# Intelligent shop floor scheduling using multi agent systems

*Minakshi Kumari*, *minakshik@mech.iitd.ac.in*,
*Research Scholar, Mechanical Engineering Department, IIT-Delhi, India*

*Nikhil Chilwant, Anand Prajapati,*
*UG Student, Mechanical Engineering Department, IIT-Delhi, India*

*M. S. Kulkarni,*
*Associate Professor, Mechanical Engineering Department, IIT-Delhi, India*

## Abstract

Production scheduling becomes more complex as some other function like maintenance gets coupled with it. Multi Agent Systems are considered as intelligent solution providers in such complex decision making environments. The paper presents a conceptual framework for a Multi Agent System for integrated scheduling and maintenance.

**Keywords:** Intelligent scheduling, Multi agent systems, Integrated approaches

### Introduction

Current age manufacturing systems are characterised by an environment full of uncertainties and evolving dynamics. With ever growing market volatility, manufacturers are in a continuous pressure to innovate, adapt and respond to changes in least possible time without hampering the product quality that too at the best possible price. With no surprises, the effect of this has propagated to the shop floor and it will not be wrong to say that the efficiency of a manufacturing system closely depends on how well its shop floor functions are tuned and ready to respond to changes. In the context of a shop floor, the onus of responsiveness lie on the shop floor functions namely production scheduling and maintenance. Integrating these shop floor functions has gained the attention of researchers in the recent past. Intuitively, such integration gives a sense of facilitating better, optimal and robust decision making environment on the shop floor but imperatively the complexity of decision making increases.

For a system where information involved is necessarily distributed, the system components are heterogeneous and the system is so dynamic that content is changing rapidly- modularity, distribution, abstraction and intelligence are the four ways suggested in literature to handle the complexity of such a system (Weiss 1999). Multi Agent based decision support systems are growing as a paradigm for developing distributed intelligent manufacturing systems and has gained a lot of interest as a suitable technology to develop systems that demand distribution, flexibility, robustness and re-configurability (Leitao 2008). Use of Multi Agent systems for dynamic scheduling is reported in the literature during the past decade. However, an approach to develop a multi agent system wherein multiple shop floor functions are considered jointly is not yet reported. Most of these existing agent systems work on a reactive, predictive or real time adaptive decision making under uncertainties. But in real life, manufacturing system decisions cannot be categorised into any one of these categories solely. To enumerate it, a rescheduling may have to be done reactively but machine health may have to be predicted beforehand so as to come up with a robust initial schedule. Moreover, the prediction of machine health cannot be reactive; instead it has to be a knowledge based decision. So, in a nut shell, a distributed system design for a manufacturing shop floor ought to have a blend of these decision making strategies and it should be efficient enough to switch its mechanism as and when required by different functions. The current paper aims at presenting a framework for designing a Multi agent based decision support system for a manufacturing shop floor wherein production scheduling and maintenance functions are considered jointly. The agent system proposed is as per the BDI (Belief-Desire-Intention) architecture. The paper gives a detailed account of types of agents required for an integrated manufacturing system, their relative organization, communication, co-ordination, negotiation, co-operation, their action plans and their individual beliefs-desires-intentions.

**Problem Overview**

Among various aspects that result in the feasible execution of an optimal schedule, availability of machines is one of the major constraints, ensuring which is the role of maintenance function Moreover; a planned maintenance can be taken up only if the machine has no production activity scheduled on it. Similarly, proper maintenance ensures good product quality, in absence of which rejections and reworks may be high resulting in failure to meet the production target. To state it more explicitly, there exist some coordinates of commonalities that result in an overlap between these two shop floor functions. Also, any uncertainty associated with any of these functions propagates its effects to other functions. For example, if the customer demands are erratic, production planning and scheduling has to be flexible. Consequently, the planned maintenance schedule has to keep adjusting itself which may leave some undesirable effect on product quality due to high process variability. Similarly, other uncertainties like due date change, waiting times, product mix, availability of raw material, machine breakdowns, spare part availability, processing time, operator availability etc. have an effect on these functions. Hence, integrating these shop floor level operational activities is needed for effective decision making. Integration ensures an optimal decision making environment but there are other issues that crop up with it.

