ESTABLISHING AGILE SUPPLY NETWORKS THROUGH COMPETENCE PROFILING

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Focusing on the organisational competence notion, this work introduces a methodology to find suitable engineering Small-Medium Enterprise (SME) partners and to suggest effective agile supply networks. The ideas described have been tested with over two hundred engineering SMEs in the North East region of England. Participant companies are mainly engaged in the defence and aerospace industry.

1. INTRODUCTION

Finding appropriate partners is of key importance for the prosperity of a business. Within the digital enterprise concept establishing dynamically and rapidly viable supply networks for customised design and manufacturing capabilities becomes a key challenge.

The increased complexity of engineering systems in sectors such as automotive, aerospace and defence, has necessitate the migration to concurrent design and production methods (Kusar et al, 2004). However, concurrent methods lack the ability to respond to unpredicted changes in environmental conditions. When an unpredicted event occurs, which could be either a late customer request, the failure of an agent, or some other external environmental impact, the concurrent process is interrupted. An agile supply network establishment process will evaluate the impact of the event, and the supply network will be restructured accordingly but with minimal impact to directly unaffected agents. The aim is to minimise the total impact to the development process that a network is engaged with.

Agility is seen (Lau et al, 2003; Jiang and Fung, 2003) as the ability to rapidly react to changes in the environment, be they expected or not. When applied to design and manufacturing, this is seen to be the ability to change resources rapidly to design and produce a different assembly or product. Thus, an agile manufacturer is able to rapidly respond to changes in product demand or when an unpredicted event occurs, which could be either a late customer request, the failure of an agent, or some other external environmental impact.

Virtual enterprises have been seen as the main media for establishing "collaborative supply networks" by authors (Armoutis and Bal, 2001; Camarinha-Matos and Afsarmanesh, 2003). This paper introduces agility within the supply network setting by providing the ability to identify partners and setting dynamically partnerships, virtual enterprise, in response to unexpected changes during the development process. Previous work has developed a framework for competence profiling of SMEs to support electronic collaboration (Armoutis and Bal, 2003), and this is used in this work as a basis for agile supply network establishment.

2. PARTNER IDENTIFICATION AND APPRAISAL

An increasing number of business/trade directories have emerged providing the main means for on-line partner/supplier identification. Examples of them can be found in regional portals, such as:

- the '*n-e-life*' (at www.n-e-life.com/forbusiness/miniwebsites.php) in the North East region of the UK
- 'China Sourcing' (at www.china-sourcing.com), which promotes the products offered by companies across China
- the 'Asia Trade Hub' (at www.asiatradehub.com), which lists companies across all major Asian counties
- the 'Alibaba International' (at www.alibaba.com) manufacturing directory primarily serving SMEs, with one million registered users from over 200 countries

What is common is the limited information provided about listed companies. For instance *n-e-life* provides only contact details for its listed companies. In addition, companies are usually classified according to their end products, as for example in China Sourcing and Alibaba, an approach that is insufficient for innovative, higher value added work. As argued by Meyer and Utterback (1993), it is those skills and assets that exist in a firm that result in the development of new successful products delivered in chosen markets. Products are only instances of what an engineering company can do and does not show all it does.

Concentrating on the partnership formulation literature, an area that is attracting research interest is that of partner selection within an SME based virtual enterprise setting. In suggesting, creating and sharing a Computer Integrated Manufacturing (CIM) system to SMEs, Samadhi and Hoang (1998) proposed a method for assisting companies in selecting suitable partners. This operates on the basis that one or several manufacturers play the role of the initiator(s) in leading the collaboration. The work presented by Samadhi and Hoang (1998) introduces factors such as culture and manufacturing infrastructure, significant factors in the process of partnership formulation. However, as the same authors state, the approach is not suitable for companies that use very special or unique manufacturing processes. Such partnerships lose one of the significant benefits of collaboration. This is collaboration among companies with complementary competences, which this paper places particular emphasis on.

