for human beings by using software agents in the evaluation and selection of partners. We believe that using agents will enable the processing of detailed evaluation criteria faster and more efficiently.

1.3 Agent-based Approach

The agent-based approach uses software agents (hereafter referred to as agents) to represent the partners, who may be human beings or organizations, of a VE. In this approach, the VE and its formation process are supported by a multi-agent architecture. The fact that the VE and its formation process are described using the notion of agents can be considered as a contribution of this work. Using agents to represent the partners of a VE supports the selection of partners, based on detailed selection and evaluation criteria, in a quick and efficient way.

An overview of the agent-based approach is shown in Figure 1.1 and it consists of the following:

Agent-based model of a VE which is based on ideas from Enterprise Modelling and represents the main entities in a VE and the relationships between these entities.

VE formation process which describes how a VE is formed, in particular how the partners of a VE are selected. The VE formation process is analysed in terms of the interactions among the agents and can be represented as an Agent Interaction Protocol (AIP).

Multi-agent architecture which supports VE formation.

The agent-based model of the VE plays a central role in this approach. The model is used to define the VE and contains all the information that is required for the formation of the VE, such as the requirements for the partners. The model provides the input to the VE formation process and, once the VE is formed, it can be updated with the new information about the agents that are the partners. It can also be used during the operation of the VE. The model and the VE formation process provides the input for the multi-agent architecture.

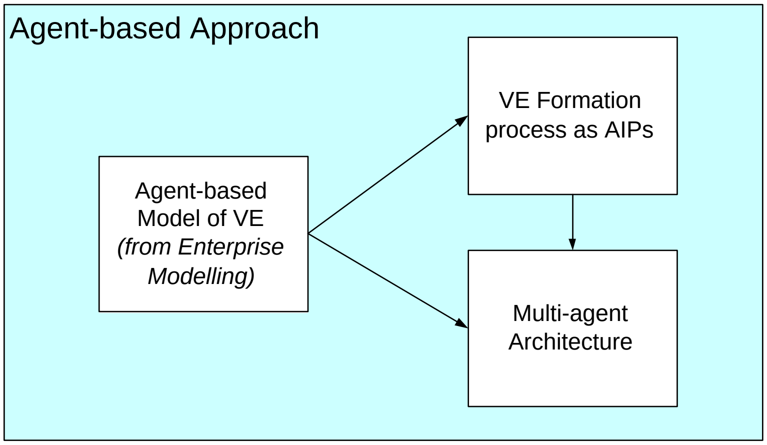

Figure 1.1: Agent-based Approach

1.4 Research Questions

The work presented in this thesis focuses on supporting VEs, in particular, the formation of VEs, using agents. (The definition of agents that is considered in this thesis is given in Section 2.2.) This thesis intends to answer whether representing the partners of a VE as agents can support the partner evaluation and selection process during the formation of a VE.

The main research question that this thesis attempts to answer is:

MRQ: How can we support the formation of VEs using agents?

In order to be able to answer this question, it is important to have an understanding of what a VE is. Thus, in elaborating this question, we define a set of research questions that address the concept of VEs as well as the agent-based support more specifically. The set of research questions are as follows:

RQ1: What is a VE and how is it formed?

- What is the definition of a VE?
- Do all (instances of) VEs have the same formation process?
- How is the formation of a VE related to the rest of the lifecycle of a VE?

RQ2: Can we represent a VE and its entities as agents?

- Can we represent the goals of the VE and of the partners participating in it?
- Can we represent the requirements for the partners in a VE?
- Can we represent the attributes of the partners in a VE?

RQ3: Can the VE formation process be modelled in terms of agent interactions?

- What are the kinds of interactions involved in the VE formation process?
- What information is exchanged between agents during the VE formation process?
- What is the sequence of interaction between the agents?

RQ4: How can we determine the best team of agents (or partners) for a VE?

If questions RQ1-4 can be answered and an agent-based approach is proposed, then it is important to determine the applicability of this approach for different instances of VEs. Thus, we have:

RQ5: Is the proposed agent-based approach suitable for all VEs?

RQ6: What are the common requirements for providing an agent-based support for the formation of VEs?

The agent-based support for the formation of VEs is aimed at representing the partners of a VE as agents and delegating some decision-making abilities to the agents during the VE formation process.

1.5 Research Context

The research presented in this thesis is based on literature and industrial experience in Enterprise Modelling (mostly prior to starting the PhD). In addition, the author participated in two research projects, CAGIS and Globeman 21, during the course of this work. Below is a brief description of the two projects:

[CAGIS:] Cooperative Agents in the Global Information Space, a Norwegian research project financed by Norwegian Research Council. This project explored the cooperative aspects of working in a distributed environment, in particular the process model, the document model and the transaction model that are required to support the cooperation. The project participants included members from four different research groups in the Department of Computer and Information Sciences, NTNU. See [CAGIS, 2001] for more information.

[GLOBEMAN 21:] Global Manufacturing in the 21st Century, a part of the Intelligent Manufacturing Systems program, [IMS, 2003], was an international research project established to demonstrate how to move global manufacturing practices from rigid supply chain structures into globally distributed, dynamic networks of agile enterprises. The project participants were from five regions, Australia, Canada, Europe, Japan and USA, consisting of 17 research institutions and 20 industrial partners. See [GLOBEMAN 21, 1999] for more information.

1.6 Research Method

The research context helped formulate some preliminary ideas and results. Based on these, an agent-based model to describe a VE was developed. The process of forming a VE was described using a simple hypothetical example and a prototype multi-agent

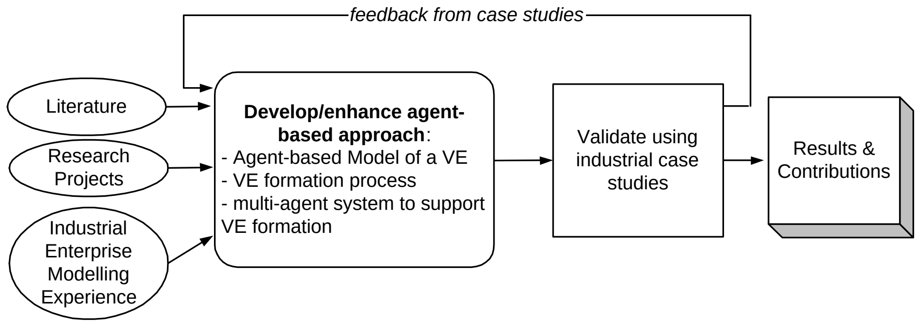

Figure 1.2: Research Method and Process

system was developed to support the VE formation process. This example was then evaluated and developed further based on feedback from industrial case studies. This process is presented in Figure 1.2.

The research method adopted for this work is a combination of theoretical and empirical work, [Sørensen, 2002]. The research context provided the theoretical part of the research and the case studies provided the empirical part. A combination of both these approaches seemed suitable for this work as the theoretical approach helped consider a holistic view of a VE and the empirical approach ensured that the ideas that were developed based on the theoretical approach were applicable out in the industry.

1.7 Research Activities and Contributions

The initial ideas for the work presented in this thesis were formulated based on the author's industrial experience in Enterprise Modelling, the work in the Globeman21 project as well as the literature related to the work. Due to the multi-disciplinary nature of the work, the spectrum of literature that is relevant is very wide. However, due to time constraints and to be able to scope the work well, the main literature that was studied was limited to Enterprise Modelling and Integration, DAI and Agents. Based on experience and the literature, some preliminary results were developed, which included the agent-based model of the VE, VE formation and partner selection process and an implementation to select the best team of partners for a VE. Industrial case studies were used to validate these preliminary results. The results obtained contribute to both the DAI and Enterprise Modelling and VE communities. The final results have been published in international conferences and journals and are described as contributions of this work.

The agent-based approach, described in Section 1.3, can also be considered as a contribution of this work as this approach offers a way to describe a VE in terms of agents and to define the VE formation process as interactions among the agents in a VE.

An overview of the research activities and contributions is shown in Figure 1.3. The contributions of the work presented in this thesis can be summarized as follows:

C1: An agent-based definition of a VE. This definition is based on the literature review and is used as a working definition in this thesis.

C2: Agent-based model of VE. This is a model of the agent (or an agent architecture) to represent the partners and Virtual Enterprise Initiator (VE Initiator) of a VE.

C3: AIPs for VE formation process(es). The various VE formation processes are presented as a set of interactions among the parties involved as AIPs.

C4: A multi-agent architecture to support VEs. This is an adaptation of an existing architecture, designed for distributed cooperative work, to support the formation of VEs.

C5: A framework to evaluate the applicability of the agent-based approach for VEs. This is based on the feedback from industrial case studies.

C6: Requirements for an agent-based support for the formation of VEs. This is also based on the feedback from industrial case studies.

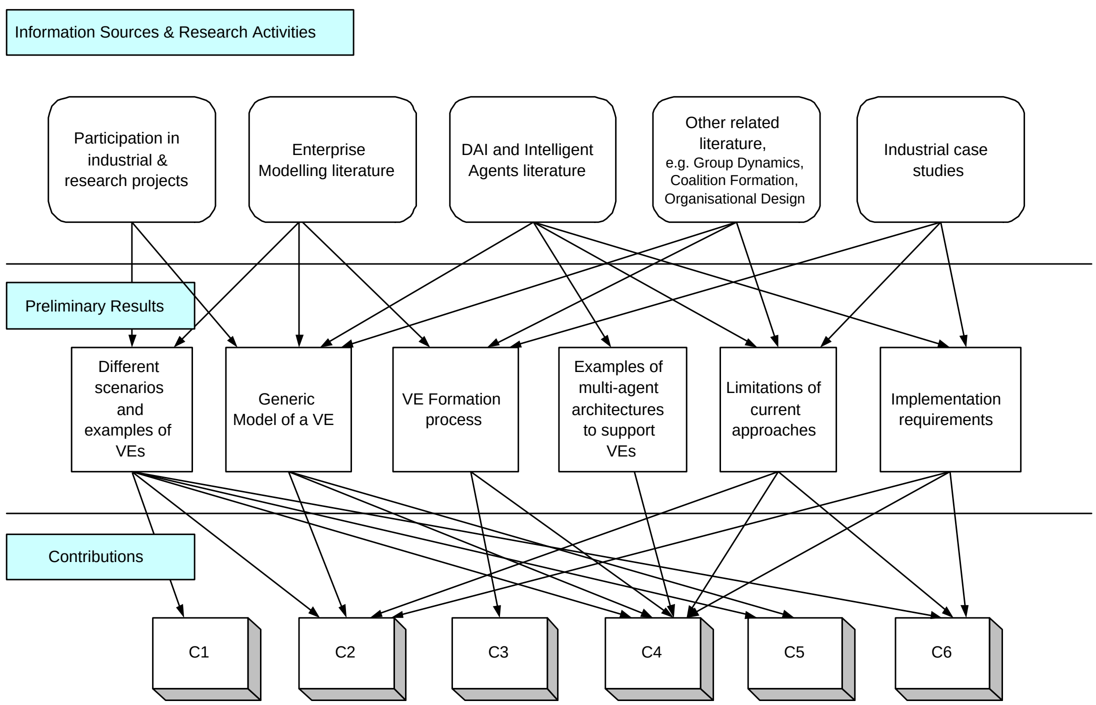

Figure 1.3: Research Activities and Contributions

The contributions are described in a number of papers, **Papers 1-7**, which are included as a part of this thesis. In addition to the papers, the publications included in the bibliography as [Petersen et al., 1999], [Szegheo and Petersen, 2000a], [Szegheo and Petersen, 2000b], [Petersen et al., 2002], [Rao and Petersen, 2003] and [Petersen, 2003] are also a result of the work done for this thesis.

1.8 Thesis Outline

This thesis contains an overview of the literature, a description of the work and an overview of the results and contributions. The details of the research and the results and contributions are described in a set of papers. Since it is difficult to obtain a comprehensive overview of the literature from the papers, a review of the related literature is included as a part of this thesis. Hence, the section on Literature Review is longer than the section on Research and Results.

An outline of the structure of this thesis is shown in Figure 1.4.

Chapter 2 outlines the basic concepts by providing a brief introduction to the main areas of research that are addressed in this thesis.

Chapters 3 provides a review of the literature on VEs, including a review of the various definitions of VE and terminology related to the concept of a VE. It also gives an overview of the characteristics of VEs and identifies the role of agents in VEs.

Chapters 4 provides a review of the literature on agent-based models for VEs, including methodologies for developing agent-based systems. An agent-based definition of a VE, in answer to **RQ1**, is proposed in this chapter.

Chapters 5 provides a review of the literature on agent and multi-agent architectures related to the concept of VEs and identifies the limitations of current approaches.

Chapters 6 presents the agent-based approach for VE formation and the agent-based model for representing the entities in a VE. The work described in this chapter has been published in Papers 1, 2, 3 and 4.

Chapters 7 validates the agent-based approach using several industrial cases and discusses the strengths of the approach and the possibilities of using it.

Chapters 8 summarizes the feedback from the case studies and proposes improvements to the agent-based model presented in Chapter 6. The results described in this chapter has been published in Papers 5, 6 and 7.

Chapters 9 evaluates the work that is presented in this thesis, where the answers to the research questions are evaluated against the contributions and the papers that are presented as a result of this work.

Chapters 10 summarizes and discusses the lessons learned and future directions for this work.

In addition, a number of papers have been included to support the work presented in this thesis:

Paper 1 describes the agent-based model for a VE.

Paper 2 describes how the agent-based model can be used to select the best team of partners for a VE, with the help of an implementation.

Paper 3 describes how the lifecycle of a VE can be modelled using the AGORA multi-agent architecture.

Paper 4 describes how the formation of VEs can be supported in AGORA, with the help of an implementation.

Paper 5 describes an evaluation framework for determining the applicability of the agent-based approach for VEs.

Paper 6 describes the requirements for an agent-based approach to support the formation of VEs, based on two case studies.

Paper 7 describes how the different partner selection processes for VEs can be represented as AIPs.

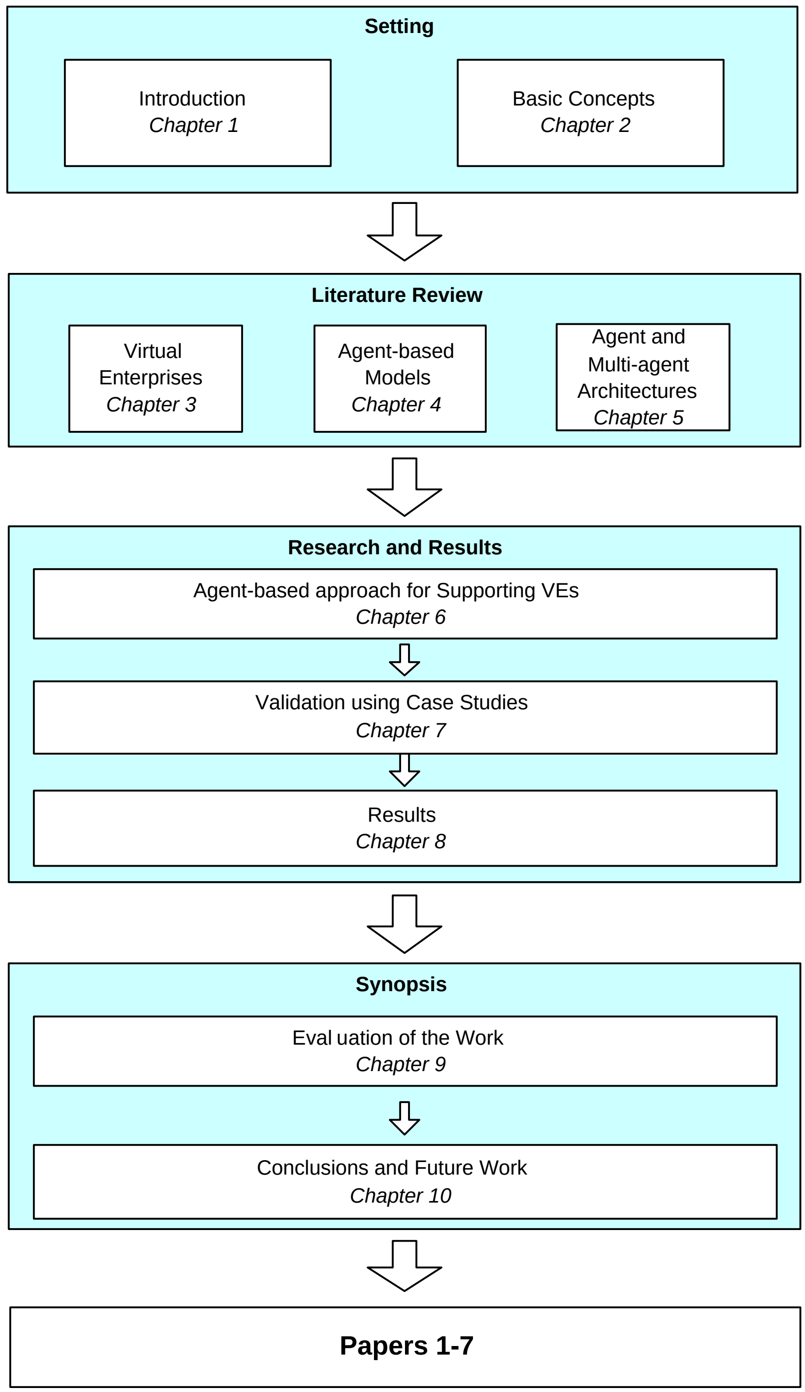

Figure 1.4: Outline of the Thesis

Chapter 2

Basic Concepts

This chapter provides a brief overview of the various fields of research that are referred to and have influenced the work presented in this thesis. The aim of this chapter is not to give a complete overview of the fields; rather to provide an overview of the basic concepts and the views that have been adopted for this work.

2.1 Distributed Artificial Intelligence

DAI is considered as a subfield of Artificial Intelligence (AI) by some authors, e.g. [Moulin and Chaib-draa, 1996]. It is concerned with situations in which several systems interact to solve a common problem. A good example is the control of aircrafts where often human beings as well as computers are involved in keeping track of the airspace and in making decisions. Multi-agent systems and Distributed Problem Solving have been identified as two main areas of research within DAI, [Bond and Gasser, 1998].

Multi-agent Systems: (MAS) is concerned with the behaviour of a collection of autonomous agents aiming to solve a given problem. It is concerned with the societal view of agents, where a collection of agents work together to solve a problem.

Distributed Problem Solving: is concerned with the task of solving a problem which can be divided into a number of subproblems, and the complete problem is solved by cooperation and sharing knowledge about the problem and its evolving solutions.

2.2 Intelligent Agents

The terms "Intelligent agents", "software agents" and "agents" have been used to mean one and the same thing. Software agents have evolved from MAS. Since MAS are an area of research within DAI, it inherits many of the goals and potential benefits of DAI. It also inherits those due to AI such as operation in the knowledge level, reusability and platform independence, [Nwana, 1996]. Since agents, within the the context of DAI, refer to a software component, it is sometimes called software agents and since agents are believed to have notions that are described as intelligent behaviour, they are sometimes called intelligent agents. In this thesis, we will use the term "agents".

Several definitions of an agent have been proposed by numerous sources and to date, there is no definition that is universally agreed upon. One of the most commonly cited definition is the one proposed by Wooldridge and Jennings in [Wooldridge and Jennings, 1995], where they define an agent in terms of its attributes. They also introduced a weak and a strong notion of agency, and defined the attributes of an agent according to these two notions. They defined a weak agent as a hardware or a software-based computer system that has the following properties:

- Autonomy - operate without the direct intervention of human beings.
- Social ability - interact with other agents or human beings via an agent communication language.
- Reactivity - perceive the environment and react in a timely fashion to changes in the environment.
- Pro-activeness - exhibit goal-oriented behaviour by taking the initiative.

A strong notion of agency denotes agents that have mentalistic notions such as knowledge, beliefs and intentions. This notion is favoured by the AI community while the weaker notion is more popular among the software engineering community. In addition to the weak and strong notions of agency, agents could also have the properties mobility, veracity, benevolence and rationality.

Several definitions of an agent and a taxonomy for agents are presented in [Franklin and Graesser, 1996]. In [Nwana, 1996], a discussion of what is not an agent is given, where he judged some software components such as expert systems and distributed computing applications against properties of agents to determine if these components could be referred to as agents. For example, expert systems are not autonomous and distributed computing applications communicate at a lower level (symbolic level) than agents do (agents communicate at the knowledge level).

For the work presented in this thesis, we use the definition proposed in [Wooldridge and Jennings, 1995]. The properties that are most important for our work are pro-activeness or goal-oriented behaviour, autonomy and social ability, in particular, to conduct sophisticated interactions such as negotiations.

2.3 Enterprise Modelling

There are several definitions of enterprise models and Enterprise Modelling; e.g. Vernadat defines Enterprise Modelling as the process of building models of whole or part of an enterprise (e.g. process models, data models, resource models, new ontologies, etc.), [Vernadat, 1996], while Bernus defines Enterprise Modelling as a collective name for the use of models in Enterprise Engineering and Enterprise Integration. A model, in this case, is any construct on paper or in a computer or any other medium, that shares some common properties with the real or contemplated system that is being modelled, [Bernus, 1999].

For our work, we take the view that has been presented by the above definitions, where we build a model to represent a VE, in terms of its entities and the relationships between the different entities.

2.4 Enterprise Integration

Enterprise Integration is concerned with providing seamless communication, cooperation and coordination between enterprises as well as among the different functionalities within a single enterprise. It is aimed towards improved interoperability. Enterprise Integration is concerned with facilitating information, control and material flows across organizational boundaries by connecting all the necessary functions and heterogeneous functional entities in order to improve communication, cooperation and coordination within the enterprise, such that the enterprise behaves as a whole, [Vernadat, 1996].

Enterprise Modelling facilitates Enterprise Integration in business processes by integrating processes, organizations, goals and customers, [Gruninger, 2003].

Part II

LITERATURE REVIEW

Chapter 3

Virtual Enterprises

3.1 Introduction

VEs have been a means of meeting the challenges of global collaboration, competition and operations. It has been an active research field among people and organizations across industries and diverse research groups. The European research project VOSTER (IST-2001-32031), [VOSTER, 2003] is a clear indication of this. VOSTER aims to collect, analyse and synthesize the results from a number of leading European research projects on Virtual Organization (VO). Some of these projects are Prodnet, ESPRIT project no. 22.647, completed in 1999, COVE, Cooperations Infrastructure for Virtual Enterprises and Electronic Business, [COVE, 2003]. Two other international research projects from the Intelligent Manufacturing Systems program are Globeman 21, [GLOBEMAN 21, 1999], and Globemen, which stands for Global Engineering and Manufacturing in Enterprise Networks, [GLOBEMEN, 2002]. The author participated in the Globeman 21 project, and thus, the views of a VE expressed in this thesis are influenced partly by this.

The rest of this chapter reviews the literature on VEs to answer **RQ1** and to provide a brief overview of the current research in the area of VEs. Based on the literature review, we describe a VE as a set of characteristics, propose a preliminary answer to **RQ1** and discuss the role of agents in VEs.

3.2 Virtual Enterprises, Extended Enterprises and Extended Enterprise Engineering

The concept of Extended Enterprises (EE) or Extended Enterprise Engineering (EEE) is often used in the context of VEs. Several authors use the terms VE, EE and VO as synonyms. In the rest of this section, several definitions of these concepts are reviewed to understand what they really are and to clarify the definition of a VE. This is done by categorizing the literature according to the source of the article, or the research community, as we believe that this has an influence on the definitions. Literature from the Manufacturing, Organizational Research, Computer Science, Distributed Artificial Intelligence (DAI) and Enterprise Modelling and Integration communities are reviewed.

3.2.1 Manufacturing

The manufacturing community in general seems to focus on the concept of an EE, [Jagdev and Browne, 1998] and [Childe, 1998]. An EE in a manufacturing scenario is a partnership among manufacturing enterprises and involves very close collaboration between the manufacturer, the customer and the supplier. Since the manufacturing industry has strong roots in supply-chain management, this view of an EE is not surprising.

Another reason for this view could be due to the fact that today's manufacturing companies are expected to deliver environmentally benign and technically advanced products. This adds a pressure on the companies to feel responsible for the entire lifecycle of their product, e.g. the components that are assembled in the factory as well as the operation of the product after it leaves the factory; all this becomes a part of the supply chain. Hence, there is a greater need for closer collaboration between the supplier, the manufacturer and the customer.

The concept of a VE is addressed in [Szegheo, 1999], [Vesterager et al., 1999] and [Jagdev and Browne, 1998], where they discuss the relationships between an EE and a VE. In [Jagdev and Browne, 1998], a VE is defined as a temporary network of independent companies that are linked using information technology. It is interesting to note that, in this definition, the focus is on the technology that links them rather than the roles of the independent companies such as a supplier or a manufacturer.

The concept of a "cluster" is often used, e.g. [Rabelo et al., 2000] and [Mejía and Molina, 2000]. A cluster is defined as an "aggregation of companies from diverse industries, with well-defined and focused competencies, with the purpose of gaining access to new markets and business opportunities by leveraging their resources", [Mejía and Molina, 2000].

3.2.2 Organizational Research

In Organizational Research, the term "Virtual Organization" was introduced by Davidow and Malone, [Davidow and Malone, 1992], who define a VO as a corporation that is able to gather and integrate a massive flow of information throughout its organizational components and act intelligently upon that information. They regard Information Technology as a predominant part of an enterprise and a vital property for their success.

In [Byrne et al., 1993], a VE is defined as a temporary network of independent companies formed to share skills and costs as well as to gain access to each other's markets. In [Venkatraman and Henderson, 1998], they view VOs as organizations where "virtualness" is a strategic characteristic. Virtualness is described as a strategy that reflects three independent vectors: virtual encounter (customer interaction), virtual sourcing (asset configuration) and virtual expertise (knowledge leverage). They view VOs as a strategic approach focused to create, nurture and deploy intellectual and knowledge assets and that Information Technology is a central issue in this view.

In [Fox et al., 1998b], a VO is described as one that is formed on strategic alliances (two or more companies agreeing to act together as a single strategic unit) or one that concentrates on the activities that it does best and outsources the rest. They also emphasize the role the developments in the field of electronic communications play in enabling VOs.

It is interesting to note that the Organizational Research community addresses the concept of VEs and uses terms such as "Virtual Office", "Virtual Work" and "Virtual Teams". They do not, however, address the concept of an EE, nor do they distinguish between EEs and VEs.

3.2.3 Computer Science

Similar to the organizational Research community, the Computer Science community also seem to address VEs rather than EEs. Most of the definitions of VEs that they have proposed have been influenced by the development of distributed computing capabilities and the evolution of the Internet and the World Wide Web. Such definitions can be found in [Fielding et al., 1998] and [Mowshowitz, 1999]. In his article, Mowshowitz describes a virtual office with respect to other virtual "constructs" such as the virtual memory in computers, network switching (which sets up a logical path in contrast to the physical circuit), virtual teams and virtual reality.

A popular term within this community is "network teams or communities", which refers to groups of people that are connected via the Internet [Hattori et al., 1999]. In [Garita and Afsarmanesh, 2001], a VE is defined as a interoperable network of pre-existing enterprises that collaborate by means of specific Information Technology components towards the achievement of a common goal. In general, it is assumed that the Internet provides the medium for exchanging business and technical information required for conducting business. Therefore, organizations that desire to compete in the global marketplace need to be capable of conducting business in a virtual sense. They need the information exchange capability and process flexibility to support a wide range of potential supply chain partners. Hence, within the Computer Science and distributed computing community, there has been a tendency to think of VEs as a network of organizations that are connected via the Internet.

3.2.4 Distributed Artificial Intelligence

The most common view among the DAI community is that a VE is a temporary, cooperative network that is formed by independent, autonomous companies to exploit a particular market opportunity, [Clements et al., 1997], [Fischer et al., 1996], [Oliveira and Rocha, 2000] and [Ruß and Vierke, 1998]. Other views incorporate properties of VEs such as "rapidly configured, multi-disciplinary network of firms", [Ambroszkiewicz et al., 1998], goal-oriented behaviour, where goals are achieved through cooperative work among the partners, [Oliveira and Rocha, 2000], decentralized control of activities, [Szirbik et al., 1999], and commitment among the autonomous partners [Jain et al., 1999].

The DAI community attempts to realize or support VEs using multi-agent systems and therefore some of the properties listed above reflect properties of intelligent agents. Agents being cooperative entities, considerable attention is given to facilitating cooperation among the partners of a VE, which forms the basis for their common understanding and a decentralized control and management of the enterprise. The DAI community does not address the concept of an EE.

3.2.5 Enterprise Modelling and Integration

The Enterprise Modelling and Integration community views a VE as "an association of entities, or partners, formed with the view of together satisfying some jointly agreed-on mission", [Bernus, 1997]. In [Bernus and Uppington, 1998], they state that a VE forms a coordinated (with information links at all levels of the decision hierarchy) value chain of a product. In the TOVE (TOronto Virtual Enterprise) project, they have a distributed view of an enterprise, where organizational units communicate and cooperate in problem solving [Fox et al., 1993b]. In [Vernadat, 1996], there is no distinction between an EE and a VE. Both EE and VE are defined as an enterprise mostly made of functions provided by other enterprises and relying heavily on the use of standards, computer communications and electronic data interchange. In [Olegario, 2001], a VE is defined as a temporary alliance of independent companies with complementary core competencies that appear as a single entity to the external environment.

Although the main literature refers to a VE only, there is work being done in defining a design methodology for VEs, where the lifecycle of a VE is taken into account, [Bernus, 1997] and [Szegheo and Petersen, 1999]. Hence, the Enterprise Modelling and Integration community seems to view the aspect of VEs in a broader context than some of the other communities.

3.2.6 Relationship between Extended and Virtual Enterprises

The main source of literature on the distinction between EE and VE and their relationship is based on the contributions from the international research project, Globeman 21, [GLOBEMAN 21, 1999]. In this project, they made a clear distinction between the two concepts and defined their relationship in terms of the lifecycles of the two entities. They refer to the concept of EE as a network of enterprises that collaborate and share core competencies. This network becomes operational when they need to fulfill a specific customer demand and does so by forming a VE, which delivers to the customer and then dissolves. The VE will then consist of some of the partners of the network. Several VEs can be formed from this network and can operate in parallel. The relationship between EE and VE were initially proposed in [Vesterager et al., 1999] and later discussed in [Szegheo, 1999] and [Vesterager et al., 2001].

The Globeman 21 framework for EE, which illustrates the relationship between the two concepts in terms of their lifecycle phases is shown in Figure 3.1. It can be seen that when the VE enters it's operational phase, the lifecycle of the product that is developed by the VE begins.

This view of the EE and the VE assumes that there is always an EE, from which a VE is formed. This view seems to be shared by the manufacturing and the Enterprise Modelling and Integration communities. The other communities who only define VEs assume that it is an independent entity and do not consider where the partners come from, nor assume that the partners have prior knowledge of one another before the formation of the VE.

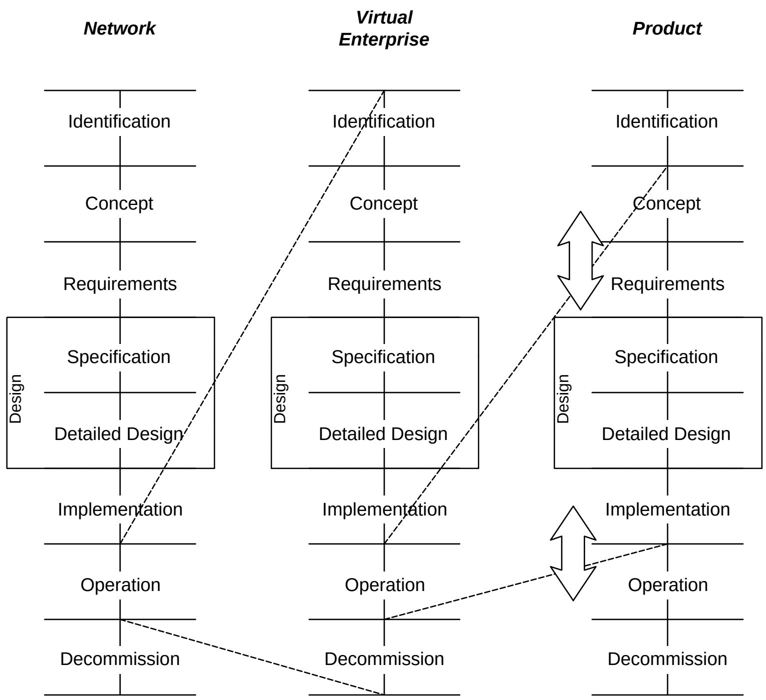

Figure 3.1: Globeman 21 Framework for Extended Enterprises, (Vesterager 1999)

3.3 VERAM

The need for supporting the rapid formation of VEs and a VE Reference Architecture were identified and the ideas for one were presented in the Globeman21 project, [Vesterager et al., 1999]. Figure 3.1 shows this. These ideas were later developed in the project Globemen, the successor to Globeman21, [Karvonen, I. et. al, 2001].

An architectural framework, called Virtual Enterprise Reference Architecture and Methodology (VERAM), which aims to support the set up (or formation) and operation of VEs was presented in [Kazi and Hannus, 2002] and [Zweger et al., 2002]. It is inspired by GERAM (Generic Enterprise Reference Architecture and Model), [IFIP-IFAC Task Force, 1998]. VERAM acts as a framework for the positioning of key components that support VEs such as elements that support modelling, set up (or formation) management and ICT support of VEs, reference models, supporting tools and infrastructures.

VERAM consists of three layers as shown in Figure 3.2. The three layers are:

1. Virtual Enterprise Concepts

2. Virtual Enterprise Reference Architecture (VERA)

3. VERAM components

Examples of how VERAM can be used to develop VEs are available from [Bernus and Noran, 2002] and [Bernus et al., 2002].

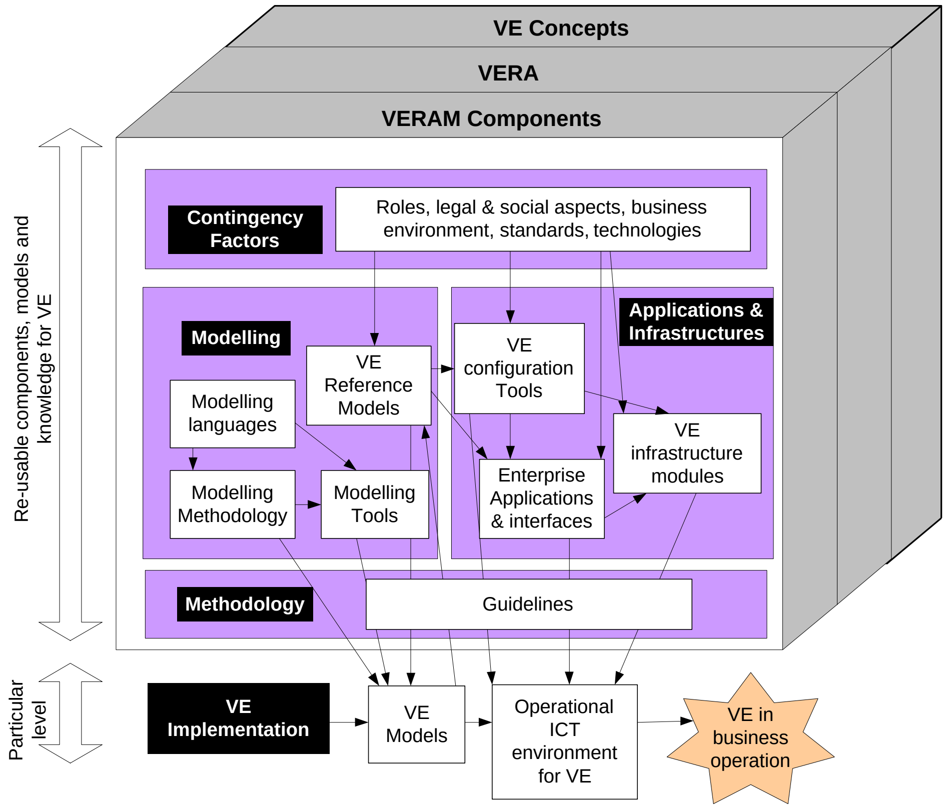

Figure 3.2: VERAM - Virtual Enterprise Reference Architecture and Methodology, (Zweger 2002)

3.3.1 Virtual Enterprise Concepts

The Virtual Enterprise concepts layer introduces the concepts of the VE and the Enterprise Network. The relationship between the Enterprise Network and the VE is illustrated in Figure 3.1. The Enterprise Network is described as a cooperative alliance of enterprises established to jointly exploit business opportunities through setting up VEs. They define a VE as a "customer solutions delivery system created by a temporary and a reconfigurable ICT enabled aggregation of core competencies". The main purpose of the Enterprise Network is to establish mutual agreement among its members on issues such as common standards, intellectual property rights, standards so that these time-consuming issues are dealt with by the time a VE is formed to deliver to a customer, [Zweger et al., 2002]. The VE concepts can also include a VE ontology, [Kazi and Hannus, 2002]. See Section 3.5 for a discussion on VE ontologies.

3.3.2 Virtual Enterprise Reference Architecture

VERA helps answer questions such as *what* to consider and *when* to consider something during the set up of a VE, [Vesterager et al., 2002]. VERA is based on the modelling framework and associated concepts of GERAM, named GERA (Generic Enterprise Reference Architecture), ([IFIP-IFAC Task Force, 1998] and illustrates the logical, recursive relationship between the Enterprise Network, the VE and the product. GERA contains three modelling dimensions:

1. Lifecycle view - which describes the phases in the lifecycles of each entity. Figure 3.1 illustrates this view of VERA.

2. Genericity - which comprises generic, particular and partial levels. The generic level includes what is general, the particular level denotes the specific entity in question and the partial level denotes what is common to a group or type of entities.

3. Modelling view - which comprises of function, information, organization and resources.

The activities that should be considered during the set up of a VE, in particular within VERA, are discussed in [Tølle and Vesterager, 2002].

3.3.3 VERAM Components

VERAM components consist of tools, applications and models that can be used during the formation and operation of VEs and Enterprise Networks. It also contains guidelines that indicate how these tools, applications and models should be used in practice, i.e. a methodology which describes how an enterprise should use the various components of the VERAM architectural framework, [Zweger et al., 2002]. A brief description of the main components are given below:

- Modelling - this part allows enterprises to analyse, prepare and (re)-design the VE's business processes, partner roles, contracts, etc. It contains modelling languages which define the generic modelling constructs, modelling methodologies to support the modelling process by means of guidelines, modelling tools to support the modelling process and VE reference models which capture characteristics that are common to several VEs. An example of how different types of reference models can be mapped onto VERAM is shown in [Tølle et al., 2002].

- Applications and infrastructures - this part contains the components that perform or support the processes as described in the modelling section. They provide the technological realization of the VE.

- Methodology - this part contains guidelines on modelling.

- Contingency factors - this part contains "situational factors" or conditions which affect the set up of the VE and "design parameters" which describe different set ups for VEs.

3.4 Virtual Enterprise Classifications

Similar to VE definitions, there are many VE typologies and classifications. Some of the classifications that are relevant to the work presented in this thesis are presented in this section.

In [Camarinha-Matos and Afsarmanesh, 2001] and [Camarinha-Matos et al., 1998], they classify VEs according to the following facets:

- Duration - some VEs are established towards a single business opportunity whereas others may span over a number of business opportunities, thus lasting longer.
- Typology of the network - some VEs may have a fixed structure where partners are not allowed to join after the VE is formed whereas in some VEs, the structure may be more dynamic where partners are allowed to leave and join.
- Participation - an enterprise or a partner in a VE may be allowed to participate in just one VE or several VEs simultaneously.
- Coordination - which reflects the type of organization. For example, centralized coordination reflects a dominant partner whereas a democratic alliance indicates that there is no dominant partner. Another approach is a federation of partners where the partners achieve their goals by creating a joint coordination structure.
- Visibility scope - related to typology and coordination. If the VE is viewed as a network of nodes or partners, this reflects the dependencies among the partners.

In [Bernus et al., 1997], they identify several different types of VEs:

- One-of-a-kind engineering endeavours, organized as major projects, often on an international scale.
- Consortia for production, research or service - an alliance of partners limited to a common mission.
- General project group set up by business executives.

In [Tølle, M. et. al., 2003], a VE lifecycle-based approach is used to distinguish different types of VEs (the lifecycle phases are shown in Figure 3.1). They propose that the type of VE that is formed depends on the customer request. For example, if a customer requests for a quotation of a specific product, then a configuration or quotation VE is formed. Similarly, if a customer requests for the implementation, construction or the production of a specific entity, then a construction, production or project VE is formed. The different types of VEs proposed by them are listed below:

- Configuration or quotation VEs during the concept, requirements and preliminary design phases of the lifecycle.
- Construction, production or project VEs during the preliminary design, detailed design and implementation phases of the lifecycle.
- Service or maintenance VEs during the operation phase of the lifecycle.

- Decommission VEs during the decommission phase of the lifecycle.

For our work, we consider the project-based view of VEs, [Bernus et al., 1997], where a VE is considered analogous to a project group set up to achieve a specific objective. The members of the project team thus corresponds to the partners of a VE. The project-based view or project-oriented organizations have been considered as a way of organizing work to allow for the adaptability and agility that is required in today's business world. This view is taken by the Virtual Design Team (VDT) at Stanford University, e.g. [Levitt et al., 2001].

3.5 Virtual Enterprise Ontologies

The most commonly quoted definition of an ontology is "*a formal explicit specification of a shared conceptualization*", [Gruber, 1993]. Several kinds of representations, such as thesauri and data models, are often referred to as ontologies although they lack formality. Nevertheless, there are two essential components that are common to all uses of the term "ontology", [Gruninger, 2003]:

1. a vocabulary of terms

2. some specification of meaning for the terms.

Ontologies have recently received enormous attention, in particular due to the interest in The Semantic Web, [Berners-Lee et al., 2001], and the developments in the field of multi-agent systems. Tim Berners-Lee, the creator of the web, considers ontologies as a major part of his work on The Semantic Web and envisions that it will allow software agents to communicate among themselves. The growing interest in ontologies in the agent community is no doubt due to the increasing use of agent-based systems in the user community. In fact, the Roadmap for Agent-based Computing, compiled by Agent Link, identifies ontologies and the support of semantic infrastructures for open agent communities as one of the technical challenges faced by the researchers and developers of agent-based systems in the near future, [Luck et al., 2003]. Similarly, there is a need for ontologies supporting VEs as VEs involve information exchange between heterogeneous entities, over heterogeneous tools and applications. In the VERAM framework, a VE ontology presents VE concepts and VE reference architectures and focuses on the description of shared concepts related to VEs for the purpose of enabling shared understanding and communication, [Kazi and Hannus, 2002].

In [Gruninger, 2003], Gruninger describes a language for Enterprise Modelling as a language for specifying ontologies and describes the most widely used ones: Unified Modelling Language (UML) for the specification of class diagrams for object-oriented software, EXPRESS model information, in particular in the design, building and maintenance of products, DAML+OIL and KIF. Gruninger describes an Enterprise Modelling Ontology as something that must be able to represent concepts in several domains, such as activities, time and resources, as well as integrate these domains and support interoperability among tools using different ontologies. He describes three such ontologies: Edinburgh Enterprise Ontology, TOVE and ENV 12204. In the following subsections, I will describe some of these modelling languages and ontologies that I believe are most relevant to the work presented in this thesis.

It is perhaps important to mention that there have been initiatives to develop a Unified Enterprise Modelling Language (UEML), which will contribute to a clear definition of the common semantics of formalisms and support improved interoperability and communication between modelling agents in heterogeneous environments, [Chen et al., 2002].

Agent-based ontologies for modelling VEs or electronic organizations have been proposed by Dignum et. al., [Dignum and Dignum, 2002]. They view organizations as agent societies and the concepts of norms and institutions are used to cope with the challenges of social order. In [Vázquez-Salceda and Dignum, 2003], they describe how an electronic organization can be specified by defining formal relations between the norms that specify the institutional regulations and the rules and procedures within the organization, such that agents will operate within the organization according to the institutional norms.

Although ontologies specifically for VEs have not been addressed, we believe that ontologies for enterprises, in general, will address issues that need to be addressed by VE ontologies too. It is important to highlight that the need for an ontology is mostly due to information exchange among people and computers and to support interoperability, which is one of the most important issues in VEs.

3.5.1 Languages for Enterprise Modelling

DAML+OIL is an integration of two separate efforts, DARPA Agent Markup Language (DAML), [DAML, 2003], and Ontology Interface Layer (OIL), [Fensel et al., 2003], and is the successor to OIL. The most distinguishing thing about DAML+OIL is that it has been primarily designed for The Semantic Web and is intended to be compatible to emerging web standards such as RDFS (Resource Description Framework Schema) and is aimed at supporting the use of ontologies across the web.

KIF (Knowledge Interchange Format), [Genesereth and Fikes, 1992], was designed to support the interchange of knowledge among heterogeneous computer systems and is based on first-order logic. KIF has been used as a language to express information to be exchanged among a set of agents, see [Genesereth and Ketchpel, 1994] and [Genesereth, 1997].

3.5.2 Ontologies for Enterprise Modelling

The Edinburgh Enterprise Ontology, [Uschold et al., 1998], was developed in the Enterprise Project at the Artificial Intelligence Applications Institute, University of Edinburgh, for integrating methods and tools for capturing and analysing key aspects of an enterprise, based on an ontology for enterprise modelling. The Edinburgh Enterprise Ontology has five top-level classes for integrating the various aspects of an enterprise: activities and processes, strategy, organization, marketing and time. While it is very strong on the strategy related concepts (e.g. goals and policies), it does not support the characterization of products and services.

Of particular importance to the work presented in this thesis is TOVE, developed by the Enterprise Integration Laboratory, University of Toronto, which provided inspiration for this work, [Fox et al., 1996] and [Fox et al., 1998a]. Although the name

TOVE includes VE, it does not explicitly address the notion of a VE. It is focused on enterprise integration and the development of a computerised model that can be understood by both human beings and computers, [Fox and Gruninger, 1994]. However, TOVE does provide a good foundation for the development of models for VEs. A brief description of TOVE is given in the following subsection.

3.5.3 TOVE: TOronto Virtual Enterprise

TOVE provides a rich and precise representation of generic knowledge about an enterprise such as goals, organizational structure and activities. Three important aspects of TOVE are:

1. It can be used to describe an enterprise in a formal way, thus describing an enterprise in a computable form as well as avoiding the possibility of ambiguity. An example of this can be seen in [Gruninger et al., 2000].

2. It focuses mostly on the operational phase of the lifecycle of an enterprise. However, it is applicable to the complete lifecycle of a VE, (e.g. [Gruninger et al., 2000]).

3. It allows the representation of several domains of an enterprise such as activities, [Gruninger and Fox, 1994], requirements, [Lin et al., 1996], cost, [Tham et al., 1994] and resources, [Fadel et al., 1994].

The TOVE project introduced the notion of a "common sense enterprise model", which is a model that is able to answer common sense questions about an enterprise, [Fox et al., 1993b] and [Fox and Gruninger, 1998]. The model answers questions using its inference or deductive capabilities. In this respect, they proposed an evaluation criteria for such models, where the competency of a model is determined by its ability to answer questions.

Another important aspect of TOVE is the agent-based infrastructure proposed in [Barbuceanu and Fox, 1994] and [Fox et al., 1996]. In this model, an agent (information agent to be more specific), is introduced as a component of the information structure supporting collaborative (or virtual) enterprises. The enterprise is modelled as a set of agents that collaborate. They distinguish between two types of agents: functional and information agents. Functional agents plan and control activities in the supply chain, while information agents support other agents by providing information and communication services. There are different kinds of functional agents, each representing a function in the enterprise. They are order acquisition agent, logistic agent, scheduling agent, resource agent, dispatcher agent and transportation agent. Description logic is used to model the agents. This particular agent-based infrastructure for VEs will be discussed in detail in Section 5.2.4.

3.6 Virtual Enterprise Formation

The creation phase of the lifecycle of a VE is one of the less developed phases, [Rabelo et al., 2000]. It is interesting to have an overview of how the formation of a VE is considered within the lifecycle of a VE.

Characteristics	**Manuf.**	**Org. Res..**	**Comp. Sc.**	**DAI**	**Ent. Mod.**
Partnership of enterprises	X				
Strategic alliance of companies		X			
Collaboration among partners	X				X
Temporary network of independent companies	X	X	X	X	
Exists for a limited time				X	
Able to gather & integrate flow of information		X			X
ICT		X	X		X
Virtualness		X	X		
Goal-oriented				X	
Commitment-based				X	
Shares skills, costs, risks and markets		X		X	

Table 3.1: Main Characteristics of VEs

In VERAM, the VE is formed when the EE goes into operation and the product is developed during the operation phase of the VE. Thus, we can say that the VE is formed during the identification, concept, requirements, specification and detailed design phases of the lifecycle of a VE, see Figure 3.1.

Another description of the lifecycle of a VE is used in [Camarinha-Matos and Afsarmanesh, 2001], where four phases: creation, operation, evolution and dissolution describe the lifecycle. It is interesting to note that creation phase is the first phase and it includes the selection of partners, negotiation of contracts with the partners and the definition of access rights. Oliveira et. al define the lifecycle of a VE as consisting of the four phases: identification of needs, selection of partners, operation and dissolution, [Oliveira and Rocha, 2000].

The above three views of the lifecycle of a VE are aligned, although the view taken by VERAM is more extensive as it considers the lifecycle of a VE within a broader context. Thus, it takes into account that there may be preliminary work done prior to the lifecycle of the VE in the identification of concepts and requirements. For our work, we will consider this view of the lifecycle of a VE. In particular, we consider the selection of partners to take place during the detailed design phase of the lifecycle.

3.7 Characteristics of Virtual Enterprises

The main characteristics of VEs expressed in the definitions reviewed in Section 3.2 can be summarized as shown in Table 3.1.

The characteristics listed in Table 3.1 can be integrated to define a set of characteristics for a VE as described below:

Partnership of enterprises that collaborate : or a strategic alliance, where the enterprises are aligned not just at the activities level, but also at the level of their business goals. Such an alliance requires trust, commitment and a mutual interest among the partners to achieve their goals. The partners achieve their goals through collaboration.

Temporary network of enterprises with a limited lifetime : where two or more independent enterprises get together to exploit a particular market opportunity or to meet a specific customer demand. Such a network will work together and collaborate until they meet the customer's demands and then disseminate. Thus, they have a limited lifetime.

Communication and information flow : supported by Information Technology, where there is a lot of emphasis on the importance of enhanced intra- and inter-enterprise communication and the flow of information among the enterprises. There is a need to improve the social and cultural skills in an enterprise. Most of the definitions of VEs emphasize the importance of Information Technology for the existence of both of these entities. This emphasis is noted across all areas that were reviewed. This characteristic is important to VEs since to achieve collaboration among the partners, they have to communicate and exchange information.

Sharing of skills, costs and markets : where the partners of a VE share their skills by having each enterprise focus on the area of competence that they specialize in. The trend to move away from outsourcing is replaced by enterprises forming a partnership where they can share complementary competencies. This also encourages enterprises to focus their attention on their core competency. Similarly, costs and markets are also shared by enterprises. So, rather than competing with peer enterprises, a strategic alliance is formed to share the market, skills, costs, risks and profits.

Goal-oriented and commitment-based : This characteristic is a consequence of some of the other characteristics described above. For example, if a VE is formed to meet a specific customer demand within a limited amount of time, the VE will have to work in a goal-oriented manner to meet that demand. Similarly, if the enterprises in a VE share their costs, they each have to make a commitment to meet their goals in order to succeed.

