JEIM
26,4

400

Received 16 March 2012
Revised 2 May 2012
6 May 2012
16 May 2012
Accepted 18 June 2012

Information support technologies of integrated production planning and control for OEM driven networked manufacturing

Framework, technologies and case

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Abstract

Purpose – The purpose of this paper is to study the information support technologies of integrated production planning control for OEM (original equipment manufacturer) driven networked manufacturing systems, and offer implications to firms for implementing networked manufacturing.

Design/methodology/approach – OEM driven networked manufacturing and its operations modes and support technologies are first discussed. Then, integration framework of production planning and control is proposed and relative technologies are discussed. Finally, a case of the application of information support technologies in networked manufacturing is illustrated.

Findings – Both theory analysis and case experience show that information integration and sharing are critical for effective operations of OEM driven networked manufacturing and an integrated production planning and control system can benefit firms for successfully operating a networked manufacturing system.

Practical implications – It is valuable to develop and apply integrated production planning and control systems in OEM driven networked manufacturing, Firms should pay more attention to information sharing and communication with partners and utilize advanced information technologies to synchronize the operations of partners.

Originality/value – Integration framework of production planning and control proposed in this paper has originality and the technology strategies are also practical. Managerial ideas, technology framework and application strategies of integrated production planning and control are helpful for firms to implement OEM driven networked manufacturing.

Keywords Networked manufacturing, Information technology, Production planning and control, Integration, Case, Supply chain, Theoretical model, Coordination mechanism, OEM, Operations management

Paper type Research paper

1. Introduction

Volatile economic environment, global market and customized demand are constantly challenging manufacturing firms (Choy *et al.*, 2004). Fierce market competition and wide application of information technology (IT) are deconstructing traditional value chain, i.e. vertical integrated organizations are giving way to more flexible networked

This paper is funded by National Science Foundation of China (70972079).

Journal of Enterprise Information Management
Vol. 26 No. 4, 2013
pp. 400-426

1741-0398
DOI 10.1108/JEIM-03-2012-0005

forms of coordination (Puschmann and Alt, 2004), which lead to the emergence of collaborative business (Niehaves and Plattfaut, 2011). Networked manufacturing, or distributed manufacturing, is one kind of new collaborative business patterns in the era of IT. There are several reasons of forming networked manufacturing. The first reason is competition pressure. Under today's changing market environment and global competition pressure, original equipment manufacturer (OEM) companies have increasingly focussed on their core competencies and outsourced part or all of their manufacturing operations to third-party manufacturers (e.g. contract manufacturer (CM)) and formed global business networks (Noori and Lee, 2000; Kuhn, 2006; Sousa and Voss, 2007; Xu *et al.*, 2008), which can strengthen their competition capability. The second reason is resource utilization. Resource shortage in one region or country also makes some firms to search resource in other regions or countries. For example, firms in western countries now usually lack labor resource, but own advantage in capital and technology resources. On the contrary, firms in Asian counties and regions usually own comparative advantage in labor resource but lack capital and technology resources. So, these two types of firms can form networked manufacturing to fully utilize their own resources. The third reason is learning. There is a learning opportunity for firms when they form alliance with other firms. Because different firms have different management experience and culture, through networked manufacturing system, partners can learn from each other on the management experience. This is a fast way to improve a firm's management ability (Li *et al.*, 2010).

Although networked manufacturing has advantage in increasing competitive ability for partners, different problems exist in networked manufacturing system. Since different firms have different business goals and strategies, if there are not coordination mechanisms or support technologies, conflict and contradiction will often occur among partners, which consequently low the entire system efficiency, especially in production operations management. Because networked manufacturing activities go across different functions and firms, the production planning and control (PPC) work is more difficult than traditional manufacturing mode. In order to synchronize the operations of different partners in the networked manufacturing system, IT has become a main support tool for operations of networked organizations and inter-enterprise integration (Kirchmer, 2004). Particularly, internet technology has provided organizations with vast opportunities to operate beyond their traditional physical boundaries (Gunter *et al.*, 2006; Harrigan *et al.*, 2008). Usually, most enterprises apply enterprise resource planning (ERP) to support their own business operations. However, different firms have different ERP systems, and these systems can not share information each other (Davenport and Brooks, 2004; Moller, 2005). Thus, in order to support the synchronous operations of the networked manufacturing, an integrated PPC system which can share information across partners is needed.

There are two groups of literature relative to this paper. The first group is about general problems of OEM, and the second group is about PPC for networked manufacturing.

There are some authors have focussed on general problems of OEM, especially on the operations and strategy of OEM. Noori and Lee (2000) explore how OEM and suppliers can form a fractal manufacturing partnership (FMP) and improve flexibility and responsiveness. They analyze the structure characteristics of FMP as well as the benefit, risk and challenge facing FMP. Lyons *et al.* (2006) discuss the relationship between proximate supply and OEM build-to-order capability in the environment of vehicle production industry. Sousa and Voss (2007) use case study to examine the operations of OEM and its different subcontractors. Kros *et al.* (2006) analyze the impact of adoption of just-in-time production systems by different OEMs on the inventory profiles of their suppliers. The research finds that OEM suppliers in different industries have shown mixed results in the impact of JIT implementation on inventory performance. Li *et al.* (2010) study the learning trajectory in offshore OEM cooperation. They empirically examine the links between learning intent, capability enhancement, etc from perspective of local suppliers in offshore OEM cooperation in China. Recently, Komoto *et al.* (2011) analyze the long-term relationships between OEMs and stakeholders in their supply chains from perspective of life cycle using simulation.

As regards the second group literature on PPC in networked manufacturing context, there are also two streams. One stream literature focuses on information structure and technology enablers, while another stream focuses on mathematical modeling. For the first stream, Montreuil *et al.* (2000) study the strategic framework for designing and operating agile manufacturing, enabling to collaboratively plan, control and managing day-to-day contingencies in a dynamic environment. Akkermans and Horst (2002) discuss the managerial aspects of IT infrastructure standardization in networked manufacturing firms. Mezgar *et al.* (2000) introduce the system modules of cooperative production planning for the small-and medium-sized enterprise network and its economic benefit. Soares *et al.* (2000) describe the requirements analysis and system specification of an order promise module to be used as part of a broader decision support system for production and operations planning of a virtual enterprise. Lu and Yih (2001) propose a framework of agent-based collaborative production control for multiple-line collaborative manufacturing environment. Frayret *et al.* (2004) also study mechanism for coordination and control in distributed and agent-based manufacturing. Wang *et al.* (2004) propose a new reference model of networked manufacturing using hierarchical multi-view modeling principle of computer-integrated manufacturing (CIM). Hao *et al.* (2005) propose an internet-enabled framework based on web service and agents for cooperative manufacturing management. Caridi *et al.* (2006) study the linking autonomous agents to collaborative planning, forecasting and replenishment (CPFR) to improve supply-chain management. Leitao (2009) survey the literature in manufacturing control systems using distributed artificial intelligence techniques (i.e. multi-agent system and holonic manufacturing system principle) and discuss reasons of weak adoption by industry and challenge for future. Huang *et al.* (2009) design five protocols associated with order management in collaborative manufacturing, and the protocols are also implemented in a distributed computing environment. Mourtzis (2011) discusses the collaboration among manufacturing companies regarding planning and control, proposes a software framework based on internet and XML technology. Kristianto *et al.* (2011) also study the advanced planning and scheduling with collaboration processes in agile supply and demand networks. Germain *et al.* (2011) introduce the holonic manufacturing executive system (HMES) for networked production of European project MABE. Egri *et al.* (2011) discuss the collaboration and cooperation in supply networks and planning mechanism.