Scheduling and maintenance functions have certain function specific goals to be achieved which may not be in line with each other’s goal. For example, at any instance, for any given machine, the priority for scheduling function may be the completion of a rush order but for the same machine, a planned maintenance activity may be the priority of maintenance function. Similarly, there can be situations where delaying a priority order completion just for the sake of a scheduled maintenance activity may not be desirable as the machine health/state may not be so critical.

In addition to these inter functional conflicts; intra functional decisional dilemma may also exist. For example, at any point in time, whether assigning a particular job to a particular machine would be profitable or splitting it into two batches and assigning them to two of the machines keeping in view the machine specifications, completion time, machine health, other jobs in queue and subsequent process capacity may be a choice to be made. In order to reach to the best possible solution in such an environment, a detailed know how of the possible moves of each other and the expected end effect of each move on the system performance should be known. Hence, a lot of logical information sharing, coordination and cooperation and above all, intelligence is required. Decision making in such multifaceted environment gets tough, and at times it gets beyond human capability to mentally simulate all possible scenarios and reach to an effective or optimum decision. This gives way to devising an intelligent agent system for a shop floor which is equipped with human like reasoning capability, sociability but devoid of the computational and similar other constraints of human brain.

## Literature Review

Multi agent system paradigm characterized by decentralization and parallel execution of activities by autonomous entities derives its origin from distributed artificial intelligence. There is no single definition to the concept of agents, and researchers based on their varying interpretations, have their own definitions (Russel and Norvig 1995; Wooldridge and Jennings 1995; Ferber 1999; Wooldridge 2002). Ferber (1993) defined an agent as a real or a virtual entity able to act on itself and on the surrounding world, generally populated by other agents. Its behavior is a result of its observations, its knowledge and its interactions with the world and other agents. Ferber (1993*)* defined a multi-agent system (MAS) as an artificial system composed of a population of autonomous agents, which cooperate with each other to reach common objectives, while simultaneously each agent pursues individual objectives. Adjustable autonomy, co-operation, intelligence and adaptation are some of the important characteristics of an agent. There are several agent architectures, ranging from reactive agents, operating in a stimulus–response manner, to deliberative agents characterized by their pro-active reasoning and goal- oriented behaviour. A well-known deliberative and cognitive agent- type is belief–desire–intention (BDI) architecture (Wooldridge 2002). Besides manufacturing, agent systems have found their applicability in e-commerce, e-business, air traffic control, process control and telecommunications.

One of the earliest attempts to introduce the heterarchical control approach, using agents to represent physical resources, parts and human operators, and implementing scheduling oriented to the parts was made by Duffie and Piper (1986). CORTES (Sadeh and Fox, 1989), (YAMS) (Parunak 1998), Rock Island Arsenal (AARIA) (Parunak *et al.* 1998) were the some of the earliest attempts to develop agent based structures in manufacturing. Butler and Ohtsubo (1992) developed a dynamic scheduling mechanism for local resource allocation at the local work. Based on Lagrange relaxation concepts Gou *et al.* (1998) defined a scheduling algorithm. It works on a centralized coordination among the individual holons to improve the schedule. Heikkila *et al.* (1997) proposed a holonic approach for manufacturing scheduling and control in a manufacturing cell. Sugimura *et al.* (1996) used an object oriented approach to model the manufacturing operations for real time scheduling of assembly lines. A real time scheduling in an existing FMS was attempted by Cheung *et al.* (2000).

