# 1

# Agent Technology in Modern Manufacturing

## 1.1 Introduction

With the development of internet, computer, management, and manufacturing technologies, the manufacturing industry is undergoing a huge transformation from traditional manufacturing to agile manufacturing, networked manufacturing, virtual manufacturing, service-based manufacturing, and cloud manufacturing. These new manufacturing systems are characterized by smartness, integration, and flexibility, and can be well described as Agent technology. The cooperation and communication of multiple agents can be adopted to improve the performance of manufacturing systems.

## 1.2 Agent and Multi-Agent System

Research and application of Agent technology stem from a series of studies on distributed artificial intelligence conducted by MIT researchers in the 1970s.[1] Distributed artificial intelligence mainly focuses on solving distributed agent problems. There are two important branches:[2] distributed problems and Multi-Agent Systems (MASs). The distributed problems were conducted at an early stage in the distributed artificial intelligence area. The distributed problems have been extended to Multi-Agent Systems. The Multi-Agent System is a system with Agents of different abilities to complete collaboratively certain tasks or achieve certain objectives.[3–5]

*Multi-Agent-Based Production Planning and Control*, First Edition. Jie Zhang.
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### 1.2.1 Agent

The concepts, properties, and research methods of Agent technology are developed from artificial intelligence. It is difficult to define either artificial intelligence or Agent. Many different definitions have been given by different schools for different requirements. The earliest concept of Agent was defined based on the concurrent actor model proposed by Hewitt in the early 1970s.[6] In the concurrent actor model, Hewitt defined a term—*actor* with the characteristics of self-organization, interaction, and parallel execution. The most classic and widely accepted definition was given by Wooldridge, et al.[7] The definition contains "weak definition" and "strong definition". The weak definition defines an Agent as a hardware and software system with autonomous ability, social skill, and responsive and predictive ability; the strong definition includes the properties of the weak definition and also the properties of knowledge, mobility, veracity, rationality, and so on.

Computer science researchers[8] consider that an Agent is a computer system based on software and hardware; it also has autonomy reactivity, socialability, proactiveness, and other properties. From the perspective of the evolution of software design methods, agent-based software engineering methods are proposed on the basis of object-oriented software engineering methods. Moreover, decomposition and abstraction methods of complex software systems, distributed computing capabilities, interactive coordination mechanism, calculation model, and software architecture have been proposed.

Researchers in artificial intelligence are more inclined to a narrow point of view, except for the above properties. It is therefore necessary to give a more specific meaning for an Agent. Terms such as *belief*, *intention*, and *commitment* are used to describe an Agent. An Agent tries to mimic a human's thinking and intelligent behavior: for example, what the Agent is doing, what the Agent knows, what the Agent wants, and so on. This definition is developed on the basis of AI knowledge symbols. Shoham[9] thought an Agent was a symbolic reasoning system, which contained the expression of symbols on environment and expected behavior.

Therefore, an Agent is an intelligent individual. Wooldridge and Jennings[7] proposed that an Agent should have four basic attributes: autonomy, reactivity, social ability, and initiative. Sargent[10] considered that the most basic attributes of an Agent were reactivity, autonomy, goal-orientation, and environmental resistance. An Agent was defined by Muller[11] as follows: 1) it is necessary to have other Agents and a virtual world where an Agent exists; 2) an Agent can perceive a virtual world and influence the virtual world; 3) an Agent can at least partly represent the virtual world; 4) an Agent is target-oriented and has the ability to arrange its own activities; 5) an Agent can communicate with other Agents. Most researchers think that an Agent should not only meet basic properties, but should also have other properties according to application requirements: for example, mobility, learning and adaptability, interactivity, planning ability, rationality, persistent or time continuity, and so on. Three directions of current research are intelligence, agency, and mobility.[12] From the intelligence point of view, an Agent is an expert system; *agency* means that an Agent can be used to represent the role of a man and machine; while mobility means that an Agent can move or run on a different machine on the internet.

