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MULTI-AGENT-BASED REAL-TIME SCHEDULING MODEL FOR RFID-ENABLED UBIQUITOUS SHOP FLOOR

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ABSTRACT

Because of the lack of timely feedback manufacturing information during production execution stage, real-time production scheduling is very difficult to be implemented. In this paper, an overall architecture of multi-agent based real-time scheduling for ubiquitous shopfloor environment is proposed to close the loop of production planning and control. Several contributions are significant. Firstly, wireless devices such as RFID are deployed into value-adding points in a ubiquitous shopfloor environment to form Machine Agent for the collection and processing of real-time shopfloor data. Secondly, Capability Evaluation Agent is designed to optimally assign the tasks to the involved machines at the process planning stage based on the real-time utilization ration of each machine. The third contribution is a Real-time Scheduling Agent model for manufacturing tasks scheduling / re-scheduling strategy and methods according to their real-time feedback. Finally, a Process Monitor Agent model is established for tracking and tracing the manufacturing execution based on a critical event structure.

KEYWORDS

Multi-agent, Real-time Scheduling, Ubiquitous Manufacturing, Auto-ID, RFID

1. INTRODUCTION

Manufacturing scheduling is the process of selecting and assigning manufacturing resources for specific time periods to the set of manufacturing processes in the plan (Shen et al., 2006). It is the important manufacturing planning actives which deal with resource utilization and time span of the manufacturing operations. Agent-based manufacturing scheduling systems are a promising way to provide this optimization (Chan et al., 2002). Recently, rapid developments in wireless sensors, communication and information network technologies (e.g. radio frequency identification - RFID or Auto-ID, Bluetooth, Wi-Fi, GSM, and infrared) have nurtured the emergence of Ubiquitous Manufacturing (UM) (Huang et al., 2010; Zhang et al., 2011) as core Advanced Manufacturing Technology in next-generation manufacturing systems. A UM system is based on wireless sensor network that facilitates the automatic collection and real-time processing of field data in manufacturing processes (Jun et al., 2009). It will facilitate the real-time shop-floor scheduling in a ubiquitous manufacturing environment.

Despite of the significant progress of agent technologies and real-time manufacturing data collection, the following research questions still exist in applying real-time scheduling methods to real-life manufacturing shopfloors.

(1) In process planning stage, the task is only assigned to a type of machine; it is not assigned to a certain machine. As a result, the tasks may be not optimally assigned among the machines and has adverse effect on scheduling stage. Without considering real-time machine workloads and shop floor dynamics, process planning may become suboptimal or even invalid at the time of execution.

(2) Due to the lack of manufacturing information capturing and processing methods, current shop-floor monitor is inaccurate, incomplete, inconsistent, and presents time-delay. In addition, it has not integrated with scheduling system. Therefore, the real-time shop-floor scheduling is difficult to implement.

In this paper, we integrate the advantages of multi-agent and auto-ID technologies powered ubiquitous manufacturing technologies to implement real-time shop-floor scheduling. The proposed multi-agent real-time scheduling architecture aims to close the loop of production planning and control from process planning to finished products.

The rest of the paper is arranged as follows. Section 2 will review the relevant literature under three categories of multi-agent system for manufacturing, real-time scheduling, and ubiquitous manufacturing. Section 3 presents the overall architecture of multi-agent based real-time shop-floor scheduling. The multi-agent models such as Machine Agent, Capability Evaluation Agent, Scheduling Agent, and Process Monitor Agent are discussed in Section 4. Section 5 describes the software framework of the proposed multi-agent based real-time shop-floor scheduling system. Conclusions and further works are summarized in Section 6.

2. LITERATURE REVIEWER

The research considered in this paper can be portrayed against the literature along several directions. They are (1) multi-agent system for manufacturing, (2) real-time scheduling, and (3) ubiquitous manufacturing.

