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A multi-agent architecture for outsourcing SMEs manufacturing supply chain

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ABSTRACT

In the present, global and competitive market customer's demands are very volatile. It is very difficult for small and medium size enterprises (SMEs) to satisfy their customer with quality product in reasonable price. Large firms are spending huge amount of their budget in generating technology development. To cope with this competitive market, usually, SMEs concentrate on their core expertise and outsource some non-core items or activities. The outsourcing decision (when, what, whom) is very crucial for small-scale industries. Realizing this scenario, in this article, an automated self-adaptive multi-agent system has been proposed. The proposed system will help SMEs to take an appropriate decision to mitigate the uncertainty in supply chain. The developed system exploits the "Outsourcing of operations" feature by its agents to conclude the manufacturing processes faster and reduce the idle time of certain machines with less human intervention. The communication protocol for agents has been described to give an insight of their communication. It was explained how various agents like outsourcing, material planning and supplier selection will come into action at different stages and take appropriate outsourcing decisions. Therefore, this multi-agent architecture will facilitate small scale manufacturing industries to execute their manufacturing processes and complex logistics issues efficiently. The execution of proposed architecture has been described in the simulated case study.

1. Introduction

SMEs are seen as a symbol of innovation and competition in various industrial sectors. The revenue generated by them accounts for 50% of GDP and their workforce accounts for 60% of employment in the developed countries [1]. However, they are considered as 'underachiever' when it comes to doing business abroad. The Foreign Direct Investment (FDI) associated with SMEs is marginal and their contribution to exports is only 30%. The main reasons for their limited success are lack of resources (financial [2], technical [3] and relevant market information [3]), insufficient government support [4] and inability to deal with global affairs (international prices, unavailability of foreign business stakeholders etc.) [5]. Moreover, their revenue has suffered a lot because of recession in past decade. Also, the modern customer is looking for quality products at lower prices. Then, there is a time constraint i.e. they have to deliver the products in a short notice of time. All these above factors, collectively have affected the sustainability of SMEs. Therefore, they are working on various measures to address it like cost cutting in terms of inputs, redundancy of staff etc.

In the past, SMEs usually, buy only raw materials from outside and perform rest of the operations in-house. However, to compete in present market scenario, sometimes, they even outsource some of their operations. Outsourcing is contracting out some of the business activities such as manufacturing, maintenance, accounting or logistics to the third party. It usually helps company to focus on their core business issues while minimizing different costs associated with non-core activities. This outsourcing of certain operations to external industrial partners has significantly brought down the expenses incurred and the time taken in manufacturing a product. The main advantages of outsourcing activities are [6–14]: (a) low manufacturing costs, (b) minimize uncertainty related to the risk-pooling effect, (c) less capital investment, (d) more emphasis on core competency, (e) better capacity adjustment, (f) enhanced flexibility, (g) better response to the customer's requirement, (h) Quality improvement by better use of supplier's technical knowledge, (i) better use of new technology of the contracting partner. However, these outsourcing activities make the entire process complex and will only be helpful when SMEs take appropriate decision regarding what to outsource, when to outsource and whom to outsource. In all these processes, the

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manufacturing plant has to interact with more than one industry and negotiate the price and terms and conditions of the deal. Keeping the same in mind, in this article, multi-agent architecture has been designed. The proposed multi-agent architecture will help industry to take appropriate decision with the help of different artificial intelligent techniques. Multi-agent system (MAS) originates from distributed artificial intelligence. MAS are defined as an assembly of intelligent, self-interested software entities known as agents who work collectively to solve complex problems with more precision and less time and human intervention. These agents are autonomous in nature as they are active entities, which are capable of self-decision-making. They are designed to make a decision to execute or not a requested task by considering its goals, priorities and the situation [15]. Agents for communication among themselves and with the human users deploy Agent Communication Language (ACL) [16]. MAS are also capable of intra firm and inter firm interactions [17].