The approaches developed for integrating production scheduling and maintenance, in past three decades, started with single machine, single product scheduling problem with multi objective optimization. The approach was further extended to single machine multi-product kind of scenario (Sloan and Shanthikumar 2000). The various objectives considered for job scheduling have been minimizing the total weighted completion time of jobs, minimizing the maximum lateness of the job (Graves and Lee 1999), maximizing long run expected average profit (Sloan and Shanthikumar 2000), minimizing the costs of earliness, tardiness, due- window starting time, due window size (Ji *et al.*, 2007), minimize the maximum weighted tardiness (Cassady and Kutanoglu 2003), minimizing the make span for scheduling (Moradi *et al.* 2011). Time for maintenance (Graves and Lee 1999), variable maintenance time subjected to machine degradation (Pan *et al.* 2010), resource availability (Wang and Yu 2010) and system unavailability for the maintenance were some of the maintenance constraints considered for jointly optimizing the functions (Moradi *et al.* 2011). Heuristics like Chaotic Partial Swarm Optimization (Leng *et al.* 2006), based on genetic algorithm (Moradi *et al.* 2011), filtered beam search algorithm (Wang and Yu 2010) have been used for finding the optimum solution while considering production scheduling and maintenance together. (Bouzini-Hassini *et al.* 2012) presented a multi-agent scheduling method that integrates both planning and maintenance activities. The authors believed that the plan selection must depend on information about machines maintenance and states to offer realistic schedules.

## Intelligent Scheduling Framework

Like a usual agent system, the proposed agent design architecture perceives the environment as well as the current status of the physical system. By the environment reference is to the arrival pattern of the jobs, general occupancy of the resources, processing capability of machines etc. which in turn adds to the information database of the system. The current status of the physical system comprises of the system state and the machine state. By the system state, the reference is to the batches being processed, unit processing time, the corresponding due dates, average queue length and similar real time information. The machine state gives input about the health of machine, component age, any component parameter monitoring etc. Based on these perceptions, a belief set is generated which in conjunction with the system goals result in a desire or a plan creation in the agent body. Following it, the agents formulate an action plan which can be referred to as their intentions. The agent action can fall in any of the categories from informative to active, predictive or preventive depending upon the set of actions that it is required to execute. This modulation of agent beliefs, desires and executable actions as it senses the system and environment state is presented in Figure 1.

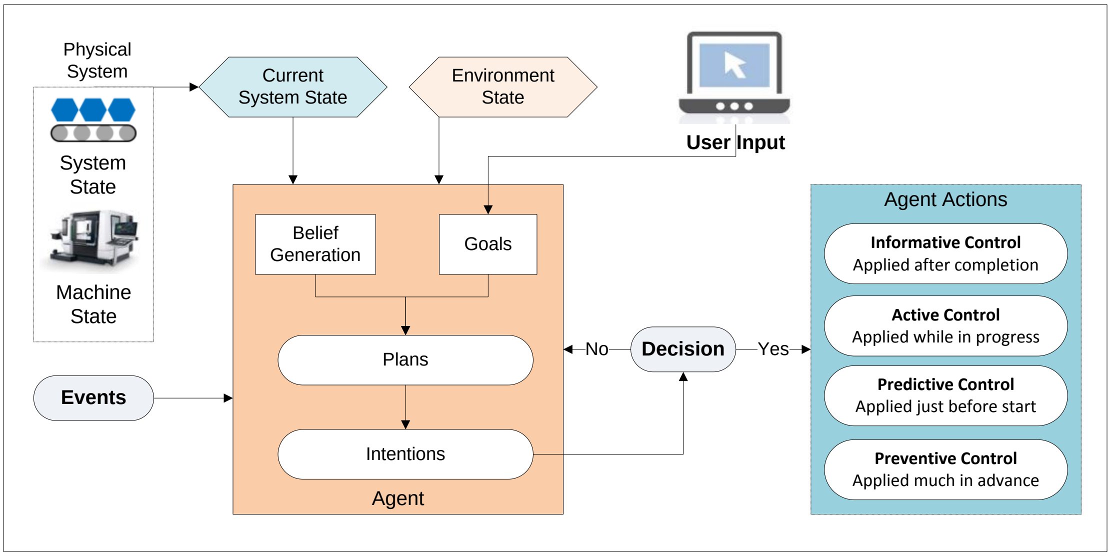


*Figure 1: Multi Agent System Design Framework*

The typical agent action plan is not purely restricted to adaptive, predictive or knowledge based approach, instead it is dynamic and varies with the set of tasks to be executed. A brief description of the agent dynamic action plans at the onset of certain events is given in Table 1. The table contains an indicative list of events and the corresponding action plans.

