Virtual Enterprise Formation supported by
Agents and Web Services

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Abstract

This chapter describes the use of software agents and Web Services to support the formation of Virtual Enterprises. The partners of a Virtual Enterprise are represented as software agents. The AGORA multi-agent architecture is used. The focus of this chapter is on the description of the services provided by each partner and the partner selection process. The concept of Agent Interaction Protocols is used to manage the interactions during the formation of the Virtual Enterprise. An implementation of the ideas and examples from industrial case studies are used for the validation of the approach and discussions. The use of Semantic Web technology and Web Services with multi-agent systems is discussed as the future directions for this work.

1 INTRODUCTION

Recent advances in communication and distributed information technology has changed the way 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.

Interest in VEs have grown in the recent years and efforts have been made in several research domains to understand, design, facilitate and support VEs in any possible way. Some of this work is reviewed in the following section. As a result of this focus, the need for technological support of VEs has risen. This chapter describes an agent-based approach to support VEs and a model to describe them. The focus of our work is to support, in particular, the formation phase of the lifecycle of a VE. The formation of a VE is considered within the context of an electronic market place where several parties compete to become partners of a VE. Software agents and Web Services are used as
solution technologies. Our approach is based on understanding a VE from an organisational perspective and using these ideas to provide technological support. Emphasis has been made to ensure that the work is not technology driven, rather a combination of organisational design ideas as well as an appropriate technology.

The objective of this work is to provide an agent-based model of the VE and a solution technology that meets the needs and challenges of the industry. The work was motivated by the fact that technological solutions will save the industry some and resources by supporting the automation of some generic operations and processing of information. The aim is not to automate the complete process, rather to support effective decision making by providing appropriate information to the decision makers. The work described in this chapter has been validated using industrial case studies.

The rest of this chapter is organised as follows: Section 2 provides an overview of related work; Section 3 describes the agent-based model of the VE; Section 4 describes the VE formation process; Section 5 describes the implementation of the approach and the model using a multi-agent architecture; Section 6 presents a validation of the work using industrial case studies; Section 7 discusses the future directions for this work and Section 8 concludes the chapter.

2 BACKGROUND

This section provides an overview of the literature that is related to this work. The research areas that have been addressed are VEs, Intelligent Agents, Multi-agent Systems and Web Services and Agents and Web Services for modelling VEs.

2.1 Virtual Enterprises

VEs have received increasing attention during the last decade, e.g. (VOSTER, 2003). 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, e.g. from Manufacturing (Jagdev & Brown, 1998), Organisational Design (Davidow & Malone, 1992) and Enterprise Modelling and Integration (Vernadat, 1996). While the definitions address their particular areas of interest, there are some common aspects in these definitions. We have reviewed several definitions of VEs to come up with our working definition of a VE, which is as follows: A VE is a group of enterprises that collaborate to achieve a specific goal. The main characteristics of VEs are that it is a temporary network of enterprises, (Jagdev & Brown, 1998), with a limited lifetime, (Fischer et al., 1996), where the partners are distributed geographically and they collaborate (Oliveira & Rocha, 2000); it is goal-oriented, (Petersen, Divitini, & Matskin, 2001), and commitment-based (Jain, Aparicio IV, & Singh, 1999); it is supported by communication and information flow, (Garita & Afsarmanesh, 2001) and the partners share their skills, costs and profits (Byrne, Brandt, & Port, 1993).
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. 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.) As the partners of the VE are distributed, they require some 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.

VEs are by definition, dynamic and flexible. 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. 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. We focus on the selection of partners for the VE in order to understand the interactions and the contents of the messages that are exchanged between the partners.

2.2 Intelligent Agents, Multi-agent Systems and Web Services

Intelligent agents, similar to VEs, do not have a universally accepted definition. The definition that we have used is one of the most cited and the one that we believe best fits our work. An intelligent agent (also referred to as a software agent or agents) can be defined as a hardware or software-based computer system that is autonomous, reacts to changes in its environment, is pro-active and exhibits goal-oriented behaviour and it has social ability to interact and communicate with other artificial and human agents (Wooldridge & Jennings, 1995). Agents communicate using and Agent Communication Language such as FIPA ACL (FIPA-ACL, 2002). An agent that exhibits these characteristics is referred to as a weak agent. A strong notion of agency denotes agents that have mentalistic notions such as knowledge, beliefs and intentions. This notion is favoured by the Artificial Intelligence community while the weaker notion is more popular among software engineers.