3.8 Definition of a Virtual Enterprise

Based on the above review of VE related literature, an answer to **RQ1**, (What is a VE and how is it formed?) can be proposed.

- **What is the definition of a VE?** A VE is *a group of enterprises that collaborate to achieve a specific goal.*

VE Characteristics	**Agent Property**
Partners that collaborate	Autonomous agents that have social ability
Temporary and limited lifetime	Computational entities and can support efficient formation of VEs
Communication	Social entities
Consists of a variety of skills	Can be defined to possess a specialized set of skills
Goal-oriented and commitment-based	Proactive and work towards achieving goals

Table 3.2: VE Characteristics and Agent Properties

- **Do all (instances of) VEs have the same formation process?** There are similarities in the formation process of all VEs. This is why it is possible to develop a framework such as VERAM to support the formation of VEs. However, there may be differences depending on the industry and the particular product that the VE will develop. This is indicated by the fact that VERA has dimensions of genericity and the contingency factors included in the VERAM components.

- **How is the formation of a VE related to the rest of the lifecycle of a VE?** The GERA view of a VE shows the phases of the lifecycle of a VE. The formation of the VE takes place during the first 4 phases of its lifecycle (namely during the Identification, Concept, Requirements and the Preliminary and Detailed Design phases). VEs can be formed by configuring the right group of enterprises from the Enterprise Network to deliver to a customer. The enterprises in a VE are selected based on their competencies and their willingness to share their competencies, resources and markets.

3.9 The Role of Agents in VEs

In this section, the reasons why agents are a suitable means of supporting VEs are considered. First, the characteristics of VEs identified in Section 3.7 and how they correspond to agent properties are considered, see Table 3.2.

One of the requirements of technologies supporting VEs is *coordination* functionalities such as distributed resource management and scheduling, [Camarinha-Matos and Afsarmanesh, 1997]. In [Klein, 1996], Klein defines the need for coordination or collaborative processes when the task to be performed by a single entity is too large. VEs are formed in such situations, where the partners of a VE will perform the task(s) through collaborative processes. Klein suggests flexible coordination approaches in organizations such as explicit representation of their goals. Agents being *goal-oriented* or pro-active, thus, becomes an appropriate means of supporting coordination.

The distributed nature of agents does not require the co-location of the partners of a VE. VEs are formed by several partners agreeing to collaborate and share skills and information. Thus, the role of *negotiation* in a VE is central to the formation of a

VE as well as the operation and success of a VE. The short lifespan of the VE means that the partners that participate in one VE may also be negotiating on a contract with another VE. By delegating agents to do this job, the partners have the time to do the actual work required in the VE. The ability to delegate responsibilities to agents and agents being reusable components makes them a suitable means of representing the partners in a VE.

VEs are composed of partners that collaborate, yet they may also be competing. This raises an interesting notion about agents. While agents are goal-directed and pursue their own goals, they are also capable of behaving cooperatively. Cooperative behaviour of agents is necessary to achieve a common goal with other agents, through collaboration. Sandholm defines self-interested agents as agents that act to maximize individual profit while cooperative agents will act to maximize social welfare, i.e. for the good of the VE, [Sandholm and Lesser, 1997]. An interesting distinction between self-interested or competitive and cooperative agents, in the context of electronic commerce, was given in [Guttman and Maes, 1998]. They define *competitive negotiation* between two parties as resolving a conflict over a single mutually exclusive goal whereas *cooperative negotiation* is when two parties negotiate over multiple independent, but non-mutually exclusive goals. For example, if a VE and a partner negotiate over the price of work, it can be considered as competitive negotiation, whereas if they negotiate over the price as well as the delivery date and the time period when the work will be conducted, this can be considered as cooperative negotiation.

3.10 Discussion

There is a considerable amount of interest in VEs from several research and industrial areas. Although there are different opinions about the concept of VE and the focus differs, there is a general consensus of what a VE is. The easiest way to describe a VE is in terms of its characteristics, (see Section 3.7).

An important aspect of VEs is communication and information flow among the partners of a VE, which may be supported by computers (or software agents). Thus, there is a need for the information to be represented and described in a way that can be understood by more than one enterprise as well as by computers. This is an important issue that is dealt with in the field of Enterprise Integration, (see [Gruninger, 2003] for a discussion). Thus, some of the work done in supporting VEs has been inspired by the Enterprise Integration community and the two areas of work have a lot of common aspects.

VERAM highlights the different kinds of components that are required to support the formation and operation of VEs. Among these is the support to model a VE and the applications and infrastructures to support the realization of the VEs. In particular, there is a need to be able to form VEs and move them to an operational phase as soon as possible. The short lifetime of VEs requires that VE should be formed as quickly as possible. Thus, there is a need to support the formation of VEs quickly and efficiently.

Finally, based on the characteristics of a VE that were identified, the role of agents in the context of VEs was defined.

Chapter 4

Agent-based Models

4.1 Introduction

Several approaches, techniques and methods have been used to model a VE. An overview of these is given in [Gastinger and Szegheo, 2000]. Agent-based modelling is no doubt an important means of modelling the VE. However, there are several other approaches that do not use agents. For example, [Yu and Mylopoulos, 1993] and [Fuxman et al., 2001] describe a goal and actor-oriented organizational model for an "intentional" organization. In their model, an organization involves actors who have strategic dependencies among each other. The types of the dependencies are goal, soft goal, task, and resource and these dependencies describe the agreement between the actors. This model defines the actors by their interfaces and dependencies. But, it does not describe the internal contents of the actors themselves. e.g. what the goals of an actor are. The notion of Active Knowledge Modelling is used in [Petersen and Szegheo, 2000] and [Lillehagen et al., 2002] to model a VE. An Active Knowledge Model is a visual externalization of enterprise aspects that can be operated on (viewed, traversed, analysed, simulated, adapted and executed) by industrial users, [Lillehagen et al., 2002].

In this chapter, the concepts of agent-based (or agent-oriented) modelling and modelling methodologies will be introduced. Work done on teams and coalitions of agents are reviewed and agent-based models for the formation of VEs are presented. Finally, the answer to **RQ1** will be refined to provide an agent-based definition of a VE.

4.2 Agent-based Modelling

Agent-orientation or agent-based concepts allow seamless integration of business rules modelling and information modelling and attempts to capture the dynamic aspects of business situations, [Tavetar and Wagner, 2000]. In [Wagner, 2000], he distinguishes between passive and active entities; passive entities are objects and active entities are agents. It is argued that object orientation does not capture communication and interaction in the high-level sense of business processes.

Extensions have been proposed to the Unified Modelling Language (UML), [UML Resource Centre, 2003], to allow agent-based modelling, Agent UML [Bauer et al., 2001]. In particular, Agent UML proposes means of modelling interactions among agents. In [Yu, 2001], agents are described as "intentional actors", where the actors are strategic entities and relationships between actors can be modelled. The relationships can indicate different types of dependencies such as goal, task and resource dependencies.

An agent-based approach for the design of organizational information systems, called Agent-Object-Relationship (AOR), was proposed in [Wagner, 2000]. In this approach, an organization is modelled as a complex "institutional agent" defining the rights and duties of its subagents that act on its behalf. The information items in the system are viewed as beliefs or knowledge and mentalistic notions such as commitments and claims can be modelled. He also proposed a graphical notation for modelling. The notion of an agent is assumed as an entity that senses or perceives something, reasons about it and then acts.

Kendall argues that role modelling is appropriate for intelligent agent systems as they emphasize social or interactive behaviour, work towards accomplishing a goal and role models can be patterns that can be documented and shared, [Kendall, 1998]. Based on characteristics of agents such as goal-oriented behaviour and social ability, a role is defined to have a context, responsibilities (services, tasks and goals), collaborators (other roles that it interacts with), external interfaces (access to services), relationships to other roles (aggregation, specialization, etc.), expertise (domain ontology, task models), coordination and negotiation capabilities and learning capabilities. This approach is important to the area of VEs as such patterns of roles and role models can be maintained in a reference library that can be used by VE creators to enable fast and efficient formation of VEs.

4.3 Methodologies for Agent-based Modelling

Another area of research that has gained increasing attention recently has been the development of methodologies for the design and specification of agent-based systems. One of the most cited methodologies is GAIA, which is motivated by the fact that current methodologies do not support interactions and agent organizations, [Wooldridge et al., 2000]. It considers a societal view of agents and supports the design of systems from the requirements stage to the detailed design and implementation stages. The main concepts are that of roles and interactions, where a role model and an interaction model are created and the agents and their capabilities are specified based on these. A role has attributes such as activities, permissions (what a role is allowed to do) and responsibilities.

Another methodology is the Australian Artificial Intelligence Institute (AAII) methodology which distinguishes between an external model and an internal model of an agent, (taken from [Wooldridge, 2002]). The external model considers the agent's interactions with other agents while the internal model is concerned with the internal contents of the agent such as beliefs and intentions. This methodology advocates the definition of the agent using the Belief Desire Intention (BDI) approach, [Rao and Georgeff, 1998].

Kendall et. al. propose a methodology for developing agent-based systems for enterprise integration. They propose an agent-based system corresponding to an IDEF (ICAM definition) model by mapping IDEF concepts to an agent-based system by using use cases, [Kendall et al., 1996]. An actor (or a resource) in the IDEF model is mapped to an agent, a function with a control output is an agent's goal and plan, the input from an actor corresponds to the beliefs and multiple actors per function are mapped to collaborations.

A methodological framework for the design of inter-enterprise cooperation, within the context of a VE, is proposed in [Tata and Boughzala, 2003]. They proposed three models of integration: by data where agents share data, by processes where agents synchronize their actions and processes and by knowledge where agents use and share knowledge to perform some common processes. They describe how coordination can be achieved by such integration.

4.4 Agent Teams and Coalitions

We view a VE as a team of partners. Thus, it is important to see how the concept of a team is considered in the agent and DAI communities. Contributions have been made to define teams and teamwork. Most of this work is based on agent theory and is aimed at providing support to the design of teams of agents. For example, a means of forming teams of agents at runtime is described in [Tidhar et al., 1992]. Here, a team is defined in terms of a joint plan and the execution of a joint plan and the notion of skills is used to define what a team can or cannot achieve. They also suggest some strategies for the formation of teams and the representation of the knowledge in a team, [Tidhar et al., 1998].

Other models of teamwork include STEAM [Tambe, 1997] and team formation by dialogue in [Dignum et al., 2000]. STEAM is based on the joint intentions theory, [Cohen and Levesque, 1991], which has been a source of inspiration for work on teams in the agent and DAI community. Another important contribution is Jennings' joint responsibility framework, [Jennings, 1993a], based on human teamwork models. This model is based on the idea that being a part of a team implies some sort of responsibility towards the other members of the team; joint responsibility. Jennings built on the work of Cohen et. al. by distinguishing between the commitment that underpins an intention and the associated convention, where a commitment is a pledge or a promise to do something, and conventions are means of monitoring commitments, e.g. specifying when a commitment can be abandoned.

In [Barbuceanu and Lo, 2000], they propose a formalism for how individual agents can team up with other agents, to form an organization or a team, to achieve their goals. The team is determined by the total cost of it.

The STEAM teamwork model is used in [Tambe et al., 2000], which describes a framework for finding the right agent for an organization in cyberspace. Their work focuses on enabling software developers to build large-scale agent organizations in cyberspace. The system provides a means of defining organization roles and their requirements and matching agents that meet these requirements. More recently, there has been work done in immersing a team of agents within a human organization [Pynadath et al., 2000].

The RETSINA model of teamwork is described in [Sycara and Giampapa, 2002]. RETSINA provides matchmaking capabilities that have been used to match a requester and a service provider, through a middle agent, [Sycara et al., 1999], and these capabilities have been used in AgentStorm to form a team of agents that provide support to human beings, [Sycara and Giampapa, 2000].

The above mentioned models of teamwork mainly address the possibility and capability of an individual to join a team. They are designed to support the automation of teamwork and use the notion of joint plans and plan execution and rely on tasks that are described apriori. While they address issues that are relevant to our model of the VE, they can be considered as complementary rather than alternative approaches to the one presented in this thesis.

An important contribution in coalition formation among agents was presented in [Sandholm and Lesser, 1997]. Each entity that wants to form a coalition is represented by a negotiating agent that is self-interested. Sandholm et. al. considers coalition formation as consisting of three activities: coalition structure generation where the agents are partitioned into coalitions within which they coordinate their activities, solving the optimization problem where the agents pool their activities to solve them together and dividing the value generated by the activity among the members of the coalition.

4.5 Agent-based Models for VE Formation

Agent-based models for VEs, where the focus is on the formation of VEs, were not explicitly reported in the literature. However, several architectures, such as the ones described in [Oliveira and Rocha, 2000] and [Rabelo et al., 2000] address the VE formation phase. From an agent and DAI perspective, ideas used in RETSINA and the matchmaking capabilities in LARKS [Sycara et al., 2002], (these systems are described in Chapter 5), will be useful in the formation of VEs.

The research in Web Services is another area where there will be relevant models for the selection of partners for a VE. In a Web Services-oriented view of a VE, the partners of the VE will provide services to or consume services from each other within an electronic market. This view of a VE is discussed in [Petersen et al., 2002]. Similarly, in [Field and Hoffner, 2002], the selection of partners for a VE was considered in terms of Web Services, where the issue of representing the partners were addressed and some essential properties for the matchmaking engine were proposed.

Ideas from multi-attribute utility theory (MAUT) and constraint optimization, (see [Keeney and Raiffa, 1976]) and multi-attribute auctions, [Bichler et al., 1999], have been used as evaluation techniques for the selection of partners. For example, in [Barbuceanu and Lo, 2000], MAUT is used to define the optimum team of agents. A multi-attribute negotiation protocol, which extends the well-known English Auction, is proposed in [Oliviera et al., 1999]. In this negotiation protocol, attributes other than the price can be taken into account, which is the case in selecting the partners for a VE.

4.6 Agent-based Definition of a VE

The answer to **RQ1** will now be refined to provide an agent-based definition of a VE.

What is the definition of a VE? - A VE is *a team of agents, which may be organizations, human beings or agents, that collaborate to achieve a specific goal.*

This will be used as a working definition for the work described in this thesis.

4.7 Discussion

The area of agent-based modelling can be related to a wide spectrum of research such as agent-based methodologies and agent theories. The agent-based models from the agent community seem to be driven by agent theories, such as the work on teams and teamwork. Another approach was to take object-oriented modelling techniques, such as UML, and propose extensions to it to model agent properties.

The approach taken in this thesis is similar to the approaches that were inspired by organizational modelling and business process modelling, where the entities and interactions within an enterprise will be considered.

Chapter 5

Agent and Multi-agent Architectures

5.1 Introduction

Several authors have proposed software agents and DAI as a means of supporting dynamic organisational forms such as VEs. The first to propose the use of agents in supply chains[1] was [Fox et al., 1993a], reported in a survey on using agents for intelligent manufacturing systems, [Shen and Norrie, 1999]. Other references to using multi-agent systems for supply chain management include [Swaminathan et al., 1998]. In [Vernadat, 1996], he suggests agent-based architectures as a means of meeting the requirements for increased modularity, reusability and maintainability of system architectures to support manufacturing. In [Levitt et al., 2001], they propose an agent-based modelling approach to project-oriented organisations engaged in knowledge work. The participants of a VE are considered as agents in [Bernus et al., 1997], whose autonomous behaviour needs to be coordinated. In [Bernus and Baltrusch, 2002], agents have been proposed as a means of supporting the control and decision framework of a VE.

In this chapter a review of multi-agent architectures or agent-based infrastructures for supporting VEs and agent architectures (micro aspects of agents, [Wooldridge and Jennings, 1995]) for the partners of a VE is given. Based on the current state-of-the-art, the limitations of current agent-based approaches are discussed.

5.2 Multi-agent Architectures for Supporting Formation of VEs

For the work presented in this thesis, the formation of a VE is considered within the context of an electronic market. Thus, of particular relevance is the work done in representing VEs within the context of an electronic market. In the rest of this section, multi-agent architectures for supporting the formation of VEs that are based on markets and brokerages are reviewed. In addition, a few architectures that use mobile agents

[1] The involvement of the companies in the supply chain at the assembly stage or the conceptual design stage of a product begins to look like set of collaborating partners, [Childe, 1998].

and the notion of an information agent are also reviewed.

5.2.1 Market Architectures

The AVE (Agents in Virtual Enterprises) project, described in [Fischer et al., 1996], provides a description of how agents can be used in the formation of a VE. One of the main components of the system that was proposed is an electronic VE market, where different enterprises can announce and obtain various information. The partners of a VE are enterprises. Fischer et. al. describes the selection of a partner as a process of matching VE goals (or subgoals) to the partial processes within the different enterprises that represent the VE.

This approach was further developed as a multi-agent architecture in [Oliveira and Rocha, 2000] and [Rocha and Oliveira, 2001], where they focus on the formation of the VE, where agents that represent the partners of a VE negotiate to become a part of the VE. The agents conduct a multi-attribute negotiation and have the ability to learn from past experiences. This approach distinguished between a "market agent"' and an "enterprise agent". The market agent plays the role of a coordinator in the electronic market, where its main goal is the formation of the VE. An enterprise agent represents an enterprise that is interested in becoming a member of a VE. While this work considers a wider aspect of multi-agent systems such as a sophisticated negotiation protocol and learning agents, it does not describe a holistic model of the VE and does not address the aspect of team formation explicitly.

A language called LARKS, for agent advertisements and requests, was defined in [Sycara et al., 2002]. They also present a flexible and efficient matchmaking process, where both syntactic and semantic matching can be conducted. The matching process uses five different filters to narrow down the set of candidates. Some of these ideas can be used to match the partners to the requirements of a VE during the formation of a VE. LARKS and the matching process are currently being incorporated into RETSINA (Reusable Task Structure-based Intelligent Network Agents) architecture, which is a reusable, distributed, multi-agent infrastructure to coordinate intelligent agents in gathering, filtering, and integrating information for the Internet and for decision support. It uses the notion of a middle-agent, which performs functions that can be analogous to those of a broker.

An institutionalized electronic organisation (e-institutions) to effectively design and construct agent societies was proposed in [Esteva et al., 2001]. The e-institutions are specified by a formal approach and contain three entities: roles, dialogic frameworks and scenes. The interactions between agents can be defined by a role-role relationship. By sharing a dialogic framework, heterogeneous agents are able to exchange knowledge with other agents. A scene is specified by a graph where the nodes of the graph represent the different states of the agent society and the arcs connecting the nodes represent the agent's actions that changes the state of a scene.

5.2.2 Broker Architectures

The Oxford English Dictionary defines a broker as an "agent buying and selling for others, middleman". The concept of a broker has been used in the design of agent-based architectures to support VE, in particular to support the formation of VEs.

In this context, brokers have been referred to as "cybermediaries", where a broker performs mediation tasks in electronic commerce, [Ávila et al., 2002]. Ávila et. al. proposes a taxonomy for the functions that can be performed by a broker within the context of VEs; explicit functions, which the broker makes available to the clients, such as selection of resources and integration of resources and implicit functions, which the broker uses to perform the explicit functions, such as the selection of algorithms for resource selection and interaction with other brokers.

An agent-based brokerage architecture was proposed in [Rabelo et al., 2000] for the moulds industry. They focus on the creation of the VE by means of a broker agent, where a client's order is received directly or via a broker. The client's order consists of a description of the deliverable, such as the size of the mould, the due date and the mould material. Thus, the competence of the partners of the VE are described as the ability to deliver the product, i.e. in terms of the deliverable. The main types of agents in this approach are brokers, facilitators which represent a set of enterprises that possess a given competence, an enterprise agent which represents a single enterprise and a consortium agent which is a temporary agent created to manage the process of creating alternative VEs for any client order. A VE is selected after creating a set of alternative VEs based on the competencies and the scheduling requirements.

The notion of an information broker is used in [Harbilas et al., 2000], where the broker stores information about enterprises. Enterprises seeking partners for a VE can obtain information about suitable potential partners through the broker agent, where the broker matches the goals (and subgoals) to find suitable partners.

Federated approaches have been suggested as a means of supporting broker architectures, [Shen and Norrie, 1999] and [Camarinha-Matos and Afsarmanesh, 2001]. It is an approach to agent interoperation where the agents are organized into what is called a federated system. The notion of a facilitator, a special class of agents to facilitate communication among the agents, is used. In this approach, instead of the agents communicating directly with each other, they communicate via the facilitator, [Genesereth, 1997].

5.2.3 Mobile Agent Architectures

Mobile Agents, (see [White, 1997] for a discussion), have been used as a solution technology for VEs, e.g. [Ambroszkiewicz et al., 1998] and [Clements et al., 1997]. In [Gijsen et al., 2002], mobile agents were suggested as a means of a trusted third party to provide IT services to the partners of a VE. It is based on scenarios where the partners may not meet the IT requirements for the VE. In this case, a component called a "dock" is installed at each partner, and a mobile agents is dispatched to each of the partners, where the mobile agent then invokes the required functionality locally. Implementations of this idea are reported in [Szirbik, 2001].

5.2.4 Information Agent Architectures

The notion of an information agent was introduced as a component in an infrastructure for supporting collaborative work in [Barbuceanu and Fox, 1994]. The information agent consists of a problem solver, based on description logic, and an agent program, which turns the problem solver into an autonomous agent. It uses the Knowledge Query and Manipulation Language (KQML) Agent Communication Language (ACL), ([Mayfield et al., 1995]), to communicate with the outside world. The information agent makes other agents (may be from other organisations) selectively aware of relevant information by providing communication and information services. This idea was applied in the domain of supply chain management, where each function, such as order acquisition and scheduling, were represented by agents. What is perhaps most important about this architecture is the fact that it was based on TOVE, thus using ideas from the Enterprise Integration community.

5.3 Agent Architectures

An approach that is common in the agent architectures is the BDI-based model of agents, e.g. PRS, [Myers, 1997], IRMA, [Bratman et al., 1988], or GRATE, [Jennings, 1993b]. However, there are other architectures of agents that are not based on any particular theory of agents (see [Wooldridge and Jennings, 1995] for an overview). These architectures are pragmatically inspired to solve a particular problem, e.g. for the purpose of electronic commerce or negotiation, [Oliveira and Rocha, 2000]. In the rest of this section, the BDI model of agents and agent architectures based on BDI and other approaches will be considered.

5.3.1 BDI Model of Agents

The BDI model of agents, [Rao and Georgeff, 1991], is concerned with the question of how an agent's beliefs about the future affect its desires and intentions. It is a logical framework based on *beliefs*, *desires* and *intentions*. In their work, they formalize intentions based on a branching-time possible worlds model, where the branches on the tree are the choices available to an agent at any point in time. Using this framework, an agent can be modelled by imposing certain conditions on the persistence of an agent's beliefs, goals and intentions. The beliefs of an agent are its beliefs about the world, its goals are its chosen desires and intentions are the goals that an agent has committed to achieving. An agent must believe in its goals.

5.3.2 BDI Agent Architectures

A BDI architecture is defined as a system and formalism that gives primary importance to intentions. They often have explicitly represented datastructures that correspond to the mental states of beliefs, desires and intentions. Examples of BDI architectures are:

PRS: Procedural Reasoning System, was perhaps the first architecture to explicitly use the BDI model. An agent has explicit representations of its beliefs, desires and intentions and a library of plans, which includes the agents goals. The plans, which are predefined, represent the options available to an agent.

IRMA: Intelligent Resource-bounded Machine Architecture, has explicit representations of its beliefs, desires and intentions, a plan library as well as components to be able to reason about the world and determining which plans to choose.

GRATE: is a layered architecture, where the behaviour of the agent is determined by its beliefs, desires and intentions. It has a domain layer which solves problems and a control and cooperation layer which ensures an agent's domain level activities are coordinated with the rest of the agents in the community.

The BDI parts of PRS and IRMA architectures are mostly focused on the agent's own self rather than the knowledge about the other agents. GRATE has an additional layer that is focused on cooperation, which contains the acquaintance or the cooperation model, [Jennings, 1994].

5.3.3 Other Agent Architectures

In [Oliveira and Rocha, 2000], they propose two different architectures for the entities in a VE: the market agent, which represents the VE, and the organisation agent, which represents a partner. The structure of the market agent includes a goal descriptor, describing the goal to be achieved, and a VE selector, which is responsible for the selection of partners for the VE, including negotiation capabilities. The goals consists of subgoals, each one described by a list of attributes.

The structure of the organisation agent comprises of three functional modules: communication module for message handling, decision making and coordination module for managing local tasks and cooperative behaviour and execution module for the execution of local tasks. In addition, the information related to the VE is kept in a VE knowledge module and the information about the agent itself is kept in an individual knowledge module, which contains the agents goals and its capabilities. The agents' knowledge is described as a list of attributes.

5.3.4 Mentalistic Notions in the VE context

The VE agents' goals, capabilities, activities and experiences can be expressed in terms of mentalistic notions such as beliefs, desires, intentions and commitments. The BDI approach has been addressed in the context of agent-based modelling. For example, in [Wagner, 2000], the information that is available to an agent is treated as its beliefs or knowledge. Similarly, in [Kendall et al., 1996], beliefs are the information that is retained within an agent (as passive objects) or what an agent knows. When a goal is achieved, there may be changes in the beliefs of the agent. Information that controls an agent's activity or its functionality (or control information) are its goals and plans.

In [Levitt et al., 2001], the mentalistic notions, commitments, beliefs and knowledge of an agent are considered. Beliefs are an agent's view of the world, commitments are what an agent has volunteered or has been assigned to do within a given period of time and knowledge is an agent's knowledge about processing tasks and coordination. Levitt et. al. distinguishes between two types of knowledge: what an agent knows about itself such as its capabilities, and what an agent knows about other agents, which are a part of its beliefs.

In [Oliveira and Rocha, 2000], although the BDI approach is not considered, commitments of other agents are represented in an agent's individual knowledge module.

It is interesting to note that Kendall et. al and Wagner et. al. do not distinguish between belief and knowledge. However, Levitt et. al. does not always consider knowledge as an agent's beliefs.

5.4 Discussion

One of the limitations of the approaches presented in this chapter is the fact that they do not consider the issue of agents and human beings collaborating, as part of the system of agents. This view is proposed in [Bernus and Baltrusch, 2002]. This raises a number of issues such as how much autonomy should be delegated to the agent, should the level of autonomy be adjustable and how could the human being's interests and desires be represented in the agents. Also, the architecture of the system as well as the agent itself will be influenced by this.

Current work done in the agent and DAI community does not use results that have already been achieved in the Enterprise Modelling and Enterprise Integration communities. Thus, rather than addressing the issues that have already been identified by these communities, the current approaches tend to reduce the problem to a computable solution, or the solution becomes what is possible rather than one that really meets the challenges posed by VEs. An example of such a reduction is assuming that a partner in a VE is an organisation, in which only the goals and the processes need to be considered during the selection of partners.

Another limitation of current approaches is the fact they don't always take into account the complete lifecycle of the VE. Rather, they isolate a particular phase in the lifecycle and provide a solution to some problems identified within that phase. This limits the possibility of having a holistic view of the whole VE and to be able to answer questions such as which goal(s) of the VE is a particular partner working towards achieving.

Little or no consideration is given to the team aspects of a VE or the cooperative behaviour of agents. Thus, when representing the capabilities of an agent as a set of attributes, only attributes reflecting the individual ones are considered. And finally, there is a lack of solutions based on real case studies.

In this thesis, we have taken the view of Enterprise Modelling and Enterprise Integration and tried to address the issues that have already been identified by these communities. So, rather than design the most complex agent system, our focus has been to build on existing technology to support the formation of VEs as they happen in the real world.

Part III

RESEARCH AND RESULTS

Chapter 6

Agent-based Approach

6.1 Introduction

This chapter addresses the research questions **RQ2**, **RQ3** and **RQ4** and describes the agent-based approach. The work described in this chapter has been published in the **Papers 1, 2, 3 and 4**. Figure 6.1 gives an overview of the work that was done and how the results were achieved. The contents of the box labelled "Developed Agent-based Approach" are described in detail in this chapter.

The partners of a VE are represented by agents. During the VE formation process, individual entities compete to become partners of a VE. The formation of the VE is supported by providing decision support to select the best team of partners for a specific VE.

The formation of the VE is one of several phases in the lifecycle of the VE. The lifecycle of a VE can be analysed using ideas from Enterprise Modelling and Enterprise Reference Architectures (e.g. VERAM, [Kazi and Hannus, 2002]). Figure 6.2 shows the formation stage of a VE within a lifecycle context. Before a VE is formed, it's concepts and goals have to be defined. The requirements from the customer sets the requirements for the VE team and in order for the VE to be able to deliver to its customer, the right team has to be formed. During the formation stage of a VE, the individual entities compete and negotiate to become the partners of the VE.

An important aspect of using agents is that ideas from Electronic Commerce and electronic market places can be considered in bringing together individual entities that want to form a VE, [Rocha and Oliveira, 1999]. In this respect, the agents can operate within the context of an electronic market during the formation stage of the VE. All the agents that are interested in becoming partners of a VE are at an electronic market, where the VE is announced. They can propose bids as in an auction and the agents that meet the requirements and propose the best bids are then selected. When the VE is formed, the partners that have been selected constitute the VE and work together to deliver to the customer.

The main components of the agent-based approach are:

- An agent-based model of a VE.
- A process for VE formation, expressed as an AIP.

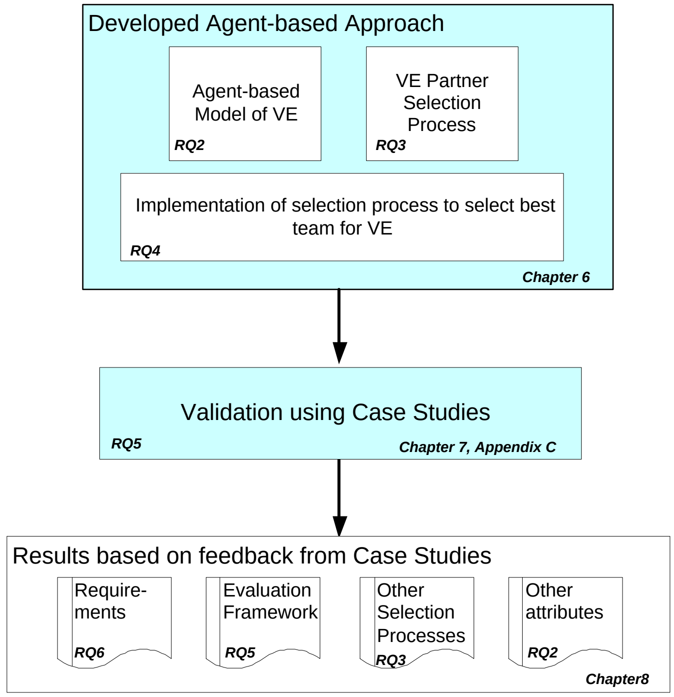

Figure 6.1: Overview of Research and Results

- A multi-agent architecture to support VE formation.

6.2 Agent-based Model

This section addresses the research question **RQ2**. The agent-based model for a VE presented in this section is described in **Paper 1**. The main inspiration for the model is TOVE, (see Section 3.5.3 for a description), [Fox et al., 1996].

Figure 6.3 shows the entities in the metamodel of a VE. Based on the definition of a VE given in Chapter 4, (*a team of agents, which may be organisations, human beings or agents, that collaborate to achieve a specific goal*), an important entity in a VE is its *goals*. Some work must be done to achieve the goals; thus some *activities* must be performed. Taking a functional view of activities, (e.g. as in IDEF modelling), some resources are required to perform the activities. Some entity must perform the activity and based on the nature of the activity, there will be some requirements that must be met by the entity that performs it. The notion of *roles* have been used to specify the work that must be performed and to specify the *requirements* that must be met to fill that role. *Agents* have been used to represent the partners of the VE. Thus, agents must meet the requirements for a role to perform an activity. Introducing the notion of a role helps in identifying reusable definitions of work and the associated requirements that the agent must meet to do that work, (see e.g. [Kendall, 1998]). This view of the metamodel is common in enterprise models that are used in industry, e.g. METIS Generic Enterprise Model, [METIS, 2003].

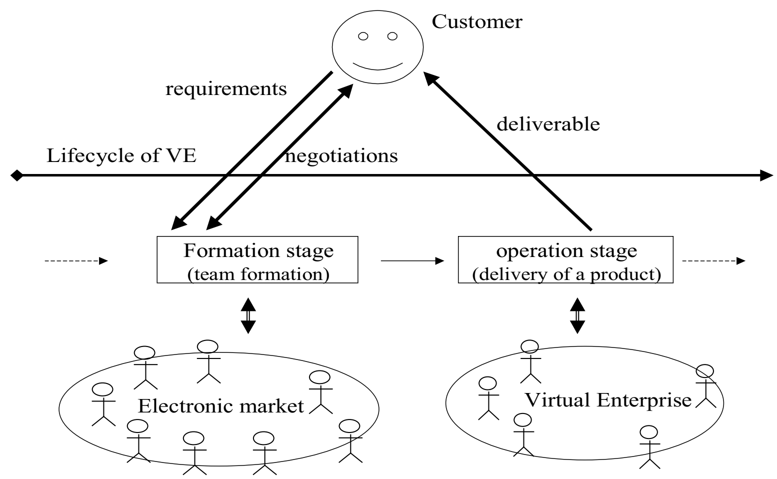

Figure 6.2: Formation of a VE from a Lifecycle Perspective

The entities in the model are described using attributes; the relationships among the entities are represented using predicate calculus and a set of rules represent how they can be used. An overview of the metamodel is shown in Figure 6.3 and a complete description of the model is provided in Appendix B.

For the work presented in this thesis, only the contents of the model that are relevant for the formation of a VE have been considered. However, it is important to consider the complete model to be able to understand how the different entities affect one another. For example, how does the selection of a particular agent affect the goals of the VE?

The agents in a VE can be classified as:

VE Initiator : who takes the initiative to form the VE. The VE Initiator may also be the customer.

VE Partner : who are the agents that form the VE. A partner may also be the VE Initiator.

6.2.1 The Role of the Model

The agent-based model of the VE plays a central role in the agent-based approach. It provides input to the VE formation process and the multi-agent architecture. Before a VE is formed, we assume that the requirements for the partners of the VE are available. These are defined in the model of the VE, which is constructed during the early phases (e.g. requirements and design phases) in the lifecycle of the VE. The role of the model in the lifecycle of a VE is shown in Figure 6.4.

When a VE is designed, its goals, the activities that must be performed, the roles that perfom the activities and the requirements for the roles are identified and represented in the model. The goals, roles and the requirements for the roles are provided

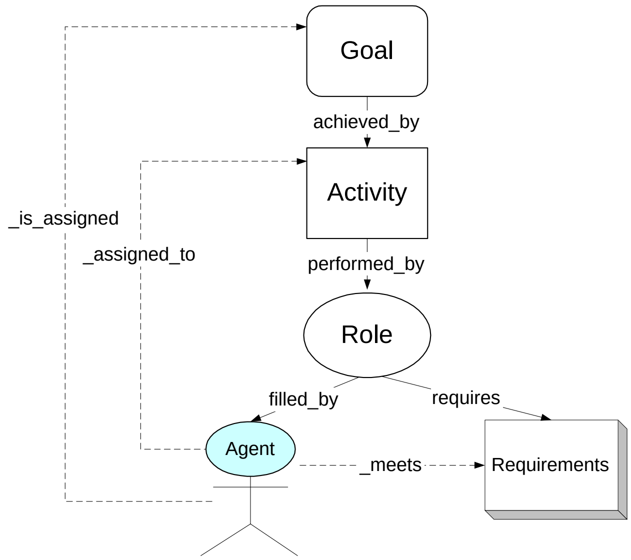

Figure 6.3: VE Metamodel Overview

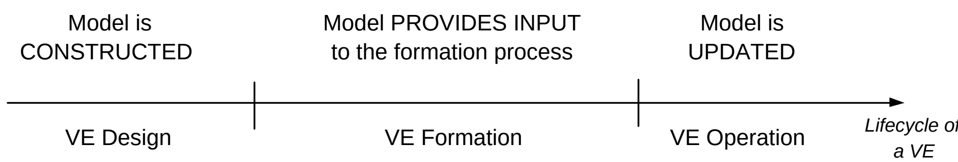

Figure 6.4: The Role of the Model in the Lifecycle of a VE

by the model for the VE formation process. Once the VE is formed, the model can be updated to include the information about the agents that have been selected and the agents that have been assigned to the goals and the activities of the VE. This information can be used during the operation of the VE for various purposes such as querying the VE, e.g. [Petersen, 2003].

The agent-based model not only provides the input for the VE formation process and the multi-agent architecture, but it can also be considered as a record of the VE. It can also be generalised as a reference model for similar VEs in the future, allowing quick formation of VEs.

6.2.2 Model of an Agent

The components of the agents's knowledge-base are based on the model of the VE. Each agent contains a set of goals, a set of activities and a set of requirements. In this approach, the same agent architecture has been considered for both the agents representing the VE Initiator and the partners. This is because the VE Initiator does not always play the role of a "broker" only, but can also be a partner in the VE. During the formation process, the VE Initiator represents the VE and thus the information represented by the VE Initiator reflects the VE whereas the information represented by the VE Partners reflects that particular partner.

Mentalistic Notions of Agents

As most agent architectures consider the mentalistic notions of agents, it is interesting to consider how the components of the agent's knowledge-base correspond to these. In the context of a VE, the VE Initiator negotiates with a Potential Partner and eventually hires him/her on the basis of what the VE Initiator *believes* the partner is capable of delivering. This can also be interpreted as the VE Initiator's expectations of the partner. Similarly, the partner will also have beliefs about the VE Initiator.

The contents of the agent's knowledge base can be mapped to the BDI model, [Rao and Georgeff, 1991], as follows:

- Goal - corresponds to the *desires* of an agent or what an agent wants to achieve.
- Activity - corresponds to the *intentions* of an agent or what it has (chosen) to do to achieve one or more of its goals.
- Requirements or capabilities - corresponds to *beliefs*.

The beliefs of the VE Initiator are the requirements for the VE and the information contained in the bid from the Interested Partner (i.e. the capabilities of the Interested Partner) are its beliefs about the other agent. These beliefs, once they are verified to be true, then become the VE Initiator's knowledge about the other agent. Similarly, the requirements of the VE Initiator are the beliefs that an Interested Partner has about the VE Initiator.

6.2.3 Attributes of Agents

A detailed set of attributes for the VE Initiator and partner agents were presented in **Paper 2**. The agents were described by a set of attributes and these attributes formed the basis for the evaluation of the agent as a partner in the VE. The attributes that were considered were those required for the agents to propose a bid and negotiate to become a partner in the VE.

An agent representing the VE Initiator is described by the attributes goals, availability requirements and other requirements such as the skills and cost. Since a VE is a goal-oriented entity that has a time limit and each goal is defined in terms of a deadline and a maximum amount of money, the attributes of the agent representing the VE reflect these.

The VE Initiator announces a VE and requests for proposals from the Interested Partners. The VE announcement contains the requirements, (based on the attributes of the VE Initiator), that must be met by the agent. Thus, the attributes of the agent must match the requirements.

6.3 VE Formation Process

This section addresses the research question **RQ3**. The VE formation process and the selection of partners presented in this section have been published in **Paper 2**.

The VE formation process assumes that before a VE is formed, a complete model of the VE is available, i.e. its goals, the activities that must be performed to achieve the goals, the roles that perform the activities and the requirements for the roles.

During the formation of a VE, a partner evolves from someone who is interested in becoming a partner to someone who is actually a partner in the VE. The partners go through the following stages, (see Figure 6.6 for an illustration of these stages):

Interested Partner - one that is interested in becoming a partner and submits a bid.

Potential Partner - one that is considered as a partner for the VE and a contract is negotiated.

VE Partner - one that is selected as part of the VE team after a process of negotiation.

In general, the terms VE partner or partner is used to refer to an agent in a VE and the terms described above are used when referring to the partner during the explicit stages of the selection process.

The VE formation process is considered within the context of an electronic market. The VE Initiator announces a VE and requests for bids from agents that are interested in becoming partners of the VE. Agents who are interested, propose a bid, where the contents of the bid correspond to the requirements expressed in the VE announcement (analogous to an Instructions to Bid document). The VE Initiator then evaluates the bid based on the evaluation criteria. The agents whose bids that do not meet the requirements are informed that their bids are rejected. The VE Initiator then negotiates with the agents whose bids meet the requirements (Potential Partners). Finally, a contract is awarded to the best Potential Partner(s). This process can be considered as a set of interactions among the agents and thus can be shown as an AIP, using Agent UML, [Bauer et al., 2001], in Figure 6.5.

An AIP shows the sequence of communication between two agents and the type of communication, more precisely, the communicative act or performative of the message that was exchanged, ([FIPA, 2002] and [Labrou and Finin, 1998] respectively). FIPA (Foundation for Intelligent Physical Agents) ACL communicative acts have been used in the AIP to describe the communication between the agents. The AIP for VE formation and selection of partners can be compared to the basic auction protocols, [Bauer et al., 2001], and the Contract Net Protocol, [Davis and Smith, 1988]. However, depending on the actual selection process, there may be additional interactions between the VE Initiator and the Interested and Potential Partners, such as requesting for more information.

6.3.1 Selecting Partners

A VE and an agent are both, by definition, goal-oriented entities. Therefore, an agent that performs an activity in a VE must have its goals aligned with the goals of the VE, (see Section B.3.6 for a definition of goal alignment). Thus, the first step in the selection of partners is to align their goals. Then, the agents are matched against the required skills and availability to select the Potential Partners. Then, using some evaluation criteria, the Potential Partners are ranked to identify the best individuals for the VE.

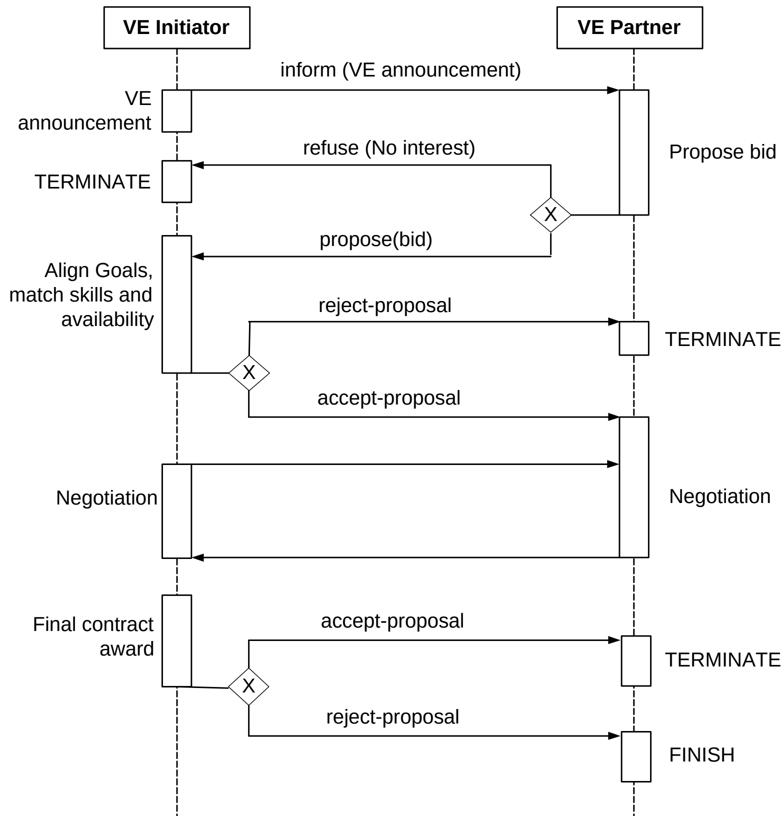

Figure 6.5: Agent Interaction Protocol for VE Formation

This process is illustrated in Figure 6.6. The best set of individuals can be selected by considering attributes of agents that describe their individual qualities.

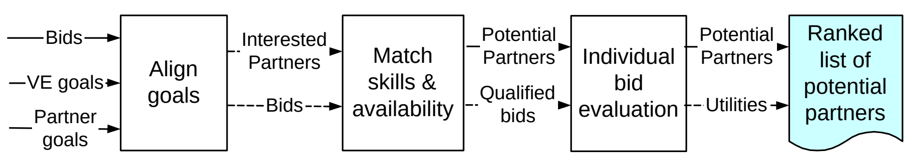

Figure 6.6: Selecting the Best Partners for a VE

The process illustrated in Figure 6.6 considers the selection of the best individuals. However, a VE is a *team of partners*. The best set of individuals is not always the best team of partners that collaborate. Thus, it is important to consider the individuals that are selected as a team of partners as shown in Figure 6.7.

Paper 2 illustrates an example, where MAUT has been used to select the best team of partners for a VE and discusses the selection of a set of individuals versus a team.

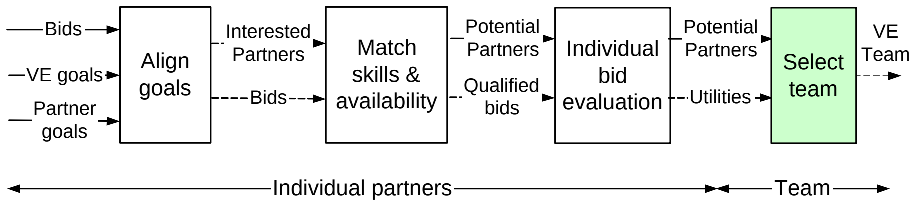

Figure 6.7: Selecting the Best VE Team

6.4 AGORA Multi-agent Architecture

The AGORA multi-agent architecture, hereafter referred to as AGORA, has been used to implement the VE formation and partner selection process described in the above sections.

AGORA is a multi-agent architecture that supports a flexible, conceptual method for modelling cooperative work in a distributed setting, [Matskin et al., 1998], [Sæle et al., 1999] and [Matskin et al., 2001]. It provides the infrastructure that is necessary to support the complete lifecycle of a VE. More specifically, the formation and partner selection process can be supported by the market-based infrastructure provided by AGORA for agents to meet and exchange information. In addition, AGORA facilitates collaboration among agents by supporting negotiation and coordination.

The central concept of AGORA is that of an *Agora Node*, which facilitates communication, coordination and negotiation among the agents. When an Agora Node is created, three default agents are created and connected to the Agora Node automatically. They are the *Agora Manager* (for performing general management functions), *Coordinator* (for supporting a coherent behaviour among agents at any Agora Node) and *Negotiator* (for dealing with conflict resolution via negotiation). Agents can register at the Agora Node and participate in cooperative activities, supported by the Agora Node. A standard Agora Manager implements general management functions such as the registration of agents and matchmaking. The coordinator and negotiator are agents that manage corresponding protocols. A description of AGORA and the structure of a single agent in AGORA is available from **Paper 4** and [Rao and Petersen, 2003].

6.4.1 VEs in AGORA

A description of how AGORA could be used to support the lifecycle of a VE was published in **Paper 3** and [Petersen et al., 1999].

The AGORA multi-agent architecture can be adapted to support the formation of VEs. The components of AGORA can be mapped to VEs as follows:

- The cooperative point, or the interaction medium, is the Agora Node.
- The partners of a VE are represented by the agents registered at that node.
- The VE Initiator is represented by the Agora Manager for that node.

- The cooperative work such as coordination and negotiation are provided by the Coordinator and Negotiator agents.

An Agora Node for VE formation is created by the VE Initiator, who is the manager of that Agora (an agent created by default). The agents that are registered at this node receive the VE announcement and the agents that propose a bid become Interested Partners. These agents represent the actual human beings or organisations that want to join the VE.

Each step in the VE formation process, e.g. goal alignment or negotiation, can be considered as a cooperative point and Agora Nodes can be created to represent each of these. Each Agora Node provides the right context and the support for the work that would be done at that Agora Node, e.g. an agent to support a specific negotiation technique can be used at the negotiation Agora Node. This capability is provided by AGORA. Also, using separate Agora Nodes ensures privacy and information security, i.e. only the agents that qualify from each step are then allowed to register at the Agora Node representing the next step. Note that since the different Agora Nodes are created by the VE Initiator, it is the Agora Manager for each node. Also, AGORA provides the capability to create a new Agora Node and to automatically register a selected set of registered agents from the current node at the new node.

6.5 Implementation

This section addresses the research question **RQ4**. For the work presented here, there are two separate implementations. The first one is reported in **Paper 2**, where the AGORA architecture was not used explicitly. The second implementation uses AGORA and is reported in **Paper 4** and [Rao and Petersen, 2003].

6.5.1 Partner Evaluator

The first implementation consists of a "partner evaluator" where the attributes and attribute values for Interested Partners can be given as input, and based on the evaluation criteria specified, either a ranked list of Potential Partners or a ranked list of potential teams of partners (combinations of individuals) was available as the output. See Figure 6.8.

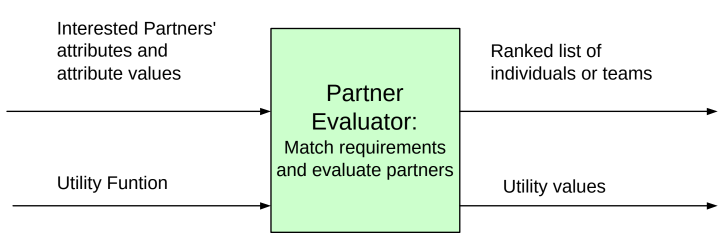

Figure 6.8: Partner Evaluator

Ideas of MAUT and multi-attribute optimization were used to select the best partners for a VE. Since the requirements of a VE and the attributes of an agent are both sets of attributes, MAUT seemed a good technique for evaluating the best partners. The partner evaluator also supports multi-attribute negotiation, where the VE Initiator can negotiate with a Potential Partner. The negotiation is based on the utility values, i.e. at every round in the negotiation, the utility values for the bid are calculated and these are used to determine when to terminate the negotiation process. The negotiation is terminated when the bids are at a pareto optimum.

This implementation was focused on using the idea of MAUT as an evaluation criteria. However, the partner evaluator was developed such that it could be incorporated into the AGORA architecture. The partner evaluator could be a part of the VE Formation Agora, where it receives input from the registered agents (Interested Partners), via the Agora Manager (VE Initiator). The input for the partner evaluator, which consists of the attribute names and values for each Interested Partner and the utility function, can be given as a text file. Similarly, the output, which consists of the ranked list of individuals or teams and their utility values, is also available as a text file. The partner evaluator was implemented using Java, [Benes and Meyer, 2000].

6.5.2 Selecting Partners in AGORA

The second implementation used the AGORA architecture and the focus was on the AIP and the information that is exchanged between the agents and the matching rules. Ranking of Potential Partners was not conducted in this implementation. The partners were selected by matching the attributes of the Interested Partner agents to the requirements of the VE (represented by the VE Initiator agent). The requirements were defined as a set of constraints and the matching rules were written in Prolog . In the AGORA architecture, the information consisting of an agent's communications and interactions with other agents are represented in an agent's plan file. Thus, the instructions on matching the requirements are contained in the VE Initiator's plan file.

In this implementation, the complete VE formation process was implemented. An AIP was created to represent the VE formation and partner selection process. The AIP described the messages that were exchanged between the VE Initiator and the Interested and Potential Partners, the sequence of the messages and the information that was exchanged. The AIP was then used to create the agents' plan files. The matching rules were based on the evaluation criteria.

Since AGORA provided the basic communication and interaction infrastructure, it was possible to make changes in the AIP as desired. The complete AIP for the VE formation process, the structure of the Agora Nodes, the matching conditions and the corresponding plan and action files for the agents are described in **Paper 4**.

Chapter 7

Validation Using Case Studies

7.1 Introduction

Validating research in Enterprise Modelling is a challenge as there are no standard means of validating models. There are two possible ways of validating the agent-based approach:

1. By implementing the initial ideas. However, this does not validate that the ideas actually represent what happens in industry. The implementation may thus be a reduction of the actual problem.