*Table 1: Agent Action Plan Summary*

| Event | Level | Agent Action Plan | Category |
|---|---|---|---|
| Job Arrival | Shop Floor | Check for priority, due date and performance criteria | *Active Control* |
| | | Due date feasible: *accept the job* | |
| | | Due date not feasible: *Find if due date can be extended. If yes, accept the job with modified due date, else reject.* | |
| | | Job accepted: *set the operation due dates* | |
| | | Announce the first operation | |
| **Scheduling** | | | |
| Job Bidding/ Operation Advertised | Machine level | Job listed in the machine capability database: *Eligible to bid* | *Predictive-Informative Control* |
| | | Eligible machine agents: *Evaluate the consequence of accepting the operation on the effect of the chosen scheduling/dispatching rule on the pre-decided performance criteria (tardiness, penalty, lead time etc.)* | |
| | | Machine agents: *Bid for the operation with their estimate of cost and completion time.* | |
| | | Bid meets due date requirement with minimum cost: *Operation awarded* | |
| | | Operation completed: *Repeat the same bidding procedurefor the next operation.All eligible machine agents ntitled to bid.* | |
| Preventive Maintenance request | Machine level | a. Consider the maintenance request as a job: *Schedule it for the machine such that the due date for the maintenance activity is strictly adhered and maintenance team/spares is available during that period. Minimize tardiness* | *Preventive Control* |
| | | b. Consider the maintenance request as a job: *Schedule it for the machine such that no additional tardiness is added due to maintenance and maintenance team/ spares is available during that period.* | |
| **Rescheduling** | | | |
| Machine Failure | Machine Level | Wait for machine to resume processing. | *Active Control* |
| | | Reschedule all rush/high priority jobs on other machines and allow other jobs to wait till the machine is repaired | |
| Due Date Change | Shopfloor level | ***Job not released on to the shop floor*** | Active Control |
| | | Check for the due date feasibility. | |
| | | New due date feasible: *accept the job with the new due date.* | |
| | | Due date not feasible: *Find if due date can be extended. If yes, accept the job with modified due date, else reject .* | |
| | Machine level | ***Job already released on to the shop floor*** | |
| | | In the queue of a machine: *Consider it as a new entry and apply one of the scheduling rules with the new due date and priority.* | |
| | | Being processed on a machine: *Allow completion and consider the new due date and priority for future scheduling.* | |

## Agent Organization

The agent framework comprises of agent types which are a representative of various aspects of a production system. The design constitutes of a customer agent as a representative of market, global and a local scheduling agents pertaining to scheduling function and machine element and support agent for maintenance function. In addition to these, each machine is treated as an active entity called as machine agent. These agents work as a group to facilitate the overall process of job arrival, allocation to machines ensuring their timely completion and delivery along with ensuring good health of machines. Figure 2 presents a schematic layout in which various functional agents can be organized and the way they can communicate among them. The arrows indicate the communication among the agents. In Figure 2, $M_1$, $M_2$,....,$M_n$ represent the machine agents.

