東　　海　　大　　學

工業工程與經營資訊研究所

博士論文

結合 RFID 與代理人技術之整合性生產規劃與控制模式

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RFID and Agent based Agile Manufacturing Planning and Control System

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摘要

本研究隨著產業全球化的趨勢，今日的製造環境所重視的是在有限的企業資源下如何提升顧客服務水準（例如：縮短接單到出貨時間及降低存貨成本等）。然而，目前所使用的製造規劃與控制系統所提供的功能僅侷限於製造廠，當擴及到整體供應鏈時，往往需要其他的系統整合技術。無線射頻識別系統的應用，帶來即時性的資訊，藉由主動獲得這些即時性的資訊，可以有效提升整體供應鏈績效。

然而，即使無線射頻技術可帶來即時性的資訊，後端如果沒有一套健全的應用系統，將無法使這些資訊獲得最有效的應用。因此，本篇論文結合 RFID 及代理人技術提出一敏捷式製造規劃與控制系統（agile manufacturing planning and control system;AMPCS），整體而言，本研究目的為：

1. 應用無線射頻技術與多重代理人系統，提出一個可以快速且動態的回應企業外部與內部變動的製造規劃與控制系統之系統架構；
2. 提出一 bidding 機制演算法以產生現場作業排程；
3. 以東海大學自動化實驗室為環境，實做並驗證此系統架構。

關鍵字詞：無線射頻識別系統、多重代理人、製造規劃與控制

RFID and Agent based Agile Manufacturing Planning and Control System

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Abstract

In today's manufacturing enterprise, the performance of customer service level (e.g., short ordering-to-delivery time, low price) is highly dependent on the effectiveness of its manufacturing planning and control system (MPCS). However, the function of today's manufacturing planning and control is limited inside a manufacturing system and cannot effectively enhance the performance objectives (e.g., customer service level) in a supply chain environment which usually includes several components. Currently, RFID allows the accurate and detailed information of products to be followed in real time across the supply chain. However, RFID technique cannot support a rapid decision-making in a distributed and heterogeneous manufacturing environment. On the contrary, a multi-agent approach may be applied in a distributed and autonomous system which allows negotiation-based decision making. Although MAS can be employed in distributed and dynamic environment, it can not make the correct decision without the real-time information.

To cope with these requirements, it is necessary to develop a manufacturing planning and control system (MPCS) which employs the RFID technique and multi-agent system (MAS) to quickly and dynamically respond to the external and internal environment changes. Therefore, the objective of this research is to introduce an agent-based manufacturing planning and control system (AMPCS) framework and develop a system analysis and design method for an agent-based MPCS. In order to develop AMPCS, an agent-based MPCS in an automated manufacturing cell (AMC) in the Automation Laboratory of Tunghai University is implemented.

KEY WORDS：RFID, Multi-agent, Manufacturing Planning and Control

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Chapter 1 Introduction

1.1 Background

With the trend of supply chain globalization, today's supply chain network is becoming geographically spread out across the globe. Enterprises are pursuing boundary-less transactions, where raw materials are sourced from one country, manufacturing is done in another and the finished product is shipped to a variety of countries. In order to fully utilize the advantage of a supply chain alliance, RFID (*R*adio *F*requency *ID*entification) is one of the techniques employed to increase the visibility, accountability, trackability, and traceability (VATT) of the global manufacturing supply chains [61]. RFID is an electrical information-storing device, it has characteristics such as active, long-distance reading, and non-line-of-sight. RFID brings a whole new perspective to the term visibility of a supply chain [36]. Besides, RFID allows products to be tracked in real time across the supply chain providing accurate and detailed information on all items (e.g., raw material, WIP, products in factory and products in the down streams) to increase a supply chain's accountability. Furthermore, recording the changes made in every component of a product throughout its life — in other words, documenting the product's genealogy — is known as parts traceability. RFID provides the means to capture and store data in real-time on a tag that accompanies the product. RFID is ideally suited for a large number of traceability applications, especially on more complex products and assemblies [63].

1.2 Motivation

RFID technique cannot support a rapid decision-making in a distributed and heterogeneous manufacturing environment. To utilize the real-time information effectively, RFID must integrate with other application system, such as manufacturing planning and control system. Although RFID increases the VATT of a supply chain, the performance of a supply chain may not be highly improved unless the plan process, source process, make process, deliver process, and return process of a manufacturing enterprise can effectively utilize these real-time valuable information. In other words, an agile manufacturing system which is flexible, highly configurable, and easily adaptable to the dynamic changing environment must be developed [19]. To cope with these requirements, it is necessary to develop an intelligent, autonomous, and distributed manufacturing planning and control system (MPCS) which can quickly and dynamically respond to the external and internal environment changes. The performance of a manufacturing enterprise may be dramatically improved in terms of the reliability, responsiveness, flexibility, cost, and asset perspectives as stated in the supply chain operations reference (SCOR) model [32].

However, most of the current manufacturing planning and control systems employ the hierarchical planning and control approach. That is, planning is usually performed top-down, and varying from aggregate approaches with rough time periods for long-term inventory and production planning to very detailed planning with precise data (daily, hourly, or by the minute) for short-term or immediate production activities. Whereas control is made possible through monitoring production activities and providing feed-back to all system levels [3]. In this situation, a small change in one level may significantly and adversely affect the other levels in the hierarchy [19], the planning results can only be a reference for the next level’s planning and execution. Therefore, the application of multi-agent system in MPCS has developed to meet the distributed and heterogeneous environment, which causes by dynamically chan8ging customer demand and uncertainly supplies (e.g. the shortage of material). Although MAS can be employed in distributed and dynamic environment, it can not make the correct decision without the real-time information.

To cope with these requirements, it is necessary to develop a manufacturing planning and control system (MPCS) which employs the RFID technique and MAS to quickly and dynamically respond to the external and internal environment changes.

Therefore, the agent-based manufacturing planning and control system (AMPCS) has the characteristic: (1) capability of monitoring all the production process activities, (2) performing a real-time what-if simulation, (3) dynamically generating production planning and scheduling according to the shop floor situation and demand information, and (4) actively alerting each object's production activity (e.g., what it needs and where it goes) should be developed.

1.3 Research Objectives

The objectives of this research are:

1. To introduce an agent-based agile manufacturing planning and control system (AMPCS) framework, which employed the RFID technique to obtain the real-time information.
2. To implement a system analysis and design method for an agent-based MPCS by system development method.
3. To implement an agent-based MPCS in an automated manufacturing cell (AMC) in the automation laboratory of Tunghai university.

1.4 Outline of the Thesis

In chapter 2, the literature review related to the research is reviewed and evaluated. In chapter 3, the system framework of AMPCS is introduced. In chapter 4, the system analysis and system design of AMPCS is developed to describe the system function and each agent's role. Chapter 5 presents the application of AMPCS in practice in Automated Manufacturing Cell (AMC) in the Automation Laboratory of Tunghai University. Finally, a summary of this thesis is presented and areas of further research are suggested.

Chapter 2 Literature Review

In this chapter, we will review some researches that are related to our research. In section 2.1, existing manufacturing planning and control systems are reviewed. In section 2.2, we introduce the basic concept of a multi-agent system and review the applications of MAS in MPCS. In section 2.3, we introduce the basic concept of a Radio Frequency Identification (RFID) System and review the applications of RFID in MPCS.

2.1 Manufacturing Planning and Control System (MPCS)

In today's manufacturing enterprise, the performance of customer service level (e.g., short ordering-to-delivery time, low price) is highly dependent on the effectiveness of its manufacturing planning and control system (MPCS). From an information system's perspective, a MPCS, depicted in Figure 2.1, may be composed of eight major modules: (1) Demand Management (DM), (2) Inventory Planning (IP), (3) Sales and Operations Planning (S&OP), (4) Master Scheduling (MS), (5) Material and Capacity Requirements Planning (MCP), (6) Production Activity Control (PAC) or Shop Floor Control (SFC), (8) Purchasing, and (8) Performance Measurement (PM).

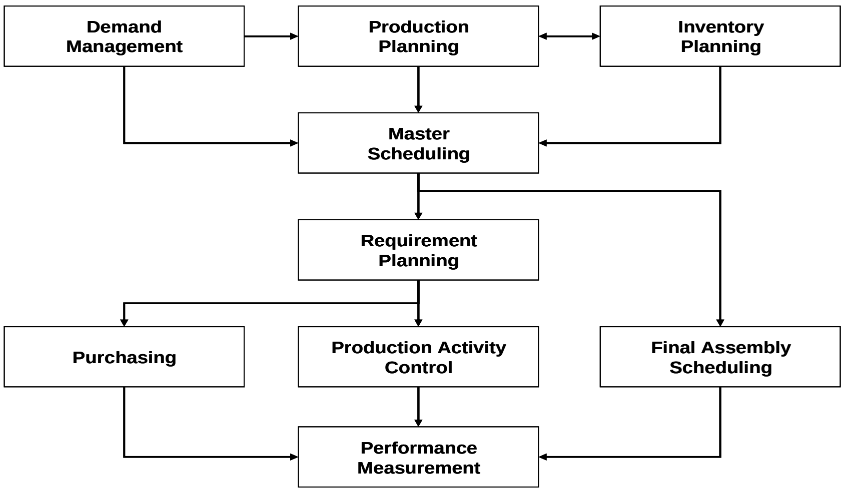

Figure 2.1 The structure of a hierarchical manufacturing planning and control system [63]

Manufacturing planning and control address decisions on the acquisition, utilization and allocation of production resources to satisfy customer requirements in the most efficient and effective way. Within a classical conception, MPCS is designed to support a system with centralized architecture. Several centralized structures have been used to classify in planning and scheduling. In summary, the structure of MPCS can be classified into three phases in which decision markings are involves:

Phase 1: Pre-release planning – deciding the jobs mix to be produced, the precedence constraints upon operations, and manufacturing resources required by the jobs. At this stage, Group Technology (GT) for formulating jobs families and Material Requirement Planning (MRP) technique are usually employed.

Phase 2: Order release control – determining the timing and sequence in releasing jobs.

Phase 3: Shop floor control – generating detailed routings for the jobs on the basis of availability of manufacturing resources and satisfying operational constraints.

Olhager and Rapp [20] designed a MPC system, where the concept of modular design is stressed as being increasingly more important for so-called open system, to provide for different types of sub-systems or stand-alone-alone systems to be connected to the MPC system. But the method or technique of manufacturing planning and control system weren’t mentioned.

Bennet [1] introduced that companies do not use the full potential of their MPCS; the average system utilization is approximately 80% of the functions and modules available. If the use of OR models in manufacturing planning and control system, it is most important that the interfaces of OR-based stand-alone systems is opened and standardized. The main points of the research are:

1. There are some factors restricting the rapid of OR techniques into MPCS.
2. The use of OR-based system takes time and resource to develop new, or

even enhance existing MPCS.

3. The manufacturing environment is constantly changing, implying that specific applications can rapidly become obsolete.

Maria [25] summarized the techniques of production and control system and introduced that there are four principal moments (eras) of evaluation of production planning technique: optimization era, heuristic era, complexity era, interactive era. It is noted that current MPCS is a hierarchical planning approach which varies from aggregate approaches with rough time periods for long-term inventory and production planning to very detailed planning with precise data (daily, hourly, or by the minute) for short-term or immediate production activities. Thus, planning is usually performed top-down, whereas control is made possible through monitoring production activities and providing feed-back to all system levels [2].

Hierarchical or central control is the most common control architecture used in manufacturing systems. As a control model for implementing CIM systems, hierarchical decomposition of shop floor activities has been commonly used in the shop floor control system (SFCS), the central part of a CIM system [6]. Generally, a central database provides a global view of the overall system, and controllers generate schedules and execute them. Hierarchical control is easy to understand and is less redundant than other distributed control architectures such as heterarchical control.

Although hierarchical control architecture has been widely used, it has its limitations [41]. The primary drawback of hierarchically controlled manufacturing systems is the difficulty of modifying these systems. Modifying the configuration of hierarchically controlled manufacturing systems is expensive and time consuming as it involves expensive software rewriting. The hierarchical manufacturing systems are becoming increasingly complex with the integration of manufacturing system components. This hinders the expansion or redesign of manufacturing systems. Another disadvantage is that the quality of the information deteriorates as it flows up and down the hierarchy. The potential single point of failure of the central controller poses another significant problem. The failure of the central controller brings the entire system operation to a halt. The inclusion of fault tolerance methods result in increased system complexity [10]. Furthermore, these systems require huge databases, which can result in data retrieval delays and data consistency maintenance problems.

Figure 2.2 represents the formalization of hierarchy and heterarchy architecture. Graphically, hierarchy can be seen as a kind of ‘‘vertical’’ distribution of control, while heterarchy is a kind of ‘‘horizontal’’ distribution of control (Trentesaux, 2009). In sufficiently heterarchical control systems, long-term optimization is hard to obtain and verify due to the difficulty of proving that a sufficient level of performance can be attained, while short-term optimization is easy to achieve.

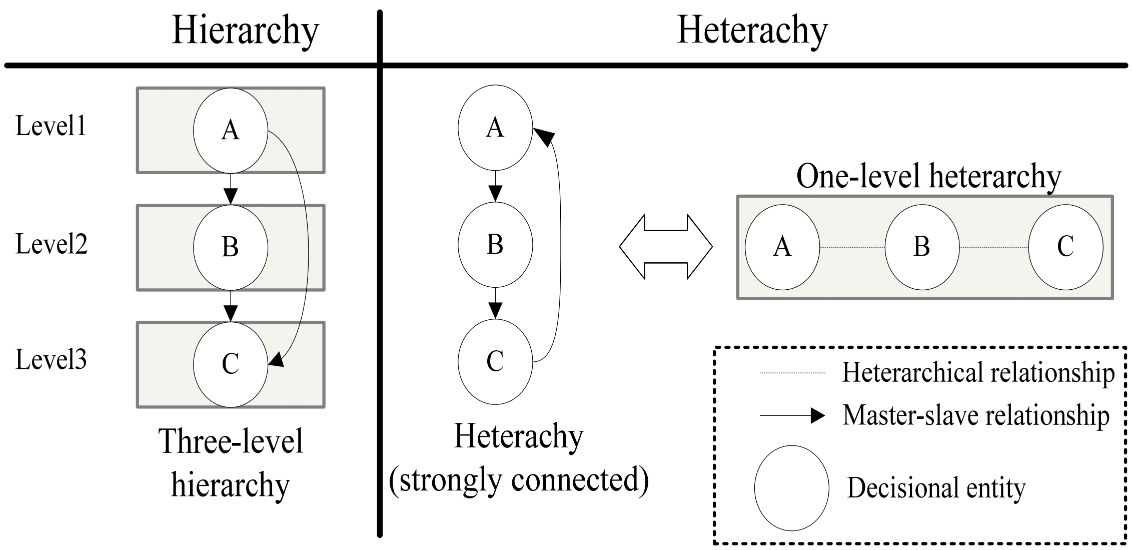

Figure 2.2 Formalization of heterachy and hierarchy architecture

In summary, hierarchical control architecture has a crucial weak point, which is that a small change in one level may significantly and adversely affect the other levels in the hierarchy. Therefore, it is normally said that hierarchical control is much more suitable for production in a steady environment than in a dynamically changing environment because it is so difficult to apply control hierarchy changes immediately to the equipment. Multi-agent systems (MAS) have been widely used to model such fully heterarchical control systems. The desire to integrate both hierarchical and heterarchical mechanisms into a distributed control system can be seen as an essential characteristic of the MAS paradigm, allowing users to benefit from the advantages of both approaches. Of course, it does not deny the relative drawbacks.

2.2 Multi-Agent System (MAS)

According to O'Hare and Jenning's definition, a MAS is a network of problem solvers that work together to solve problems that are beyond their individual capabilities [31]. Besides, a MAS is an artificial intelligence system composed of a population of autonomous agent that cooperate with each other to reach common goals, while simultaneous pursuing individual objects [3]. In an agent system, the agent specification framework must be capable of capturing the following aspects [63]:

1. The belief agents: the information they have about the environment, which may be incomplete or incorrect.
2. The ongoing interaction agents: how agents interact with each other and their environment over time.
3. The goals that agents will try to achieve.
4. The actions that agents perform and the effects of these actions.

Many manufacturing paradigms such as a bionic/biological manufacturing system (BMS) [57, 58], a holonic manufacturing system (HMS) [59, 60], and a fractal manufacturing system (FrMS) [61–63] have been proposed. Tharumarajah et al. [57] provide a comprehensive comparison among a BMS, a HMS, and an FrMS in terms of design and operational features. An FrMS is a new manufacturing concept derived from the fractal factory introduced by

Warnecke [63]. It is based on the concept of autonomously cooperating multi-agents referred to as fractals. The basic component of the FrMS, referred to as a basic fractal unit (BFU), consists of five functional modules including an observer, an analyzer, a resolver, an organizer, and a reporter [61,62]. The fractal architectural model represents a hierarchical structure built from the elements of a BFU, and the design of a basic unit incorporates a set of pertinent attributes that can fully represent any level in the hierarchy [56]. In other words, the term 'fractal' can represent an entire manufacturing shop at the highest level or a physical machine at the bottom-level. Each BFU provides services according to an individual-level goal and acts independently while attempting to achieve the shop floor level goal. An FrMS has many advantages for a distributed and dynamic manufacturing environment. Automatic reconfiguration of a system through a dynamic restructuring process (DRP) is the most distinctive characteristic of the FrMS.

Lim *et al.* [3] has proposed a multi-agent based dynamic process planning and production scheduling system and Kwangyeol [19] developed a FrMS which focused on formal modeling of agents and the characteristics of a fractal manufacturing system. The framework and the characteristics of agents used in developing these two multi-agent based manufacturing planning and scheduling systems may be applied in a distributed and heterogynous environment, the agents can autonomously perform the tasks based on the shop floor production status and external demand information stored in the related data bases. However, if the information did not update timely, the agent-based planning system cannot timely and effectively respond to the changing situations. Shaw *et al.*[8] employed software agents to develop an integrated manufacturing planning and predictive process model in which agents can control the shop floor production activities according to a set of predetermined control commands. However, this model cannot effectively respond to the current external and internal dynamic changing environments. Krothapalli and Deshmukh [19] proposed a multi-agent manufacturing system framework in which parts and machines are considered as agents with communication capabilities. The local data is gathered by communicating with other agents and also from local sensors. The primary objective of a part is to finish all the processing before the due date, while that of a machine is to maximize the utilization rate. Both parts and machines are governed by a set of rules, which help them to realize these objectives. The main advantage of this architecture is that agents do not have to rely on a particular component (central controller) to execute their instructions.

2.2.1 Agent-based Production Schedule

Within a MAS problem solving domain, a complex system is decomposed into several autonomous and loosely coupled subsystems represented by agents. These agents will then interact collectively to solve a defined problem, which could be part of a complex problem which has been broken down. Each agent determines its course of actions, although other agents may influence an agent's decision by forwarding appropriate messages. In the MAS, agents that represent the subsystems are able to solve problems in their domain with their own thread of control and execution. The characteristics of autonomous, intelligence, distributed decision-making architecture of agents have attracted many researchers in manufacturing control domain solving complex problems, nevertheless in the study of planning and production scheduling. Generally, the agent-based scheduling approaches found in the literature can be grouped into two categories based on the interaction mechanism used by the agents. They are the bidding-based methods and the non-bidding-based methods. The following review discusses the research work in both methods.

For the bidding-based methods, agents execute bidding to produce production schedules. The bidding process begins with an agent, namely ‘‘manager’’ decomposes a task into manageable sub-tasks and announces these sub-tasks to other agents termed ‘‘constructors’’ (Figure 2.3). Those contractors with the capability of deal with the sub-tasks will bid for the tasks. Eventually, the manager will allocate individual sub-tasks to corresponding agents based on some criteria. For the bidding-based methods, agents perform bidding to produce schedules.