2.1. MULTI-AGENT SYSTEM FOR MANUFACTURING

Agent technology is a branch of Artificial Intelligence (AI) and has been widely accepted and developed in manufacturing applications for its autonomy, flexibility, reconfigurability, and scalability (Sikora, 1998, Macchiaroli, 2002 and Maturana, 2004). An agent based concurrent design environment (Krothapalli, 1999) has been proposed to integrate design, manufacturing and shop-floor control activities. A compromising and dynamic model in an agent-based environment (Sikora, 1998) has been designed for all agents carrying out their own tasks, sharing information, and solving problems when conflicts occur. Papakostas et al., (1999) describe a flexible agent based framework for manufacturing decision m aking. Some mobile agent-based systems (Shin et al., 2004) have been applied to the real-time monitoring and information exchange for manufacturing control. Jia et al. (2004) proposed an architecture where many facilitator agents coordinate the activities of manufacturing resources in a parallel manner. Jiao et al. (2006) applied the MAS paradigm for collaborative negotiation in a global manufacturing supply chain network. Besides, in various kinds of applications such as distributed resource allocation (Bastos et al., 2005), online task coordination and monitoring (Lee and Lau, 1999 and Maturana et al., 2004), or supply chain negotiation (Wu, 2001), the agent-based approach has played an important role to achieve outstanding performance with agility. Monostori et al. (2006) introduce the software agents and multi-agent systems and discuss the open issues and strategic research directions in all domains of manufacturing where problems of uncertainty and temporal dynamics, information sharing.

2.2. REAL-TIME SCHEDULING

In order to satisfy customer requirements and meet the delivery time punctually in MTO (Make to Order) environments, production scheduling and planning is an important process for avoiding delay in the production process and for improving manufacturing performance. Previous approaches focus on the process allocation of equipment to production tasks before the production starts (Wong et al, 2006). Aghezzaf (2007) adopts a mixed integer programming model for developing a capacity and warehouse management plan that satisfies the expected market demand with the lowest possible cost. Mendes et al. (2009) integrate a genetic algorithm with heuristic priority rules to solve resource constrained project scheduling problems. Guo et al. (2008) propose a genetic algorithm for solving the order scheduling with multiple constraints for maximizing the total satisfaction level of all the orders while minimizing their total throughput time. Recently, real-time scheduling strategies and methods are investigated to facilitate production management. Buyurgan et al. (2008) present a framework that employs the analytical hierarchy process (AHP) in advanced manufacturing systems for real-time scheduling and part routing. Poon et al. (2011) describe a real-time production operations decision support system (RPODS) is proposed for solving stochastic production material demand problems. By considering various uncertainties such as uncertain processing time, uncertain orders and uncertain arrival times, Guo et al (2011) propose a mathematical model for order scheduling problem with the objectives of maximizing the total satisfaction level of all orders and minimizing their total throughput time. Cho et al. (2007) use a continuous control-theoretic approach for distributed production scheduling at the shop floor and machine capacity control at the CNC level.

2.3. UBIQUITIOUS MANUFACTURING

In the past ten years, rapid developments in wireless sensors, communication and information network technologies (e.g. radio frequency identification - RFID or Auto-ID, Bluetooth, Wi-Fi, GSM, and infrared) have nurtured the emergence of Ubiquitous Manufacturing (UM) (Huang et al., 2009) as core Advanced Manufacturing Technology (AMT) in next-generation manufacturing systems (NGMS). A UM system is based on wireless sensor network that facilitates the automatic collection and real-time processing of field data in manufacturing processes. In this way, the error-prone, tedious manual data collection activities are reduced or even eliminated (Jun et al., 2009). UM provides a networked manufacturing environment free from excessive and difficult wiring efforts in manufacturing workshops (Jones, 1999). In UM, real-time visibility and interoperability have been considered core characteristics (Huang et al., 2008) that close the loop of production planning and control for adaptive decision making. By taking advantage of data capacity stored in an RFID tag, Qiu et al. (2007) propose a RFID-enabled framework in support of manufacturing information integration. A new paradigm, called UbiDM: Design and Manufacture via Ubiquitous Computing Technology (Suh et al., 2008), has been proposed for the design and manufacturing of a product by using ubiquitous computing technology. The importance of the UM has also been widely identified for strategic research and development in industrialized European Union, North Americas, and Japan where manufacturing is widely considered as one of the major means of creating the national wealth. In a UM framework, management and control facilities of shop floor are required to implement real-time traceability, visibility and interoperability in improving the performance of shop-floor planning, execution and control by using workflow management architecture (Zhang et al., 2010) and RFID-enabled smart gateway (Zhang et al., 2011). Besides, the facilities must be able to effectively deal with the complex manufacturing information following the standard schemas and transmit it in time between workstations, shop floors and enterprise.