In the literature, plethora of research has been conducted to address different issues related to outsourcing activity in manufacturing supply chain [18–28]. During the study, Zheng et al. [29] found that information sharing is a critical issue for different segments of distributed manufacturing. In order to address this issue, they suggested web based multi-function scheduling system. Knowledge and communication within different segment is an integral part of manufacturing supply chain [30]. Suggested a multi-agent architecture to establish the effective communication and coordination among the distributed global manufacturing networks [31–34] proposed a decentralized information system to establish the link between the global manufacturing networks. The goal was to address the issue related to due date of customer in distributed manufacturing supply chain [35]. Proposed genetic algorithm (GA) based approach to generate plans for single and distributed manufacturing systems [36]. Utilized the beauty of fuzzy rule and developed multi-agent architecture to address the issue related to the imprecise information and fault recovery in a distributed network [37]. Suggested a distributed multi-agent architecture for fault diagnosis system in artillery command system. To minimize the production cost and lateness of the customer order [38], proposed a multi-agent scheduling systems for a distributed manufacturing environment. Multi-agent mediator architecture for distributed manufacturing was proposed by [39]. In distributed architecture for knowledge sharing [40], proposed a multi-agent system (MAS) in an e-business domain [41]. Reviewed the development and use of a multi-agent modeling techniques and simulations in the context of manufacturing and supply chain management [42]. Conducted a study to find out the challenges and research opportunity related to application of multi-agent architecture in holonic manufacturing systems [43]. Highlighted the application of MAS in improving the coordination of manufacturing supply chains associated with major uncertainties [44]. Utilized multi-agent system in conjunction with auction based negotiation approach for distributed multi project scheduling [45]. Applied multi-agent system to production planning and scheduling framework for mobile robots [46]. Discusses the architecture of a framework, which is using RFID enabled multi-agent system for flexible manufacturing shop [47]. Presents an overview of using multi-agent system with bio inspired methods to solve complex problems of reconfigurable manufacturing systems [48]. Proposes a real time solution for an automotive supply chain to execute multi-level decision-making process in order to enhance their service levels and profits [49]. Implemented a web based tool to a precision engineering SME to improve their production planning and their consequent performance. In the literature, there are plenty of attempts being made to address various outsourcing issues of manufacturing supply chain. However, there is not enough research being done in outsourcing operations of manufacturing SMEs. Outsourcing a particular operation is a complicated decision and requires lots of human interference. In the past, researchers have applied various meta-heuristic techniques, mathematical modeling, multi criteria decision making etc. There was not a single method, which was single handedly able to address problems of different types in different scenarios. It makes this phenomenon more complex. In this paper, algorithm portfolio is utilized by multi-agent system, which is capable to select appropriate method or algorithm depending upon the situation. Therefore, this multi-agent system is automated in its decision-making.

This article proposes self-adaptive multi-agent architecture to address this issue. The beauty of this automated system lies in the ability of precise multi-tasking of its agents. Outsourcing, material planning agent and supplier selection agent are responsible for outsourcing some of the internal operations of the manufacturing industry to the external industrial partners in order to bring down the manufacturing time and manufacturing price of the final product. Maintenance agent looks after the planning and execution of the maintenance policies for the machines in the manufacturing plant. Additionally, it can also make provision for outsourcing of the maintenance of certain machines to some external industrial partners according to the circumstances. Purchase order collection agent takes the order from the client and interacts with the planning agent to finalize the due date of delivery for the products. If there is a case where the client wants the delivery of the products earlier and is adamant in its approach leaving no room for negotiation then purchase order collection agent interacts with planning agent and outsourcing and material planning agent to outsource certain number of the internal operations of the manufacturing plant to external industries in order to meet the deadlines proposed by the client. These agents interact with each other using an agent communication language called Multi-agent logic language for encoding Teamwork (MALLET).

2. Agent framework

The proposed multi-agent architecture for outsourcing supply chain is presented in Fig. 1. It consists of purchase order collection agent, outsourcing and material planning agent, supplier selection agent, planning agent, knowledge base agent, maintenance agent, reconfiguration agent and forecasting agent. All these agents work in collaboration with each other. The properties of each agent are described below.

2.1. Purchase order collection agent

This agent receives the order from the clients for the manufacturing unit. It confirms the due date for the delivery of the ordered products by interacting with planning Agent. If the client mentions a deadline and the planning agent (after looking at its manufacturing plan) says that it cannot meet the deadlines, looking at its capacity (number of machines available) and the current workload. Then, the purchase order collection agent tries to negotiate with the client. If the client is strict about the deadline then some of the operations are outsourced to an outsourcing partner by taking help of outsourcing and material planning agent and gets the product manufactured within the given time limit. Then, it decides the mode of payment whether it is cash, cheque, online banking, wires transfer, bank draft or paying in installments depending on its communication with administrative agent and hence confirms with the client. He further decides the way of delivery of the ordered products with the help of transport agent. It could be either through road transport using lorries, via railways, or using airfreight by reaching a consensus with the client. This agent is in continuous touch with the knowledge base agent

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