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Towards a Reconfigurable Supply Network Model

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Abstract

As organisations increasingly need to cope with planned or unplanned strategic and operational changes, the capability to easily and quickly reconfigure their supply chains is becoming an important criterion. In this paper, we propose a set of characteristics and benefits of a so called Reconfigurable Supply Network that allows rapid adjustment of supply chain entities at all levels of enterprises within the network. We propose the use of a Reconfigurable Manufacturing System design principle as a starting point towards building such a model. We extract the key characteristics of Reconfigurable Manufacturing Systems and extend these characteristics to a supply network. We then discuss design principles to enable reconfigurability in a supply network.

Keywords: Reconfigurable, Supply Network, Modularity

1. Introduction

Rapid business changes are becoming a norm [1], especially since competitive advantages are not always sustainable, only temporary [2]. In the pace of technological and market changes founded by complexity, information and fluctuations [3], organisations have to develop strategies to enable easy reconfiguration of their supply network, as the ideal supply network for one set of conditions is almost surely not ideal for another [4].

The purpose of this paper is to provide an initial approach for developing a Reconfigurable Supply Network (RSN). An RSN is one that is designed for easy rearrangement or change (addition/removal) of supply network entities in a timely and cost-effective manner. Our vision of RSN is one that allows for rapid reconfiguration, akin to the grid manufacturing concept and intelligent product driven supply chain [5], incorporating *intelligence* enabled by emerging technologies such as web services, intelligent software agents and RFID.

The motivation for this work came with the realisation that in order to enable an intelligent supply network there is a basic need to examine ways to enable easy reconfiguration of the supply network to meet current and future industrial requirements. We note that there are existing literatures on achieving agility, flexibility and responsiveness, but limited in examining the issue of reconfiguration, a prerequisite towards enabling a highly adaptable intelligent system.

An *Extended Enterprise* focuses on the sharing of information across the supply chain to achieve overall value creation and delivery systems through a confederation of organisations [6]. However, it focuses on existing supply chain partners and does not allow, in principle, quick reconfiguration or addition/removal of supply chain partners as all supply chain processes are deeply embedded within each confederated partners. On the other hand, the concept of an *Agile Enterprise* is extended from flexible manufacturing systems [7] where the concept of agility refers to the use of "market knowledge and virtual corporation to exploit profitable opportunities in a volatile marketplace" [8]. This is similar to a *Virtual Enterprise*, which is described as a network of organisations from which temporary alignments are formed [9] to rapidly obtain the products that they want [10, 11]. In such a way, both agile and virtual enterprise are driven by market opportunities rather than other strategic factors.

General supply chain literature has also examined the issue of reconfiguration [12] but with the focus on enabling information sharing and lacks a methodology towards understanding and developing an RSN at all levels of the enterprise.

In this paper, we will first explore the relevant issues of reconfigurable manufacturing systems as a basis for developing an RSN model. We will then look at some of the supply network and enterprise modelling techniques and propose a conceptual model that could enhance our understanding of supply networks. Furthermore, we propose a methodology and a set of characteristics towards achieving an RSN. Finally, we will suggest a way forward to build a reconfigurable supply network model.

2. Reconfigurable Manufacturing Systems

The previous section motivated the investigation of RSNs. This section extracts lessons from the Reconfigurable Manufacturing Systems (RMS) and product design literatures in order to draw analogies that may be applied on RSNs. Specifically, this discussion is divided into two parts; the benefits of reconfigurable manufacturing systems, and its characteristics.

2.1 Benefits of Reconfigurable Manufacturing Systems

Within the field of RMS, Mehrabi et al [13] define an RMS as: "[A manufacturing system that] is designed for rapid adjustment of production capacity and functionality in response to new circumstances by rearrangement or change of its components". This definition implies that the benefits of a reconfigurable manufacturing system arise from a constantly changing marketplace. With respect to RMS, these changes include 1.) increasing frequency of new product introductions due to shorter product life cycles, 2.) changes in parts for existing products to improve product customisation 3.) large fluctuations in the quantity and mix of product demand 4.) changes in government safety and environmental regulations and 5.) changes in process technology resulting in higher quality products [14].

The primary benefit of an RMS is the ability to react to these changes rapidly and cost-effectively. In order to achieve this benefit, an RMS must be rapidly (re)designed for new product applications, change quickly over to those new products, adjust capacity fast and incrementally, and finally incorporate the introduction of manufacturing processes for increased product variety [15].