The second stream of literature relating to PPC in networked manufacturing focusses on mathematical modeling. Gnoni *et al.* (2003) deal with lot sizing and scheduling problem of a multiple-site manufacturing system with capacity constraints and multi-product and multi-period demand. Similarly, Leung *et al.* (2003) study the multi-site aggregate production planning with multi-objective using goal programming approach. Jolayemi and Oloruniwo (2004) develop a deterministic model for planning production and transportation quantities in multi-plant and multi-warehouse environment with extensible capacities. Ling *et al.* (2006) study the distributed production planning with supplier selection using analytical target cascading (ATC) method. Dudek and Stadtler (2005) study a negotiation-based production planning between supply-chain partners. Bollaksil and Fransoo (2009) study a OEM manufacturing firm that outsources some of its production activities to a CM using mathematical modeling method, they compare three order release strategies. Lin *et al.* (2009) study an interactive meta-goal programming-based decision method to support collaborative manufacturing. Chung *et al.* (2010) apply genetic algorithm (GA) to study the multi-factory production planning problem. Jung (2011) studies a fuzzy AHP-GP approach for integrated production planning considering manufacturing partners.

Although there have been some researches on the problem of distributed PPC for networked manufacturing system, little attention is paid to the integration of PPC, especially about the production control strategies of OEM-driven networked manufacturing. In this paper, we study the integration strategies of PPC and their application in OEM-driven networked manufacturing. Theory development and case study is combined together. The main contributions of the paper lie in two aspects. First, a new multi-layer coordination integration framework of PPC for networked manufacturing is proposed. Second, new technologies, such as radio frequency identification (RFID)-based order tracking system and multi-echelon coordination production control mechanism are presented. To our best knowledge, there is not literature systematically investigating the integrated PPC system for OEM-driven networked manufacturing system.

The rest of this paper is organized as follows. Section 2 introduces the research agenda and methodology. Section 3 first discusses the OEM-driven manufacturing and its operation modes, and then discusses information support technologies for networked manufacturing systems. In Section 4, an integration framework of PPC for OEM-driven networked manufacturing is proposed, and relative technologies are discussed. In Section 5, a case is used to illustrate how to use IT technologies to support PPC in networked manufacturing. Finally, the conclusions and further research directions are summarized in Section 6.

2. Research agenda and methodology

The goal of this paper is to investigate the information support technologies of PPC for OEM-driven networked manufacturing from two aspects. First, we theoretically propose a technology solution of PPC for OEM-driven networked manufacturing. Second, we use case study to discuss the application of information technologies supporting PPC for OEM-driven networked manufacturing in practice. Under this goal, the agenda of this paper includes the following questions:

(1) What characteristics do the OEM-driven networked manufacturing systems have with respect to information technologies application?

(2) Are there any special requirements of PPC for OEM-driven networked manufacturing systems?

(3) What is the integral framework of PPC for OEM-driven networked manufacturing systems?

(4) What technologies and operational mechanism of PPC are needed in the integrated PPC for OEM-driven networked manufacturing systems?

Research methodology is determined by the characteristics of the studied issue. In order to answer above questions, several phases of the research are needed. First, as basis of theory, a conceptual and qualitative analysis based on thorough literature review is conducted, meanwhile, as theory application background, an enterprise examination and information collection is also carried out. Second, based on literature review and enterprise examination, we propose a new integration framework of PPC for OEM-driven networked manufacturing, this framework will fully consider the operational characteristics and technologies requirements of OEM-driven networked manufacturing. Third, under the integration framework, detail technologies and managerial ideas are then derived out and discussed. Forth, in order to verify the practicality and reasonableness of the proposed technologies and managerial ideas, we use the collected information from the examined enterprise to illustrate the application of information technologies in networked manufacturing, and present the experience implications of the company. Figure 1 shows the research scheme and technique path.

3. OEM networked manufacturing modes and support technologies

In this section, we discuss the OEM-driven networked manufacturing and its operations modes, and then the relative information support technologies.

3.1 OEM-driven networked manufacturing modes

There are two types of OEM networked manufacturing modes. The first one is full outsourcing (i.e. product outsourcing) OEM networked manufacturing (FPO-OEM). The second one is partially outsourcing (i.e. part/component outsourcing) OEM networked manufacturing (PO-OEM).

3.1.1 Full product outsourcing OEM networked manufacturing. In the first networked manufacturing, OEM outsources all production tasks to OEM suppliers, i.e. CMs. Figure 2 shows the basic operations processes of FPO-OEM networked manufacturing.

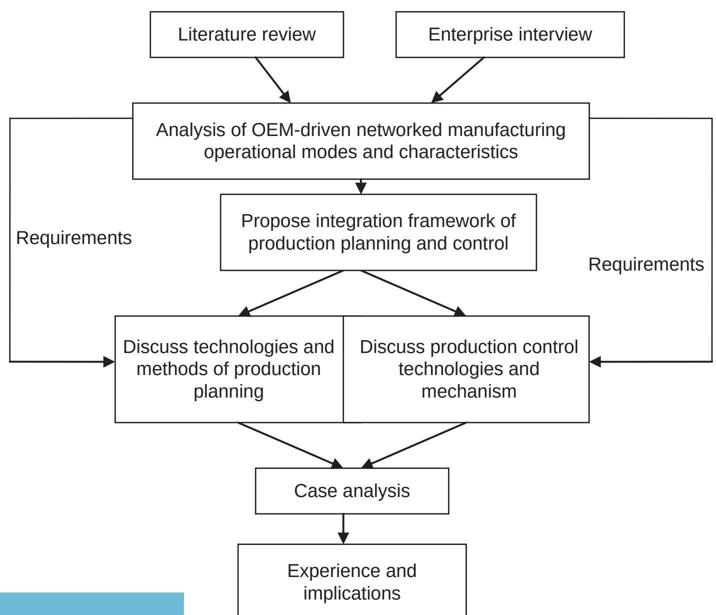


Figure 1.
Research scheme and technique path

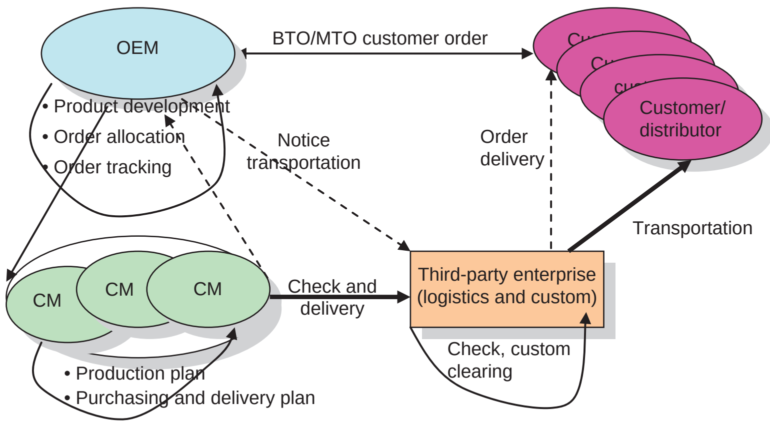


Figure 2.
Full product outsourcing OEM networked manufacturing system

In the FPO-OEM networked manufacturing system, OEM, CMs and third-party enterprise (TPE) comprise the main partners of the system. OEM receives customer orders and then outsources orders to different CMs, i.e. it is responsible for the product development, order allocation and order tracking. CMs are responsible for the production plan making, raw materials purchasing and delivery plan making. TPE is responsible for the logistics and custom clearing and exporting. In this system, there is frequently information sharing and communication on the customer orders, production and delivery among OEM, CMs and TPE.