3. 3. ARCHITECTURE OF MULTI-AGENT BASED REAL-TIME SHOP-FLOOR SCHEDULING

The overall architecture of multi-agent based real-time shop-floor scheduling is shown in Figure-1. It aims to implement real-time scheduling for a ubiquitous shop-floor environment. Through auto-ID technologies, the dynamic manufacturing information could be captured. Then, at process planning stage, the tasks could be better assigned according to the real-time status and capacity of each machine. It will provide accurate information for production scheduling. During execution stage, the dynamic scheduling can be achieved based on the real-time manufacturing data.

Four agents are designed in this research to fulfil real-time shop-floor scheduling. They are briefly described as follows:

(1) Machine Agent (MA)

It is responsible for capturing the real-time manufacturing data by equipping auto-ID devices and processing the captured data as meaningful manufacturing information. Then, the real-time workstation application services can be provided.

(2) Capability Evaluation Agent (CEA)

It is used to evaluate the capability of the machines. Based on the real-time status transmitted by machine agent, the process planning can assign the tasks to optimal machines.

(3) Real-time Scheduling Agent (RSA)

It provides intelligent model and algorithm to optimally plan or re-plan the start time and finish time of each process of each task according to the real-time shopfloor information.

(4) Process Monitor Agent (PMA)

It is responsible for reflecting the real-time status of different manufacturing resources. During production execution, disturbances and changes of shopfloor are timely tracked and traced, and the loop of production planning and control for real-time shop-floor scheduling could be achieved.