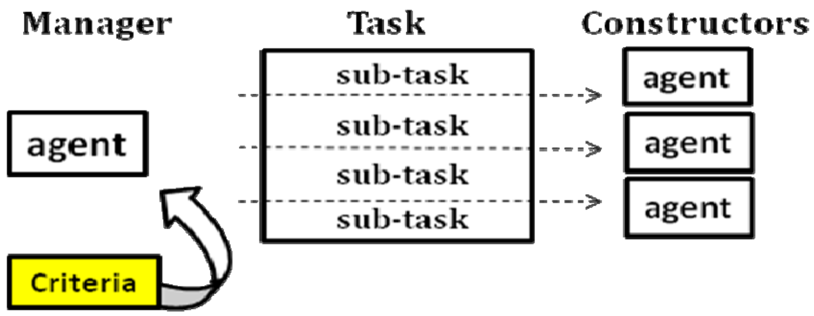

Figure 2.3 Bidding based method

Gu, Balasubramanian and Norrie,(1995) is one of the bidding-based methods employed for process planning and scheduling. Despite a successful development of an agent bidding method, a number of conceptual models are still proposed to verify the feasibility of using MAS in a distributed production planning and control environment (Lima, Sousa, & Martins, 2006). The conceptual models have proved their feasibility of employing these models in a simulated manufacturing environment. However, no discussion is provided on how to ensure the global performance is achieved in a dynamic scheduling environment. This achievement is an important measure for the research of this paper, in which the ultimate objective is to obtain an optimized production schedule, given the dynamic variations in demand patterns across products and changing product mixes.

The inspiration of the research of this paper has been provoked by currency-based bidding mechanisms found in literature, which can be adopted for improving the coordination of agent bidding and negotiation to achieve system and cost optimization. Lin and Solberg (1992) use a currency bidding mechanism to ensure the overall shop floor performance is achieved. This happens when the price values employed reach their balance. Other researchers have adopted an optimization approach such as genetic algorithm (Deshpande & Cagan, 2004; Maione & Naso, 2003) to ensure the attainment of global objectives in a distributed agent bidding environment. As the nature of a MAS involved distributed decision-making where agents bid and negotiation until the objective functions are achieved, high communication overhead with long processing time is resulted. Responding to this issue, some researchers have proposed to integrate hierarchical and heterarchical control mechanisms to form a hybrid coordination and control mechanism for MAS (N. Kumar, Tiwari, & Chan, 2008; Wong, Leung, Mak, & Fung, 2006a) A mediator is used to observe the agent negotiation process to avoid exhaustive negotiation which will lead to high communication overhead. Wong *et al.* (2006b) has further analyzed the hybrid coordination and control mechanism by comparing the performance generated using the hybrid mechanism and the one obtained using the traditional heterarchical mechanism.

The results produced using the hybrid mechanism is found to outperform those obtained using pure heterarchical mechanism in terms of producing a shorter makespan. However, the above reviewed works are designed to address the process planning and scheduling without taking into consideration shop floor disturbances such as machine breakdown, change of production volume, change of process plan, etc. This consideration is another aspect of achievement aimed by the research of this paper.

For the non-bidding-based methods, agents do not perform bidding but interact with one another via information exchange, either directly or indirectly to generate process plans and production schedules. Organizational self-design (Ottaway & Burns, 2000) and ant society (Blum & Sampels, 2004; R. Kumar, Tiwari, & Shankar, 2003; C. W. Leung, Wong, Mak, & Fung, 2010) are two well known non-bidding-based methods. Within the ant society, ants (representing agents) do not negotiate or bid but exchange information by updating pheromones deposited at various machines and/or crossings. The information received is used to determine the best scheduling solution for production. The constraint-based Architecture for Multi-agent Planning and Scheduling (CAMPS) proposed by Miyashita (1998) is another non-bidding-based method proposed to address manufacturing shop floor planning and scheduling. The main drawback of this method is that the Planner Agent follows a fixed process plan (i.e., uses pre-fixed resources for each task).

Caridi and Sianesi (2000) also employ a non-bidding-based method for planning and scheduling in a mixed product assembly line. Results obtained from a case study reviewed that the proposed method does not perform any better than the traditional heuristic approach proposed by Bautista *et al.* (1996). Hence, this proves the significant of carrying out performance evaluation between agent-based methods and non-agent-based methods to validate the need for developing yet another MAS-based methodology. As overall, not many non-bidding-based methods were developed because it is difficult for a distributed system to achieve its global performance without the aid of agent bidding or negotiation.

2.2.2 Agent-based Manufacturing Control

Figure 2.4 summarizes the different ways to distribute control decisions from centralized control systems to design non-centralized control systems based upon two basic design choices: the choice of using hierarchical relations and the choose of using heterarchical relationship [60]. Given the different ways of distributing control decisions, it is feasible to construct an architecture typology that is inspired by Dilts, Boyd, & Whorms (1991).

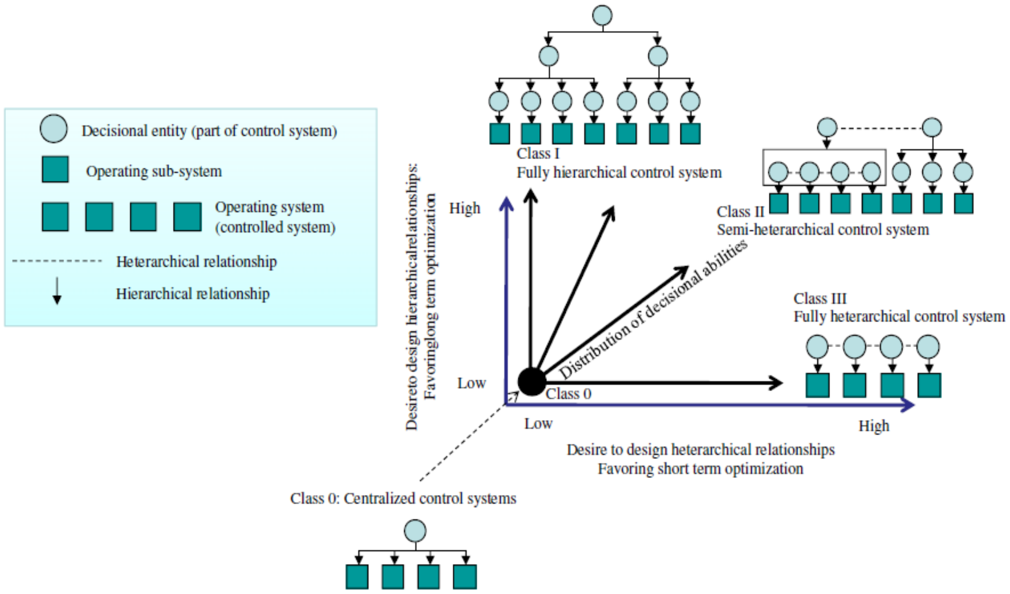

Figure 2.4 Comparison between centralized system and non-centralized system

Table 2.1 Summary of agent-based manufacturing control system

Authors	**Distributed control class**	**Mechanism**	**Modeling approach**	**Application**
Wang *et al.*	III	Negotiation	Multi-agent, constraint propagation	Supply chain formation
Seilonen *et al.*	III	Negotiation	Multi-agent BDI (belief-desire-intention)	Hybrid process reconfiguration
Lim *et al.*	III	Iterative bidding	Multi-agent Simulated annealing	Process planning and scheduling
Pujo *et al.*	III	Negotiation	Holonic	FMS control
Borangiu *et al.*	II	Negotiation	Holonic	FMS control
Aissani *et al.*	III	Negotiation and reinforcement learning	Multi-agent, reinforce learning	Process industry scheduling and maintenance
Wang *et al*	II	Negotiation and bidding	Multi-agent MaSE	FMS control

In summary, the application of multi-agent system in MPCS has developed to meet the distributed and heterogeneous environment, which causes by dynamically changing customer demand and uncertainly supplies (e.g. the shortage of material). Although MAS can be employed in distributed and dynamic environment, it can not make the correct decision without the real-time information.

2.3 RFID system

RFID allows products to be tracked in real time across the manufacturing environment providing accurate and detailed information on all items (e.g., raw material, WIP, finished products) to increase a manufacturing environment's accountability. So, this section introduces the RFID and the application of RFID in manufacturing planning and control system.

RFID (*R*adio *F*requency *ID*entification) is an electrical information-storing device, it has characteristics such as active, long-distance reading, and non-line-of-sight. Katina [23] introduced the pros and cons of RFID. The advantages of the application of RFID is shown as follows: automatic non-line-of-sight scan, reduced manpower, enhanced visibility, asset tracking and returnable items, item level tracking, traceable warranties and product recalls, *ea al.* But it still has some disadvantages such as cost, lack of standards, interface and reading considerations, and privacy concerns to cause the deployment issues.

Currently, only few researches studying the applications of RFID in manufacturing systems, Currently, only few researches studying the applications of RFID in manufacturing systems, Yagi *et al*. has proposed a RFID-based system in construction industry in which each part attached with RFID tag to perform the part tracking for a construction project, however, this system did not integrate with other applications (e.g., planning system) [67]. Besides, a framework of product life cycle support system has been developed through the integration of RFID and agent approach to effectively manage the production and assembly process in a highly customization industry [61].

Junichi *et al.* [22] has proposed a RFID-based system in construction industry in which each part attached with RFID tag to perform the part tracking for a construction project, however, this system did not integrate with other applications (e.g., planning system). Besides, a framework of product life cycle support system has been developed through the integration of RFID and agent approach to effectively manage the production and assembly process in a highly customization industry [32]. Schuh *et al*. [63] has proposed the approach to set up a network of sensors for online order identification and localisation in production by employing RFID technology, Programmable Logic Controllers (PLC) and Personal Digital Assistants (PDA). However, this research only proposed a software architecture, which allows for a consistent interaction of the heterogeneous planning and control systems, it did not describe the system implementation process and the planning and control mechanism.

Frederic *et al*. [63] proposed a real-time location system in complex manufacturing processes, in which RFID technology is employed to capture shop floor information to decide dispatching rules. McFarlane *et al.* [19] proposed an intelligent manufacturing control system based on multi-agent system and RFID technology. Tsai and Huang [20] constructs a real-time scheduling and rescheduling system based on RFID information for fully automated fabs. This research mainly focus on employing RFID technology to capture timely production information to help shop floor manager to re-generate production and operations schedule in a dynamic manufacturing environment, but not on planning and controlling a manufacturing system.

Usually, a RFID solution needs to be an event-driven system. By its nature, a RFID-enabled business process is an event-driven process, which is real time. RFID applications are also very dynamic, with the possibility of multiple, simultaneous events happening all at once, making it critical for organization to design RFID applications not only respond to these dynamic requirements, but also be quickly alerted or adjusted as need dictate. So, even if we have RFID system, the AMPCS cannot be developed without an application system, which can cope with each manufacturing event in a distributed dynamic environment, such as multi-agent system.

Although RFID technique can bring the real-time information, it cannot support a rapid decision-making in a distributed and heterogeneous manufacturing environment. To utilize the real-time information effectively, RFID must integrate with other application system, such as manufacturing planning and control system. To cope with these requirements, it is necessary to develop a manufacturing planning and control system (MPCS) which employs the RFID technique and MAS to quickly and dynamically respond to the external and internal environment changes.

Chapter 3 The System Framework of AMPCS

3.1 Research Problem

Based on current researches, the main drawbacks of hierarchical planning systems may be summarized as follows.

1. Structural rigidity: It is difficult to add, modify, or delete resources. To modify structure, the system is required to be shutdown and all data structures of higher levels need to be updated [22].
2. Difficulty of designing a control system: It is necessary for a hierarchical system designer to consider the large number of interrelationships related to failures and to explicitly program the relationships in order to get a fault tolerant system [17].
3. Lack of flexibility: Production planner and scheduler of higher level controllers assume deterministic behavior of their lower level components. Unforeseen disturbances such as machine breakdown which may invalidate the planned production schedule [22].

Besides, the application of MAS in developing a MPCS has obtained a numbers of potential benefits. However the following obstacles still need to be overcome [17]:

1. Ill suited information flows:

   Lack of communication among particular production units and low utilization of available information processing solutions is generally what makes the production difficult to understand, model and plan.

2. Frequent changes of manufacturing environment:

   Production is flexible, frequent changes of production targets, manufacturing facilities, system knowledge and planning strategies are inevitable.

3. Lack of global information:

Since each intelligent agent only attempts to achieve its objective without considering the global objective, there might be a contradiction-problem between local objective and the overall system performance [17].

4. Difficulty in predicting system performance:

   Since the interaction of intelligent agents may lead to unstable dynamics, it is difficult to predict system performance or the behavior of individual parts [26].

RFID is an electrical information-storing device, it has characteristics such as active, long-distance reading, and non-line-of-sight. RFID allows products to be tracked in real time across the supply chain providing accurate and detailed information on all items (e.g., raw material, WIP, products in factory and products in the down streams) to increase a supply chain's accountability. Therefore, this research may combine the RFID technique and MAS to develop the agent-based agile manufacturing planning and control system (AMPCS).

3.2 Research Framework

Based on the RFID technique, the agent-based agile manufacturing planning and control system (AMPCS) has the capability of monitoring all the production process activities, performing a real-time what-if simulation, planning and analysis, actively alerting each object's production activity (e.g., what it needs and where it goes). Therefore, the main characteristics/functions of an AMPCS may be summarized as follows.

1. Timely generate accountable production and operations schedule:

   AMPCS may not only increase the visibility of shop floor information but also ensure the accountability of production and operations schedule based on the timely and active production information (e.g., machine's actual operation start/end time), collected from items (i.e., work pieces) and equipments attached with RFID tags.

2. Actively monitor and control the execution of shop floor operations:

    AMPCS may not only effectively track and guide shop floor operations through the RFID technique according to the planned operations schedule, but also control the progress of shop floor operations to meet the planned schedule by classifying the causes of abnormality and alert related modules to identify the feasible alternatives once an abnormal event (e.g., machine breakdown) is detected. In addition, AMPCS also have the capability of effectively tracing the timely detailed production information for each demand order through RFID technique.

3. Real-time evaluate production performance:

    AMPCS may evaluate both the effectiveness (e.g., cycle time, on time delivery) of the generated production and operations schedule and the performance (e.g., WIP and manufacturing cycle time) of shop floor execution. The later will be the reference for continuous improvements.

In order to fulfill the aforementioned characteristics, Figure 3.1 depicts the framework of an AMPCS which is composed of three major modules: (1) the advanced manufacturing planning (AMP), (2) the RFID-based manufacturing control (R-MC), and (3) the performance analysis (PA). The proposed AMPCS can also integrate with external information application systems (e.g., demand management system and purchasing system) to respond to the external changing environment. The role and functions of AMP, R-MC and PA are briefly described as follows.

1. Advanced Manufacturing Planning (AMP)

    The agent-based AMP module is responsible for generating accountable production and operations schedule based on the demand (e.g., forecast and customer order) information inputs from master production schedule (MPS) and the timely and active production information and events provided by the RFID-based manufacturing control (R-MC) module and PA module, respectively.

2. RFID-based Manufacturing Control (R-MC)

R-MC module plays the role of effectively tracking and controlling the execution of a manufacturing system in which production items and manufacturing resources attached with RFID tags may actively feedback production status (e.g., current production location, processed time) to and receive production operations schedule from advanced manufacturing planning (AMP) module.

3. Performance Analysis (PA)

PA module is an event-driven monitoring mechanism which evaluates the inbound, production, and outbound logistics performance of a manufacturing system. Specifically speaking, PA module is responsible for monitoring and evaluating the normal and abnormal events of each manufacturing order’s shop floor operation tasks. Whenever an abnormal event (e.g., machine breakdown) is detected, PA module will classify the causes of abnormality and alert related modules (e.g., AMP module) to identify the feasible alternatives (e.g., a new operations schedule) and evaluate the effectiveness of the new alternative. Besides, PA module will also employ a simulation sub-module to evaluate the effectiveness of production and operations schedule and the performance of shop floor execution, based on the real-time manufacturing information provided by RFID technique.

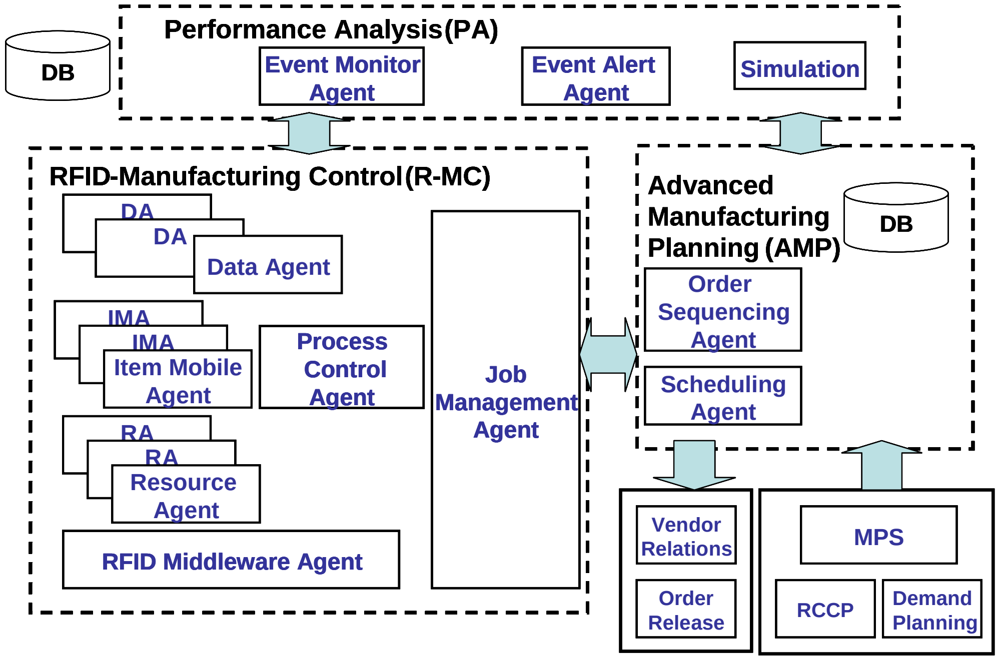

Figure 3.1 The infrastructure of AMPCS

3.2.1 Agents in AMPCS

In this research, a software engineering methodology called MaSE (Multi-agent Systems Engineering) is employed to develop AMPCS [31]. The agents in AMPCS are classified into two categories: soft agents and mobile agents. Soft agents are further classified into two categories: execution agents and information agents [3]. Execution agents are responsible for carrying out procedures and making decisions. Information agents are responsible for providing information or data to other agents upon request. Mobile agents are capable of executing and moving freely within an electronic network and can also communicate with other agents. The functions of agents in AMPCS, depicted in Figure 3.1, are briefly described as follows.

Execution agents:

1. *Order Sequencing Agent (OSA):* An order sequencing agent is responsible for generating demand order's priority.
2. *Scheduling Agent (SA):* A scheduling agent takes care of generating production schedule based on demand order and released MO's production

status obtained from JMA. Besides, SA will also generate shop floor operations schedule according to the bidding results (manufacturing resource for each MO's operation) obtained from PCA.

3. *Job Management Agent (JMA):* This agent is responsible for releasing manufacturing order (MO) based on production schedule and reviewing each MO's progress by updating the production information (quantity and time of finished items and WIP).
4. *Process Control Agent (PCA):* A production control agent provides the manufacturing routing and production instruction to each item mobile agent (IMA). *In* order to control each item's production progress, PCA continuously monitors the shop floor operations and obtains production information from each IMA. Besides, this agent is in charge of managing the bidding process, which consists of two tasks: (1) send bidding request to related resource agents and (2) select an appropriate manufacturing resource for a specific operation task based on each resource's utility.
5. *Event Monitoring Agent (EMA):* An event monitoring agent may monitor the manufacturing activities related to each MO, lot, and item.
6. *Event Alert Agent (EAA):* An event alert agent is responsible for sending the warning message to alert shop floor operators or scheduling agent (SA) to modify the abnormal shop floor operation event.

Information agents:

1. *RFID Middleware Agent (RMWA):* Each RFID middleware agent may represent the middleware software, which is employed to read data from and write data to RFID tag.
2. *Data Agent (DA):* Each data agent is responsible for collecting and providing data from/to IMA or RA through RMWA by using RFID technique. Besides, execution agents may also query data from database via DA. For instance, PCA will query an item's manufacturing routing from database via DA since PCA needs to provide production instruction to IMA.