2. Using industrial case studies which will validate the initial ideas with respect to the actual problem. However, obtaining information for case studies for this kind of subjects is a challenge.

In order to preserve the nature of the problem and not simplify it for implementation, the agent-based approach presented in Chapter 6 was validated using a number of industrial cases, [Yin, Robert, 1994]. This chapter addresses the research question **RQ5**. The main aim of the validation process was to see how the agent-based approach can be used to support VEs in industry. The case studies were also used to identify the strengths and weaknesses of the approach.

The case studies were selected so as to cover a wide variety of situations where VEs were formed. Initially, situations where a VE was formed with a set of partners that could be either individuals or organizations were considered. Companies that initiated the formation of the VE and actually participated in the VE as well as companies that acted purely as VE Initiators (mostly hired by the customer) and assisted in the formation of the VE were also considered. The approaches used by the companies, in general, in forming VEs by looking at individual scenarios were studied.

7.2 Case Descriptions

A brief overview of the cases will be provided in this section. A detailed description of the cases and the analysis of the agent-based approach is presented in Appendix C.

BFS

Business and Financial Consulting Group, (BFS), is an independent private consulting firm registered in the Republic of Maldives, that offers all aspects of business, financial, economic and social consulting services. They maintain a database of highly qualified consultants in various fields and draws upon these resources to form the teams that work on their projects. These consultants are analogous to the partners of the VE. BFS forms a team of people to work on the project by identifying the different roles that are required to perform the activities and by selecting the relevant people to fill the roles. The partners can negotiate with BFS during the formation of the VE.

Statoil

Statoil, Norway, is a company that operates in the oil and offshore industry, on a global scale. The particular scenario that was analysed was the selection of several groups of students (university level) who will work together as teams during their summer holidays on some projects specified by Statoil. Each team, in this case can be considered as a VE. Statoil is popular among the students and therefore, a huge number of students apply for this opportunity. Although a thorough evaluation is conducted before selecting the best students, there is no opportunity for the students to negotiate.

DNVS

Det Norske Veritas Software (DNVS), Norway, is an independent business unit of Det Norske Veritas Ship Classification Society, (DNV). They are responsible for delivering technical analysis, life-cycle support and knowledge management applications to DNV as well as external clients world wide. They operate in the maritime industry on a global scale. They felt that they were currently operating in a saturated market and thus, decided to form an alliance, or VE, with another company with complementary skills, technology and markets, in order to expand their own customer base.

PTL

Prosjekt og Teknologiledelse AS (PTL), Norway, is hired by a customer to assist them to evaluate bids in the selection of a contractor for large scale projects in various domains. For example, in the construction industry for the construction of a hospital. They specialize in the selection of the project team or the partners of the VE that will eventually be formed to deliver to the customer. The VEs that they assist to create usually comprise of several organizations and they have to take into consideration the skills of the individuals from each organization that will work in the VE.

ODA

Organization Development Alliance AS (ODA), Norway, is hired by a customer to assist them to evaluate bids in the selection of a contractor for large scale projects. The projects vary from IT to the offshore industry. ODA conducts an evaluation where they focus on the risk management aspects of the project, or VE, and eventually proposes a way of managing the risks of the project.

7.2.1 Comparison of the Cases

During the analysis of the cases and discussions with the case providers, a number of characteristics of the VE that affects the formation process were identified. Using these characteristics, the different cases can be compared as shown in Table 7.1. Since quantitative data was unavailable, qualitative indicators, such as high, medium and low, have been used.

Characteristic	**BFS**	**Statoil**	**DNVS**	**PTL**	**ODA**
Geographical Context	Local	Local (National)	Global	Local (National)	Local (National)
Specialization of skills required for VE	Medium	Low	High	High	High
Level of detail of the VE when VE is formed	High	High	Low	Low	Low
Duration of the VE	Medium	Short	Long	Long	Long
Consideration of team aspects	Medium	High	High	High	High
Scale of VE: Money	Medium	Small	Large	Large	Large
Complexity of VE	Medium	Low	High	High	High

Table 7.1: Comparison of Cases

7.3 Validation Process

The case studies were used to validate the agent-based approach as follows:

1. Creating an agent-based model of the case: modelling the case using the agent-based model for the VE, (described in Section 6.2). This involved identifying the goals of the VE, the activities that need to be performed to achieve the goals of the VE, the roles to perform the activities and the requirements for the roles.

2. Comparing the attributes: looking at the requirements for the roles and the kinds of attributes that were considered in the case and comparing these to the attributes that have been used in the selection process described in Section 6.2.3. This is really a comparison of the evaluation criteria.

3. Comparing the selection process: comparing the partner selection process that was used in the cases to the selection process described in Section 6.3.1.

4. Identifying negotiation points: identifying if and when there is negotiation in the partner selection process in the case. It also involved identifying the issues that were negotiated upon.

7.4 Case Studies Analysis

This section summarizes the analysis results from the case studies.

7.4.1 Modelling the Case

The VE metamodel was in line with the way the VE was designed and implemented. It was possible to model the VE using the goals, the activities, the roles and the requirements. However, none of the VEs were explicitly thought in terms of these modelling constructs. Therefore, it was not always possible to obtain all the relevant information to construct a detailed model of the VE. Only a high-level model of the VEs could be developed.

The level of detail of the VE varied among the different cases. BFS was looking at specific roles for their VE, e.g. a road design engineer. Thus, they were able to specify the requirements for a specific individual, who will in fact perform the activity. PTL mostly looked at VEs where the VE was defined at a very high-level, e.g. for a VE to construct a hospital, they would look for partners to fill the roles such as an architect or a builder, where they would be looking for organizations that will fill these roles. Thus, the model that could be constructed was at a higher level than, for example, that for BFS.

It appears that as the size of the project increases, e.g. DNVS, PTL and ODA, the level of detail of the VE at the formation stage is low, whereas for smaller projects, it was possible to define the VE in greater detail before it was formed, e.g. BFS and Statoil.

7.4.2 Comparison of Agent Attributes

The attributes that were considered in Section 6.2.3, which represent the partner evaluation criteria, are very simple compared to the cases. All the cases considered the collaborative capabilities of the Potential Partners in their set of attributes. The complexity of the attributes varied according to the complexity of the VE. For example, Statoil used a simple set of attributes such as the student's year of study and their work experience, based on a Curriculum Vitae. BFS had structured their requirements for the roles such that they were looking at three distinct categories; (i) skills, (ii) availability and (iii) cost.

ODA and PTL, due to the high risk factor of the VEs that they help form, had very detailed, sophisticated evaluation criteria. One significant difference in the way the attributes were designed was in the way they looked at skills. PTL considers "capacity" of the Potential Partner rather than skills. Capacity is the quantity of relevant competencies (or skills) that are available for the VE, and this takes into account the skill and the availability of it at any time. Both ODA and PTL helped form VEs where the partners were organizations or coalitions of organizations (i.e. VEs). Thus, the set of attributes that they were looking for were different from those of an individual.

The VE formed by DNVS was a strategic alliance, where they were not trying to meet a specific customer's request, but their objectives were driven by the business objectives of the two companies and the current market trends. So, the attributes that they considered in their partner evaluation criteria were of a higher level than what had been considered in the approach considered in this thesis.

7.4.3 Comparison of Selection Processes

None of the selection processes considered goal alignment explicitly. They assumed that if two entities have expressed an interest in working together, then their goals must be aligned. The skills and availability matching process was not a one-step process, rather, it consisted of several steps. In BFS, the skills and availability matching process was a two-step processes as their requirements for the roles were structured into skills, availability and costs. They first checked if the skills match and considered availability only if the skills matched the requirements.

A more advanced process can be considered when the Potential Partner is invited for an interview or some form of verification of the facts that they have presented in the bid. For example, Statoil interviewed its Potential Partners and ODA interviewed and invited them for a workshop.

7.4.4 Negotiation Points

Statoil did not give their Potential Partners any opportunities to negotiate as they had more than enough Interested Partners that they could choose from. PTL did not conduct negotiation before the VE is formed and a contract is signed. This is because their customer was the Norwegian government and there are some laws that prohibit negotiation before a contract is signed. BFS negotiated with its Potential Partners mostly on price. ODA negotiated on the price for some specific work or a deliverable. DNVS negotiated on the financial assets that would be contributed by each partner.

All the cases considered negotiation as an ongoing process. BFS considered negotiation as a means of resolving goal conflicts that may arise during the operation phase of the lifecycle of the VE.

7.5 Discussion

The main conclusions from the analysis of the case studies are discussed in the following subsections.

7.5.1 Applicability of the Agent-based Approach

Figure 7.1 gives an indication of the applicability of the agent-based approach with respect to the characteristics. The agent-based approach was more applicable in the following situations:

(a) When the VE was small scale, had low risk, was not complex and had low specialization of skills.

(b) When the number of Potential Partners was large.

(c) When the VE partners were sought within a global context than when they are sought in a local context.

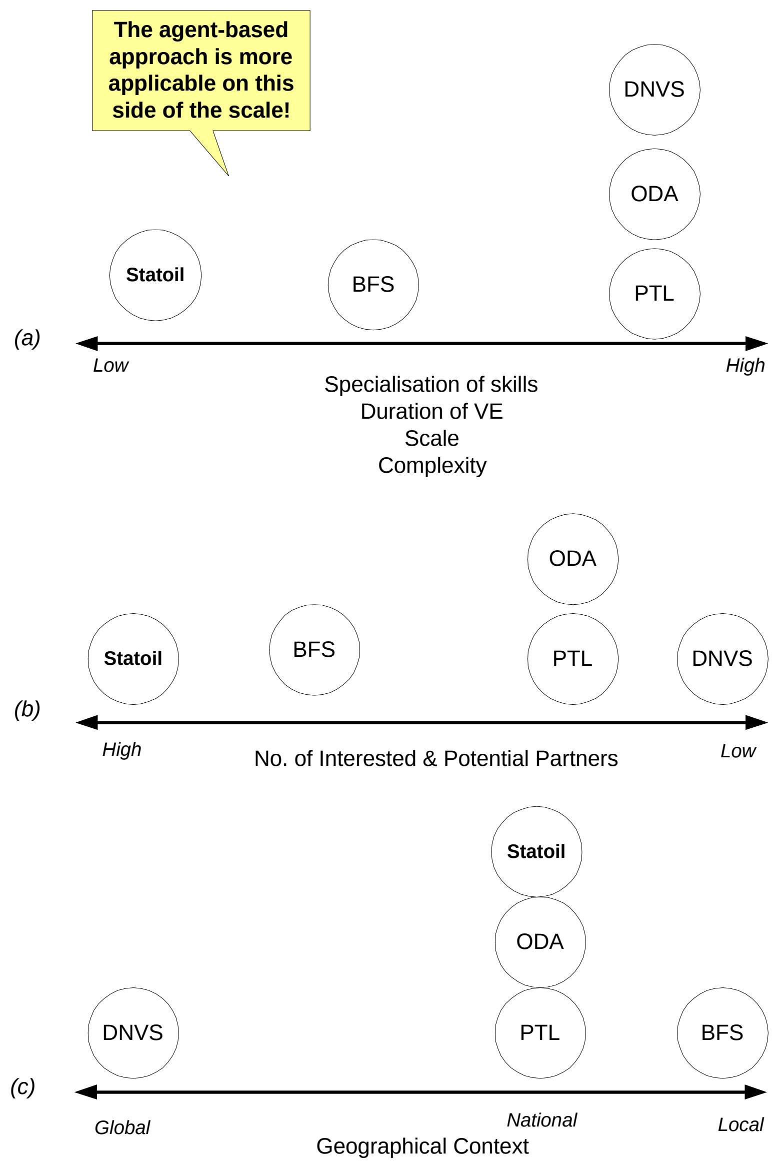

Figure 7.1: Applicability of the Agent-based Approach

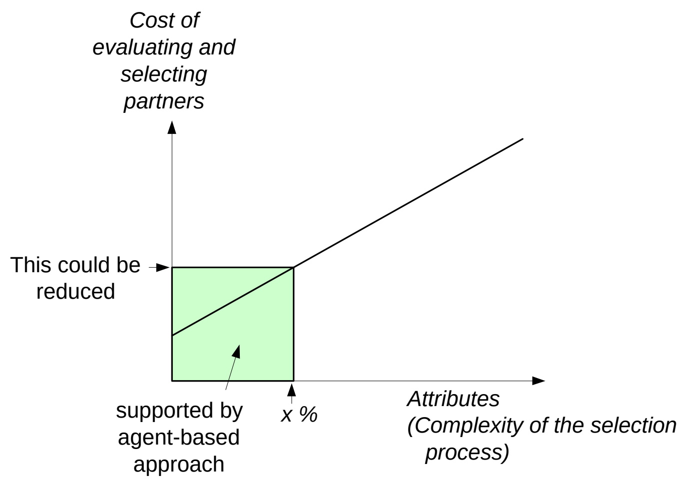

Figure 7.2: Partial Support for the Selection Process

Based on our validation results, Statoil will be the one to benefit most from the agent-based approach since the task of selecting a few partners from a large number can be made more effective using such a technology. In this case, the requirements for the skills can also be represented easily. BFS will also benefit from the agent-based approach in the situations where they have a bigger geographical context and when they have a large number of Potential Partners. For DNVS, PTL and ODA, they can benefit from our agent-based approach by using it for situations where there are several Potential Partners. In such cases, our approach will help them "short list" some of the Potential Partners quickly and efficiently, by conducting a very coarse match of the requirements of the skills of the Potential Partners. They can then evaluate this selection more thoroughly using manual methods. This will save them time and resources.

7.5.2 Partial Support for the Selection Process

Based on the analysis of the agent-based approach with respect to the cases, it was possible to identify its strengths and how it can be used to provide some level of support for the evaluation of the bids and selection of partners for a VE. Although this approach cannot be used to conduct the complete evaluation and partner selection process for all of the cases, it can be used to conduct a very coarse prequalification of the partners. This is particularly important where the number of Interested and Potential Partners is large. This would make the selection process more efficient and cost effective. Figure 7.2 shows that by supporting a percentage of the evaluation criteria, (e.g. a subset of the requirements and the attributes), the agent-based approach can contribute to reducing the cost of conducting the evaluation. Thus, it would be interesting to see how much of the selection process can be supported by this approach and this will be the next step in the case studies analysis.

7.5.3 Querying the Model

The case studies also provided questions that could be used to query the model, which could be used as a means of evaluating the model, i.e. the type of questions that the model must be able to provide an answer to for it to be considered suitable to support the formation of VEs. This idea is based on the concept of ”competency questions”, proposed in [Gruninger and Fox, 1995]. Examples of such questions are:

- How can one know when the VE formation is complete?
- What are the skills required to perform a particular activity?
- Which activities and goals are affected by the lack of a particular activity?

The use of such questions and how the model can be used to answer these have been published in the paper listed as [Petersen, 2003] in the bibliography.

Chapter 8

Results

This chapter summarizes the results based on the analysis and feedback from the case studies, presented in Chapter 7. These results address the research questions **RQ5** and **RQ6** and provide improvements to the answers to **RQ2** and **RQ3**. The results have been published in the **Papers 5, 6 and 7**.

8.1 Evaluation Framework

The characteristics to compare the different cases, presented in Section 7.2.1, can be described as an *evaluation framework* for determining the applicability of the agent-based approach to a particular VE. This framework helps answer **RQ5** and is described in **Paper 5**.

8.2 Requirements

This section addresses the research question **RQ6** and provides the requirements for an agent-based approach to support the formation of Virtual Enterprises by analysing industrial case studies. Two case studies, provided by ODA, where VEs in which a group of partners that delivers to a customer and the customer work together, were analysed. The details of the analysis and the requirements for the agent-based approach that were obtained from this analysis have been published in **Paper 6**. A summary of the requirements is given below:

1. A language to represent the capabilities of the partners.

2. Flexibility to define the set of attributes.

3. Flexibility to define the selection process.

4. Evaluation of partners that are VEs.

5. Flexibility in negotiation.

8.3 Selection Processes

The case studies revealed that there are a number of ways in which partners can be selected for a VE, i.e. there is no single, universal selection process, rather, the selection process differed across different VEs. This difference is due to a number of reasons such as the information contained in the VE announcement where the Interested Partners are invited to propose a bid containing only some information required for selection. The different selection processes that were identified from the case studies and the corresponding AIPs have been published in **Paper 7**. An overview of the selection processes and the AIPs will be given in the rest of this section. (AIPs are presented in Agent UML and uses FIPA ACL communicative acts.)

BFS has a pre-compiled database that contains the names and skills of people who have expressed their wish to work on BFS projects. When BFS needs to find people to fill the roles of a VE, they look at the requirements of skills for the roles and find a match from the database. They then check if the desired person fulfils the availability requirements and if s/he does, agree on a price for the work. In this case, the information gathering and matching part of the selection process is an iterative process where the Interested Partner is first asked to submit his/her skills. The Interested Partner is asked to provide his/her availability only if the skills match the requirements. Similarly, s/he is required to provide how much s/he will charge for the work only if s/he meets the skills and availability requirements.

During the selection process, the VE Initiator may choose to verify if the bid proposed by the Interested Partner contains information that is true, i.e. that the Interested Partner is not lying. Statoil and ODA invited their Potential Partners for an interview. In addition to interviews, ODA invited the Potential Partners to a workshop where the potential VE team was asked to solve a problem collaboratively. This gave ODA an opportunity to judge if the Potential Partners had experience in collaborative projects. Figure 8.1 shows the AIP for an enhanced matching and partner selection process for the formation of VEs, based on the case studies.

8.4 Suggestions for Improving the Agent-based Model

Finally, the results from the validation using the case studies is used to suggest improvements to the agent-based model that was presented in Chapter 6. This section helps refine the answers to **RQ2** and **RQ3**.

Metamodel

Similar to the different selection processes, there are different evaluation criteria. Thus, the sets of requirements that are considered in matching the Interested Partners to roles differ. In order to be able to represent partners that have to meet the different sets of requirements, the agents representing the partners must have a set of requirements that can be defined by the user. The set of attributes that describe an agent as well as the other entities in the model must be flexible. Thus, the attributes describing each entity in the modelling language and the type hierarchy described in Appendix A must be a flexible set of attributes that can be defined by the user.

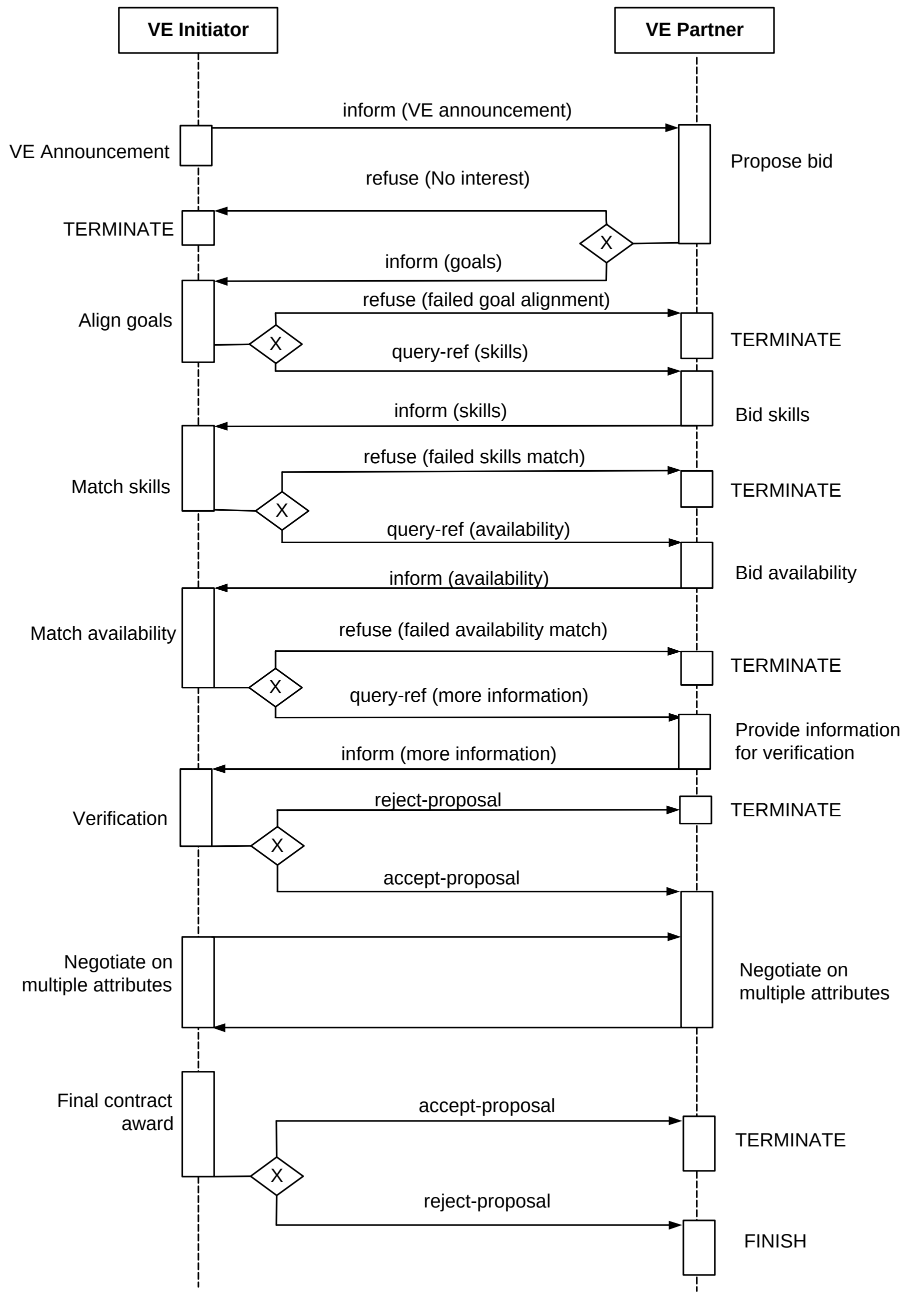

Figure 8.1: AIP for Enhanced Matching and Selection Process

Requirements and Attributes

The case studies indicated that the requirements for the roles in a VE that an agent has to meet are usually structured into different kinds of requirements. This structure can be generalized as follows:

- Skills requirements
- Availability requirements
- Cost requirements
- Other requirements (e.g. social issues such as attitudes, responsibility.

Agent Model

The fact that some of the selection processes have a verification process implies that there must be some way in which the agents must be able to contain information that they could submit to the VE Initiator for verification. An agent's activity structure can be used to contain this information. The new activity structure, thus, not only represents an agents activities, but also indicates if the activity has been performed by the agent in the past as well as other related information. This can be considered as an agent's *experience structure*. See **Paper 7** for a discussion.

To support an agent's experience structure, the following attributes can be added to an agent's activity:

- No. of times an activity has been performed - to indicate the experience of the agent in performing the activity.
- The other agent(s) with whom the activity has been performed in the past to provide information about an agent's collaboration history.

Part IV

SYNOPSIS

Chapter 9

Evaluation

This chapter evaluates the work presented in this thesis by considering the answers to the research questions, the contributions and considering how these have been addressed in the papers that are presented as a part of this thesis. It also provides the evaluation of the research method, the theoretical background, the choice of case studies and the lessons learned from this work.

9.1 Answers to the Research Questions

The main research question, that was presented in Chapter 1, is:

MRQ: How can we support the formation of VEs using agents?

The main research question **MRQ** has been answered, in general, by proposing an agent-based approach to support the formation of VEs. This has been validated using case studies, the results of which indicated that the approach can be used to support the industrial needs. In addition, the validation also provided requirements to the approach that can be used to improve it.

In order to be able to support VEs and their formation, a good understanding of VEs and how they are formed is required. Thus, **MRQ** was detailed in six simpler questions, RQ1-6. The answers proposed by this thesis to the questions RQ1-6 are:

RQ1: The answer to **RQ1** defines a VE in an agent context: *a team of agents, which may be organizations, human beings or agents, that collaborate to achieve a specific goal*. This agent-based definition of a VE has been used in this work as the working definition. It can be seen from the literature and the case studies that there are different VE formation processes. The formation of a VE takes place during the early phases in the lifecycle of a VE, e.g. when the VE's requirements are identified and the VE is designed.

RQ2: The answer to **RQ2** provides a means of describing a VE as an agent-based model. A description of this model is provided in Chapter 6 and published in **Paper 1**. The goals and requirements of the VE as well as the attributes of the partners can be represented in this model. In addition to the model of a VE,

	RQ1	**RQ2**	**RQ3**	**RQ4**	**RQ5**	**RQ6**
Paper 1		X				
Paper 2			X	X		
Paper 3						
Paper 4				X		
Paper 5					X	
Paper 6						X
Paper 7		X	X			

Table 9.1: Research Questions and Papers

which consists of agents as one of its entities, the model of the agent itself and the contents of its knowledge base was proposed in **Paper 7**.

RQ3: The answer to **RQ3** was obtained by expressing different VE formation processes in terms of AIPs and by including the information that is exchanged during these interactions in the knowledge base of the agents in the agent-based model of a VE. Expressing the VE formation process as AIPs describes the kinds of interactions, the information that is exchanged and the sequence of interactions. A simple VE formation process was described in **Paper 2** and the different VE formation processes obtained from the case studies were expressed as AIPs in **Paper 7**.

RQ4: The answer to **RQ4** is not simple as the answer to the question "what is the best VE" is not simple. In fact, the best VE must be the VE that best fits its specifications or requirements. This thesis does not address the issues governing the evaluation of a VE itself. Rather, a VE is considered as a set of requirements for its roles and the best VE is considered as the best team of partners that meet these requirements. **Paper 2** selected the best team of agents for a VE using a set of attributes that took into account the team aspects in contrast to a set of attributes that defined the individual qualities of an agent. **Paper 4** shows the matching criteria to select the partners of a VE, within a multi-agent architecture.

RQ5: The answer to **RQ5** is provided as a framework to determine the applicability of the agent-based approach to different VEs. The framework consists of a set of characteristics of the VE which help to determine when the agent-based approach would be most suitable. This framework is described in **Paper 5**.

RQ6: The answer to **RQ6** is provided in the form of high-level requirements that must be met by any agent-based approach designed to support the formation of VEs, where the partners of a VE are represented by software agents. The requirements, based on two case studies, are presented in **Paper 6**.

An overview of the research questions that were addressed in the papers presented in this thesis is given in Table 9.1. All the papers used the answer to **RQ1** as the working definition of a VE.

The contributions of this work answer the research questions and an overview of this is given in Table 9.2.

	RQ1	RQ2	RQ3	RQ4	RQ5	RQ6
C1	X					
C2		X		X		
C3			X			
C4				X		
C5					X	
C6						X

Table 9.2: Research Questions and Contributions

9.2 Evaluation of Contributions

The contributions of this work are based on literature from both the DAI and Enterprise Modelling and VE communities, and thus contribute to both these communities. A summary of the contributions are given below:

C1: The agent-based definition of a VE, based on a review of VE related literature, can be considered as a contribution to both the DAI and Enterprise Modelling and VE communities.

C2: The agent-based model of a VE provides a description of a VE and provides the input that is required by the multi-agent architecture to support the VE formation process. Obtaining the input for the VE formation process from a model and the design of such a model (based on the ideas of Enterprise Modelling) can also be considered as a contribution to both the DAI and Enterprise Modelling and VE communities.

C3: Analysing and representing VE formation processes as AIPs helps to define agent plans. In the literature, most AIPs for VE formation are based on standard protocols such as auctions. However, considering actual VE formation processes as AIPs can be considered as a contribution to the DAI community.

C4: The multi-agent architecture that is developed to support VEs is an adaptation of an existing multi-agent architecture. Due to time and resource constraints, a complete implementation of all the ideas presented in this thesis was not possible. However, the adaptation of a general multi-agent architecture to support distributed cooperative work to the context of VE formation can be considered as a contribution of this work, in particular, to those responsible for forming VEs.

C5: The framework to evaluate the applicability of the proposed agent-based approach is an inexpensive indicator of when the approach is suitable to adopt and helps to fill a gap in evaluation methods for the applicability of a particular technology for different instances of VEs. This can be considered as a contribution to those responsible for forming VEs.

C6: The requirements for an agent-based support for the formation of VEs, identified through case studies, can be considered as a contribution to the DAI community.

The work presented in this thesis was based on both theoretical (literature-based) as well as empirical research (case studies). Thus, the contributions can also be categorized as such:

- Contributions **C1** and **C2** are based on theoretical research, based on the literature review.
- Contributions **C3**, **C5** and **C6** are based on empirical research, based on the feedback from the case studies.
- Contribution **C4** is a results of the contributions **C1**, **C2** and **C3**.

The contributions of the work have been published in the papers presented in this thesis. Table 9.3 gives an overview of the contributions that have been addressed in the papers.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
Paper 1		X				
Paper 2		X				
Paper 3				X		
Paper 4				X		
Paper 5					X	
Paper 6						X
Paper 7			X			

Table 9.3: Contributions and Papers

9.3 Limitations of the Agent-based Approach

The evaluation of the agent-based approach using industrial case studies helped identify some limitations of the approach:

- It was not possible to capture the semantics of the attributes and the richness of all the evaluation criteria.
- It lacked attributes that captured the cooperative aspects of the partners (this is related to the first limitation).
- Only one level of partners were considered, or it assumed that a partner is an individual entity and not a VE itself.

9.4 Evaluation of Research Method

The research method combined theoretical and empirical approaches. This helped provide a broad understanding of the concepts, the problem domain as well as an appreciation for the problems that were faced by the industry. The theoretical approach helped consider a holistic view of a VE. While this helped retain the genuine problems faced by the industry, it also made it difficult to scope the problem to a simple, computable solution. Nevertheless, to provide a comprehensive solution to such problems is beyond the scope of a PhD thesis.

9.5 Evaluation of Theoretical Background

Due to the multi-disciplinary nature of the work, it was impossible to consider all the different areas of research that would have influenced and contributed to this work. Thus, only the areas of DAI and agents, Enterprise Modelling and Integration were considered as the main theoretical background for this work. These research areas were initially chosen due to the author's background and interests. Broadening the theoretical background by considering Organisational Design, Group and Teamwork and Coalition Formation would add value to the work.

9.6 Choice of Case Studies

The cases were chosen to represent a broad variety of VEs in industry. If different cases had been chosen, it might have been possible to identify more cases that would benefit from the agent-based approach. For example, if well defined VEs, such as projects, had been chosen, it might have been easier to obtain a quantitative analysis.

Since **C5** and **C6** are direct results from the case studies, a different choice of cases may have provided different results, e.g. an extended set of requirements. However, the variety in this selection helped identify a broad set of characteristics to analyse VEs and to consider for the applicability of the approach.

Choosing case studies for validation was not an easy task. It was time consuming and involved the analysis of a lot of information, some of which were not always relevant. The main challenge was in identifying the right cases, and once they were identified to find a case provider that had the time as well as the willingness to cooperate. There were some cases, where the case provider was willing to provide the information. However, the case also involved other parties, i.e. the partners of the VE. Thus, there were legal problems in obtaining and publishing the relevant information. This limited the scope of the case studies and the kinds of analysis and validation that could be conducted.

9.7 Lessons Learned

The work presented in this thesis has been published in international conferences and journals. This proved a fruitful way of conducting the research as it provided valuable feedback. However, since each paper considered a specific problem (or examples), there may be inconsistencies in some of the examples presented, e.g. in the parts of the agent-based model that were defined within the scopes of the different papers. The description of the agent-based model presented in this thesis (in Chapter 6 and Appendix B) can be considered as the final version of the model.

The multi-disciplinary nature of the thesis also played a role in writing the papers. It was often difficult to get the right focus for the papers because depending on the reviewer and his/her background, the contents of the paper were interpreted differently. However, this helped enrich the feedback that was received for this work.

Chapter 10

Conclusions and Future Work

This chapter concludes the thesis by summarizing the results and contributions of this work. The challenges in multi-disciplinary research and validating research in the area of VEs are discussed. Finally, directions to continue this research and future work are outlined.

10.1 Summary of Results and Contributions

An agent-based approach to support the formation of VEs was proposed in this thesis. The main idea of this approach is that agents can be used to represent the partners of a VE during the formation of a VE and the interactions among the agents can be expressed as an AIP. The agents can negotiate on behalf of their users, thus saving time and making the VE formation quick and efficient. The concept of a VE and agent-based approaches to support VEs were studied, as reported in the literature, to define an agent-based definition of a VE.

The proposed agent-based approach consisted of:

- an agent-based model of a VE, which is based on ideas from Enterprise Modelling and represents the main entities in a VE and the relationships between these entities.
- a VE formation process which describes how a VE is formed, in particular how the partners of a VE are selected. This process is expressed as an AIP.
- a multi-agent architecture which supports VE formation.

The agent-based model plays a central role in the agent-based approach and provides input to the VE formation process and the multi-agent architecture. The agent-based approach was validated using industrial case studies. The analysis of the case studies indicated that the process of forming a VE was not always the same and different evaluation criteria were used to select the partners of a VE. Based on the feedback from the case studies, the agent-based model was enhanced to support the various information that was exchanged between the agents during the VE formation.

VE formation processes were analysed as AIPs, in terms of interactions between agents, the sequence of interactions and the information that is exchanged. AIPs were used to represent the VE formation scenario in the AGORA multi-agent architecture.

10.2 Challenges

One of the challenges faced during the course of this work was the multi-disciplinary nature of it. This often made it difficult to position the work as well as scope the literature that should be studied. It was also difficult to find the right balance such that the issues faced by both the research communities (DAI and agents and Enterprise Modelling and Integration) were addressed as well as to ensure that the work was acceptable as a contribution in both fields.

There are a number of challenges in validating research on VEs. First, the issue of validating a VE itself has not been addressed by the research community. Thus, any approach that supported the formation of VEs does not guarantee that the VE formed will actually be an acceptable VE. The only way to validate a VE that is formed is by determining if it meets its requirements. But, there is no way to validate these requirements.

Another challenge is in obtaining the relevant information for validation. Often, such information is sensitive to the business of any VE (or the partners in the VE) and is unavailable for analysis or publication.

10.3 Directions for Future Work

A detailed analysis of the cases (provided the information is available) can be conducted to see how much of the evaluation criteria can be represented using the agent-based model and to identify a generic set of requirements and attributes. Similarly, the generic negotiation protocols and the issues that are negotiated upon can be identified and supported. Thus, the agent-based model could be enhanced to contain this information and this can be used to partially support any VE formation process, thus reducing the time and resources that are used in the VE formation.

Another direction for future work is to study the interaction between the agent and its user. This is based on the notion that the agent representing the user and the user are seen as one entity to the outside world. Thus, the architecture of the agent and its user, as a single agent, can be considered. This raises issues such as adaptable autonomy of the agent.

Finally, the concept of VEs as a coalition or a team of agents can be studied further using ideas from work that has been done in the fields of agent theory and team and coalition formation.

Part V

PAPERS

Paper 1

Title

An Agent-based Model to Support the Formation of Virtual Enterprises

Main Result

An agent-based model for a VE, where agents represent the partners of a VE.

Reference in Thesis

This paper is referenced from Chapter 6, Section 6.2.

Published in:

Proceedings of the *International ICSC Symposium on Mobile Agents and Multi-agents in Virtual Organisations and E-Commerce (MAMA'2000)*, Woolongong, Australia, December, 2000, Woolongong, Australia.

Copyright

An Agent-based Model to Support the Formation of Virtual Enterprises

Sobah A. Petersen* **and Michael Gruninger****
*Dept. of Computer & Information Sciences, Norwegian University of Science & Technology, 7491 Trondheim, Norway. Email: sap@idi.ntnu.no
**Enterprise Integration Laboratory, University of Toronto, 4 Taddle Creek Road, Toronto ON M5S 1A4, Canada. Email: gruninger@eil.utoronto.ca

Abstract

This paper presents an agent-based model to support the formation of Virtual Enterprises. The model proposes the main concepts of a Virtual Enterprise: goals, activities, roles, agents and skills and competencies. One of the main steps in the formation of a VE is the selection of partners. We believe that this step can be delegated to agents, where the agents represent the partners of a VE. Our model describes the entities in a VE, their relationships and how they can be used in the form of rules. We believe that this is an important step towards the development of agent-based systems to support Virtual Enterprises.

Keywords: Virtual Enterprise, Agents, Enterprise Modelling

1. Introduction

Recent advances in communication and distributed information technologies have changed the way that business is conducted. Enabled by technologies such as the Internet and Electronic Commerce, enterprises have gone beyond the geographical and sociocultural boundaries and have become entities that not only compete in the global market, but, also draw their resources from an international market. Today, businesses advertise globally for their resources and organisations no longer require their employees to be co-located to perform their work. The global search and selection of resources impose additional challenges which require new ways of dealing with them.

The concept of a Virtual Enterprise (VE) is becoming increasingly popular in the business community. Since this concept is relatively new, the generic concepts of it are not formalised. Thus, the different applications that support VEs are based on specific scenarios. Some of these applications are agent-based and are designed to operate in heterogeneous and distributed environments.

In this paper, we aim to describe the concepts that apply to a VE and to define a generic model of a VE such that agents can be used to represent the partners in a VE. The model is designed to support the formation of a VE, in particular, the selection of partners for a VE. We consider the formation of VEs from the point of view of human resource management. We investigate the steps that are involved in the formation to identify the different entities that are involved, their attributes and their interactions. Based on these, we define an agent-based model for designing and supporting the formation of VEs, where the human resources competing to become partners in the VE are represented by software agents.

1.1 What is a VE?

A VE can be defined as *a goal-oriented constellation of (semi)autonomous distributed entities. Each entity, which can be an organisation and/or individual, attempts to maximise its own profits as well as contribute to defining and achieving the overall goals of the VE. VEs are not rigid organisational structures within rigid frameworks, but rather, (heterogeneous) ensembles, continuosly evolving over time*, (Petersen et. al., 2000). VEs are formed to achieve a particular set of goals and have a shorter span of life than a traditional enterprise.

We consider a VE as a scenario that emerges in a world where individual entities, either people or organisations, come together as a team to achieve a specific goal. Electronic billboards and market places can be used to facilitate initial contact among the individuals. In this case, the individuals will bid and negotiate to get a job and the best one will win the contract. Once the goal is achieved, the VE can either disseminate or evolve by changing it's goal. An example of such a VE is a research project where several organisations and universities that have a common vision join forces to conduct some research.

The entities that constitute the VE are the partners of the VE. Since VEs do not have a rigid organisational framework, the selection of partners become one of the most important activities in the formation of the VE. VEs need to be formed very quickly in order to meet the deadlines of the goals and there is a need to form VEs often. In order to support the rapid formation of VEs, we believe that a model that describes the complete VE in terms of its entities and the relationships among them is important.

1.2 Agents in VEs

One of the advancing technologies that have been applied to support VEs is software agents, where the entities in a VE are represented by agents. The nature of the agents, by definition (Wooldridge & Jennings, 1995), enables the decentralised control that is required in VEs. The distributed nature of agents does not require the co-location of the partners of a VE. The short lifespan of the VE means that the partners that participate in one VE may also be negotiating on a contract with another VE. By delegating agents to do this job, the partners have the time to do the actual work required in the VE. The ability to delegate responsibilities to agents and agents being reusable components makes them a suitable means of representing the partners' interests in the negotiation process.

Agents have been used to support VEs in several applications. In (Barbuceanu & Fox, 1994), agents were used to represent the different entities in a distributed supply chain (e.g. supplier); in (Fischer et. al., 1996), agents are described as a useful metaphor for the design and operation of VEs; in (Jain et. al. 1999), the notion of commitments is used to manage the autonomy of an agent in a VE. Mobile agents also have been applied to represent VEs. Examples of such applications are described in (Ambroszkiewicz et. al., 1998) and (Szirbik et. al., 1999).

More recently, in (Tambe et. al., 2000), a framework for finding the right agent for an organisation in cyberspace is described. Their work focusses on enabling software developers to build large-scale agent organisations in cyberspace. The system provides a means of defining organisation roles and their requirements and matching agents that match these requirements.

While several applications have been described in the literature, they seem to focus on a specific aspect of a VE and solve that specific problem. They do not address the concept of a VE in a holistic manner and therefore it becomes difficult to generalise the scenarios.

1.3 Modelling the VE

In order to delegate the formation of a VE to agents, it is important to be able to describe the scenario in an unambiguous way. Agents are computational entities that operate in distributed environments. The agents that form the VE may be heterogeneous entities, often designed and developed by different parties. Thus, there is a need to support the development of these agents to ensure that they are able to collaborate in forming a VE. A generic agent-based model of a VE is a step towards fulfilling this need.

Our work focusses on representing the VE as a model by analysing the entities in a VE, their relationships and how they can be used in an agent context. An important contribution in modelling enterprises was made in (Fox & Gruninger, 1998), where a formal description of an enterprise was given. This work was later developed to describe how the structure of an enterprise can be linked to its behaviour, by using agents and ontologies, (Fox et. al., 1996). Although this work does not address the particular concept of a VE, it provides the foundations for a model of a VE.

In our model, the entities are described using attributes, the relationships are represented using predicate calculus and a set of rules represent how they can be used. The rules can be used by an algorithm in an application. In particular, we address the selection of partners to form a VE and describe the parts of the model that are important for this activity.

By modelling the complete scenario, we are able to see how the different entities in the model fit together. For example, how the selection of a particular agent is affected by the goals of the VE. Several applications focus on matching the skills of an agent to the requirements, (e.g. (Tambe et. al., 2000)). They, however, fail to describe things such as what these skills are and how they are derived. In addition to describing the VE, the model also help answer queries about the VE such as: what are the skills required to perform an activity or what are the shared goals in a team? Also, the model can be used as a means of verification for the VE.

In this paper, we propose a scenario for the formation of a VE and a model to support the scenario. In particular, we support the step that involves the selection of resources for the VE by illustrating how the model can be used to support allocation and planning of resources, identification of teams and checking the completion of the VE formation process. Our model does not impose a particular implementation, rather a specification for any implementation.

The remainder of this paper is organised as follows: Section 2 describes the scenario of the formation of a VE; Section 3 describes the agent-based model; Section 4 illustrates some examples of how the model can be used in the formation of a VE and Section 5 contains the conclusions and an overview of the future work.

2. Scenario

VEs are formed to meet a specific customer request, or they may be formed to look for a customer request, e.g. to bid for a project. One of the main activities in forming a VE is the *selection of the right human*

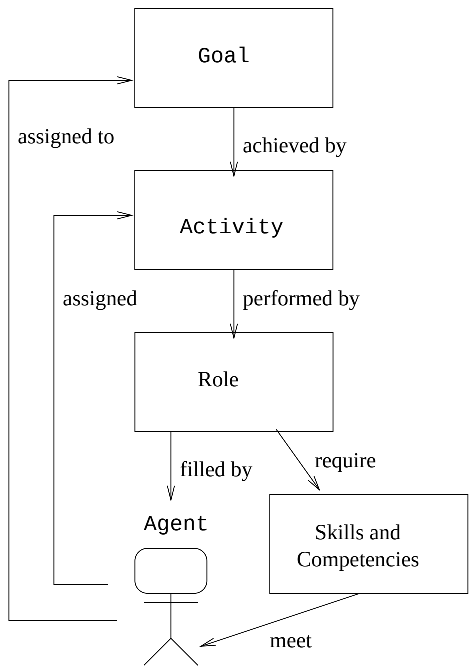

Figure 1: Scenario and Entities

resources and forming a team that has the right competencies and skills. In order to support the quick and efficient formation of VEs, there is a need to understand this process.

We have identified the following three roles, which can be performed by software agents:

1. The customer
2. The VE Initiator - the person that takes the initiative to form a VE. (Note that this may also be the customer.)
3. VE Partners - the people that form the VE. (Note that the VE Initiator can also be a VE Partner.) During the formation of the VE, the partners go through the following stages:
   (a) Interested partner - one that is interested in joining the VE and puts in a bid for the work.
   (b) Potential partner - one that is considered for the VE and a contract is negotiated. The ones that are selected from these eventually become VE partners.

We assume that when a VE is formed to perform a specific job, a series of collaborative activities take place before all the partners in the VE are assembled and they are assigned activities. The steps that are involved in forming a VE can be summarised as follows:

1. Customer and the VE initiator agreeing on the job to be done.
2. Identifying the goals and defining the requirements.
3. Defining activities to achieve the goals.
4. Identifying the roles and the skills and competency requirements to perform the activities.
5. Finding and selecting the partners to fill these roles.

We believe that these steps can be supported by an agent-based model. The different roles in the VE will be represented by software agents and these agents will negotiate to obtain the roles that they are interested in performing. Our model is focussed on step 5 and examples of how this step can be supported using the model is described later in the paper.

3. The Model

The main purpose of the model is to represent the VE and to identify and define the agent-based model for the formation of a VE. The model must provide unambiguous definitions of the entities and the relationships in a VE, which are prerequisites for achieving agent-based support. Based on the above scenario, we have identified the following entities for our model:

- **Goals** (which are achieved by performing:)
- **Activities** (which are performed by:)
- **Roles** (which require:)
- **Skills** and competencies (which are met by:)
- **Agents** (or a group of agents, Teams) (which also has goals, are assigned goals and perform activities.)

Figure 1 shows these entities and how they relate to each other. Our model contains definitions of these entities. We define them in terms of their attributes, their relationships among each other and how they can be used. The relationships among the different entities are defined in predicate calculus. A set of rules on which an algorithm can operate illustrates how the model can be used.

Consider the example where *a customer orders 100 pens, to be delivered by 15 April 2001, and at a cost of $100.* We illustrate the model and how the model can be used by using this simple example.

3.1 Goals

A goal can be considered as a state that must be achieved. e.g. VE Goal: Deliver pens to customer. The goal can then be assigned to an activity that should be performed to achieve the goal.

To use the goals in agreeing with the customer and in selecting the appropriate human resources, we need to be able to define what we mean by goals. In Section 3.1.1, we have defined a set of attributes for goals. In order to define the activities of the VE and to draw up an activities plan, the model needs to support a way of representing goal composition, the ordering of goals, goal interaction and dependencies and goal conflicts and violations. Since the goal is considered as a state to be achieved, we need to define what we mean by goal achievability and changes in a goal.

3.1.1 Attributes of Goals: In order to be able to define a goal precisely, we define it in terms of attributes. By defining the attributes, we are able to see, for example, if a goal is aligned or has changed, etc. If a goal is not aligned, then, we know the specific attributes that we need to negotiate upon to reach an agreement. A goal can be defined in terms of the following attributes:

- Area of application or product : e.g manufacturing pens.
- Due date : e.g. 15 April 2001.
- Maximum cost : e.g. $100.00
- Quantity : e.g. 100
- Quality : e.g. less than 2% defective.
- Location : e.g. Toronto, Canada.
- Goal achievement condition (e.g. 95%)
- State (e.g. achieved, achievable, unachievable).

3.1.2 How Goals can be used: Since we define a VE as a goal-oriented constellation of autonomous, distributed entities, and we define a team as such a constellation that has common goals, we believe that one of the issues that we must support is goal alignment. When the VE Initiator agrees with the customer to deliver, they must ensure that their goals are aligned. Similarly, when the VE is assembling the partners, it is important that the goals of the partners and those of the VE are aligned. In order to achieve goal alignment, we need to define what we mean by it.

- Two goals are aligned iff all their attribute values match.
- Two goals are equal iff all their attribute values are equal.
- Two goals are similar iff the attribute value "product" of one goal is equal to the attribute value "product" of the other goal.

For example, if the goal of the VE is to deliver 100 custom-designed pens to the customer and there is a partner that meet all the skills requirements, but has a goal to produce pens for large scale orders with a minimum of 1000 pens, then their goals are not aligned. Similarly, we can define how a goal is achieved, violated, changed and affected. For example, is the goal achieved by delivering 95 pens instead of hundred pens? Is the goal changed when the deadline is extended by one week? The following statements define these conditions:

- An atomic goal is achieved iff the goal achievement condition is fulfilled.
- A goal conflict or a violation occurs iff a goal is not achieved.
- A goal is changed if one or more of its attribute values change.
- A goal is changed if a new subgoal is added, deleted or replaced.
- A goal is changed if a new attribute is added, deleted or replaced.
- If a change in g1 violates g2, g1 affects g2.
- If a change in g1 causes a change in g2, then g1 affects g2.

Based on the above statements, if the goal achievement condition is defined as 95% or less, the goal is achieved by delivering 95 pens. If the deadline is extended by one week, an attribute value of the goal is changed, thus changing the goal.

3.2 Activities

An activity is the basic transformation action that represents the operation of an enterprise, (Fox et. al., 1996), and they can be used to define a plan of activities that are required to achieve a goal. One of the main purpose of the activities plan is to identify the roles that are required to perform the activities and their requirements. Similar to the goals' model, the activities model must also provide means of defining the structure of the activities, the sequencing of activities and the dependencies among the activities.

3.2.1 Attributes of the Activity: Some of the attribute values of an activity are derived or dependent on the attribute values of the goal that is achieved by performing the activity. Different attribute values have significance in the different phases of the lifecycle of the VE. The attributes of the activities are defined as follows:

- Start date
- Completion date (less than due date of goal).
- Max Cost (less than or equal to max cost of goal).
- Role(s) to perform the activity.
- Is assigned to a goal
- Is assigned to an agent (or a group of agents).
- State : e.g. ongoing, completed, enabled, suspended, cannot-be-performed.

For example, the attribute "max cost" is defined in the design phase and is used as a check in the operations phase, whilst the attribute "state" is used in the operations phase only.

3.2.2 Activities and Roles: The main attribute of a role is the function that it performs within an activity. The current model considers the role as an entity that relates an activity to an agent. Activities are performed by roles which require skills and competencies. These skills and competencies are met by agents that fill the roles to perform the activities. An agent can fill several roles. Roles are related to activities and skills as follows:

```
has(activity, role).
requires(role, set_of_skills).
```

3.3 Agents

In our model, we consider agents to be goal-oriented, cooperating (working towards a common goal) as well as self-interested (maximising own profit). The cooperative and self-interested behaviours may appear to conflict one another. However, since the agents are competing in an open market, they try to reach an optimisation of the behaviours.

3.3.1 Attributes of Agents: The main attributes of an agent that are used to recognise it are its name and the IP address. In addition to these, an agent has goals and an ontology for communication.

As seen from Figure 1, the agent has relationships with several other entities such as goals, activities and roles. The relationships are represented as predicate calculus clauses, as follows:

- An agent has goals - has(agent, set_of_goals).
- An agent is assigned to a goal - assigned_to(goal).
- An agent is assigned to an activity - assigned(activity).
- An agent has skills - has(agent, set_of_skills).
- An agent performs a role in a VE - performed_by(role, activity, agent).
- An agent belongs to one or more teams: member(team, agent).
- An agent is available at a certain time - available(agent, start_time, end_time).
- An agent charges a price to some work or for an amount of its time (i.e. to perform a specific activity) - charges_per_hour(agent, price).

3.3.2 Agent's Skills and Competencies: In our model, we assume that skill and competency are synonymous. The skills of an agent are multi-attribute entities. An agent may have one or more skills, each of which can be described by the following attributes:

- Skill : e.g. designing pens, manufacturing pens.
- No. of years of experience : e.g. 5.
- Skill rating : e.g. [1 - 10].
- Performance rating (how fast it can work) : e.g. [1 - 10].

The above attributes are easier to represent in quantitative terms and can be used in a multi-attribute negotiation. Some of the other attributes that are harder to convert into a quantitative form but are very relevant in a VE are:

- An agent makes a commitment to perform an activity.
- An agent takes a risk in joining a VE.
- An agent's willingness to take responsibility.
- The style of management that an agent is used to, i.e. the level of empowerment that an agent works best at.