2.2 Characteristics of Reconfigurable Manufacturing Systems

In order to achieve the benefits illustrated in the previous section, an RMS must have a number of key characteristics. Mehrabi [15] identifies them to be:

- *Modularity*: The degree to which all system components, both software and hardware are modular.
- *Integrability*: The ability with which systems and components maybe readily integrated and future technology introduced.
- *Convertibility*: The ability of the system to quickly changeover between existing products and adapt to future products.
- *Diagnosability*: The ability to quickly identify the sources of quality and reliability problems that occur in large systems.
- *Customisation*: The degree to which the capability and flexibility of the manufacturing system hardware and controls match the application (product family).

The above characteristics enable rapid reconfiguration of manufacturing systems. We will extend these characteristics to suit the concept of an RSN later in section 4.1.

3. Supply network and enterprise modelling

Taylor [16] suggests that there are three categories of business models: a) conceptual, b) mathematical, and c) simulation models. Each of them offers different capabilities and limitations. Conceptual models are informal and descriptive, while mathematical and simulation models are more formal and used for prediction and business optimization. Shapiro [17] provides an overview of how mathematical programming optimization can be used for modelling and optimization of supply chain networks. He also analyzes conceptual models for strategic planning and supply chain operations optimization. In recent years researchers tend to focus more on supply chain networks rather than traditional linear supply chain models. McDonald and Rogers [18] describe how value transfer in the supply chain evolves from the traditional linear model to a "holistic" supply network model. Similarly, Ayers [19] explores the evolution from the traditional supply chain to a supply network

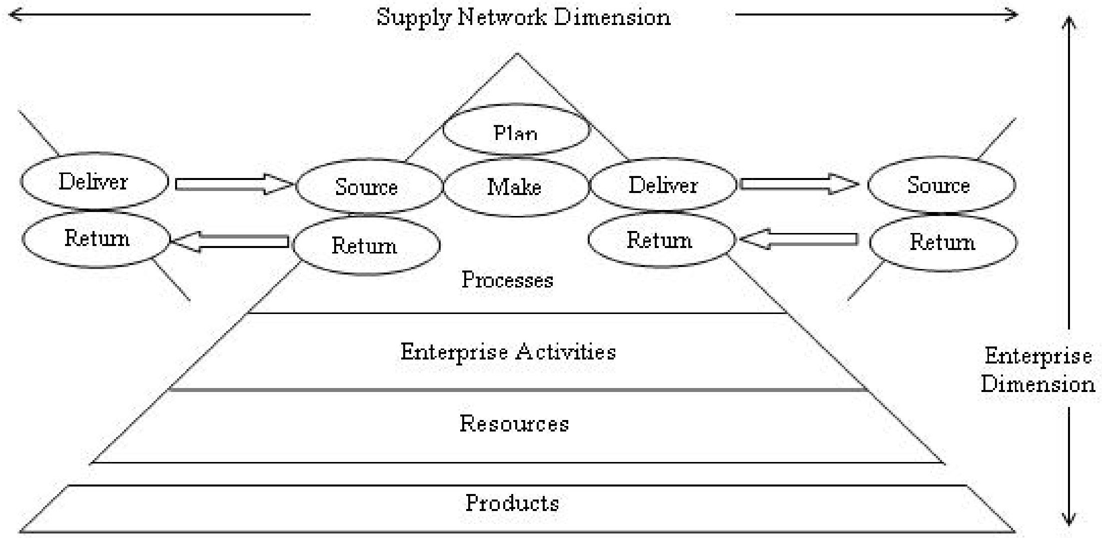

Fig. 1. Supply Network and Enterprise Model

of partnerships. McCormack and Johnson [20] propose a conceptual supply network model which they use to examine the impact of internal and external situational factors on the performance and the "esprit de corps" of the supply network. Dong et al. [21] and Ettl et al. [22] are examples of analytical approaches to supply network modelling.

Apart from supply chain modelling, there has been extended work in enterprise modelling as well. Vernadat [23] provides a profound description of the most important manufacturing-focused enterprise modelling reference architectures including ISO, CEN ENV 40 003, CIMOSA, GIM, PERA, ARIS and GERAM.

In the next section we will propose a conceptual model by which we can address supply network reconfiguration issues.