Mobile Agents:

1. *Item Mobile Agent (IMA):* IMA represents an item attached with a RFID tag and may employ RFID technique to perform an item's manufacturing activity according to planned operations schedule and production instruction.
2. *Resource Agent (RA):* Resource agent represents a manufacturing resource attached with a RFID tag and is responsible for providing timely manufacturing resource's production information (e.g., machine's operation time). A RA will process operation tasks according to shop floor operations schedule. In addition, RAs will join the bidding process and reply the bidding information to PCA when they receive the bidding request from PCA.

Figure 3.2 depicts the agent classes included in AMP, R-MC, and PA modules, and the information communication (i.e., message) among the distinct agents (the line with arrow). For instance, SA in AMP module will generate the production schedule based on demand priority and production information (e.g., WIP) from OSA and JMA, respectively. Furthermore, SA will also generate the operations schedule. To overcome the structural rigidity in HPS, the decision for assigning an appropriate manufacturing resource to each operation task is obtained from the bidding process between PCA and RA.

At the shop floor execution level, an IMA, embedded with a RFID tag, will process the operation task based on the production instruction from PCA. IMA will send the production information to PCA through RMWA and DA to check whether it needs to continue its next operations or to finish the corresponding MO whenever an IMA completes an operation task. Then, PCA will send the production information (i.e., an operation task's actual start/end time) to JMA to check whether this manufacturing order is completed or not. When an IMA replies 'abnormal' message to PCA, SA may consequently receive that 'abnormal' message. Through the bidding process, PCA may select another appropriate manufacturing resource and SA may need to re-generate a new operations schedule and send this new operations schedule to IMA to continue its operation task.

An event monitoring agent (EMA) may monitor each MO, lot, and item's manufacturing activities based on the event information obtained from JMA, PCA, and IMA, respectively. Whenever EMA receives an 'abnormal' message, it will classify the abnormal cause and notice EAA to send 'warning' message to related agents (e.g., SA). Besides, simulation sub-module will evaluate both the expected performance of production and operations schedule (e.g., due-date performance) and the performance of production execution.

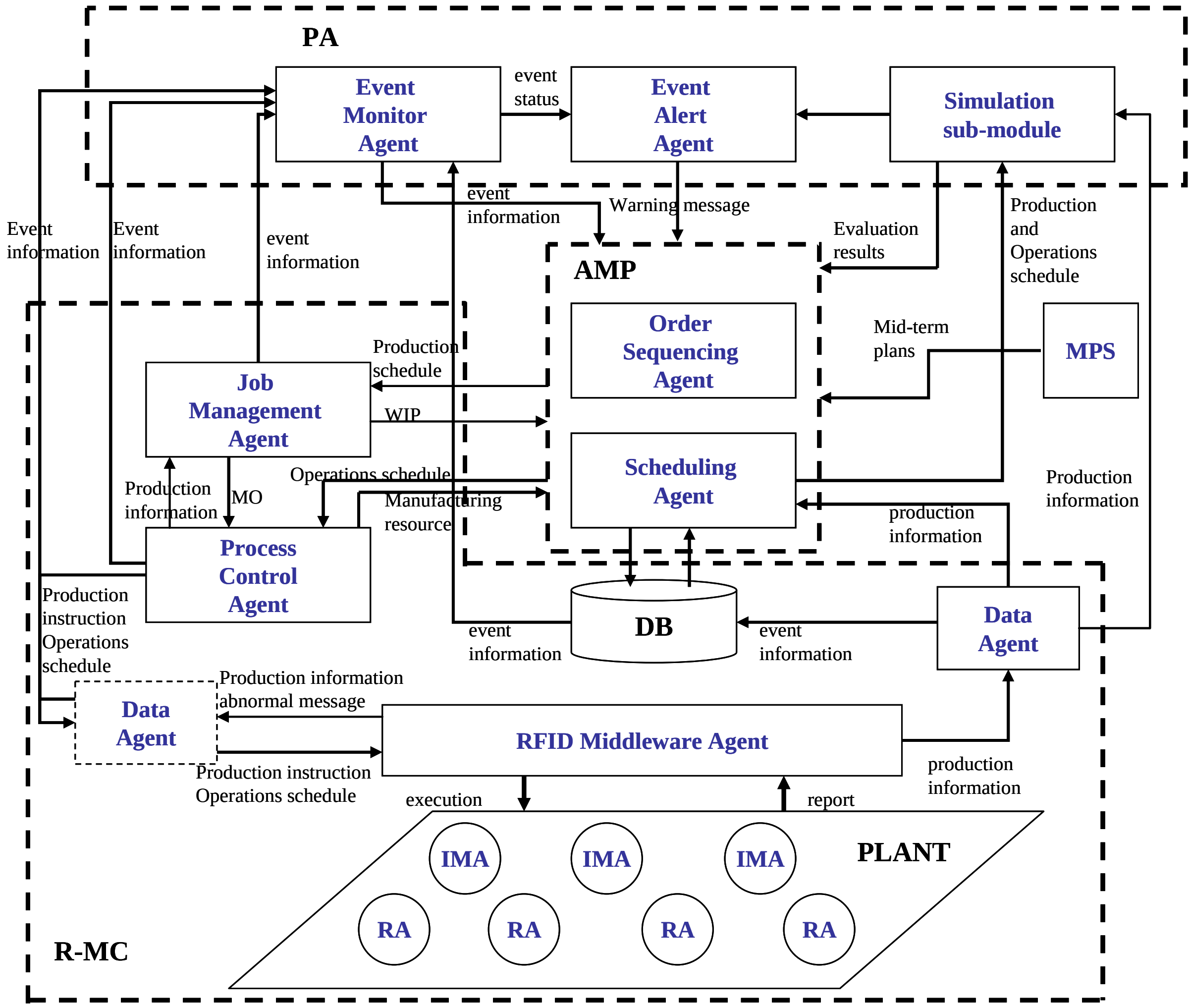

Figure 3.2 The message passing among the agents in AMPCS

3.2.2 RFID in AMPCS

RFID tags may be categorized into either active or passive types and supports three types of memory: read-only memory (ROM), read/write (R/W), or write once/read many (WORM). Due to the characteristics of an AMPCS, passive and R/W RFID tags are selected and attached to item mobile agent (IMA) and resource agent (RA) which may autonomously complete their assigned jobs based on the production instruction/information stored in their attached RFID tags. Central part of Figure 3 depicts the RFID tag's data structure of IMA and RA, which may be divided into two kinds of data: pre-allocated data and flexible data. Pre-allocated data will be written by RFID middleware agent (RMWA), a special mediator agent responsible for reading/writing data from/to RFID tag, and data agent (DA), and flexible data in RFID tag will be updated based on the operation status of IMA and RA in the shop floor.

In AMPCS, the content of RFID tag attached in each IMA and RA will vary with the progress of the shop floor operation (see left part of Figure 3.3), which may be described as follows:

1. Based on the negotiation protocol (generate production schedule (P1) in Figure 4.2), AMPCS may generate each manufacturing order's planned start/end time.
2. Based on the negotiation protocol (generate shop floor operations schedule (P2) in Figure 4.3), AMPCS may generate each operation task's planned start/end time.
3. Before IMAs start their operations tasks, they may need to write pre-allocated data into their RFID tags through DA and RMWA, respectively.
4. IMA writes 'check-in time' into its IMA's RFID tag when it enters the corresponding manufacturing resource based on "Routing ID" and "WS ID".

5. IMA may select available manufacturing resource according to the negotiation protocol (manufacturing control (P3) in Figure 4.4) and write ‘Item ID’ into RA’s RFID tag through RMWA.
6. RA, which is selected by IMA in step 5, may change its status from ‘idle’ to ‘busy’ and write ‘start time’ into its RFID tag.
7. After a manufacturing resource finished an operation task, its corresponding RA will change its status from ‘busy’ to ‘idle’ and write ‘end time’ into RA’s RFID tag.
8. IMA may write the ‘check-out time’ into its RFID tag at the time it leaves the manufacturing resource.
9. IMA may check ‘Routing ID’ stored in RFID tag to determine if there exists remaining operations. If there are remaining operations, go back to step 3 for the next operation and IMA may send the ‘check-in time’ and ‘check-out time’ into database through RMWA and DA, otherwise, go to step 10.
10. IMA may change its status from ‘unfinished’ to ‘finished’ and report the production information to R-MC and PA modules through RMWA and DA.

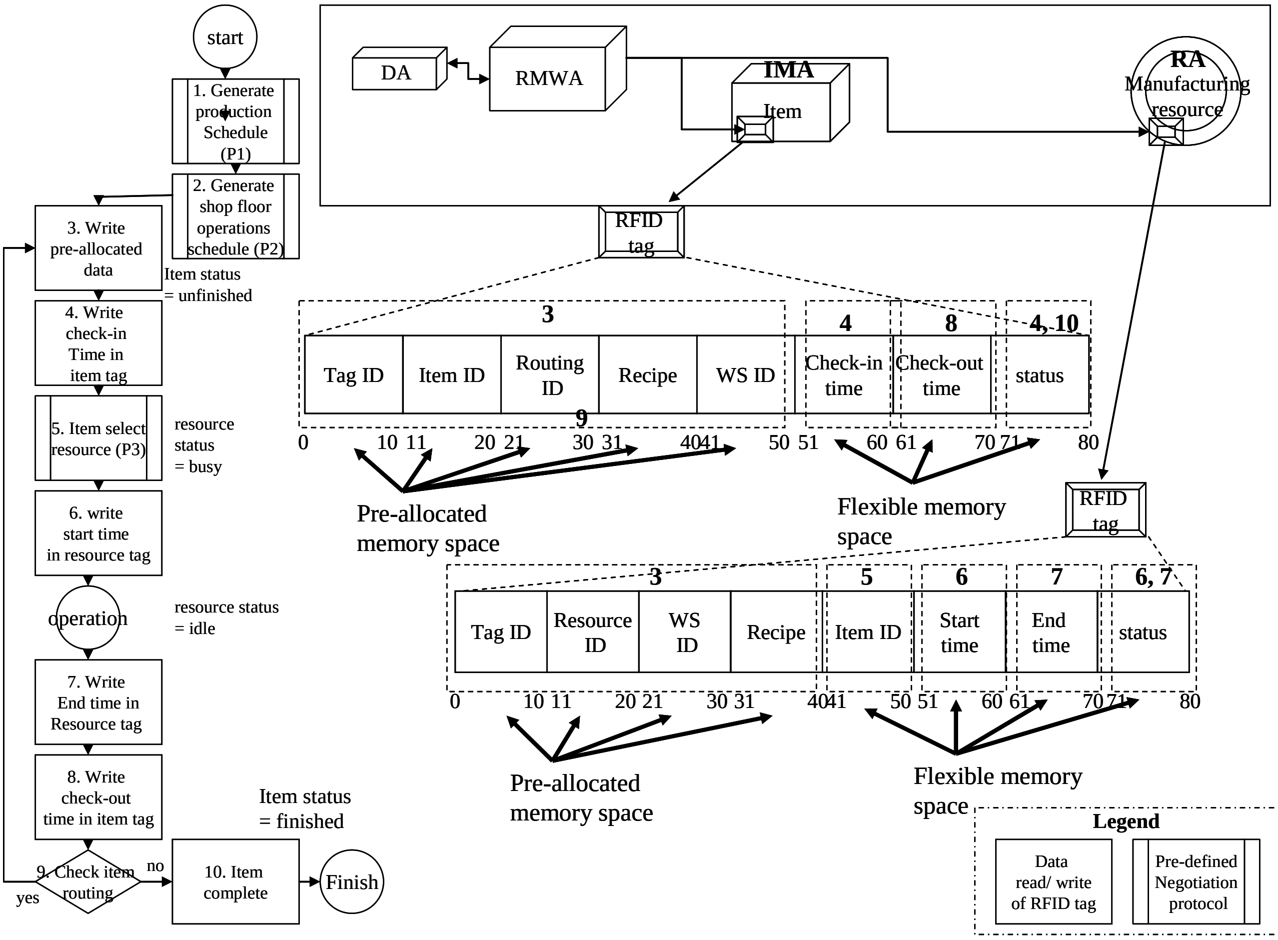

Figure 3.3 The data structure of RFID tag and operation process affecting tag information

Chapter 4 The System Analysis and Design of AMPCS

According to the framework of AMPCS the system analysis and design phase will be described as follows. Chapter 4.1 may describe the system development method of AMPCS. Chapter 4.2 may describe the system process of AMPCS and the negotiation protocol among each agent. The communication message among each agent the class diagram of AMPCS may described in Chapter 4.3. Chapter 4.4 may represent the architecture of agent which includes each agent's inter-construction and the procedures of generating production schedule and shop floor operations schedule.

4.1 System Development Method of AMPCS

The MaSE methodology is a specialization of more traditional software engineering methodologies. The procedure of employing MaSE to develop an agent-based system needs to follow the phases and steps shown in Figure 4.1. The MaSE analysis phase consists of three steps: (1) capturing goals, (2) applying use cases, and (3) refining roles. The design phase has four steps: (1) creating agent classes, (2) constructing conversations, (3) assembling agent class, and (4) system design [22]. The steps of the analysis and design phase will be described as follows：

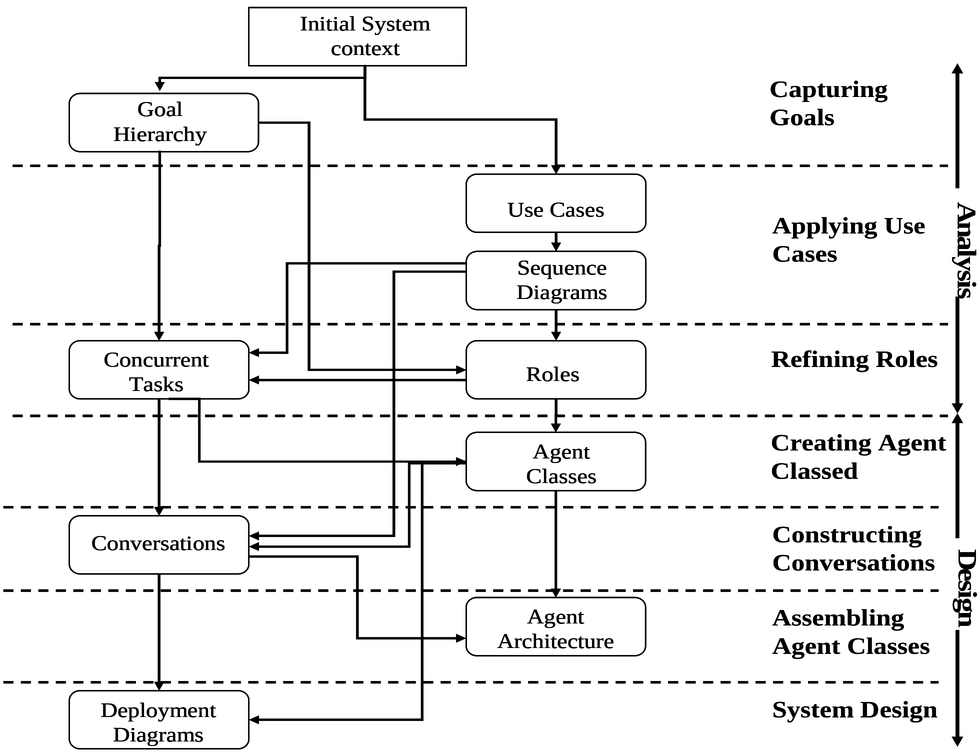

Figure 4.1 MaSE Phase [22]

The purpose of the MaSE analysis phase is to generate a set of roles whose tasks describe what the system has to do in order to meet overall requirements. The approach in the MaSE analysis phase is to define the system goals from a set of functional requirements and then define the roles to meet those goals. While a direct mapping from goals to roles, MaSE employes the use cases approach to help validating the system goals and derive an initial set of roles, the analysis phase is complete of each role has been defined. The MaSE analysis phase may be summarized as follows:

1. Identify goals from user requirements and construct a goal hierarchy diagram.
2. Identify use cases and create sequence diagrams to help identifying an initial set of roles and communications paths.
3. Transform goals into a set of roles by using the following module:
   (1) Create a role model to capture roles and their associated tasks.
   (2) Define a concurrent task model for each task.

The purpose of the MaSE design phase is to define the overall system organization by transforming the roles and tasks defined in the analysis phase into agent types and conversations. Four steps are involved in the MaSE design phase: the first step is creating agent classes, in which the designer assigns roles to specific agent types. Then, constructing conversations, the actual conversations between agent classes are defined. The third step, is assembling agent classes, the internal architecture and reasoning process of the agent classes are designed. Finally, the designer defines the actual number and location of agents in the deployed system. The MaSE design phase may be summarized as follows:

1. Assign roles to specific agent classes, and identify conversations by examining concurrent task models based on the roles played by each agent class.
2. Construct conversations by extracting the messages and states defined for each communication path in concurrent task models, adding additional messages and states for added robustness.
3. Define the internal architecture of agent classes using component and connectors. If is necessary to ensure that each action defined in a conversation is implemented as a method in the agent architecture.
4. Define the final system structure using deployment diagrams.

MaSE not only provides the generality and the application domain, but also supports for automatic code generation. The identified roles are driven by the capturing goals. The goal of MaSE is to guide the designer from the initial system specification to the implemented agent system. But an agent-based system still needs the communication language to define the communication message of negotiation protocol and the agent inter-constructions to define the agent's status of agent-based system. Therefore, we may employ sequence diagram to describe the system process and negotiation process among each agent in chapter 4.2. Then, KQML and BDI are deployed to define the communication language and the agent inter-constructions in chapter 4.3 and 4.4, respectively.

4.2 Negotiation Process of AMPCS

1. System operation process in AMPCS

The system operation process of AMPCS, depicted in Figure 4.2, may be modeled by using UML's sequence diagram, each agent's activity and the information passing among each agent of AMPCS are briefly described as follows.

Step 1: OSA will first collect the information of MPS and determine demand order's priority.

Step 2: OSA will trigger SA to generate production schedule based on demand, current work-in-process (WIP), and available capacity obtained from OSA, JMA, and PCA, respectively.

Step 3: SA will collect real time production information, such as item's operation status and resource's status from IMA and RA through RMWA and DA, respectively, and generate shop floor operations schedule based on the selected manufacturing resource obtained from PCA.

Step 4: Simulation sub-module is employed to evaluate the feasibility of production and operations schedule in terms of pre-determined performance target. Then, SA will send the feasible schedule to JMA.

Step 5: JMA will release manufacturing orders (MOs), which are generated from production schedule, to PCA.

Step 6: RA will receive operations schedule from SA to be the reference of executing manufacturing activities.

Step 7: IMA receives production instruction from PCA through RFID Middleware Agent (RMWA) and begins or continues that item/ lot's specific manufacturing activity.

Step 8: IMA sends 'request for production (RFP)' message to RA, and RA will respond 'accept' or 'reject' message.

Step 9: If RA is available (i.e., status = idle), RA will send “acknowledged RFP” message to IMA, go to step 10. Otherwise, RA will send “reject” message to IMA, and notice IMA to send “warning” message, go to step 11.

Step 10: IMA will start to execute the operations task based on the production instruction.

Step 11: EMA may track the cause and request EAA to send “warning” message to alert SA to modify operations schedule.

Step 12: SA may re-generate a new production and operations schedule and request simulation sub-module to evaluate the performance (go back to step 4).

Step 13: IMA will request RMWA and DA to send this item’s production information to JMA and check if there are some remaining unfinished operations.

Step 14: PCA will send “production instruction” message to IMA through RMWA and DA if there are some remaining unfinished operations, and go to step 15. Otherwise, the completion information will be sent to JMA.

Step 15: Repeat step 7 to step 14 until all IMAs complete all the operations.

