A Multi-Agent Self-Adaptive Architecture for Outsourcing Manufacturing Supply Chain

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Abstract In present day's economy of recession and frequent market fluctuations, it is difficult to satisfy the customer with the products and services at reasonable price. The prices of resources are increasing consistently and the manufacturing industries have to optimize the use of resources so as to make a trade-off between the cost incurred and the services provided to the customer. Realizing this scenario, this article proposes an automated system equipped with artificial intelligence to deal with these complexities and difficulties. This automated system has the capability of self-decision-making and is further complemented by the feature of reconfiguring its operation according to the various uncertainties in the Supply Chain. It utilizes multi agent architecture for its operations. It focuses on adding some additional features to the conventional multi agent architecture for improving the efficiency of the Supply chain and optimizing the make span. It exploits the "Outsourcing of operations" feature by its agents to conclude the manufacturing processes faster and reduce the idle time of certain machines. This article also presents the concept of outsourcing of the manufacturing plant. This multi agent architecture will facilitate small scale manufacturing industries to execute their manufacturing process and complex logistics issues efficiently.

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1 Introduction

In this modern age of Globalization and competitive market, customers have numerous options and their sole approach is to get the high quality product in minimal cost. The manufacturing industries have to do lots of alterations in their traditional work ethics in order to meet this requirement like cost cutting in terms of the raw materials and other mandatory inputs purchased and bringing down the miscellaneous expenses within the plant. Furthermore, they have to smartly reframe their policies to tackle the serious issue of current slowdown in global economy and the consequent market fluctuations.

Traditionally, manufacturing industries used to get only the raw material from external industrial partners or vendors but these days due to the market scenario getting complex day-by-day, they are even outsourcing some of their internal operations to external industries. This outsourcing of certain operations to external industrial partners has significantly brought down the expenses incurred and the time taken in manufacturing a product. Furthermore, there is lot of crucial decisions taken by manufacturing industries in terms of choosing a proper supplier for their raw materials, an outsourcing partner, selection of materials etc. In all these processes, the manufacturing plant has to interact with more than one industry and negotiate the price and terms and conditions of the deal. To ease off all these complexities, demand for automated system incorporating artificial intelligence in the manufacturing industries is rising.

In the past plenty of research has been conducted to resolve the issues related to information sharing in distributed manufacturing environment [1–3]. Knowledge and communication within different segment is an integral part of manufacturing supply chain. Chan and Chan [1] suggested a multi-agent architecture to establish the effective communication and coordination among the distributed global manufacturing networks. References [2, 4–6] 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. Li et al. [7] proposed genetic algorithm (GA) based approach to generate plans for single and distributed manufacturing systems. U-lieru and Norrie [8] 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. Gefang et al. [9] 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 [10] proposed a multi agent scheduling systems for a distributed manufacturing environment. Multi agent mediator architecture for distributed manufacturing was proposed by Maturana and Norrie [11]. In distributed architecture for knowledge sharing [12] proposed a Multi agent System (MAS) in an e-business domain. Lee and Kim [13] reviewed the development and use of a multi-agent modeling techniques and simulations in the context of manufacturing and supply chain management. Leitão [14] cdecides the amount of raw materialonducted a study to find out the

challenges and research opportunity related to application of multi agent architecture in holonic manufacturing systems.

This article proposes 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 and 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.

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 air freight by reaching a consensus with the client. This agent is in

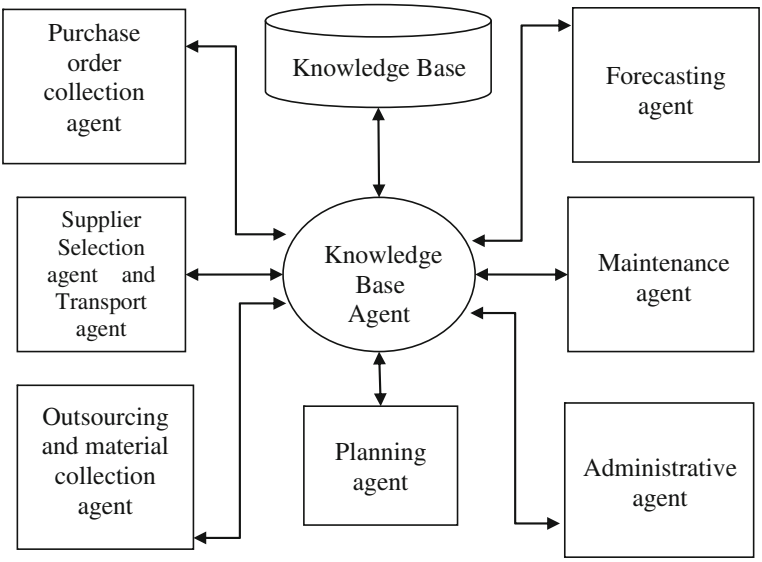

Fig. 1 Proposed multi-agent architecture

continuous touch with the knowledge base agent throughout its activities. This agent can update itself both online and offline.