A multi-agent system is a system composed of several agents, collectively capable of reaching goals that are difficult to achieve by an individual agent or a monolithic system. It is concerned with the societal view of agents, where a collection of agents work together and collaborate to solve a problem.

A Web Service is a software system identified by a URI, whose public interfaces and bindings are defined and described using Extensible Markup Language (XML). Web Services can interact with each other in a manner prescribed by their definitions using XML-based messages conveyed by Internet protocols (W3C). Web Services should be capable of being defined, described, and discovered. It is noted that Web Services do not merely provide static information, but allow one to affect some action or change in the world, e.g. the sale of a product or the control of a physical device.
What makes Web Services attractive is the ability to integrate the Web Services developed by different organisations together to fulfil a user's requirements. Such integration is based on the common standards of Web Service interfaces, regardless of the languages that have been used to implement the Web Services and the platforms where the Web Services are executed. Industry as well as academia has proposed standard languages for Web Services specification, invocation and process description. The industrial standards include Universal Description, Discovery, and Integration (UDDI) (Bellwood et al.) for service discovery, Web Services Description Language (WSDL-S) (Chinnici et al., 2006) for service specification of interfaces, and Simple Object Access Protocol (SOAP) (Box et al., 2001) for service invocation. The languages proposed by academia focus on the annotation of the meaning of Web Services using Semantic Web technologies. The languages from academia include OWL-S, formerly DAML-S, (OWL-S), WSMO (WSMO), METEOR-S (METEOR-S) and WSDL-S (WSDL-S).

2.3 Agents and Web Services for Modelling Virtual Enterprises

Based on the properties of VEs described earlier in this chapter, there is a strong motivation to use agents as the solution technology for modelling and realising VEs. The nature of agents, by definition, enables 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. Several authors have proposed software agents as a means of modelling dynamic organisational forms such as VEs. The first to propose the use of agents in supply chains\(^1\) was (Fox, Chionglo, & Barbuceanu, 1993), reported in a survey on using agents for intelligent manufacturing systems (Shen & Norrie, 1999). An agent-based modelling approach to project-oriented organisations engaged in knowledge work is proposed in (Levitt et al., 2001). There have also been attempts at modelling enterprises using computational techniques. An example of this can be seen in (Bernus & 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.

In (Petrie & Bussler, 2003), they propose the use of Web Services and ideas from multi-agent system to create “service agents” to create dynamic VEs. They argue that UDDI and WSDL are insufficient to support service discovery and composition and could draw from the ideas of academic multi-agent systems research to develop more sophisticated Web Services that could support the formation of VEs. An architecture and a methodology for agent-based Web Service discovery and composition using symbolic reasoning is described in (Küngas, Rao, & Matskin, 2004).

Agent-based models that focus on the formation of the VE are described in (Oliveira & Rocha, 2000) and (Rabelo, Camarinha-Matos, & Vallejos, 2000). In a Web Services-oriented view, the partners of a VE will provide services to or consume services from each other within an electronic market. Such a view is discussed in (Field & Hoffner, 2002) and (Petersen, Rao, & Tveit, 2002).

\(^1\) The involvement of companies in the supply chain has been referred to as resembling a set of collaborating partners, (Childe, 1998).
3 MODEL OF A VIRTUAL ENTERPRISE

We consider 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. 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. Using ideas from Enterprise Modelling, we have developed an agent-based model that shows the different entities that are in the VE and their relationships, see Figure 1.

![Figure 1: Model of VE](image)

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. The agent can be represented by a human being, an organisation or software. A role requires a certain set of skills. The agent that fills the role meets the skills requirement. Once the VE is formed, relationships can be established between the agent and the goals and activities to indicate the goal(s) of the VE the agent will attempt to fulfil and by performing which activities. Thus, an agent is assigned one or more goals and is assigned to one or more activities.

Goals and activities can be decomposed into subgoals and subactivities. 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. 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. A detailed description of the model is available from Petersen & Gruninger, 2000).

Although we focus on the contents of the model that are relevant for the formation of a VE, 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 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 people that form the VE. 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.