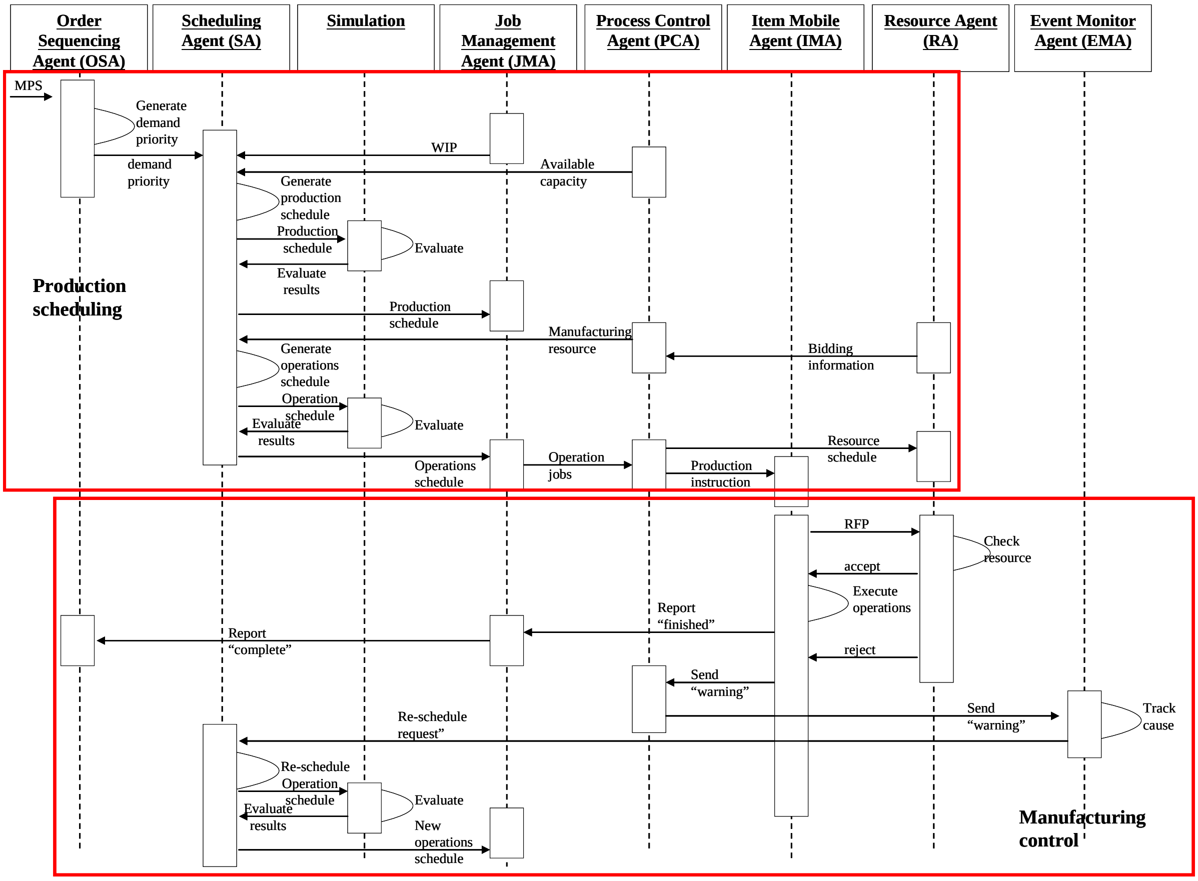

Figure 4.2 The system operation process of AMPCS

2. Production schedule in AMPCS

Based on the system operation process of AMPCS, we will further describe how does scheduling agent (SA) employs a bidding mechanism to coordinate related agents to effectively generate production and operations schedule. The negotiation protocol of production schedule and operations schedule generating procedure are shown in Figures 4.3 and 4.4, and the major negotiation activities among JMA, SA, PCA, IMA, and RA are briefly described as follows.

(1) Generate production schedule (P1)

SA will receive demand order and timely production information, such as WIP and available capacity from JMA and PCA (see Figure 4.3 for illustration). Since different scheduling algorithms may pursue different performance measurements (e.g., minimum WIP, the shortest cycle time), SA in AMPCS may also employ a numbers of appropriate scheduling algorithms to generate adequate production schedule. "First-In First-Out (FIFO)" based scheduling algorithm employed by SA, will backwardly generate each manufacturing order's planned start/end time based on demand due date and manufacturing lead time.

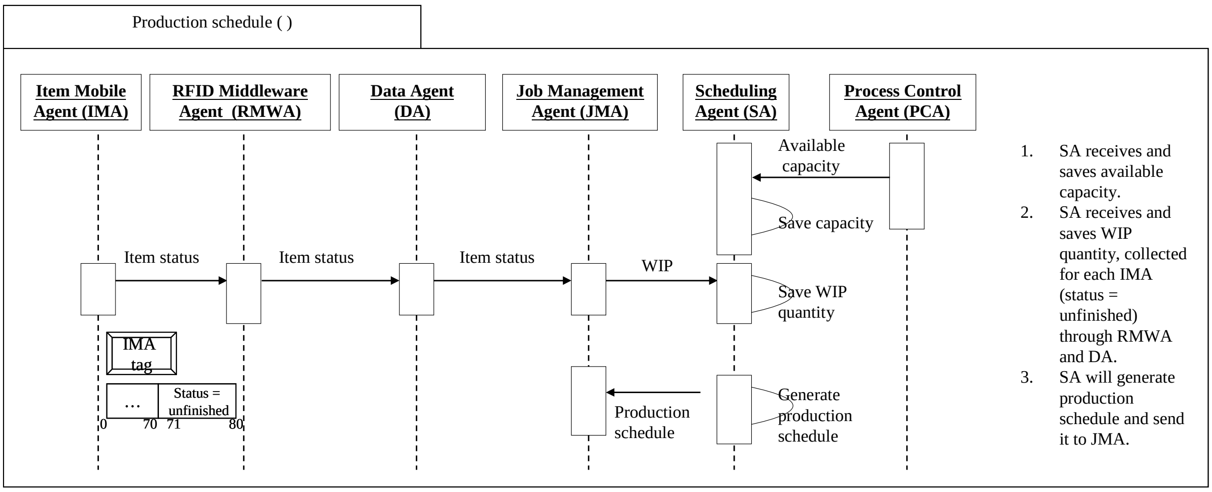

Figure 4.3 Negotiation Protocol of production schedule generating procedure

(2) Generate operations schedule (P2)

a. Receive production information:

SA needs to receive and save the start/end time of each manufacturing order (MO) from JMA (See Figure 4.4(a) for illustration).

b. Bidding protocol:

The bidding protocol employed by PCA to select an appropriate manufacturing resource for each operation task is depicted in Figure 4.4(b). At the time that an operation of a specific MO with the expected due date needs to be scheduled to a suitable resource (i.e., machine), PCA will first send 'bidding request' to related RAs which are candidate for processing the requested operation. Then, each RA, participated in the bidding, will reply bidding information {manufacturing resource ID, production quantity, processing time, due date, resource status} to PCA.

Consequently, PCA will select one "winner" resource, based on each bidding resource's utility assessment.

Utility = (unit production time/processing time)*resource status rate

in which resource status rate $= \begin{cases} 1 & \textit{if resource status is idle}; \\ 0.5 & \textit{otherwise.} \end{cases}$

c. Generate operations schedule:

SA will first receive the bidding results (i.e., assigned manufacturing resource for an operation task) from PCA. Then, SA will generate each individual operation task's planned start/end time based on forward scheduling algorithm. For any resource assigned to an operation task through the bidding process, if it is idle at the scheduling time, the planned start time is the current scheduling time if that operation task is a MO's first operation task, otherwise, the planned start time is its preceding operation's planned end time. On the contrary, if the assigned resource is busy at the scheduling time, the planned start time is equal the scheduled available time of the assigned resource. The planned end time of each operation task is equal its planned start time plus assigned resource's processing time. Consequently, simulation sub-module is employed to evaluate the feasibility of planned operations schedule (e.g., due date performance) and reply the evaluation results to SA.

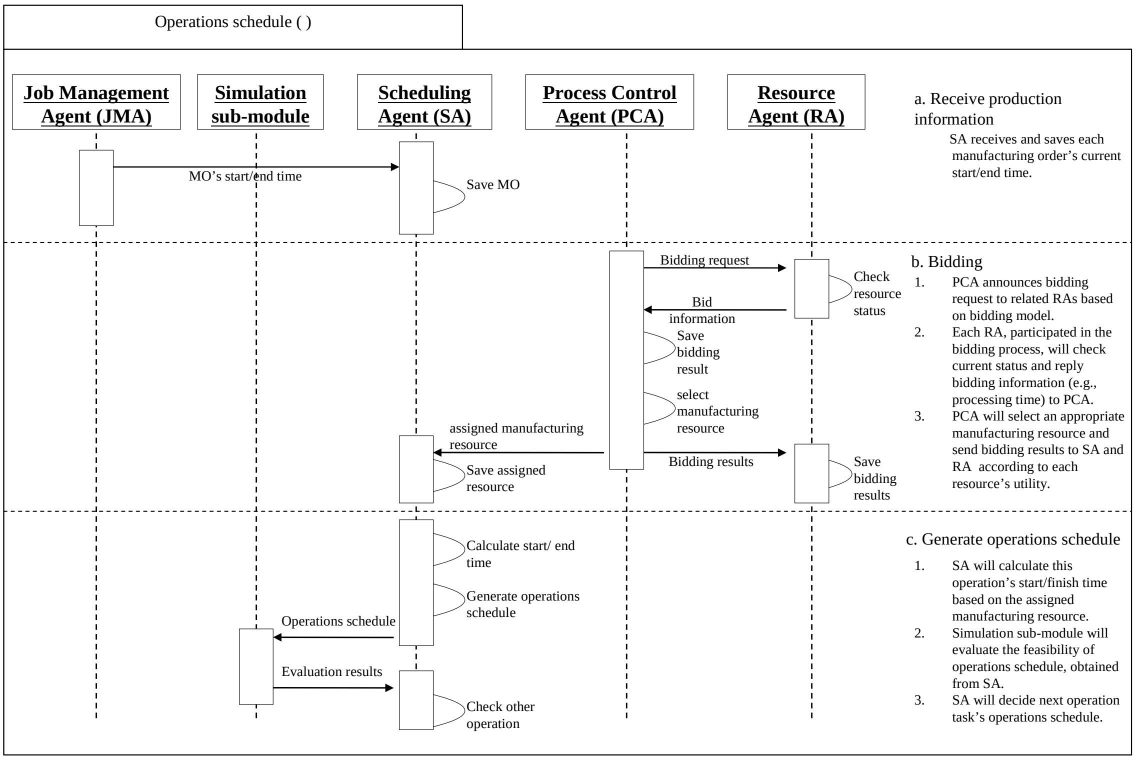

Figure 4.4 Negotiation protocol of operation schedule generating procedure

3. Manufacturing control in AMPCS

After process control agent (PCA) received operations schedule from scheduling agent (SA), RFID-based item mobile agents (IMAs) and resource agents (RAs) will coordinate to complete the production operations based on operations schedule. Since the RFID tag of each IMA will attach production instruction (i.e, item_ID and recipe_ID), which is generated from operations schedule (i.e., item_ID, resource_ID, operation_ID, and operation time), an IMA will automatically send the “request for production” message to the scheduled RA for its next operation when an item’s current production operation is done. If the scheduled RA is available (status=’idle’), it will send a “ready for production” message to the request for production (RFP) IMA, the new operation may begin. However, if the scheduled RA rejects the RFP for some reasons, then, the RFP IMA will trigger PCA to send warning to EMA to find out the cause, then, EMA may request EAA to send a re-schedule request to SA to generate a new feasible operations schedule, evaluated by simulation sub-module. Consequently, all IMAs and RAs will execute according to new production instructions and resource schedule released by PCA.

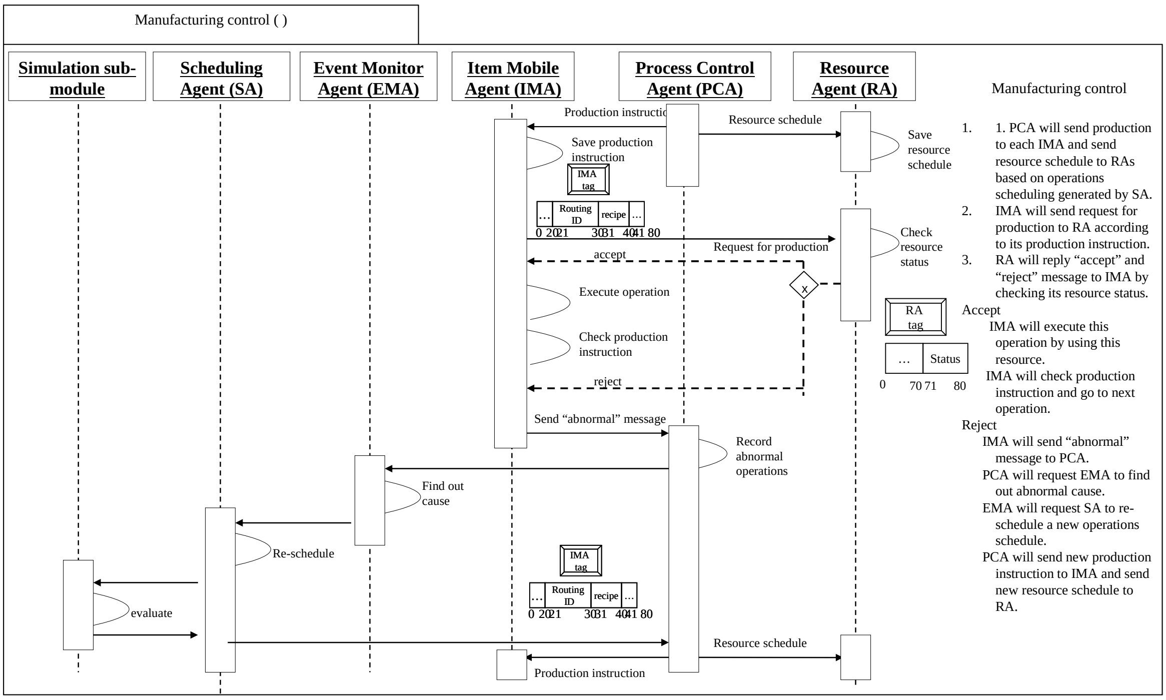

Figure 4.5 Negotiation protocol of manufacturing control procedure

In AMPCS, PA module is responsible for not only evaluating the effectiveness of production and operations schedule generated from AMP module, but also monitoring and evaluating the performance of shop floor execution, based on the real-time manufacturing information provided by RFID technique. The evaluation mechanism in PA module may be described as follows.

(1) Evaluation of production and operations schedule

a. Normal situation/event

At the normal situation, production and operations schedule generated by SA needs to be evaluated by the simulation sub-module of PA module. If the performance of SA’s planning results cannot meet the predetermined target (e.g., on time delivery percentage, WIP level), event alert agent (EAA) will send a message to request SA to re-generate a new production and operations schedule by adjusting planning parameters/constraint or employing different scheduling generation algorithms.

b. Abnormal situation/event

In a dynamic and competitive environment, a number of external and internal unexpected abnormal events may occur, the planned production schedule and shop floor operations also need to be effectively adjusted. In AMPCS, abnormal events may effectively be detected by means of comparing the planned production information with the actual execution information stored in the agents (e.g., IMA and RA) attached with RFID tag. Table 4.1 lists several common abnormal events handled by an AMPCS, for example, a machine breakdown abnormal event, the cause is listed in the first row of Table 4.1, may be recognized by event monitoring agent (EMA), then, EAA will send an alert message to request SA to re-generate a new alternative production and operations schedule. Consequently, the simulation sub-module will be employed to evaluate the performance of this new production schedule.

Table 4.1 Sampled abnormal events handled by AMPCS

Category	Sampled abnormal events	Sampled causes	Information source in AMPCS
Internal	Machine breakdown	Operation resource's actual operation time is much larger than planned operation lead time.	Resource Agent
	High scraping	Actual throughput is less than planned throughput.	Item Mobile Agent
External	Rush order	Order's requested lead time is less than the normally quoted lead time	Order Sequencing Agent
	Change of order's quantity or due date	Order's due date is postponed or ahead than before	Order Sequencing Agent

(2) Evaluation of the performance of production execution

In AMPCS, a number of performance measures may be evaluated, resource's utilization and WIP quantity are two common measures related to RA and IMA, respectively.

a. Operation resource's utilization

Simulation sub-module may effectively evaluate each operation resource's utilization rate based on the timely actual operation time (i.e., end time - start time) recorded in the RFID tag of its corresponding RA.

b. WIP quantity

Simulation sub-module may effectively evaluate WIP quantity, based on the timely status information recorded in the RFID tag of each IMA residing in the shop floor, by aggregating the total quantity of IMA whose status is "unfinished".

4.3 The Communication Message of AMPCS

The communication messages of AMPCS are defined using KQML, the knowledge Query & Manipulation Language, has been developed under a DARPA funded project and is probably the most well-known and widely-implemented agent communication language [26]. A KQML message usually has the form:

```
(perfName
   :sender A            :receiver B
   :content X           :language L          :ontology N
   :reply-with W        :in-reply-to P)
```

This is a message from A to B in reply to a previous message identified by P. Any message sent in respond to this message should include: in-reply-to W. The content X has a syntax like that specified by the language L whose terms are taken from ontology N. The message's meaning is determined by the combination of perfName and the content X.

The communication message of AMPCS is defined with KQML. The contents of KQML, which is classify into three parts, such as (1) the communication message of system process, (2) the communication message of production schedule generation, and (3) the communication message of manufacturing control. The message content will be introduced as followed:

1. System process

The communication message of the negotiation process of system process includes two kinds of messages: (1) alert message and (2) information message. Alert message is respond to change the agent's status or trigger agent to do some tasks to achieve the system goals. The information message is the necessary data which agent needs to achieve its related work. Take the alert message which is form JMA to DA for instance, the message content, which is request to update job information, means JMA request DA to provide the latest job information. So, JMA send an alert message means "job information", and DA will collect the latest job information and feedback the message, which contains job information to JMA.

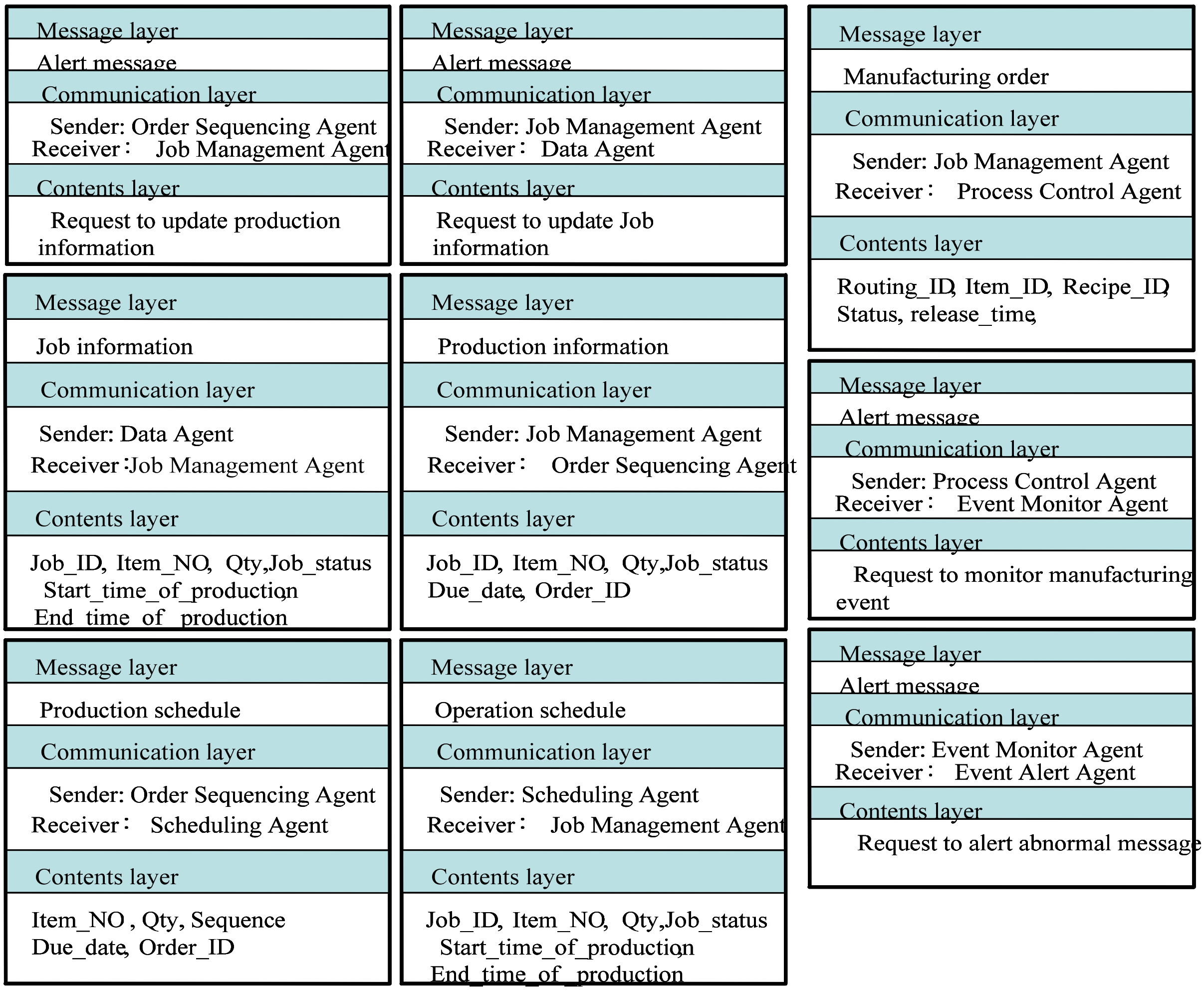

Figure 4.6 The communication message of system process

2. Production schedule generation

The communication message of the negotiation process of production schedule generation includes two kinds of messages: (1) alert message and (2) information message as same as the negotiation process of system process. Take the information message which is form PCA to RMWA for instance, the message content, which is about the information of manufacturing routing, means PCA provides the manufacturing routing, such as Routing_ID, Item_ID, Receipe_ID, and status, to RMWA to achieve RMWA's goals (e.g., generate manufacturing command).