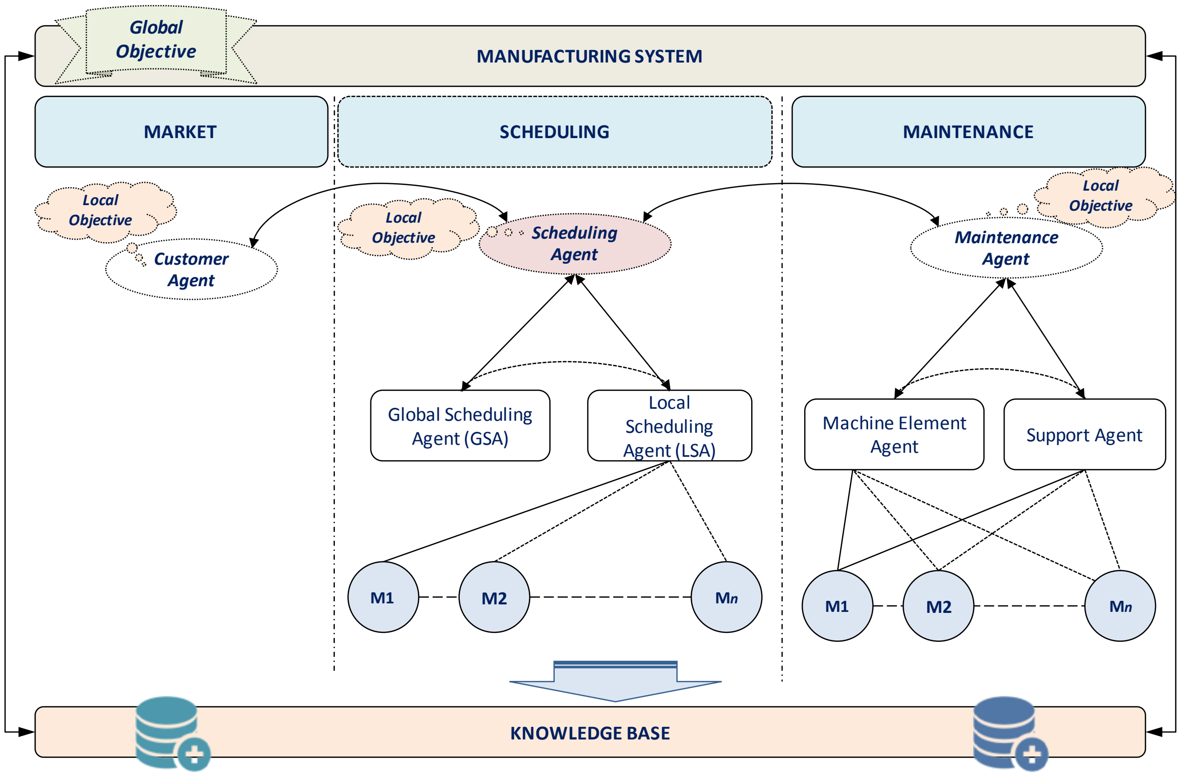


*Figure 2: Agent Organization and Interaction Layout*

## MAS Working

Each of these agent types namely customer agent, global and local scheduling agents, machine element and support agent are registered to a common area referred to as blackboard and have a designated space allocated to each of them wherein they can advertise or post their domain specific information. After registration, agents subscribe for other agents' of their interest. Access to each others' domain information is conditional, for example, a local scheduling agent shall definitely have an access to the machine element agent space on the blackboard so that it is aware of the machine health before allocating a job to it. But the same agent may or may not have any access to the customer agent space.

With the arrival of a new job, the customer agent advertises it to the Global scheduling agent with its specifications. The Global scheduling agent advertises the same job to the Local scheduling agents (LSAs). The LSAs looking at the operational specifications and based on its average queue length communicates a completion time to the global scheduling agent. The GSA communicates the maximum of all the completion times quoted by the LSAs to the customer agent as the expected due date of the job. If the customer agrees to the due date quoted by the GSA, it can accept or may decline the offer. If the customer is ready to accept an extended due date, the job is accepted. With the acceptance of the job, the process of bidding for first operation in the sequence of operations begins. The lowest bidding LSA is allocated the operation completion task. The entire bidding process is repeated again for the next operation. The machine element agent keeps a track of information like component health like component age, any failure notification and repair information of the machines and coordinates with the spares agent for spare availability. The typical feature of this agent system is in the way it treats a preventive maintenance activity. A planned maintenance activity is treated as a normal job in the queue of a machine which has a known completion time and has a penalty associated with its delay. The completion of job is again notified on the blackboard. After the completion of operation one, the same job undergoes the complete chain of bidding to the processing allocation cycle. Figure 4 presents the complete process flow of the proposed multi agent system design.