3.1.2 Part/component outsourcing OEM-driven networked manufacturing. The second type operations mode of OEM networked manufacturing is part/component outsourcing OEM-driven networked manufacturing, it is shown in Figure 3. In this mode, OEM has two function departments. The first department is called marketing center (MC), and the other department is called production center (PC). MC is

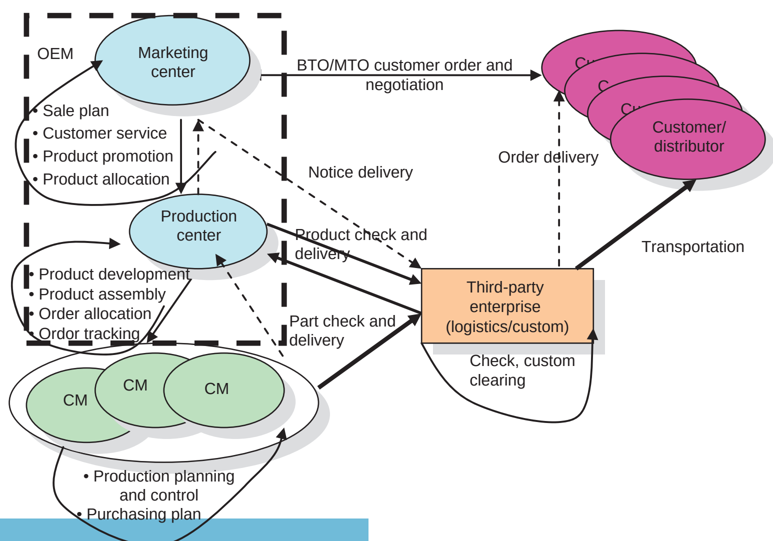


Figure 3.
Part/component outsourcing OEM networked manufacturing system

responsible for receiving orders from customers, product promotion, customer service and sale plan. PC is responsible for the production assembly planning, product development and order allocation and tracking. PC not only allocates part production tasks to different CMs, but also needs to assemble the product. CMs are responsible for the part production and raw materials purchasing. In this mode, not only there is information sharing and communication between MC and PC within OEM, but also there is information sharing and communication between PC of OEM and CMs. Thus, this type networked manufacturing system needs more IT support during production and delivery than full product outsourcing networked manufacturing system.

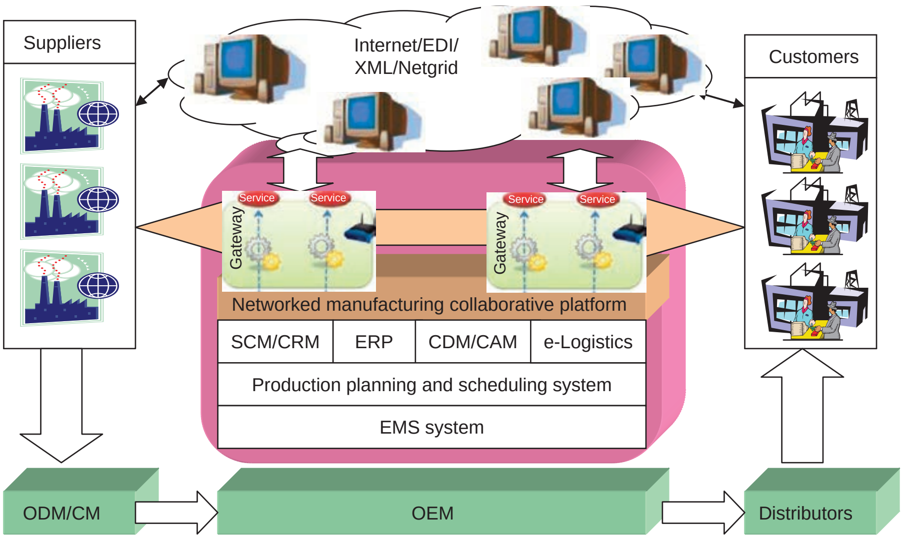
From the above analysis, it is obvious that there are some characteristics of OEM-driven networked manufacturing with respect to IT application. First, no matter full product outsourcing OEM networked manufacturing or partially outsourcing OEM networked manufacturing, information sharing and communication among different enterprises is critical for successfully operating the network manufacturing systems. Second, traditional ERP systems used in manufacturing firms internally cannot support these inter-organizational manufacturing systems. Third, information of PPC is the most important information resource for operating the whole supply chain of OEM manufacturing network. Therefore, in the following sections, we discuss how to use IT to support the operations of these OEM-driven networked manufacturing systems. We first theoretically propose an IT framework of PPC, and then use case study to empirically discuss the application of IT supporting the PPC in networked manufacturing environment.

3.2 Information support technologies of OEM networked manufacturing

In the inter-organizational network, a strong IT infrastructure can support and coordinate the decisions of partners (Daim *et al.*, 2011; Lewis and Talayevsky, 2004). OEM-driven networked manufacturing system is an inter-organizational network system comprising partners located in different regions or countries with various business goals. Under this environment, the decisions of planning and control are undertaken by collaborative and coordinative units of different organizations. Thus, IT technology is a prerequisite for implementing networked manufacturing. Since the concept of CIM was initiated by Dr Joseph Harrington in 1973, many researchers have studied the integration technology of manufacturing systems. Based on the characteristics of OEM-driven networked manufacturing, we construct the integration architecture of networked manufacturing, which is shown in Figure 4. The architecture depicts the basic organization structure and technology structure.

The bottom of the networked manufacturing integration architecture shows the organization structure and supply-chain process from ODM/CM to OEM and then distributors. OEM is the core of the network, and original design manufacturers (ODMs) and CMs and distributors as partners. CMs and ODMs are suppliers of OEM while distributors are customers of OEM. All partners are linked through internet/XML/EDI, net grid and other information technologies, which are shown in the top level of the architecture. With the development of new computation and network technology, such as cloud computation, new IT supporting environment of distributed manufacturing will emerge.