3.1 Scope of the model

Ross [24] suggests that every modelling technique should be characterized by the definition of the purpose, the range, the viewpoint and the detailing level of the model. In order to address supply network reconfigurability, in this section we propose an enterprise model which describes both the intra-organizational structure and the inter-organizational interactions of an enterprise. The range of this model spans from main business processes down to specific organizational resources with regard to intra-organizational structure, and covers both inbound and outbound interactions of a firm with regard to supply network interactions. This model describes the organization from an operational point of view, focusing on the supply-network-related processes of the organization. Moreover, the model provides definitions for the different operational elements which will be studied with respect to reconfigurability; however it does not provide a detailed description of the attributes of these elements or how these may interact with each other.

3.2 The supply network and enterprise model

According to Vernadat [23], an enterprise model is a consistent set of special purpose and complementary models describing the various facets of an enterprise to satisfy some purpose of some business users. Having described the purpose of the model in subsection 3.1, we use two complementary models to achieve this purpose. First, we use the definitions of functional components at different organizational levels, provided by Vernadat [23], that compose a generic organizational model. This part of the model describes the intra-organizational facet of our model. Secondly, we adopt the Supply Chain Operations Reference (SCOR) model [25] under which the inter-organizational interactions are modelled and a supply network perspective is given to our overall model. The two models are integrated in the processes modelling level and form a two-dimensional overall model, as depicted in Figure 1.

On the supply network dimension the business processes that realize the supply network interaction are provided as defined by SCOR [25]. These are *Plan, Source, Make, Deliver* and *Return.*

On the enterprise dimension a hierarchical structure of functional components is defined. At the higher level lie the business processes which consist of a sequence (or partially ordered set) of enterprise activities, the execution of which is triggered by some event and will result in some observable or quantifiable end result. At the next level, enterprise activities are defined as a set of partially ordered basic operations executed to perform the things to be done within an enterprise. Activities are performed by the functional entities of the enterprise and transform an input state into an output state. Activities are carried out by resources which are human or technical entities and can play a role in the realization of a certain class of tasks, when available [23].

At the lowest level lie products. Although not a part of the organizational structure itself, they provide input and output to the physical system and the resources of the organization, as defined by systems organization theory [23] and by general systems theory [26] as Vernadat remarks. Hence, processes (and the activities that compose them), resources and products are the organizational entities that are subject to reconfiguration.

Based on this model, in the next section we suggest the characteristics of an RSN, demonstrate the benefits that stem from this ability and propose the basic principles of designing a reconfigurable supply network.

4. Towards a Reconfigurable Supply Network Model

It is not the aim of this paper to provide a definitive model on an RSN. However, in this section, we will discuss the characteristics and benefits that could be derived from such a supply network. We will also examine ways in which such a network could be built.

4.1 Characteristics of a Reconfigurable Supply Network

In Section 2.2, we discussed the characteristics of Reconfigurable Manufacturing Systems (RMS). We will now extend these characteristics to a supply network. While the RMS literature largely focuses on resources (and to some extent on product) within a manufacturing facility, an RSN consists of products, resources as well as processes within all levels of enterprises across the supply network. Therefore, in order to adapt the characteristics of RMS to RSN, we append the definitions of these characteristics to include the supply network entities identified in section 3.2. We propose the following characteristics of an RSN:

- *Modularity*: The degree to which all product, process and resource entities at all levels of enterprises of supply network are modular.
- *Integrability*: The ability with which all enterprises within the supply network and their processes and resources maybe readily integrated and future process and resources introduced.
- *Convertibility*: The ability of the product, process and resource entities within enterprises of supply network to quickly changeover between existing products and adapt to future products.
- *Diagnosability*: The ability to quickly identify the sources of problems, which hamper supply network effectiveness and efficiency, which occur across the supply network.
- *Customisation*: The degree to which the capability and flexibility of the supporting infrastructure for supply network match the application (supply chain activities).

These characteristics will enable the supply network entities to be rapidly rearranged resulting in easy reconfiguration of a supply network.

4.2 Benefits of a Reconfigurable Supply Network

A Reconfigurable Supply Network with the characteristics described in the previous section allows rapid adjustment of supply chain processes to achieve strategic and operational objectives such as:

- Rapid response to changes in customer requirements
- Rapid outsourcing/in-sourcing activities
- Rapid addition or removal of supply network partners
- Achieving a responsive manufacturing system

These benefits are not an exhaustive list but provide an indication of the types of scenarios where it would be most beneficial to have such a supply network. As a general rule, the more a supply network is subjected to planned or unplanned changes, the more it will benefit from having a Reconfigurable Supply Network.