## The BDI architecture

Agents generally face two challenges: one is to know how frequently to alter its plan and the other is what if it works with no prior plan. Both these issues can bring either a decision making handicap or may completely defy the purpose of a multi agent system design. To overcome this, the Belief-Desire-Intention (BDI) architecture for agent development is recommended. The agent generates a set of beliefs based on its environment but unless it gets a solid reason to convert it into a goal or rather a commitment, it does not come with an executable set of alternatives. The current multi agent system design is also based on BDI architecture and the beliefs, desires and intentions of each of these agents are summarized in Table 2.

*Table 2: Summary of Beliefs-Desires-Intentions of various agents*

| Agent Type | Beliefs | Desires | Intentions |
|---|---|---|---|
| Customer Agent | Jobs under negotiation, expected due date of job | Negotiate with global scheduling agent | Get the job processed |
| Global scheduling agent | Bids from local scheduling agent, details of negotiation with customer etc. | Negotiate with customer for due date<br>Optimal allocation of jobs to local scheduling agents | Minimise maximum penalty<br>Maximise on time delivery |
| Local scheduling agent | Average processing time, Job sent from global scheduling agent, Jobs in queue etc. | Dynamic scheduling for penalty minimization<br>Bidding for a new job | Optimal sequencing |
| Maintenance agent | Machine’s health status<br>Spare availability | Negotiate with local scheduling agent for maintenance schedule | Minimise down time.<br>On time Preventive Maintenance |

