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A multi-agent based framework for supply chain risk management

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ABSTRACT

The high level of complexity of supply chains and the inherent risks that exist in both the demand and supply of resources – especially in economic downturns – are recognized as major limiting factors in achieving high levels of supply chain performance. The use of modern information technology (IT) decision support systems is fast becoming an indispensable tool for designing and managing complex supply chain systems today. This paper develops a framework for the design of a multi-agent based decision support system for the management disruptions and mitigation of risks in manufacturing supply chains.

1. Introduction

The increasing call for mass customization in many industries has made today's global supply chains very complex, requiring a multitude of parallel information and physical flows to be controlled to ensure high customer service levels. This increased complexity raises the level of uncertainty and risks that companies are faced with Manuj and Mentzer (2008). The wide range of risks along the supply chain (both from supply and demand side) may impose negative implications upon supply chain performance. There is an eminent need for organizations to have necessary strategies to manage these risks and disruptions, so that they can achieve the necessary level of agility for effective mass customization.

Constructive collaboration among business partners in supply chains is vital in any attempt to mitigate risks and ameliorate disruptions, to achieve responsiveness and to offer a high customer service level (Hallikas et al., 2004). Many successful modern organizations have shifted from an opportunistic dogma of cooperation to a synergetic ethos of collaboration and aligned their supply chain processes.

The use of Information and Communication Technology (ICT) tools is perceived as a paramount facilitator for the realisation of this collaborative perception, offering the capabilities of information sharing, customer sensitivity and process integration (Wu and Angelis, 2007). The conventional IT, however, (which is based on legacy systems) has not provided sustainable solutions for collaborative Supply Chain Management (SCM). It lacks real-time adaptability in supply chains and focuses on dyadic contexts of collaboration rather than collaboration amongst a plethora of partners (Akkermans et al., 2003). It is also characterized by inflexibility for the reconfiguration of supply chains processes and high development and maintenance costs (Botta–Genoulaz et al., 2005).

The use of multi-agent modelling (a sub category of artificial intelligence) can be an alternative decision making tool for collaboration within supply chains. In computer science, an agent can be defined as a software entity, which is autonomous to accomplish its design objectives, considered as a part of an overall objective, through the axiom of communication and coordination with other agents (Gilbert, 2007). Through this paradigm of software architecture, the management of supply chain processes can be perceived as facilitated by several autonomous decision making entities (software agents), each responsible for specific activities and performing different roles. These agents interact and cooperate with other agents, within and across organizations, in order to solve problems beyond their individual knowledge or expertise, and to promote a higher performance for the entire system (Stone and Veloso, 2000).

In this paper, a multi-agent based framework is proposed as the conceptual basis for the design of a DSS that facilitates collaborative disruption risk management in manufacturing supply chains. The framework supports the fulfilment of production, event and disruption risk management constituted by coordination, communication and task agents and draws on principles and theories of SCM, agent based simulation and computer science.

The remainder of the paper is organised in four sections. In the first section, the usefulness of a multi-agent system (MAS) framework for supply chain risk management (SCRM) is discussed through a brief review of an expansive SCRM literature, a

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comparison between conventional IT solutions and MAS and a discussion of the application of software agents to different supply chain problems. The second section presents the analytical approach that has been utilized, the process for the development of the framework and its features in detail. With the use of a hypothesized scenario, the third section presents the processes for supply chain disruption management that an MAS designed with the logical structure of the proposed framework will follow. The paper concludes with a discussion of the limitations and managerial implications of the framework and potential extension of the research.

2. Literature review

The SCM literature is rife of studies that investigate supply chain risk phenomena and provide models for the analysis and mitigation of several types of supply chain risks (financial, operational and strategic) that occur both in the supply and demand side of supply chains. Zsidisin and Ritchie (2008) and Juttner (2005) provide comprehensive reviews of the literature and models used for an effective SCRM. Several authors have also proposed disruption management strategies for SCRM. Zsidisin and Smith (2005) discuss how early supplier involvement can reduce the likelihood of supply disruptions and Chopra and Sodhi (2004) highlight mitigation strategies for different types of risks, which manufacturing organizations apply to deal with uncertainty. They identify drivers for a wide variety of different risks and pinpoint alternative proactive mitigation strategies for each corresponding risk. Other researchers have focused specifically on information systems risks. Kleindorfer and Saad (2005) underline the importance of collaborative information sharing as the vehicle to shed light upon vulnerabilities within the supply chain, to manage disruptions under a cost efficient manner and to devise strategies for their effective control in a crisis situation.