These attributes are not described in our current model and are subjects for future work.

4. Using the model

To illustrate how the model can be used in the formation of a VE, we consider step 5 in our VE formation scenario : *finding and selecting partners*. This step includes allocating resources to activities by matching skills, resource planning to ensure that each agent is allocated activities that it can perform within the required time and identifying agents within the different teams.

4.1 Resource Allocation

When a VE sets out to advertise for resources, the goals of the activities, the roles that are required to perform the activities and the skills and competency requirements for the specific roles are known. Here, a possible algorithm is:

```
if has(agent, skills) and
   (agent's goals are aligned with the goals
              of the VE) and
   (agent is available at the right time
              for the right cost)
then performed_by(role, activity, agent).

if assigned(goal1, activity1) and
           assigned_to(activity1, Agent1),
then assigned_to(goal1, Agent1).
```

The attributes of the agent's skill can be used in a multi-attribute negotiation to select the best partner in terms of the skills. The selection criterion will depend on the algorithm that is applied.

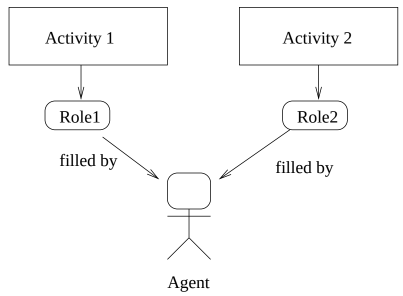

Figure 2: Same Agent allocated to two Activities

We can assume that when an agent is assigned an activity, it is authorised to perform that activity. Also, since the agent is bidding to get that activity, it only bids for the activities that it is authorised to perform and has the authority to utilise the resources that are required to perform the activity.

4.2 Resource Planning

The model can be used in planning the activities and assigning agents to activities, see Figure 2. For example, the following rule checks if the same agent is allocated to perform two different activities at the same time:

```
if performed_by(Role1, Activity1, Agent) and
   performed_by(Role2, Activity2, Agent) and
   equal(completion_date(Activity1),
               completion_date(Activity2))
then (negotiate agent's time allocation
           and assignment of activities).
```

The attributes that are used for the negotiation varies according to the task. For example, if two activities require the same skills, but need to be performed at different times, then the same agent can perform the two activities, if it is available at the required times.

4.3 Team Identification

One of the main aspects of a VE is team formation. A VE can be considered as a coalition or a team. In our model, we consider a team as a set of agents that share one or more goals. All the agents in a VE share the high-level VE goal and two agents that work on the same activity also belong to the same team as shown in Figure 3. Thus, a VE can contain several sub-teams.

```
if performed_by(Role1, Activity, Agent1) and
           performed_by(Role2, Activity, Agent2)
then (there exists a team Team such that
             member(Team, Agent1) and
     member((Team, Agent2).)
```

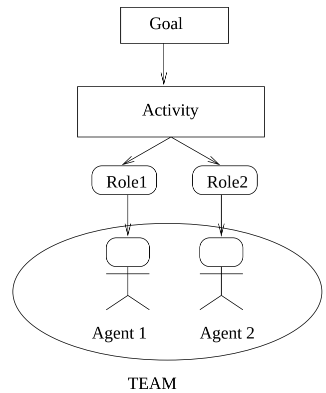

Figure 3: Agents in the same Team

In addition to the skills and competencies of an agent, it is important to consider other factors in a team formation. For example, the cost of forming a team (Barbuceanu & Lo, 2000) and (Sandholm & Lesser, 1997) and the roles and responsibilities within a team. Our current model does not address these issues. The subject of team formation in a VE is left to be explored in the future.

4.4 Test for Completion

Rules can be created to provide a means of verification for the completion of the formation of the VE. For example, if all goals are assigned activities, and if all activities are assigned to one or more agents (i.e. all the roles are filled), then the VE is formed and ready for operation.

5. Conclusions and Future Work

This paper presents an agent-based model to support the formation of Virtual Enterprises. The model provides an unambiguous description of the concepts goals, activities, roles, agents and skills and competencies. These concepts can be used in the design and development of agent-based systems to support VEs. A scenario for the formation of a VE and a model to support the scenario is proposed. In particular, we support the selection of resources for the VE by illustrating how the model can be used to support allocation and planning of resources, identification of teams and checking the completion of the VE formation process.

This model needs to be further developed to cover all the steps that take place in the formation of a VE as well as to include the other phases in the lifecycle of the VE such as operations. Other important issues include the enhancement of the agent model to support the softer attributes of human resources such as commitments, responsibilities and style of management.

Acknowledgements

This research is supported, in part, by a research grant from Det Norsk Veritas, Norway, and the CAGIS project, funded by the Norwegian Research Council.

References

Petersen, S.A, Divitini, M., Matskin, M., 2000. "An Agent-based Approach to Modelling Virtual Enterprises", International Journal of Production Planning and Control. *To appear.*

Wooldridge, M. and Jennings, N., 1995. "Intelligent Agents: Theory and Practice". *Knowledge Engineering Review*, vol. 10, no. 2, p. 115-152.

Fischer, K., Ḿuller, J.P., Hemig, I. and Scheer, A., 1996. "Intelligent Agents in Virtual Enterprises", Proc. of the First International Conference and Exhibition on the Practical Applications of Intelligent Agents and Multi-Agent Technology, Aprill 1996, London, U.K., p.205-204.

Barbuceanu, M. and Fox, M.S., 1994, "The Information Agent: An infrastructure agent supporting collaborative enterprise architectures", In Third Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises, 1994.

Jain, A.k., Aparicio IV, M. and Singh, M.P., 1999. "Agents for Process Coherence in Virtual Enterprises", In *Communications of the ACM*, March 1999, Vol. 42, No. 3, p. 62-69.

Ambroszkiewicz, S., Cetnarowicz, K. and Radko, B., 1998. "Enterprise Formation Mechanisms based on Mobile Agents", in Holsten, A. et. al. (eds.), Proc. of the Workshop on Intelligent Agents in Information and Process Management, KI'98, TZI-Bericht, No. 9, 1998, p. 23-34.

Szirbik, N.B., Hammer, D.K., Goosenaerts, J.B.M. and Aerts, A.T.M., 1999. "Mobile Agent Support for Tracking Products in Virtual Enterprises", AGENT'99, Seattle, U.S.A., May 1999, Workshop Notes, ACM.

Tambe, M., Pynadath, D. and Chauvat, N., 2000, "Building dynamic agent organizations in cyberspace", IEEE Internet Computing (to appear).

Fox, M.S., Gruninger, M., 1998. "Enterprise Modelling", AI Magazine, AAAI Press, Fall 1998, p. 109-121.

Fox, M.S., Barbuceanu, M. and Gruninger, M., 1996, "An Organisation Ontology for Enterprise Modelling: Preliminary Concepts for Linking Structure and Behaviour", *Computers in Industry*, Vol. 29, 1996. p. 123-134.

Barbuceanu, M. and, Lo, W., 2000. "Integrating Individual, Organisational and Market Level Reasoning for Agent Coordination", to appear in Werner, Horn (ed.), Proceedings of ECAI-2000, Berlin, Germany, Aug. 2000, IOS Press.

Sandholm, T. and Lesser, V., 1997. "Coalitions among Computationally Bounded Agents". *Artificial Intelligence*, 94(1), Special issue on Economic Principles of Multiagent Systems, p. 99-137.

Paper 2

Title

Using Agents to Support the Selection of Virtual Enterprise Teams

Main Result

The attributes of the agents that represent the partners of a VE, an implementation of a "partner evaluator" and a discussion on the issues facing the selection of partners.

Reference in Thesis

This paper is referenced from Chapter 6, Sections 6.2.3, 6.3 and 6.5.

Published in:

Proceedings of the *Fourth International Bi-conference Workshop on Agent-oriented Information Systems (AOIS-2002),* at AAMAS 2002, Bologne, Italy, July 2002.

Copyright

Using Agents to Support the Selection of Virtual Enterprise Teams

Sobah Abbas Petersen and Monica Divitini

Department of Computer and Information Science,
Norwegian University of Science and Technology,
N-7491 Trondheim, Norway
{sap, monica}@idi.ntnu.no

ABSTRACT

Virtual Enterprises are dynamically constituted by individual entities that come together as a team to achieve specific goals. This dynamic nature imposes strong demands on the formation of the Virtual Enterprise since the capability of effectively putting together the best team of individuals is key to the success of the Virtual Enterprise itself. In this paper, we propose an agent-based model to support the formation of Virtual Enterprises. In our approach, each individual entity is represented by an agent who, in the context of an electronic market place, competes to become partners of a VE. The paper describes the attributes of the agents that are required and the issues facing the selection of the partners. In particular, it stresses the need to select partners by considering not the individual entities alone, but also how they can contribute to the desired *team of partners*.

KEYWORDS

Virtual Enterprise, Team Formation and Electronic Markets

1. Introduction

Recent advances in communication and distributed information technologies have changed the way that business is conducted. Enabled by technologies such as software agents and Electronic Commerce, enterprises have gone beyond the geographical and sociocultural boundaries and have become entities that not only compete in the global market, but also draw their resources from an international market. The trend of outsourcing seems to be replaced by strategic alliances, where enterprises or individuals work together towards a common goal and share their responsibilities as well as their profits. The concept of a Virtual Enterprise (VE) has emerged as a means of dealing with this new type of alliance.

A VE can be described as a scenario that emerges in a world where individual entities, human beings, software agents or organisations, come together as a team to achieve a specific goal. There have been several attempts at defining VEs from different research communities and there are several definitions of the concept as summarized in [15]. VEs can be characterised as a network of independent (heterogeneous) individuals or enterprises [10]. VEs exist for a limited amount of time, [7], [14]. The entities that constitute the VE are the partners of the VE. The partners collaborate among themselves [5], are goal-oriented [16], commitment-based [11] and share their skills, costs, profits, risks and markets [4].

The partners cooperate to achieve a set of goals and then move on to join another VE. VEs do not have a rigid, permanent organisational framework. Rather, they are a *team of partners* that have common goals and are committed to fulfilling these goals. Thus, the success of the VE is strongly dependent on the commitment, the performance and the delivery capabilities of its partners. In this paper, we consider VEs where the partners are human beings.

One of the most important stages in the lifecycle of the VE is the formation of the VE. Since VEs have a limited lifetime, they need to be formed very quickly in order to meet the deadlines of the goals and there is a need to form VEs often. An important part of the formation of the VE is the selection of its partners. They are selected on the basis of their ability to fulfil the requirements of the VE. Since all the partners have to work as a team, these requirements must address not only the individual partners of the VE, but also how the partners fit into a team. When selecting a team of partners from a global resource pool, how can we determine the *best team*? What is *best* in this situation? In order to be able to define this, we need to have answers to questions such as what do we require from the partners? What are the attributes we're looking for in the partners? How can we judge each partner or a team of partners? How can we compare two partners or two teams of partners?

Some of the above information may not be available apriori or may evolve during the selection of the partners. Another issue in defining some of the above information is the fact that partners are human resources. While the capabilities of a human being can be expressed in quantitative terms, not all aspects of their behaviour, in particular their cooperative behaviour can be expressed so clearly. This makes it harder to express the attributes of the desired partner and the desired team in clear unambiguous terms.

It is also important to bear in mind that the formation of the VE is one of several phases in the life cycle of the VE. The lifecycle of a VE can be analysed using ideas from Enterprise Modelling and Enterprise Reference Architectures (e.g. GERAM, Generic Enterprise Reference Architecture and Modelling, [12]).

Fig. 1 shows the formation stage of a VE within a lifecycle context. Before a VE is formed, it's concepts and goals have to be defined. The requirements from the customer sets the requirements for the VE team and in order for the VE to be able to deliver to its customer, the right team has to be formed. During the formation stage of a VE, the individual entities compete and negotiate to become the partners of the VE. When the VE is formed, the partners that have been selected constitute the VE and work together to deliver to the customer.

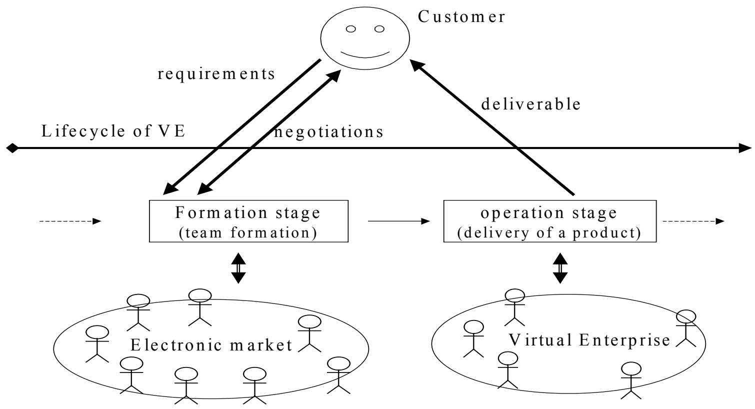

Fig. 1. Formation of a VE from a lifecycle perspective

We have chosen agents as the solution technology for our work, where software agents (hereafter referred to as agents) represent the partners of a VE. The distributed nature of agents does not require the co-location of the partners of a VE. The short lifespan of the VE means that the partners that participate in one VE may also be negotiating on a contract with another VE. By delegating agents to do this job, the partners have the time to do the actual work required in the VE. The ability to delegate responsibilities to agents and agents being reusable components makes them a suitable means of representing the partners in a VE. Another important aspect of using agents is that ideas from e-commerce and electronic market places have been considered as a suitable means of supporting advanced inter-organisational relationships and bringing together individual entities that want to form a VE [18]. In this respect, the agents can operate within the context of an electronic market during the formation stage of the VE, as illustrated in Fig. 1.

This paper considers a VE where individual entities compete to become partners of a VE. The partners of the VE are represented by software agents. The formation of the VE is supported by providing decision support to select the best team of partners for a specific VE. We discuss the issues faced in the selection of the partners. We also propose that the selection of partners by considering individual partners alone does not necessarily result in the best *team* of partners for the VE and we describe an example of selecting the partners for a VE. The remainder of this paper is organised as follows: Section 2 describes an agent-based model for the VE, the agents and their attributes in detail; Section 3 describes the process of selecting a team of partners for the VE; Section 4 describes an example of the formation of a VE; Section 5 reviews some of the literature that is related to this work and Section 6 discusses the conclusions and the work that is planned for the future.

2. Model Overview and Agent Attributes

In order to support the rapid formation of VEs, a model that describes the complete VE in terms of its entities and the relationships among them is important. An agent-based model for VEs is proposed in [16]. Fig. 2 shows the different entities that are in the model and their relationships. A VE has a *goal* (or a set of goals) that is/are achieved by a set of *activities* that are performed by *roles* which are filled by *agents*. A role requires a certain set of *skills*. The agent that fills the role meets the skills requirement. The entities in the model are described using attributes; the relationships among the entities are represented using predicate calculus and a set of rules represent how they can be used. One of the strengths of this model is the fact that the entities are not only described by how they relate to or depend on each other, but also by considering the internal contents of them in terms of attributes.

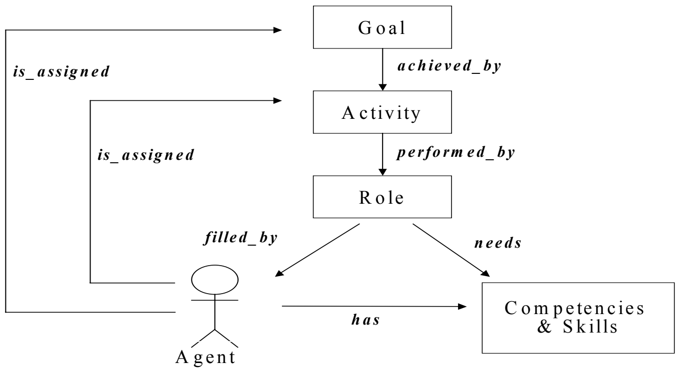

Fig. 2. VE Model Overview & Scenario

In this paper, we focus on the contents of the model that are relevant for the formation of a VE. However, it is important to consider the complete model to be able to understand how the different entities affect one another. For example, how does the selection of a particular agent affect the goals of the VE? Such a question can only be answered if we see the link from the agent to the goals of the VE. A complete model is also helpful in determining the kind of information that is flowing among the different entities. This in turn helps in designing the agents and the communication and collaboration among the agents.

The agents can be classified as *VE Intiator* (who may also be the customer), who takes the initiative to form the VE and *Partner* (who may also be the VE Initiator), who are the people that form the VE. A Partner evolves from someone that is interested in becoming a part of the VE to someone who is actually a part of the VE. During the formation of a VE, the partners go through the following stages (see Fig. 3 for an illustration of these stages):

- Interested Partner – one that is interested in becoming a part of the VE and submits a bid for the work.

- Potential Partner – one that is considered for the VE and a contract is negotiated.
- VE Partner – one that is selected as part of the VE team after a process of negotiation.

The agents are described by a set of attributes and these attributes form the basis for the evaluation of the agent as a partner in the VE and during the selection of the VE team. We do not consider the complete model of the agent. Rather, we consider the attributes that are required for the agents to propose a bid and negotiate to become a partner in the VE. An agent representing the VE Initiator is described by the attributes shown in Table 1.

Table 1. Attributes of the VE Initiator

Attribute	***Description***
Goal(s)	The VE's goal(s)
Availability	The time frame that the partners are required for, i.e. the time frame for the VE.
VE requirements	The skills and other information that are required by the VE and the constraints on these attributes.
Deadline	Bid closing date

An agent representing a VE Partner is described by multiple attributes, some of which may in turn be described by a set of attributes themselves, e.g. a particular skill of an agent. Each attribute is weighted to calculate a utility value that is used in the selection process. Table 2 shows the set of attributes describing an agent representing a VE partner.

Table 2. Attributes of a VE Partner

Attribute	***Description***
Goal(s)	The partner's goal(s)
Availability	The time period that the partner is available to do the work.
Skill(s)	Something that the partner can do, e.g. java programming
No. of skills	The no. of things that the partner can do.
Cost per hour	How much the partner expects to be paid for each hour of work.
Total no. of hours	The total no. of hours that the partner takes to perform the job.
Performance rating	Indication of how efficient the person is at performing a specific task.
Level of commitment	How committed the partner is at doing the work.
Risk	The risk(s) involved in including a partner in the VE.

The skills of a VE Partner (or an agent) are described as a set of multiple attributes that have constraints. Each agent may have one or more skills, each of which can be described by the attributes skill, (e.g. java programming), no. of years of experience, (e.g. 2) and skill rating, (e.g. [1-10]). Examples of some constraints for these attributes are the minimum no. of years of experience that is required for a skill or the lowest acceptable level of skill rating for a skill.

Some of the attributes given in Table 2 are not easy to represent in quantitative terms (e.g. commitment). In order to be able to create a quantitative model that can be used in multi-attribute negotiations, we have tried to come up with a quantitative value for the attributes. We have detailed some of the attributes as follows:

- *Availability* – the time period that the partner is available. The availability of a partner is matched against the time that the VE Initiator needs a VE team. This value is constrained by a start date and an end date.
- *The total cost of having a partner* – the total cost charged for doing the job (total no. of hours * the charge per hour).
- *Level of commitment* – is measured in terms of a "commitment breaking cost" which is the cost that the partner must pay to the VE if the partner breaks the commitment before the goals of the VE are achieved. Thus, the higher this value is, the more preferable for the VE. We have expressed this as a percentage of the total cost. (In reality, this may not be so rigid as the commitment breaking cost may be a function of the status of the activity as well.)
- *Risk* – the risk of having a partner is simplified as (the total cost of having a partner – the commitment breaking cost). Thus the higher the commitment breaking cost, the lower the risk.

3. Selection of VE Partners

3.1 Selection Process

Fig. 3 gives an overview of the selection process. The first subprocess "align goals" is to check if the goals of the VE and the goals of the partner are aligned. If this is true, the partners now becomes Interested Partners and their skills and availability are matched against the requirements of the VE in the subprocess "match skills and availability". The skills are matched by conducting a string match. The Interested Partners are now Potential Partners and their individual bids are evaluated and ranked in the subprocess "Individual bid evaluation". The best set of partners selected by considering individual bids may not necessarily be the best team. (We discuss this further in Section 3.4.) Therefore, a fourth subprocess, "Select team", is included where the Potential Partners are considered as a team during the selection.

The first 3 subprocesses consider individual partners while the fourth subprocess considers a team of partners and the evaluation is conducted based on different criteria.

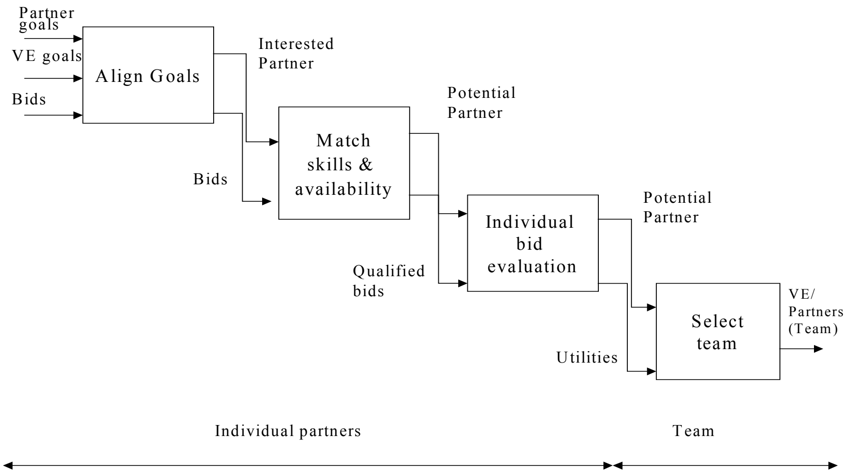

Fig. 3. Selecting partners for a VE

3.2 Communication

Fig. 4 shows the communication that takes place between the VE Initiator and the Partners. The VE is announced by inviting Interested Partners to bid and the announcement contains the following information:

- The goals of the VE
- The skills that are required for the VE
- The time frame for the VE
- The deadline for the response to the announcement

The Interested Partners respond to the announcement by sending in a bid, which contains the following information:

- The goals of the partner
- List of attributes and their values (the attributes include the skills of the partner)

The bids are qualified if the goals are aligned and a minimum no. of skills are matched. Skills that do not match are ignored. The bids that are disqualified are informed of their failure to qualify and the VE Initiator then prepares to negotiate with the partners that submitted bids that qualified; i.e. the Potential Partners.

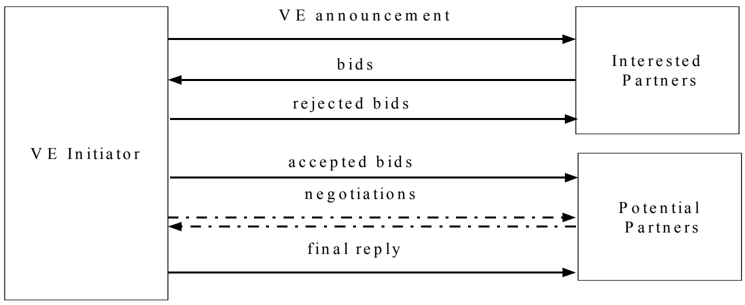

Fig. 4. Communication during the formation of a VE

In addition to the above information, both the announcement and the bid will carry the name, identification and address of the sender and receiver agents. But since we're not considering a specific implementation of a multi-agent architecture, the details of this information have been left out.

3.3 Bid Evaluation

The bids are evaluated using a multi-attribute utility function. For each qualifying bid, the attribute values are checked to see if they meet the constraints. If the values do not meet the constraints, then they are assigned the value zero. Each attribute is weighted and the utility function is as follows:

$$\text{Utility Value} = \Sigma(\text{attribute value} * \text{weight})$$

Since the values may span a wide range, the values are normalised before the calculation. The utility values are calculated for all the qualified bids and the values are ranked, where the highest utility value is at the top. This list is then submitted to the VE Initiator. The VE Initiator can then choose the best (highest ranked) Potential Partners for the VE or s/he can choose to negotiate with the Potential Partners for a better bid. Instead of selecting a number of highest ranked Potential Partners, the VE Initiator can also choose the best team for the VE.

The evaluation is based on the set of attribute values that are included in the utility function and the weights that are assigned to them. The utility function can be changed by choosing a different set of attributes and/or by changing the weightings that are assigned to the attributes.

3.4. Team Selection

We believe that the concept of a team is an important point in forming a VE as the partners have to collaborate and work together as a team to achieve the goals of the VE. Therefore, we consider the selection of the team as a separate subprocess in the selection of the partners and consider the attributes of a team rather than the attributes of an individual in the utility function to determine the best team of partners.

The selection of the best team can be based on several criteria and the best team may not always be the team that consists of the highest ranked Potential Partners. For example, a VE may have constraints such as a total budget that the VE Initiator can pay its partners. There may be other such constraints. In the example in Section 4, we have considered the following attributes as the main factors determining the utility function for the selection of a team:

- The total cost of the partners in a team.
- The total risk of having the partners in the team.

Consider the situation where the VE is looking for a set of skills that several people possess and the variation of the level of the skill is not so high. In such a situation, the skills of the partner may not play such an important role in selecting the team, whereas the cost of hiring the people may play a bigger role. Another situation could be where we are looking for very specific skills and the degree of variation of the skill level is high. In such a situation, the skill of the partner may play a more significant role than in the previous situation. Therefore, in this situation, a higher weight might be put on the skills of the partner.

Due to the reasons explained above, we also believe that the attributes that define the best team for a VE cannot always be defined apriori and there is often a need to change or redefine the utility function to select a team during the selection process. Therefore, it becomes necessary to support this flexibility in defining the utility functions that are used in selecting both individual partners as well as the team of partners. This is one of the areas where we continue our research.

3.5. The role of Negotiation

Negotiations can take place in several places:

1. The VE Initiator negotiates with the Interested Partner on the initial bid (using the lowest values based on the bids from all the Interested Partners). This would mean that the ranking is done based on the last (best) offers made by the Interested Partners.
2. The VE Initiator negotiates with the Interested Partner on selected attribute values after the ranking. e.g. the highest ranked Potential Partners may not fulfil the cost constraint of the team. Thus, the VE Initiator may negotiate with the highest ranked (or all of the) Potential Partners to reduce their costs and risks.

Negotiations are based on a multiple set of attributes and the aim of the negotiation is to obtain a set of attribute values that are at a pareto optimum.

4. Example

Consider a VE formed to design the Internet homepage for a company, [3]. The VE Initiator is looking for 2 partners with the relevant programming skills. IP-A, IP-B, IP-C and IP-D are Interested Partners and they bid to become a part of the VE. The attributes and the values for each partner that are considered for the evaluation and the constraints and the weightings that are applied in the utility function are shown in Table 3.

Table 3. The attributes, their utilities and weightings

Attribute (Constraints), (Weightings)	***IP-A***	***IP-B***	***IP-C***	***IP-D***
Area of relevant skills (HTML, XML, Java), ()	Java, XML	HTML, XML	Java, XML, HTML	Cobol, HTML
For each skill:				
No.of years of experience (>=2), (50)	5,6	4,3	5,3,5	10,2
Skill rating (>=6), (50)	10,9	8,3	6,6,6	10,2
Performance rating (>=6), (30)	9	6	8	9
No. of relevant skills (>=2), (5)	2	2	3	1
Availability (calculated) (), (25)				
Start date (1.11.01), ()	1.10.2001	1.10.2001	1.10.2001	1.10.2001
End date (1.12.01), ()	1.1.2002	1.1.2002	1.1.2002	1.1.2002
% time available	100	80	50	100
Total Cost (calculated) (), (25)	48,000	38,400	36,000	40,000
Cost per hour (<NOK500), ()	300	300	450	250
Commitment breaking cost	50%	35%	35%	10%
Risk for the VE (calculated) (), (15)	24,000	24,960	23,400	36,000

In this example, we assume that the goals of the Interested Partners are aligned with the goals of the VE. So, the next step is to conduct the skills matching. This is done by matching the skills of the Partners against those that are required by the VE and then checking the no. of skills that are relevant. It can be seen that IP-D does not meet the minimum no. of skills that are required and will not be considered in the evaluation. The utility values are calculated using the following equation:

Utility Value for each partner = (skills_value*35%) + (cost_value*25%) + (risk_value*15%) + availability_value*25%)

By calculating the utility values for each partner, we get the following ranking:
IP-A: Utility = 101, IP-C: Utility = 94, IP-B: Utility = 68

Based on this evaluation, the VE Initiator could choose IP-A and IP-C to form the VE team. A team, however, is not necessarily based on the same kinds of attributes that were considered for the above ratings; i.e. the best team could be based on a different utility function. In this example, we have considered the combined cost of the team and the combined risk of the team as the factors defining the utility function for the team. The utility value for a team is calculated using the following equation:

Utility Value for a team = (total_cost_value*70%) + (total_risk_value*30)

Using the values and weightings shown in Table 4 to calculate the utility value for each combination of the team consisting of 2 partners, we get the highest utility value for the team consisting of IP-B and IP-C.

This simple example demonstrates that the highest ranked partners don't necessarily form the best team. Thus, it is important to support both these steps so that the VE Initiator has the possibility to select the best team. Supporting both these steps also demands the need for the flexibility to define a different utility function for teams.

Table 4. Attributes of teams for the VE

Team combination	*Total Cost (max. cost),(weighting=70)*	*Risk for the VE (max. risk),(weighting=(30)*	*Utility Values*
IP-A and IP-B	48,000 + 38,400 = 86,400	86,400 – (48,000*0.5 + 38,400*0.35) = 48,960	23
IP-A and IP-C	48,000 + 36,000 = 84,000	84,000 – (48,000*0.5 + 36,000*0.35) = 47,400	25
IP-B and IP-C	38,400 + 36,000 = 74,400	74,400 – (38,400*0.35 + 36,000*0.35) = 48,360	31

In this example, the two steps are shown in isolation and therefore, the ranking of the partners may appear to be redundant. However, given the variety of situations where the formation of a VE takes place, it is desirable that the system provides the VE Initiator with as much information as possible. It is then the responsibility of the VE Initiator to evaluate the information depending on the specific situation. Alternatively, it is possible to connect the two steps directly to include the ranking as a parameter in the utility function to determine the best team.

5. Related Work

An important contribution in modelling enterprises was made in [8], where a formal description of an enterprise was given. This work was later developed to describe how the structures of an enterprise could be linked to its behaviour, by using agents and ontologies [9]. Although this work does not address the particular concept of VEs, it provided the foundation for our model of a VE.

Agents have been used to support VEs in several applications. In [2], agents were used to represent the different entities in a distributed supply chain (e.g. supplier) and in [11], the notion of commitments is used to manage the autonomy of an agent in a VE. Mobile agents also have been applied to represent VEs. Examples of such applications are described in [1] and [21].

Of particular relevance to our work is the work done in representing VEs within the context of an electronic market. The AVE (Agents in Virtual Enterprises) project, described in [7], provides a description of how agents can be used in the formation of a VE. One of the main components of the system that was proposed is an electronic VE market, where different enterprises can announce and obtain various information. This approach was further developed as a multi-agent architecture in [14], where they focus on the formation of the VE, where agents that represent the partners of a VE negotiate to become a part of the VE. The agents conduct a multi-attribute negotiation and have the ability to learn from past experiences. While this work considers a wider aspect of multi-agent systems, it does not describe a holistic model of the VE and does not address the aspect of a team formation explicitly.

The concept of a team is used in [23], which describes a framework for finding the right agent for an organisation in cyberspace. Their work focuses on enabling software developers to build large-scale agent organisations in cyberspace. The system provides a means of defining organisation roles and their requirements and matching agents that meet these requirements. More recently, there has been work done in immersing a team of agents within a human organisation [17]. The multi-agent system, RETSINA provides matchmaking capabilities that have been used to match a requester and a service provider, through a middle agent, [19]. These capabilities have been used in AgentStorm to form a team of agents that provide support to human beings, [20]. While these works address issues that are relevant to our model of the VE, they mainly address the possibility and capability of an individual to join a team and they do not consider the team as a whole, trying to optimize its composition. In this perspective they can be considered as complementary rather than alternative approaches to the one presented in this paper.

Contributions have been made by the DAI community to define teams and teamwork. Most of this work is based on agent theory and is aimed at providing support to the design of teams of agents. For example, a means of forming teams of agents at runtime is described in [24]. Here, a team is defined in terms of a joint plan and the execution of a joint plan. It also suggests some strategies for the formation of teams. Other models of teamwork include STEAM [22] and team formation by dialogue in [6]. These models are designed to support the automation of teamwork and use the notion of joint plans and plan execution and rely on tasks that are well-described apriori. In our model, we use the notion of activities, which is inspired more by the Enterprise Modelling community rather than the DAI community. The entity activity in our model is a higher-level concept that denotes some work that needs to be performed by the team. Since the objective of our work at this stage is not to automate these activities, we have not considered activities within the context of plan execution. We believe that the activities of a VE cannot always be described completely nor automated, partly because some of these activities are performed by human beings.

6. Conclusions

The main contribution of this paper lies in the description of a VE as a team of partners and how the potential partners of a VE can be represented by agents during the formation of the VE. The formation of the VE is supported by providing decision support to select the best team of partners for a specific VE. The paper describes in detail the attributes of the agents that are required and the issues facing the selection of the partners. It also proposes that the selection of partners by considering individual partners alone does not necessarily result in the best *team* of partners for the VE and illustrates this through a simple example.

The ideas presented in this paper have been implemented in JAVA. The implementation consists of a module that takes the attributes, their values, constraints and weightings and performs the bid evaluations. The output is a list of Potential Partners that are ranked according to the evaluation. Similarly, an evaluation for the best team is also conducted. This module is designed as a calculating mechanism that can be used within a multi-agent architecture. Our next step is to incorporate it into the AGORA multi-agent architecture, which is designed to support distributed working, [13]. Although we have chosen a particular multi-agent architecture, this module is designed such that it can be used by any architecture that is built around the concept of electronic markets.

Our main area of research will be in completing the model of the VE, in particular the attributes of the agents representing the VE and some of the “soft attributes” of an agent such as personality and management related ones, e.g. the style of management that a partner is used to or the level of empowerment that a partner works best at. We also need to address the cooperative and collaborative capabilities of a partner and how to represent them. Further enhancements of the model will be done based on industrial case studies.

7. Acknowledgements

We thank Lars Daniel Benes and Morten Meyer for implementing these ideas and Prof. Mihail Matskin for interesting discussions and his support for this work.

8. References

1. Ambroszkiewicz, S., Cetnarowicz, K. and Radko, B., Enterprise Formation Mechanisms based on Mobile Agents. In Holsten, A. et al. (eds.), *Proc. of the Workshop on Intelligent Agents in Information and Process Management*, KI'98, TZI-Bericht no.9-1998.
2. Barbuceanu, M. and Fox, M.S., The Information Agent: An infrastructure agent supporting collaborative enterprise architectures, In *Third Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises*, 1994.
3. Benes, L. D. and Meyer, M., GOPAMAN Multi-attribute Decision Making and Negotiation. *MSc Theses*, Norwegian University of Science & Technology, Trondheim, Norway, Dec. 2000.
4. Byrne, J. A., Brandt, R. and Port, O., *The Virtual Corporation*, Business Week, February 8, 1993, p. 36-40.
5. Childe, S. J., The Extended Enterprise - a Concept of Co-operation, *Production Planning & Control*, 1998, Vol. 9, No. 3, p. 320-327.
6. Dignum, F., Dunin-Keplicz, B. and Verbrugge, R., Agent Theory for Team Formation by Dialogue, *Intelligent Agents VII, Agent Theories Architecture and Language (ATAL2000)*, LNAI 1986, Castelfranchi, C. and Lesperance, Y. (eds.), 2000, p. 150-166.
7. Fischer, K., Muller, J. P., Heimig, I. and Scheer, A., Intelligent Agents in Virtual Enterprises, 1996. *Proc. of the First International Conference and Exhibition on The Practical Applications of Intelligent Agents and Multi-Agent Technology*, U.K.
8. Fox, M., Barbuceanu, M. and Gruninger, M., An Organisation Ontology for Enterprise Modelling: Preliminary Concepts for Linking Structures and Behaviour, *Computers in Industry*, Vol. 29, 1996, p. 123-134.
9. Fox, M. and Gruninger, M. Enterprise Modelling, *AI Magazine*, AAAI Press, Fall 1998, p. 109-121.
10. Jagdev, H. S. and Browne, J., The extended enterprise - a context for manufacturing, *Production Planning & Control*, 1998, Vol. 9, No. 3, p. 216-229.
11. Jain, A. K., Aparicio IV, M. and Singh, M. P., Agents for Process Coherence in Virtual Enterprises, in *Communications of the ACM*, March 1999, Vol. 42, No. 3, pp. 62-69.
12. IFIP-IFAC Task Force, GERAM: Generalised Enterprise Reference Architecture and Methodology, Version 1.6.2, available from http://www.cit.gu.edu.au/~bernus/
13. Matskin, M., Divitini, M. and Petersen, S. A., An Architecture for Multi-Agent Support in a Distributed Information Technology Application. *International Workshop on Intelligent Agents in Information and Process Management on the 22nd German Annual Conference*

on Artificial Intelligence in Bremen (KI-98), TZI-Bericht Nr. 9, Germany, 15-17 September, 1998, p. 47-58.

14. Oliveira, E. and Rocha, A. P., Agents' Advanced Features for Negotiation in Electronic Commerce and Virtual Organisation Formation Process*, European Perspectives on Agent Mediated Electronic Commerce*, Springer Verlag, June 2000.
15. Petersen, S. A., Extended and Virtual Enterprises – A Review of the Concepts, Technical Report 2/02, Dept. of Computer and Information Sciences, Norwegian University of Science & Technology, Trondheim, Norway, ISSN-NO:0802-6394, 2002.
16. Petersen, S. A., Gruninger, M., An Agent-based Model to Support the Formation of Virtual Enterprises, *International ICSC Symposium on Mobile Agents and Multi-agents in Virtual Organisations and E-Commerce (MAMA'2000)*, in Woolongong, Australia, 11-13 Dec. 2000.
17. Pynadath, D., Tambe, M., Arens, Y., Chalupsky, H., et. al., Electric Elves: Immersing an Agent Organisation in a Human Organisation, *Proceedings of the AAAI Fall Symposium on Socially Intelligent Agents --- the human in the loop*, 2000.
18. Rocha, A. P. and Oliveira, E., Electronic Commerce: a technological perspective, in *The Future of Internet*, March 1999.
19. Sycara, K., Lu, J., Klusch, M. and Widoff, S., Matchmaking Among Heterogeneous Agents on the Internet. *Proceedings AAAI Spring Symposium on Intelligent Agents in Cyberspace*, Stanford, USA, 1999.
20. Sycara, K. and Giampapa, J., AgentStorm, MURI: Integrating Intelligent Agents into Human Teams, 2000, available from http://www-2.cs.cmu.edu/~softagents/presentations/AgentStorm.ppt
21. Szirbik, N. B., Hammer, D. K., Goossenaerts, J. B. M. and Aerts, A. T. M., Mobile Agent Support for Tracking Products in Virtual Enterprises. *AGENT'99*, Seattle, USA, May 1999, Workshop Notes, ACM.
22. Tambe, M., Towards Flexible Teamwork, *Journal of Artificial Intelligence Research*, Vol. 7, 1997, p. 83-124
23. Tambe, M., Pynadath, D. and Chauvat, N., Building Dynamic Agent organizations in Cyberspace, *IEEE Internet Computing* (to appear).
24. Tidhar, G., Rao, A. S., Ljungberg, M., Kinny, D. and Sonenberg, E. A., Skills and Capabilities in Real-Time Team Formation, Technical Report, No. 7, Australian Artificial Intelligence Institute, 1992.

Paper 3

Title

An Agent-based Approach to Modelling Virtual Enterprises

Main Result

An approach to modelling the complete lifecycle of a VE using the AGORA multi-agent architecture.

Reference in Thesis

This paper is referenced from Chapter 6, Section 6.4.1.

Published in:

Special Issue on Enterprise Modelling, *International Journal of Production Planning and Control*, 2001, Vol. 12, No. 3, pages 224-233.

Copyright

An Agent-based approach to modelling Virtual Enterprises

Sobah A. Petersen, Monica Divitini and Mihhail Matskin

Department of Computer and Information Science,

Norwegian University of Science and Technology,

N-7050 Trondheim, Norway

{Sobah.Petersen, Monica.Divitini, Mihhail.Matskin}@idi.ntnu.no

KEYWORDS

Virtual Enterprises, Enterprise Modelling, Agents, Multi-agent Systems, Cooperative Work.

ABSTRACT

This paper describes how Virtual Enterprises (VEs) can be modelled using the AGORA multi-agent architecture, designed for modelling and supporting cooperative work among distributed entities. The model consists of a structure of Agoras and agents, where Agoras are facilitators of cooperative work for agents and the agents represent the partners of the VE, the cooperative mechanisms and the service providers. The distributed and goal-oriented nature of the VE provides a strong motivation for the use of agents to model VEs. The main advantages of this approach are that the structure of Agoras provides a homogeneous modelling environment throughout the lifecycle of the VE, traceability of the VE activities and a history of the VE. In addition to these, it is important to point out that, agents being computational entities, the resulting model provides an easy and efficient passage from the model to the computational support that is required by the VE.

1 INTRODUCTION

Virtual Enterprises (VEs) have recently received increasing attention. Due to the advancement of distributed information technology and the changing needs of the business community, enterprises are expected to be more agile and responsive. The concept of a VE is a means of meeting these new expectations. Although a universally accepted definition of the term is still missing, there have been several attempts at defining VEs from different areas of application. Some of these are listed below:

- A temporary network of independent companies who are linked using information technology (Jagdev and Browne, 1998).
- A corporation that is able to gather and integrate a massive flow of information throughout its organisational components and intelligently act upon that information (Davidow and Malone, 1992).

- A temporary, cooperative network that is formed by independent, autonomous companies to exploit a particular market opportunity (Fischer et. al, 1996; Ruβ and Vierke, 1998; Clements et. al., 1997).
- An enterprise that is mostly made of functions provided by other enterprises and relies heavily on the use of standards, computer communications and electronic data interchange (Vernadat, 1996).
- An amorphous entity which is a combination of different companies or individuals that have been combined to complete specific projects or business propositions and development (Lawrence, 1998).

While all these definitions address their particular area of interest, there are some common aspects in these definitions. We have reviewed these to come up with our working definition of a VE, which is as follows: *A goal-oriented constellation of (semi)autonomous distributed entities. Each entity, which can be an organisation and/or an individual, attempts to maximise its own profits as well as contribute to defining and achieving the overall goals of the VE. VEs are not rigid organisational structures within rigid frameworks, but rather (heterogeneous) ensembles, continuously evolving over time.*

Enterprise modelling has been used to understand and represent traditional enterprises and their behaviours (Vernadat, 1996; Fox and Gruninger, 1998). While enterprise modelling plays a significant role in traditional enterprises, its role becomes even more important in VEs. Unlike traditional enterprises that are established and continue to exist over a long period of time, VEs are established to answer more contingent needs and can have a shorter span of life. Due to the dynamic and flexible nature of VEs, there is a greater need to build models to help understand them and their evolution.

The agile and virtual nature of enterprises entails a greater degree of cooperation (Fox and Gruninger, 1998). This cooperation is required both to perform work and to adapt the constellation to the varying needs of the environment. The goal-oriented and distributed nature of VEs implies that there is no central control; rather, the control is decentralised. The goals are achieved through complex and varied interactions. Enterprise models provide the support that is required in the analysis of VEs and the interactions within a VE and they are powerful tools for analysing and understanding the flexible nature of VEs.

The entities that constitute the VE are the partners, who play different roles, and the customer(s). (For example, in a simple manufacturing scenario, the partners can be the supplier and the manufacturer.) In addition to this, the VE will include information sources, such as documents and reports, and supporting software tools. As the partners of the VE are distributed,[1] they require some

[1] Distribution in this context refers to the distribution of competencies among the partners of a VE. We refer to the description of the term from CSCW (Computer Supported Cooperative Work). See (Schmidt & Bannon 92).

kind of support for their cooperative work. This is achieved by sharing of common goals and knowledge, which can be supported by tools that support collaboration. To deal with the dynamics of the cooperative work context, the partners will need to renegotiate their goals and activities from time to time. Also, as the partners represent different organisations, the information sources are most likely to be distributed and heterogeneous.

The remainder of this paper is organised as follows; Section 2 describes how a VE can be modelled using agents; Section 3 describes the lifecycle of a VE; Section 4 describes the basic design principles of AGORA; Section 5 describes how AGORA can be used to model the VE; Section 6 contains a brief overview of related work and Section 7 provides a summary and describes the issues that need to be addressed in the future.

2 USING AGENTS FOR MODELLING VIRTUAL ENTERPRISES

There have been attempts at modelling enterprises using computational techniques. An example of this can be seen in (Bernus and Nemes, 1999), where they model an organisation as a set of individual, autonomous, cooperative agents maintaining a set of objectives, where the behaviour of the entire organisation is an emergent property. Similarly, in our work, we have considered agents as the basic concept for modelling VEs. An agent can be defined as a hardware or software-based computer system that is autonomous, reacts to changes in its environment in a timely fashion, is pro-active by taking initiative and by exhibiting goal-oriented behaviour and it has social ability to interact and communicate with other artificial and human agents (Wooldridge and Jennings, 1995). Based on the properties of VEs described earlier in this article, there is a strong motivation to use agents as the solution technology for modelling and realising VEs. The nature of agents, by definition, enable decentralised control of the enterprise, which is desirable in a dynamic and flexible environment, and the behaviour of the complete enterprise emerges as a result of the behaviours of the individual agents.

Another strong point in favour of the adoption of agents is their versatility. They can play two main roles. First, they provide a flexible means of modelling the VE in terms of cooperative work among the agents. Second, they can be used to provide active support to the members of the VE. Thus, agents being computational entities, the resulting model provides an easy and efficient passage to the computational support that is required by VEs. In this paper, we will focus on the first aspect.

To set up an integrated environment for the partners of a VE to cooperate, it takes time and effort and often this may be too long for the short lifecycle of a VE. Therefore, it is important to provide an integrated, homogeneous environment that can be easily set up. We propose the specialisation of a multi-agent architecture, AGORA, for modelling VEs. AGORA is an architecture that supports a flexible, conceptual method for modelling cooperative work in a distributed setting (Matskin et. al., 1998; Matskin, 1999). Given the goal-oriented and distributed nature of a VE, the interactions that take place within it are, by nature, cooperative. We therefore assume that an architecture providing support for cooperative work (in its multi-facet forms) provides a proper starting point for modelling VEs. In the proposed architecture, the cooperating entities within a VE, (e.g. the partners), are represented by agents. In addition to being a facilitator of cooperative work, AGORA also provides a homogeneous modelling environment throughout the lifecycle of the VE. Due to the distributed nature of VEs, a modelling environment that supports distribution as well as one that is versatile enough to support a model of the VE throughout its complete lifecycle is essential.

3 THE LIFECYCLE OF VIRTUAL ENTERPRISES

In a VE, the customer(s) presents his/her requirements and the VE is then responsible for delivering to the customer. This process can include the formation of the VE (or rather its evolution to meet the requirements of the customer) and its operation. In fact, this process will involve the complete lifecycle of the VE itself. Hence, *we believe that an important step forward can be achieved by looking at the complete lifecycle of a VE and by providing a homogeneous modelling environment, from its conception to its completion.* In order to reach this goal, solutions proposed in the research field of enterprise modelling could prove to be extremely useful.

There are several approaches for modelling enterprises, although none of them were specifically designed for VEs. Some of the earlier approaches include diagramming techniques such as SADT and the IDEF languages. Other approaches include GRAI/GIM, which essentially concentrates on the decision-making aspects of an enterprise; CIMOSA which supports the integration of enterprise operations; and PERA (Purdue Enterprise Reference Architecture) which describes the functions or tasks of an enterprise in terms of management and control and customer services. For an overview of modelling approaches, see (Vernadat, 1996; Fox and Gruninger, 1998).

We have found in the Generic Enterprise Reference Architecture and Methodology (GERAM), (IFIP-IFAC Task Force, 1998), a useful framework for describing, in a coherent way, the lifecycle of an enterprise and for defining the associated support. Unlike the other approaches, GERAM focuses on the methods, models and tools which are needed to build an enterprise and addresses the complete lifecycle of an enterprise. It also allows the coverage of the lifecycle of an entity that is produced by the enterprise. The lifecycle aspect becomes increasingly important in the case of VEs as they have a shorter lifespan which can be defined more clearly. Also, the frequency at which a VE is established demands a good understanding of its lifecycle.

Let us consider the lifecycle of a VE using GERAM. The different phases are described briefly:

1. **Identification Phase**: the need for the VE is identified and the relations between the VE and its environment are defined.

2. **Concept Phase**: the concepts underlying the VE are defined, which includes the objectives, strategies, and business plans. This phase will provide input to the definition of the requirements and high-level business processes of the VE.
3. **Requirement Phase**: the descriptions of operational requirements of the VE are described in this phase. These include the functional, behavioural and the information requirements.
4. **Design Phase**: the VE is specified, which includes the identification of necessary information and resources. At the end of this phase, the functional, behavioural, resource and information requirements of the VE are defined.
5. **Implementation Phase**: the activities required to establish a VE, such as allocation of resources and development of the necessary services, are performed.
6. **Operation Phase**: the activities of the VE that fulfil its desired mission are defined. This includes obtaining the resources and developing the products.
7. **Decommissioning Phase**: the activities that are needed to redesign a VE at the end of its lifecycle are defined. This includes the disassembly of the VE, capturing and reuse of its knowledge.

The scenarios at each phase can be modelled by identifying the different *roles* that are performed by the partners and the cooperative work among the different roles. Then, the work that is conducted and the resources (e.g. information sources) that are required for the work are identified to define a *work context*. Such a scenario can be modelled using agents, where the partners are represented by agents. Agents could also be used to support the participants in their cooperative work and to establish a work context. Explicit tools are required for supporting the cooperative work in a VE. Such a support is provided by AGORA, which is a multi-agent architecture designed to support cooperative work in a distributed setting as described in the next section.

A separate model of each phase shows fragments of the lifecycle of the VE and has limited value. It is important to be able to model the scenarios at each of the phases of the lifecycle in a uniform manner as well as support an integrated model of all the phases, where the relationships among the different phases and the evolution of the VE can be followed. Such a model can be provided by AGORA.

4 A DESCRIPTION OF AGORA

The AGORA multi-agent architecture is designed to support cooperative work in a distributed setting. The central concept in this architecture is that of an *Agora*, which is both a place where agents can meet and establish a common context for cooperative work and a place where they can get support for a particular cooperative activity (Matskin et. al., 1998; Matskin, 1999). Figure 1 describes the different entities that comprise the AGORA architecture.

Several types of agents are associated to an Agora. A first distinction can be made between *default* and *registered* agents. Default agents, collectively identified as *Agora Manager*, are associated by default to each Agora at its creation. They include an information agent to manage the information about agents that are registered at an Agora; a planner agent to coordinate the activities within the Agora; and support agents to perform services such as matchmaking and the definition of ontologies.

Registered agents can be categorised as follows:

- *Participants* - agents representing the participants of the cooperative effort. In the case of VEs, for example, these are the agents that represent the partners and the roles that they play.
- *Cooperative mechanisms* - specific agents that support cooperative work among the participants[2]. In AGORA, *coordination* and *negotiation* agents are considered.
- *Service agents* - agents that provide services such as access to information sources and tools. For example, an agent that is registered at an Agora may require a certain information source, such as a document, in order to conduct its work. A specialised service agent can obtain the document for the agent. In our current implementation, we do not make a distinction between participants and service agents; service agents play the role of participants representing information sources.