As the previous presentation demonstrates, an Agent should have the following properties:[13–21]

1) *Autonomy:* An Agent can control its behavior and internal state by itself, and it cannot be controlled by others. This is used to differentiate an Agent with other concepts such as process and object.
2) *Reactivity:* An Agent can feel the environment and respond appropriately to environment-related events.
3) *Sociality:* An Agent is in a social environment constituted by multiple Agents. These Agents exchange information with each other in some interactive methods. These Agents collaborate with each other to solve different problems and help other Agents complete related activities. Agents exchange information by a communication language.
4) *Initiative:* The reaction of an Agent to the environment is a goal-directed initiative behavior. In some cases, the behavior of the Agent is triggered by its own requirements. The reactive behavior is a kind of positive behavior or an active communication with the environment.

5) *Adaptability:* An Agent can respond to environmental changes, adopt a goal-oriented action at the appropriate time, and learn from its own experience, the environment, and the interaction process with other Agents.
6) *Interoperability:* An Agent can work with other Agents to complete complex tasks, which is a social behavior.
7) *Learning ability:* An Agent can learn from the surrounding environment and cooperative experiences so as to improve its own capability.
8) *Evolutionary development:* An Agent can improve itself through learning, and reproduce and follow Darwin's natural selection rule "survival of the fittest".
9) *Honesty:* An Agent does not intend to deceive users.
10) *Rationality:* the action taken by an Agent and its consequences will not harm its own interest and other Agents' interests.
11) *Persistence:* An Agent is ongoing, not temporary, its status should be consistent, which is not in contradiction with property (8).
12) *Mobility:* An Agent should have the ability to move independently in the network, while its status remains unchanged.
13) *Reasoning:* An Agent can reason and forecast in a rational manner according to accumulated past knowledge, states of the current environment, and other Agents.
14) *Others*: philanthropic, adventurous or conservative, helpful or hostile, and so on.

The above attributes show that an Agent is similar to a person, which provides a new method for solving complex problems in computer science and artificial intelligence. Although an Agent may have a variety of properties, researchers and developers do not need to develop one Agent or an Agent system with all the attributes. Agents with several attributes and Multi-Agent systems with several attributes are developed according to actual requirements.

### 1.2.2 Multi-Agent System

Agent Systems can be classified into two classes: Single-Agent Systems and Multi-Agent Systems (MASs). The research of a Single-Agent System focuses on simulating human intelligent behavior; it concentrates on investigating human intelligent behavior such as computing ability, reasoning ability, memory, learning ability and intuition, and so on. The research of a MAS focuses on the collaborative process among autonomous intelligent Agents that generate their corresponding behaviors or solve problems by coordinating Agent goals and planning Agents. In the problem-solving process, these Agents share all their knowledge about related problems and methods in order to achieve a global objective, or their own local objectives.[22–25]

As regards a MAS, a computing system aims to complete collaboratively certain tasks or achieve objectives by some Agents. The system consists of multiple autonomous or semi-autonomous Agents.[26] In a MAS, each Agent cooperates with other Agents to complete a complex task that cannot be solved by single Agent. All the Agents are autonomous, running in a distributed mode, or even heterogeneous. The subroutine, function, or process of each Agent are different, its goal and behavior are relatively autonomous and independent. Each Agent cooperates with other Agents in order to deal with conflict among them. A MAS has advantages of traditional distribution concurrent problem, and it runs in an interactive communication mode. Compared with a single Agent, each Agent in a MAS has incomplete information and it is able to solve problems, the data is dispersed or distributed, and the computing process is asynchronous, concurrent, or parallel. A MAS is very suitable to express an environment with a variety of methods and entities. A MAS has the following features:

1) *Sociality*. In a MAS, an Agent may be in a social environment constituted by several Agents and may have the information and knowledge from other Agents. Agents communicate with each other by using a special language to complete the cooperation and negotiation activities. For example, in an Agent-based manufacturing process production management system, Multi-Agents representing the roles of customers, sales, production management, material procurement and quality inspection departments cooperate together to complete production tasks.
2) *Autonomy*. In a MAS, when an Agent sends out a service request, other Agents that have this service ability and interest will accept it. One Agent cannot force another Agent to provide service.