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. A detailed description of the attributes are provided in (Petersen & Divitini, 2002).

### 4 VIRTUAL ENTERPRISE FORMATION

This section discusses the formation of a VE from a lifecycle perspective and describes the VE formation process that we have considered.

#### 4.1 Virtual Enterprise Lifecycle

The focus of our work is on the formation of the VE. Hence it is perhaps interesting to consider the lifecycle of the VE and in particular, the formation phase of the VE. The formation stage of a VE within a lifecycle context is shown in Figure 2. Before a VE is formed, its 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 & 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 VE formation process that we consider 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 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.

### 4.2 Partner Selection

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. 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. This process is illustrated in Figure 3. The best set of individuals can be selected by considering attributes of agents that describe their individual qualities such as their availability, competencies and experiences.
The process illustrated in Figure 3 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.

4.3 VE Team of Partners

We believe that the concept of a team is an important point in forming a VE as the partners have to collaborate and work as a team to achieve the goals of the VE. 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 constraints such as the total risk of having the partners in the team. Thus, it is important to 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 to determine the best team of partners, see Figure 4.

4.4 Agent Interaction Protocols

The VE formation process can be considered as a set of interactions between the VE Initiator and the VE Partners. This process can be 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 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).
The interactions among the agents can be shown as an Agent Interaction Protocol, using Agent UML (Bauer, Müller, & Odell, 2001), see Figure 5.

![Agent Interaction Protocol for VE Formation](image)

**Figure 5: Agent Interaction Protocol for VE Formation**

5 IMPLEMENTATION

We have adapted the 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, Divitini, & Petersen, 1998) and (Matskin et al., 2000). It provides an infrastructure to implement software agents and agent-based market places.

5.1 AGORA Multi-agent Architecture

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, some agents are created by default 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 among the agents in the node) and Negotiator (for dealing with conflict resolution via negotiation).
In addition to the Agora node, the system also has registered agents. The cooperating entities within a VE, i.e. the partners, can be represented by agents and registered at the Agora node, see Figure 6.

![Figure 6: AGORA Multi-agent Architecture](image)

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 7. An agent uses the *Message Proxy* and the *Log System* to interact with the outside world, (e.g. the human user that it represents). It communicates with other agents using FIPA ACL, and the FIPA messages are sent and received through the Message Proxy.

We have used a Prolog-based presentation for messages, facts and rules in the *Knowledge Base*, implemented using the XProlog system ("XProlog"). 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.
5.2 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 VE 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. The requirements of the agents are represented as attributes of the agent (in the VE model).

<table>
<thead>
<tr>
<th>Entity</th>
<th>VE Initiator</th>
<th>VE Partner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals</td>
<td>Goals of the VE</td>
<td>Goals of the partner</td>
</tr>
<tr>
<td>Activities</td>
<td>Activities that need to be performed to achieve the goals of the VE.</td>
<td>Set of experience of the partner.</td>
</tr>
<tr>
<td>Capabilities</td>
<td>Requirements (skills, time, costs, etc.) for the roles of the VE.</td>
<td>Work that the partner is capable of doing.</td>
</tr>
</tbody>
</table>

Table 1: Information represented by the Agent Model

5.3 AGORA for VE Formation

A structure of Agora nodes can be created to support various processes such as the VE formation process and any agent can be registered at one or more Agora nodes. The Agora nodes for VE Formation are presented in Figure 8. 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.

![Figure 8: AGORA structure for VE Formation](image)

5.4 Example

In this subsection, we use a simple example to illustrate the VE 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.