These agents register at an Agora by submitting their name and address, their interests, competencies, goals and any other information that is relevant. The registration process can be customised depending on the application area. A new Agora can be created from an existing Agora and agents can register at any time and at several Agoras at the same time. For example, if two participants would like to conduct a negotiation, they can create a new Agora and register at this Agora to conduct the negotiation. The Agora Manager manages the communication among the different Agoras.

AGORA provides the flexibility that is required to model the VE by identifying the participants of work and the co-operative mechanisms at each cooperative point and by introducing the concept of an Agora as a facilitator of cooperative work. The Agora gives a practical support for negotiation and co-ordination in the multi-agent system by providing an infrastructure and templates for co-operative points. This means that Agoras provide not only the support for a particular type of co-operative work, but also the accumulation and the re-use of knowledge about such a support. Openness is an essential feature of the AGORA approach; i.e. all the basic elements of the considered co-operative work support, such as the negotiation and coordination protocols, default services etc., can be redefined by the user or the agent.

---

[2] It is perhaps important to point out that the cooperative work may be between two humans beings, between a human being and a software agent or between two software agents. The cooperative mechanisms supporting these three situations can be different.

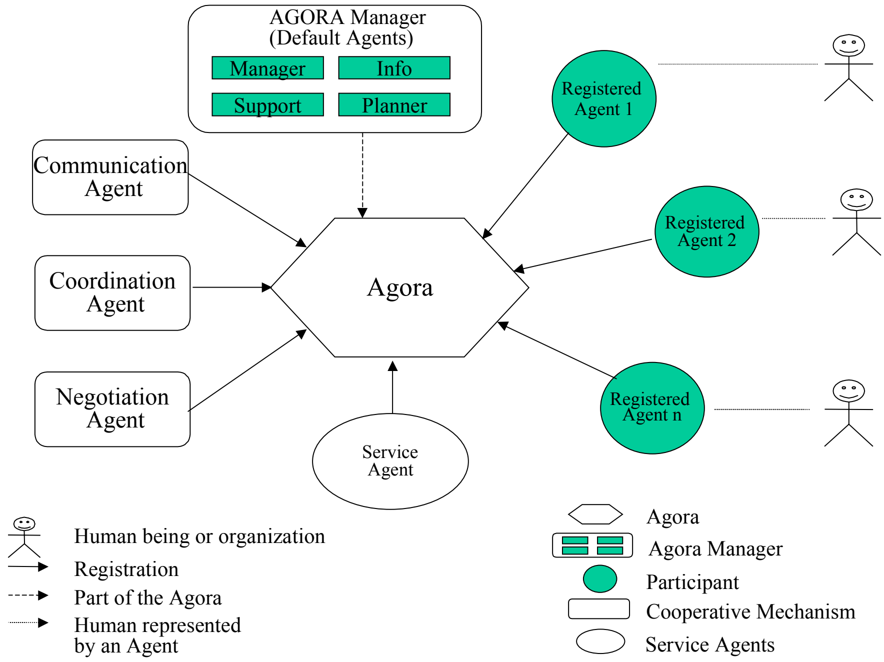

Figure 1: The AGORA multi-agent architecture

5 MODELLING VIRTUAL ENTERPRISES USING AGORA

The components of the AGORA multi-agent architecture can be mapped to VEs as follows:

- The partners of the VE are represented by agents (as participants of the cooperative effort).
- The cooperative points are represented by Agoras.
- The cooperative work, such as coordination, is supported by cooperative mechanisms.
- The work context, such as information sources and software, are represented by service agents.

A VE can be initiated by creating a VE Agora. This can be done by the customer(s) or the initiator(s) of the VE. Once the Agora is created, the agents representing the customer(s) or the initiator(s) can be registered.

Each phase in the lifecycle of a VE can be identified as a cooperative point and corresponds to an Agora. In order to provide a local context, a new Agora can be created for each phase, where the set of Agoras thus created constitutes a structure of Agoras and agents. This structure represents the complete VE. In order to describe how the AGORA multi-agent architecture can be used to model the different phases in the lifecycle of a VE, we have modelled the Requirement and Implementation phases. These phases have been chosen as they contain the different kinds of cooperative work that are present throughout the lifecycle. For the purpose of illustration, the scenarios described below are simplified.

5.1 The Requirement phase of a VE

The main roles in the Requirement phase of the VE are the customer, the initiator(s) of the VE (which can also be the customer) and one or more partners that are interested in forming the VE. These parties interact to specify the customer requirements and to define the operational requirements of the VE. This involves coordination of activities and negotiation to arrive at an agreement. In addition, there may be a need for information access and searching (e.g. if the customer requirements are available on an electronic file or the results of the Requirement phase are stored as a document or a model), which are supported by service agents. We can assume that a customer contacts the initiator(s) and the initiator(s) contacts other parties that are interested. There will be coordination and negotiation between the customer and the initiator(s) as well as among the interested partners.

The roles and interactions described above can be modelled using Agoras and agents as shown in Figure 2. A Requirement Agora is created to represent the Requirement phase of the VE. The customer and the interested partners who were registered at the VE Agora and the other associated Agoras (e.g. Concept Agora) will be automatically accessible from the Requirement Agora. In addition to this, new partners are able to register their agents at the Agora at any time. For the partners to conduct their work in defining the operational requirements of the VE, they require some computational support, such as word processors and modelling tools, and some information sources such as documents. These entities are accessed by using service agents, such as information and tools agents, that are also registered at an Agora.

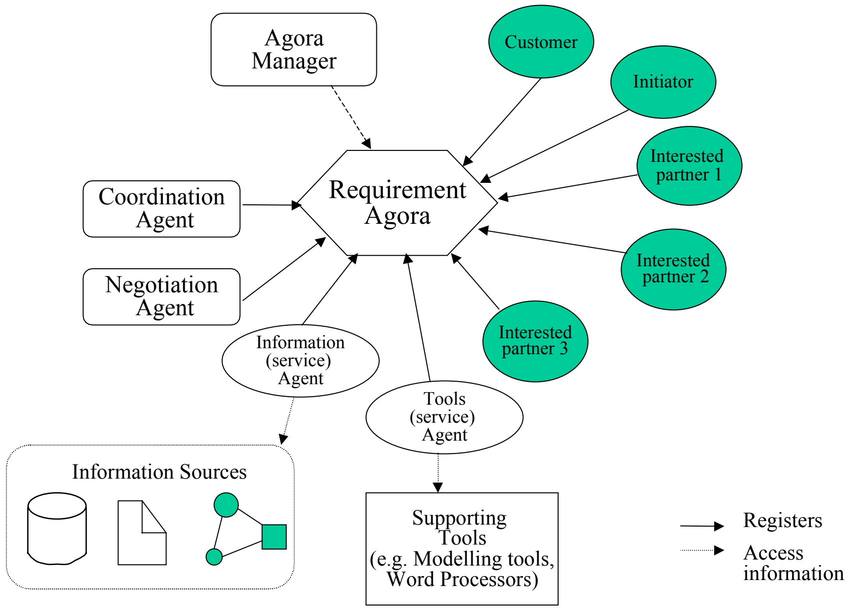

Figure 2: The Requirement Agora

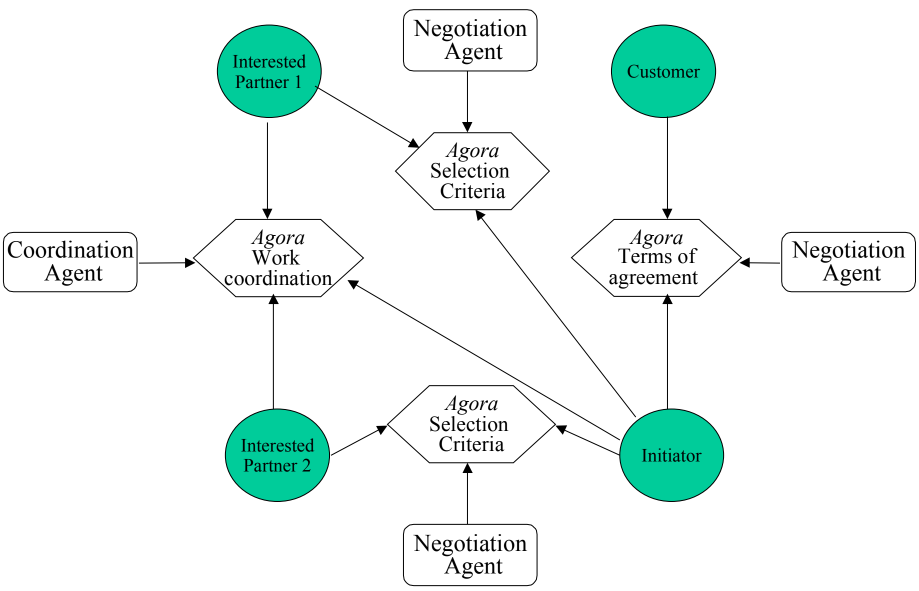

Figure 3: Cooperative work in the Requirement phase[3]

The cooperative work, involving coordination and negotiation, can be supported by expanding the Requirement Agora, shown in Figure 3 to a structure of several Agoras, where the different Agoras

[3] This is a simplified picture, where the Agora Manager and the information sources are not shown.

support a particular point of cooperative work in the VE. For example, when the customer and the initiator need to negotiate about the terms of their agreement, they can establish an Agora for this, "Agora Terms of agreement", and register at this Agora. Their negotiation is then supported by a negotiation agent, also registered at this Agora. Similarly, the negotiations between the initiator and an interested partner during the partner selection process is conducted via the Agoras, "Agora Selection Criteria", and negotiation agents. The interested partners (the initiator may also be an interested partner) coordinate their work by establishing "Agora Work coordination" and with the help of a coordination agent registered at this Agora.

5.2 The Implementation phase of a VE

The main roles that are cooperating in the Implementation phase are the customer and the potential partners (identified through the Requirement and Design phases). The initiator of the VE may be a potential partner. In this phase, the main interactions will be among the potential partners. The interactions with the customer will be limited and will be more for clarification purposes rather than negotiations.

This phase involves the allocation of resources to the various activities of the VE. The activities of the VE and the resource requirements are available from the Design phase. These requirements are matched with the potential partners to form the VE. The terms of participation or cooperation among the VE participants are agreed upon by coordination and negotiation. This can involve sending out a proposal to all the potential partners and receiving offers, which can be handled by a coordination agent that has such a protocol embedded in it. One such protocol is the Contract Net Protocol (Davis and Smith, 1988), where the coordination agent assumes the role of a manager and announces the required work to the potential contractors. The potential contractors then review the work and send bids to the manager, who will then evaluate the bids and allocate work. During the evaluation of the bids and the selection of a suitable contractor, it is common to negotiate the terms of the contract. A negotiation agent can be obtained to conduct this. In the implementation phase, one of the potential partners can assume the role of the manager and the others are the potential contractors.

An Implementation Agora can be created, where the customer, the potential partners, the information sources and the supporting tools are automatically accessible from the Implementation Agora. In addition to this, the cooperative mechanisms, such as the coordination and negotiation agents and the service agents are also accessible from this Agora. This means that the current work context is maintained. If new partners join the VE, they can be modelled by registering their agents at the Agora. Similarly, new service agents, such as a matchmaking agent, can be obtained from the Agora.

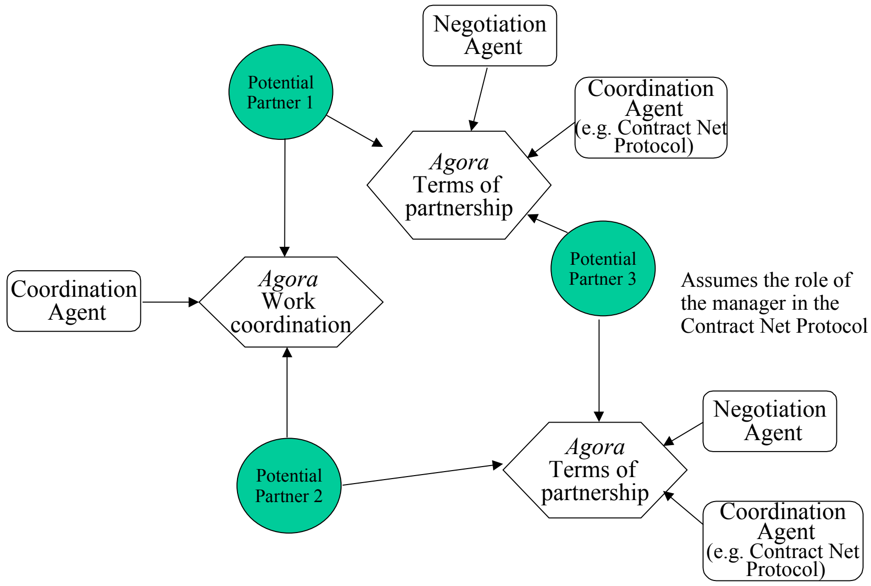

Figure 4: Cooperative work in the Implementation phase

The Implementation Agora can be expanded to represent the cooperative work, as shown in Figure 4. The potential partner that assumes the role of the manager (as in the Contract Net Protocol) will negotiate with the other potential partners to establish the terms of the partnership. This can be done by creating "Agora Terms of partnership" and registering at these Agoras. Negotiation and coordination agents that are registered at these Agoras can be used to support the cooperative work. Similarly, when two or more potential partners need to coordinate some work, they establish "Agora Work coordination" and register at this Agora. The coordination agent(s) registered at this Agora will support the cooperative work.

5.3 Towards an Integrated Model

The complete lifecycle of the VE is modelled through a structure of Agoras, where one or more Agoras represent a phase in the lifecycle. For example, a VE Agora is created initially. From this, other Agoras can be created at any time to represent the cooperative work and the different phases of the lifecycle. In addition to being able to create a structure of Agoras and enhance this structure at any time during the lifecycle, the AGORA architecture also supports the maintenance of the work context from one Agora to another, enabling the continuation of the cooperative work. For example, when a new Agora is created from any Agora, the agents that are registered at that Agora, the cooperative mechanisms, the service agents, the information sources and the supporting tools are automatically accessible from the new Agora.

It is interesting to note how the role of one of the participants evolves with the evolution of the Agoras. For example, in the Requirement Agora, one of the participants is registered as an interested partner. During the Design phase, this participant may be identified as a potential partner and is therefore accessible from the Implementation Agora as a potential partner. The participant can be the same registered agent and represents the same human being or organisation. The relationships between the participant and the human being or organisation indicates this.

As can be seen from the scenarios described above, the relationships between the Agoras are varied. Agoras can be created from a VE Agora to represent the different phases in order to provide a local context for each phase of the lifecycle. A new Agora can be created from one phase to represent another phase, indicating the evolution of the Agoras. This indicates the cooperative work among the different phases. Each Agora can be expanded into several other Agoras to support the cooperative work. It is also possible that Agoras exchange information about the agents that are registered at them. In this paper, we have focused our efforts on modelling the phases of the lifecycle of the VE in a uniform manner. The different types of relationships that are possible among the Agoras will be a subject for our future work.

One of the main advantages of the integrated model is that the participants of the VE are able to maintain a local context, while, at the same time, they have a global overview of the activities of the VE. In addition to this, the AGORA architecture also provides the capabilities to develop a homogeneous modelling environment for the VE. The ability to develop an integrated model, with relationships among the cooperative work conducted throughout the lifecycle helps avoid disjointed, isolated pieces of work that are not easy to reuse. The complete model that is available at the end provides a traceable history of the lifecycle of the VE. The users also have the flexibility to choose their working methodology (e.g. sequential, concurrent), which is provided by the ability to create new Agoras at anytime, from any Agora.

6 RELATED WORK

Contributions in this area of work come from both the enterprise modelling community as well as the Distributed Artificial Intelligence community and can be analysed from different perspectives. In this paper, we have considered the use of agents as the paradigm for modelling VEs.

There have been attempts at modelling enterprises using computational techniques. Object-orientation and distributed object technologies have been used to support enterprises and business processes. Although these models have their strengths, such as modularity and encapsulation, object-based modelling does not allow the encapsulation of the behaviour of the object and hence, does not have full control of its behaviour (Jennings and Wooldridge, 1998).

The AVE (Agents in Virtual Enterprises) project, described in (Fischer et. al, 1996), provides a description of how agents can be used in the formation of a VE. One of the main components of the system that was proposed is an electronic VE market, where different enterprises can announce and obtain various information. The individual organisations are represented by agents who exchange information through the VE market. An interesting aspect of the AVE project is their use of process models to define the processes and goals of the VE and to allocate the processes (or tasks) to the participants of the VE. Although this may be compared to an Agora, it does not explicitly address cooperative work.

In (Ambroszkiewicz et. al., 1998; Clements et. al., 1997; Szirbik, 1999), mobile agents are used to model a VE. While mobility is a convenient feature, it provides a different technical solution rather than a conceptual one.

Multi-agent architectures have been used for coordinating, planning and scheduling supply chain activities, (Barbuceanu and Fox, 1994; Sadeh et. al., 1999). For example, in (Barbuceanu and Fox, 1994), an integrated supply chain was modelled using agents, where the different functions are performed by agents. The notion of an information agent was introduced as a component in an infrastructure for supporting collaborative work in enterprise architectures. The information agent makes other agents (may be from other organisations) aware of relevant information by providing communication and information services. The idea of such an agent can be used within the AGORA architecture as a special kind of a service agent. However, AGORA also provides other support. This work focussed on the functional aspects of the agents rather than the cooperative work that took place among them.

While the autonomy of an agent is desired, it is important to manage it to ensure that the enterprise does not behave arbitrarily. Jain et. al. proposes the notion of commitments as a means of managing the autonomy among agents that form a VE (Jain et. al., 1999). In (Cloutier et. al., 1999), NetMan, a commitment-oriented agent-based approach to managing coordination among a network of manufacturing enterprise was described. Although we believe that this is an important issue, it has not been addressed in AGORA yet.

Holonic manufacturing systems have been gaining popularity among the manufacturing enterprises, (Bussman, 1998; Bongaerts, 1995). In comparison to traditional distributed information systems, holonic systems introduce the idea of goal-directed behaviour among the individual entities of the system. Holons are multi-agent systems, they form hierarchies of holons (holarchies) and are subject to control from holons that are higher in the holarchy. In (Ruβ and Vierke, 1998), they describe a holonic multi-agent system to configure a VE. Their work looks at the structure of a VE and does not address the cooperative work within a VE.

7 SUMMARY AND CONCLUSIONS

In this paper, we have described how VEs can be modelled using the AGORA multi-agent architecture, designed for supporting cooperative work among distributed entities. The model consists of a structure of Agoras and agents. The agents represent the participants of the VE, the cooperative mechanisms and the service providers. The main advantages of this approach are that the structure of Agoras provides a homogeneous modelling environment throughout the lifecycle of the VE, traceability of the VE activities and a history of the VE. In addition to these, it is important to point out that, thanks to the versatility of agents, AGORA can play two main roles. First, it provides a flexible means of modelling the VE. Second, it can be used to provide active support to the partners of the VE. Thus, agents being computational entities, the resulting model provides an easy and efficient passage to the computational support that is required by the VE.

We have used GERAM as the framework for modelling the different phases in the lifecycle of the VE. For each phase of the lifecycle of the VE, the roles performed by the participants and the cooperative work among them are modelled using Agoras and agents. The resulting integrated model representing the complete VE can be described by the relationships among the different Agoras. The work context of the different Agoras is maintained by the ability to access agents from different Agoras.

The details of the cooperative work and the roles and interactions among the participants need to be elaborated. Similarly, the relationships among the Agoras and the definition of the work context are subjects for future work. In our system, the work of an organisation is partly delegated over to an agent. Hence, the issues of trust, security and the legal aspects of the business also need to be addressed.

8 REFERENCES

Ambroszkiewicz, S., Cetnarowicz, K. and Radko, B., 1998. **Enterprise Formation Mechanisms based on Mobile Agents**. In Holsten, A. et al. (eds.), Proc. of the Workshop on Intelligent Agents in Information and Process Management, KI'98, TZI-Bericht no.9-1998, p. 23-34.

Barbuceanu, M. and Fox, M. S., 1994. **The Information Agent: An Infrastructure Agent Supporting Collaborative Enterprise Architectures**. UK Conference on Planning, June 1994.

Bernus, P. and Nemes, L**.,** 1999. **Organisational Design: Dynamically Creating and Sustaining Integrated Virtual Enterprises**. In F. Chen, D. Cheng and J. Zhang (Eds.), Proc. IFAC World Congress, Vol-A, London: Elsevier (1999), p.189-194.

Bongaerts, L., Valckenaers, P., Van Brussel, H. and Wyns, J., 1995. **Schedule Execution for a Holonic Shop Floor Control System**. in Proc. of the ASI-95 of NOE on ICIMS (Advanced

Summer Institute '95 of the Network of Excellence in Intelligent Control and Integrated Manufacturing Systems), Lisboa, June 1995, p.115-124.

Bussmann, S., 1998. **An Agent-Oriented Architecture for Holonic Manufacturing Control**. in: Proc. of 1st Int. Workshop on Intelligent Manufacturing Systems, EPFL, Lausanne, Switzerland, p. 1-12.

Clements, P. E., Papaioannou, T. and Edwards. J., 1997. **Aglets: Enabling the Virtual Enterprise**. In Wright, D et al. (Eds.), Proc. of Mesela '97 - 1st Int'l Conf. on Managing Enterprises - Stakeholders, Engineering, Logistics and Achievement. Mechanical Engineering Publications Ltd., July 1997.

Cloutier, L., Frayret, J., D'Amours, S., Espinasse, B. and Montreuil, B., 1999. **A Commitent-oriented Approach to Networked Manufacturing**. In Proc. of IEPM'99 International Conference on Industrial Engineering and Production Management, (book 2), Glasgow, U.K., July 1999, p. 487-496.

Davidow, W. H., and Malone, M. S., 1992. **The Virtual Corporation: Structuring and Revitalizing the Corporation for the 21st Century**. Harper Business.

Fischer, K., Muller, J. P., Heimig, I. and Scheer, A., 1996. **Intelligent Agents in Virtual Enterprises**. Proc. of the First International Conference and Exhibition on The Practical Applications of Intelligent Agents and Multi-Agent Technology, April 1996, London, U.K., p. 205-224.

Fox, M.S., Gruninger, M., (1998), **Enterprise Modelling**, AI Magazine, AAAI Press, Fall 1998, p. 109-121.

IFIP-IFAC Task Force, 1998. GERAM: Generalised Enterprise Reference Architecture and Methodology, Version 1.6.2., available from http://www.cit.gu.edu.au/~bernus/

Jagdev, H. S., and Browne, J., 1998. **The Extended Enterprise- a Context for Manufacturing**. Production Planning & Control, 1998, Vol.9.No.3, p. 216-229.

Jain, A. K., Aparicio IV, M. and Singh, M. P., 1999. **Agents for Process Coherence in Virtual Enterprises**. In Communications of the ACM, March, Vol. 42, No. 3, p. 62-69.

Jennings, N. and Wooldridge, M., 1998. **Agent Technology Foundations, Applications and Markets**. Springer-Verlag.

Jennings, N., Faratin, P., Johnson, M. J., O'Brien, P. O. and Wiegand, M., E., 1996. **Using Intelligent Agents to Manage Business Processes**. Proc. of the 1st International Conference and Exhibition on The Practical Applications of Intelligent Agents and Multi-Agent Technology, April 1996, London, U.K., p. 345-360.

Lawrence, E., Corbitt, B., Tidwell, A., Fisher, J., and Lawrence, J.R., 1998. **Internet Commerce: Digital Models for Business.** Wiley, Brisbane.

Matskin, M., Divitini, M. and Petersen, S. A., 1998. **An Architecture for Multi-Agent Support in a Distributed Information Technology Application**. In Holsten, A. et al. (eds.), Proc. of the

Workshop on Intelligent Agents in Information and Process Management, KI'98, TZI-Bericht no.9-1998, p. 47-58.

Matskin, M., 1999. **Multi-Agent Support for Modeling Co-operative Work**. In: T. Yongchareon, F. A. Aagesen, V. Wuwongse (Eds.) Intelligence in Networks. The Fifth International Conference SMARTNET'99, 22-26 November 1999, Thailand, Kluwer Academic Publishers, p.419-432.

Ruβ, C. and Vierke, G., 1998. **Agent-based Configuration of Virtual Enterprises**. In Holsten, A. et al. (eds.), Proc. of the Workshop on Intelligent Agents in Information and Process Management, KI'98, TZI-Bericht no.9-1998, p. 123-127.

Sadeh, N. M., Hildum, D. W., Kjenstad, D. and Tseng, A., 2000, **MASOT: An Agent-Based Architecture for Coordinated Mixed-Initiative Supply Chain Planning and Scheduling.** International Journal of Production Planning and Control, Vol. 11. This issue.

Schmidt, K. and Bannon, L., 1992. **Taking CSCW Seriously: Supporting Articulation Work**. CSCW, Kluwer Academic Publishers, vol. 1, no. 1-2, p. 7-40.

Davis, R. and Smith, R. G., 1988. **Negotiation as a Metaphor for Distributed Problem Solving**. In A. H. Bond and L. Gasser (Eds.), Readings in Distributed Artificial Intelligence, Morgan Kaufmann Publishers, p. 333-356.

Szirbik, N. B., Hammer, D. K., Goossenaerts, J. B. M. and Aerts, A. T. M., 1999. **Mobile Agent Support for Tracking Products in Virtual Enterprises**. AGENT'99, Seattle, USA, May, Workshop Notes, ACM.

Vernadat, F. B., 1996. **Enterprise Modeling and Integration Principles and Applications**. Chapman and Hall Publishers.

Wooldridge, M. and Jennings, N., 1995. **Intelligent Agents: Theory and Practice**. Knowledge Engineering Review, vol. 10, no. 2, p. 115-152.

Paper 4

Title

Virtual Enterprise Formation with Agents - an Approach to Implementation

Main Result

Implementation of the VE formation process, in particular, the matching of the agent's attributes to the requirements of a VE, using the AGORA multi-agent architecture.

Reference in Thesis

This paper is referenced from Chapter 6, Sections 6.4 and 6.5.

Published in:

Proceedings of the *IEEE/WIC International Conference on Intelligent Agent Technology (IAT2003)*, Halifax, Canada, October 2003.

Copyright

Virtual Enterprise Formation with Agents – an Approach to Implementation

Sobah Abbas Petersen[1], Jinghai Rao[1], Mihhail Matskin[2]
[1]*Department of Computer and Information Sciences,*
Norwegian University of Science and Technology, 7491 Trondheim, Norway
Email: {sap, Jinghai}@idi.ntnu.no
[2]*Department of Microelectronics and Information Technology,*
Royal Institute of Technology, SE-164 40 Kista, Sweden
Email: misha@imit.kth.se

Abstract

The formation of a Virtual Enterprise and the selection of its partners is an important process in the lifecycle of a Virtual Enterprise. In this paper, we present the Virtual Enterprise formation process as an Agent Interaction Protocol and an approach to its implementation. We have focussed on the selection of partners within the formation process in order to understand these interactions and the contents of the messages that are exchanged between the agents. Based on this, we describe how the AGORA multi-agent architecture can be used to support the formation of a Virtual Enterprise.

1. Introduction

The formation of a Virtual Enterprise (VE) is an important phase in the lifecycle of a VE. The selection of the partners that will do the work in the VE is central to the formation phase and is one of the success factors for a VE, [2]. We consider a VE as *a team of partners that collaborate to achieve a specific goal*. The partners of a VE may be human beings, organisations and/or software agents.

In this paper, we present a multi-agent architecture, AGORA, to support the formation of VEs. We believe that software agents, (or agents), are a suitable means of representing the partners of a VE. One important reason is that by delegating the agents to conduct the negotiation on behalf of the partners, the partners could then have the time to do the actual work required in the current VE.

We have developed an agent-based Enterprise Model of a VE by analysing the entities in VEs, their relationships and how they can be used in an agent context. In our model, the VE has a goal, which is achieved by a set of activities, which are performed by a set of roles. The agents that fill these roles are the members of the VE and the agents are selected on the basis of how well they meet the requirements for the roles.

The idea of using agents to represent the partners in a VE is not new, e.g. [6], where an electronic market and auctions are used to select the partners of a VE. We have used AGORA to support the formation of VEs, within the context of an electronic market place, [5]. We describe the AGORA architecture as well as the architecture for a single agent to represent the partners in a VE. The interactions among the agents during the VE formation process is described as an Agent Interaction Protocol (AIP) and the VE formation scenario is illustrated using a simple hypothetical example.

The rest of this paper is organised as follows: Section 2 describes the VE formation process, Section 3 presents the model of a single agent, Section 4 describes the AGORA architecture, Section 5 illustrates how AGORA can be used to support VE formation using an example, Section 6 discusses the conclusions.

2. Virtual Enterprise Formation

VEs have a limited lifetime; thus they need to be formed very quickly in order to meet the deadlines of the goals and there is a need to form them often. An important part of the formation is the selection of partners, who are selected on the ability to fulfil the VE's requirements.

The agents in a VE can be classified as *VE Initiator* (who may also be the customer), who takes the initiative to form the VE, and *VE Partner* (who may also be the VE Initiator), who are the entities that form the VE. A VE Partner evolves from someone that is interested in becoming a part of the VE and submits a bid, *Interested Partner*, to someone that is considered for the VE and a contract is negotiated, *Potential Partner*, to someone who is actually a part of the VE.

The first step in the process of selecting partners for a VE is the alignment of the goals of the Interested Partners with the goals of the VE. The second step is matching the Interested Partners to the requirements of the roles. The requirements are structured into skills and capabilities, availability and cost requirements. The third step is the verification of the information provided in the bids. This is to ensure that the Potential Partner indeed has the experience and the means of delivering to the VE as claimed. In reality, this is often conducted in the form of interviews and workshops. Once the verification is conducted, the VE Initiator and the Potential Partners (or the Potential Partners themselves) negotiate to agree upon the terms of the contract.

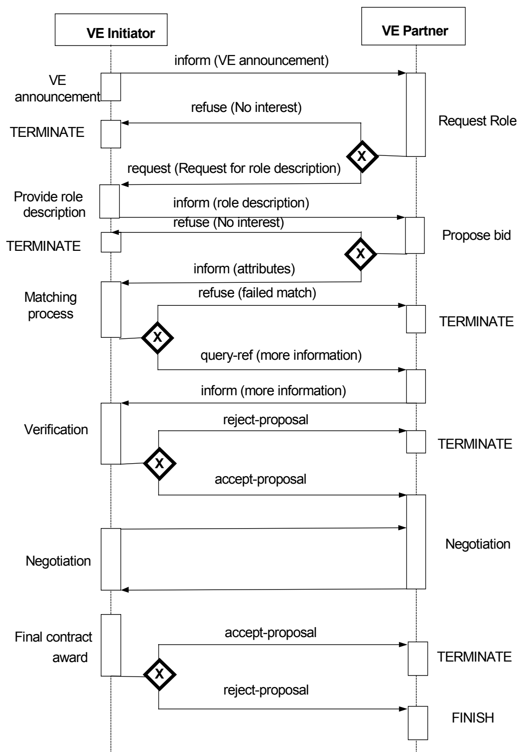

Figure 1: Agent Interaction Protocol for VE Formation

The selection process can be expressed as an AIP, the basic idea of which is similar to that of auctions and the Contract Net Protocol [3]. The AIP corresponding to the formation of a VE is shown in Figure 1.

3. Model of an Agent

The components of an agent's knowledge base required to support the selection process are its goals, activities and capabilities, which are described by a set of attributes. In addition, an agent has a rule base to support its decision making process and a plan to tell it what to do at any point in time. In our approach, we consider the same agent architecture for both the VE Initiator and the partners. This is because the VE Initiator does not always play the role of a "broker" only, but can also be a partner in the VE. The information that is represented by the goals, the activities and the capabilities of the VE Initiator and the VE Partners are slightly different and this is summarised in Table 1.

Table 1: Information represented by the Agent Model

Entity	VE Initiator	VE Partner
Goals	Goals of the VE	Goals of the partner
Activities	Activities that need to be performed to achieve the goals of the VE.	Set of experience of the partner.
Capabilities	Requirements (skills, time, costs, etc.) for the roles of the VE.	Work that the partner is capable of doing.

4. Forming Virtual Enterprises Using AGORA

In this section, we describe the AGORA multi-agent architecture and how it can be used to support VEs.

4.1. AGORA Multi-agent Architecture

AGORA is a multi-agent infrastructure which provides support for implementation of software agents and agent-based marketplaces, [5]. The central concept is that of an Agora node which is a cooperative node facilitating communication, coordination and negotiation among the agents. When an *Agora node* is created, the default agents are created and connected to the agora node automatically. They are the *Agora Manager* (for performing general management and matchmaking functions), *Coordinator* (for supporting a coherent behaviour between agents in the node) and *Negotiator* (for dealing with conflict resolution via negotiation).

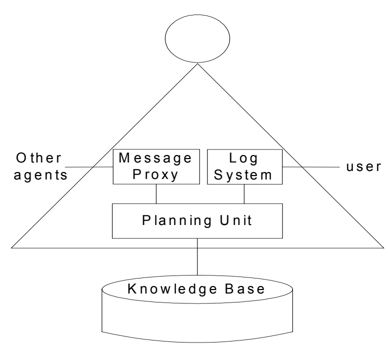

Figure 2: Structure of an Agent

In addition to Agora nodes and default agents, the system also has *registered agents*. In a general marketplace scenario, the registered agents can act as either buyers or sellers. The structure of a single agent, either a default agent or a registered agent is illustrated in Figure 2. An agent uses the *Message Proxy* and the *Log System* to interact with the outside world, (e.g. the human user). It communicates with other agents using FIPA

ACL, [4], and the FIPA messages are sent and received through the Message Proxy.

We use a Prolog-based presentation for messages, facts and rules in the *Knowledge Base*, implemented using the XProlog system, [1]. In order to integrate the FIPA messages with the Knowledge Base, a *Compiler* between FIPA messages and Prolog clauses is implemented.

The *Planning Unit* decides the agent's next action by a set of explicitly defined rules. In Agora, the plan is specified in a XML-based scripting language. Each step in the plan has an action to be performed and post-conditions. The action refers to an outgoing FIPA message or a method (function) written in Java or Prolog. Post-conditions are described as a reaction of the agent to a communicative act received from another agent.

4.2. Virtual Enterprises in AGORA

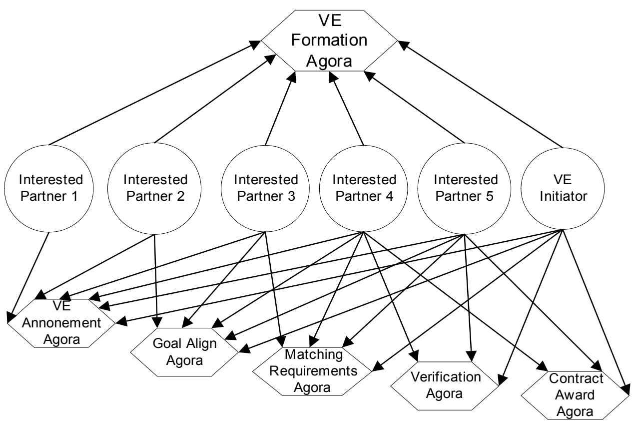

Figure 3: The AGORA Multi-agent Architecture

A description of how AGORA could be used to support the lifecycle of a VE was presented in [7]. The Agora nodes for VE Formation are presented in **Figure 3**. It contains a general Agora node (VE Formation) for the complete process and separate Agora nodes for each step in the VE formation process. Registered Agents (Interested Partners) can be registered in more than one Agora node. Each Agora node provides the right context for the specific step in the formation process, i.e. the right support and a meeting place for all the participants. Having a separate Agora node for each step ensures information security and privacy, e.g., an Interested Partner whose bid has been refused cannot register at the next Agora node.

5. Example

We use a simple example to illustrate the formation process and the selection of partners by matching agents to roles in a VE. Consider a VE formed to design and create an Intranet for a company. The main goal of the VE, "Create an Intranet", can be decomposed into two subgoals, "Design Intranet" and "Create Intranet". The two subgoals are achieved by performing the activities, "Design Intranet" and "Create Intranet". The two roles that are required for this VE are an "Intranet Designer" and a "Webpage Developer". The VE Initiator is looking for two partners that meet the requirements for these roles. In the rest of this section, we will describe how the formation process of this VE is implemented in AGORA.

5.1. VE Announcement

The VE announcement consists of the main goal of the VE and the set of roles that need to be filled (at VE Announcement Agora node).

```
ve_announcement(
     goal(create_intranet, 280203,40000),
     roles([intranet_designer,
             web_program_developer])).
```

If an agent is interested in performing any of the roles, it requests for more information on that specific role. The VE Initiator will then respond with the requirements for the requested role(s). Table 2 shows the set of requirements and the matching conditions for the role Webpage Developer.

Table 2: VE Requirements and Matching Conditions

Requirements	Range & Matching Conditions
Skills	HTML, JAVA, XML
Min. no. of skills required	>=2
Experience	>=2 years
Availability	Start_date<010103, end_date=<280203, 80% of the time, Matching condition: computed no. of hours =<300
Cost per hour	<60
Performance rating	Range: 1..10, >=6
Commitment	Range: 1..10, >7

The Interested Partners return bids after receiving the requirements for the roles. In the bids, the Interested Partners, (e.g. for the role of Webpage Developer), fill their values for required attributes as shown below:

```
bid_skill(programmer1,
  role(Webpage_developer),
  attributes(skills([java,xml,html]),
     experience_by_year(3),
     performance_rating(7),
     commitment(8)).
```

5.2. Matching Agent to Roles

The partner's goals are aligned with that of the VE if there is a goal in the VE's goal structure that matches that of the partner's (at the Goal Alignment Agora node). The matching is based on the attributes of the goal. The requirements for the roles are structured into skills, availability and cost requirements. The matching process consists of matching first the skills, then the availability and finally the costs (at the Matching Requirements Agora node). If the Interested Partner meets all the requirements for the role, s/he becomes a Potential Partner and the VE Initiator would now like to verify if s/he actually does have the experience claimed in the bid. Thus, the VE Initiator requests for the Potential Partner's activities or experience structure (at the Verification Agora node). The VE Initiator informs the Potential Partners whose bids are rejected and a contract is signed with the Potential Partners whose bids are accepted (at the Contract Award Agora node).

5.3. Agent Plans

An agent's plan consists of all the communication exchange and protocols. The part of the VE Initiator's plan file that corresponds to the process of matching an agent's skills to the requirements is shown below:

```
<step>
  <id>match_skill</id>
  <action>match_skill</action>
  <case>
    <postcondition>
      <performative>inform</performative>
      <ontology>VE</ontology>
    </postcondition>
  <nextstep>match_availability</nextstep>
  </case>
  <case>
    <postcondition>
      <performative>refuse</performative>
      <ontology>VE</ontology>
    </postcondition>
  <nextstep>TERMINATE</nextstep>
  </case>
</step>
```

Some steps in the plan file refer to agent actions which are presented separately in action files. There are two kinds of bodies in an action: *wrapper* for a message that can be predefined, and *implementedBy* for a message that cannot be predefined. The part of the action file for the VE Initiator for matching the skills is shown below:

```
<action>
  <id>match_skill</id>
  <implementedBy>
    <code>
      <codeLanguage>xprolog</codeLanguage>
      <codeMethod>match_skill</codeMethod>
    </code>
  </implementedBy>
</action>
```

6. Conclusions

This paper describes how the AGORA multi-agent architecture can be used to support the formation of VEs. The partners in a VE are represented by agents and the VE formation process is expressed as an AIP. We have used a simple example to illustrate our approach and to describe the implementation. We have not addressed the negotiation process(es) during the VE formation although we believe that this is an important part of the process. We plan to extend our work to include a more detailed description of the VE requirements and to support the automatic translation of AIPs to agents' plans.

7. Acknowledgements

This work is partially supported by the Norwegian Research Foundation and the ADIS project.

8. References

[1]. http://www.iro.umontreal.ca/~vaucher/xprolog/

[2]. Camarinha-Matos, L. M., H. Afsarmanesh, "Virtual Enterprise Modelling and Support Infrastructures: Applying Multi-agent System Approaches", in *Multi-agent Systems and Applications*, M. Luck, V. Marik, O. Stpankova, R. Trappl (Eds.), LNAI 2086, Springer, 2001.

[3]. Davis, R., R. G., Smith, "Negotiation as a Metaphor for Distributed Problem Solving", A. H. Bond and L. Gasser (Eds.) *Readings in Distributed Artificial Intelligence*, Morgan Kaufmann Publishers, 1988, pp. 333-356.

[4]. FIPA ACL http://www.fipa.org/

[5]. Matskin, M., O. J. Kirkeluten, S. B. Krossnes and Ø. Sæle. "Agora: An Infrastructure for Cooperative Work Support in Multi-Agent Systems", T. Wagner, O. Rana (Eds.) *Infrastructure for Agents, Multi-Agents, and Scalable Multi-Agent Systems*. Springer Verlag, LNCS, Volume 1887, 2001, pp.28-40

[6]. Oliveira, E. and A. P. Rocha, "Agents' Advanced Features for Negotiation in Electronic Commerce and Virtual Organisation Formation Process", *European Perspectives on Agent Mediated Electronic Commerce*, Springer Verlag, June 2000.

[7]. Petersen, S. A., M. Divitini, M. Matskin, "An Agent-based Approach to Modelling Virtual Enterprises", *Int. Journal of Production Planning & Control*, Vol. 12, No. 3, Issue Apr. 2001, pp. 224-233.

Paper 5

Title

An Agent-based Evaluation Framework for Supporting Virtual Enterprise Formation

Main Result

An evaluation framework to determine the applicability of the agent-based approach to VEs.

Reference in Thesis

This paper is referenced from Chapter 8, Section 8.1.

Published in:

Proceedings of *IEEE 12th International Workshop on Enabling Technologies, Infrastructures for Collaborative Enterprises, (WET-ICE2003)*, Linz, Austria, June 2003.

Copyright

An Agent-based Evaluation Framework for Supporting Virtual Enterprise Formation

Sobah Abbas Petersen
Department of Computer and Information Sciences,
Norwegian University of Science and Technology, 7491 Trondheim, Norway
Email: sap@idi.ntnu.no

Abstract

Virtual Enterprises are complex entities and represent a number of business situations. We have analysed an agent-based approach to support the formation of Virtual Enterprises using several industrial case studies. We present our results as an evaluation framework to identify the applicability of the approach to support the formation of Virtual Enterprises. It is an inexpensive indicator of when the approach will be suitable to adopt and it helps to fill a gap in the evaluation methods for the applicability of a particular technology for a particular Virtual Enterprise situation.

Keywords
Virtual Enterprise, Agent-based approach, Evaluation Framework

1. Introduction

Virtual Enterprises (VEs) can be described as a scenario that emerges when individual entities, human beings, software agents and/or organisations, collaborate to achieve a specific goal. There are several definitions of a VE, (see [7] for an overview), for example, a temporary network of independent companies, a group of people connected via the Internet, a coordinated value chain of a product, and where organisational units communicate and cooperate in problem solving. We have chosen the VE as a project-based enterprise, [3], where project team members are considered as the partners of the VE. These definitions highlight certain characteristics of VEs such as VEs consist of distributed entities, thus making the control as well as expertise distributed, and individual entities that coordinate and cooperate.

The technology of software agents and multi-agent systems is believed to be suitable for building systems which display the characteristics mentioned above, [12]. Thus, it is no surprise that this technology has gained popularity in recent years, e.g. [2] and [6].

The selection of the right team of partners is crucial to the success of the VE and thus, the formation of the VE becomes an important part of the lifecycle of the VE. In this paper, we present an *agent-based approach* for supporting the formation of VEs by providing decision-making support to the partners of a VE. We believe that software agents, hereafter referred to as agents, are a suitable means of representing the partners of a VE. One important reason is that by delegating the agents to conduct the negotiation on behalf of the partners, the partners could then have the time to do the actual work required in the current VE.

VEs are complex entities and represent a number of business situations, [3]). Thus, there is no technological solution that will fit all VE situations and it is costly to develop a technical solution for each situation. Before embarking upon a project to develop a technology to support a VE, it is necessary to understand very clearly the applicability of the envisaged technology to the particular VE situation.

We have used several industrial case studies, [13], to evaluate our approach by attempting to model the cases using the approach and to see if the approach is applicable to the different cases. As a result of this evaluation, we have developed an *evaluation framework* to indicate the applicability of the approach to a particular VE situation. The evaluation framework is presented as a set of high-level criteria that can be applied to various situations of VEs. Figure 1 illustrates the relationship between the *approach* and the *framework*.

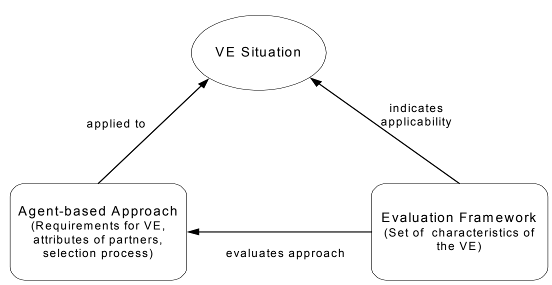

Figure 1: Agent-based Approach and Evaluation Framework

In this paper, we describe how the evaluation framework can be applied by using industrial case studies. The remainder of this paper is organised as follows: Section 2 describes where our work fits in with respect to work done in evaluating agent-based systems, Section 3 describes our agent-based approach using a simple hypothetical example; Section 4 describes the industrial cases; Section 5 describes the evaluation framework and the evaluation of our approach using the cases; Section 6 discusses the evaluation framework and the selection of the cases.

2. Existing Evaluation Methods

While there have been efforts made in describing the kinds of situations where agent systems are appropriate, and the pitfalls in developing agent systems, [12], there are no means of indicating how applicable a particular solution is to a particular scenario. Agent-based systems can be evaluated by formal methods such as model checking, (e.g.[11]), where a system is verified against its specifications. Other approaches in evaluating technology can be seen in the CSCW and the HCI communities where a system is evaluated with respect to how it supports a group of users. In HCI, a lot of work has been done on usability, e.g. [5]. More recently, attempts have been made to develop usability heuristics, a low cost technique, also for the evaluation of groupware system, e.g. [1]. All these methods evaluate a system that already exists.

A VE is a complex setting, involving the collaboration of several entities namely, humans, organisations and software agents. Thus, a system that supports a VE will also be complex. Therefore, the evaluation of an agent system or a CSCW application in the traditional way is no longer adequate. We need to extend these to evaluate the proposed technology with respect to its applicability to various VE situations.

The Enterprise Engineering community has developed a reference model for VEs, [10], based on the work for traditional enterprises, [4]. The purpose of this work is to support the fast and efficient modelling of VEs and the development of an infrastructure to support VEs. These, however, are not evaluation frameworks and thus, do not give a clear indication of the applicability of a particular approach or a technology to a particular VE situation.

When we consider the adoption of a particular technology by a group of users, there is a need for the users to identify their requirements and how well a particular technology meets their requirements. Usually, a system does not exist at this point. But, the users need an inexpensive indicator to help them decide if a particular technology should be adopted or not. The evaluation framework proposed in this paper is aimed at meeting such needs of the users and for supporting this phase in the design cycle of a system to support the formation of a VE.

3. Agent-based Approach

Before a VE is formed, it's concepts and goals have to be defined. The requirements from the customer sets the requirements for the VE partners and in order for the VE to be able to deliver to its customer, the right team of partners has to be formed.

In developing the agent-based solution, the first step was to develop the agent-based model for a VE, [9]. This can be summarised as identifying the roles of the VE, the requirements for the roles and the attributes of the partners as best as we can to represent the real situation. The second step was to use the model to select the best team of partners. The selection process is shown in Figure 2, where the partners' goals are aligned with the goals of the VE and their attributes are matched against the requirements for the roles.

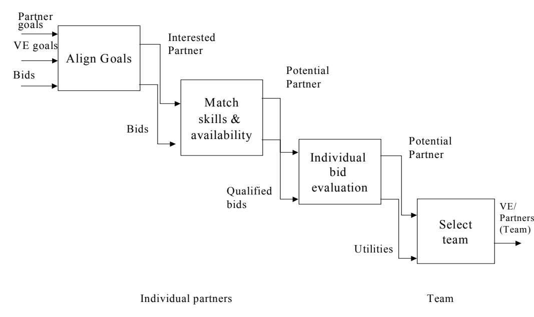

Figure 2: Selecting the Partners for a VE

Consider a VE formed to design the Internet homepage for a company. A *VE Initiator*, who decides to form a VE to perform this job, looks for 2 partners with the relevant programming skills. IP-A, IP-B, IP-C and IP-D are *Interested Partners* (ones that are interested in joining the VE) and they bid to become a partner in the VE. The bids that do not meet the requirements for the VE are rejected. The VE Initiator then negotiates with the *Potential Partners* before selecting the VE team. The interactions among the agents, i.e. between the VE Initiator and the partners, during the VE selection are shown in Figure 3.

Each of the Interested Partners can be represented by an agent, which has a set of attributes that describes their skills and capabilities. Similarly, the VE Initiator can also be represented by an agent, which is described by a set of requirements for the partners' skills and capabilities. We have described this scenario in detail with an implementation in [8]. By using hypothetical values and matching constraints for the requirements and the attributes, we were able to select 2 partners that satisfied the requirements.

Figure 3: Interactions between the Agents

The selection criteria can be based on a set of attributes of the Interested Partners and how well these attributes match the requirements. A summary of the attributes are given below:

- The partner's goal(s).
- The time period that the partner is available to do the work.
- Specific skills of the partner
- Cost of partner (based on the total no. of hours and the cost per hour).
- Performance rating: an indication of how efficient the partner is at performing a task.
- How committed the partner is to doing the work.
- The risk(s) involved in including a partner.

In addition to the above attributes which reflect the individual agent, the selection of the best team can be considered using the total cost of the partners in a team and the total risk of having the partners in the team.

The hypothetical example described in [8] proposed how our agent-based approach can be used to support the formation of VEs. This is a simple example designed to fit our approach. However, VEs in industry may be different. Thus, the next step in our research was to look at various situations in industry where project groups or VEs are formed and if these situations can be supported by our approach.

4. Description of Cases

Since our goal is to evaluate the applicability of our approach, we have tried to cover a variety of situations in our case studies. We primarily looked for cases where a VE was formed with a set of partners that could be either individuals or organisations. We looked at companies that initiated the formation of the VE and actually participated in the VE as well as companies that acted purely as VE Initiators (mostly hired by the customer) and assisted in the formation of the VE. We studied the approaches used by the companies, in general, in forming VEs by looking at individual scenarios. In this section, we will give a brief description of the cases.

4.1. Company A: Small Consulting Company

Company A is an independent private consulting firm that offers all aspects of business, financial, economic and social consulting services. It maintains a database of highly qualified consultants in various fields and draws upon these resources to form the teams that work on their projects. These consultants are analogous to the partners of the VE. Company A forms a team of people to work on the project by identifying the different roles that are required to perform the activities and by selecting the relevant people to fill the roles. The partners can negotiate with the company during the formation of the VE.

4.2. Company B: Student Project Groups

Company B is a company that operates in the oil and offshore industry, on a global scale. The particular scenario that we analysed was the selection of several groups of students who will work together as teams during their summer holidays on some projects specified by Company B. Each team, in this case can be considered as a VE. Company B is popular among the students and therefore, a huge number of students apply for this opportunity. Although a thorough evaluation is conducted before selecting the best students, there is no opportunity for the students to negotiate.