The growing need for collaboration between companies with complementary competences is cited by Lau and Wong (2001). Recognising that the process of

searching and identifying partners is the most crucial as well as time-consuming part in the formation of a virtual organisation, Lau and Wong (2001) propose a partner selection and information infrastructure for SME manufacturers. The proposed partner selection scheme is integrated into a 'Virtual Enterprise Network' (VEN) infrastructure that incorporates the task of production scheduling and allocation of jobs to different plants based on the capabilities of each plant. Lau's and Wong's infrastructure does not propose a structured approach to capturing and presenting engineering SME competences. This is an essential requirement for the formation of virtual organisations that has been also acknowledged by Camarinha-Matos and Afsarmanesh (2003) as a challenging issue that requires further research.

A Web-based supplier selection tool is also described by Tang et al (2004). This is part of a Web-based environment for cooperative stamping product development, 'CyberStamping'. Based on the principles of early supplier involvement, CymberStamping acts as a supporting environment and interface between customer and die supplier. Having initially defined the structure of the partnership chain by using a product tree, the customer invites tooling bids, which then evaluates and selects partners. CyberStamping focuses only on one competence within one industrial sector. That is the 'metal stamping tool and die' within the automobile sector. Conversely, a cross engineering view would enable the development of a product through the matching of a number of complementary competences which may not be directly relevant to the sector the product belongs to. In addition, selection of suppliers is dependant on the assumption that quantitative data such as lead times are available to companies, which is not true for many SMEs. Commenting on the conceptual basis of CyberStamping, customers may not always be the users of the system. SMEs may wish to take the "initiator" role, by conceptualising a product, identifying potential collaborators, and managing the development and manufacturing project. Hence, SMEs may look for peer "collaborators", not suppliers, to undertake large-scale projects that they could not possibly undertake on their own. Such relationships have gain increased research interest by variety of authors such as Harland et al (2004) and Xu et al (2005). Supply chains, as Tang et al (2004) envision, are mainly represented by links in sequential-horizontal format between the different levels of tiers. Virtual enterprises enable the virtual link to also exist in a vertical fashion through collaborations. In this way, a "true" network supply chain is established, which could more accurately be termed a "collaborative supply network".

3. COMPETENCE PROFILING

Virtual enterprises are defined as a way of organising business activities where different and independent partners exploit business opportunity by establishing an enterprise co-operation (Goldman, 1995). They are groups of loosely connected companies possessing certain core competences. The process of searching and identifying appropriate partners is for authors, such as Camarihna-Matos (2003) and Lau (2001; 2003), the key to successful formation of the virtual enterprise. Most important for this process is the analysis of each partner core competencies (Wiendahl and Lutz, 2002) and their coherence with the market needs.

In response to the virtual enterprise paradigm, a methodology has been developed to address the identified requirements of rapid competence identification, search, and matching. The methodology consists of four main stages:

1. Competence data collection: An on-line questionnaire has been development to assist in collecting and updating competence related information. Companies can load their competence information by registering on the 'Competence Profiling' web-site. The questionnaire aims at revealing the key skills and capabilities of engineering SMEs by focusing on both hard and soft factors, such as:
   - Company key indicators e.g. type of business and key markets
   - Awarded standards
   - Key manufacturing and management process capabilities
   - Core skills
   - Business philosophy
2. Normalizing: To ensure comparability among the various companies and correct use of the on-line tools, training and validation of the provided company data is provided. The 'normalising' stage also allows estimation of the quality of the identified competences. Since some of the information requires subjective judgement, the assistance of experts is considered essential within the normalisation process. Visits to the company premises by experts are organized and further-on validation and assistance is provided in capturing and assessing key competences.
3. Making competence information available for searching: In this stage competence information is stored in the relevant database which enables users to search for the appropriate set of business skills and capabilities to undertake a customer specific project. For this purpose the web-based Competence Search module has been developed (Figure 1).
4. Partnership formulation: In this final stage, companies with appropriate complementary competences are identified and matched to generate viable dynamic partnerships in response to a project need.