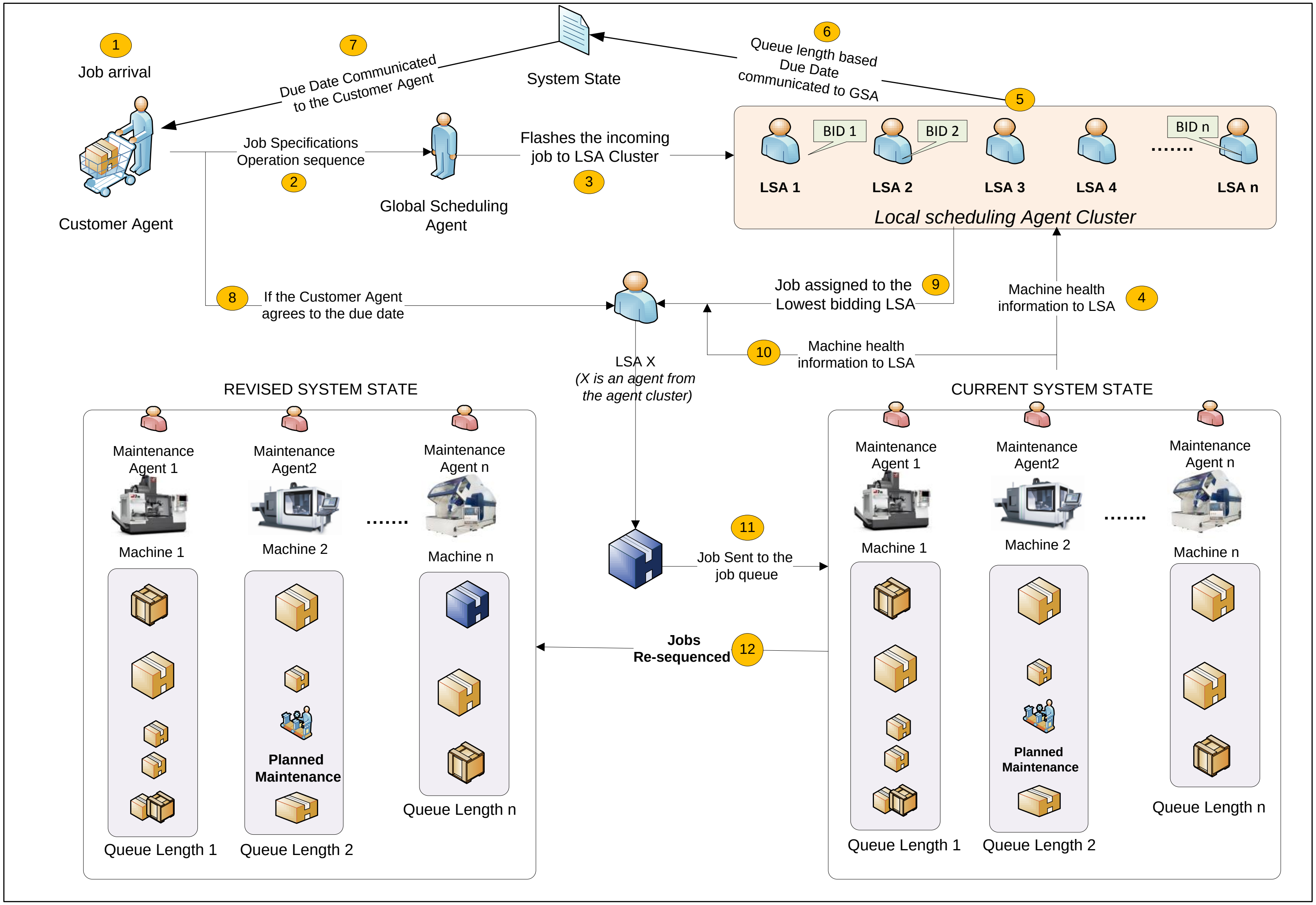


*Figure 3: Multi Agent System Process Flow*

## Challenges

The characteristics on which multi agent systems are built are so strong that if deployed successfully they can result in ending the drudgery of decision making. Moreover, they are virtual identities blessed with all human like behavioral aptitude but they are devoid of biasness, which, in a way, augments their capability. But there are many challenges in their deployment. The suggested framework has been designed with a notion that a system where it can be deployed will be suitably equipped with real time information recording, monitoring and retrieval mechanism which may not be the case for some of the cases. Also, the suggested system design has to be tailored or fine tuned to the requirements of every individual manufacturing or deployable environment. Frequency of addition/alteration in the knowledge layer of any agent is also a challenge. Other challenges with the time taken for stabilization of the multi-agent system in a particular environment also exist.

## Conclusion

Despite all existing challenges, agent technology ensures a mechanism for effective decision making in distributed decision making environments. Delegating the power of decision making to individual agents, while maintaining coherence among them, is the essence of a multi agent system. In the context of a production system where extent of overlap among the various functions like production scheduling, maintenance and product quality are high, analyzing the impact of individual decision making on the overall system goal is very crucial. Hence, a decision support system capable of absorbing the local disruptions and with a rational reasoning ability to help attain the manufacturing goals is required. The current paper is an attempt to draw attention to a methodology of development of a multi-agent system considering scheduling and maintenance function jointly. The approach can be extended to other shop floor functions too.

## References


Bouzini-Hassini, S., Benbouzid-Sitayeb, F., & Aknine, S. (2012). A Multi Agent Scheduling Integrating Planning and Maintenance for Generalized Floor Shops. In *Proceedings of the International MultiConference of Engineers and Computer Scientists* **(Vol. 2)**.

Butler, J., Ohtsubo, H., 1992. ADDYMS: architecture for distributed dynamic manufacturing scheduling. In: Famili, A., Nan, D.S., Kim, S.H. (Eds.), *Artificial Intelligence Applications in Manufacturing.* The AAAI Press, pp. 199–214

Cassady, C. R., & Kutanoglu, E. (2003). Minimizing job tardiness using integrated preventive maintenance planning and production scheduling. *IIE Transactions*, ***35*****(6)**, 503-513.