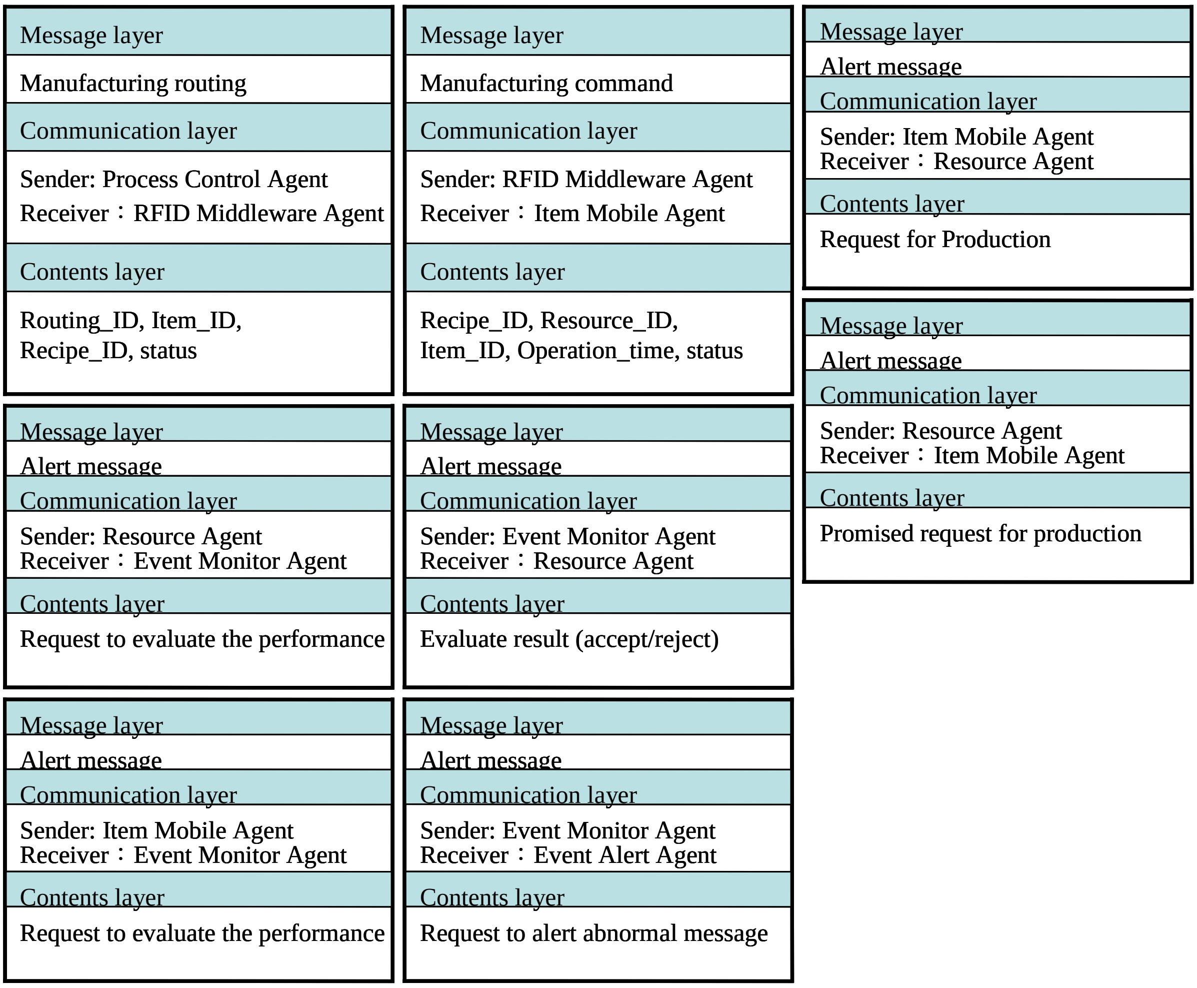

Figure 4.7 The communication message of production schedule generation

3. Manufacturing control

The communication message of the negotiation process of manufacturing control includes two kinds of messages: (1) alert message and (2) information message as same as the negotiation process of system process. Take the alert message which is form PCA to IMA for instance, the message content, which is unfinished message, means PCA alert DA this lot/item still has incomplete manufacturing tasks to do.

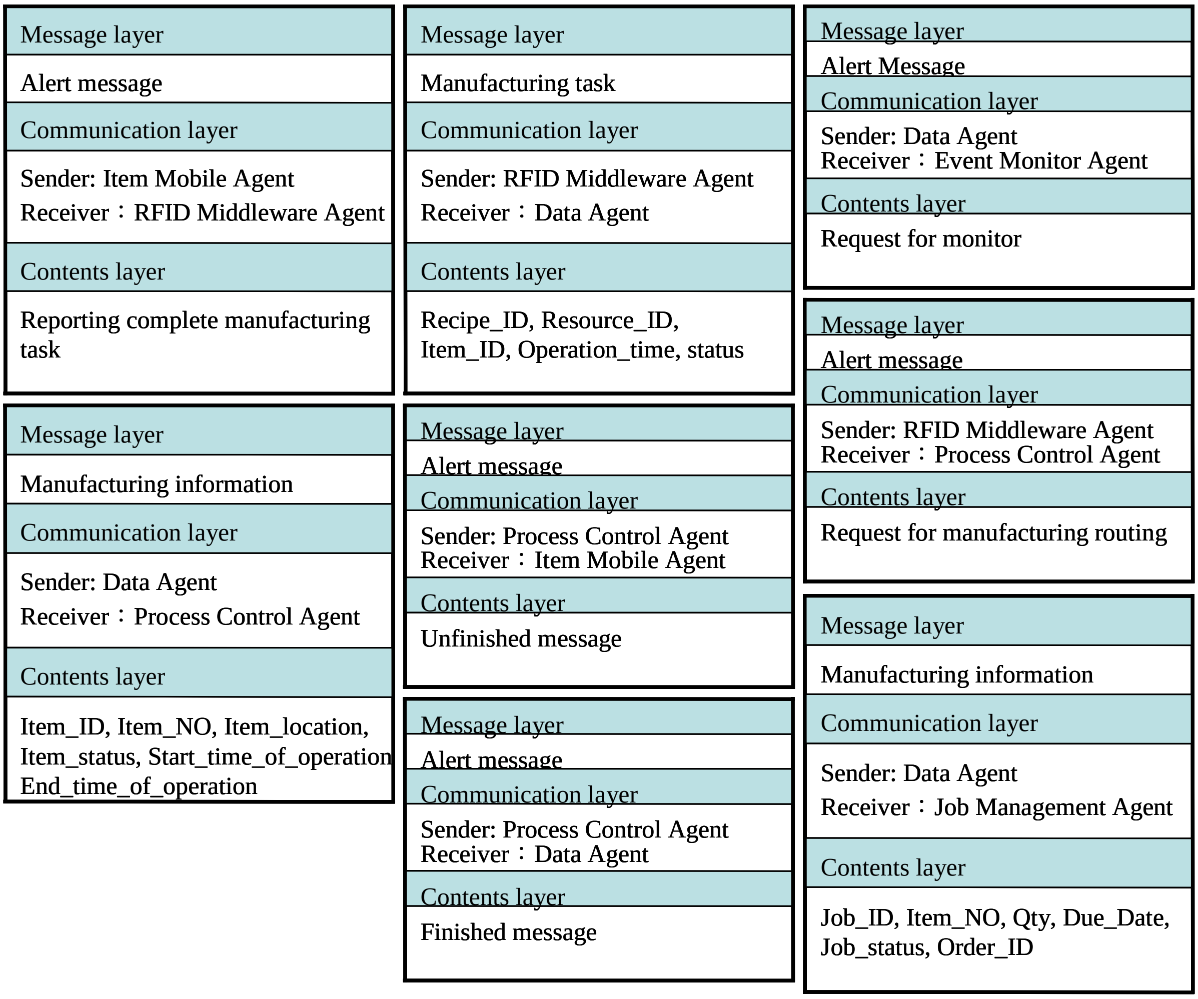

Figure 4.8 The communication message of manufacturing control

To summarize the communication message of each agent, the communication message of AMPCS, which is summarized in Table 4.2, includes two kinds of messages: (1) alert message and (2) information message. Alert message is responsible for changing the agent's status or trigger agents to do some tasks to achieve the system's goals, and information message is responsible for providing the necessary data according to the request. Take the alert message "request to update job information" from JMA to DA as an example, this message represents that JMA requests DA to provide the latest job information. In AMPCS, DA will collect the latest MO's information and feedback the MO's information (e.g., MO_ID, Item_ID, Qty) to JMA.

Table 4.2 Communication message of each agent

Message layer	Communication layer		Contents layer
	sender	receiver	
Alert message	OSA	JMA	Request to update production information
Alert message	JMA	DA	Request to update Job information
Alert message	PCA	EMA	Request to monitor manufacturing event
Alert message	EMA	EAA	Request to alert abnormal message
Alert message	IMA	RA	Request for production
Alert message	RA	IMA	Promised request for production
Alert message	RA	EMA	Request to evaluate the performance
Alert message	EMA	RA	Evaluate result
Alert message	IMA	EMA	Request to evaluate the performance
Alert message	IMA	RMWA	Reporting complete manufacturing task
Alert message	PCA	IMA	Finished/unfinished message
Manufacturing order	JMA	PCA	MO_ID, Item_ID, Order_ID, Start_time_of_production, End_time_of_production
MO's information	DA	JMA	MO_ID, Item_ID, QTY, MO_status, Start_time_of_production, End_time_of_production
Operation schedule	SA	PCA	Operation_ID, Item_ID, Resource_ID, QTY, Start_time_of_operation, End_time_of_operation
Production schedule	SA	JMA	Item_ID, QTY, Order_ID, Start_time_of_production, End_time_of_production
Manufacturing routing	PCA	RMWA	Routing_ID, Item_ID, Recipe_ID, Status
Production instruction	RMWA	IMA	Recipe_ID, Resource_ID, Item_ID, Operation_time, status
Resource information	DA	PCA	Recipe_ID, Resource_ID, Item_ID, Operation_time, status
Item information	DA	PCA	Item_ID, Item_location, Item_status, Start_time_of_operation, End_time_of_operation

The system framework of AMPCS presented in this research includes a number of agents which need to send and receive message and data between each other, the data model of AMPCS is depicted in Figure 4.8. Take JMA for an example, the information that received from AMP module is manufacturing order, which includes MO_ID, Item_ID, Qty, Order_ID, Start_time_of_production, and end_time_of_production. However, JMA's responsibility includes not only releasing manufacturing orders, but also collecting the MO's information. Therefore, a message status (e.g. MO_status) is required. When a manufacturing operation is completed, its IMA will send "complete" message to PCA through RMWA and DA. Consequently, PCA will change the MO_status from "incomplete" to "complete" if all the operations are completed. Consequently, JMA will collect the quantity of finished items and completion time through DA.

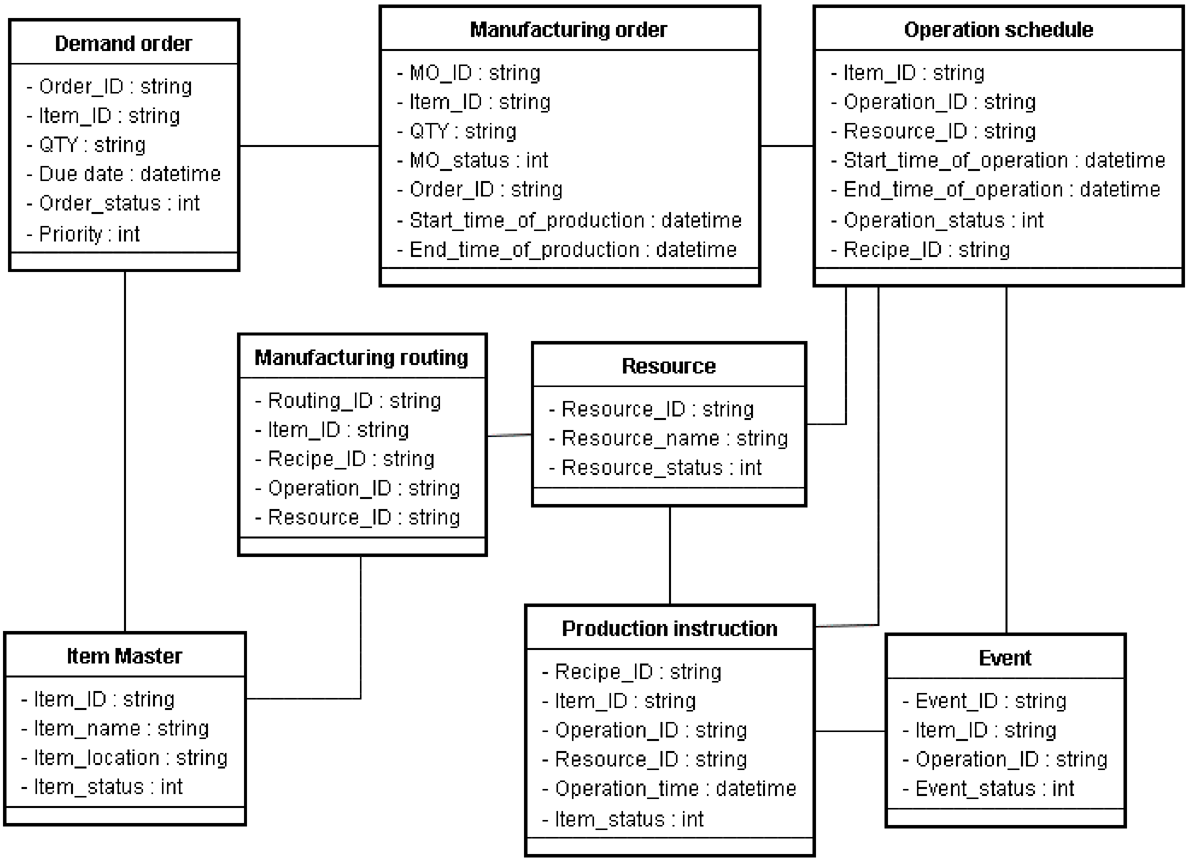

Figure 4.9 The data model of AMPCS

4.4 The Architecture of Agents in AMPCS

The Belief-Desire-Intention (BDI) agents are developed by employing a set of specialized object-oriented models. In this research, there are two models: external and internal [19].

From the external viewpoint, the system is decomposed into agents, their responsibilities, the services they perform, the information they require, and their external interactions. These characteristics are captured in two models: the Agent Model and the Interactions Model.

1. The **Agent Model** describes the hierarchical relationship between different abstract and concrete agent classes, and identifies the agent instances that may exist within the system, their multiplicity, and when they come into existence.
2. The Interaction **Model** describes the responsibilities of an agent class, the services it provides, associated interactions, and control relationships between agent classes. The external viewpoint and associated models are captured in MaSE Agent Class Diagrams using agent classes and conversations.

From the internal viewpoint, the elements required by particular agent architectures are modeled for each agent using three models that describe its informational and motivational state and its potential behavior:

1. The **Belief** Model describes the information about the environment and internal state that an agent of that class may hold, and the action is may perform.
2. The Goal **Model** describes the goals that an agent may possibly adopt, and the events to which it can respond.
3. The **Plan Model** describes the plans that an agent may possibly employ to achieve its goals or respond to events it perceives. It consists of a

plan set which describes the properties and control structure of individual plans.

4.4.1 Agent Inter-constructions of AMPCS

Since the communications messages between separate roles or agents can be mapped by KQML, we will design each agent's architecture in AMPCS by employing BDI method. Each agent's architecture contains goal module, belief module, and plan module. For achieve the goal of each agent, the belief value in each agent will change by other agent's, and plan module will check belief to choose the appropriate plan (e.g., plan1 or plan 2) to execute, and each plan may contains different tasks to choose (e.g., generate order sequencing or update order information), so different parameters of plan will be choose to do the related tasks. Each agent's architecture will be described as follows:

1. Order Sequencing Agent (OSA)

   The OSA is responds to generate daily production schedule. There are two plans needed to do: (1) communication, (2) Task. The task contains three implementation procedures:

   (1) Update order information: to collect the information of MPS.

   (2) Generate order sequencing: to determine order sequencing according to due date and order priority.

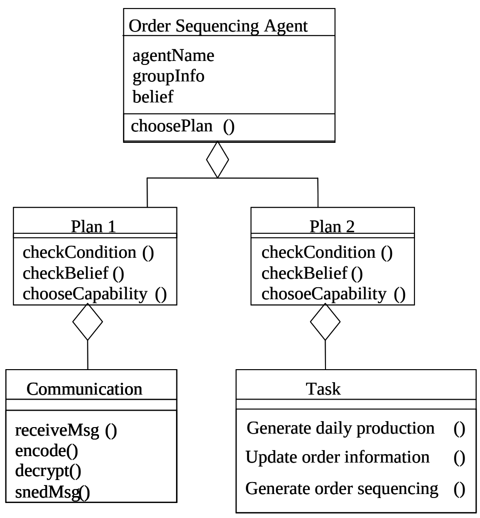

Figure 4.10 The inter-construction of Order Sequencing Agent

2. Scheduling Agent (SA)

The SA is responds to generate shop floor operation sequencing and scheduling. There are two plans needed to do: (1) communication, (2) Task. The task contains two implementation procedures:

(1) Generate production schedule: to determine production schedule based on demand order.

(2) Generate shop floor operations schedule: to determine operations scheduling based on bidding results.

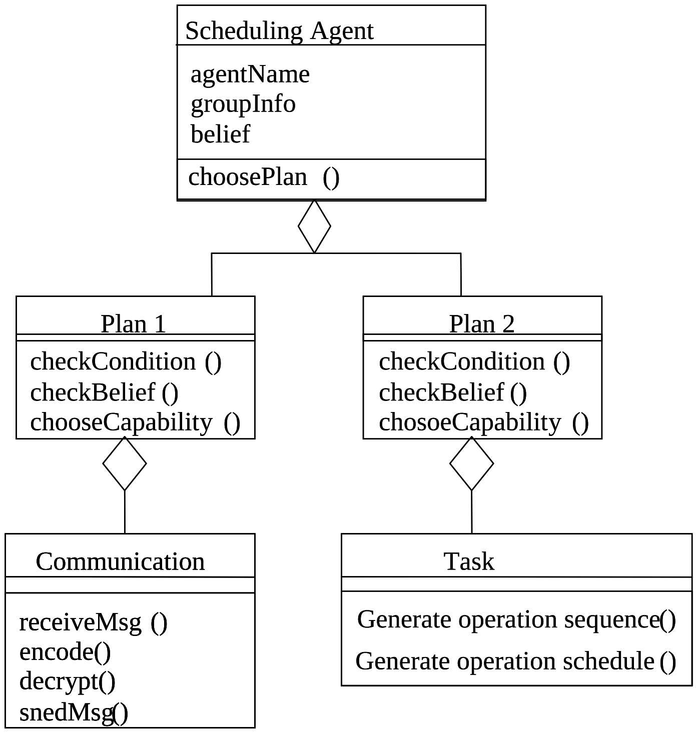

Figure 4.11 The inter-construction of Scheduling Agent

3. Job Management Agent (JMA)

The JMA is responds to review and release manufacturing order and provide the information of finished goods. There are two plans needed to do: (1) communication, (2) Task. The task contains four implementation procedures:

(1) Update production information: to update the information (e.g., time, quantity) of finished item.