The middle box of the integration architecture includes the main technology functions of networked manufacturing. Among these functions, production planning and scheduling system and manufacturing executing system (MES) are the two basic operations management components, especially the production planning and



Notes: CM, contract manufacturer; ODM, original design manufacturer; OEM, original equipment manufacturer

Figure 4. Integration architecture of networked manufacturing

scheduling system, which is the core of the system. In most companies, the production plan is integrated with other modules in ERP system, but some companies have an independent production planning and scheduling system. The interacting activities diagram of PPC in networked manufacturing is depicted in Figure 5. This diagram shows the whole interactions among partners of the network from customer's order generation to order delivery.

The main support technologies of PPC for networked manufacturing include the following four components:

(1) ERP: this is the infrastructure of operations management of manufacturing system. It mainly manages the internal resources and processes of the firm.

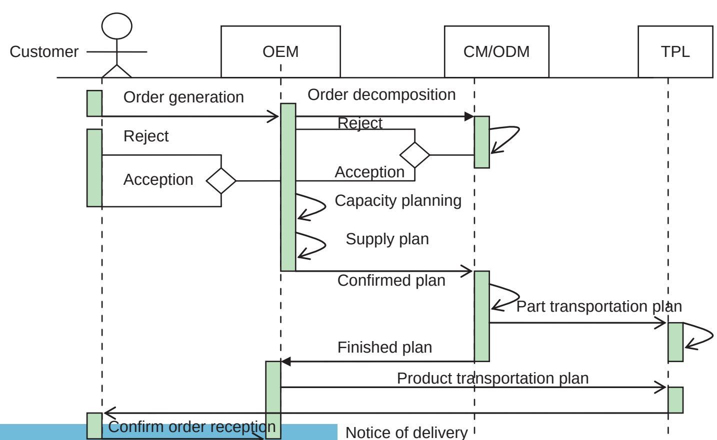


Figure 5. Activity diagram of production planning and control of networked manufacturing

However, new generation of ERP system will have robust and strong flexible ability, and it can seamlessly links to other internal and external information systems of the firm.

(2) Supply-chain management (SCM)/customer relationship management (CRM): SCM is an integrated management philosophy and a system as well, which manages and controls the activities of supply chain. CRM is a support technology for customer service during product sale, which can feedback customer requirements and demand information to the manufacturer, and enhance the relationship with customers. All SCM and CRM systems can seamless link with ERP.

(3) E-logistics: third-party logistics firms are the partners of the networked manufacturing system, who support the materials transportation and warehousing service. E-logistics offers an online service of logistics for partners of networked manufacturing, such as vendor managed inventory (VMI).

(4) MES and e-manufacturing. MES is linked with ERP and scheduling system, which feedbacks production information to the planning and scheduling system and offers importation execution information for production control. E-manufacturing includes computer aided designing (CAD) and computer aided manufacturing (CAM), etc. digital manufacturing technologies. These technologies are basis of networked manufacturing.

4. Integrated PPC for OEM networked manufacturing

In this section, we propose a new integration framework of PPC for OEM networked manufacturing system, and discuss the characteristics of the framework, relative technologies and its innovative managerial ideas.

4.1 Integration framework of PPC

Although a lot of advanced technologies and methods have been developed for supporting PPC in manufacturing, there are also some special requirements of OEM-driven networked manufacturing which traditional systems are far from enough, such as flexibility, coordination ability and online information sharing.

Flexibility. This is a very important requirement for PPC system in networked manufacturing. Because of the complexity of the network, uncertainties in OEM supply chain are more remarkable than that in a single enterprise, so the PPC system must have higher flexibility than that used in a single firm.

Coordination ability. Since the production activities of networked manufacturing are across different partners, so PPC system should have good coordination ability to solve the conflicts occurring between partners.

Online information sharing. Information sharing is a critical factor for synchronizing the operations of OEM-driven networked manufacturing. Through online information sharing, OEM and its partners can quickly respond to customer demand.

Based on these characteristics of OEM networked manufacturing, we construct an integration framework of PPC for networked manufacturing. Figure 6 shows the basic structure of the integration framework.

Apart from meeting the basic requirements of OEM manufacturing system, the framework includes many new managerial ideas. The innovative ideas of the framework lie in three aspects.

First, the framework fully utilizes all kinds of new IT technologies, such as internet/ XML, RFID and agent technology. These new information technologies extend the

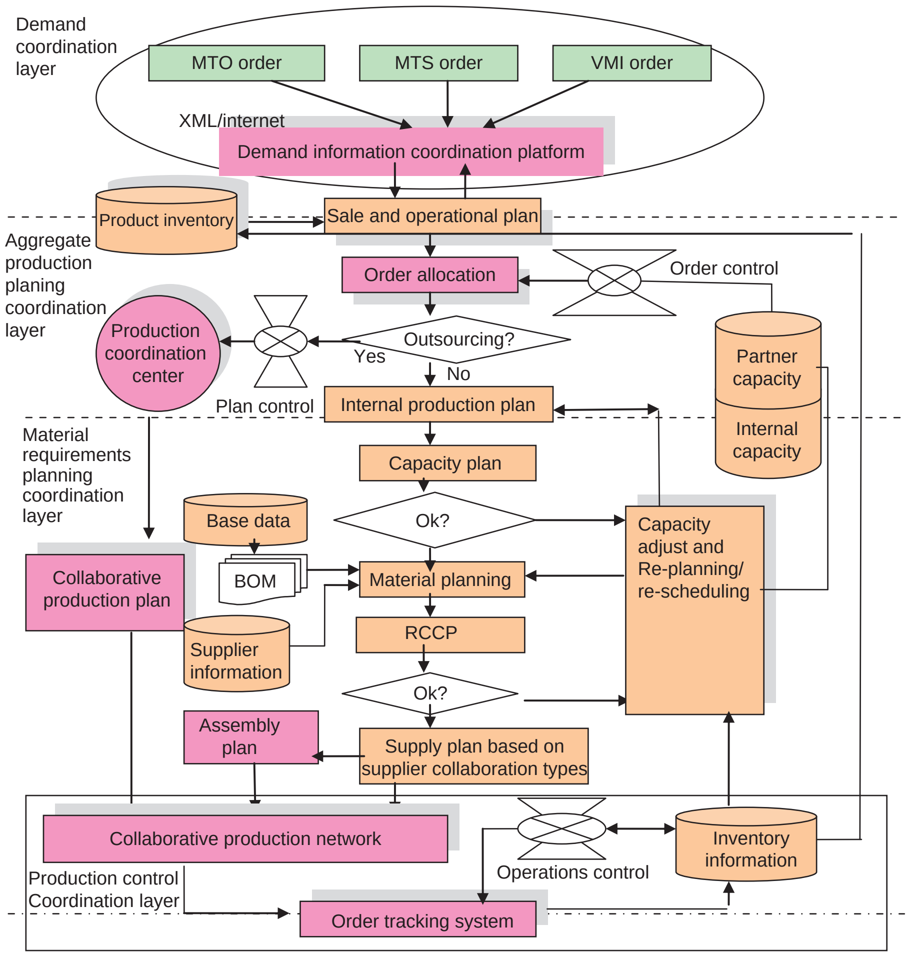


Figure 6.
Integration framework of production planning and control for networked manufacturing

information communication ability of internal and external units of firms, especially the information communication ability of OEM with its partners.