The existing studies that are found in the literature have been instrumental in identifying and analysing several causes of disruptions and risks in supply chains. The majority of them, however, are based on case studies and empirical evidence, which limits their generalizability beyond the specific contexts and the extension of the strategy beyond dyadic relationships. Melnyk et al. (2009) provide an innovative formalized methodology in mitigating disruptions in supply chains with the use of discrete event simulation. Their approach extends previous studies; however, their study is limited by the lack of real-time adaptability of their model that is evidenced in supply chains. Methodologies that can overcome this limitation like agent based modelling are considered very useful in this respect.

The agent based technology is acknowledged as one of the most promising technologies for effective management of supply chains that are characterized by high levels of uncertainty (Brooks and Davenport, 2004; Lou et al., 2004) due to its vital characteristics of:

- *Autonomy*: agents are aware of their environment operating without human intervention to some extent in order to fulfil their objectives (Jennings and Wooldridge, 1995)
- *Social ability*: an agent can interact with other agents or humans through the use of an agent communication language (Moyaux and Chaib-draa, 2006).
- *Reactivity*: agents can perceive their environment and respond to specific changes in this environment (Parunak, 1999)
- *Pro-activeness*: agents do not simply respond to changes in their environment, but can initiate actions (Moyaux and Chaib-draa, 2006).

Despite the fact that the technology is relatively old and well known, in today's business reality multi-agent software platforms are not used widely for the management of business processes. Electronic resource planning systems (ERP) are still the most common software selection for managing a company's processes (Burka et al., 2005). The latest advancements of ERP systems that incorporate the integration of SCM processes give rise to promises that they can lead to significant improvements (Kelle and Akbulut, 2005).

The efficacy of conventional ERP systems, however, to provide real time synchronization among supply chain partners – which is necessary for effective SCRM – is limited. Their design has been based on the need for integration with legacy systems. This restricts their ability to meet the high level of agility required for decentralized control (Karwowski et al., 2007). The inflexible nature of ERP systems to adapt to rapidly changing business environments in a cost efficient manner, has forced many organizations to fit their processes according to the capabilities of the ERP system in order to save funds and time (Helo et al., 2005).

The latest generation of ERP systems that utilize Service Oriented Architecture and web services for process management has the potential of providing real time information on several activities in an enterprise (Tarantilis et al., 2008), which can speed up the decision making process and lead to better integration amongst supply chain partners. Their modular design increases their flexibility, making them more applicable to several managerial processes. Their computational capability for managing very complex processes, however, is limited (Helo et al., 2005), and their role is confined only in the timely flow of information about the condition of several processes. A considerable amount of time and funds is also required in order to yield benefits from the latest ERP technologies, implying that only organizations that can afford the required high level of investment will be able to achieve responsiveness, and overall to reinforce their competitive advantage. The multi-agent architecture for an SCM (Fig. 1) offers an opportunity to overcome the shortcomings of conventional ERP technology, providing a plethora of advantages.

Through their learning capability, an MAS can demonstrate efficiently the proactive and autonomous behaviour of the participating agents in mitigating risks and rectifying supply chain disruptions in real time (Kwon et al., 2007; Lu and Wang, 2007). They can also promote a high level of cross organizational collaboration in a computational and cost efficient manner (Swaminathan et al., 1998).

The inherent distributed nature of agent based technology (in that, a problem solution is distributed to different agents) gives the significant advantage of ease in dealing with the high level of complexity of global supply chains in contrast with conventional information technology (Akkermans et al., 2003). This is enhanced by the fact that each of the agents has a specific expertise and a computational efficiency in dealing with this complexity in combination with easiness of development in a short time frame (Lu and Wang, 2007). With this approach, re-configuration of the whole supply chain can become a reality in a timely fashion and with a low cost.

These benefits can be materialised by incorporating existing legacy systems. An expert system for inventory management, or an ERP system, for example, can be integrated with multi-agent software. The main technique applied is to "wrap" around the legacy code with an agent based software, without the need to rewrite the whole legacy code, in order to "agentify" it into a normal agent (Genesereth and Ketchpel, 1994). On this basis, the wrapping software is used as a "facilitator" to interpret messages from an agent to legacy software and vice versa, aiming at providing an understandable communication platform for both sides (Davidsson and Wernstedt, 2002).