5.4.1 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). The main goal is defined by the goal, the startdate and the maximum cost.

```prolog
ve_announcement(
    goal(create_intranet, 280206, 40000),
    roles([intranet_designer, webpage_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>
<thead>
<tr>
<th>Requirements</th>
<th>Range &amp; Matching Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skills</td>
<td>HTML, JAVA, XML</td>
</tr>
<tr>
<td>Min. no. of skills</td>
<td>&gt;=2</td>
</tr>
<tr>
<td>required</td>
<td></td>
</tr>
<tr>
<td>Experience</td>
<td>&gt;=2 years</td>
</tr>
<tr>
<td>Availability</td>
<td>Start_date&lt;010106, End_date=&lt;280206, 80%</td>
</tr>
<tr>
<td></td>
<td>of the time, Matching condition: computed no.</td>
</tr>
<tr>
<td></td>
<td>of hours =&lt;300</td>
</tr>
<tr>
<td>Cost per hour</td>
<td>&lt;60</td>
</tr>
<tr>
<td>Performance rating</td>
<td>Range: 1..10, &gt;=6</td>
</tr>
<tr>
<td>Commitment</td>
<td>Range: 1..10, &gt;7</td>
</tr>
</tbody>
</table>

Table 2: VE Requirements and Matching Conditions

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:

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

### 5.4.2 Matching Agent to Roles

The partner’s goals are aligned with those 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. The two best Potential Partners for the roles can now be selected. The best Potential Partners can be evaluated using Multi-attribute Utility Theory and Multi-attribute Optimisation (Keeney & Raiffa, 1976). Similarly, the best team of Potential Partners can also be evaluated using the criteria for the teams and an
appropriate utility function. A detailed example of selection of partners for a VE is described in (Petersen & Divitini, 2002).

The VE Initiator can now verify if the selected Potential Partners actually do have the experience claimed in the bids. Thus, the VE Initiator may request for the Potential Partners’ activities or experience structures (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).

6 VALIDATION USING CASE STUDIES

We have validated our approach and the agent-based model of the VE using several industrial case studies. Finding industrial case studies and relevant data from industry was a difficult task as the information that is required for the validation process is sensitive to the business. For these reasons, the companies that have provided us case studies have been kept anonymous.

6.1 Case Descriptions

An overview of the cases is provided below:

- **Company A**: a private consulting firm 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.
- **Company B**: 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. Each team, in this case can be considered as a VE.
- **Company C**: a company that operates on a global scale in the maritime industry. They are responsible for delivering technical analysis, life-cycle support and knowledge management applications to clients world wide.
- **Company D**: a company specialised in project management and selection of contractors in the construction industry. They were hired by a customer to assist them to evaluate bids in the selection of a contractor 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 organisations and they have to take into consideration the skills of the individuals from each organisation that will work in the VE.
- **Company E**: a company that specialises in bid evaluation and selection of contractors for very large scale projects in the off-shore and oil industries. They conduct an evaluation where they focus on the risk management aspects of the project, or VE.
A comparison of the cases is summarised in Table 3.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographical Context</td>
<td>Local</td>
<td>Local</td>
<td>Global</td>
<td>Local</td>
<td>Local</td>
</tr>
<tr>
<td>(National)</td>
<td></td>
<td>(National)</td>
<td>(National)</td>
<td></td>
<td>(National)</td>
</tr>
<tr>
<td>Specialisation of skills required for VE</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of detail of the VE when the VE is formed</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of the VE</td>
<td>Medium</td>
<td>Short</td>
<td>Long</td>
<td>Long</td>
<td>Long</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consideration of team aspects</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scale of VE: Money</td>
<td>Medium</td>
<td>Small</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complexity of VE</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Table 3: Comparison of Cases

6.2 Validation Process

The case studies were used to validate the approach and the model of the VE as follows:

- Creating an agent-based model of the case: modelling the case using the agent-based model for the VE. 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.
- 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. This is a comparison of the evaluation criteria.
- Comparing the selection process: comparing the partner selection process that was used in the cases to the selection process that is described in this chapter.
- 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.

6.3 Analysis

An overview of the analysis is provided in this section. The VE metamodel was in line with the way the VEs were designed and implemented. It was possible to model the VEs using the goals, the activities, the roles and the requirements. However, none of the VEs in the cases 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. One observation is that as the size of the project increases, e.g. Companies C, D and E, 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. Companies A and B.

The generic attributes that we had considered, 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, Company B used a simple set of attributes such as the student's year of study and their work experience, based on a Curriculum Vitae. Companies D and E, due to the high risk factor of the VEs that they help form, had very detailed and sophisticated evaluation criteria.

None of the selection processes in the cases 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. For example, Company A 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. While our selection process was in line with the selection processes used by the cases, most of the cases had a more detailed process and the processes varied according to the project.