Outsourcing and material planning agent: This agent is in continuous communication with planning agent and forecasting agent. It has all the records of the available raw material within the manufacturing unit. The moment forecasting agent sends information about the future demand, it makes a decision about the different kinds of material and their respective quantities needed and sends this information to the supplier selection agent to look for the appropriate supplier to get it from. It also takes decision if a particular operation/part has to be implanted or outsourced and this decision will be based on the due date, expectations of the customer, and available resources in plant. If he finds that particular operation/part has to be outsourced it looks for the outsourcing partner or if there is any accessory which needs to be imported in order to complete the product being manufactured.

Supplier selection agent: The moment this agent get information from outsourcing and material planning agent it starts looking for the available suppliers of the raw. It could use the database of knowledge base agent and look for the company records of past deals with various suppliers and check their feedback. It can have a look in catalogues (online and printed) of various reputed suppliers, supplier and commodity directories, Trade journals and trade shows, and various trade advertisements. It can use its professional contacts and networking or might look for the other capable suppliers on the Internet. Selection of the supplier is being done by evaluating it with three different and independent procedures. Firstly, it looks for the few major factors which are listed below in order of their priority:-

1. Availability
2. Quality of the material being supplied
3. Cost
4. Reliability
5. Distance of the supplier from manufacturing unit.

Then, it also takes into account the technical expertise of the supplier by considering factors like design engineering capability, sustaining engineering capability, Facilities and equipment used, output capacity, Long term potential, Flexibility to ramp up and down quickly and responsiveness, Logistics expertise, and Track record of cost reductions.

Finally, it looks at the Financial and management aspects of the supplier. It reviews the supplier by their financial history, Balance sheet, Income statement, and credit worthiness. It further looks at the efficiency of the their executive and management team, management controls, and information systems. Then it checks their policy framing techniques like Policies organization structure and decision making, Alignment with the mission, corporate culture, values and goals of their corporate structure and their ability to integrate procurement systems.

Planning Agent: This agent deals with the planning and organization of various operations in manufacturing unit. It generates the manufacturing plan which includes when the products will be manufactured, their quality, and the methods used. This agent depicts which machine will be used and when it will come into operation in order to manufacture a particular product. This agent is continuously in touch with the maintenance agent. It is done in a way to minimize the idle time for the machines. These days the manufacturing lines are flexible in nature. It also decides the storage for the raw material and other materials needed for the manufacturing, Furthermore; it chooses the optimum place to store the raw materials considering the minimum logistics and storage expenses. It is also responsible for the easy availability of raw materials to the machines in the manufacturing unit and make sure that exact amount of raw material is available in the manufacturing unit as excess or deficiency of the material can affect the efficiency of the manufacturing unit.

As soon as the new order arrives the planning agent takes appropriate manufacturing decision using employing artificial intelligence technique such as genetic algorithm (GA), simulated annealing (SA), tabu search (TS), ant colony optimization (ACO), and bee colony optimization (BCO). However, in the literature it was observed that no random search algorithm exists that can be regarded as best suited strategy for a particular type of problem. Selection of the algorithm depends on nature of the problem. Keeping the same in mind in this article planning agent uses algorithm portfolio concept [15]. Algorithm portfolio is a collection of different algorithms and/or different copies of the same algorithm running on different processor. The portfolio algorithm is exploited through combining the algorithms and analyzing their performances on multiple processors as well as on a single processor. The main task of the portfolio is to choose the algorithms that lead to a high level of performance on a given problem instance, that is, to bring out near-optimal solutions

in stipulated time frame. This leads to minimization of the computational cost, increase in the diverse problem solving capability, and maintenance of the quality from the best. The algorithm portfolio system will start working as soon as the new problem instance arrives and will be characterized by allocating a time limit to provide the solution. Thus, initially the allocator will assign an experimentation time to various algorithm agents and will decide the priority order of the algorithm agents. The data collected during the experimentation from each algorithm agent will be fetched to the selector agent on the basis of whom it decides the algorithms to be bunched in a portfolio to solve the stage problem at hand. These algorithms are run for an over a number of iterations. At the end of iteration, the control agent will assign improved knowledge to each algorithm agent. Thus, rather than making a single decision about the final selection of an algorithm agent for the remaining time, the selector will revisit its choice over and over.

Knowledge Base Agent: This agent is connected with all the other agents such as outsourcing and material planning agent, supplier selection agent, planning agent, forecasting agent, and maintenance agent. This agent stores all the information related to the manufacturing processes. It is done by collecting information from all the other agents and monitoring their activities. It holds the information about the current status of components being processed in order to manufacture a product, the order in which they are processed and their processing times Furthermore, it stores the information regarding the successful and unsuccessful decisions made by other agents. It helps so that the mistakes committed in the past are not repeated. This agent can update itself both online and offline.