Second, the framework extends the idea of traditional manufacturing resource planning (MRP), and adds more functions for connecting internal and external units of manufacturing firms, such as demand information coordination platform, production coordination center, order tracking system, etc. These new functions largely strengthen the ability of traditional MRP system.

Third, the multi-layer coordination integration idea is inbuilt in the framework, i.e. demand coordination layer, aggregate production planning coordination layer, material requirements planning coordination layer and production control coordination layer. Through this multi-layer coordination integration mechanism, PPC are closely integrated.

In Figure 6, the yellow-colored components are activities of the internal OEM, and rose-colored components are interactive activities of OEM with other partners. The main functions and their characteristics of the framework are depicted as follows.

First, demand coordination layer: in this layer, a demand information coordination platform is designed for the demand collection and coordination with customers. There are different types of demand information, such as VMI information, MTO (make-to-order) and MTS (make-to-stock) demand information, etc. Through this platform, customers can automatically place orders and track orders online, which largely increase the ability of customers' interaction with partners. More and more companies have analogical information communication platforms.

Second, aggregate production planning coordination layer: the second layer is the aggregate production planning coordination layer. The main work in this layer includes order allocation through bidding with network partners, sale and operations plan (SOP) considering outsourcing. Our innovative idea in this framework is that we extend traditional production planning system framework by adding a production coordination center and order allocation function in the system. Consequently, the production planning function is extended from single-factory to multi-factory. This multi-factory production planning function is very important for OEM, which embodies the global resource utilization ability of the OEM firms.

Third, material requirements planning coordination layer: according to the basic principle of production plan decision, the next step following aggregate production planning is material requirements planning. Unlike traditional MRP system, in our integration framework, material requirements planning decision model takes the collaboration relationship of suppliers into accounting, i.e. when make the purchasing plan for different materials in the decision model, it considers the relationships of suppliers (e.g. close, loose and normal relationships). Since for different partners with different relationships, the transaction costs are different, such as transportation cost and ordering cost. Therefore, in the model, we add a new supplier information base as input of material requirements planning. This new idea is also adaptable for the requirements of multi-collaboration modes in OEM networked manufacturing systems.

Fourth, production control coordination layer: the fourth layer of the framework is the production control coordination layer. In this aspect, notable innovative ideas include two points.

First, RFID-based order flow tracking system. RFID is a new IT, which has been a hot discussing topic in academia and practice. It can largely improve and enhance the information sharing ability among partners and the productivity of networked manufacturing. Based on the special requirements described in Section 4.1, we construct an order flow tracking system for OEM networked manufacturing production control, which will be detailed in the next section.

Second, multi-echelon coordination control mechanism. In the framework, we design a three-echelon control system. The first echelon is order control, which controls order allocation in demand management and SOP. The second echelon is plan control, which controls the order release in aggregate production planning. The third echelon is operation control, which controls the order operation in the network. Through these three-echelon control activities, all partners of networked manufacturing can synchronize their operations activities and quickly respond to customer demand.

In the next section, we will detail the principle of the production control of networked manufacturing.

4.2 Production control technologies of networked manufacturing

Different from the single factory production control, networked manufacturing production control is more complicated. Because it needs more information communication and coordination among network partners, so the control strategies are different from normal production control strategies in a single firm. In this paper, we propose new control strategies for networked manufacturing system, i.e RFID-based order tracking technology and multi-echelon coordination control strategy.

4.2.1 RFID-based order tracking system of networked manufacturing. Networked manufacturing consists of different partners, e.g. supplier, ODM, CM, OEM, distributors and third-party logistics (TPL). These organizations maybe located in different regions and countries and traditional ERP system cannot link them together or easily to track the order flow among them, so a new order tracking technology is needed.

RFID is a new information transferring technology using radio frequency. It makes enterprise information system evolve from a local computing system to a global computing system. It can increase the information sharing and transferring ability among relative partners in the network. It is a new technology for integrating supply-chain operations (Wamba, 2012). Currently, RFID is mainly used to automate logistics processes. However, it will be widely used in manufacturing to improve productivity (speed up the production efficiency). Especially in MES, RFID can largely increase the shop floor control ability.

RFID technology includes four aspects (Ivantysynova and Ziekow, 2008). First, RFID tags: the tags are attached to physical objects and store at least a unique identifier of the objects that they are attached to. Second, RFID readers: these hardware devices can identify, store and transfer RFID information to other information systems. Third, RFID middleware: the RFID middleware is software which can run in a single machine or distributed machines. Its functions are to buffer, aggregate and filter data from different readers and to reduce the load for application. Fourth, application: the RFID data can be used by a variety of software systems, such as ERP and MES systems in manufacturing.

Based on the RFID technology and networked manufacturing, we design an order flow tracking and information sharing system for networked manufacturing, as shown in Figure 7.

4.2.2 Multi-echelon coordination control mechanism of networked manufacturing. For effectively control production activities of networked manufacturing, in our integrated PPC system, we design a three-echelon control points, i.e. order control, plan control and operation control. These three control points comprise the multi-echelon coordination control mechanism as illustrated in Figure 8.

In this three-echelon control system, there is a three-echelon coordination mechanism used to support the control activities during production control. The three-echelon coordination mechanism consists of decision coordination, information coordination and operational coordination. Through this multi-echelon coordination control system, all production activities of networked manufacturing can reach synchronization.

During the production process, various uncertain factors, such as supplier disruption and other changes of inside production conditions, require re-plan or re-schedule the production. Both re-planning and re-scheduling are strategies for adjusting production activities when production conditions or outside environment conditions have changed. Some rules/actions can be taken to adjust the original plan to meet uncertainties. Table I lists out some strategic actions.

5. Case study

In the above sections, we have theoretically and technically discussed the relative information and operational methodologies of PPC for implementing networked