(2) Manufacturing order review: to review manufacturing orders according to production schedule.

(3) Manufacturing order release: to release manufacturing orders according to production schedule.

(4) Manufacturing order reporting: to report the manufacturing order if the items of these manufacturing order is all finished.

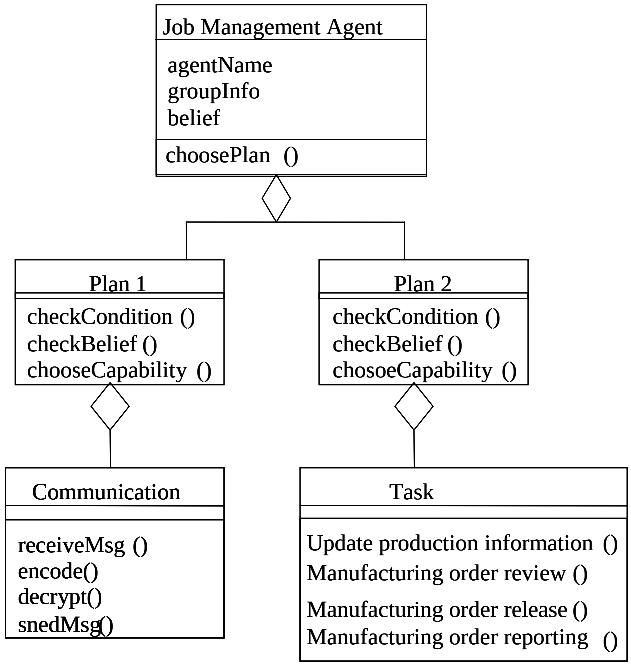

Figure 4.12 The inter-construction of Job Management Agent

4. Process Control Agent (PCA)

The PCA is responds to provide each lot/item's manufacturing routing, the shop floor production status, and production instruction. There are two plans needed to do: (1) communication, (2) Task. The task contains five implementation procedures:

(1) Manufacturing routing check: to provide each lot/item's manufacturing routing.

(2) Make production instruction: to send production instruction to related lot/item according to its manufacturing routing.

(3) Check lot/item's status: to check if there are some other unfinished operation tasks of lot/item.

(4) Lot/item report: to report the lot/item's production information when an item finished one operation.

(5) Lot/item release: to release the lot/item according to operation schedule.

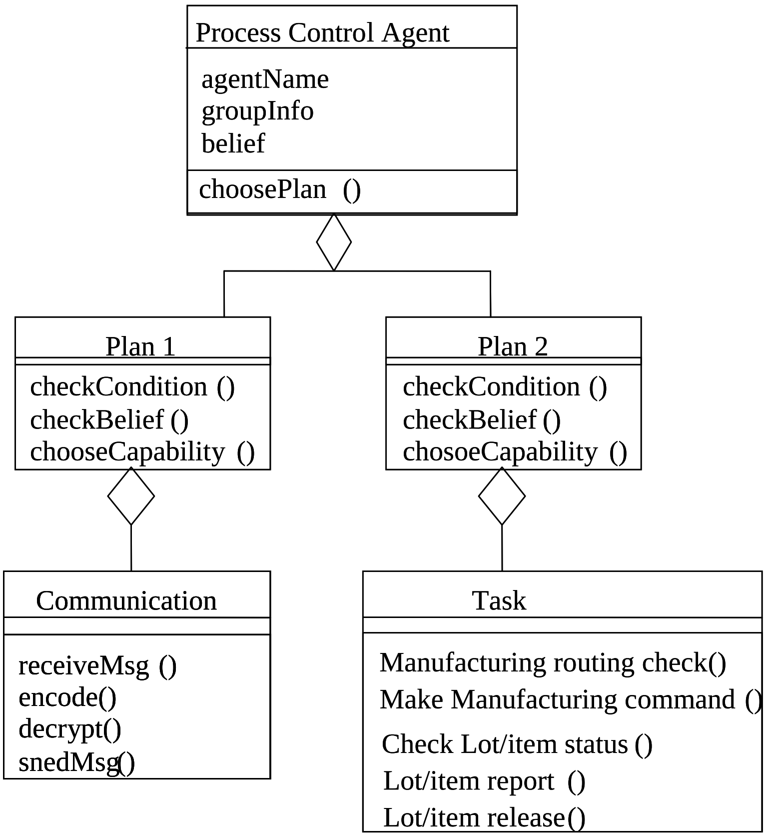

Figure 4.13 The inter-construction of Process Control Agent

5. RFID Middleware Agent (RMWA)

The RMWA is responds to read data from and write data to RFID tag, there are two plans needed to do: (1) communication, (2) Task. The task contains three implementation procedures:

(1) Read Lot/item data: to read the manufacturing completion message from IMA.

(2) Write manufacturing command to Lot/item: to write the manufacturing routing obtained from PCA to the lot/item attached with RFID tag.

(3) Review manufacturing command: to request DA to send the manufacturing routing.

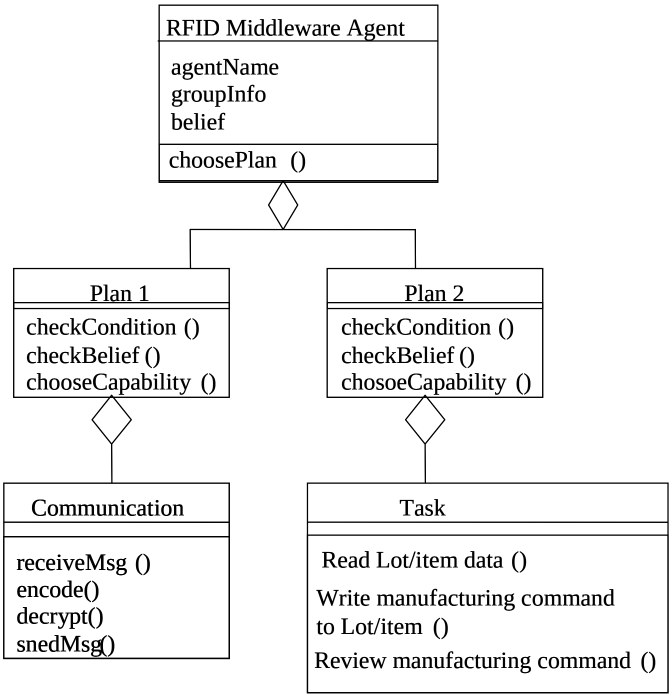

Figure 4.14 The inter-construction of RFID middleware Agent

6. Item Mobile Agent

The IMA is responds to perform a lot/item's manufacturing activity, there are two plans needed to do: (1) communication, (2) Task. The task contains six implementation procedures:

(1) Receive manufacturing command: to receive manufacturing command (e.g., production instruction)through RMWA from PCA

(2) Send request for production: to send the request for production to RA to obtain the manufacturing resource according to production instruction.

(3) Execute the manufacturing tasks: IMA will execute the manufacturing task according to production instruction.

(4) Receive promised resource: to receive the promised resource from RA.

(5) Lot/item check in: Lot/item will move to the manufacturing location and check in when receive the production instruction.

(6) Lot/item check out: Lot/item will leave from the manufacturing location and check out when finished one manufacturing task.

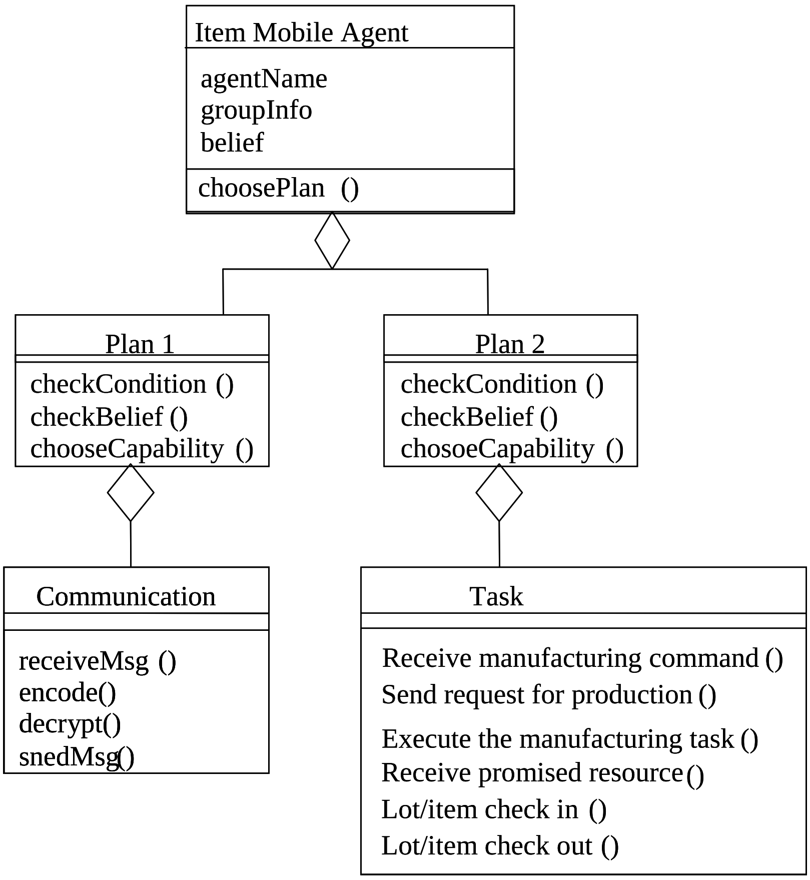

Figure 4.15 The inter-construction of Item Mobile Agent

7. Resource Agent

The RA is responds to provide manufacturing resource's production information, there are two plans needed to do: (1) communication, (2) Task. The task contains three implementation procedures:

(1) Review resource status: to review the request for production form IMA.

(2) Machine/tool loading: Machine/tool will be loading when promise the request for production from IMA.

(3) Machine/tool unloading: Machine/tool will be unloading when finished one manufacturing task.

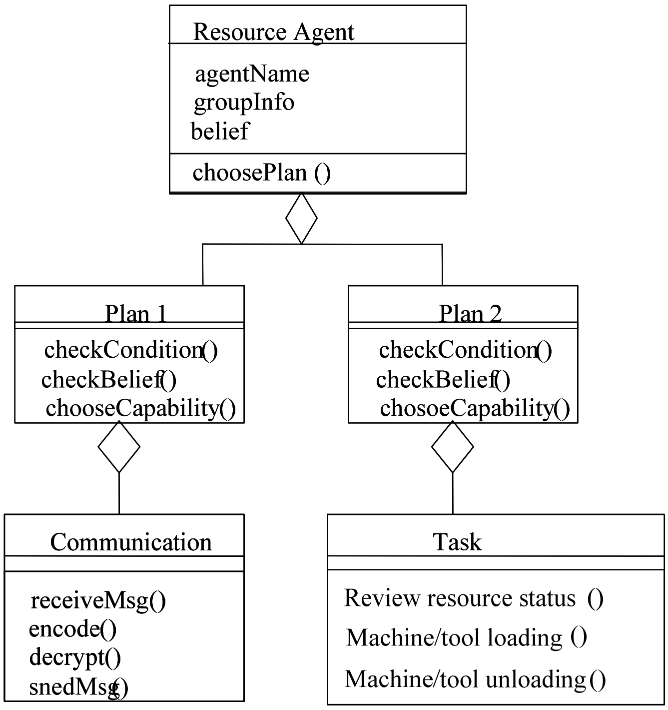

Figure 4.16 The inter-construction of Resource Agent

8. Data Agent

The DA is responds to collect and provide information from/to other agents, there are two plans needed to do: (1) communication, (2) Task. The task contains three implementation procedures:

(1) Collect data: to collect related data when receive the request for data form other agent.

(2) Transform data: to transform the data format when the data form different agents.

(3) Transact data: to transact data to the related agent, which send the request for data.

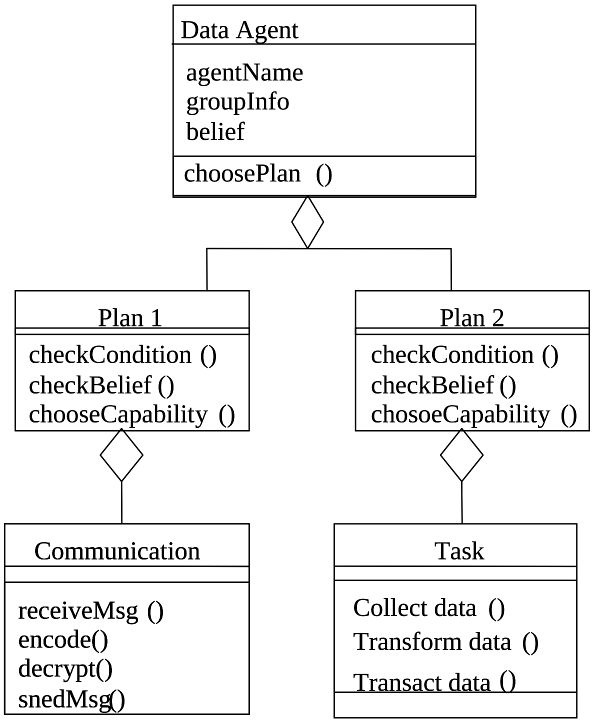

Figure 4.17 The inter-construction of Data Agent

9. Event Monitor Agent

The EMA is responds to monitor and evaluate the perform of manufacturing activities, there are two plans needed to do: (1) communication, (2) Task. The task contains four implementation procedures:

(1) Monitor manufacturing events: to determine the manufacturing events is either normal or abnormal according to the pre-determined performance indicator.

(2) Review performance indicator: to review the total performance.

(3) Check the performance of resource: to check the performance of resource.

(4) Check the performance of Lot/item: to check the performance of Lot/item.

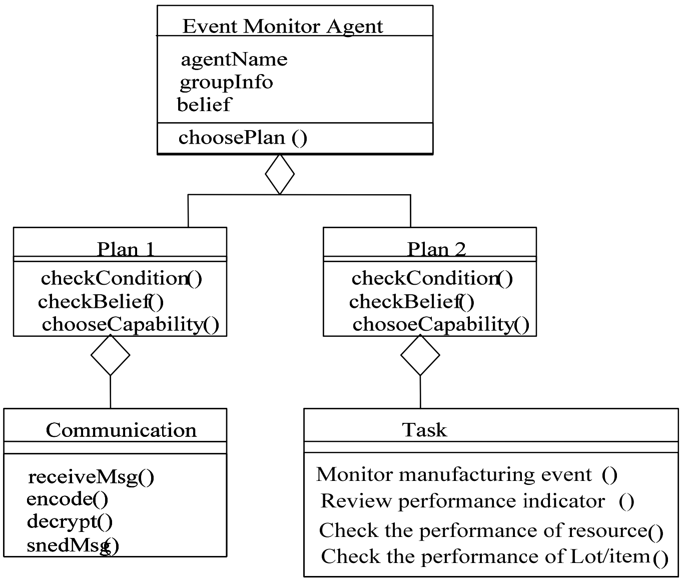

Figure 4.18 The inter-construction of Event Monitor Agent

10.Event Alert Agent

The EAA is responds to send the alert message, there are two plans needed to do: (1) communication, (2) Task. The task contains one implementation procedures:

(1) Send warring message: to send warring message to alert related agents.

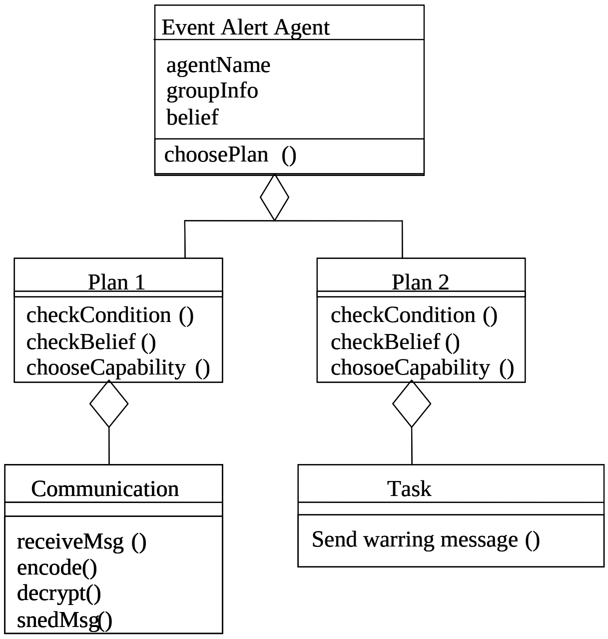

Figure 4.19 The inter-construction of Event Alert Agent

4.4.2 Manufacturing Planning and Scheduling Mechanism

AMPCS contains two manufacturing plans: (1) production schedule and (2) shop floor operations schedule. This research may use different rules or algorithm to enhance the manufacturing performance within different production situation. Negotiation protocols are the rules used by scheduling agent (SA) to make decisions on the shop floor. The negotiation protocols studied can be categorized into seven control schemes (shown in Table 4.3).

Table 4.3 Simple bidding criteria

Criteria name	**Priority index**	**Attribute**
Shortest processing time (SPT)	Min q_{mn}	Processing time
Largest remaining processing time (LRPT)	Max $\sum_{m' \in u_{mn}} q_{m'n}$	Processing time
Shortest ratio of remaining processing time to imminent processing time (SRRTIOM)	Min $\frac{1}{q_{mn}} \sum_{m' \in u_{mn}} q_{m'n}$	Processing time
Earliest due date (EDD)	Min d_{mn}	Due date
Currency value	Max C_{mn}	Due date
Critical ratio (CR)	Min $\frac{D_{mn}}{\sum q_{mn}}$	Due date
First come first served (FCFS)	Min a_m	Arrival time

q_{mn} = processing time of the *n*th operation of part *m*

u_{mn} = set of successive operations of the *n*th operation of part *m*

C_{mn} = currency value of the *n*th operation of part *m*

$a_m(d_m)$ = the arrival time (due date) of part *m*

In this research, we employ FCFS as implementation rule. Figure 4.19 and Figure 20 depicted the production schedule generation procedure and shop floor operations schedule procedure, respectively.

```
Procedure: Production scheduling
  load total demand (Dij); // i=demand number; j=demand item
  Set demand priority (Pi) base on demand due date;
  for (total demand (Dij))
  {
   Load Dij, i=1; //use first-in first-out (FIFO)
  {
    Generate related manufacturing order (MOijk) based on Item's structure; // k= manufacturing order ID
    for (all manufacturing order (MOijk) of each demand (Dij))
      {
      get each demand item's lead time (Tijk);
      calculate each manufacturing order's operation time;
      if manufacturing order's demand item is end item
        {
        set work order's end time (WETijk) = demand due date (DDij);
        set work order's start time WSTijk = WETijk - Tijk;
        }
        else
       {
        get manufacturing order's demand item;
        set child manufacturing order's end time = parent manufacturing order's start time;
        set work order's start time WSTijk = WETijk - Tijk;
       }
     Check another demand Dij (i= i+1), until total demand are finished.
  }
```

Figure 4.20 The production schedule generation procedure

```
Procedure: operations schedule
  load manufacturing order (MOijk); // i=demand number; j=demand item; k= manufacturing order ID
  get related operation tasks OPijkl based on item's routing; // l = operation ID
  check candidate resources Rijklm for each operation task OPijkl; // m= manufacturing resource
  For (all the first operation task (OPijkl) of each manufacturing order (MOijk) );
  {
    Bidding for available resource; // Bidding process
    Announce bidding request (BRijkl) to manufacturing resource (Rijklm); //PCA's task
    Bidding request (BRijkl) =
    {
      Head {bidding request_ID, operation_ID};
      Time_Data {bid_validity_time};
      Communication_Data {volume, processing time, resource_status};
      Task_Spec {resource_ID, item, delivery_time};
     }
    Bid resource reply bidding information (Bidijklm); // RA's task
    Bidding information (Bidijklm) : =
    {                                                                    Each MO's first operation task
      Head {bidding request_ID, bidder_ID,}
      Bid_Specification {bid_validity_time}
      Communication_Data {processing time, resource_status}
      Task_Spec {resource_ID, item, delivery_time}
    }
    calculate each bidding resource's utility based on processing time (Tijklm) and resource status; // PCA's task
    Utility = (unit production time/processing time)*resource status rate (idle=1/ busy=0.5)
    get the winner resource;
    Generate Start time (RSTijkl) and End time (RETijkl) of the first operation (OPijkl) of each manufacturing order (MOijk) ; // forward scheduling algorithm
    if assigned manufacturing resource (Rijklm) for this operation is idle;
    {
      set RSTijkl = current scheduling time;
      RETijkl = RSTijkl + Tijklm;
    }
    else
    {
      set RSTijkl = RETijkl'; // start time of the scheduling operation tasks (OPijkl) is equal the available time of the assigned resource (OPijkl'); l' scheduled operation task
      RETijkl = RSTijkl + Tijklm;
    }
  }
  --------------------------------------------------------------------------------
  For (all other operation tasks (OPijkl'') of each manufacturing order (MOijk) ); // l'' = the succeeding operation ID of each MO's first operation task
  {
    bid for manufacturing resource through bidding process;
    get the winner resource;
    Generate Start time (RSTijkl'') and End time (RETijkl'') of the succeeding operation (OPijkl'');
    if assigned manufacturing resource (Rijkl'm) for this operation is idle;
    {                                                                    Other operation tasks
      set succeeding operation's start time RSTijkl'' = the preceding operation's end time RETijkl;
      RETijkl'' = RSTijkl'' + Tijkl''m;
    }
    else
    {
      set  the scheduling operation's start time = the available time of the assigned resource;
      RETijkl'' = RSTijkl'' + Tijkl''m;
    }
  }
```

Figure 4.21 The shop floor operations schedule generation procedue

Chapter 5 Implementation of AMPCS

5.1 System Implementation Description

In this section, we will illustrate the characteristics of an agent-based manufacturing planning and control system (AMPCS) for the automated manufacturing cell (AMC) in the automation laboratory of Tunghai University, consisting of one CNC 2-axis lathe, one CNC 3-axis milling machine, one RV-M2 robot, two WIP buffers , one feeder and one ASRS (depicted in Figure 5.1).