3) *Cooperation*. In a MAS system, Agents with different objectives work collaboratively to solve the problem through mutual cooperation and negotiation. The coordination process consists of resource sharing coordination, the producer/consumer relationship collaboration, tasks/subtasks relationship collaboration.

The Multi-Agent System theory is developed on the basis of the Single-Agent model and structure, which focuses on investigating interoperability, consultation and cooperation among Agents on the basis of the Single-Agent theory. The consultation and collaboration activities in a MAS are realized based on social organization theory and modeling and implementing theory. The social organization theory provides a society-oriented conceptual model about integration, interaction, communication and collaboration; while the modeling and implementing theory is used to eliminate the gap between the society-oriented conceptual model and the reality. Therefore, the process to develop a MAS consists of the following aspects:[27–30]

1) *Agent model*. An Agent model is developed in order to meet the requirements of individual autonomy, group interaction and the environment. The organizational structure, knowledge composition and operation mechanism of an Agent are described in a certain level of abstraction.
2) *MAS architecture*. The asynchronous, consistency, autonomy and self-adaptive features of an Agent are affected by selecting an architecture. This will determine information transmission channels and transmission ways for a single Agent internal intelligence collaborative behavior.
3) *Interaction and communication*. The interaction activity is a basic requirement for multiple Agents to collaborate with each other. The communication activity is the basis for the interaction activity. The communication activity includes two aspects: the first is to construct the underlying communication mechanism, and the second is to construct or select an Agent communication language.
4) *Consistency and collaboration*. Consistency describes the overall features of distributed artificial intelligence systems. Collaboration expresses the behavior and interaction patterns among agents. Good collaboration is important to

achieve the stability and consistency of the system's overall behavior. An efficient MAS should trend toward the overall consistency quickly through less learning.

5) *MAS planning*. MAS planning activity is a kind of adaptation planning activity, which reflects the continuous changing process of the environment.[31]
6) *Conflict management*. Conflict in the collaborative process is very common. Conflict can be classified into three classes: resource conflict, objective conflict, and result conflict.[32]

## 1.3 Agent Technologies in Manufacturing Systems

The development of Agent technology borrows many ideas and technological achievements from computer science, sociology, organizational science, economics and ecology and other disciplines, which has obvious advantages in many ways: extensive adaptability for real-world applications, simplicity of design and good systematicness and others.[33, 34] Agent technology has been widely applied in manufacturing, communications, air traffic control, traffic management, information management systems, business process management, remote diagnostics and education and entertainment and many other fields,[35–39] which had achieved remarkable results. This section focuses on introducing Agent technology application in modern manufacturing.

### 1.3.1 Contemporary Manufacturing Systems

The third industrial revolution through the development and usage of computer technologies is affecting the manufacturing industry in a serious way. From the early 1970s, several influencing and representative manufacturing modes and relevant technologies had been presented, for example, the Toyota JIT system in 1980s, the Agile manufacturing system and the networked manufacturing system that were famous in 1990s. These advanced manufacturing modes reflect changes in different periods of external demand, manufacturing models, and related technical support, and reflect the evolution process: "information integration – process integration – inter-enterprise integration".

In this section, we will introduce the current situation and trends of the manufacturing industry, present a literature review concerning production planning and control technologies, and analyze problems and solutions.

Supported by the US Congress and the Defense Department of United States in 1991, the Iacocca institute and the other 13 companies prepared a "21st Century Manufacturing Enterprise Strategy" report, which proposed a new strategy – agile manufacturing to revitalize the manufacturing sector. As a new manufacturing model, agile manufacturing quickly got the recognition and support of US industry, government agencies and the community, and soon became a theoretical research and manufacturing practice hotspot.