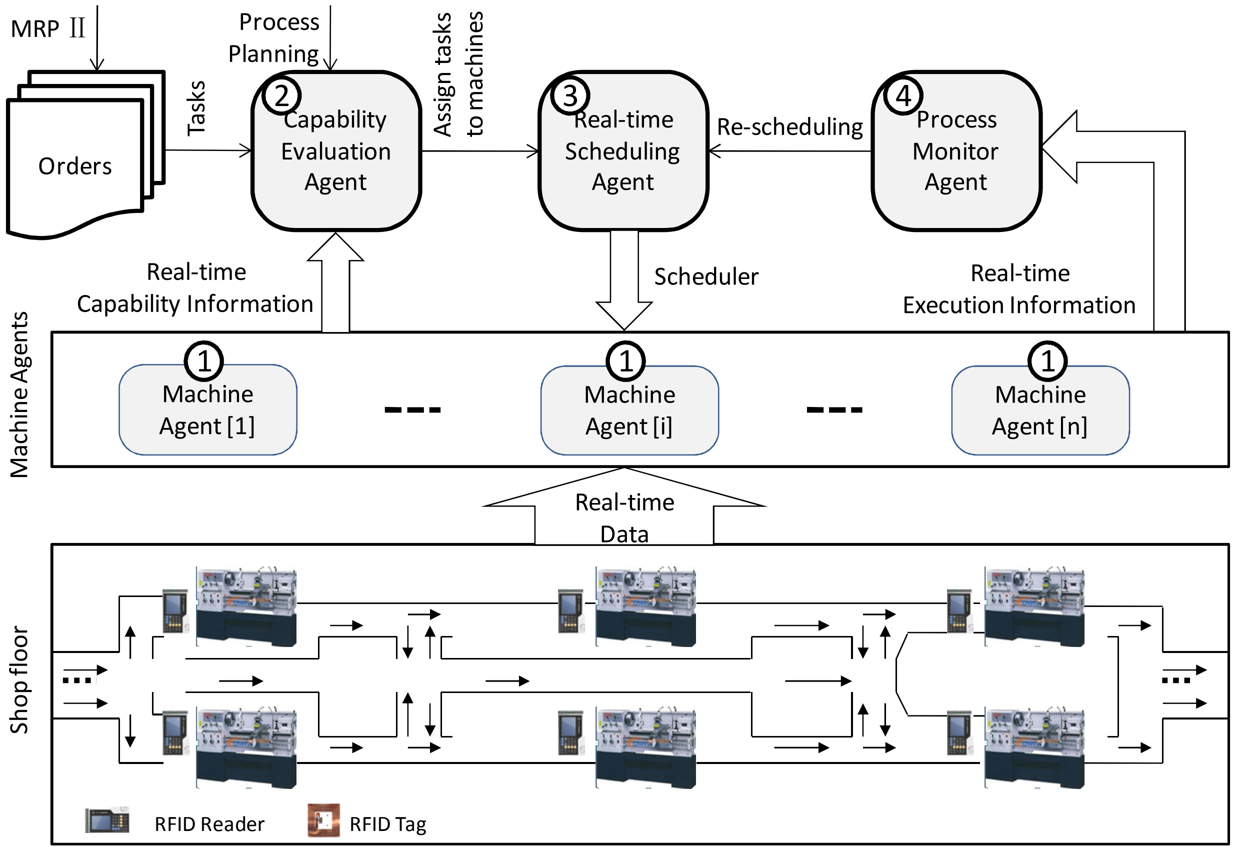

Figure 1 – Architecture of multi-agent based real-time shop-floor scheduling

4. MULTI-AGENT MODELS

4.1. MACHINE AGENT MODEL

MA is responsible for wrapping the workstation applications to process the complex real-time data captured from Auto-ID devices such as RFID. On one hand, it is used to connect and centrally manage the multiple types of auto-ID devices for capturing real-time manufacturing data according to a specific logic flow. On the other hand, it is also used to process the captured manufacturing data to meaningful manufacturing information and provide real-time workstation application services.

Figure-2 shows the MA model. It is implemented with intelligence logics so as to sense and identify the real-time manufacturing status of each machine. It includes two components, namely data capturing and application service.

(1) Data Capturing

This component aims at managing the behaviours of auto-ID devices installed at a machine to capturing the dynamic data of the manufacturing resources. It consists of two modules.

Definition and auto-driven module is used to wrap various drivers of heterogeneous auto-ID devices to form a driver library which enables the newly plugged auto-ID device to be "Plug and Play" with only simple definition of some basic parameters. Two driven modes, standard interface driven and the third-part driven, are designed in this module.

Standard data capturing module is responsible for wrapping heterogeneous auto-ID devices into standard methods so that their perception functions can be easily invoked under a uniform model. Two types of methods, namely "readingData (Parameter [1], Parameter [i])", "writingData (Parameter [1], Parameter [i])", are involved in this module.

(2) Application Services

This component aims to provide value-added information based on the captured manufacturing data by auto-ID devices. It also consists of two modules.

Reasoning module is designed to enhance the intelligence of the MA. It will make MA know which type of manufacturing resource is coming or leaving the machine. Rule-based methods are adopted to accelerate MA to make decision based on real-time manufacturing environment and production logics. The fundamental element of a rule is function. A function has a name, a set of arguments, and a return value. Function itself can be an argument of another function. All the rules are described in a standard structure and stored in an XML file which can be further updated. The MA can apply the corresponding rule by choosing and loading it from the XML file.

Real-time information processing module is used to deal with the various real-time data captured by auto-ID devices installed at the machine side. Contrast to reason module, it focus on how to form more meaningful real-time manufacturing information. For example, the 'getMaterials' processing method will deal with all the data relevant to materials of this machine and return detailed real-time information such as used materials, produced semi-finished products etc.