4.3. Company C: Strategic Alliance

Company C operates in the maritime industry on a global scale. They feel that they are currently operating in a saturated market and thus, decided to form an alliance (VE) with another company with complementary skills, technology and markets, in order to expand their own customer base.

4.4. Company D: Building Construction Project

Company D is hired by a customer to assist them to evaluate bids in the selection of a contractor for large scale projects in various domains. For example, in the construction industry for the construction of a hospital. They specialise in the selection of the project team or the partners of the VE that will eventually be formed to deliver to the customer. The VEs that they assist to create usually comprise of several organisations and they have to take into consideration the skills of the individuals from each organisation that will work in the VE.

5. Evaluation

In this section, we present our evaluation framework, which is based on a set of characteristics that affect the formation of the VE. We then discuss the different cases in the light of this framework and present the evaluation results.

5.1. Evaluation Framework

During the evaluation of the different cases, we identified a number of characteristics that played a significant role in the formation of the VE. These characteristics were identified while attempting to model the cases using our agent-based approach and through discussions with a person from the companies. The evaluation framework is based on these and consists of the following set of characteristics :

- **Geographical context**: This is the geographical context in which partners are sought. In our example, we assume that the system is available on the Internet and that the partners can be sought on a global basis.
- **Specialisation of the skills required for the VE**: This is an indication of the amount of potential partners that may be bidding to become partners in the VE; i.e. the more specialised the skill, the less the amount of people that will meet the skill requirements. The greater the number of partners, the more the number of interactions (e.g. negotiations, coordination of work) that take place among them. In our example, we looked for people that had skills in webpage development and programming such as Java, XML and HTML.
- **Level of detail of the VE when VE is formed:** This characteristic indicates how detailed the requirements, the goals and the roles that need to be filled in the VE are described when the VE is formed. In our example, we have identified the roles of the VE to the level of detail such that the people that fill these roles will (or can) actually do the work themselves.
- **Duration of the VE**: The duration of the VE gives an indication of the length of time that the VE lasts. For our example, the duration of the VE was only a month.
- **Consideration of team aspects:** This gives an indication of how the partners' abilities or potential to collaborate was considered when they were selected. In our example, this was not considered explicitly.
- **Scale of the project:** This characteristic indicates the scale of the VE in terms of money. Our example was a very small scale VE, involving just a few thousand US$.
- **Complexity of the project**: This characteristic gives an indication of the VE in terms of its goals, the number of different partners, the risk factor and the amount of uncertainties that are faced by the VE. In our example, the complexity was very low as only 2 partners are sought and the risks were small.

5.2. Applying the Framework

In this section, we evaluate the applicability of our agent-based approach for the different cases by applying the framework described above.

- **Geographical context**: The geographical context of the VEs varied from local to global. Company A looked for its partners locally while Company C, although looking for one partner only, looked globally. Companies B and D looked nationally for the partners for their VEs.
- **Specialisation of the skills required for the VE**: The range of skills that were sought by the different cases varied immensely. For example, Company B was not looking for very specialised skills, rather a variety of skills and the combination of skills one partner could offer. Company B was faced with the task of selecting just a few partners from a very large number of potential partners. In some cases, the skills that were sought were highly specialised. For example, Company D looked for a partner that was an architect (organisation) specialized in hospital design.
- **Level of detail of the VE when VE is formed:** Often, a VE is described at a very high level. For example, when Company D looks for the partners of a VE to design and build a hospital, they look for the high level roles in the VE such as the architect firm, building organisation and the project management organisation. Thus, they do not have to describe the VE in the level of detail where the specific roles within each of these high level roles are described. Similarly, when Company C looks for a partner with complementary skills and markets, they just define the high level roles and requirements for these roles.
- **Duration of the VE**: The duration of the cases varied from 3 months, (summer projects at Company B), to several years, e.g. the duration of a VE responsible for the design and construction of a hospital.
- **Consideration of team aspects:** The collaboration ability of the partners was not always considered explicitly; rather based on (relationship) history of the potential partners. For example, Companies A and D practised this approach.
- **Scale of the project:** The scale of the projects varied from short summer projects that did not have any financial consequences, (e.g. Company B), to a few hundred thousand $ (e.g. Company A) to bigger projects. (Note that we have chosen not to include any figures here as this may be sensitive information. However, judging from the nature of the business, we can safely assume that some of the cases are of very large scale.)

- **Complexity of the project:** The complexity of the projects also varied from well-scoped research
- projects (e.g. Company B) to complex construction projects, (Company D).

Table 1: Comparison of the Cases

Characteristic	*Our Example*	*A*	*B*	*C*	*D*
Geographical Context	Global	Local	Local (National)	Global	Local (National)
Specialisation of skills required for VE	Low	Medium	Low	High	High
Level of detail of the VE when VE is formed	High	High	High	Low	Low
Duration of the VE	Short	Medium	Short	Long	Long
Consideration of team aspects	Medium-high	Medium	High	High	High
Scale of project: Money	Small	Medium	Small	Large	Large
Complexity of project	Small	Medium	Small	High	High

A comparison of the cases are summarised in Table 1. We were not able to get adequate information to assess the economic scale and the complexity of the VEs in a more quantitative or qualitative way. Thus, we were not able to consider these characteristics in detail. Very often, as the scale of the project increases, so does the complexity; e.g. in large construction projects that involve several partners and have a high risk. However, this may not always be the case; e.g., a VE to deliver a software solution where the number of partners are relatively low and an easily adaptable solution already exists, the VE may stand to earn a lot of money, but the risks are low.

5.3. Evaluation Results

Our analysis is based on attempting to model the different cases using our approach and on discussions with a person from the companies. Based on our analysis results, we believe that Company B will be the one to benefit most from our technology since the task of selecting a few partners from a large number can be made more effective using our approach. In this case, the requirements for the skills can also be represented easily. Company A will also benefit from the approach in the situations where they have a bigger geographical context and when they have a large number of potential partners. For Companies C and D, they can benefit from our approach by using it for situations where there are several potential partners. In such cases, our approach will help them "short list" some of the potential partners quickly and efficiently, by conducting a very coarse match of the requirements of the skills of the potential partners. They can then evaluate this selection more thoroughly using manual methods. This will save them time and resources.

The characteristics scale and complexity seems to be one of the factors that influence the choice of technology. If the VE will itself generate a lot of income and has a high risk, the initiators of the VE are willing to put in the required resources, both in terms of money and effort, to ensure that the right partners are selected.

One of the most important aspects of agents is their ability to support sophisticated interactions such as negotiations. Thus, the approach seemed more appropriate for VEs that involved a large number of interactions among the agents. The applicability of our agent-based approach to support the formation of VEs depended on the characteristics in the framework as described below. Our agent-based approach was more applicable in the following situations:

1. When the VE partners were sought within a global context rather than within a local context.
2. When the number of potential partners were large.
3. When the VE was small scale, had low risks, was not complex and had low specialisation of skills.

Another interesting aspect that we identified was that in those cases where the applicability of the approach was considered low, there was still a degree of applicability where there are some gains to be made. For example, the possibility to use the approach for some prequalification or shortlisting, thereby saving time and money. The degree to which the approach is applicable will vary from case to case.

6. Conclusion

VEs are a business scenario and often depict complex situations. Thus, the evaluation of a technology to support such a situation will also be complex and requires a variety of information. Our analysis is based on qualitative information as we were unable to conduct a quantitative analysis as the companies were not able to provide such information due to reasons of confidentiality. A lot of our analysis is also based on the interviews and the discussions with the various companies. However, we believe that a qualitative analysis is adequate to identify if our agent-based approach is applicable to a particular VE situation.

Unlike evaluations of agent-based systems with respect to a particular theory, our evaluation framework itself can be evaluated with respect to a particular situation. Had we chosen different cases, we might have identified more cases that would benefit from our approach. However, we believe that the variety in this selection helped us identify a broader set of characteristics for our framework. It is also important to note that the same cases can also be used for a more detailed evaluation of our agent-based approach.

The evaluation framework helps to identify the applicability of an agent-based approach to support the formation of VEs for different business situations. It is an inexpensive indicator of when the proposed agent-based approach will be suitable to adopt. It does not require any prototyping or complex analysis of the situation and it helps to fill a gap in the evaluation methods for agent-based systems.

7. Acknowledgements

This work is partially supported by the Norwegian Research Foundation in the framework of the Information and Communication Technology (IKT-2010) program and the ADIS project. The author would like to thank Prof. Divitini for her valuable comments and feedback, the people who provided the inputs for the cases and Prof. Matskin for interesting discussions.

8. References

[1]. Baker, K., Greenberg, S., Gutwin, C. Empirical Development of a Heuristic Evaluation Methodology for Shared Workspace Groupware, ACM Conference on Computer Supported Cooperative Work, ACM Press, New Orleans, Lousiana, USA, 2002.

[2]. Barbuceanu, M., Fox, M.S., The Information Agent: An infrastructure agent supporting collaborative enterprise architectures, In 3rd Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises, 1994.

[3]. Bernus, P., Bertok, P., Nemes, L., Modelling Dynamic Management Features of Virtual Enterprises, in *Computer Applications in Production Engineering*, Plonka and G. Olling (Eds.), Chapman and Hall, London, 1997, p. 643-655.

[4]. IFIP-IFAC Task Force, GERAM: Generalised Enterprise Reference Architecture and Methodology, Version 1.6.2, available from http://www.cit.gu.edu.au/~bernus/

[5]. Nielsen, J., *Usability Engineering*. Academic Press, 1993.

[6]. Oliveira, E. and Rocha, A. P., Agents' Advanced Features for Negotiation in Electronic Commerce and Virtual Organisation Formation Process, European Perspectives on Agent Mediated Electronic Commerce, Springer Verlag, June 2000.

[7]. Petersen, S. A., Extended and Virtual Enterprises – A Review of the Concepts, Technical Report 2/02, Norwegian University of Science & Technology, Trondheim, Norway, 2002.

[8]. Petersen, S. A., Divitini, M., Using Agents to Support the Selection of Virtual Enterprise Teams, Proc. of 4th International Workshop on Agent-Oriented Information Systems (AOIS-2002), Bologne, Italy, July 2002.

[9]. Petersen, S. A., Gruninger, M., An Agent-based Model to Support the Formation of Virtual Enterprises, International ICSC Symposium on Mobile Agents and Multi-agents in Virtual Organisations and E-Commerce (MAMA'2000), in Woolongong, Australia, 11-13 Dec. 2000.

[10]. Tølle, M., Bernus, P. and Vesterager, J., Reference Models for Virtual Enterprises, in Collaborative Business Ecosystems and Virtual Enterprises, (PRO-VE'02), Sesimbra, Portugal, May 2002, p.3-10.

[11]. Wooldridge, M., Fisher, M., Huget, M. and Parsons, S., Model Checking Multi-agent Systems with MABLE, Proceedings of the First International Joint Conference on Autonomous Agents and Multi-agent Systems, Bologne, Italy, July 2002.

[12]. Wooldridge, M. and N. R., Jennings, Pitfalls of Agent-Oriented Development, in K. P. Sycara and M. Wooldridge, (Eds.), Agents '98: Proc. of the 2nd Int. Conference on Autonomous Agents, ACM Press, May 1998.

[13]. Yin, R. K., Case Study Research Design and Methods, Second Edition, Sage Publications, 1994.

Paper 6

Title

Requirements for an Agent-based Approach to Support Virtual Enterprises

Main Result

Requirements of the agent-based approach, based on two industrial case studies.

Reference in Thesis

This paper is referenced from Chapter 8, Section 8.2.

Published in:

Process and Foundations for Virtual Enterprises, Proceedings of IFIP Working Conference on Virtual Enterprises, PRO-VE03, L. M. Camarinha-Matos and H. Afsarmanesh (Eds.), Kluwer Academic Publishers, 2003.

Copyright

REQUIREMENTS FOR AN AGENT-BASED APPROACH TO SUPPORT VIRTUAL ENTERPRISES

Sobah Abbas Petersen[1], Geir J. Husøy[2], Edgar Karlsen[2], Mihhail Matskin[3]
[1] Dept. of Computer and Information Science, Norwegian University of Science and Technology, Trondheim, Norway, Email: sap@idi.ntnu.no
[2] The Organisation Development Alliance AS, Akersgaten 43, 0158 Oslo, Norway Email: {geir.johan.husoy,edgar.karlsen}@oda.as
[3] Dept. of Microelectronics and Information Technology, Royal Institute of Technology, SE-164 40 Kista, Sweden, Email: misha@imit.kth.se

In this paper, we present the requirements for an agent-based approach to support the formation of Virtual Enterprises by analysing the approach using two industrial case studies. We believe that there are two important aspects of selecting the partners for a Virtual Enterprise; (i) matching the correct partner to the requirements, and (ii) the process in which the partners are evaluated and selected. Our analysis showed that the system must provide support for a language to represent the capabilities of the partner, the evaluation of different kinds of partners, flexibility in defining the evaluation criteria, the selection process and the negotiation process.

1. INTRODUCTION

A Virtual Enterprise (VE) can be considered as a scenario where a number of entities (organisations, software agents or human beings) collaborate to achieve a specific goal. There are several types of VEs, e.g. a consortium for one-of-a-kind manufacturing or a project group to take advantage of a particular market situation, [1]. The success of a VE is dependent on the performance of its partners. Hence, the formation of the VE and the selection of the partners for the VE is an important process in the lifecycle of a VE, [3].

In this paper, we analyse an agent-based approach to support the formation of VEs using 2 case studies. Our approach is aimed towards supporting the decision making process for human beings or organisations during the formation of VEs. We believe that software agents, hereafter referred to as agents, are a suitable means of representing the partners of a VE. Agents, by definition are able to support sophisticated interactions such as negotiations, [7]. The ability to support detailed, multi-attribute negotiation is an advantage of this approach. Thus, by delegating the agents to conduct the negotiation on behalf of the partners, the partners could then have the time to do the actual work required in the current VE. We believe that there are two important steps in selecting the partners of the VE; (i) how well the partners meet the requirements of the VE and (ii) the process in which they are selected.

We describe the agent-based approach by using a simple hypothetical example of a VE, where we consider the roles of the VE, the requirements for the roles, the attributes of the agents and the selection process. In order to provide the right kind of support for the numerous VEs in the industrial world, we believe that such an approach must be applied to real situations. It is only through such evaluations that we will be able to obtain a true indication of the strengths and weaknesses of the approach and the requirements for such an approach.

In this paper, we present the requirements of an agent-based system to support the formation of VEs based on 2 industrial case studies. The remainder of this paper is organised as follows: Section 2 describes our agent-based approach, Section 3 describes the ODA model, section 4 describes the 2 cases, Section 5 describes the analysis of our approach using the cases, Section 6 presents the set of requirements based on the analysis, Section 7 discusses the work related to this and Section 8 discusses the conclusions.

2. THE AGENT-BASED APPROACH

Before a VE is formed, it's concepts and goals have to be defined. The requirements from the customer sets the requirements for the VE partners and in order for the VE to be able to deliver to its customer, the right team of partners has to be formed. In developing the agent-based approach, the first step was to develop an agent-based model for a VE. The model can be used to define the goals, the activities and the roles that are required for the VE. Agents that meet the requirements for the roles can fill the roles. A detailed description of the model is available from [12]. Developing a model of the VE can be summarised as identifying the roles of the VE, the requirements for the roles and the attributes of the partners. The second step was to use the model to select the best team of partners. The selection process includes the alignment of the partners' goals with the goals of the VE and matching their attributes to the requirements for the roles.

Consider a VE formed to design the Internet homepage for a company. A *VE Initiator*, who decides to form a VE to perform this job, looks for 2 partners with the relevant programming skills. IP-A, IP-B, IP-C and IP-D are *Interested Partners* (ones that are interested in joining the VE) and they bid to become a partner in the VE. Each of these Interested Partners can be represented by an agent, which has a set of attributes that describes its skills and capabilities. Similarly, the VE Initiator can also be represented by an agent, which is described by a set of requirements for the partners' skills and capabilities. We have described this scenario in detail with an implementation in [11]. It also explains the techniques that were applied to select the 2 best partners. By using hypothetical values and matching constraints for the requirements and the attributes, we were able to select 2 partners that satisfied the requirements.

The selection criteria can be based on a set of attributes of the Interested Partners and how well these attributes match the requirements. The attributes that we considered are the partner's goal(s), the time period that the partner is available to do the work, the specific skills of the partner, the cost of having the partner (based on the total no. of hours and the cost per hour), the performance rating which is an indication of how efficient the partner is at performing a task, the commitment of the partner to do the work and the risk(s) involved in including the partner in the VE.

In addition, the selection of the best team can be considered using the total cost of the partners in a team and the total risk of having the partners in the team.

3. ODA MODEL

We have selected 2 cases where The Organisation Development Alliance AS (ODA), on behalf of a customer, evaluates a number of bids to select the best project team or the VE for a large scale project (ODA is the VE Initiator). ODA has developed a model to evaluate "integrated project teams", a VE in which a group of partners that delivers to a customer and the customer work together for large scale projects. The evaluation method is focused on identifying potential risks and designing a project management strategy aimed at mitigating the risks. The ODA Model is based on understanding the preconditions for effective project execution. It identifies 3 main aspects that must be considered in the preparation and execution of evaluation; see Figure 1. The evaluation criteria are tailor-made to the scope of work and the customer contract and execution philosophy. The aim is to identify the team or VE with the best capabilities to execute the scope of work in question within the established framework. The main aspects of the ODA Model are, [2]:

1. **Incentives** - the risk and reward structure.
2. **Trust** - the ability and attitude to work in close co-operation.
3. **Authority** – the co-operation model, e.g. the type of alliance.

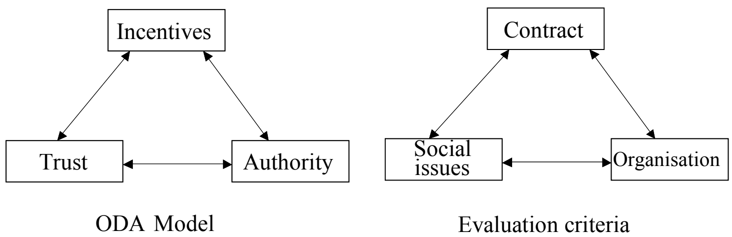

Figure 1: ODA Model and corresponding Evaluation Criteria

Based on this model, ODA has developed a framework for evaluating and selecting partners, which is tailor-made for each evaluation. The incentives, contract and execution philosophy must be established prior to the evaluation process. If a customer wants a closely integrated framework, the experience and attitude of the potential partner(s) to work integrated with the customer will be a critical evaluation criterion. The evaluation criteria can be broadly categorised as contract, social issues, and organisation, where each of these categories can be described in detail with a set of attributes that reflect the requirements for the partner. These 3 criteria can be described as follows:

1. **Contract** - corresponds to incentives, describes the suggested contractual model, which includes the details of execution of the work.
2. **Social Issues** - corresponds to trust, describes attitude towards working integrated.
3. **Organisation** - corresponds to authority, describes the project organisation, the proposed co-operation model and the individual and team competence.

4. DESCRIPTION OF THE CASES

An overview of the 2 cases is given in Table 1. Since our aim is to identify a general set of requirements, we have chosen 2 cases from 2 different application areas.

Table 1: Overview of the Cases

Characteristics	*Case 1*	*Case 2*
Industry/domain	Oil and gas	IT
Purpose	Increase production through water injection	Increase efficiency through new hardware and software support
Scale ($)	300 million	35-40 million
Expected duration of the VE	4 years	3 years
Time taken for VE formation	4-6 weeks	4-6 weeks
No. of partners in VE	2	2
Kind of partners	Individual companies	Consortium
Specialisation of the skills in the VE (High, Medium, Low)	High	High
Complexity of the VE (High, Medium, Low)	High	High

4.1 CASE 1

Case 1 is taken from a capital project in the oil and gas industry, with the objective to facilitate increased production through a new water injection platform and modifications to existing installations. The main focus of this evaluation is to select the partners that show most motivation to work the customer, as a VE.

Selection Criteria: The selection criteria were categorised into 4 groups:

1. The proposed contractual framework between the partners of the VE and the VE and the customer. This included details about the execution of the work as well as issues such as the distribution of risks and profit.
2. The experience of the partner.
3. The organizational model of the VE and the skills and competencies of the individual members within each partner organisation.
4. Social issues or team and collaborative aspects which describe how the VE will solve a problem collaboratively (e.g. with the customer or sub-suppliers).

Selection Process: The selection process consisted of evaluating each interested partner against the requirements to select some potential partners. Then, they were called in for interviews and to a workshop to solve a problem collaboratively. A number of issues, such as price, incentives and bonuses, change of personnel, improvement of services, and other terms and conditions of the contract, were then negotiated upon before the final selection was done. An overview of the selection process is shown in Figure 2.

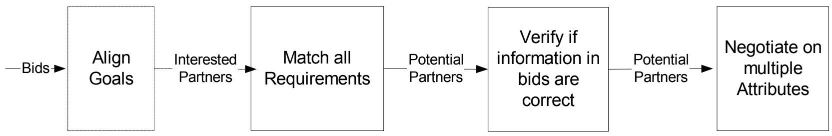

Figure 2: Case 1: Selection Process

4.2 CASE 2

Case 2 is based on a project aiming to upgrade software and hardware to all personnel of a large government body represented in all main rural areas of the country. Service and training were also a part of the contract. In this case, ODA had to select a single partner. However, the potential partners consisted of several sub-departments within one organisation.

Selection Criteria: The selection criteria, which can be used to derive the attributes of the agents, were categorised into 3 groups as follows:

1. Price – the price of the infrastructure, the total package delivered.
2. The complete system where the development of the system was considered. In addition to how well the system met the requirements, the planning, organisation of the delivery team and the execution of the development project were also considered.
3. The long-term maintenance contract.

Selection Process: The selection process is similar to that of Case 1. However, in this case, the main purpose of the negotiation process was to agree upon the contents of the tasks to be performed by the VE, for a particular price. Also, the type of information that the potential partner is requested to submit for verification is different from that of Case 1. This is related to both the different scope of work and execution model chosen by the customer, which leads to different criteria and instruction to bidders.

5. ANALYSIS

In this section, we analyse our agent-based approach with respect to the 2 cases. Based on this analysis, we present the limitations and strengths of our approach and discuss how it can be used to support ODA in their evaluation and partner selection processes.

5.1 Analysis of our Approach

We have used our agent-based approach to model the 2 cases, where we focused on representing the requirements for the partners and the attributes of the partners. We then tried to see how the sets of attributes and the ODA selection process compared with those that were used for our simple example. By reviewing our approach in the light of the 2 cases, we were able to identify the following:

- **Representation**: The ODA evaluation criteria is very rich and cannot be represented by quantitative or qualitative information only. Since the agents represent human beings or organisations, the attributes reflect characteristics of human beings and organisations such as commitment and responsibility. In addition, the team dynamics also has to be considered. In our approach, we have tried to represent the attributes as quantitative values, which, alone, do not capture the richness of the evaluation criteria or the semantics of the attributes.
- **Attributes**: ODA has a very rich set of attributes that consider the individual aspects as well as the team aspects. The attributes are categorized into several groups whereas, in our example, we have considered one set of attributes.
- **Selection Process**: In both the cases, goal alignment was considered implicitly, by assuming that the potential partners had proposed a bid because the goals are aligned. In our approach, since we define a VE as a goal-oriented entity, we

consider goal alignment as an important aspect and, thus, ask the Interested Partners to submit their goals. Both the cases have an explicit information verification process where they conducted interviews and workshops with the Potential Partners. Note that our simple example did not illustrate the aspect of negotiation, although to facilitate negotiation is one of the main aims of this approach.

- **Type of partner**: The cases show that the partners of a VE could be a coalition of partners (i.e. a VE themselves). See Figure 3. Our approach considers one level of partners only, thus, assuming that all partners are individuals.

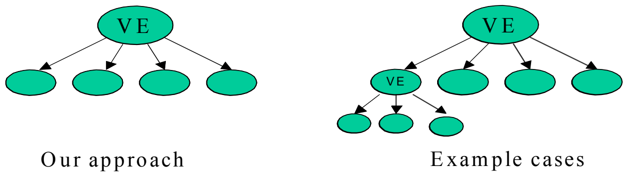

Figure 3: Type of Partner

5.2 Limitations of Our Approach

Based on the above analysis, we have identified the following limitations of our approach.

- It was not possible to capture the semantics of the attributes and the richness of the evaluation criteria using our approach.
- Our approach considers one level of partners, or assumes that the partner is an individual entity and not a VE itself.
- Our approach lacks attributes that truly capture the cooperative aspects of the partners. (This is related to the limitation listed first.)

5.3 Support for ODA's Evaluation Process

Based on the analysis of our approach with respect to the cases, we identified that our approach cannot be used to conduct the complete evaluation and partner selection process for either of the cases. However, it can be used to provide some degree of support for ODA such as to conduct a coarse prequalification of the partners. This is particularly important where there are a number of potential partners. This would make ODA's process more efficient and cost effective. By supporting a percentage of the evaluation criteria, (e.g. a subset of the requirements and the attributes), our approach can contribute to reducing the cost of conducting the evaluation. Thus, it would be interesting to see how much of the process can be supported by our agent-based approach and this will be the next step in our analysis.

The ability to support multi-attribute negotiation is an advantage of this approach, although, in the 2 cases considered, it was not so simple to identify exactly when negotiation takes place and to find simple attributes that were negotiated upon.

6. REQUIREMENTS

We can summarise the overall requirements for an agent-based approach as shown below. The approach must provide support for:

1. **A language to represent the capabilities of the partners** - the user must be able to represent the capabilities of the partners for all situations where the partners may be human beings, organisations, software agents or VEs.
2. **Flexibility to define the set of attributes** - the user must be able to define the set of requirements and the attributes as required for any VE situation.
3. **Flexibility to define the selection process -** the user must be able to define the selection process, i.e. to define when goals are aligned, what is matched and which attributes are negotiated upon and when. There is no universal selection process. Thus, there is a need to be able to support a variety of processes, which can be defined by the user.
4. **Evaluation of partners that are coalitions or VEs –** situations where the partners that bid are VEs themselves and where the individual members within a coalition must be considered during the evaluation. In such situations, there is a need to be able to look into the coalition as well as obtain a collective view of the coalition.
5. **Flexibility in negotiation** – The user must be able to define when a negotiation should take place during the selection process, between which entities and upon which set of attributes.

7. RELATED WORK

Agents have been used to support the formation of VEs in several applications, e.g. in[13], the notion of a broker is used and [14] uses mobile agents. Of particular relevance to our work are the VE formation scenarios considered within the context of an electronic market place, e.g. [8]. While this work considers a wider aspect of multi-agent systems such as learning, it does not address the complexity of representing the requirements and the capabilities of an agent as a set of attributes reflecting a human being or an organisation. In [4], the selection of partners for a VE was considered in terms of Web Services, where the issue of representation was addressed. They propose some essential characteristics of a matchmaking engine.

An important aspect in representing the attributes of the partners is the ability to model the notion of trust and commitment among the partners. In [6], the notion of commitments is used to manage the autonomy of an agent in a VE and the notion of trust is addressed in [5].

Some high-level requirements for modelling a VE are given in [1], and a set of open challenges in the area of VEs is listed in [3]. One such challenge is to provide support for the complete lifecycle of the VE. In this paper, we have focussed on the formation phase only. However, our approach can be extended to cover the full lifecycle, [10].

8. CONCLUSION

In this paper, we have presented the requirements for an agent-based approach to support the formation of a VE. The requirements are derived by analysing the approach using 2 industrial case studies. The analysis is based on the attributes considered in the evaluation criteria and the selection process. In addition to the requirements, we also discuss the limitations and the strengths of the approach.

During the analysis process, we also identified that although the approach does not fully support the complex evaluation criteria that were used in both the cases, it can still provide some degree of support. The next phase in our work will be to conduct a more detailed analysis of the cases to obtain a better indication of how much of the VE formation process can be supported by our approach.

9. ACKNOWLEDGEMENTS

This work is partially supported by the Norwegian Research Foundation in the framework of the Information and Communication Technology (IKT-2010) program and the ADIS project.

10. REFERENCES

[1]. Bernus, P., Bertok, P., Nemes, L., Modelling Dynamic Management Features of Virtual Enterprises, in *Computer Applications in Production Engineering* 97, Plonka and G.Olling (Ed), Chapman and Hall, London, 1997, p. 643-655.

[2]. Borgen, S.O., Husøy, G. J., Karevold, K. I., Karlsen, E., Olsen, B. E., The ODA Model - Incentives, Authority and Trust in Integrated Offshore Organizations, Report of the Petropol programme, NFR, Jul. 1998.

[3]. Camarinha-Matos, L. M., Afsarmanesh, H., Virtual Enterprise Modelling and Support Infrastructures: Applying Multi-agent System Approaches, in *Multi-agent Systems and Applications*, M. Luck, V. Marik, O. Stpankova, R. Trappl (eds.), Lecture Notes in Artificial Intelligent LNAI 2086, Springer, ISBN 3-540-42312-5, Jul. 2001.

[4]. Field, S. and Hoffner, Y., In Search of the Right Partner, in *Collaborative Business Ecosystems and Virtual Enterprises*, L. M. Camarinha-Matos (Ed.), Kluwer Academic Publishers, 2002, p.55-62.

[5]. Gans, G., Jarke, M., Kethers, S., Lakemeyer, G., Ellrich, L., Funken, C., Meister, M., Towards (Dis)Trust-Based Simulations of Agent Networks. in: Proc. of the 4th Workshop on Deception, Fraud, and Trust in Agent Societies, Montreal, May 2001, p. 49-60.

[6]. Jain, A. K., Aparicio IV, M. and Singh, M. P., Agents for Process Coherence in Virtual Enterprises, in *Communications of the ACM*, March 1999, Vol. 42, No. 3, pp. 62-69.

[7]. Jennings, N. R., Faratin, P., Norman, T. J., O'Brien, P. and Odgers, B., Autonomous Agents for Business Process Management, *Int. Journal of Applied Artificial Intelligence,* 14 (2), p.145-189.

[8]. Oliveira, E. and Rocha, A. P., Agents' Advanced Features for Negotiation in Electronic Commerce and Virtual Organisation Formation Process*,* European Perspectives on Agent Mediated Electronic Commerce, Springer Verlag, Jun. 2000.

[9]. Petersen, S. A., Divitini, M., Matskin, M., An Agent-based Approach to Modelling Virtual Enterprises, In the special issue on Enterprise Modelling of International Journal of Production Planning and Control, Taylor & Francis, Vol. 12, No. 3, 2001, pp. 224-233.

[10]. Petersen, S. A., Divitini, M., Matskin, M., An Agent-based Approach to Modelling Virtual Enterprises, In the special issue on Enterprise Modelling of International Journal of Production Planning and Control, Taylor & Francis, Vol. 12, No. 3, 2001, pp.224-233.

[11]. Petersen, S. A., Divitini, M., Using Agents to Support the Selection of Virtual Enterprise Teams, Proc. of 4th Int. Bi-Conference Workshop on Agent-Oriented Information Systems (AOIS-2002, Bologne, Italy, Jul. 2002.

[12]. Petersen, S. A., Gruninger, M., An Agent-based Model to Support the Formation of Virtual Enterprises, International ICSC Symposium on Mobile Agents and Multi-agents in Virtual Organisations and E-Commerce (MAMA'2000), in Woolongong, Australia, 11-13 Dec. 2000.

[13]. Rabelo, R. J., Camarinha-Matos, L. M., Vallejos, R. V., Agent-based Brokerage for Virtual Enterprise Creation in the Moulds Industry, in E-Business and Virtual Enterprises – Managing Business-to-Business Coorporation, L. M. Camarinha-Matos et. al. (Ed.), Kluwer Academic Publishers, 2000, pp. 281-290.

[14]. Simões-Costa, S., Rabelo, R. J., Supporting the Creation of Virtual Enterprises Using Mobile Agents, in Collaborative Business Ecosystems and Virtual Enterprises, L. M. Camarinha-Matos (Ed.), Kluwer Academic Publishers, 2002, pp.371-378.

Paper 7

Title

Agent Interaction Protocols for the Selection of Partners for Virtual Enterprises

Main Result

VE formation processes expressed as agent interaction protocols, based on industrial case studies.

Reference in Thesis

This paper is referenced from Chapter 8, Sections 8.3 and 8.4.

Published in:

Multi-Agent Systems and Applications III, 3rd International Central and Eastern European Conference on MultiAgent Systems, CEEMAS 2003, Prague, V. Mařík and J. P. Müller and M. Pěchouček (eds.), LNAI 2691, Springer Verlag, 2003, pages 606-615.

Copyright

Agent Interaction Protocols for the Selection of Partners for Virtual Enterprises

Sobah Abbas Petersen[1] and Mihhail Matskin[2]

[1] Department of Computer and Information Science,
Norwegian University of Science and Technology,
N-7491 Trondheim, Norway
[2] Department of Microelectronics and Information Technology,
Royal Institute of Technology,
SE-164 40 Kista, Sweden
sap@idi.ntnu.no, misha@imit.kth.se

Abstract. A Virtual Enterprise can be described as an organisational form that emerges when individual entities form a team to achieve a specific goal. The ability to assemble the best team is key to the success of the Virtual Enterprise and this imposes strong demands on its formation. In this paper, we present an agent-based model of a Virtual Enterprise, where the partners of a Virtual Enterprise are represented by software agents. We show how this model can support the different processes that are used in selecting the partners. We do this by analysing the agent interaction protocols for the different partner selection processes and by adapting it to provide the necessary agent-based support. We also describe the contents of the knowledge base of a single agent and how it can be used in the selection processes.

1 Introduction

A Virtual Enterprise (VE) can be described as an organisational form that emerges when individual entities form a team to achieve a specific goal. An example of such a team is a project group. There have been several attempts at defining VEs from different research communities. A summary of these is given in [14]. We have reviewed these definitions to come up with a working definition: *a team of partners that collaborate to achieve a specific goal*. The partners may be human beings, organisations (or part of organisations) or software agents. Unlike traditional enterprises that are established and continue to exist over a long time, VEs are established to deliver a specific product or a service. VEs have a shorter life span and this means that the partners that participate in one VE may also be negotiating on a contract with another VE. Thus, there is a need to form VEs very quickly and frequently.

We believe that software agents, hereafter referred to as agents, are a suitable means of representing the partners of a VE. One important reason for this is that by delegating the agents to look for the next VE and conduct the negotiation on behalf of the partners, the partners would then have the time to do the actual work required in the current VE. Thus, we believe that agents could be used to represent the partners of a VE and to support the efficient formation of VEs. We consider the formation of VEs within the context of electronic markets, (see [11] for an overview), where the agents bid and compete to become the partners of a VE. The partners' bids are evaluated according to some criteria.

Industrial case studies have revealed a number of different processes and evaluation criteria that have been used to select the partners during the formation of a VE. We have analysed the different selection processes as agent interaction protocols, where an agent interaction protocol describes the sequence of communication between two agents and the contents of the messages. In this paper, we present an agent-based model for a VE and the model of a single agent in a VE. We describe how these models can be used to support the different agent interaction protocols and thus the different selection processes.

The rest of this paper is organised as follows: Section 2 describes the agent-based model of a VE; Section 3 describes the model of an agent; Section 4 describes how the different agent interaction protocols from the different selection processes are supported by our models; Section 5 reviews some of the literature related to this work and Section 6 discusses the conclusions and the work that is planned for the future.

2 Model of a Virtual Enterprise

We have developed an agent-based Enterprise Model of a VE by analysing the entities in a VE, their relationships and how they can be used in an agent context, [15]. An important contribution in modelling enterprises was made in [6] and this has been a source of inspiration for our model. In our model, the VE has a *goal* which is achieved by a set of *activities* which are performed by a set of *roles*. See Figure 1. The agents that fill these roles are the members of the VE and the agents are selected on the basis of how well they meet the requirements for the roles. For our work, we assume that the goals, the activities, the roles and their requirements are available before the VE is announced and that this information is used in the VE announcement.

The complete model of a VE is important in order to be able to understand how the different entities affect one another. For example, how does the selection of a particular agent affect the goals of the VE? Such a question can only be answered if we see the link from the agent to the goals of the VE. A complete model is also helpful in determining the kind of information that is flowing among the different entities. This in turn helps in designing the agents and the communication and collaboration among the agents.

The agents in a VE can be classified as:

VE Initiator (who may also be the customer), who takes the initiative to form the VE.

VE Partner (who may also be the VE Initiator), who are the members that form the VE.

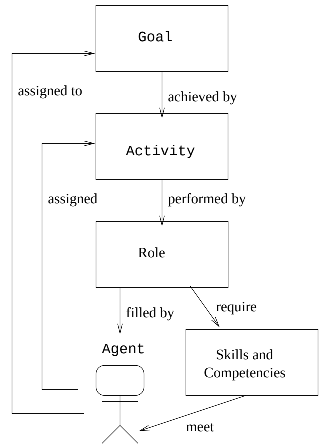

Fig. 1. Model of a Virtual Entreprise

A VE Partner evolves from someone that is interested in becoming a part of the VE to someone who is actually a part of the VE. We use the terms *Interested Partner*, one that is interested in becoming a part of the VE and submits a bid for the work, and *Potential Partner*, one that is considered for the VE and a contract is negotiated.

3 Model of an Agent

There are several agent architectures that uses a knowledge base of an agent, e.g. [8]. We have taken a pragmatic approach in designing our agent architecture to represent the knowledge that is required for the formation of a VE. Thus, we have only considered the basic components of the agent's knowledge base at this stage in our work. Each agent contains a set of goals, a set of activities and a set of capabilities, see Figure 2. The information that is represented by the goals, the activities and the capabilities of the VE Initiator and the VE Partners are slightly different. The VE Initiator agent represents the VE and thus the information represented by the VE Initiator reflects the VE whereas the information represented by the VE Partners reflects that particular partner. Table 1 summarises this. Although the information represented by the goals, the activities and the capabilities of the VE Initiator and VE Partners differ, we consider the same representation and structure for the different entities.

3.1 Goals

A goal can be considered from several points of view. e.g. strategic goal [17] and a product-oriented-view of goal [13] and [5]. In this paper, we have considered the product-oriented view of a goal and describe a goal or a subgoal using the following attributes: the name of the goal, product area (the area that the agent/VE

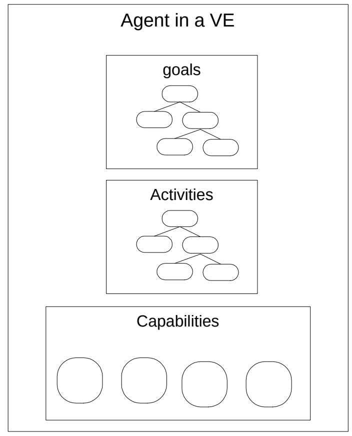

Fig. 2. Model of a Single Agent in a VE

Entity	**VE Initiator**	**VE Partner**
Goals	Goals of the VE	Goals of the partner
Activities	Activities that need to be performed to achieve the goals of the VE	Set of *experiences* of the partner
Capabilities	Requirements (skills, time, costs, etc.) for the roles of the VE	Work that the partner is capable of doing in a VE

Table 1. Information Represented by the Agent Model

intends to work on), deadline (the final date the agent/VE must deliver to the VE/customer) and cost (the amount of money that is associated with the work).

We consider the goal structure as a simple tree structure where a goal (or a subgoal) can have one or many subgoals, [3]. Any goal or a subgoal that does not have a subgoal is an atomic goal. An Interested Partner's goal is aligned with the goals of the VE if it matches one of the (sub)goals of the VE Initiator.

3.2 Activities

Similar to goals, the activities are also a tree structure where an activity (or a subactivity) can have one or many subactivities. An activity is performed towards achieving one or more goals. Activities are also defined by a set of attributes that describe the activity in terms of time constraints, resource requirements, relations to other activities as well as other related information, [6].

We consider the activities of a VE Partner as a set of experiences based on the activities that it has performed in the past. An agent bids for an (sub)activity in a VE to achieve one or more of its own goals and this (sub)activity is chosen based on the set of capabilities of the agent. By performing an activity in a VE, a new experience is added to its experience set. In this paper, we consider how the experience set can be used in the various selection processes used by VEs. Thus, we do not consider how it is updated every time the agent performs an activity in the VE.

3.3 Capabilities

The capabilities of an agent are a list of attributes, some of which may itself also be a set of attributes. The capabilities of a VE Initiator are the list of requirements for the roles in a VE. The requirements can be structured into different kinds of requirements, such as skills and experience related requirements, (e.g. set of required, skills, minimum no. of years of experience required, minimum level of skill), availability requirements and cost requirements.

The capabilities of a VE Partner is a set of attributes that meet the requirements of a VE and this is used in matching the Interested Partners to the roles in a VE.

4 Agent Interaction Protocols for Matching and Selecting VE Partners

4.1 Generic Agent Interaction Protocol

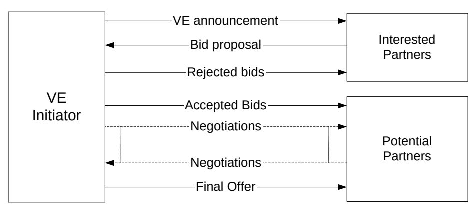

Fig. 3. Generic Agent Interaction Protocol

The interactions that takes place between the VE Initiator and the VE Partners are shown in Figure 3. VE is announced by sending out an invitation to bid. The Interested Partners respond to the announcement by proposing a bid. The bids are then qualified according to a set of criteria. The bids that do not meet the requirements are rejected and the VE Initiator then prepares to negotiate with the Potential Partners.

The agent interaction protocol presented above is a generic one that support the basic process of forming VEs. We are currently conducting a series of industrial case studies and we have identified the need for several agent interaction protocols depending on the specific selection procedure chosen by the VE Initiator. For example, if a VE is formed to deliver something simple such as an intranet for a small company, the skills that are required are widely available and the degree of variation in the skills are not critical. So, a simple matching of required and available capabilities may be enough. However, if a VE is formed to deliver a more complex product such as a ship, the skills that are required are more specialised and not that widely available. In such a VE, the cooperative behaviour of the partners will also play a significant role. Thus, a more detailed set of requirements will be considered in the matching process. The general agent interaction protocol described above needs to be adapted to cater to the needs of a particular VE. For different selection processes, the agent interaction protocol will be different depending on the information that is communicated and the sequence of communication.

4.2 Advanced Matching Process

In a more advanced selection process, the VE Initiator may request for the information in several steps. For example, in one of our case studies, Business and Financial Consulting Group (BFS)[1], [1], uses the selection process shown in Figure 4 to select people to work on their projects. BFS has a pre-compiled database that contains the names and capabilities of people who have expressed their wish to work on BFS projects. So, when BFS needs to find people to fill the roles of a VE, it looks at the requirements of skills for the roles and finds a match from the database. They then check if the desired person fulfils the availability requirements and if s/he does, they then agree on a price for the work.

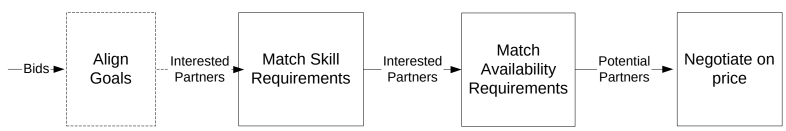

Fig. 4. Advanced Matching and Selection Process

The information gathering and matching part of the agent interaction protocol shown in Figure 5 is an iterative process where the agent is first asked to submit its skills. The agent is asked to provide its availability only if the skills match the requirements. Similarly, the agent is required to provide how much it will charge for the work only if it meets the skills and availability requirements. Although the negotiation in this case is based on a single attribute, i.e. the price charged by the agent, the negotiation can also be based on multiple attributes.

[1] BFS is a consulting firm registered in the Maldives that mans its projects by selecting resources from a pre-compiled database. BFS' project teams operate as a VE.

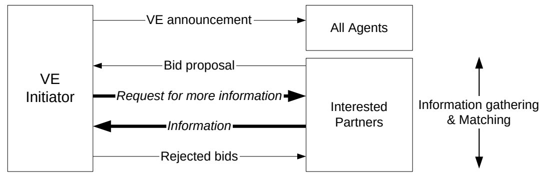

Fig. 5. Agent Interaction Protocol for Advanced Selection Processes

The expression of interest to work with BFS on a specific project can be assumed as alignment of goals of the VE and the Interested Partner. BFS does not consider this step explicitly during the matching process. However, there may be situations where goal alignment is considered explicitly during the operation phase of the lifecycle of the VE. The information that is required for this multi-tiered matching process is based on the requirements for the roles of the VE, where the requirements are structured into skills requirements, availability requirements and cost requirements. The matching conditions and constraints can be defined to match the attributes of the agents to the requirements. For example, for matching the skills, the match could be based on string matching or, for availability matching, the start and end dates for an activity associated to a role can be defined as a set of constraints.

4.3 Verification of Information During Selection

During the selection process, the VE Initiator may chose to verify if the bid proposed by the Interested Partner contains information that is true, i.e. that the Interested Partner is not lying. See Figure 6. Case studies have revealed a more detailed and stringent selection process where different approaches have been used to verify the claims made in the bid. A common approach is to call in the Interested Partners for an interview if they meet the basic requirements.

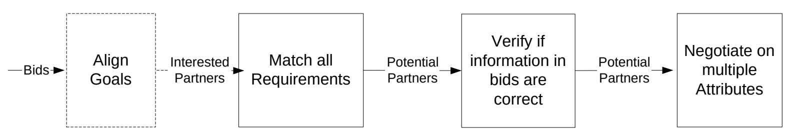

Fig. 6. Matching and Selection Process with Verification

Organisation Development Alliance AS (ODA)[2], [2], conducts detailed interviews with the Potential Partners to verify if they are actually capable of

[2] ODA AS is a Norwegian company that selects contractors (single or alliances of companies) for very large scale projects. The team of contractors operate as a VE.

delivering. In addition to interviews, ODA often invites the Potential Partners to a workshop where the possible VE team is made to solve a problem collaboratively. This gives ODA an opportunity to judge if the Potential Partners have experience in collaborative projects.

Scenarios such as the one described above can be supported by requesting for additional information from the Potential Partners after the matching process. See Figure 7. Note that the matching process may be multi-tiered as described in Section 4.2. In this case, in addition to matching the goals (implicitly or explicitly) and the requirements for the roles, the VE Initiator requests the Potential Partner to submit its activities (experience) structure to verify if the experience that is claimed can be matched to an activity in the experience tree of the Interested Partner. This process can also be strengthened by requesting the Potential Partner to submit additional material that could be checked electronically, such as authenticated references.

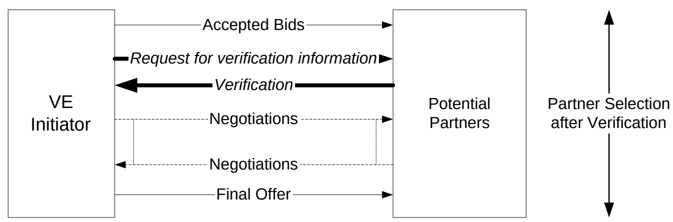

Fig. 7. Agent Interaction Protocol for a Selection Processes with Verification

5 Related Work

An important contribution in modelling enterprises was made in [6] where a formal description of an enterprise was given. This work has since been developed to specify the structure of an enterprise and to support reasoning about an enterprise, [7]. Our model of the VE is inspired by this work. However, we do not provide a formal specification of the VE.

Most of the recent agent models employ a BDI-based model [16]. We have not underlined the BDI aspect of our model in this paper. However, the VE agents' goals, activities/experiences and roles/capabilities in our model can be expressed in terms of beliefs, desires and intentions as well. Our agent architecture can be related functionally to those implemented, for example, in PRS [12], IRMA [4] or in GRATE [8]. The parts of the knowledge base presented in these architectures are mostly focused on the agent's own self rather than the knowledge about the other agents, the acquaintance or the cooperation model, [9]. Our agent model is designed such that it can be enhanced to include the cooperation model and the set of rules.

Fischer et. al., [5], describe the selection of partners in a VE as a process of matching VE goals (or subgoals) to partial processes within the different enterprises that represent the partners of the VE. The matching process does not explicity consider the competency and skills requirements of the potential partners. In [13], the VE announcement is a set of n-tuples which represent the requirements as attributes and a reserve price. These examples consider a single agent interaction protocol and thus, do not describe the details of the contents of the messages between the agents. In [13], they distinguish between the Market (VE Initiator) agent architecture and the Organisation (VE Partner) agent architecture. The Market Agent contains a goal descriptor and a VE selector while the Organisation Agent contains knowledge about the VE as well as individual knowledge. We use the same basic architecture for both the VE Initiator and VE Partner agents so that the VE Initiator can also be a VE Partner, i.e. it can initiate a VE, where it is a partner of that VE.

6 Conclusions and Discussion

In this paper, we have shown how an agent-based model of a VE can be used to support the different selection processes that are used in selecting the partners for a VE, where the partners of a VE are represented by agents. We do this by analysing the agent interaction protocols. We have shown how the models of both the VE and the agent itself fit well with the selection process, where the selection process takes into account the goals of the agents, their activities/experiences as well as their capabilities. We have also shown that the agent interaction protocols can be effectively adapted to the VE formation process.

The two cases revealed that matching the roles of a VE to agents is a multi-tiered process, where the requirements are structured into different categories and each of these categories are considered separately. Further, the selection process is made more stringent by adding a verification subprocess to the selection process. The verification subprocess takes into account the activity structure of an agent in addition to the goals and the requirements for the roles.

In the future, we plan to implement the ideas presented here using the AGORA multi-agent architecture, [10]. We also plan to extend the work on representing the experience of an agent and the verification of information during the selection process.

7 Acknowledgements

This work is partially supported by the Norwegian Research Foundation in the framework of the Information and Communication Technology (IKT-2010) program and the ADIS project. We would like to thank Rifaath Jaleel from BFS, Maldives and Edgar Karlsen from ODA, Norway for providing case studies.

References

1. Business and financial consulting group pvt. ltd. http://www.consultbfs.com/.
2. Organisation development alliance, as. http://www.oda.as/.
3. M. Barbuceanu and W. Lo. A multi-attribute utility theoretic negotiation architecture for electronic commerce. In Carles Sierra, Maria Gini, and Jeffrey S. Rosenschein, editors, *aa2000*, Barcelona, Catalonia, Spain, June 2000.
4. M. E. Bratman, D. J. Israel, and M. E. Pollack. Plans and resource-bounded practical reasoning. *Computational Intelligence*, 4:349–355, 1988.
5. K. Fischer, J. P. Muller, I. Heimig, and A. Scheer. Intelligent agents in virtual enterprises. In *Proc. of the First International Conference and Exhibition on The Practical Applications of Intelligent Agents and Multi-Agent Technology*, U.K., 1996.
6. M. S. Fox, M. Barbuceanu, and M. Gruninger. An organisation ontology for enterprise modelling: Preliminary concepts for linking structure and behaviour. *Computers in Industry*, 29:123–134, 1996.
7. M. Gruninger, K. Atefi, and M. S. Fox. Ontologies to support process integration in enterprise engineering. *Computational and Mathematical Organisation Theory*, 6(4):381–394, 2000.
8. N. R. Jennings. Specification and implementation of a belief-desire-joint-intention architecture for collaborative problem solving. *Intelligent and Cooperative Information Systems*, 2(3):289–318, 1993.
9. N. R. Jennings. *Cooperation in Industrial Multi-agent Systems*. World Scientific, 1994.
10. M. Matskin, O. J. Kirkeluten, S. B. Krossnes, and Ø. Sæle. Agora: An infrastructure for cooperative work support in multi-agent systems. In T. Wagner and O. Rana, editors, *Infrastructure for Agents, Multi-Agents, and Scalable Multi-Agent Systems, Lecture Notes in Computer Science,*, volume 1887. Springer Verlag, 2001.
11. R. H. Guttman A. G. Moukas and P. Maes. Agent-mediated electronic commerce: A survey. *Knowledge Engineering Review*, 13(3), 1998.
12. K. L. Myers. User guide for the procedural reasoning system. Technical report, Artificial Intelligence Center, SRI International, Menlo Park, CA, 1997.
13. E. Oliveira and A. P. Rocha. *European Perspectives on Agent Mediated Electronic Commerce*, chapter Agents' Advanced Features for Negotiation in Electronic Commerce and Virtual Organisation Formation Process. Springer Verlag, June 2000.
14. S. A. Petersen. Extended and virtual enterprises - a review of the concepts. Technical Report 2/02, Dept. of Computer and Information Sciences, Norwegian University of Science and Technology, Trondheim, Norway, 2002.
15. S. A. Petersen and M. Gruninger. An agent-based model to support the formation of virtual enterprises. In *International ICSC Symposium on Mobile Agents and Multi-agents in Virtual Organisations and E-Commerce (MAMA'2000)*, Woolongong, Australia, December 2000.
16. A. S. Rao and M. P. Georgeff. Modeling rational agents within a BDI architecture. In R. Fikes and E. Sandewall, editors, *Proceedings of Knowledge Representation and Reasoning (KR&R91)*, pages 473–484. Morgan Kaufmann Publishers: San Mateo, CA, 1991.
17. M. Uschold, M. King, S. Moralee, and Y. Zorgios. The enterprise ontology. *Knowledge Engineering Review, Special Issue on Putting Ontologies to Use*, 13, 1998.