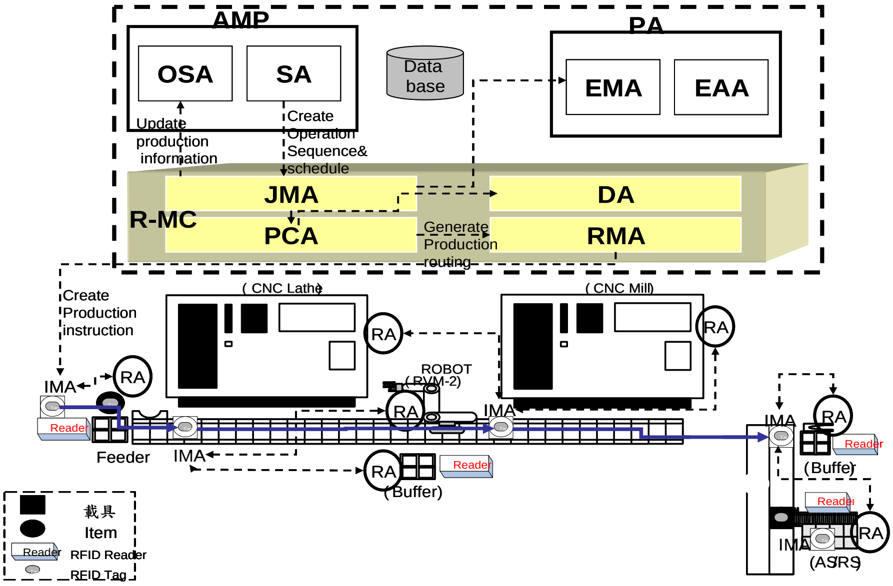

Figure 5.1 The layout of automated manufacturing cell and its corresponding AMPCS

Object-oriented programming languages (e.g., C++, Visual Basic, Java) has become popular among researchers for implementation purposes. Microsoft Visual Basic (VB) programming language is used to implement the framework developed within this study. In the preliminary implementation, Microsoft SQL is used as a database to store information (e.g., item data). The database is accessible by all the agents created in VB. In VB, each individual agent is views as a single object. Each object contains its own procedures to be carried out.

In this research, we employ VB to develop the agents of AMPCS for the AMC depicted in Figure 5.2 according to the following agent creating/setting procedure:

1. Create agent server: Set up a host sever to be the agent server, which is the central data host of related agents.
2. Create agent lists: To identify each agent's name, which may be used in AMPCS.
3. Set up communication host address: Select related agents, which are created in agent lists, and set up the host address to represent these agents.
4. Define communication procedure: Identify each agent's communication procedure according to the negotiation protocol, described in chapter 4.1, and the communication data based on the definition of KQML described in chapter 4.2.
5. Test communication protocol: Test whether each agent's function and communication is ready or not. If agent's status is not 'ready', we may need to go back to step 3 to re-set up each agent's host address, otherwise, go to step 6.
6. Store agent's configuration: Store agent's creating lists and host address.

The system main screen is depicted in Figure 5.2 which includes three major functions: (1) demand order management, (2) production schedule generation, and (3) shop floor control. Firstly, we may initialize the related data among each agent from database. System may update the master production schedule (MPS) to order sequencing agent (OSA) to decide each demand order's priority. Then, each agent may respond its communication data to related agent (shown in the right side of Figure 5.2). Scheduling agent may receive the work in process (WIP) data from job management agent (JMA) and capacity data from process control agent (PCA) to generate production schedule.

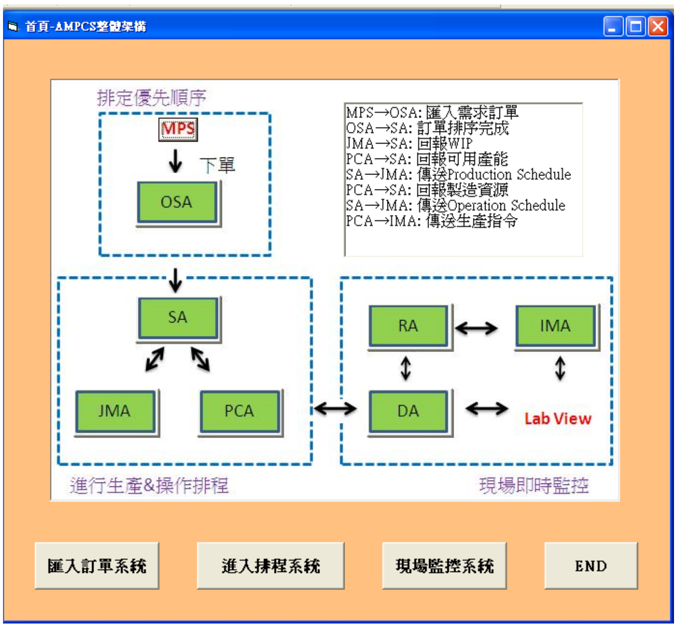

Figure 5.2 The system main screen of AMPCS

When OSA got MPS data, it may decide each demand order’s priority according to each order’s due date. Take Figure 5.2 as illustration, we have two demand orders: due date of order 1 and order 2 are 2010/1/5 and 2010/1/8, respectively. Therefore, order 1’s priority is higher than order 2. Then OSA may translate the demand data to SA to generate production schedule.

Figure 5.3 The demand order management screen of AMPCS

Besides, we may also view the detail information from each agent. Figure 5.4 depict the demand order's information, which contains current Order_ID, Item_ID, QTY, Due Data, Order_Status, and Priority.

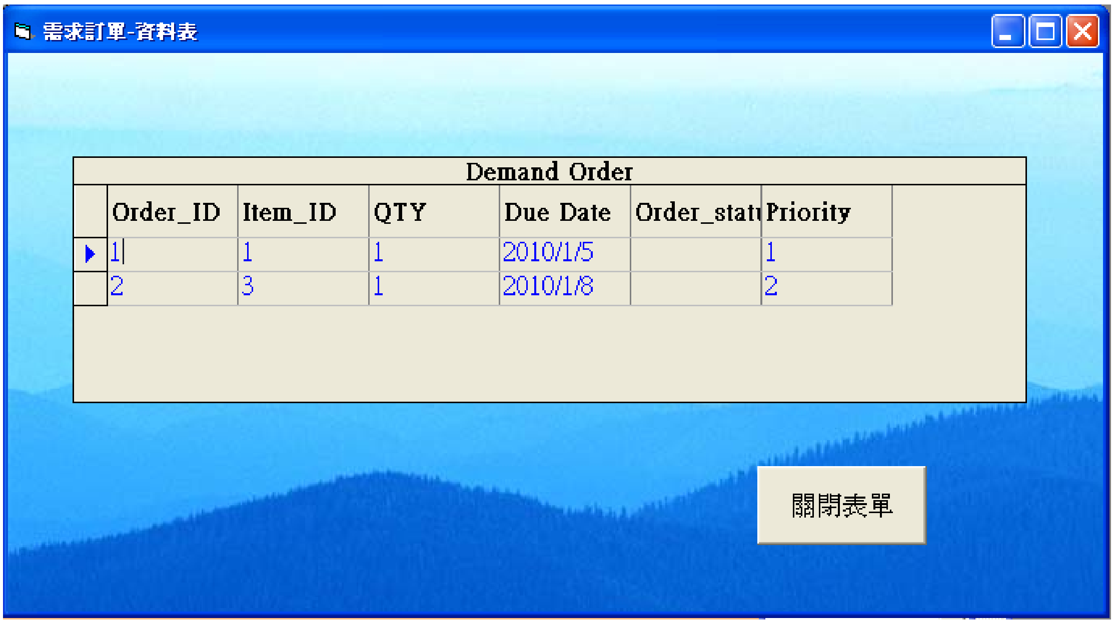

Figure 5.4 The demand order data from OSA

When SA receives demand data from OSA, it may ask JMA and PCA to feedback WIP data and resource information and generate production schedule. To generate shop floor operations schedule, SA needs to choose suitable resource to complete shop floor operation jobs. Take Figure 5.5 for example, when we click "choose resource" bottom, system will calculate the utility of related resource and represent the results. Then system may generate the shop floor operations schedule based on chosen resource.

Figure 5.5 The production schedule generation screen of AMPCS

Besides, we may also view the detail production information from each agent. Figure 5.6 depict the manufacturing order's information in JMA, which contains current MO_ID, Item_ID, QTY, and MO_Status.

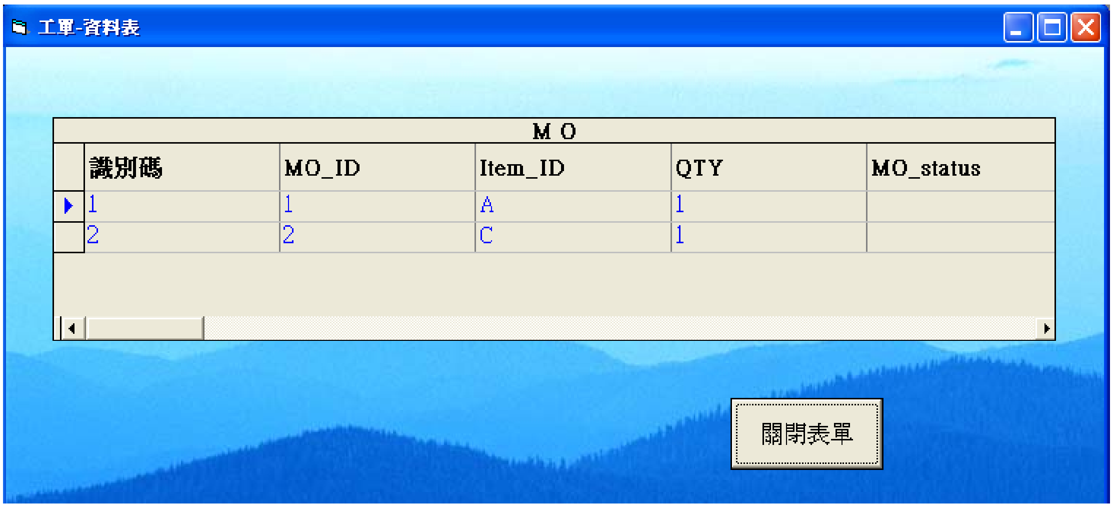

Figure 5.6 The manufacturing order data from JMA

Figure 5.7 depicts the operations schedule information in SA, which contains Item_ID, Qperation_ID, Resource_ID, Start_time_of_operation, and

End_time_of_operation.

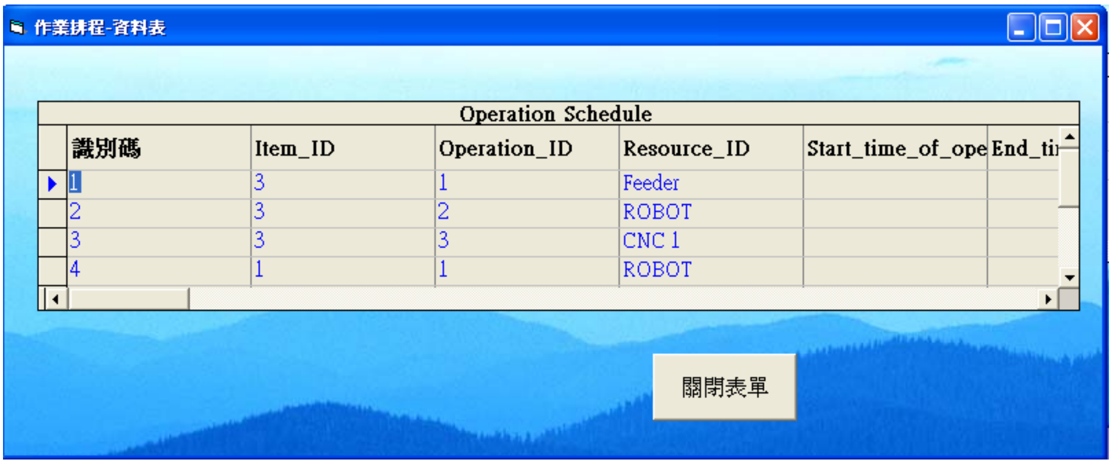

Figure 5.7 The operations schedule data from SA

Figure 5.8 depicts the production instruction information in PCA, which contains Recipe_ID, Item_ID, Qperation_ID, Resource_ID, Operation_time, Item_start_time, and Item_end_time.

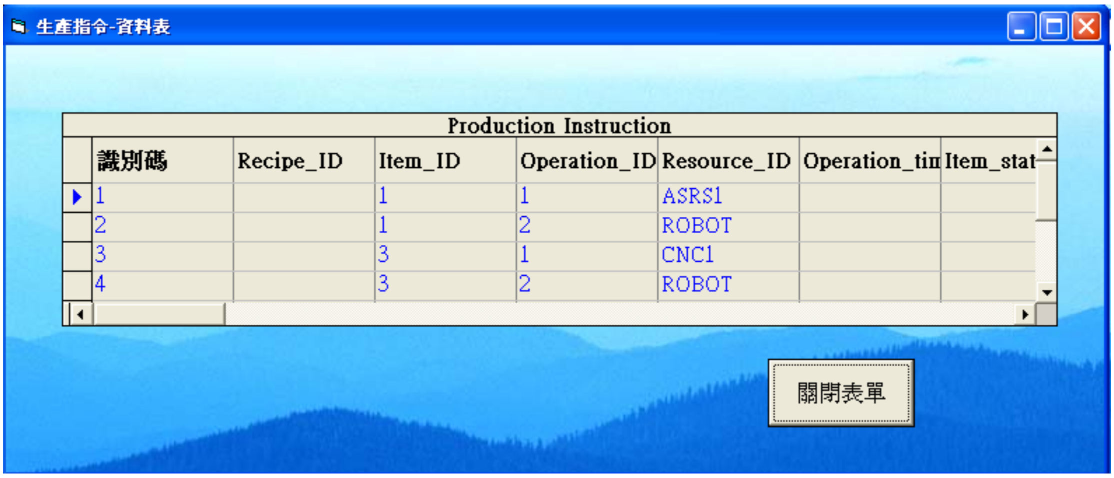

Figure 5.8 The production instruction data from PCA

After SA release operations schedule to shop floor, shop floor control screen may monitor each operation job's status based on this schedule. We employ RFID tag, which embedded in each item and manufacturing resource, to trace each item's and each resource's manufacturing status. As shown in Figure 5.9, item A has completed the first operations job at work station "WS01" and prepared to enter next work station "CNC" to do its operations job.

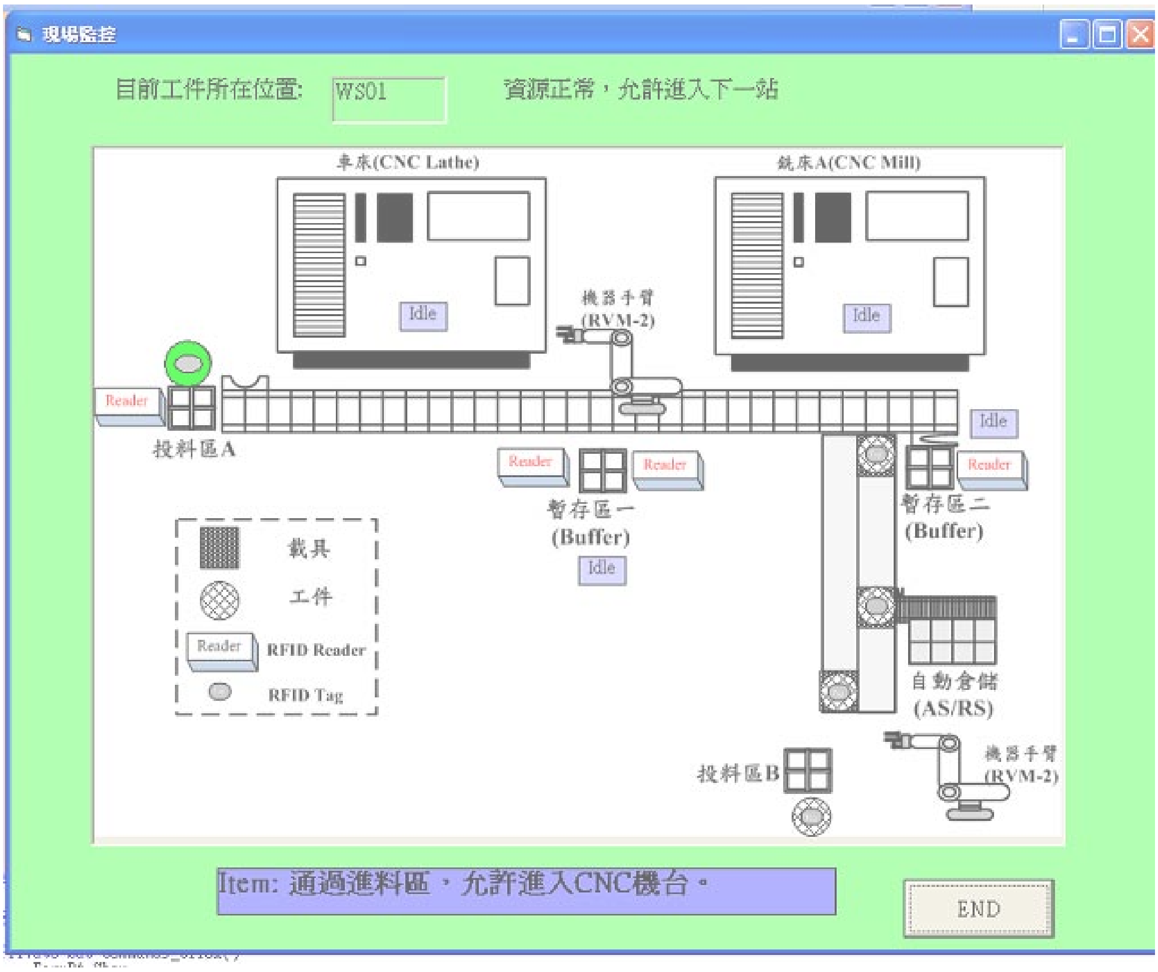

Figure 5.9 The shop floor control screen of AMPCS

5.2 Case Scenarios of AMPCS

1. Generate production schedule scenario

Major participated agents: OSA, SA, JMA

To generate production schedule, order sequencing agent (OSA) will first decide demand order's priority based on each demand order's due date. As shown in Table 5.1, demand order 1's priority is 1 since its due date is earlier than that of demand order 2. Based on the production schedule generating procedure and algorithm described in Figure 4.2 and 4.19, the end time of each demand order's last MO may be equal the demand order's due date and the start time is equal the end time subtract this MO's production lead time. For instance, scheduled start/end time of MO_{111}=30/60. Consequently, all the operations of each MO also need to be scheduled, which is illustrated in the next scenario.