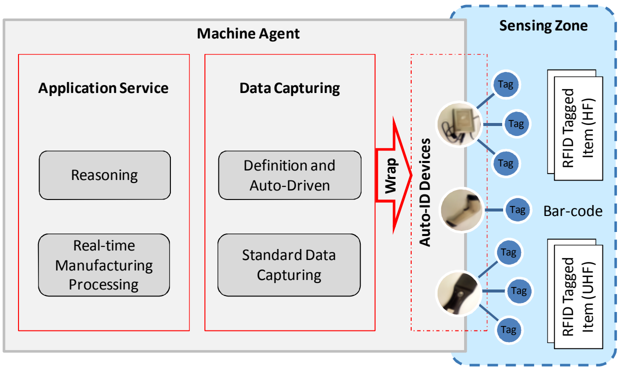

Figure 2 – Machine agent model

4.2. CAPABILITY EVALUATION AGENT MODEL

CEA is used to evenly assign the processes of tasks to the involved machines. Its model is shown in Figure-3. For each task, it consists of 'n' processes. For each process [i], according to its process planning, CEA will find an optimal machine with the corresponding capability based on a bid competitive mechanism. Without considering real-time machine workloads and shopfloor dynamics, process plans may become suboptimal or even invalid at the time of execution.

As shown in Figure-3, a Utilization Ratio (UR) is used in CEA to evaluate the capability of each machine and chooses an optimal one for each process [i]. In bid stage, for each process, the group of the machines with the corresponding capability will be selected at first. Then, the MAs relevant to these machines bid this task. They must report their real-time status e.g. current used capacity to CEA. Finally, the CEA will calculate the URs of these MAs and then evaluate the optimal one according to the objective function. The objective function is:

$$Min(UR_i) = UC_i / TC_i \times 100\% \quad (1)$$

In this formulation, UR_i is the utilization ratio of machine 'i'. UC_i is the used capability of machine 'i', it is dynamically changed with the changed queue of the machine 'i'. TC_i is the total capability of machine 'i', it is a constant that represents a time period.

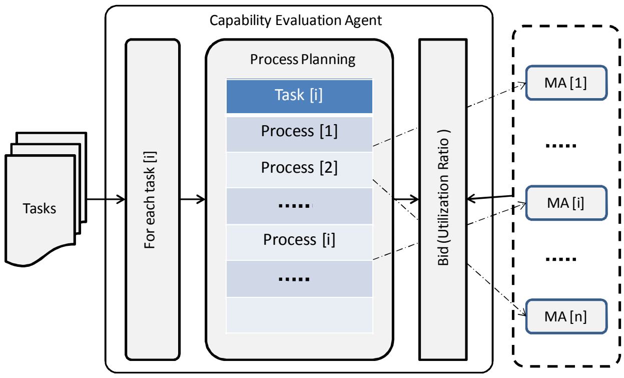

Figure 3 – Capability evaluation agent model

4.3. REAL-TIME SCHEDULING AGENT MODEL

RSA is designed to implement real-time scheduling. Its overall model is shown in Figure-4. Its inputs include the initial information from CEA and the real-time manufacturing execution information from PMA. Its outputs are the task queues that includes a series of $\{i, j, k, ST, FT\}$. Here, $\{i, j, k, ST, FT\}$ represents the process 'j' of task 'i' is assigned to machine 'k', it will be started at 'ST' and finished at 'FT'.

Three modules, namely mathematic module, solving module and re-scheduling module are involved in RSA.

(1) Problem Formulation

Before given the mathematic formulation, the corresponding notations are defined at first. The details can be seen in Table-1.