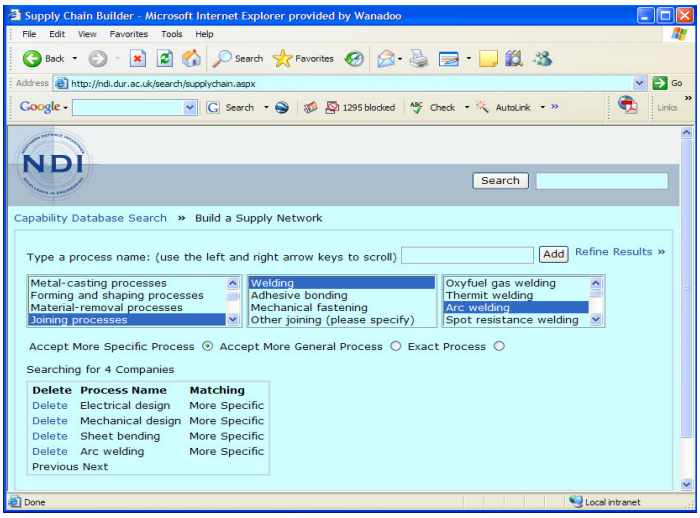

Figure 1 - Competence Search Module

Several variations of the Competence Profiling have already been tested and validated within the automotive and general engineering sectors (Armoutis and Bal, 2003; Bal and Armoutis, 2005). This new and improved development allows implementation and testing in the product development process of the aerospace and defence industry. The sector is technology driven and focused on demanding and rigorous quality standards. It is also characterized by intense international competition and high product complexity. Product development and manufacturing is many times a large-scale multi-partner task.

3. COMPETENCE PROFILING FOR THE AEROSPACE AND DEFENCE INDUSTRY

A non-profit trade association that has developed and established a programme of marketing and business development support has been employed to test the competence profiling methodology. Although not an engineering company itself, the association's views and beliefs about the engineering SME sector have a particular importance as it supports and represents over 200 engineering, manufacturing and specialist service companies in the North of England with the overwhelming majority consisting of engineering SMEs. Its operational focus is the defence and aerospace industry, which represents the source of business opportunities with which the association matches the supply chain capability of member companies.

The defence and aerospace association was interested in competence profiling as a tool for facilitating the process of identifying and matching the abilities of its member companies in response to prime defence and aerospace contractors' requests. Its existing method of identifying and matching the skills and capabilities of its member companies heavily relies upon the knowledge and familiarity that the

association's employees have with the competences of each member company. No structured methodology was followed in capturing, storing, searching and matching the key abilities of the member companies. In addition, prime defence contractors often requested detailed and structured information about the key capabilities of the association's member companies. To handle such requests, the association relies on profiling forms provided by prime contractors on a case-by-case basis. It is usually the situation that the trade-association profiles the same companies more than once, thus wasting resources and time. Therefore, there was a need for a single common form that would be able to provide appropriate structured information regarding the abilities of the member companies.

3.1 The Land System Scenario

One of the recent enquires the trade association received was the identification of a group of companies capable to design and manufacture a land system. A simplified scenario of a battle tank development project is applied in this paper to demonstrate the effects of competence profiling. Consider the tank development is controlled by Integrator A for Customer 1. The product is split into 5 modules, namely: hull; turret; engine; electronic systems; and track-wheels. For each module an agent is brought into the virtual enterprise which will design and build the aircraft and is controlled by Integrator A.

Each agent within the virtual enterprise follows their own development process, typically following the form illustrated in Figure 2. This scenario can now be applied to illustrate the effects that competence profiling has on each of the following 4 classifications of external event. It should be considered that the expected time for each agent to complete its work is the same period, i.e. the critical chain is dictated by each agent equally, and a delay to any agent represents a delay to the overall time of the process.

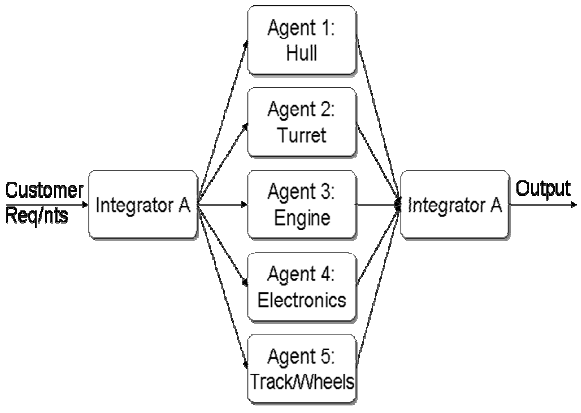

Figure 2 - A simplified virtual enterprise for tank development

Trivial Event: With a trivial event the problem can be resolved completely at the local level and only a small time penalty is incurred. Taking agent 1 as the first

example, the hull may be required to have 1 more emergency exit, rather than the original 1 specified. This external event has the effect of reducing how close the agent is to achieving the necessary output because the agent is now further from the desired solution than before the event. This loss of work is illustrated in Figure 3.