Bibliography

Ambroszkiewicz, S., Cetnarowicz, K., and Radko, B. (1998). Enterprise Formation Mechanisms based on Mobile Agents. In Holsten, A. et. al., editor, *Proceedings of Workshop on Intelligent Agents in Information and Process Management, KI'98*. pp. 23–34.

Ávila, P., Putnik, G. D., and Cunha, M. M. (2002). Brokerage Function in Agile Virtual Enterprise Integration - A Literature Review. In Camarinha-Matos, L. M., editor, *Collaborative Business Ecosystems and Virtual Enterprises*, Kluwer Academic Publishers, pp. 65–72.

Barbuceanu, M. and Fox, M. S. (1994). The Information Agent: An infrastructure agent supporting collaborative enterprise architectures. In *Proceedings of the Third IEEE Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET-ICE 1994)*. Morgan Town, West Virginia, U. S. A.

Barbuceanu, M. and Lo, W. (2000). Integrating Individual, Organizational and Market Level Reasoning for Agent Coordination. In *ECAI-2000*. Berlin, Germany, pp. 343–347.

Bauer, B., Müller, J. P., and Odell, J. (2001). Agent UML: A Formalism for Specifying Multiagent Interaction. In Ciancarini and Wooldridge, M. J., editors, *Proceedings of Agent-oriented Software Engineering*, Springer-Verlag, pp. 91–103.

Benes, L. D. and Meyer, M. (2000). GOPAMAN: Multi-attribute Decision Making and Negotiation. Master's thesis, Norwegian University of Science and Technology.

Berners-Lee, T., Hendler, J., and Lassila, O. (2001). The Semantic Web. *Scientific American*, pp. 28–37.

Bernus, P. (1997). Busines Evolution and Enterprise Integration. In Kosanke, K. and Nell, J., editors, *Proceedings of International Conference on Enterprise Intergration Modelling, ICEIMT97*. Springer-Verlag, pp. 140–151.

Bernus, P. (1999). What, Why and How to Model in the Enterprise. In *Proceedings of IFIP International Enterprise Modelling Conference IEMC'99*. Verdal, Norway.

Bernus, P. and Baltrusch, R. (2002). Better Models for Agile Virtual Enterprises - The Enterprise and its Constituents as Hybrid Agents. In Karvonen, I. et.

al., editor, *Global Engineering and Manufacturing in Enterprise Networks GLOBEMEN*, Julkaisija Utgivare Publisher, Finland, pp. 91–109.

Bernus, P., Baltrusch, R., Vesterager, J., and Tølle, M. (2002). Fast Tracking ICT Infrastructure Requirements and Design, Based on Enterprise Reference Architecture and Matching Reference Models. In Camarinha-Matos, L. M., editor, *Collaborative Business Ecosystems and Virtual Enterprises*, Kluwer Academic Publishers, pp. 293–302.

Bernus, P., Bertok, P., and Nemes, L. (1997). Modelling Dynamic Management Features of Virtual Enterprises. In Plonka and Olling, G., editors, *Computer Applications in Production Engineering 97*, Chapman and Hall, London, pp. 643–655.

Bernus, P. and Nemes, L. (1999). Organizational Design: Dynamically Creating and Sustaining Integrated Virtual Enterprises. In Chen, H., Cheng, D., and Zhang, J., editors, *Proceedings of IFAC World Congress*. pp. 189–194.

Bernus, P. and Noran, O. (2002). Using the Globemen Reference Model for Virtual Enterprise Design in After Sales Service. In Karvonen, I. et. al., editor, *Global Engineering and Manufacturing in Enterprise Networks GLOBEMEN*, Julkaisija Utgivare Publisher, Finland, pp. 71–90.

Bernus, P. and Uppington, G. (1998). Co-ordination of Management Activities - Mapping Organizational Structure to the Decision Structure. In Conen, W. and Neumann, G., editors, *Coordination Technology for Collaborative Applications, organizations, Processes and Agents*, Springer-Verlag, pp. 25–37.

Bichler, M., Kaukal, M., and Segev, A. (1999). Multi-attribute Auctions for Electronic Procurement. In *proceedings of the First IBM IAC Workshop on Internet-based Negotiation Techniques*. Yorktown Heights, N.Y., U.S.A.

Boman, M., Bubenko Jr., J. A., Johannesson, P., and Wangler, B. (1997). *Conceptual Modelling*. Prentice Hall.

Bond, A. H. and Gasser, L. (1998). *Readings in Artificial Intelligence*. Morgan Kauffman, San Mateo, CA.

Bratman, M. E., Israel, D. J., and Pollack, M. E. (1988). Plans and Resource-bounded Practical Reasoning. *Computational Intelligence*, 4:349–355.

Byrne, J. A., Brandt, R., and Port, O. (1993). The Virtual Corporation. *Business Week*, 8:36–40.

CAGIS (2001). Cooperative Agents in the Global Information Space. URL `http://www.idi.ntnu.no/~cagis/`.

Camarinha-Matos, L. M. and Afsarmanesh, H. (1997). Virtual Enterprises: Life-cycle Supporting Tools and Technologies. In Molina, A., Sanchez, J., and Kusiak, A., editors, *Handbook of Life Cycle Engineering: Concepts, Tools and Techniques*, Chapman and Hall.

Camarinha-Matos, L. M. and Afsarmanesh, H. (2001). Virtual Enterprise Modelling and Support Infrastructures: Applying Multi-agent System Approaches. In Luck, M., Mařik, V., Stpankova, O., and Trappl, R., editors, *Multi-agent*

Systems and Applications, Springer-Verlag, Lecture Notes in Artificial Intelligence LNAI 2086.

Camarinha-Matos, L. M., Afsarmanesh, H., Garita, C., and Lima, C. (1998). Towards an Architecture for Virtual Enterprises. In *Proceedings of the Second IMACS International Multiconference on Computational Engineering in Systems Applications (CESA'98)*. Nabeul-Hammamet, Tunisia.

Chen, D., Vallespir, B., and Doumeingts, G. (2002). Developing an Unified Enterprise Modelling Language (EUML) - Requirements and Roadmap. In Camarinha-Matos, L. M., editor, *Collaborative Business Ecosystems and Virtual Enterprises*, Kluwer Academic Publishers, pp. 247–254.

Childe, S. J. (1998). The Extended Enterprise - a Concept of Co-operation. *International Journal of Production Planning and Control*, 9(3):320–327.

Clements, P. E., Papaioannou, T., and J, E. (1997). Aglets: Enabling the Virtual Enterprise. In Wright, D. et. al., editor, *Proceedings of Mesela '97 - First International Conference on Managing Enterprises - Stakeholders, Engineering, Logistics and Achievement*. p. 425.

Cohen, P. and Levesque, H. (1991). Teamwork. *Nous, Special issue on Cognitive Science and AI*, 25(4):487–512.

COVE (2003). COoperation infrastructure for Virtual Enterprises and electronic business. URL `http://www.uninova.pt/~cove/`.

DAML (2003). DARPA Agent Markup Language. URL `http://www.daml.org/`.

Davidow, W. H. and Malone, M. S. (1992). *The Virtual Corporation: Structuring and Revitalizing the Corporation for the 21st Century*. Harper Business.

Davis, R. and Smith, R. G. (1988). Negotiation as a Metaphor for Distributed Problem Solving. In Bond, A. H. and Gasser, L., editors, *Readings in Distributed Artificial Intelligence*, Morgan Kauffmann, pp. 333–356.

Dignum, F., Dunin-Kęplicz, B., and Verbrugge, R. (2000). Agent Theory for Team Formation by Dialogue. In Castelfranchi, C. and Lesperance, Y., editors, *Intelligent Agents VII, Agent Theories Architecture and Language (ATAL2000), LNAI 1986*. Springer-Verlag, pp. 150–166.

Dignum, V. and Dignum, F. (2002). Towards an Agent-based Infrastructure to Support Virtual Organizations. In Camarinha-Matos, L. M., editor, *Collaborative Business Ecosystems and Virtual Enterprises*, Kluwer Academic Publishers, pp. 363–370.

Esteva, M., Rodriguez, J. A., Sierra, C., Garcia, P., and Arcos, J. L. (2001). On the Formal Specifications of Electronic Institutions. In Dignum, F. and Sierra, C., editors, *Agent-mediated Electronic commerce (The European AgentLink Perspective)*, Springer-Verlag, LNAI 1991, pp. 126–147.

Fadel, F. G., Fox, M. S., and Gruninger, M. (1994). A Generic Enterprise Resource Ontology. In *Proceedings of the Third IEEE Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET-ICE 1994)*. Morgan Town, West Virginia, U. S. A.

Fensel, D., Van Harmelen, F., and Horrocks, I. (2003). OIL and OIL+DAML: Ontology Languages for the Semantic Web. In Davies, J., Fensel, D., and Van Harmelen, F., editors, *Towards the Semantic Web, Ontology-driven Knowledge Management*, John Wiley and Sons Ltd., pp. 11–31.

Field, S. and Hoffner, Y. (2002). In Search of the Right Partner. In Camarinha-Matos, L. M., editor, *Collaborative Business Ecosystems and Virtual Enterprises*, Kluwer Academic Publishers, pp. 55–62.

Fielding, R. T., Whitehead Jr., E. J., Anderson, K. M., Bolcer, G. A., Oreizy, P., and Taylor, R. N. (1998). Web-Based Development of Complex Information Products. *Communications of the ACM*, 41(8):84–92.

FIPA (2002). FIPA Agent Communication Language. URL `http://www.fipa.org/`.

Fischer, K., Müller, J., Hemmig, I., and Scheer, A.-W. (1996). Intelligent Agents in Virtual Enterprises. In *Proceedings of First International Conference and Exhibition on the Practical Applications of Intelligent Agents and Multi-Agent Technology (PAAM-96)*. London, U.K., pp. 205–204.

Fox, M. S., Barbuceanu, M., and Gruninger, M. (1996). An Organization Ontology for Enterprise Modelling: Preliminary Concepts for Linking Structure and Behaviour. *Computers in Industry*, 29:123–134.

Fox, M. S., Barbuceanu, M., Gruninger, M., and Lin, J. (1998a). An Organization Ontology for Enterprise Modelling. In Prietula, M., Carley, K., and Gasser, L., editors, *Simulating Organizations: Computational Models of Institutions and Groups*, AAAI/MIT Press, pp. 131–152.

Fox, M. S., Chionglo, J. F., and Barbuceanu, M. (1993a). The Integrated Supply Chain Management System. Technical report, Enterprise Integration Laboratory, University of Toronto.

Fox, M. S., Chionglo, J. F., and Fadel, F. G. (1993b). A Common Sense Model of the Enterprise. In *Proceedings of the Second Industrial Engineering Research Conference*. Norcross GA: Institute for Industrial Engineers, pp. 425–429.

Fox, M. S. and Gruninger, M. (1994). Ontologies for Enterprise Integration. In *Proceedings of the Second Conference on Cooperative Information Systems*. Toronto, Canada.

Fox, M. S. and Gruninger, M. (1998). Enterprise Modelling. *AI Magazine*, Fall:109–121.

Fox, T. L., Pedigo, R., and Remingon, W. S. (1998b). Building the Virtual Organization with Electronic Communication. *EM - Electronic Contracting. EM - Electronic Markets*, 8(3).

Franklin, S. and Graesser, A. (1996). Is it an Agent, or just a Program?: Taxonomy for Autonomous Agents. In *Proceedings of the Third International Workshop on Agent Theories, Architectures, and Languages*. Springer-Verlag.

Fuxman, A., Giorgini, P., Kolp, M., and Mylopoulos, J. (2001). Information Systems as Social Structures. In *Second International Conference on Formal*

Ontologies for Information Systems (FOIS-2001). Ogunquit, USA.

Garita, C. and Afsarmanesh, H. (2001). A Study of Information Management Approaches for Support Infrastructures. *COVE Newsletter*, (1).

Gastinger, A. and Szegheo, O. (2000). Enterprise Modelling Approaches. In Rolstadås, A. and Andersen, B., editors, *Enterprise Modelling: Improving Global Industrial Competitiveness*, Kluwer Academic Publishers, pp. 55–70.

Genesereth, M. R. (1997). An Agent-based Framework for Interoperability, Software Agents. In Bradshaw, J. M., editor, *Software Agents*, AAAI Press/The MIT Press, pp. 317–346.

Genesereth, M. R. and Fikes, R. (1992). Knowledge Interchange Format. Technical Report KSL-92-01, Knowledge Systems Laboratory, Stanford University.

Genesereth, M. R. and Ketchpel, S. P. (1994). Software Agents. *Communications of the ACM*, 37(7).

Gijsen, J., Szirbik, N., and Wagner, G. (2002). Agent Technologies for Virtual Enterprises in the One-of-a-Kind-Production Industry. *International Journal of Electronic Commerce*, 7(1):9–35.

GLOBEMAN 21 (1999). Globeman 21 Concepts. URL `http://ims.toyo-eng.co.jp/`.

GLOBEMEN (2002). Global Engineering and Manufacturing in Enterprise Networks. URL `http://globemen.vtt.fi`.

Gruber, T. R. (1993). A Translation Approach to Portable Ontology Specifications. *Knowledge Acquisition*, 5:199–220.

Gruninger, M. (2003). Enterprise Modelling. In Bernus, P., Nemes, L., and Schmidt, G., editors, *Handbook on Enterprise Architectures*, Springer-Verlag, pp. 515–541.

Gruninger, M., Atefi, K., and Fox, M. S. (2000). Ontologies to Support Process Integration in Enterprise Engineering. *Computational and Mathematical Organization Theory*, 6(4):381–394.

Gruninger, M. and Fox, M. S. (1994). An Activity Ontology for Enterprise Modelling. In *Submitted to the Workshop on Enabling Technologies - Infrastructures for Collaborative Enterprises*. West Virginia University, U. S. A.

Gruninger, M. and Fox, M. S. (1995). Methodology for the Design and Evaluation of Ontologies. In *Workshop on Basic Ontological Issues in Knowledge Sharing, IJCAI-95*. Montreal, Canada.

Guttman, R. H. and Maes, P. (1998). Cooperative vs. Competitive Multi-Agent Negotiations in Retail Electronic Commerce. In *Proceedings of the Second International Workshop on Cooperative Information Agents (CIA'98)*. Paris, France.

Harbilas, C., Dragios, N., and Karetsos, G. (2000). A Framework for Broker Assisted Virtual Enterprises. In Camarinha-Matos, L. M., Afsarmanesh, H., and Rabelo, R. J., editors, *E-Business and Virtual Enterprises - Managing Business-to-Business Cooperation*, Kluwer Academic Publishers, pp. 73–80.

Hattori, F., Ohguro, T., M., Y., Matsubara, S., and Yoshida, S. (1999). Socialware: Multi-agent Systems for Supporting Network Communities. *Communications of the ACM*, 42(3):55–61.

IFIP-IFAC Task Force (1998). GERAM: Generalised Enterprise Reference Architecture and Methodology. Technical Report Version 1.6.2.

IMS (2003). Intelligent Manufacturing Systems. URL `http://www.ims.org/`.

Jagdev, H. S. and Browne, J. (1998). The Extended Enterprise - A Context for Manufacturing. *International Journal of Production Planning and Control*, 9(3):216–229.

Jain, A. K., Aparicio IV, M., and Singh, M. P. (1999). Agents for Process Coherence in Virtual Enterprises. *Communications of the ACM*, 42(3):62–69.

Jennings, N. R. (1993a). Controlling Cooperative Problem Solving Using Joint Intentions. *Artificial Intelligence Magazine*, 14(4):79–80.

Jennings, N. R. (1993b). Specification and Implementation of a Belief-Desire-Joint-Intention Architecture for Collaborative Problem Solving. *Intelligent and Cooperative Information Systems*, 2(3):289–318.

Jennings, N. R. (1994). *Cooperation in Industrial Multi-agent Systems*. World Scientific.

Karvonen, I. et. al, editor (2001). *Global Engineering and Manufacturing in Enterprise Networks GLOBEMEN*. Julkaisija Utgivare Publisher, Finland.

Kazi, A. S. and Hannus, M. (2002). Virtual Enterprise Reference Architecture and Methodology. In *Proceedings of eWork and eBusiness in AEC, ECPPM 2002*. Slovenia.

Keeney, R. and Raiffa, H. (1976). *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. John Wiley and Sons.

Kendall, E. A. (1998). Agent Roles and Role Models: New Abstractions for Intelligent Agent System Analysis and Design. In Holsten, A. et. al., editor, *Proceedings of the Workshop on Intelligent Agents in Information and Process Management, KI'98*. pp. 35–46.

Kendall, E. A., Malkoun, M. T., and Jiang, C. H. (1996). A Methodology for Developing Agent-based Systems for Enterprise Integration. In Bernus, P. and Nemes, L., editors, *Modelling and Methodologies for Enterprise Integration*, Chapman and Hall, pp. 333–344.

Klein, M. (1996). Challenges and Directions for EI: A Distributed AI Perspective. In Bernus, P. and Nemes, L., editors, *Modelling and Methodologies for Enterprise Integration*, Chapman and Hall, pp. 319–332.

Labrou, Y. and Finin, T. (1998). Semantics and Conversations for an Agent Communication Language. In Huhns, M. N. and Singh, M. P., editors, *Readings in Agents*, Morgan Kaufmann, pp. 235–242.

Levitt, R. E., Jin, Y., Oralkan, G. A., Kunz, J. C., and Christiansen, T. R. (2001). Computational Enterprise Models: Towards Analysis Tools for Designing Organizations. In Olsen, G. M., Malone, T. W., and Smith, J. B., editors, *Coordination Theory and Collaboration Technology*, Lawrence Erlbaum Associates, Publishers, pp. 623–649.

Lillehagen, F., Dehli, E., and Fjeld, L. (2002). Utilising Active Knowledge Models in an Infrastructure for Virtual Enterprises. In Camarinha-Matos, L. M., editor, *Collaborative Business Ecosystems and Virtual Enterprises*, Kluwer Academic Publishers, pp. 353–360.

Lin, J., Fox, M. S., and Bilgic, T. (1996). A Requirement Ontology for Engineering Design. *Concurrent Engineering: Research and Applications*, 4(4):279–291.

Luck, M., McBurney, P., and Preist, C. (2003). *Agent Technology: Enabling Next Generation Computing, A Roadmap for Agent Based Computing*. Agent Link.

Matskin, M., Divitini, M., and Petersen, S. A. (1998). An Architecture for Multi-Agent Support in a Distributed Information Technology Application. In Holsten, A. et. al., editor, *Proceedings of the Workshop on Intelligent Agents in Information and Process Management, KI'98*. pp. 47–58.

Matskin, M., Kirkeluten, O. J., Krossnes, S. B., and Sæle, Ø. (2001). AGORA: An Infrastructure for Cooperative Work Support in Multi-Agent Systems. In Wagner, T. and Rana, O., editors, *Infrastructure for Agents, Multi-Agents, and Scalable Multi-Agent Systems, Lecture Notes in Computer Science*, Springer-Verlag, volume 1887, pp. 28–40.

Mayfield, J., Labrou, Y., and Finin, T. (1995). Evaluation of KQML as an Agent Communication Language. In Wooldridge, M. J., Müller, J., and Tambe, M., editors, *Intelligent Agents II, Proceedings of IJCAI-95 Workshop (ATAL)*. Springer-Verlag, Montreal, Canada, pp. 347–360.

Mejía, R. and Molina, A. (2000). Virtual Enterprise Broker: Processes, Methods and Tools. In Camarinha-Matos, L. M., Afsarmanesh, H., and Rabelo, R. J., editors, *E-Business and Virtual Enterprises - Managing Business-to-Business Cooperation*, Kluwer Academic Publishers, pp. 81–90.

METIS (2003). METIS GEM Generic Enterprise Modelling Template. URL `http://www.metis.no/`.

Moulin, B. and Chaib-draa, B. (1996). An Overview of Distributed Artificial Intelligence. In O'Hare, G. M. P. and Jennings, N. R., editors, *Modelling and Methodologies for Enterprise Integration*, John Wiley and Sons, pp. 3–56.

Mowshowitz, A. (1999). Virtual Organization. *Communications of the ACM*, 40(9):30–37.

Myers, K. L. (1997). User Guide for the Procedural Reasoning System. Technical report, Artificial Intelligence Center, SRI International, Menlo Park, CA.

Nwana, H. S. (1996). Software Agents: An Overview. *The Knowledge Engineering Review*, 11.

Olegario, C. C. (2001). A Partial Enterprise Model for the Management and Control in an Extended Enterprise Scenario. Master's thesis, School of Computing and Information Technology, Griffiths University, Brisbane, Australia.

Oliveira, E. and Rocha, A. P. (2000). Agents' Advanced Features for Negotiation in Electronic Commerce and Virtual Organization Formation Process. In *European Perspectives on Agent Mediated Electronic Commerce*, Springer-Verlag.

Oliviera, E., Fonseca, J., and Steiger-Garção, A. (1999). Multi-criteria Negotiation on Multi-agent Systems. In *Proceedings of International Central and Eastern European Conference on MultiAgent Systems, CEEMAS 1999*. St. Petersburg, Russia.

Petersen, S. A. (2003). Using Competency Questions to Evaluate an Agent-based Model for Virtual Enterprises. In Camarinha-Matos, L. M. and Afsarmanesh, H., editors, *Process and Foundations for Virtual Enterprises, Proceedings of IFIP Working Conference on Virtual Enterprises, PRO-VE03*. Kluwer Academic Publishers.

Petersen, S. A., Divitini, M., and Matskin, M. (1999). An Agent-based Approach to Modelling Virtual Enterprises. In *Proceedings of IFIP International Enterprise Modelling Conference IEMC'99*. Verdal, Norway.

Petersen, S. A., Rao, J., and Tveit, A. (2002). Virtual Enterprises: Challenges in Selecting and Integrating Computational and Human Resources. In Burg, B., Dale, J., Finin, T., Nakashima, H., Padgham, L., Sierra, C., and Willmott, S., editors, *Agentcities: Challenges in Open Agent Environments*, Springer-Verlag, (in print process), LNCS.

Petersen, S. A. and Szegheo, O. (2000). A Model-based Methodology for Extended Enterprise Engineering. In Ghodous, P. and Vandorpe, D., editors, *Advances in Concurrent Engineering, Proceedings of CE2000*. Lyon, France, pp. 40–49.

Pynadath, D., Tambe, M., Arens, Y., and Chalupsky, H., et. al. (2000). Electric Elves: Immersing an Agent Organization in a Human Organization. In *Proceedings of the AAAI Fall Symposium on Socially Intelligent Agents — the human in the loop*.

Rabelo, R. J., Camarinha-Matos, L. M., and Vallejos, R. V. (2000). Agent-based Brokerage for Virtual Enterprise Creation in the Moulds Industry. In Camarinha-Matos, L. M., Afsarmanesh, H., and Rabelo, R. J., editors, *E-Business and Virtual Enterprises - Managing Business-to-Business Cooperation*, Kluwer Academic Publishers, pp. 281–290.

Rao, A. S. and Georgeff, M. P. (1991). Modelling Rational Agents within a BDI-architecture. In Fikes, R. and Sandewall, E., editors, *Proceedings of Knowledge Representation and Reasoning (KR&R91)*. Morgan Kaufmann Publishers: San Mateo, CA, pp. 473–484.

Rao, A. S. and Georgeff, M. P. (1998). Modelling Rational Agents within a BDI-Architecture. In Huhns, M. N. and Singh, M. P., editors, *Readings in Agents*, Morgan Kaufmann, pp. 317–328.

Rao, J. and Petersen, S. A. (2003). Implementing Virtual Enterprises using AGORA Multi-agent System. In Eder, J. and Welzer, T., editors, *Informa-*

tion Systems for a Connected Society, CAiSE'03 Forum. Klagenfurt/Velden, Austria, pp. 193–196.

Rocha, A. P. and Oliveira, E. (1999). Electronic Commerce: A Technological Perspective. *The Future of Internet*.

Rocha, A. P. and Oliveira, E. (2001). Electronic Institutions as a Framework for Agents' Negotiation and Mutual Commitment. In P.Brazdil and A.Jorge, editors, *Progress in Artificial Intelligence (Proceedings of Tenth EPIA), LNAI 2258*. Springer-Verlag, pp. 232–245.

Ruß, C. and Vierke, G. (1998). Agent-based Configuration of Virtual Enterprises. In Holsten, A. et. al., editor, *Proceedings of the Workshop on Intelligent Agents in Information and Process Management, KI'98*. pp. 123–127.

Sæle, Ø., Kirkeluten, O. J., and Krossnes, S. B. (1999). Shells for Multi Agent Applications. Master's thesis, Norwegian University of Science and Technology.

Sandholm, T. W. and Lesser, V. (1997). Coalitions among Computationally Bounded Agents. *Artificial Intelligenc, Special issue on Economic Principles of Multiagent Systems*, 94(1):99–137.

Shen, W. and Norrie, D. H. (1999). Agent-based Systems for Intelligent Manufacturing: A State-of-the-art Survey. *Knowledge and Information Systems*, 1(2):129–156.

Sølvberg, A. and Brasethvik, T. (1997). The Referent Model Language. Technical report, Norwegian University of Science and Technology, Trondheim, Norway.

Sørensen, C. (2002). This is Not an Article - Just Some Food for Thoughts on How to Write One. Technical Report 121, London School of Economics and Political Science.

Swaminathan, J., Smith, S., and Sadeh, N. (1998). Modelling Supply Chain Dynamics: A Multiagent Approach. *Decision Sciences*.

Sycara, K. and Giampapa, J. (2000). MURI: Integrating Intelligent Agents into Human Teams. URL `http://www-2.cs.cmu.edu/~softagents/presentations/`.

Sycara, K. and Giampapa, J. (2002). Team-oriented Agent Coordination in the RETSINA Multi-agent System. In *Proceedings of the Workshop on Teamwork and Coalition Formation, at AAMAS2002*. Bologne, Italy.

Sycara, K., Lu, J., Klusch, M., and Widoff, S. (1999). Matchmaking Among Heterogeneous Agents on the Internet. In *Proceedings of the 1999 AAAI Spring Symposium on Intelligent Agents in Cyberspace*.

Sycara, K., Widoff, M., Klusch, M., and Lu, J. (2002). LARKS: Dynamic Matchmaking among Heterogeneous Software Agents in Cyberspace. *Autonomous Agents and Multi-agent Systems*, 5(2):173–203.

Szegheo, O. (1999). Investigating the Extended Enterprise and the Virtual Enterprise. In *Proceeding of International Conference on Industrial Engineering and Production Management IEPM'99 (Book 2)*. Glasgow, U.K., pp. 477–485.

Szegheo, O. and Petersen, S. A. (1999). Extended Enterprise Engineering - A Model-based Framework. In Chawdry, P. K., Ghodous, P., and Vandorpe, D., editors, *Advances in Concurrent Engineering, Proceedings of CE99*. Bath, U.K., pp. 3–10.

Szegheo, O. and Petersen, S. A. (2000a). Extended Enterprise Engineering - A Model-based Framework. *Concurrent Engineering Research and Applications*, 8(1).

Szegheo, O. and Petersen, S. A. (2000b). Modelling of the Extended Enterprise. In Rolstadås, A. and Andersen, B., editors, *Enterprise Modelling: Improving Global Industrial Competitiveness*, Kluwer Academic Publishers, pp. 231–246.

Szirbik, N. B. (2001). How Third Trusted Parties can support Negotiations in Mobile-Agent Systems for Virtual Enterprises. In Wagner, G., Karlapalem, K., Lesperance, Y., and Yu, E. S., editors, *Proceedings of the Third International Workshop on Agent-Oriented Informations Systems (AOIS2001)*. iCue Publishing.

Szirbik, N. B., Hammer, D. K., Goosenaerts, J. B. M., and Aerts, A. (1999). Mobile Agent Support for Tracking Products in Virtual Enterprises. In *Workshop Notes, ACM, AGENT'99*. Seattle.

Tambe, M. (1997). Towards Flexible Teamwork. *Artificial Intelligence*, 7:83–124.

Tambe, M., Pynadath, D., and Chauvat, N. (2000). Building Dynamic Agent Organizations in Cyberspace. *IEEE Internet Computing*, 4(2):65–73.

Tata, S. and Boughzala, I. (2003). Modelling Contribution for Virtual Enterprise Support. In *Proceedings of the Twelfth IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET-ICE 2003)*. Linz, Austria.

Tavetar, K. and Wagner, G. (2000). Combining AOR Diagrams and Ross Business Rules Diagrams for Enterprise Modelling. In *Proceedings of the Second International Workshop on Agent-Oriented Informations Systems (AOIS2000)*. Stockholm, Sweden.

Tham, D., Fox, M. S., and Gruninger, M. (1994). A Cost Ontology for Enterprise Modelling. In *Proceedings of the Third IEEE Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET-ICE 1994)*. Morgan Town, West Virginia, U. S. A.

Tidhar, G., Rao, A. S., Ljungberg, M., Kinny, D., and Sonenberg, E. A. (1992). Skills and Capabilities in Real-Time Team Formation. Technical Report 27, Australian Artificial Intelligence Institute.

Tidhar, G., Sonenberg, E. A., and Rao, A. S. (1998). On Team Knowledge and Common Knowledge. In *Proceedings of Third International Conference on Multiagent Systems (ICMAS-98)*. Paris, France, pp. 301–308.

Tølle, M., Bernus, P., and Vesterager, J. (2002). Reference Models for Virtual Enterprises. In Camarinha-Matos, L. M., editor, *Collaborative Business Ecosystems and Virtual Enterprises*, Kluwer Academic Publishers, pp. 3–10.

Tølle, M. and Vesterager, J. (2002). VEM: Virtual Enterprise Methodology. In Karvonen, I. et. al., editor, *Global Engineering and Manufacturing in Enterprise Networks GLOBEMEN*, Julkaisija Utgivare Publisher, Finland, pp. 53–70.

Tølle, M. et. al. (2003). Virtual Enterprise Reference Architecture and Methodology. Technical report, Globemen WP4 deliverable, D41 and D43.

UML Resource Centre (2003). URL `http://www.rational.com/uml/`.

Uschold, M., King, M., Moralee, S., and Zorgios, Y. (1998). The Enterprise Ontology. *Knowledge Engineering Review, Special Issue on Putting Ontologies to Use*, 13.

Vázquez-Salceda, J. and Dignum, F. (2003). Modelling Electronic Organizations. In Mařík, V., Müller, J. P., and Pěchouček, M., editors, *Multi-Agent Systems and Applications III, Third International Central and Eastern European Conference on MultiAgent Systems, CEEMAS 2003, Prague*, Springer-Verlag.

Venkatraman, N. and Henderson, J. (1998). Real Strategies for Virtual Organizing. *Sloan Management Review*, 40(1):33–48.

Vernadat, F. B. (1996). *Enterprise Modelling and Integration Principles and Applications*. Chapman and Hall.

Vesterager, J., Bernus, P., Pedersen, J. D., and Tølle, M. (2001). The What and Why of a Virtual Enterprise Reference Architecture. In *Proceedings of eWork and eBusiness 2001 Conference*. Venice, Italy.

Vesterager, J., Larsen, L. B., and Gobbi, C. (1999). Architecture and Methodology for Creating Virtual Enterprises - Results from Globeman 21. Presented at the IMS Globeman 21 Open Day, Time24, Tokyo, Japan.

Vesterager, J., Tølle, M., and Bernus, P. (2002). VERA: Virtual Enterprise Reference Architecture. In Karvonen, I. et. al., editor, *Global Engineering and Manufacturing in Enterprise Networks GLOBEMEN*, Julkaisija Utgivare Publisher, Finland, pp. 39–51.

VOSTER (2003). Virtual Organizations Cluster. URL `http://cic.vtt.fi/projects/voster/public.html`.

Wagner, G. (2000). Agent-oriented Analysis and Design of Organizational Information Systems. In *Proceedings of Fourth IEEE International Baltic Workshop on Database and Information Systems*. Vilnius, Lithuania.

White, J. E. (1997). Mobile Agents. In Bradshaw, J. M., editor, *Software Agents*, AAAI Press/The MIT Press, pp. 437–472.

Wooldridge, M. J. (2002). *An Introduction to Multi-agent Systems*. John Wiley and Sons.

Wooldridge, M. J. and Jennings, N. R. (1995). Intelligent Agents: Theory and Practice. *Knowledge Engineering Review*, 10(2):115–152.

Wooldridge, M. J., Jennings, N. R., and Kinny, D. (2000). The GAIA Methodology for Agent-Oriented Analysis and Design. *Autonomous Agents and Multi-Agent Systems*, 3(3):285–312.

Yin, Robert, K. (1994). *Case Study Research Design and Methods*, volume 5 of *Applied Social Research Methods Series*. SAGE Publications.

Yu, E. S. (2001). Agent Orientation as a Modelling Paradigm. *Wirtschaftsinformatik*, 43(2):123–132.

Yu, E. S. and Mylopoulos, J. (1993). An Actor Dependency Model of Organizational Work - With Application to Business Process Reengineering. In Kaplan, S., editor, *Conference on Organizational Computing Systems COOC'93*. Milpitas, California, USA, pp. 258–268.

Zweger, A., Tølle, M., and Vesterager, J. (2002). VERAM: Virtual Enterprise Reference Architecture and Methodology. In Karvonen, I. et. al., editor, *Global Engineering and Manufacturing in Enterprise Networks GLOBEMEN*, Julkaisija Utgivare Publisher, Finland, pp. 17–38.

Part VI

APPENDICES

Appendix A

Modelling Language Definition

A.1 Graphical Notation

The graphical notation used for modelling the VE has been developed for the work presented in this thesis. The following notations and ideas from other modelling languages have been used:

- Ideas for the most generalized entity and attributes have been borrowed from the Referent Modelling Language (RML), [Sølvberg and Brasethvik, 1997].
- Ideas for the cardinality and mapping constraints have been borrowed from the conceptual modelling language presented in [Boman et al., 1997].

Figure A.1 shows the type hierarchy and the graphical notation for the entities in the model. The basic entity, shown as a shaded rectangle, is a set. Some entities are composite entities, which are entities that can be decomposed into sub-entities. Composite entities are shown as a shaded rectangle with a relationship to itself. Each entity has a set of attributes that describes its properties. e.g. the name of the entity. The attributes for each entity are represented as a diamond.

The relationship "subclass_of" is used to indicate specialization, e.g. a role is a subtype of an entity. Different types of entities have been used to represent each entity in the enterprise:

Goal: a composite entity, shown as a rectangle with rounded corners.

Activity: a composite entity, shown as a rectangle.

Role: shown as an ellipse.

Requirements: shown as a 3-D rectangle.

Agent: shown as a simple figure of a man.

The entities in the model are related by relationships, some of which are derived. A derived relationship is established between two entities by applying some rule. The graphical notation for the relationships to depict cardinality and the mapping constraints are shown in Figure A.2. The cardinality of a relationship can indicate that an

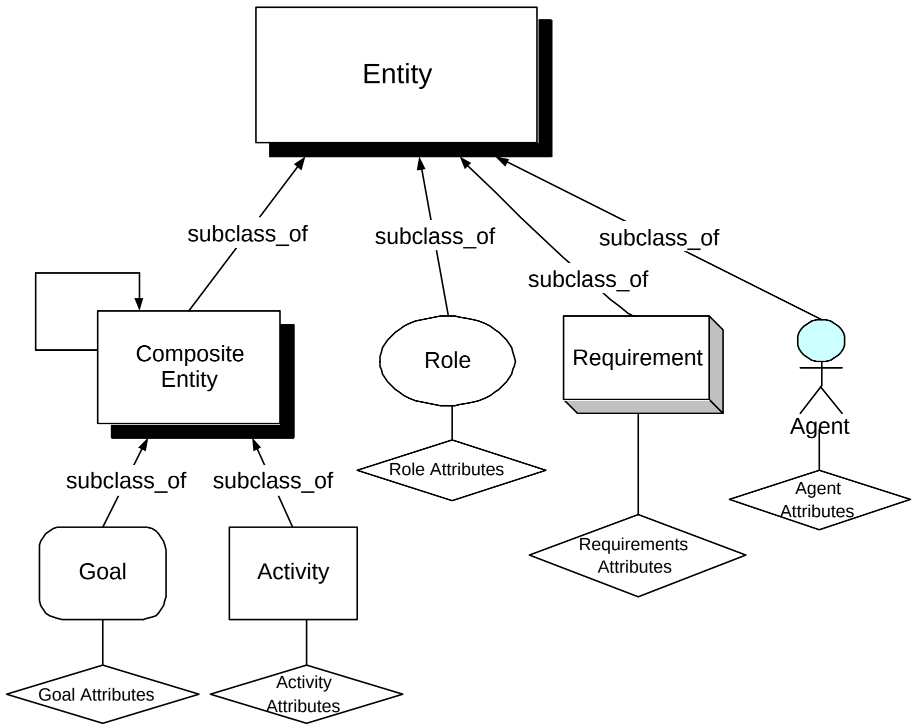

Figure A.1: Type Hierarchy and Graphical Notation for Entities

entity can be related to an unspecified number of entities, where no number is shown on the relationship, or to a specified number of entities, where a number is shown on the relationship.

A.2 Descriptive Language

The entities in the model are described using First Order Predicate Logic. We have used the following convention to represent the different kinds of predicates:

- An entity type and its attributes:
  - Entity_Type([]).
  - e.g. Goal(goal_name, product_area, deadline, max_cost).
- An attribute of an entity, where the entity goal1 has the name x.
  - %attribute(entity, attribute_value).
  - e.g. %goal_name(goal1, x).
- Relationships between two entities, where entity1 is the domain and entity2 is the range of the relationship, i.e. the relationship is in the direction from entity1 to entity2.

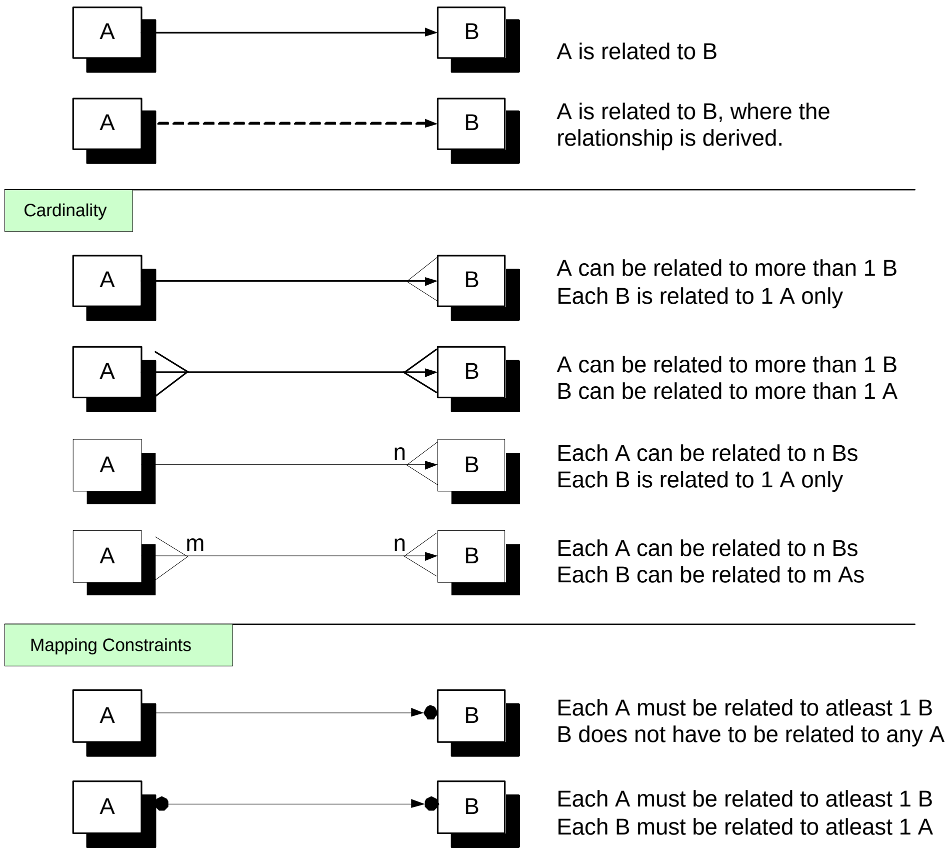

Figure A.2: Graphical Notation for Relationships

- relationship(entity1, entity2).
- e.g. achieved_by(goal1, activity1).

- Derived relationships between two entities, which is a relationship established by applying some rules on the model. entity1 is the domain and entity2 is the range of the relationship.
  - _derived_relationship(entity1, entity2).
  - e.g. _is_assigned(agent1, goal1).

- Structure of an entity, where entity2 is a sub-entity of entity1, e.g. in the goal or activity structure.
  - *structure_relationship(entity1, entity2).
  - e.g. *is_subgoal(goal1, goal2).

Appendix B

Model of the VE

This chapter provides the definition of the model of the VE. First, the metamodel for the complete VE is described and then each entity is described separately. Finally, some examples of how the model can be used by applying rules is shown.

B.1 Metamodel of a VE

Using the graphical notation described in Appendix A, the metamodel of the VE can be described as shown in Figure B.1. A VE has a set of goals that are achieved by performing a set of activities. These activities are performed by roles which are filled by agents that meet the requirements for the roles. The cardinality of the relationships indicate the following:

- Each goal may be achieved by one or many activities.
- Each activity may achieve one or many goals.
- Each activity may be performed by one or many roles.
- Each role may perform one activity only.
- Each role may be filled by one or many agents.
- Each agent may fill one or many roles.
- Each role may require one or many requirements.
- Each requirements may be required by one or many roles.

Figure B.1 shows only the cardinality of the relationships. For simplicity, the complete set of notations for the attributes and the mapping constraints for the relationships between the entities have not been included. The mapping constraints of the requirements may change from the time a VE is defined to when it is completed. For example, when a VE is defined, there are no agents filling the roles of the VE. This is discussed in the following subsections.

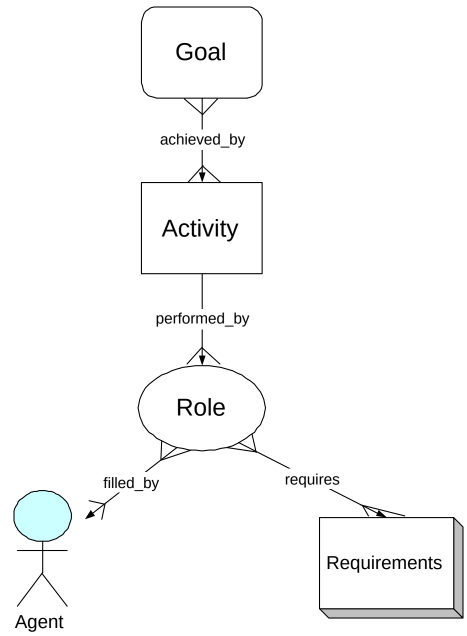

Figure B.1: Metamodel Overview (showing Cardinality)

B.1.1 VE Definition

When a VE is announced, we assume we have all the information that is required to form the VE by selecting the partners of a VE. This can be done by defining the VE by using our model. The model of the VE at this stage consists of the entities and relationships shown in Figure B.2. At this stage, the goals of the VE, the activities that must be performed to achieve the goals, the roles that are required to perform these activities and the requirements of the agents that will fill these roles, such as the agent's skills and availability, must be available. We can define the information that must be available at this point by using the mapping constraints for the relationships in the model, which are explained below:

- Each goal must be related to (be achieved_by) atleast one activity.
- Each activity must be related to (achieve) atleast one goal.
- Each activity must be related to (be performed_by) atleast one role.
- Each role must be related to (perform) atleast one activity.
- Each role must be related to (require) atleast one requirement.
- Each requirement must be related to (required by) atleast one role.
- There may be roles that are not related to (not filled_by) any agents.
- There may be agents that are not related to (fill) any roles.

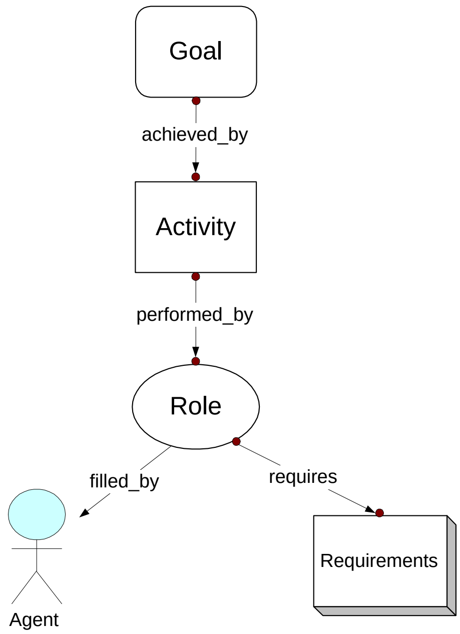

Figure B.2: Metamodel when VE is Defined (showing Mapping Constraints)

B.1.2 VE Formation Completed

The VE formation process is completed when all the roles of the VE are filled by agents. When the VE formation process is completed, all the relationships must be as shown in Figure B.3.

- Each role must be related to (filled_by) atleast one agent.
- Each agent must be related to (fills) atleast one role.

In addition, there are some derived relationships, (represented by the broken lines), where agents are assigned goals for them to work towards achieving and agents are assigned to performing activities. Some matching rules are applied to match agents to the requirements of the rules. When an agent is matched to a role and fills a role, the agents is assigned to the activity that the role performs. Similarly, the agent is assigned the goal(s) that activity (or activities) will achieve. (From the agent's perspective, its list of goals are incremented by another goal.)

- Each agent must be related to (is_assigned) atleast one goal.
- Each goal must be related to (assigned) atleast one agent.
- Each agent must be related to (assigned_to) atleast one activity.
- Each activity must be related to (assigned) to atleast one agent.
- Each agent must be related to (meets) atleast one requirement.
- Each requirement must be related to (met by) atleast one agent.

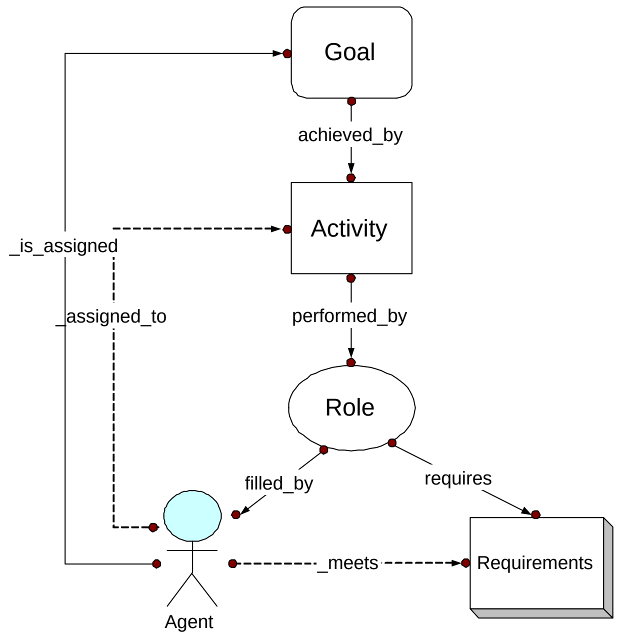

Figure B.3: Metamodel after VE is Formed (showing Mapping Constraints)

B.2 Entities in a VE

The entities in a VE, (goal, activity, role, requirements and agents), are described in this section. For each entity, the definition, a figure of the metamodel, the attributes and the relationships with the other entities in the model are described.

B.2.1 Goal

Definition

A **goal** can be considered from several points of view. e.g. strategic goal, [Uschold et al., 1998], and a product-oriented-view of goal, [Oliveira and Rocha, 2000] and [Fischer et al., 1996]. Here, we have considered the product-oriented view of a goal and describe a goal or a subgoal using a set of attributes that describe a product and the time and cost constraints it must be delivered within.

The metamodel for the entity goal is shown in Figure B.4.

Graphical Notation

The graphical notation for the entity goal is a rectangle with rounded corners.

Structure

A goal is a composite entity, which is shown by the relationship from the goal pointing to itself. A composite goal consists of one or more subgoals. Thus:

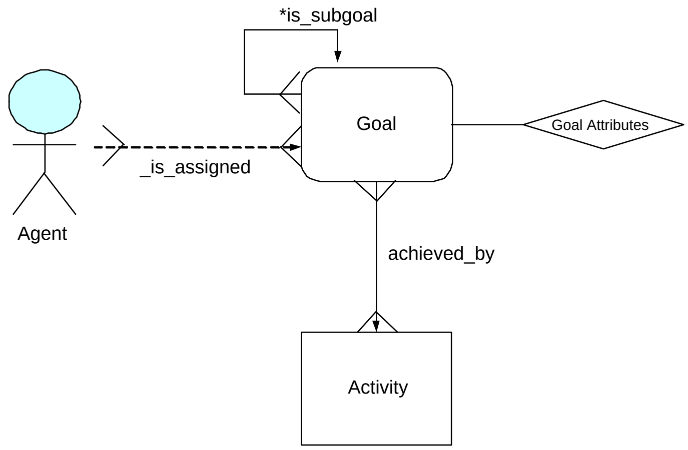

Figure B.4: Metamodel of Goal

- `*is_subgoal(goal1, goal2).`
  - where goal2 is a subgoal of goal1.

If the above clause does not return a true value for any value of goal1, then goal1 is an atomic goal, i.e. it does not have any subgoals.

Attributes

The attributes of a goal describe it in terms of the area of work, when it has to be achieved and the cost constraints. They are:

- name: the name of the goal, (e.g. goal1).
- product_area: the area that the VE intends to work on, (e.g. Webpage).
- deadline: the final date the VE must deliver to its customer, (e.g. 31.07.2003).
- max_cost: the maximum amount of money that the customer is willing to pay the VE or that the VE can afford to spend on achieving the goal, (e.g. 50,000).

The attributes of a goal are represented as a predicate as follows:

```
Goal(name, product_area, deadline, max_cost).
```

Relationships

A goal is related to the other entities in the model as follows:

- `achieved_by(goal, activity).`
  - A goal is achieved by performing some activity.
- `_is_assigned(agent, goal).`
  - An agent is assigned a goal.