Table 1- Notations

$M = \{m_1, m_2, \ldots, m_m\}$	Set of machines
$T = \{t_1, t_2, \ldots, t_n\}$	Set of tasks
N_i	The number of processes of task 'i'
$TP_i = \{p_1, p_2, \ldots, p_{N_i}\}$	Set of processes of task 'i'
(T_i, P_j, M_k)	Represents the process 'j' of task 'i' is machined at machine 'k'
$S(T_i, P_j, M_k)$	Starting time of (T_i, P_j, M_k)
$PT(T_i, P_j, M_k)$	Process time of (T_i, P_j, M_k) at machine 'k'
$D = \{d_1, d_2, \ldots, d_n\}$	Set of delivery time of T

Based on the notations, the established mathematic model is described as following.

Objective function:

$$Min\{Max[S(T_i,P_j,M_k)+PT(T_i,P_j,M_k)]\} \quad (2)$$

Subject to:

$$S(T_i,P_{j+1},M_a)-S(T_i,P_j,M_b)\geq PT(T_i,P_j,M_b) \quad (3)$$

$$S(T_x,P_c,M_k)-S(T_y,P_d,M_k)\geq PT(T_y,P_d,M_k) \text{ or}$$

$$S(T_y,P_d,M_k)-S(T_x,P_c,M_k)\geq PT(T_x,P_c,M_k) \quad (4)$$

$$d_i-S(T_i,P_j,M_k)+PT(T_i,P_j,M_k)\geq 0 \quad (5)$$

$i,x,y\in[1,n]$, $j\in[1,N_i]$, $c\in[1,N_x]$, $d\in[1,N_y]$, $k,a,b\in[1,m]$

Equation-2 is the objective function. Its value is to take the maximal value of the finishing time of the last process of all the manufacturing tasks. This value is changed with the different scheduling results. So, by minimize this value, the optimal scheduler could be obtained. Equation-3, 4 and 5 are constraints. They represent processes sequence constraint, resource constraint and delivery constraint respectively.

(2) Solving module

According to the objective function and constraints, the solving module is responsible for calculating the optimal solution based on intelligent algorithm.

For example, Genetic Algorithm (GA) has been widely studied, experimented and applied in many fields in manufacturing fields. It can be used in RSA to solve the established scheduling problem.

(3) Re-scheduling module

As described in introduction section, real-time scheduling plays an important role in current enterprise management. For each scheduler, during the execution stage, the PMA will feedback the real-time production information. Re-scheduling module is used to evaluate whether execute re-scheduling or not.

As described previously, the real-time production information is tracked and traced by PMA during manufacturing execution. When exceptions occur, re-scheduling module will firstly identify the type of the exception. Then, re-scheduling strategy is put into effect. Two strategies, namely local re-scheduling and overall re-scheduling, are designed in this module. Local re-scheduling strategy is used to schedule a small part of the tasks while other tasks' scheduler is not changed. It deals with the exceptions such as the queue exception of a machine or temporary tasks. Overall re-scheduling strategy is used to schedule all the tasks. It is seldom executed only if the majority of the tasks are exception.

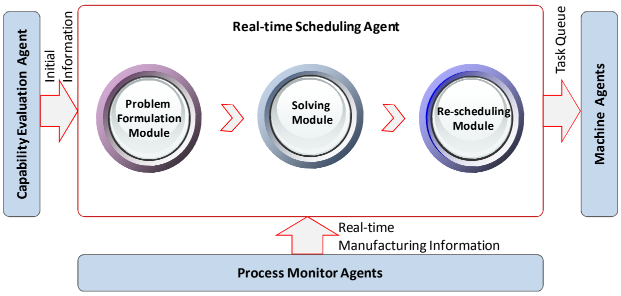

Figure 4 – Real-time scheduling agent model

4.4 PROCESS MONITOR AGENT MODEL

The PMA model is shown in Figure-5. It acts as a sandwich and plays an important role to manage and control the material and information flows in the entire shopfloor. The users or other systems can get or update the real-time WIP (Work-in-progress) information by easily sending a request to PMA.