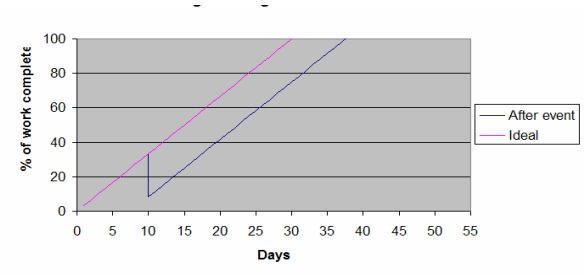

Figure 3 - Effect of trivial event

Figure 3 illustrates an external event at day 10 of a design process, with a magnitude of 25% of the work already carried out. The time taken for the agent to get back to the position at which it was before the event is in this case 8 days.

Minor Event: Empirical evidence suggests that events often require the use of additional resource, often of an expert nature, to resolve problems raised by unpredictable external events. Such an event is what this paper classifies as 'minor event'. Minor events describe events where the affected agents no longer has all the skills, resources or knowledge to develop an in-house solution, or that to do so would be more costly than the use of expert help. In this scenario the agent must rapidly identify a partner with the necessary skills, resources or knowledge to 'plug the gap' created by the event.

Agent 2 is responsible for the design and manufacture of the turret for the new tank. However, an external event dictates that the turret panels should no longer be riveted, but welded to save weight, due to new technology becoming available. In this instance Agent 2 does not possess the skills and knowledge to satisfactorily weld the turret, but the customer demands it for weight and therefore fuel and cost savings. Agent 2 still has the core competences to design and manufacture the rest of the turret structure, and so expert help is sought to assist specifically with the welding. This assistance would normally be found within the virtual enterprise, but could be assistance brought in from outside the enterprise if work were to be of assistance rather than taking control of all or part of a process.

Competence profiling enables this assistance to be rapidly found. Assuming that stages 1 to 3 of the partner profiling methodology have been completed (see paragraph 3), Agent 2 is only three steps away from identifying suitable external expertise:

1. Agent specifies and selects the competences needed in the relevant on-line database. In our scenario this is welding perhaps of a certain type.
2. Agent makes detail checks of short-listed companies as for their suitability according to a set of criteria such as technical and managerial capabilities. As authors such as McGuire and Dow (2002) and Arana (2004) suggest, particular attention needs to be also paid on softer issues such as business

philosophy and culture which contribute towards a successful partnership and linking with the rest of the virtual enterprise.

3. A company or a group of companies is identified and contacts are made to reach agreement on the work to be contracted.

This minor event has a more significant knock-back effect on the work done, and therefore imposes a greater Time-Penalty on the process. Due to the minor event above the total time is 41 days instead of the perfect 30 days. By logging in the partner profiling system Agent 2 can rapidly identify a partner with the required competence in welding. Testing with the trade association has indicated that competence profiling can improve by nearly 85% the time required to identify capable suppliers. Therefore, this agile development process can reduce the effort lost from 35% of work to 5.5%, and therefore the Time-Penalty is reduced to less than 2 days, achieving a saving of more than 9 days.

Major Event: A major event is defined by the failure of an agent to satisfy the demands put upon it by the greater organisation or system; it cannot convert its inputs into the required outputs. An example scenario similar to one seen in reality might be Agent 3, responsible for the engine, failing to design and manufacture an engine sufficiently powerful to satisfy the customer requirements it was given. The Agent simply does not have the knowledge, experience and or resources to meet the demands. This is classified as a major external event which to the rest of the virtual enterprise is unpredictable. The Time-Penalty is likely to be serious, as the work completed is likely to be reset to zero. An alternative scenario might be that an agent goes bankrupt during the project and can no longer continue their role.