B.2.2 Activity

Definition

An **activity** is usually performed by transforming its inputs into outputs, (within certain constraints such as time and costs), e.g. [Fox et al., 1993b]. The functionality of any enterprise concerns with things to be done; these are referred to as activities, processes, tasks or functions, (see [Vernadat, 1996] for an overview). In our model, an activity in a VE is an action or a set of actions that must be taken to achieve the goals of the VE. An activity is distinguished from an action in the fact that it has time and cost constraints, while an action does not, [Wagner, 2000]. We use the term activity to indicate a function in a VE that spans from a lower level activity to a higher level business process.

The metamodel for the entity activity is shown in Figure B.5.

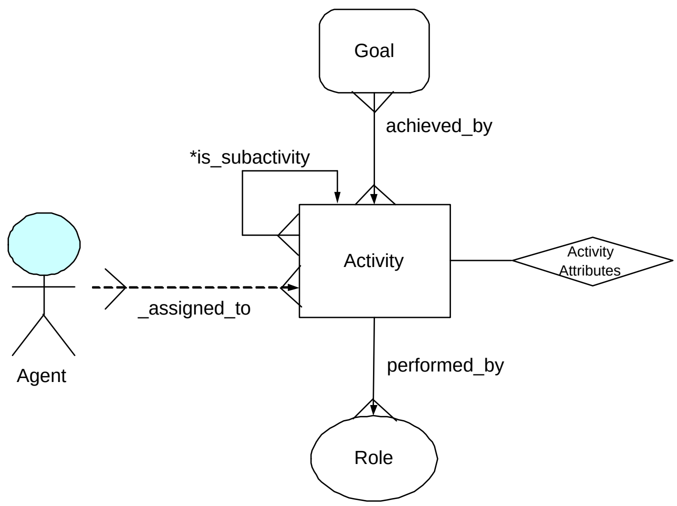

Figure B.5: Metamodel of Activity

Graphical Notation

The graphical notation for the entity activity is a rectangle.

Structure

An activity is a composite entity, which is shown by the relationship from the activity pointing to itself. A composite activity consists of one or more subactivities.

- `*is_subactivity(activity1, activity2).`

  - where activity2 is a subactivity of activity1.

If the above clause does not return a true value for any value of activity1, then activity1 is an atomic activity, i.e. it does not have any subactivities.

Attributes

The attributes of an activity represent what it is and its constraints and they are:

- name: the name of the activity, (e.g. activity1).
- start_date: the date the activity should be started, (e.g. 30.06.2003).
- completion_date: the last date the activity should be completed, (e.g. 31.07.2003).
- input: an input of an activity.
- output: an output of an activity.
- cost: the cost associated in performing an activity, (e.g. 20,000).
- state: the state of an activity, (e.g. ongoing, completed, enabled, suspended, cannot_be_performed).

The attributes of an activity are represented as a predicate as follows:

```
Activity(name, start_date, completion_date, input,
   output, cost, state).
```

Relationships

An activity is related to the other entities in the model as follows:

- `achieved_by(goal, activity).`
  - A goal is achieved by performing some activity.
- `performed_by(activity, role).`
  - An activity is performed by a role.
- `_assigned_to(agent, activity).`
  - An agent is assigned to an activity.

B.2.3 Role

Definition

A **role** in an enterprise is usually associated with some activity or a function in an enterprise, [Tølle, M. et. al., 2003]. In this model, a role performs an activity or a part of an activity. It is an abstract entity to indicate the role played by an agent within the context of a specific activity in performing that activity.

The metamodel for the entity role is shown in Figure B.6.

Graphical Notation

The graphical notation for the entity role is an ellipse.

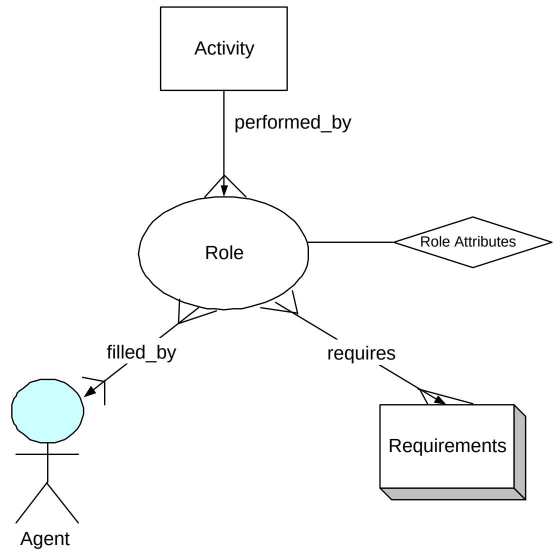

Figure B.6: Metamodel of Role

Attributes

The attributes of a role are:

- name: the name of the role, (e.g. Webpage_designer).

The attributes of a role are represented as a predicate as follows:

```
Role(name).
```

Relationships

A role is related to the other entities in the model as follows:

- `performed_by(activity, role).`
  - An activity is performed by a role.
- `filled_by(role, agent).`
  - A role is filled by an agent.
- `requires(role, requirements).`
  - A role requires requirements.

B.2.4 Requirements

The entity **requirements** in this model describes the requirements that an agent must meet to fill a role in a VE. A role has requirements (e.g. skills requirements or availability requirements) which are described as a set of attributes.

Definition

The metamodel for the entity requirements is shown in Figure B.7.

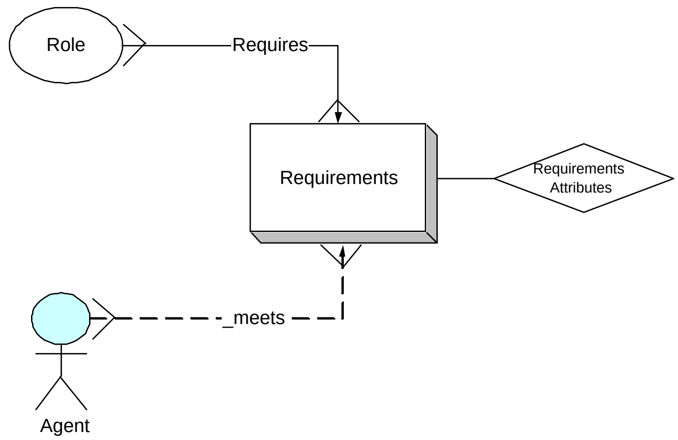

Figure B.7: Metamodel of Requirements

Graphical Notation

The graphical notation for the entity requirements is a 3-D rectangle.

Attributes

The attributes of requirements represent the skills and other information that are required by the VE and the constraints of these requirements. The attributes are:

- skills: the set of skills required for a role, (e.g. [A, B, C]).
- availability: the time period an agent must be available to fill a role, (e.g. a start date and an end date).
- cost: the max cost that can be paid to an agent to fill a role, (e.g. 20,000).
- level_of_performance: the required performance level of an agent to fill a role, (e.g. a number in the range 1 to 10).

Each attribute of requirements can be a list of attributes and are represented as a predicate as follows:

```
Requirements(skills, availability, cost,
   level_of_performance).
```

Relationships

The entity requirements is related to the other entities in the model as follows:

- `meets(agent, requirements).`

  - An agent meets some requirements.

- `requires(role, requirements).`

  - A roles requires some requirements.

B.2.5 Agent

Definition

In this model, an agent represents the partners of a VE and a partner's interests (such as the partner's goals and skills and competencies) during the formation of a VE.

The metamodel for the entity agent is shown in Figure B.8.

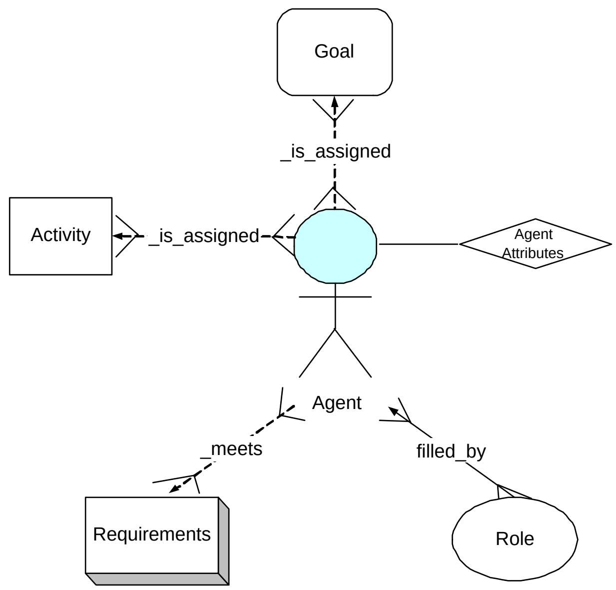

Figure B.8: Metamodel of Agent

Graphical Notation

The graphical notation for the entity agent is a simple figure of a man.

Attributes

The attributes of an agent are:

- name: the name of the agent, (e.g. agent1).

- address: the internet address of the agent.
- goals: the set of goals of the agent, (e.g. list of goals such as design_web_page).
- skills: the set of skills of the agent, (e.g. a list of skills such as java, xml, html).
- availability: the time(s) when an agent is available to fill a particular role, (e.g. a start date and an end date).
- cost: the amount that an agent will charge (per hour) to do some work, (e.g. 20,000).
- level_of_performance: a rating to indicate how good an agent is at doing something, (e.g. a number in the range 1 to 10).

The attributes of an agent are represented as a predicate as follows:

```
Agent(name, address, goals, skills, availability, cost,
   level_of_performance).
```

Relationships

An agent is related to the other entities in the model as follows:

- `filled_by(role, agent).`

  - A role is filled by an agent.
- `meets(agent, requirements).`

  - An agent meets some requirements.
- `_assigned_to(agent, activity).`

  - An agent is assigned to an activity.
- `_is_assigned(agent, goal).`

  - An agent is assigned a goal.

B.3 Using the Model

The metamodel described above provides the basic building blocks for a model. Using these basic entity and relationship types, it will be possible to use this model to establish other relationships or associations among the entities. This can be done by applying rules to the model. Rules can be defined to check a relationship in the model or to create a new one (derived relationship).

To provide a complete set of rules for the VE will be an impossible task. The set of rules will depend on the requirements for the model, i.e. how the model will be used. For our work, the model will be used mostly during the formation of the VE. In the following subsections, we describe some example of how the model can be used. We have used Prolog-like notation to describe the rules.

B.3.1 Assigning Agents to Activities

Assigning agents to activities can be considered as matching the requirements for the role that performs the activity to the capabilities of the agents based on the information contained in the bid proposed by the agent. The following set of rules can be used to assign an agent to perform an activity:

```
_meets(agent1, requirements1) :-
   match(agent1, requirements1).

_performs(agent1, role1, activity1) :-
   filled_by(role1, agent1),
   performed_by(role1, activity1).
_performs(agent1, role1, activity1) :-
   _meets(agent1, requirements1),
   requires(role1, requirements1).

_assigned_to(agent1, activity1):-
   _performs(agent1, role1, activity1).
```

The rule "_performs(agent1, role1, activity1)." will find the agent that meets the requirements for the role, unless an agents is already assigned to the activity. The rule "match(agent1, requirements1)." will match the attributes of an agent with the requirements for the role and can be defined using the desired matching constraints.

B.3.2 Identifying Teams

One of the main aspects of a VE is team formation. In our model, we consider a team as a set of agents that share one or more goals. All the agents in a VE share the high-level VE goal and two agents that work on the same activity also belong to the same team as shown in Figure B.9. Thus, a VE can contain several sub-teams. The following rule can be used to identify the agents that belong to a team.

```
_member(team1, agent1, agent2) :-
    _performs(agent1, role1, activity),
    _performs(agent2, role2, activity),
```

B.3.3 Dependencies among Activities

There is a need to be able to identify the dependencies between activities in order to be able to know, for example, when to negotiate and to identify constraints in allocating agents to activities. Activities may depend on each other for several reasons as stated below:

- Start or completion dates which will determine the sequence of the activities.
- Input and output where the output of one activity may be the input for another activity.

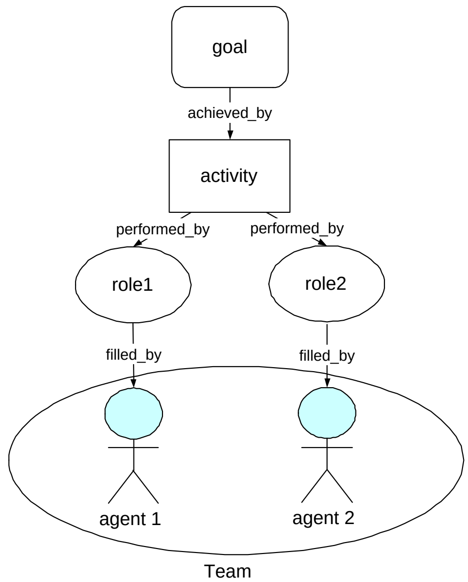

Figure B.9: Agents in the Same Team

- The agent that perform the activities where the same agent (or team of agents) are assigned to perform two activities.

Time Dependency

An activity may start before or after another activity or an activity may overlap another depending on their start and completion dates. For example, the rule below can be used to identify if two activities, activity1 and activity2, overlaps one another, as shown in the top part of Figure B.10.

```
_overlaps(activity1, activity2) :-
   %completion_date(activity1, date1),
   %start_date(activity2, date2),
   date1 > date2.
```

The bottom part of Figure B.10 shows that activity1 occurs before activity2 and this can be detected by the following rule:

```
_occurs_before(activity1, activity2) :-
   %completion_date(activity1, date1),
   %start_date(activity2, date2),
   date1 =< date2.
```

Input-Output Dependency

The sequence of activities is especially important where there is an input-output dependency between two activities. For example, if an output of activity2 is needed to

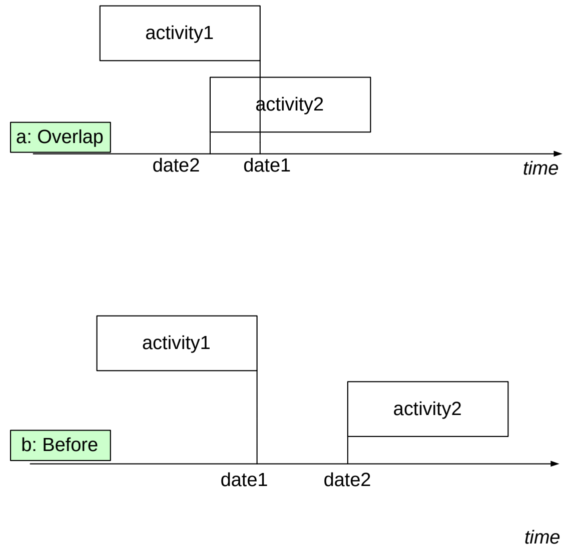

Figure B.10: Activity Dependency, a: Two overlapping activities, b: One activity occurs before another

perform activity1, then the scenario shown in the bottom part of Figure B.10 may cause a problem. An example of a rule to detect input-output dependencies is given below:

```
_io_dependency(activity1, activity2) :-
   %input(activity1, input1),
   %output(activity2, output2),
   input1 = output2.
```

Resource Dependency

Activities may depend on each other if they use the same resources. In this model, we only consider the resource that performs the activity, i.e. the agent. An example of a rule to detect resource dependency may be to detect if the same agent performs two activities, (see Figure B.11):

```
_resource_dependency(agent1, activity1, activity2) :-
   _performs(agent1, role1, activity1),
   _performs(agent1, role2, activity2).
```

B.3.4 Detecting Negotiation Points

One of the most important uses of the model will be in detecting when to negotiate with a partner of a VE and to identify the attributes that needs to be negotiated upon. In Figure B.11, agent1 fills both role1 and role2 and will perform both activity1 and activity2. If both these activities have to be completed at the same time, (i.e. there is an overlap of the two activities), then it might be necessary to consider the usage

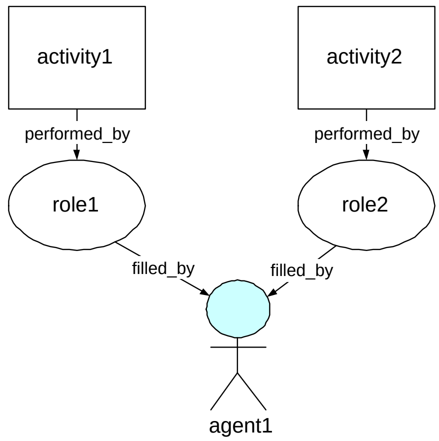

Figure B.11: Activity Dependency due to Agent

of agent1's time and to reconsider the allocation of agent1's time. Thus, it might be necessary to negotiate with agent1 about it performing activity1 and activity2.

```
_negotiate_resource_allocation(agent1, activity1, activity2) :-
   _resource_dependency(agent1, activity1, activity2),
   _overlaps(activity1, activity2).
```

Another situation where there may be a need to negotiate is about the timing of the activities, e.g. the scenario described in the above section (Section B.3.3), where activity1 needs an input from activity2. The following rule can be used to indicate that the agent that performs activity1 must negotiate with the agent that performs activity2 about the timing of the activities.

```
_negotiate_activity_timing(agent1, agent2, activity1, activity2) :-
   _io_dependency(activity1, activity2),
   _occurs_before(activity1, activity2),
   _assigned_to(agent1, activity1),
   _assigned_to(agent2, activity2).
```

B.3.5 Roles and Organisation Structure

In a VE, by definition, there is no rigid organisation structure. However, for management purposes, an organisation structure can be introduced by defining certain roles that take responsibility. Similarly, specific roles may be authorized and/or empowered to perform certain activities. Since there is no rigid organisation structure in a VE, there are no fixed organisational positions either.

A new type of relationship can be defined to indicate which role reports to which. Figure B.12 shows the metamodel of this relationship. Any role can report to one other role, i.e., for any role, there is only one reporting line, and one role may have several roles reporting to it. The following clause says that role1 reports to role2.

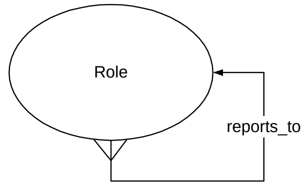

Figure B.12: Metamodel for the "reports_to" Relationship

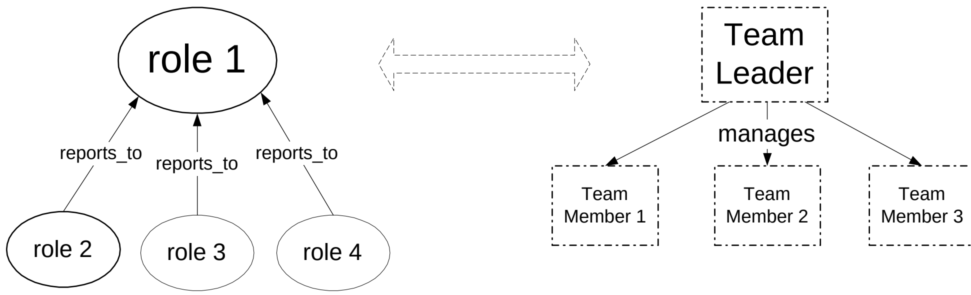

Figure B.13: Roles and Organisation Structure

```
reports_to(role1, role2)
```

The organisational structure can be deduced by the relationship among the roles. For example, in Figure B.13, role2, role3 and role4 report to role1. This can be assumed as an organisation structure of a team where role1 is the team leader and role2, role3 and role4 are the members of that team.

B.3.6 Aligning Goals

One of the steps in selecting agents to fill the roles in a VE is goal alignment, where the goals of the agent is aligned with the goals of the VE. There is a need for a precise definition of goal alignment. Here are a set of rules that can be used for goal alignment. Two goals are aligned if they are *similar* and if they *match*, which are defined as follows:

- Two goals *match* iff (one or more of) their attributes values match.
- Two attribute values *match* iff they fulfil a matching condition.
- Two goals are *similar* iff the attribute value "product_area" of one goal is equal to the attribute value "product_area" of the other goal.

The following clauses can be used to check if goal1 is aligned with goal2:

```
are_aligned(goal1, goal2):-
   are_similar(goal1, goal2),
   match(goal1, goal2).
```

```
are_similar(goal1, goal2):-
   goal(goal1, product_area1, deadline1, max_cost1),
   goal(goal2, product_area2, deadline2, max_cost2),
   product_area1 = product_area2.

match(goal1, goal2):
   match_deadline(goal1, goal2);
   match_product_area(goal1, goal2);
   match_max_cost(goal1, goal2).
```

An example of a rule to match the attribute ”deadline” of a goal, where the matching constraint is that the deadline of one goal is later than that of the other goal, is as follows:

```
match_deadline(goal1, goal2):-
   goal(goal1, product_area1, deadline1, max_cost1),
   goal(goal2, product_area2, deadline2, max_cost2),
   deadline1 >= deadline2.
```

Appendix C

Case Studies: Description of the Cases

This chapter provides the details of the case studies that were conducted for the evaluation of the agent-based approach presented in this thesis. The terminology used by the various companies have been adopted in the case studies. Although the company names have been used, a single scenario or a single instance of a VE was analysed.

The case studies were conducted by interviewing and discussing with one or two people from the companies and by reviewing literature that was provided by them.

C.1 BFS

C.1.1 Company Profile

BFS is an independent private consulting firm registered in the Republic of Maldives, established in 1999. The Group offers all aspects of business, financial, economic and social consulting services. The group through networking, memberships, and other contracts, has established strategic alliances with a number of experienced local consultants and well reputed international firms. BFS also maintains a database of highly skilled and experienced consultants in various fields and draws upon these resources to form the teams that work on their projects. These consultants and the companies that form the alliance are analogous to the partners of the VE.

The concept of a VE is new to BFS and they do not always operate a profit and risk sharing business model. They select the relevant resources from their database to fill the roles of the projects rather than advertise globally and select resources based on the bids proposed by the Interested Partners.

Information about BFS is available from their corporate webpage
http://www.consultbfs.com//.

C.1.2 Case Description

BFS forms a team of people to work on the project by identifying the different roles that are required to perform the activities and by selecting the relevant people to fill the roles.

For this case study, we analysed an example of a project where BFS formed a consortium, or a VE, with two international companies, Company A from the U. K. and Company B from New Zealand. Each company took responsibility for a particular part of the project and provided the resources to fill the roles that were required for that part of the project. BFS provided Maldivian consultants for the various parts of the project that they were responsible for (e.g. for the parts that explicitly required local knowledge and thus a Maldivian consultant). The VE was formed to bid jointly for a project, where the profits and risks were shared by the partners.

C.1.3 Modelling the Case

The VE was formed to work on the Regional Development Project for the Republic of Maldives, where the customer was the Maldivian government (more precisely, Ministry of Planning and National Development). The ultimate objective of rural development is the expansion of business and employment opportunities to generate sustainable incomes. Thus, the main goal of the VE was regional development through expansion of business and employment opportunities. Figure C.1 shows part of the goal structure for the VE, where one of the subgoals "establish basic infrastructure" is achieved by performing the activity "construct link road between two islands", which is performed by several roles such as a "land use planner" and "bridge design engineer".

Company A took responsibility for the subgoal "create income generating activities" and Company B, who has experience in civil engineering projects, took responsibility for the subgoal "establish basic infrastructure". BFS provided the local expertise and filled in the requirements for roles that needed to be filled by Maldivian nationals. The roles that BFS had to fill were administrator, computer specialist, public awareness specialist, health specialist, engineering consultant, environmental specialist and an auditing specialist.

C.1.4 Evaluation

Comparison of Attributes

In selecting the partners to fill in the various roles required for this VE, BFS did not conduct an explicit evaluation and selection process. Part of the reason for this was because the expertises that were required to fill in the roles for this VE were already available from the BFS database. Unless a person obtained from the database was unavailable or an expertise that was not available in the database was required, BFS did not look outside of their database to select the partners. For this VE, the partners for the roles that BFS had to fill were available from their database and any expertise that was unavailable, such as civil engineering, was obtained through the other companies in the consortium.

The resources or persons that were listed in the BFS database have already gone through an implicit evaluation. The general evaluation criteria that was used by BFS is summarized in Table C.1.

The partner's fees, relevant experience and qualifications are the most important attributes in the evaluation criteria. Another important attribute is the partner's connection with the customer as this helps win the bid for the project. The attribute,

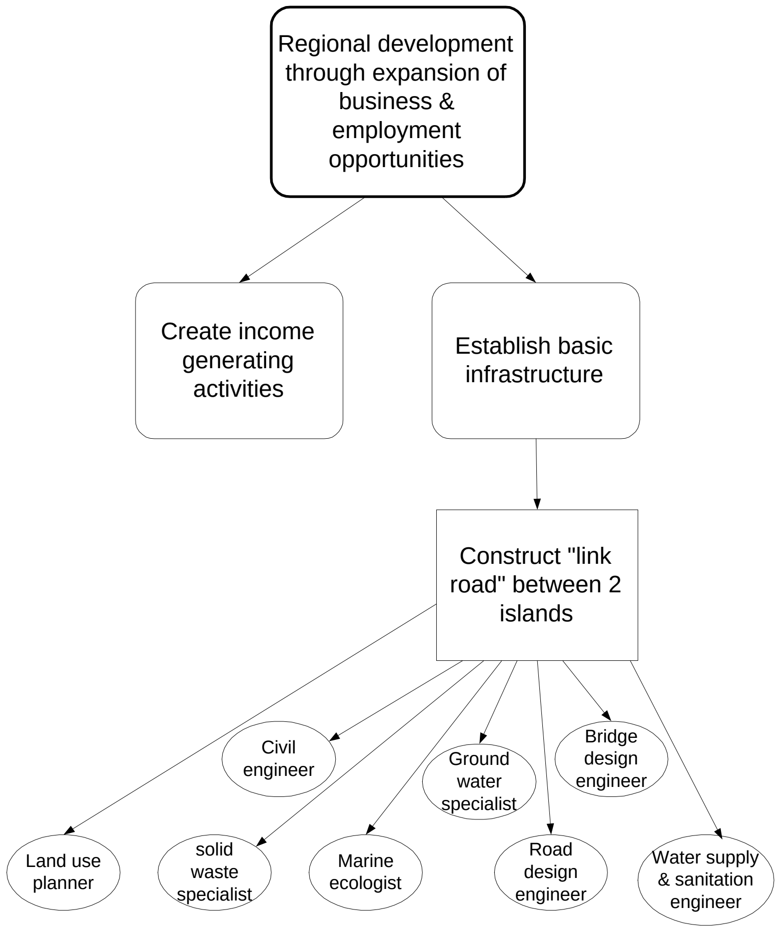

Figure C.1: BFS: Goals, Activities and Roles

Attributes	Possible Weightings
Experience in similar projects	15
Relevant qualifications	15
Past experience with the customer	5
Past experience with BFS	5
Acceptability of partner to the customer	10
Partner's fees	20
Partner's connection with the customer	10
Partner's ability to add value to the VE through external connections	5
Partner's availability and willingness to work in the VE	5
Conflict of interests	10

Table C.1: BFS: Summary of Attributes

conflict of interest, spans a broader context than just the goals. For example, if the potential partner is a direct competitor to the customer or a close associate of a competitor, BFS will consider it as a conflict of interest.

An interesting fact is that the idea of commitment and risks is not considered explicitly. These are taken care of by the contract that BFS signs with each individual partner. Also, the aspects of teamwork and collaboration are not explicit in the evaluation criteria.

Selection Process

A different selection process and evaluation criteria were applied when selecting the companies for the consortium and when selecting the local consultants to fill the roles. In selecting the members for the consortium, more emphasis was given to the strategic aspects such as goals and the responsibility taken by the individual company whereas when selecting the partners to fill the specific roles, more emphasis was given to the experience of the partners. In this particular case, the international companies wanting to bid for this project, approached BFS as they needed a local company who had the local knowledge as well as the contacts and invited BFS to form a consortium. The evaluation criteria that was used in this qualification was not explicit and therefore was unavailable.

Figure C.2 shows the general partner selection process that is used by BFS when selecting Maldivian consultants for specific roles.

Negotiation

When BFS selects partners for a project, it pre-selects from its database and then negotiates on the price charged by the partner. In the BFS case, negotiation seems to play a rather insignificant role in determining the VE team.

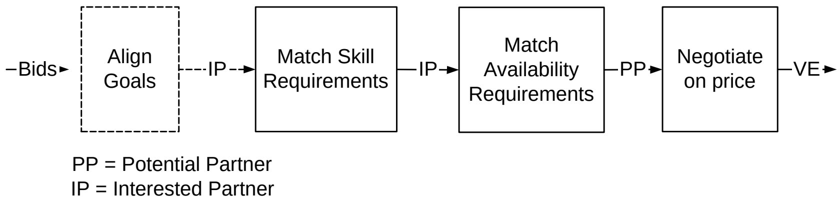

Figure C.2: BFS: Matching and Selection Process

C.1.5 Relevancy of the Agent-based Approach

BFS operates within a small community, where most people know each other or know of each other through a common contact. Therefore, it was easy to pick and select the best resources without advertising globally. BFS is also able to make good judgement of the quality of the service that they will receive from the partners because they either know them personally or have access to their work. BFS believes that their selection method is more efficient in a smaller context. Thus, our agent-based approach and the model of a VE, which are set within a global context using ideas from electronic markets and auctions is not really relevant for BFS. However, the implicit selection process and evaluation criteria that was used by BFS did not contradict ours. Thus, our approach will help BFS enhance its operations and widen its scope if they desire to operate on a more global scale.

C.2 Statoil

C.2.1 Company Profile

Statoil ASA is an integrated oil and gas company with its head office in Stavanger. The group has approximately 17,100 employees, and has operations in 25 countries. Statoil Research Centre, Trondheim, Norway, organizes projects in the summer for university students to work as teams.

Information about Statoil is available from their corporate webpage http://www.statoil.com//.

C.2.2 Case Description

Statoil's summer projects are an organized form of summer jobs for students in their third year of study at university. The idea is that better results are achieved by putting students together in interdisciplinary project teams. The teams work in groups of two to six students per project, for eight weeks. The case that we considered was "Summer Project 2002 New Statoil, Use of Fiber Optic Systems and Subsea Visualization". There were 800 applicants; 75 were selected for 25 different projects. Each project can be considered as a VE.

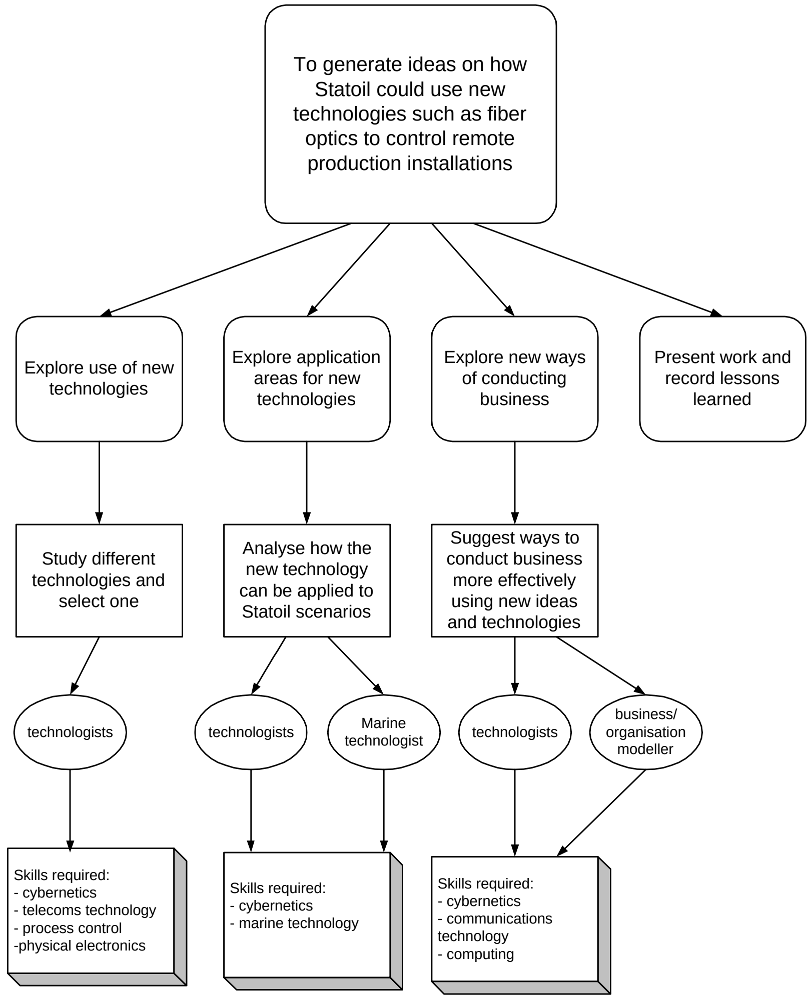

Figure C.3: Statoil: Goals, Activities, Roles and Requirements

C.2.3 Modelling the Case

The projects were well-defined. Thus, Statoil was able to identify the types of skills that they required; i.e. they could identify the requirements for the roles. Although, the projects were well-defined, due to the nature of the work that was required of the project students, the activities and roles were defined at a high-level. Figure C.3 shows the high-level goal, the activities, the roles and the requirements for the roles. Each activity in the figure represents a project. Thus, the skills requirements represent the different kinds of skills that were required to represent the multi-disciplinary team.

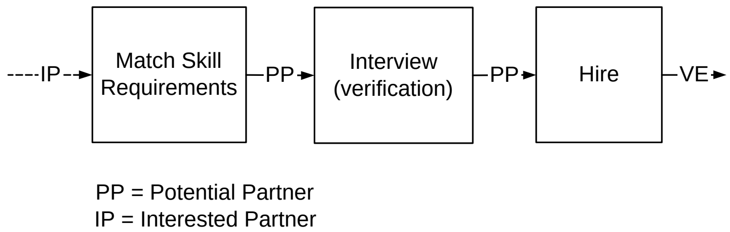

Figure C.4: Statoil: Matching and Selection Process

C.2.4 Evaluation

Comparison of Attributes

The attributes that were used in the evaluation criteria were taken from the information contained in the general application sent by the students and their CVs. Since a formal evaluation was not conducted, it was not possible to get an indication of the weightings that were assigned to the different attributes. The kinds of attributes that were considered are listed below:

- Gender - to ensure that there was a healthy balance of male and female students in each group.
- Year of study - final year students were not qualified.
- Work experience - both the amount of experience as well as the kinds of experiences.
- Choice of location - since the summer project opportunities were offered at different Statoil locations in Norway.
- University - certain Norwegian universities were given priority.
- Previous work experience at Statoil.
- Contact with someone in Statoil.

Selection Process

The selection process was based on receiving the students' applications and CVs, selecting the best and interviewing them before the final selection. However, due to the large number of applicants, it was impossible to scrutinize every single application so thoroughly. Figure C.4 shows the selection process that was used by Statoil.

Negotiation

There was no negotiation between Statoil and the Potential Partner during the selection process. However, under very special circumstances, negotiation may take place. For example, if one Potential Partner met all the requirements and was ranked top in the evaluation, but lived in another city. If this Potential Partner was absolutely the best one for the job, Statoil negotiated by requesting that s/he moved to Trondheim and that Statoil would pay the renting of a flat for 2 months.

C.2.5 Relevancy of the Agent-based Approach

Since there was no negotiation in the selection process, the main role of agents is not in facilitating this. However, due to the large number of applicants, the main role of agents in this case will be in supporting the project manager, analogous to the VE Initiator, in processing the applications and selecting the ones that match and ranking them. In fact, the agent-based approach is very applicable to this case as the requirements are simple and can be represented easily by agents. Using agents will give Statoil the opportunity to process each application thoroughly, thus being fair to each applicant. Using this approach will also solve the problem of being unable to deal with the huge amount of applications.

C.3 DNVS

C.3.1 Company Profile

DNV Software (DNVS) is an Independent Business Unit of Det Norske Veritas Ship Classification Society. It employs some 150 software developers and engineers, and is responsible for delivering technical analysis, life-cycle support and knowledge management applications to DNV as well as external clients world wide. DNVS is headquartered in Norway, and has offices in the UK, the US, Japan, Korea, Malaysia and Brazil.

Information about DNVS is available from their corporate webpage http://www2.dnv.com/software/.

C.3.2 Case Description

A VE formed between DNVS and an "external software partner" (ESP) is considered. The two companies have formed a strategic alliance where they share and exchange skills and technologies as they have complementary markets. ESP is a leader in software for engineering design, while DNVS is a leader in software for engineering analysis. The goal of this alliance is for both companies to strengthen their market positioning for existing and new market segments.

The initiative to form this alliance was of mutual interest, since both companies were looking for a potential partner to form an alliance with. The alliance was formed after several years of searching for the best candidate for the given alliance. DNVS had evaluated several potential candidates in the past, but none of the resulting alliances were believed to meet the expectation.

In the case description below, we focus on the point of view of DNVS. The kinds of attributes that were considered by DNVS in selecting a partner for the VE are summarized in Table C.2.

During the formation of the VE, the following attributes were considered:

Attributes	Description
Skills and experiences (Product)	A product that has a product-based model, is datacentric, flexible (High, Medium, Low), adaptable to different industries (High, Medium, Low) and able to add DNVS' analysis capabilities (High, Medium, Low).
Experience of the partner	Software Engineering, Software Design.
Level of understanding of design (of partner)	High, Medium, Low.
Markets (of partner)	Software for engineering design in targeted industries.
Business model	Willingness to establish a partnership (VE) with a company with complementary skills and technologies (High, Medium, Low), the line of product(s).
Timeline (w.r.t. the goal)	Time schedule, Perceived time pressure (High, Medium, Low).
Asset contribution	Financial assets invested by the partner in the VE, cost of non-conformance, cost of entering, upholding and breaking the contract (e.g. cost of leaving the VE).
Market position	Good, Bad, Moderate.

Table C.2: DNVS: Attributes considered in the Selection Process

- Objectives
- Business model
- Timeline (market opportunities)
- Asset contribution
- Skills

C.3.3 Modelling the Case

The high-level goals and the activities of the DNVS-ESP VE can be represented as shown in Figure C.5. The main goal of the VE is a combination of various business subgoals of the two companies. This goal is met by developing an integrated engineering software that can be sold to all the market segments.

C.3.4 Evaluation

Comparison of Attributes

The attributes shown in Table C.2 were never used in an explicit quantitative analysis of the different potential candidates. However, they can be summarized as shown in Table C.3 to develop a utility function for the evaluation.

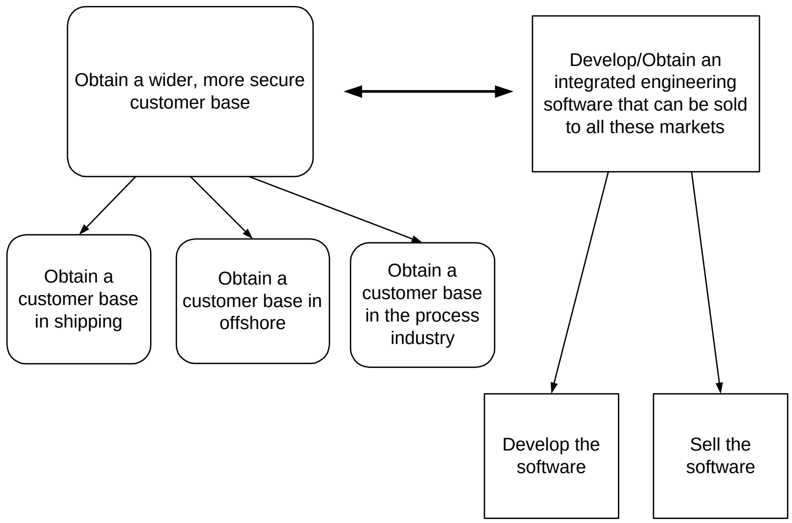

Figure C.5: DNVS: Goals and Activities

Attributes	**Possible Weightings**
Business Model	35
Timeline	25
Asset Contribution	30
Skills - Product (50), Experience (25), Understanding of the design (25)	10

Table C.3: DNVS: Summary of Attributes

The type of alliance plays a major role in the determination of the attributes that are considered for the selection of partners in the VE. The attributes that are considered in the DNVS-ESP VE are more indicative of the business goals of the individual companies in the VE rather than a particular activity that needs to be performed. For example, the attribute business model is considered more important than the skills of the partners. In fact, it appears that this was one of the areas where earlier attempts to establish such a VE failed. Another important attribute here is asset contribution where the relationship established by the two companies will be influenced by the percentage of assets that are contributed by each partner. This will also influence the ownership of the product developed by the VE.

The main difference between the initial model presented in this thesis and this case is that we have considered an example of a VE formed to develop a product for a customer, where the availability of a partner with specific skills and at a specific time period was relevant. In the DNVS-ESP VE case, the partners play a more active role where the partners mutually take initiative to form the VE to create or tap into an existing market that has expectations.

In our initial model, we have considered a lower level of some of these attributes:

- Skills - we consider more specific skills as we are looking at a VE that will hire partners that possess (or have access) to those skills.
- Timeline - we consider more specific time period in terms of start and end dates as we are looking at when an agent can start working on a specific activity.
- Asset contribution - our model did not consider this aspect of finances. This is mainly because we have considered the delivery process and how we can meet a specific customer's request and not at how to maintain the VE itself. However, we have considered some of the aspects of finance such as cost of breaking the contract which corresponds to our attribute commitment breaking cost.

Selection Process

An explicit selection process where Interested Partners propose a bid, which is evaluated according to some criteria, was not done during the formation of this VE. However, the selection process can be captured in Figure C.6.

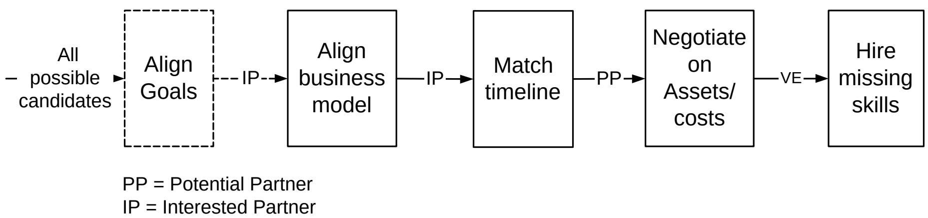

Figure C.6: DNVS: Partner Selection Process

The reason that the skills are given such a low priority in the selection process is because these two companies believe that if the required skills are not available from within the VE, they can always be hired. Hiring the necessary skills can be considered as putting a project team together and thus can be analogous to our initial model and the simple selection process that we initially proposed.

Negotiation

Based on the attributes shown in Table C.2 and the selection process shown in Figure C.6, there can be several points of negotiation. One of the most important will be to agree upon the amount of financial assets each partner will put into the VE and the influence it will have upon each partners's role in the VE and the ownership of the deliverables of the VE. The partners can also negotiate to align the timeline of the VE.

C.3.5 Relevancy of the Agent-based Approach

The VE formed between DNVS and ESP was based on strategic and business goals of the two partners, and the goal of the VE was to address to a very specialized area of applications and industries. In such cases, the number of Potential Partners may be limited and therefore, the amount of work that is required in the selection process will be less. The kinds of attributes that can be considered in the evaluation cannot be narrowed down to simple, quantitative attributes as they all have significant financial consequences for both the partners. Also, the evaluations will be somewhat subjective, based on past history and the tone of the relationship (e.g. hostile vs. friendly) that has existed between the partners.

The case, as shown above, can be analysed to fit our agent-based model of a VE. However, additional work needs to be done to detail the attributes and the selection and negotiation processes such that the true value of an agent-based system for such a case can be assessed.

C.4 PTL

C.4.1 Company Profile

PTL is a company that manages large building and construction projects, without participating in the production process itself. PTL has around 70 employees located in both Trondheim and Oslo, Norway.

Information about PTL is available from their corporate webpage
http://www.ptl.no/.

C.4.2 Case Description

PTL receives the requirements for a building and construction project from its customer and is responsible for forming the VE that will deliver to the customer. PTL, thus advertises for the partners of the VE and evaluates the bids from the Potential Partners and selects the team for the VE. Once this is done, PTL presents the selected partners to the customer and the contract is then signed directly between the customer and the partner.

The case that we considered was the selection of a VE to construct a hospital. The customer was the Norwegian government. PTL was hired to select the project team that will design, construct as well as provide the consultancy and project management for this work.

C.4.3 Modelling the Case

The VE that PTL is responsible for forming is the top-level project management team for the project. PTL uses several project management (or partnering) models. Thus, depending on the model that is used, PTL finds the partners of the VE that will be responsible for the different parts of the project such as the design and construction of the deliverable. This means that PTL identifies the activities that need to be performed at a higher level and finds the partners to perform these activities. It will then be the responsibility of these partners to further detail the activities and select the appropriate partners.

For the case we analysed, the main goal of the VE was to design and construct the hospital. The main activities consisted of designing the building, the building and construction work and the consultancy and project management. Thus, PTL looked for partners that can fill these high-level roles. Then, it was up to the partners to

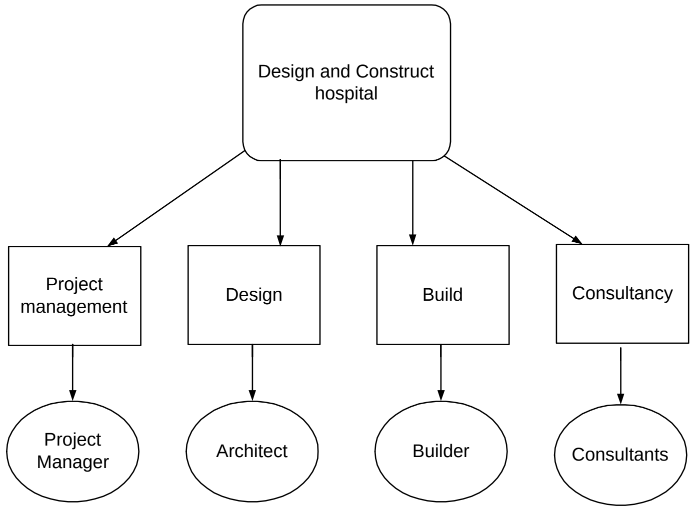

Figure C.7: PTL: Goals, Activities and Roles

further detail the VE and to select the partners for the more specific role within each activity. Figure C.7 shows a simplified model of the the high-level goal, activities and roles for the PTL VE.

C.4.4 Evaluation

Comparison of Attributes

In PTL's model of the VE, the partners represented enterprise only, i.e. the partners were VEs. An important aspect in the evaluation criteria was the "key persons" from each enterprise. Thus, the evaluation criteria considered both the attributes of the enterprise as a whole as well as the attributes of the individual key persons in the enterprise that will be participating in the VE.

PTL included aspects of teamwork and collaboration in the individual attributes such as their past experience in collaborative projects and if they had teamed up with the current Potential Partners in the past. An overview of the attributes that were considered and their weightings are given in Table C.4.

Attributes	**Possible Weightings**
Cost	30
Competency and experience	20
organization and working method	30
Capacity	20

Table C.4: PTL: Summary of Attributes

The attribute capacity looks at the quantity of relevant competence that is available for the VE at any time. In fact, this is one of the criteria that PTL found helpful in

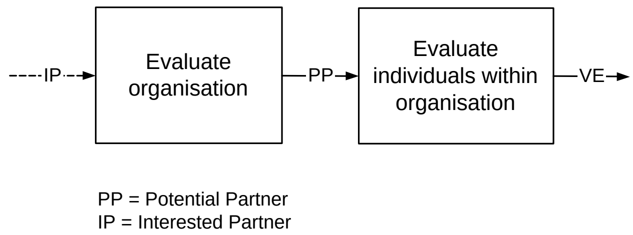

Figure C.8: PTL: Partner Selection Process

determining the quality of the different Potential Partners.

Selection Process

PTL does not consider goal alignment explicitly. They assumed that if an Interested Partner sends in a bid, then the goals that are relevant to that particular VE must be aligned. They believe that goals and goal alignment are more important in the operations stages of the lifecycle of the VE rather than during the formation stage.

PTL's "Match Skills and Availability" subprocess is a two-tier qualification process. Tier one considers general information such as past history and the Interested Partner's general ability to deliver, as an organization. Once the Interested Partner is qualified in this tier, then more specific information such as the key person's skills are considered. This two-tier process is a direct consequence of the Norwegian law "Lov om offentlig ansattelse".

Negotiation

PTL does not conduct any negotiation during the selection process as according to the Norwegian law, they cannot negotiate with a Potential Partner before selecting them. Thus, negotiations, if at all, occur after the VE is formed. PTL believes that negotiation is an ongoing process throughout the lifecycle of the VE and negotiation is often used as a means of resolving goal conflicts during the operations stage of the VE.

C.4.5 Relevancy of the Agent-based Approach

PTL's attitude towards the agent-based approach was very positive. However, they believed that the complete partner selection process cannot be automated and it would not be possible to represent the detailed evaluation criteria in such a model. However, using such an approach will make the PTL selection process more effective and it will save them time and resources.

C.5 ODA

C.5.1 Company Profile

ODA is a Norwegian company that selects contractors (single or alliances of companies) for very large scale projects. The projects range from IT to the offshore industry.

Information about ODA is available from their corporate webpage http://www.oda.as/.

C.5.2 Case Description

ODA is usually hired by a customer who wants to evaluate a set of bids proposed by companies or consortia who are interested in delivering a product or a service to the customer. The customer has a contract with ODA, where ODA conducts the bids evaluation process and provides the customer with the best organization or consortia (or VE) to perform the job.

The case that we considered was where ODA was hired to select an IT application provider, who may be a single organization or a consortium, i.e. VE. The customer was the Norwegian government.

C.5.3 Modelling the Case

The main goal of the VE was to upgrade software and hardware to all personnel of a large government body represented in all main rural areas of Norway. The details of the case was not available due to confidentiality. So, we were unable to construct the model of the VE.

C.5.4 Evaluation

Comparison of Attributes

ODA partner evaluation criteria is based on the ODA Model, which they use as a basis for determining the evaluation criteria for a particular VE. In this case, we were not able to get the details of the attributes - in fact the attributes were very detailed. However, the categories were categorized as follows:

- Price - the price of the infrastructure, the total package delivered.
- The complete system where the development of the system was considered. In addition to how well the system met the requirements, the planning, organization of the delivery team and the execution of the development project was considered.
- The long term maintenance contract.

Selection Process

The general idea of the selection process was to work out an ”Instruction to Bidder” (ITB) with the customer. An ITB is a detailed bid announcement giving instructions to the bidder on the kinds of information that should be included in the bid.

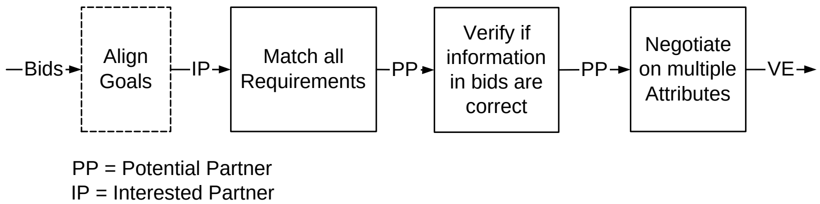

Figure C.9: ODA: Matching and Selection Process

The selection process that was used by ODA is shown in Figure C.9. Goal alignment, as in the other cases, was conducted implicitly. In addition to conducting a matching of the requirements, ODA interviews the Potential Partners and invites them for a workshops, to observe and judge if the Potential Partners are actually capable of delivering what is promised in the bid.

Negotiation

The main purpose of the negotiation process was to agree upon the contents of the tasks to be performed by the VE, for a particular price. Thus, the negotiation was based upon a multiple set of attributes.

C.5.5 Relevancy of the Agent-based Approach

The agent-based approach does not contradict with ODA's partner selection process. The main challenge is to be able to represent ODA's rich set of attributes representing the evaluation criteria. The agent-based approach could be very useful in conducting a coarse evaluation of the bids to short list the Potential Partners. This would save ODA time and resources.

Index