Virtual enterprise is an application mode of agile manufacturing. A virtual enterprise is a temporary alliance that comes together to share skills or core competencies and resources in order to respond rapidly to business responsibilities. The whole cooperation is supported by computer networks. Most of the research for virtual manufacturing focuses on organizational management, cooperative partner selection, profit assignment problems, and so on.

From 1996–2000, funds became available to support the agile manufacturing program, for example, the national industrial information system program of United States, the virtual manufacturing network program of Russia and the United States, the European information technology development program, the Japanese smart manufacturing system plan. These research projects focus on investigating virtual enterprises that run related enabling technologies, commercial operation infrastructure, collaborative design, and information integration platforms. The Ecolead program formulated a cooperative organization network including 28 units in 15 countries.

### 1.3.2 Agents in Production Planning and Control Systems

A production planning and control system is the core and key technology of production management systems. An excellent production planning and control system is an important tool to improve the overall automation level of enterprises and provide significant economic benefits for enterprises. A production-planning and control system can directly determine whether the manufacturer can complete specific tasks in accordance with the expected demand. Its core function is to manage production tasks and resource allocation and utilization in manufacturing systems, and to meet customers' demands in the best possible way. A production planning and control system should contain the following processes: decomposing product tasks, analyzing resource demands, determining the operation sequence of a job, allocating machines, and monitoring real-time task progress. Meanwhile, this system should be able to deal with sudden changes in the actual manufacturing environment, such as lack of material, random machine breakdown, order changeover and rush orders, and so on. Even though production planning and control problems are complex, Agent technology has been introduced in this field. A MAS has a certain adaptability in a dynamic environment; it can independently adjust the behavior of individuals in order to respond rapidly to sudden changes in manufacturing systems.

Parunak, et al.[40] developed a production planning and shop floor control system based on Agent technology. Shen et al.[41] studied the integrated modeling framework for business-oriented mixed Agents. Lin and Solberg[42] proposed an autonomous Agent-based integrated production planning and control framework. In their study, a general methodology that consists of a market-based model, a job priority strategy, a multi-stage negotiation technology were developed to adapt to changes in the manufacturing environment. Hadavi et al.[43] proposed a Multi-Agent distributed dynamic planning, scheduling and control system. Applications of MASs to production planning and control problems were summarized by Maria and Sergio.[44] It was noted that its related research tended to be more diverse. Baker[45] studied a MAS-based shop scheduling algorithm. Shaw[46] proposed Agent-based production scheduling and control strategies. In his study, a manufacturing unit could subcontract its task as a subcontract to other manufacturing units by using a bidding mechanism. In the study of Wang et al.,[47] the Agent technology was used to solve real-time distributed intelligent manufacturing control problems. Wiendahl et al.[48] studied a self-organizing production control system based on Agents.

Butler[49] proposed a Multi-Agent system architecture to solve distributed dynamic scheduling problems. In his study, the scheduling process was divided into two levels: the first layer was used to assign manufacturing units to jobs by using an Agent-based consultation mechanism, the second layer was adopted to allocate dynamically shared manufacturing resources. Shen and Norri[50] proposed a hybrid Agent system architecture to solve scheduling and rescheduling problems.

Many Chinese researchers have also proposed different MAS solutions for production planning and control systems. In the study by Zhang Jie, Li Penggen et al.,[51] virtual manufacturing cells were introduced to deal with production planning and control process. The system consisted of a shop floor layer, a virtual cell layer and a resource layer. On the basis of this study, some MAS-based production planning and control solutions have been developed for solving Job Shop,[52–60] reentrant Manufacturing System,[61–66] agile manufacturing systems,[67–72] and other planning and control problems for complex manufacturing systems. Zhu Qiong, et al.[73] proposed a Multi-Agent-based collaborative negotiation mechanism for solving dynamic Job Shop scheduling problems. Zeng Bo, Yang Jianjun, et al.[74, 75] proposed a Job Shop scheduling and control system that hybridizes a MAS-based Generalized Partial Global Planning (GPGP) mechanism with a Task Analysis, Environment Modeling and Simulation (TAEMS) language. Liao Qiang et al.[76] proposed a Multi-Agent-based Job Shop dynamic scheduling model by using field bus. Gao Guojun et al.[77] used Agent technology to developed a reconfigurable enterprise information system by using Agent technology. Liu Jinkun et al.[78] proposed an Agent-based steel industrial production process control system.