In practice, achieving a totally Reconfigurable Supply Network is difficult as it requires time and a collective effort. It is envisioned that once benefits are prioritised, the network could then be designed to meet these benefits in stages. The following section will propose a methodology to design such a supply network.

4.3 Designing the Network

In order to build a reconfigurable network companies must design their supply network using visible design rules and hidden design parameters [27]. Hidden design parameters are decisions that do not affect the design beyond the local module. Reforming the definitions of Baldwin and Clark [27] for the case of supply networks, visible design rules include a) an *Architecture* which specifies what modules will be part of the network and what their functions will be b) *Interfaces* that describe in details how these modules will interact and c) *Standards* for testing a module's conformity to the design rules and comparing modules' performance relative to another. Modules in the case of a supply network could either be entities that belong to any of the levels of the model in Figure 1 or whole enterprises that compose a supply network when interconnected.

In Figure 2, we provide an example of the application of the above rules in the case of collaboration practices between supply network partners by using the analogy of this design with the design of the internet according to the TCP/IP protocol

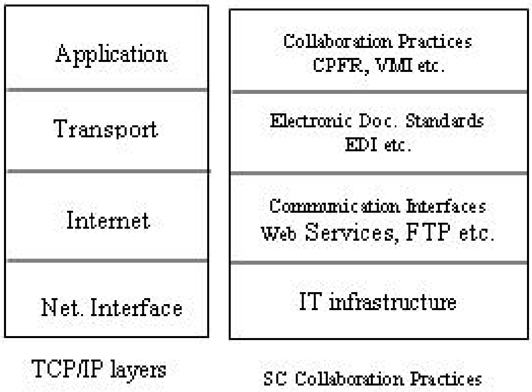

Fig. 2 Internet and Supply Network Design

[28].

Information sharing and collaboration will require the design of an infrastructure according to an *architecture* that will define different levels as shown in Figure 2. Specific *interfaces* and *standards* shall be defined for each of the levels. Moreover, the levels should be independent from each other with regard to design and operation, meaning that a change in one level should not affect the operation of another. We note that the levels mentioned at this point are different from the levels of the enterprise model presented in section 3.

In order to demonstrate the importance of the characteristics proposed in section 4.1, let us consider a simple example in which a manufacturer decides to change one of his main suppliers. Process *modularity* will enable efficient process modification at the manufacturer's side (in case a process must be changed, e.g. order receipt) without affecting other enterprise processes, therefore minimizing changeover costs. Product *integrability* will ease the changeover procedure minimizing product compatibility issues, while process *integrability* will enable the two parties to effectively integrate process (e.g. shipment and receipt) as well as to introduce new ones if necessary. Product *convertibility* from the new supplier's view will give him a competitive advantage compared to other suppliers, enabling him to convert his product to meet the manufacturer's needs. From the manufacturer's point of view, *convertibility* will enable him to modify his product and processes so that these are compatible with a wider variety of compatible suppliers. Finally, the ability of *customisation* will enable the supplier to efficiently meet any special requirement that the manufacturer has. *Diagnosability* will enable the two parties to quickly discover deficiencies in the newly established relationship and solve them.

The next step in this research will be to utilise these design principles and develop a model of an *intelligent* Reconfigurable Supply Network that exhibits the characteristics identified in section 4.1. Such a network will be able to continuously monitor its performance and automatically adapt to changing requirements, utilizing emerging information and communication technologies for efficient reconfiguration. The model will also include performance measures for these characteristics as well as an overall "reconfigurability measure" that will indicate the reconfiguration capability of a supply network. This paper provides the initial examination of an RSN network that allows for further research in intelligent information systems to support supply network processes. Current on-going research is working towards this direction.

We aim to validate our model through a series of case studies of companies that undertook some kind of supply network reconfiguration. Furthermore, we will assess the impact of specific reconfiguration scenarios on the companies. We aim at measuring the performance of each company with regard to each of the critical reconfiguration characteristics and link these measurements to the overall reconfiguration performance of the company. In this way, we shall be able to determine the correlation between these characteristic and the overall reconfiguration capability of the enterprise.

5. Conclusion

In this paper we have extracted the key characteristics of reconfigurable manufacturing systems and we propose a way for applying them in the enterprises of a supply network in order to enhance the ability of the network to be efficiently reconfigured. We do this using a model that addresses both the intra enterprise activities and the inter-enterprise interactions. We then suggest the key characteristics that the supply network entities should have and the way an RSN should be designed. Further research shall be headed towards defining a formal model for describing reconfigurable supply networks and employing the model to achieve specific supply chain improvements.

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