Cheung, H., Yeung, W., Ng, H., Fung, S., 2000. HSCF: a holonic shop floor control framework for flexible manufacturing systems. *International Journal of Computer Integrated Manufacturing* **13 (2)**, 121–138.

Duffie, N., Piper, R., 1986. Non-hierarchical control of manufacturing systems. *Journal of Manufacturing Systems* **5 (2)**, 137–139.

Gou, L., Luh, P., Kyoya, Y., 1998. Holonic manufacturing scheduling: architecture, cooperation mechanism, and implementation. *Computers in Industry* **37 (3)**, 213–231.

Graves, G. H., & Lee, C. Y. (1999). Scheduling maintenance and semiresumable jobs on a single machine. *Naval Research Logistics (NRL)*, ***46*****(7)**, 845-863.

Heikkila¨, T.,Jarviluoma,M.,Juntunen,T.,1997.Holonic control for manufacturing systems: design of a manufacturing robot cell. *Integrated Computer Aided Engineering* **4**,202–218.

Ji, M., He, Y., & Cheng, T. E. (2007). Single-machine scheduling with periodic maintenance to minimize makespan. *Computers & operations research* , ***34*(6)**, 1764-1770.

Leitão, P. (2009). Agent-based distributed manufacturing control: A state-of-the-art survey. *Engineering Applications of Artificial Intelligence*, ***22*(7)**, 979-991.

Leng, K., Ren, P., & Gao, L. (2006, June). A novel approach to integrated preventive maintenance planning and production scheduling for a single machine using the chaotic particle swarm optimization algorithm. In *Intelligent Control and Automation, 2006. WCICA 2006. The Sixth World Congress on* (**Vol. 2**, pp. 7816-7820). IEEE.

Moradi, E., Fatemi Ghomi, S. M. T., & Zandieh, M. (2011). Bi-objective optimization research on integrated fixed time interval preventive maintenance and production for scheduling flexible job-shop problem. *Expert systems with applications*, ***38*(6)**, 7169-7178.

Pan, E., Liao, W., & Xi, L. (2010). Single-machine-based production scheduling model integrated preventive maintenance planning. *The International Journal of Advanced Manufacturing Technology*, ***50*(1-4)**, 365-375.

Parunak, H.V.D., Baker, A., Clark, S., 1998. The AARIA agent architecture: an example of requirements-driven agent-based system design. In: *Proceedings of First International Conference on Autonomous Agents*, pp. 482–483.

Russel, S., Norvig, P., 1995. *Artificial Intelligence: A Modern Approach*. Prentice- Hall, New Jersey.

Sadeh, N., Fox, M., 1989. CORTES: an exploration into micro opportunistic job-shop scheduling. In: *Proceedings of Workshop on Manufacturing Production Scheduling,* Detroit.

Sloan, T. W., & Shanthikumar, J. G. (2000). Combined Production And Maintenance Scheduling For A Multiple-Product, Single-Machine Production System. *Production and Operations Management*, **9(4)**, 379-399.

Sugimura, N., Hiroi, M., Moriwaki, T., Hozumi, K., 1996. A Study on Holonic Scheduling for Manufacturing System of Composite Parts, *Japan/USA Sympo- sium on Flexible Manufacturing*

Wang, S., & Yu, J. (2010). An effective heuristic for flexible job-shop scheduling problem with maintenance activities. *Computers & Industrial Engineering*, ***59*(3)**, 436-447.

Weiss, G. (Ed.). (1999). *Multiagent systems: a modern approach to distributed artificial intelligence*. MIT press.

Wooldridge, M., 2002. *An Introduction to Multi-Agent Systems.* Wiley, New York.

Wooldridge, M., Jennings, N., 1995. *Intelligent agents: theory and practice*. The Knowledge Engineering Review **10 (2)**, 115–152.