Forecasting Agent: This agent decides the amount of raw material to be ordered and pass this information to purchase order collection agent, outsourcing and material planning agent, and supplier selection agent. This decision is taken in accordance with the market fluctuations prevailing at that moment of time. Forecasting agent consists of high performance tools for forecasting and estimating the quantitative and qualitative demands of the current trends of the market. The main objective of this agent is to minimize the error in the estimated demand pattern by considering the market fluctuations. This agent utilizes a vast set of judgmental and mathematical tools depending upon the nature of forecasting data available. It is a very complicated job to choose the best method for forecasting the demand pattern.

In the literature there are plenty of methods available for judgmental and mathematical forecasting methods such as Unaided judgment, Prediction markets, Delphi, Structured analogies, Game theory, Judgmental Decomposition, Judgmental bootstrapping, Expert systems, Simulated interaction, Intentions and expectations surveys, Conjoint analysis, Extrapolation, Quantitative analogies, Rule-based forecasting, Neural nets, Data mining, Casual model, and Segmentation. Choosing the best forecasting method for any particular situations is a very tough task, and sometimes more than a method may be appropriate. In order to choose the best forecasting method among the available, forecasting agent adopts a decision making methodology. For example in a particular situation if the agent decides to go ahead with the quantitative methods, the selection of the appropriate method will be based on the intercession tree.

Maintenance Agent: It utilizes the sensor in the machines to monitor their maintenance requirements, breakdown status, idle or in process stages etc. There are various maintenance policies being followed in the manufacturing sector having their respective advantages and shortcomings. This agent will prioritize the sequence of machine which needs maintenance or repair. It will also take decision about whether a machine can be repaired or it needs to be replaced. It will prepare a maintenance schedule in a way so that there will be minimum alterations in the working of other agents. It will further make a decision about the maintenance of machine whether it will be done in the premises or it needs to be outsourced. It maintains all the records such as information regarding repair date, warranty/guarantee of the machines. Furthermore, it has the information regarding which machines are dependent on other machines. It will communicate with the knowledge base agent for selecting the new machines. It keeps the record of the spare parts, necessary tools, lubricating oils etc. which needs to be ordered for the respective maintenance of the machines.

The Maintenance Agent is responsible for monitoring the maintenance requirements of conveyances and therefore has the ability to both access appropriate data sources and to monitor the operational state of conveyances and high value loading facilities through the interpretation of sensor data.

Administrative Agent: This agent will make sure that all the operations performed by various agents are within the legal boundaries. It will take care of agreements, warranties, guaranties, transport security, and other Health and Safety measures. It will maintain all the Accounts like salaries of employees, payments of supplier, customer's payments, and other overheads.

Communication Ontology: In the proposed agent architecture an agent can cooperate with other agent by sending help signal. Help signal can only be responded by agents who come in perceptory region of the agent who has sent signal. Mathematically, 'help' signal Hti send by ith agent for collaborative help in task 't' is defined as:

$$H_i^t = (a_i, t_t) \forall\, A^{PR_i} \ldots \tag{1}$$

where, A^{PR_i}represents the set of agents within the perception range (PR) of agent '*i*' and is defined as:

$$A^{PR_i} = \left\{ a_j \in a / a_j^{PR_i} \right\} \ldots \tag{2}$$

$$\exists A^{PR_i} \in a, \quad A^{PR_i} \wedge \neg(a_i) \ldots \tag{3}$$

and $a_j^{PR_i}$represents the 'j' agent lying in the perceptory range of agent 'i' and is defined as;

$$a_j^{PR} < \left| d_{ij} \right| < PR_i \ldots \tag{4}$$

$|d_{ii}|$ represents the distance between the agents i and j. In this architecture, Manhattan distance has been taken into account because of its effectiveness compared to Euclidean.

Distance in parallel computing scenario [16, 17]. Upon receiving a 'help' signal form agent i, agent j send a 'reply' signal r_j^i defined as