Negotiation among the partners varied; e.g. Company D only negotiated after the selection of partners at the contract signing stage while Company B did not negotiate at all as there were more than enough Interested Partners that bid. All cases considered negotiation as an ongoing process.

The results of the case studies analysis can be summarised as follows: the agent-based model of the VE and the selection process is aligned with the way industry evaluates and selects teams to perform some work. However, a greater level of detail is required to provide full-industry scale support. Thus, there is a need for flexibility in defining the attributes of the partners and the definition of the selection process.

7 FUTURE TRENDS

The recent trend in the development of solutions such as the one described in this chapter is the use of Semantic Web technology and Web Services along with agents and multi-agent systems. Semantic Web Service technology makes dynamic enterprise integration more flexible. The Interested Partners of a VE can be considered as service providers, so that Semantic Web Services can be used to describe the capabilities of the VE partners, which can be represented by software agents as service provider agents. Similarly, the VE Initiator can be represented as a service requester agent. The selection process of the software agents is considered as the matchmaking of the Web Services. The Web Services and the requests can be specified by a variety of service description languages such as OWL-S or WSDL-S, all of which can be used for dynamic service matchmaking using the service ontologies that include descriptions of the service capabilities and needs of the service consumer. Relying on related languages and inference engines, the matchmaking of Semantic Web Services aims at matching the machine understandable descriptions of the service capability and the service consumer's
goal. The services can be described by information such as: (1) information about the provider of the service, (2) information about the service's functionality and (3) information about non-functional attributes. Functional attributes include the service's inputs, outputs, preconditions and effects. Non-functional attributes include properties such as competencies, quality of service, price and location. The matchmaking can be precise matching, partial matching or matching based on semantic instance. Many service matchmaking algorithms have been proposed, e.g. (Benatallah et al., 2005) and (Constantinescu, Binder, & Faltings, 2005).

The adaptation of the AGORA multi-agent architecture for agent-based dynamic service discovery and composition, using symbolic negotiation is described in (Küngas, Rao, & Matskin, 2004). This work is complementary to the work presented in this chapter and is a natural enhancement for supporting the formation of VEs. Using an agent-based approach, the service providers, i.e. VE Initiators are able to play a more proactive role in promoting their service offers. This approach also facilitates easy discovery of services and the automatic composition of services. The default agents at each Agora node provide the support that is necessary for conducting the matchmaking of services, the coordination of the work and negotiation.

The AGORA architecture described in this chapter is a multi-agent architecture inspired by electronic markets. We are currently working on enhancing the AGORA architecture to incorporate aspects of Service-oriented architectures (SOA) and Web Services in the future (Zhang & Niu, 2006).

Combination of the agent-based approach with Semantic Web technology and Web Services offers a number of advantages. It supports a means of representing the services uniformly and due to the standardisation efforts around Web Services, it offers a greater degree of interoperability support when using heterogeneous agents and service providers. In addition, Semantic Web technology provides better semantic support in service description and discovery and the use of ontologies is facilitated.

8 CONCLUSION

This chapter describes an agent-based approach to support VEs and a model to describe them. The focus of our work is to support, in particular, the formation phase of the lifecycle of a VE. Software agents and Web Services are used as solution technologies. Our approach is based on understanding a VE from an organisational perspective and using these ideas to provide technological support.

The formation of a VE is considered within the context of an electronic market place where several parties compete to become partners of a VE. A multi-agent architecture provides a meeting place for the software agents that represent the entities that are interested in becoming members of the VE. The partners are represented by their goals and their competencies, availability as well as other information that is requested by the VE Initiator. Automatic matchmaking and formation of teams of partners are supported by the AGORA multi-agent architecture. Ideas for using Semantic Web technology and Web Services along with agents and multi-agent systems for supporting the formation of VEs is proposed as a future direction for this work.
The work was validated using a range of industrial case studies. Case Studies were selected from different industry sectors and of varying project sizes. The analysis of the case studies indicated that the agent-based approach and the model of the VE are in line with the work that is conducted in industry in selecting and forming teams of collaborative workers. However, there is a need for flexibility in representing the attributes of the agents that represent the partners and the selection process. Although there are several improvements that are required for supporting VE formation in industry, the model can be used to represent a small percentage of generic attributes and automated matchmaking which stand to make savings in costs and resources.

9 REFERENCES

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