### 1.3.3 The Existing Requirements

An Agent system can be used to coordinate production planning dynamically and control activities, adjust individual behavior, and respond rapidly to deal with product changes, machine breakdown, and other incidents. Therefore, Agent technology is suitable for the production planning and control process in manufacturing systems to make decisions. Agent-based production planning and control methods and techniques are presented in detail in this book. A Multi-Agent-based hierarchical adaptive, intelligent, collaborative production planning and control system is developed to investigate some Multi-Agent-based planning, scheduling, and control problems. Moreover, a MAS-based data acquisition technology is proposed for complex production processes in order to collect real-time data and track real-time production processes. The MAS-based technology provides a set of optimal solutions and ideas for the production planning and control process in manufacturing systems.

## 1.4 Book Organization

### 1.4.1 Purpose of the Book

Production planning, scheduling, and control optimization have become urgent demands and a trend in modern complex manufacturing systems such as weapon manufacturing systems and semiconductor manufacturing systems. In this book, weapon manufacturing systems are characterized as small-batch manufacturing systems, which are similar to typical Job Shop Manufacturing systems. The semiconductor manufacturing systems are characterized as typical re-entrant manufacturing systems. The book will focus on developing a hybrid push-pull production planning and control system architecture based on MASs to describe the characteristics of Job Shop and re-entrant manufacturing systems. The overall system objectives are completed by communicating and collaborating amongst Agents to manage and make decisions so as to respond rapidly to internal and external changes in the manufacturing environment. The production planning and control process presented in this book consists of three layers: the production planning layer, the production scheduling layer, and the production control layer. In the production planning layer, MAS-based production planning methods for distributed manufacturing systems are given. In the production scheduling layer, a Multi-Agent double feedback strategy-based scheduling method is developed for Job Shop Manufacturing systems, and a Multi-Agent hierarchical adaptive production scheduling method is proposed for Re-entrant manufacturing systems; in the production control layer, the radio frequency identification (RFID) technology and OLE for Process Control (OPC) technology and Multi-Agent Systems are integrated, and a material and equipment data acquisition method is then designed for manufacturing systems. This method is able to collect heterogeneous device data and integrate information between heterogeneous networks. This method also provides a new way for tracking real-time production processes in complex manufacturing systems and a foundation for real-time production decision-making in manufacturing systems.

### 1.4.2 Scope of the Book

This book systematically presents methods and technologies concerning Agent-based production planning systems. The content of this book is illustrated in Figure 1-1. Chapter 1 and Chapter 2 introduce advantages and applications of Agent technology. Chapter 3 presents requirements of production planning and control systems. An Agent-based push-pull production planning and control system is developed. Agent-based production planning and control technologies for distributed production systems are introduced in Chapter 4 to Chapter 9. Chapter 4 proposes a Multi-Agent contract net protocol and bid auction protocol based production planning approach for distributed production systems. Chapter 5 develops a Multi-Agent double feedback–strategy based production scheduling method for Job Shop production systems. Chapter 6 proposes a Multi-Agent hierarchical adaptive production scheduling architecture for Re-entrant manufacturing systems. Chapter 7 presents a Multi-Agent production control system. Chapters 8 and 9 present data acquisition technology based on RFID technology and OPC technology, and construct a Multi-Agent material data acquisition system and a Multi-Agent equipment data acquisition system. Chapter 10 presents the prototype of an Agent-based production planning and control system.

### 1.4.3 Content of the Book

Chapter 1 introduces Agent technologies in modern manufacturing. A short review concerning Agent technology is given to provide the background for investigating production planning, scheduling, and control approaches.