$$r_j^i = (a_j, a_i, H_i^t) \tag{5}$$

3 Case Study

A medium size manufacturing industry is being considered to demonstrate the execution process of proposed architecture. As soon as new customer has arrived, purchase order collection agent collects all information related to the order like design of the product, its specification, due date etc. Now he communicates with all other agents such as supplier selection agent, planning agent, outsourcing and material ordering agent, maintenance agent to know the current status of the plan. On the basis of the collected information such as raw material stock, machine availability, current orders in process, purchase order collection agent estimates the due date for the new order. If the industry is not able to meet the due date of his new customer, purchase order collection agent try to negotiate with the customer on due date. As soon as order is finalized purchase order collection agent pass all the information related to order to all appropriate agents. Thereafter outsourcing agent decides the production policies that are if all the operations would be implanted or few of them needs to be outsourced. Similarly material ordering agent looking at existing stock decides how, when, and what has to be ordered keeping in touch with forecasting agent. When all these are decided supplier selection agent selects appropriate partner or suppliers of the raw material. In all these process agents consult knowledge based agent to collect information related to the similar deals in the past. The history of any deal with the selected supplier is being checked in its database and if the feedback is positive then the deal is being finalized. Now planning agent plans the entire process of manufacturing. In this process planning agent uses algorithm portfolio for manufacturing planning, scheduling, and execution. After manufacturing the order is delivered to the customer. All these processes and the decision made is being tracked and stored in the Knowledge base agent for future reference.

In this case Study Company got two orders from different customer. Each order consisted of manufacturing of 5 parts. In order to manufacture the products, one of the operation needs to be outsourced which cannot be performed in the manufacturing unit. So, the outsourcing agent decided to outsource one of the operations. Detailed information related to the order such as due date, precedent relationship and type of operation is given in Tables 1 and 2. The final operation sequence generated by planning agent using algorithm portfolio is mentioned in Fig. 2. The final outcome shows the efficacy and the execution process of the proposed architecture.

Table 1 Processing time and available machines

Part no	Operation number	Processing/ outsourcing unit	Processing time
1	1	M1	5
		M2	3
	2	M2	7
	3	M3	6
	4	M2	3
		M4	3
		M5	4
2	5	M1	7
	6	M2	4
		M3	6
	7	M3	7
		M4	7
	8	M2	4
		M5	10
3	9	M1	4
		M2	5
		M3	8
	10	M4	5
	11	M4	6
		M5	5
	12	M1	4
		M5	4
4	13	M2	2
		M3	6
	14	M3	8
	15	M3	3
		M4	8
	16	M2	6
		M4	7
		M5	4
5	17	M1	3
		M3	5
	18	M3	7
	19	M4	9
		M5	6
	20	M1	6
		M5	3

Table 2 Precedent relationship between operations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

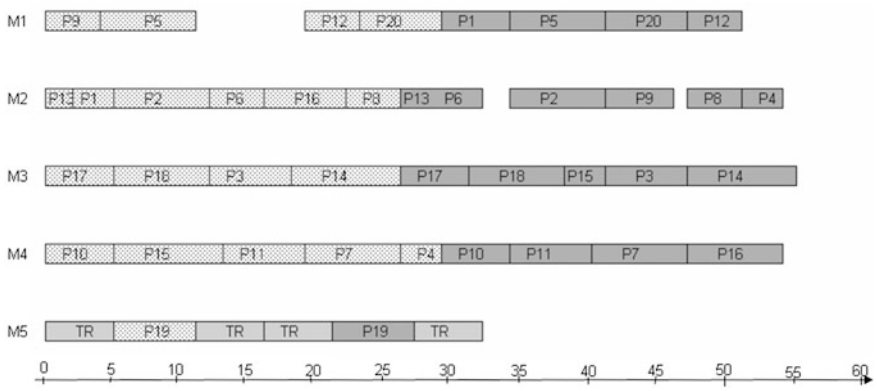

Fig. 2 Final manufacturing plan suggested by planning agent

4 Conclusion

The manufacturing industries at present are suffering from the serious consequences of inflation (in terms of resources and other inputs) and decline of global economy. The Multi agent framework proposed in this article is being devised to combat this complexity prevailing in the market. This framework being flexible in nature can be modified as per the requirement of manufacturing industries.

The other existing agent architectures in literature are generally not self-adaptive in nature. The proposed architecture is self-adaptive in nature. As soon as new order arrives it negotiate with customer on due date, automatically decides on outsourcing policy and supplier selection. In the earlier architectures, if the agent were not capable of acting alone then they usually required user's interference. However, in this proposed architecture the agents communicate among themselves to develop new skills to automatically accommodate new changes.

In the literature there is no set rule for selection of appropriate planning algorithm. While in the proposed agent architecture for a corresponding order planning agent exploit the beauty of algorithm portfolio and automatically select the suitable efficient algorithm for planning process. The maintenance agent apart from planning and execution of the maintenance policies is also capable of outsourcing the maintenance operations of the machines if they cannot be done cheaply and conveniently within the manufacturing plant. The selection of the correct forecasting method usually depends on problem environment. In literature agent architecture used only one method for forecasting. However, in this agent architecture, more than one forecasting method has been used and the agent automatically selects a particular method for a specific problem. The proposed agent architecture composed of multi agent architecture is capable of resolving the decision-making issues in manufacturing industries. This framework is capable of automatic decision making without the inputs from user interface.

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