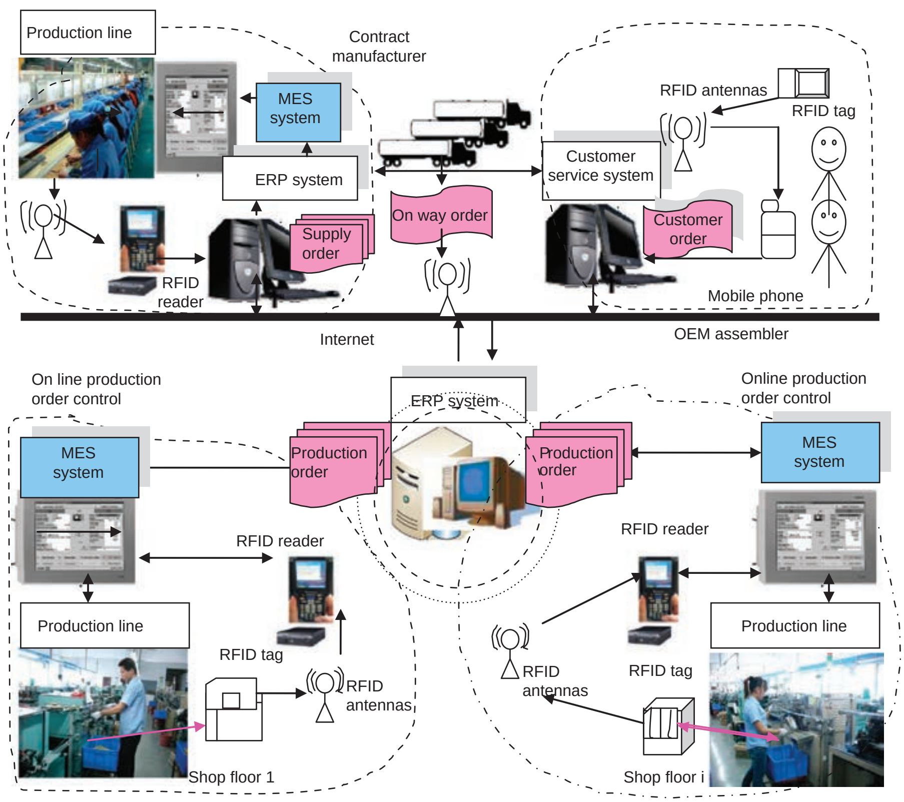


Figure 7.
Order tracking and information sharing system of networked manufacturing

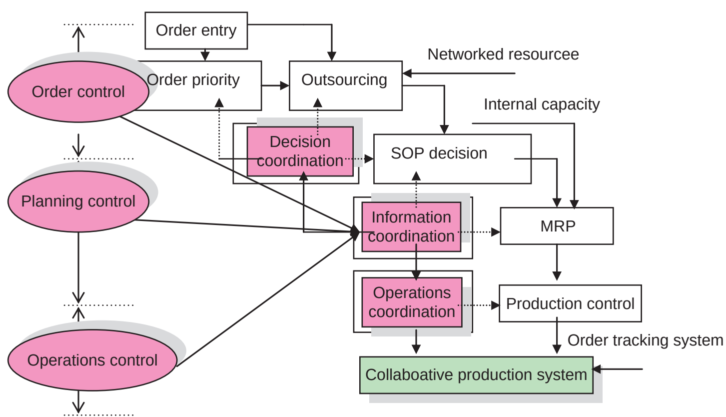


Figure 8.
Multi-echelon coordination control mechanism of networked manufacturing

manufacturing system. In order to illustrate the practice in networked manufacturing, here we take one international company as the case background to show how information technologies can support the implementation of networked manufacturing and enhance the competition ability of a company.

Table I. Selected rules/actions for re-planning the original production plan

Problems	Actions
The network node partner (CM/ODM) refuse the appraised offer	(1) Subcontract to other network partners (2) Make new offer appraise (3) Subcontract to other CM out of the network
The network node partner cannot finish the work on time	(1) Urge the network partner to finish work on time (2) Depend on the final evolution (2.1) If no perturbation in the final business, the activity is re-planned (2.2) If perturbation in the final business, the activity is re-planned and the customer is advised and explained the reasons and the future actions (1) Ask the CM to urge the supplier in order to supply on time (2) Ask the co-ordination unit to urge the supplier to supply on time
The CM's suppliers delay delivery	(1) Re-negotiate with the customers (2) Communicate with network partners to modify production plan (3) Project re-planning
Customers modify order requirements	(1) If it is not difficult, OEM support CM to reorganize it and help them on time deliver (2) If it is difficult, re-plan production or seek outside help to support CM to reorganize it
Disfunction of the production of CMs	

Source: Revised from: Mezgar *et al.* (2000)

5.1 Methodology of case study

Case study is good empirical study method. Allport (1961) argues that case study method can obtain the detailed behavior observations that other methods cannot obtain. Eisenhardt (1989) argues that case study leads researchers to find new theoretical relationships and question old ones. Mccutcheon and Meredith (1993) also think that case study can be used to explore current theory more thoroughly and support, expand or raise questions about existing theories. The purpose of our case study is to find answers to some application problems of theory and methods proposed in previous sections and also discuss the practical experience in networked manufacturing.

In this study, the case information was collected by the following steps. First, we contacted the production manager of the case company, and told him our purpose of case study and requirements. Then under his arrangement, we visited the company and conducted in-depth interviews with senor managers in departments of production and information system. The interview lasted one day including two meetings, i.e. a morning meeting with production manger and other senior managers and an afternoon meeting with engineers of information department. During the first meeting, production manager and senior managers were asked to describe the basic information of the company, the implementation of PPC and what problems they met in collaboration with partners. In the afternoon meeting, engineers were asked to describe the implementation of information system in supporting production operations of the company. They were also asked to show some implementation interfaces of the system and experience in using information technologies to make production plan and coordinate with partners.

Through this case study, we want to answer the following questions:

(1) How information technologies can practically support the PPC in a networked manufacturing system?

(2) What experience can we learn from the case company in utilizing information technologies to support PPC for OEM driven networked manufacturing?

5.2 Background introduction of case company

The name of the case company is called Coats Group CO. LTD, which is an international company with headquarters at Europe (UK). It was founded in 1775 with a more than 200 years' history and has become one of the biggest manufacturers and suppliers of industrial sewing yarn and embroidering yarn. Nowadays, Coats' business has covered overall the world with production plants and distribution channels in more than 66 counties. In 2011, the total sale income of Coats reached about 1.7 billions. China's fast development of economy and low labor cost attracted its investment. In 1982, one manufacturing plant was founded in Shenzhen, an economic special district in Guangdong province. Then Coats continuously opened other new plants in Shanghai, Qingdao and Dalian cities, respectively. The foundation of these new manufacturing plants makes the company form a supply chain network across Europe, Africa and Asia. The China headquarters of Coats is located in the factory of Shenzhou City (our case study interview activities were also conducted in this factory). The growth speed of Coats in China is very fast, during the last three years, the sale income has doubled. Currently, there are about 3,000 employees in all factories in China, and there are about 1,700 employees in the Shenzhou factory.

Figure 9 is the supply-chain network of Coats Group CO. LTD.

5.3 Demand character and production organization

The statistics data reveal that, averagely, each sub-company of Coats sales about 8,000 products every years. Totally, about 100 products (25 percent) have rather high predictability, 1,000 products (55 percent) have high predictability and the remaining 6,900 products (20 percent) have no predictability. These diverse demand and different and dispersed markets make the traditional production organization mode more and more difficult to satisfy the requirements of the whole supply chain.

Based on the characteristics of demand and market, in 2000, the company rearranged the business into different units:

(1) low cost units (LCUs);

(2) bulk production units (BPUs); and

(3) customer service units (CSUs).

LCUs are located in Asian countries, such as China, Vietnam, Malaysia and India. In these units, the product demand is predictable, large volume and stable. Since these characteristics, LCUs use MTS production mode, which can fully utilize the local advantage of low labor cost and economic scale. This kind of products are manufactured and distributed to other sub-companies for sale.