Table 5.1 Production schedule for demand order

Demand_ID (*i*)	**Quantity**	**Due date (DD_{ij})**	**Priority (P*i*)**	**Item_ID (*j*)**	**MO_ID (MO_{ijk})**	**Production_lead time**	**Start_time**	**End_time**
1	1	60	1	A (*j*=1)	MO_{111}	30	30	60
				C (*j*=3)	MO_{132}	30	0	30
				E (*j*=5)	N/A	N/A	N/A	N/A
2	1	80	2	B (*j*=2)	MO_{221}	25	45	70
				F (*j*=4)	MO_{242}	45	0	45
				G (*j*=6)	N/A	N/A	N/A	N/A

N/A: represent a purchased item

2. Generate operations schedule scenario

Major participated agents: SA, PCA, RA

SA will generate operations schedule based on the operations schedule generating procedure and bidding process described in Figure 4.3 and 4.20. We may take demand order 1 for instance, item C's manufacturing order (MO_{132}) is composed of three operation tasks, OP_{1321}, OP_{1322} and OP_{1323}. At time period 0, both operation tasks OP_{1321} and OP_{2421} may request manufacturing resource Feeder to provide service. Through bidding process, manufacturing resource Feeder may first process operation task OP_{1321} since its priority is higher than OP_{2421}, and SA may determine the planned start time and end time of OP_{1321} is at time 0 and 5 (=0+5), respectively. Since operation task OP_{1321} is scheduled to be completed at time period 5 at which ROBOT is also available, SA will determine the planned start time and end time of OP_{1322} at time 5 and 15 (=5+10), respectively. For OP_{1323}, it may be processed by either manufacturing resource CNC 1 or CNC 2, PCA will send the BR to CNC 1 and CNC 2. Consequently, CNC 1's RA and CNC 2's RA will reply the bidding information Bid_{13231} ={4; 1; 15; 30; idle} and Bid_{13232}={5; 1; 17; 30; busy}, respectively.

The bidding information Bid$_{13231}$ (Bid$_{13232}$), depicted in Table 5.2, shows that the processing time of OP$_{13231}$ (OP$_{13232}$) is 15 (17) time units and the status of CNC 1 (CNC 2) is idle (busy). Therefore, PCA will select CNC 1 as the winner resource since it has the highest utility 1 (= 15/15 * 1) and SA will determine the planned start time and end time of OP$_{1323}$ is at time 15 and 30, respectively. Operations schedule for demand orders 1 and 2 is illustrated as Gantt chart and depicted in Figure 5.10.

Table 5.2 Bidding results reported from resource agents for demand order 1

Item (*j*)	Operations (OP*ijkl*)	Bidding Request (BR*ijkl*)	Bid information (Bid*ijklm*)	Utility	Winner
A (*j*=1)	OP$_{1112}$	BR$_{1112}$:{BR$_{1112}$; OP$_{1112}$; 1; 1; 60}	Bid$_{11121}$: {1; 1; 15; 60; idle}	1	ASRS 1
			Bid$_{11122}$: {2; 1; 16; 60; busy}	0.47	
	OP$_{1111}$	BR$_{1111}$:{BR$_{1111}$; OP$_{1111}$; 1; 1; 45}	Bid$_{11111}$:{3; 1; 15; 45; idle}	1	ROBOT
C (*j*=3)	OP$_{1323}$	BR$_{1323}$:{BR$_{1323}$; OP$_{1323}$; 1; 1; 30}	Bid$_{13231}$:{4; 1; 15; 30; idle}	1	CNC 1
			Bid$_{13232}$:{5; 1; 17; 30; busy}	0.44	
	OP$_{1322}$	BR$_{1322}$:{BR$_{1322}$; OP$_{1322}$; 1; 1; 15}	Bid$_{13221}$: {3; 1; 10; 15; idle}	1	ROBOT
	OP$_{1321}$	BR$_{1321}$:{BR$_{1321}$; OP$_{1321}$; 1; 1; 5}	Bid$_{13211}$: {6; 1; 5; 5; idle}	1	Feeder

i=demand order_ID; *j*=item_ID; *k*= MO_ID; *l*= operation_ID; *m*= resource_ID;
Bidding Request: {BR*ijkl*; OP*ijkl*; item_ID; volume; due date};
Bid information: {resource_ID; volume; processing time; due date; status}

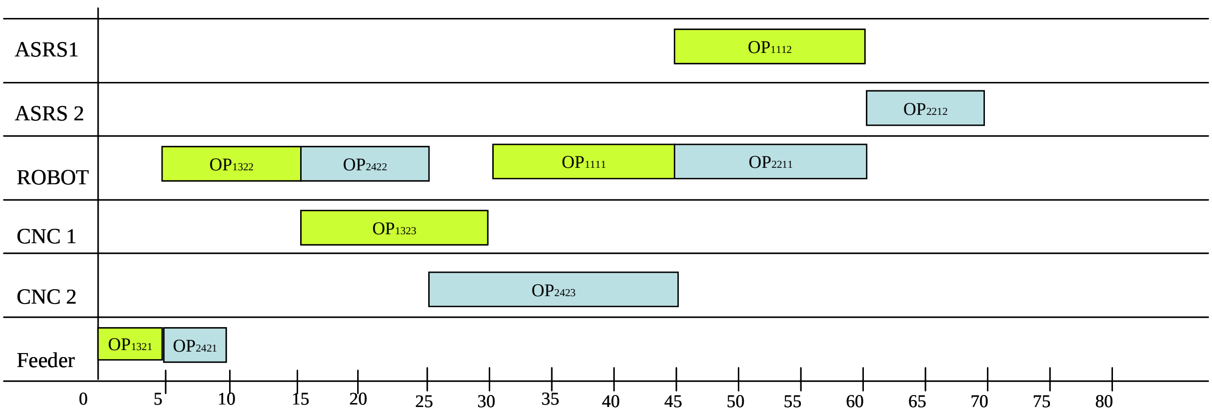

Figure 5.10 Gantt chart of operations schedule for demand orders

3. Manufacturing control scenario

At the shop floor execution level, event monitor agent (EMA) will classify abnormal causes and notice SA to re-generate an operations schedule when abnormal message is sent from item mobile agent (IMA). Take demand order 1's item A in Table 5.1 as an example, item A needs two operation tasks OP_{1111} and OP_{1112}, Figure 5.11 illustrates that item A's IMA will send the 'request for production (RFP)' to ASRS 1's RA to execute operation task OP_{1112}. However, ASRS 1's RA replies 'reject' message to item A's IMA. Consequently, IMA will send 'reject' message to PCA, which will record the abnormal situation and notice EMA to classify the abnormal cause (e.g., machine breakdown), through RMWA and DA. Therefore, EMA will notice SA to generate a new operations schedule for item A's operation task OP_{1112} through EAA. Then, PCA will bid for a new manufacturing resource ASRS 2, whose utility assessment is the highest, through bidding process. Consequently, SA will generate a revised operations schedule for OP_{1112} based on the assigned manufacturing resource ASRS 2. Finally, PCA will send the revised operations schedule, obtained from SA, to manufacturing resource ASRS 2 to process operation task OP_{1112}.

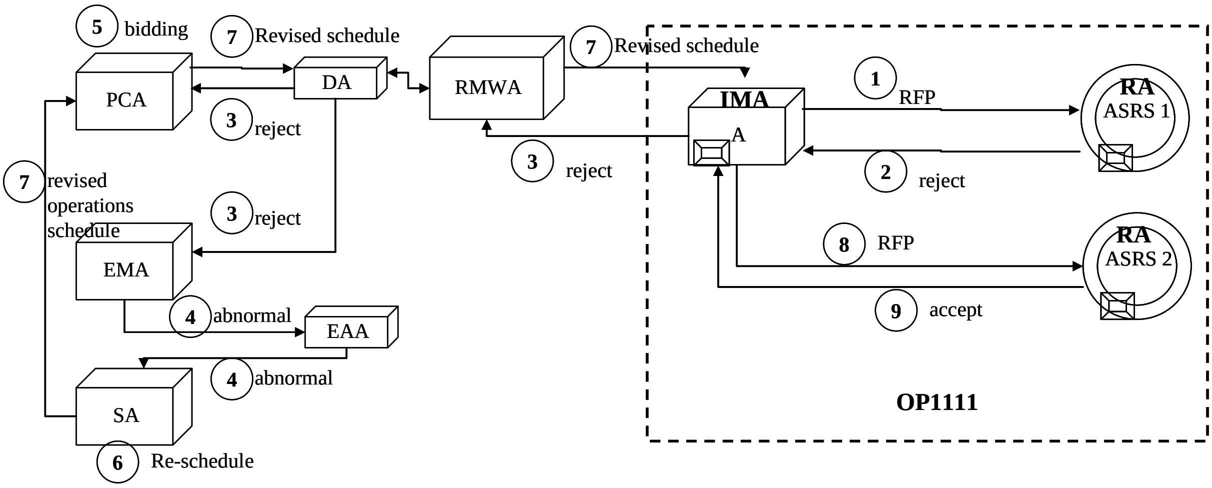

Figure 5.11 Manufacturing control scenario

Several types of disturbances that affect actual shop output should be taken into account if scheduling is to be realistic. This case scenario considers the following three different types of uncertainties:

(1) Machine Breakdown

(2) Execution time early or delay

(3) The arrival of urgent manufacturing orders

4. Manufacturing control—machine breakdown scenario

When the machine breakdown occurs, the abnormal events may be detected by means of comparing the planned production information with the actual execution information stored in the agents (e.g., IMA and RA) attached with RFID tag. Figure 5.10 shows an abnormal event monitor scenario, which represent the manufacturing resource “feeder” has “error” message. When system received this message, it needs to alert related agents to stop their operations jobs until this abnormal event is solved.

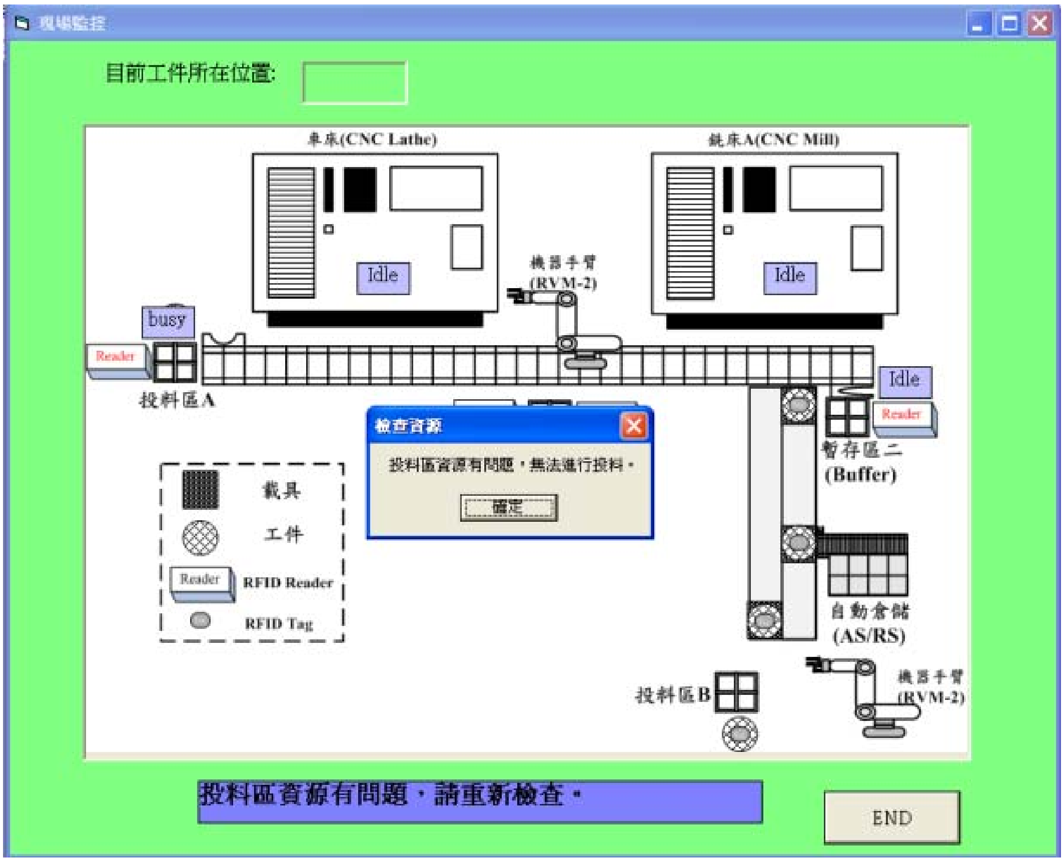

Figure 5.12 Abnormal event monitor in AMPCS

5. Manufacturing control—time early or delay scenario

Dynamic reaction to development on the shop floor is essential for realizing a truly flexible control of the manufacturing system. In order for a controlling mechanism to perform in a dynamic production environment, it must consider realize execution time from RFID tag (i.e., check out time). Whenever the actual complete time is early or delay, it will affect current schedule in shop floor. The processing time of JMA3 shows in Table 5.3. Operations noted as OP refer to sequence. The sequence of arrival for the operation (all in the same job) is: OP1 arrives at 0 with first priority. The OP3 is complete early, so the schedule needs to reschedule after 135 time units. The rescheduling result shows in Figure 5.13.

Table 5.3 Processing time of case scenario 5

Processing sequence	OP1	OP2	OP3
Planning processing time (T_{ij3}^{O})	50	30	60
Execution processing time (T_{ij3}^{EP})	50	30	55
Early or delay	none	none	early

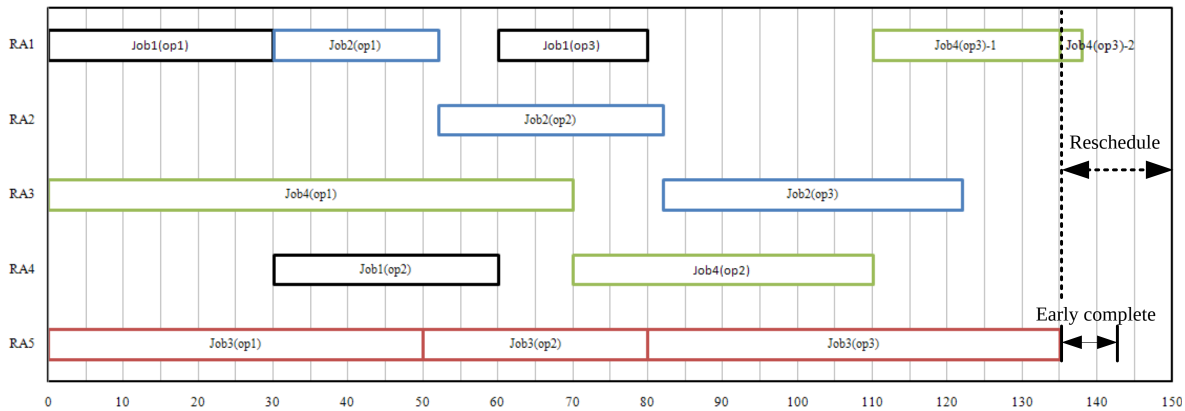

Figure 5.13 Execution results of case scenario 5

6. Manufacturing control—urgent orders scenario

When a new order arrives, it must determine whether the JMA is an urgent order or a normal order. If it is a normal order, the arrival time is assigned and schedule agent (SA) will merge into the current schedule. If it is an urgent order, then the highest priority is assigned to it and it is treated similar to an higher priority order. All the RAs required by the urgent order are released whenever they are required. This result shows in Figure 5.14.

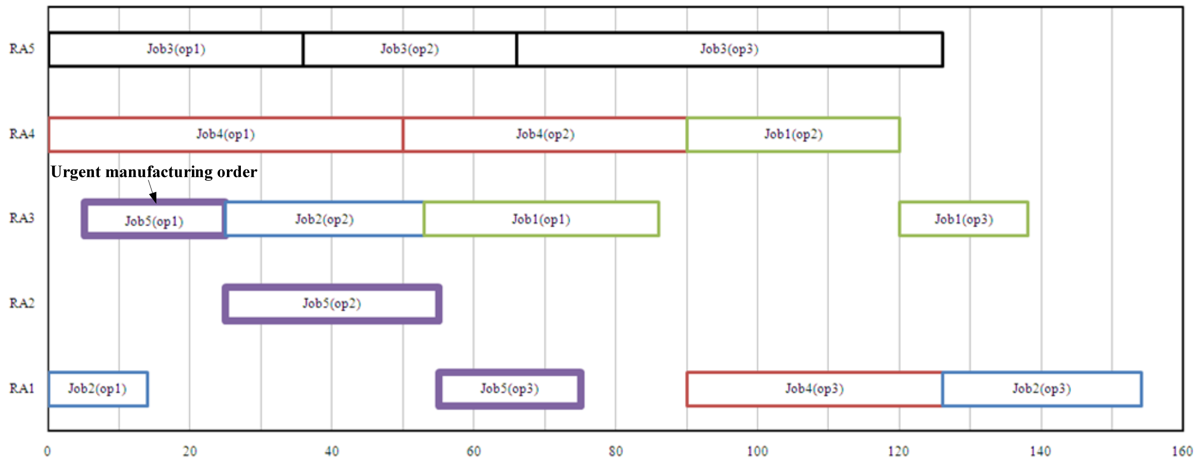

Figure 5.14 Execution results of case scenario 6

Chapter 6 Summary and Conclusion

6.1 Conclusion

RFID is an electrical information-storing device, it has characteristics such as active, long-distance reading, and non-line-of-sight. This paper presents an multi-agent based agile manufacturing planning and control system (AMPCS) framework which is event-driven and can respond dynamically to the changing business events and exceptions. In AMPCS, RFID-based manufacturing control (R-MC) module plays the role of controlling the manufacturing system in which production items (i.e., objects) and manufacturing resource attached with RFID tag may actively feedback production status to and receive production and operations schedule from advanced manufacturing planning (AMP) module. Performance analysis (PA) module may not only evaluating the effectiveness of production and operations schedule generated from AMP module, but also monitoring and evaluating the performance of shop floor execution, based on the real-time manufacturing information provided by RFID technique.

The development of an AMPCS for an automated manufacturing cell demonstrates that the integration of RFID technique, multi-agent system (MAS) in developing an agile manufacturing planning and control system can really possess the characteristics of visibility, accountability, track ability, responsiveness, and flexibility in a distributed and dynamic manufacturing environment. The future work of this research may employ RFID technique to extend to MPS and multi-site production planning level in different manufacturing environments.

6.2 Future Research

AMPCS is developed by MAS and RFID systems, this research did not consider the system process logic and the agent's procedure. Therefore, we suggest three points which should be investigated further:

1. Advanced Manufacturing Planning module is respond to generate the production and operation schedule, but we didn't describe the logic of planning and scheduling. Therefore, the planning and scheduling procedure such as heuristic should be investigated further.
2. Performance Analysis module is respond to monitor the manufacturing task in real-time, but we didn't set up the performance indicates, such as order fulfil rate. Therefore, the performance indicates which is defined to evaluate the manufacturing tasks should be investigated further.
3. AMPCS system framework is developed, but we did not implement the system instead of using agent tools, such as aglets, to design the agents, so we did not evaluate the performance of AMPCS. Therefore, the implementation and testing of a complete AMPCS should be investigated further.

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