In this situation the agent is deemed to have failed and another agent is required to take control of that specific process and join the virtual enterprise. The speed with which this can be achieved is a function of the agility of the organisation as a whole. The example shown below represents a 24 day delay to a process which should have taken 30 days, due to unpredictable failure after 24 days (Figure 4). However, the partner profiling methodology will be able to assist towards rapid identification of alternative competent companies minimising the negative time effects. The steps to follow are:

1. Integrator specifies and selects the competences needed in the relevant on-line database. In our scenario this is “diesel turbine engines”. It may also be a set of competences that are required for the successful completion of an engine development as for instance fuel consumption systems.
2. Integrator makes detail checks on short-listed companies based on predefined set of commercial, technical, managerial and cultural criteria.
3. A company or a group of companies is identified by the integrator and contacts are made for final agreement on the work to be contracted.

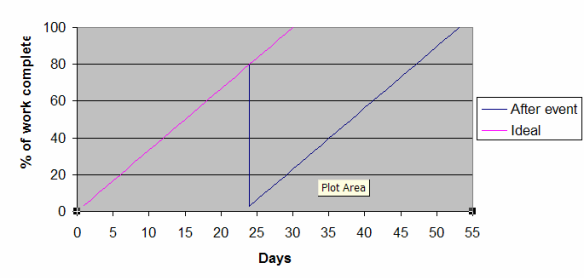

Figure 4 - Effect of a major external event

Fatal Event: The fatal event is an external event which is catastrophic to the design as a whole, not just to any individual agent. An example of a fatal event might be the introduction of legislation stating that emissions of greenhouse gases for any mode of transport must be below a given level. That is impossible to achieve with the given design. This event would impact directly the agent responsible for the engines, in our case example Agent 3. However, the effect is that the design of the overall process is fundamentally flawed. No replacement of Agent 3 will be able to produce the output required for the project to be realised.

These 4 classifications of event cover a broad spectrum of real-life events for which agile development will be of significant benefit, by reducing to a minimum the time-response of an agent or overall system, and thus the time-delay of whole projects.

4. DISCUSSION

The agile design and manufacture methodology does assume, and requires, that the development project is being undertaken in a virtual enterprise environment. The aim of the agile design and manufacture methodology is to enable rapid redeployment of work when required due to an unforeseen event occurring. These events are basically change in requirements, arising due either to customer request, internal request resulting from design work, or internal request due to an agent failing to fulfill its task. Based on a proposed classification for the severity of these events, the impact that the proposed partner profiling methodology can have towards agile development was assessed. Within this severity spectrum, it has been argued that the extreme classes are not appropriate for agile methods. However, events classified away from these extremes provide an opportunity for agile supply network establishment via competence profiling and its associated system.

The agile supply network establishment was illustrated using a simplified battle tank development scenario. While the development process in this case was completely parallel, it demonstrated how the work could be redistributed in each of the event classes. In the agile cases, it was argued that this provided a more rapid resolution to the events than would have been possible otherwise.

6. CONCLUSIONS

The increased complexity of engineering systems in conjunction with trends such as the intensification of the global competition, customer expectation of low volume and high quality custom products, and speedy development of products, mandate quick and effective application of agile principles in designing and manufacturing of products. In this paper a methodology for competence profiling is introduced, with the aim of minimising the effects on the concurrent development process due to unexpected events. The methodology was examined only against temporal effects of a development project.

Testing with engineering companies, which are often faced with the intricacy caused by unexpected changes during the development process, was very promising as evidence showed response time improvement of nearly 85 percent. Future research will go beyond the temporal impact, focusing on minimising the total impact of changes to the product development process and how this could be measured. In addition, research needs to focus on identifying explicit categorizations of competences, commonly acceptable by industry. This is what authors such as Gruber (1993) refer to as an issue of 'ontology', an explicit formal specifications of the terms in the domain and relations among them. Research is also underway in mathematical modelling of the partner selection process and how that could be turned to a multi-criteria optimisation problem. Finally, future work will include practical implementation and testing of the proposed methodology to other regions and industrial sectors.

7. ACKNOWLEDGMENTS

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