BPUs are located in east Europe (e.g. Romania) and South America (e.g. Mexico and Brazil). These units produce all MTS products which other LCUs do not produce. The characteristics of these products are predictable and large volume. Besides, these units

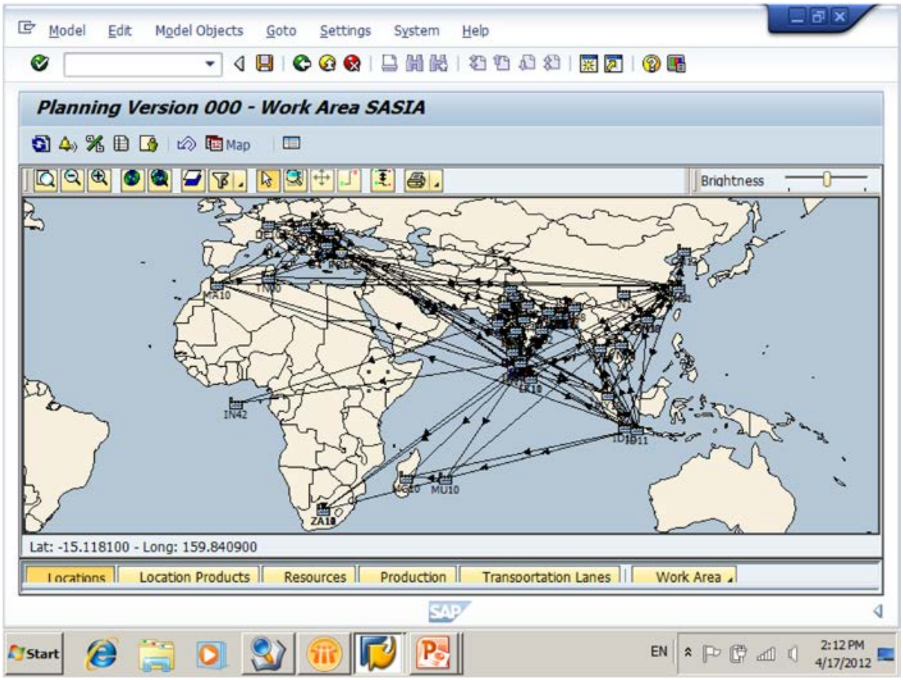


Figure 9.
Manufacturing network of coast company

produce the sporadic MTO products from other LCUs through aggregating these small lot size order products into large volume MTS products, and then use the economic scale of MTS production to produce them. Therefore, production cost and yarn color difference can be reduced, and quality is increased.

CSUs are located in regions near customers. These units are customer-oriented, and equipped with small-scale equipments. The aim of CSUs is to satisfy the customized, multiple varieties and small lot size requirements. These units mainly produce MTO products and some MTS products from other BPUs and LCUs.

Considering the feature of demand, Coats adopts a mixed production plan decision mode, which combines the centralized and decentralized decisions. The operations mechanism of this method can be depicted as follows. The factory in Shenzhou is responsible for the centralized plan making for all other manufacturing units based on the forecasted demand, and other manufacturing units are responsible for their own local plan making based on local customer orders. Every month, the headquarters' factory in Shenzhou holds a sale and operation plan meeting, in which managers from departments of sale, production and materials together with supplier representatives first make a plan review. Based on the review of the last five months' sale, supply and demand, a forecasting for future five months' demand is then made. Then the centralized plan based on forecasted demand will be determined and sent to other manufacturing units. Other manufacturing units located in Shanghao, Qingdao and Dalian then make their local plan based on their local customer orders. So, the production plan of each manufacturing unit is a summation of forecasted demand and order demand plans.

During the process of production plan making, IT plays an important role. Communication and online information sharing are necessary. The detail of IT support the PPC is described in the next subsection.

5.4 Information systems of PPC

There are three application information systems for supporting Coats business:

(1) SAP R/3: this is ERP software developed by SAP. This system handles with the daily business operations, such as production, purchasing, inventory, distribution, financial, etc. In Coats, all production units use the same ERP system, and they can share information each other;

(2) advanced planner and optimizer (APO): this software is also developed by SAP, which supports the supply-chain planning and scheduling, such as sale forecasting, planning, scheduling and global available-to-promise (GATP): APO has powerful functions in optimizing plans, which can use the ERP data and make plans for the whole supply chain network of Coats. Meanwhile, APO has good graphic user interface, it can easily show the optimization results; and

(3) order frequency analysis-capacity requirements analysis (OFA-CRA): this software was developed by Coats itself and it is one intelligent analysis system. Combining the more than 200 years' yarn manufacturing experience and the marketing information, it can give out production and inventory strategies for MTO and MTS products, and forecast equipment requirement according to the capacity of equipment.

To find out how and to what extent information systems support the coordination and collaborative planning process in Coats, during the interview, we asked production manager and information engineers questions on the implementation effect of information systems. They all confirmed that since the adoption of these information systems, work efficiency has been improved, and the accuracy of production plan also has increased. Moreover, coordination and information sharing ability have been largely strengthened. "Especially the APO system, it can offer us a lot of help in optimizing plans. We can easily obtain supply-chain plans in a short time. Without APO, it is impossible for us to run so global and networked manufacturing company," the production manager confidently told us.

5.5 PPC process

The work of PPC of Coats is realized by the supply-chain management software APO. Using advanced capacity analysis and scheduling method based on bottleneck analysis, and optimization tools developed by ILOG Company, APO can offer optimization algorithms and heuristic algorithms which are not applied in traditional MRP system, which is very suitable for supporting entire supply-chain planning and business operations.

Nowadays, in Coats, APO manages and optimizes ten factories' supply chains in nine countries. Using demand planning (DP) to control more than 40,000 factories and products combination, using supply-chain network planning (SNP) heuristic (rule-based) to handle with more than 8,500 factories and products combination; using SNP to optimize (cost-based) middle-term plan for more than 4,000 products; using PPDS (production planning and detail scheduling) to arrange more than 250 orders each day.

OFA system monthly receives sale data from European countries. Then through collection and analysis, it decides which products are MTS products and gives out the corresponding inventory strategy, and decides which products are produced at LCUs and which are produced at BPUs. MTO products are basically produced at local CSUs.

Figure 10 is the PPC system structure of Coats company.

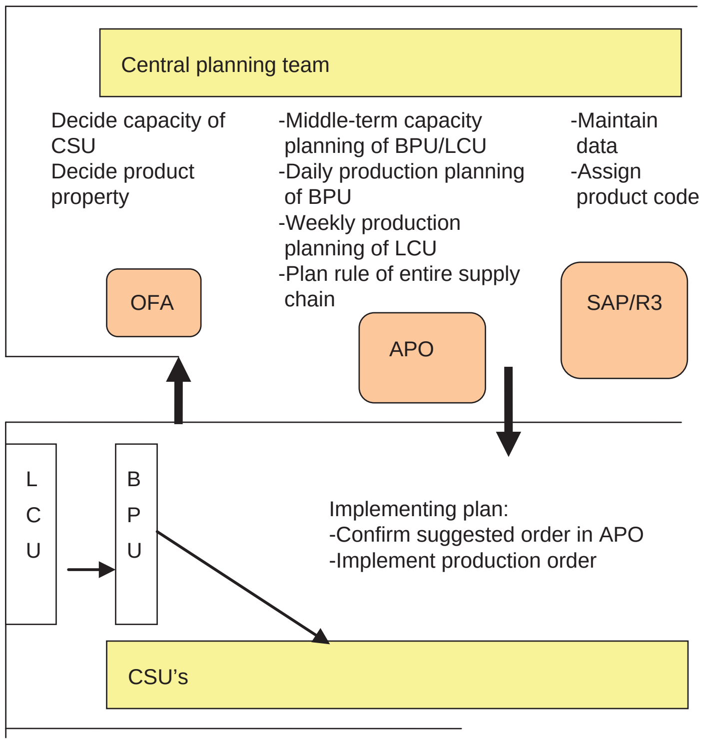


Figure 10. Integrated production planning and control system structure of coats company

Figure 10 shows the two parts of the production planning activities. The up level activities are conducted by central planning team and the low level activities are done by local production units, i.e. LCU, BPU and CSU. All activities are implemented by OFA, APO and SAP.R3 systems.