During the manufacturing execution, the real-time visibility and tractability of shop-floor WIP will be collected. At the beginning, the PMA will invoke the data source service to get the necessary information relevant to the production order such as the product BOM, schedule information etc. from the up-level EISs (Enterprise Information Systems). Based on the gotten manufacturing information and the information schema (wipML) of WIP, a new WIP instance is created, which includes the manufacturing BOM (Bill of materials) information. For each node of the manufacturing BOM, its dynamic information nodes can be captured by the distributed MAs. And the binding model is used to build up the bind relationship between the dynamic information nodes and the corresponding MAs. During execution, the huge manufacturing information captured by each gateway will be processed by critical event structure according to the RSA's request. Two main components are involved in the designed PMA to fulfil this purpose, they are:

(1) Data Source Service

It provides data acquisition, processing and updating services for sharing and integrating information between manufacturing execution level and EISs. Due to the difficulties of information sharing and integration among heterogeneous EISs, B2MML (Business to Manufacturing Markup Language) standards are adopted in this component to provide standard schemas for manufacturing elements. Through data source service, the necessary information or dynamical information can be easily extracted or updated from or to heterogeneous EISs.

The inputs of this component are the parameters of the data source of the EISs which users want to acquire or update information from or to, while the outputs are the standard information based on B2MML schemas.

(2) WIP Tracking and Tracing

It is responsible for configuring the distributed MAs according to specific logical relationship to get real-time information of WIP in the entire shopfloor.

The critical event structure is used to obtain more meaningful and actionable information from large amount of low level events and to control the event-driven information systems. It establishes an aggregation of series of the events from auto-ID devices to form high level events. Then, based on the timely information stored in repository, supervisors can monitor and control the production process of the overall shopfloor.

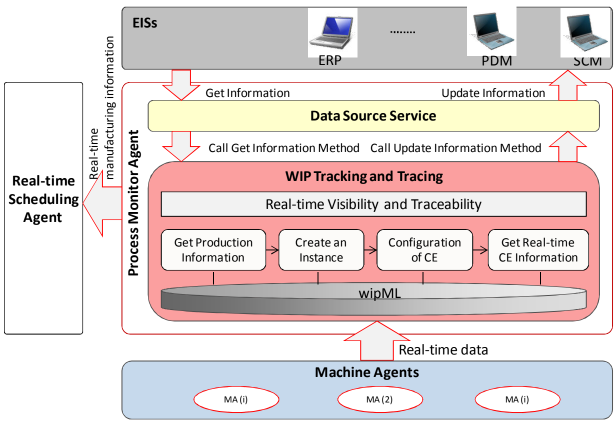

Figure 5 – Process monitor agent model

5. CONCLUSIONS

Ubiquitous Manufacturing is emerging as an advanced manufacturing technology (AMT). It relies substantially on wireless auto-ID / RFID sensors and wireless information networks for the collection and synchronization of real-time field data from manufacturing shop floors. It enables the shop-floor management to realize real-time production scheduling.

This paper has proposed a referenced multi-agent based real-time scheduling for ubiquitous shop-floor environment. The contributions are summarized as follows.

(1) A machine agent is designed to collect and process of real-time shopfloor data captured by auto-ID devices such as RFID. These auto-ID devices are deployed at machine side to form value-adding points in a ubiquitous shopfloor environment.

(2) A capability evaluation agent is designed to optimally assign the tasks to the involved machines at the process planning stage based on the real-time utilization ration of each machine.

(3) A real-time scheduling agent is designed for manufacturing tasks scheduling / re-scheduling strategy and methods according to their real-time feedback.

(4) A process monitor agent is established for tracking and tracing the manufacturing execution based on a critical event structure.

The current work will be further extended in our future research from the following aspects. Firstly, the proposed multi-agent based real-time shop-floor scheduling architecture and its models only provide a reference for ubiquitous manufacturing, and a great effort should be needed to support more various EISs of different companies. Secondly, the proposed multi-agent based scheduling model should be further extended to real-time internal logistics planning and scheduling etc.

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