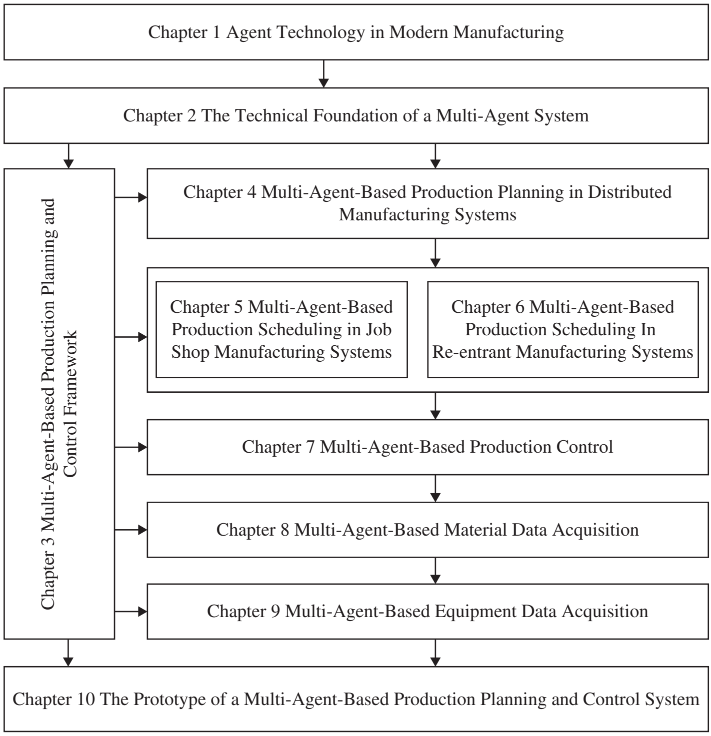


**Figure 1-1** The content of this book.

Chapter 2 presents Agent technologies used in this book, which includes three aspects, that is the structure of an Agent and a Multi-Agent System, the interaction model of a Multi-Agent System, and communication protocols and interaction protocols of Multi-Agent Systems.

Chapter 3 analyzes production planning and control activities and operation modes, and requirements of a production planning and control system. A hybrid Agent-based push-pull production planning and control system is developed.

Chapter 4 presents Agent-based production planning methods for distributed manufacturing systems. First, the production planning process in distributed manufacturing systems is investigated. Second, a production planning model and a MAS structure are developed. Third, a contract net protocol–based

MAS collaborative production planning method is proposed in which plants collaborate in a distributed manufacturing system with complete information sharing. Finally, a bidding auction protocol–based MAS collaborative production planning method is proposed where plants collaborate in a distributed manufacturing system with incomplete information sharing.

Chapter 5 presents Agent-based production scheduling methods for Job Shop manufacturing systems according to the basic principles of push and pull modes. In particular, a multi-Agent dual feedback–based production scheduling method is developed. Then, a hierarchical optimization theory–based positive feedback job scheduling method, and an ant colony negotiation mechanism–based negative feedback rescheduling method are proposed.

Chapter 6 develops a Multi-Agent-based hierarchical adaptive production scheduling architecture to describe the characteristics of re-entrant manufacturing system. A combinatorial auction–based method is developed in the system layer; a GPGP-CN based method is developed for hierarchical production scheduling processes in the machine layer; and a fuzzy neural network–based adaptive rescheduling method is developed for re-entrant manufacturing systems.

Chapter 7 proposes a Multi-Agent-based production control method by analyzing requirements of production control activities. Several important business Agents and related methods in the production control process are presented.

Chapter 8 presents the basic concepts and function requirements of material data acquisition, and develops a Multi-Agent RFID technology–based material data acquisition system.

Chapter 9 presents a Multi-Agent OPC technology based equipment data acquisition system.

Chapter 10 presents both hardware architecture and software architecture of an Agent-based production planning and control prototype system.

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