First, demand plan module in APO makes forecasting based on the historical data from SAP R/3 system, which uses different forecasting models, such as smoothing average, exponential smoothing, Holt-winters and Croston models. DP module can automatically fit models. DP produces weekly forecasting with a horizon of 12 months. These forecasting data will be transferred to SNP module.

Then, SNP module will based on normal accuracy requirement determine plans of production, purchasing and distribution. Using SNP algorithm, APO can then produce material requirements, these requirements consider the lot size, transportation cycle, etc. suppliers factors. Similarly, SNP also determines production plan of BPUs and purchasing plan for LCUs. At last, PP/DS module further considers the problems which SNP has not considered and then makes a more detail production plan with time accuracy up to seconds. All these plans will be transferred to SAP R3 for implementation.

Figure 11 is the workflow of PPC system at Coat. The PPC system is divided into 13 steps. From first to third step is DP; from forth to sixth step is SNP; from seventh to twelfth step is PPDS. The last step is implement production order by SAP R3.

Figure 12 is input data of APO for sale forecasting. The module can use different forecasting models, such as moving smoothing average, causal regression, Croston

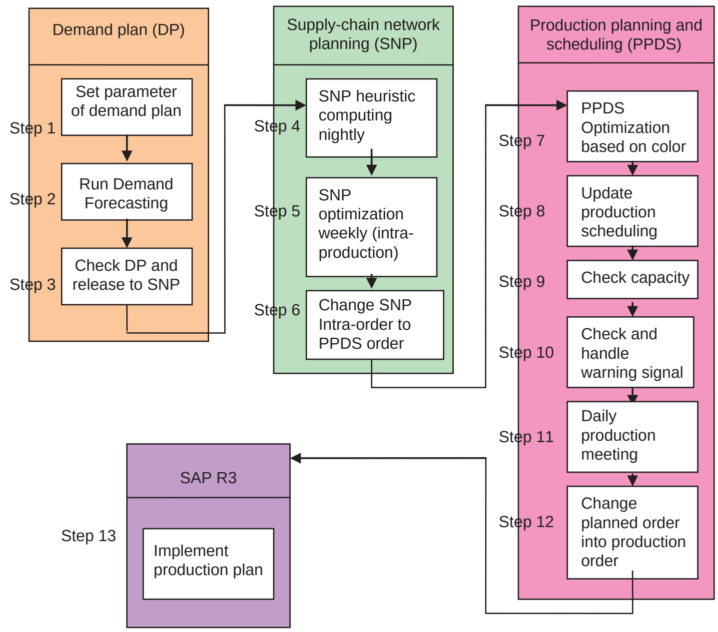
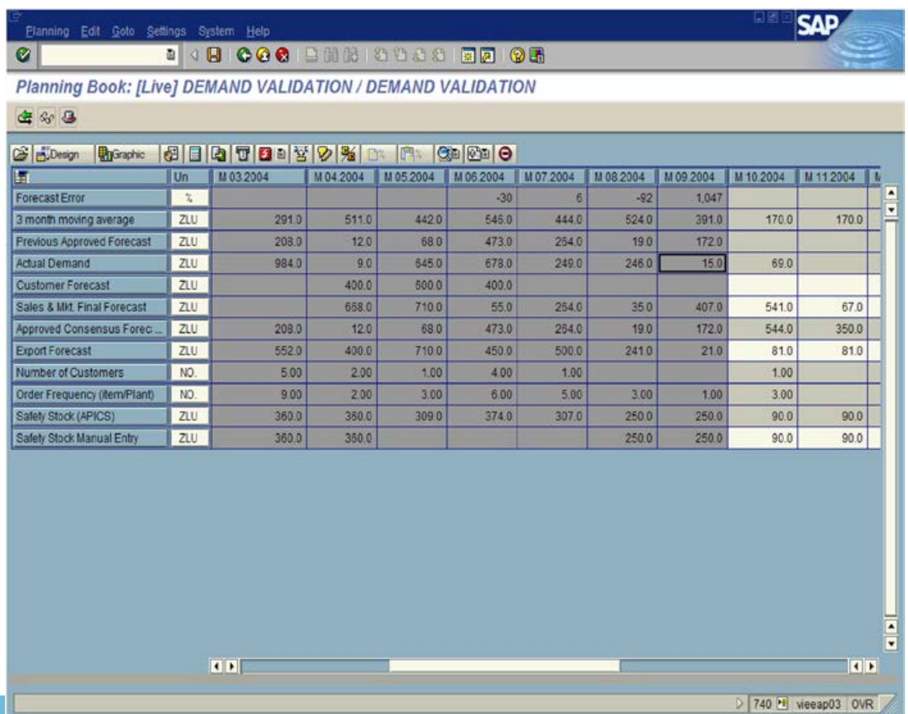


Figure 11.
Workflow of production plan of coats company



	Un	M 03.2004	M 04.2004	M 05.2004	M 06.2004	M 07.2004	M 08.2004	M 09.2004	M 10.2004	M 11.2004
Forecast Error	%				-30	6	-92	1,047		
3 month moving average	ZLU	291.0	511.0	442.0	546.0	444.0	524.0	391.0	170.0	170.0
Previous Approved Forecast	ZLU	208.0	12.0	68.0	473.0	264.0	19.0	172.0		
Actual Demand	ZLU	984.0	9.0	645.0	678.0	249.0	246.0	15.0	69.0	
Customer Forecast	ZLU		400.0	500.0	400.0					
Sales & Mkt. Final Forecast	ZLU		668.0	710.0	55.0	264.0	35.0	407.0	541.0	67.0
Approved Consensus Forec...	ZLU	208.0	12.0	68.0	473.0	264.0	19.0	172.0	544.0	350.0
Export Forecast	ZLU	552.0	400.0	710.0	450.0	500.0	241.0	21.0	81.0	81.0
Number of Customers	NO.	5.00	2.00	1.00	4.00	1.00			1.00	
Order Frequency (item/Plant)	NO.	9.00	2.00	3.00	6.00	5.00	3.00	1.00	3.00	
Safety Stock (APICS)	ZLU	360.0	360.0	309.0	374.0	307.0	250.0	250.0	90.0	90.0
Safety Stock Manual Entry	ZLU	360.0	360.0				250.0	250.0	90.0	90.0

Figure 12.
Sale forecasting confirmed result

model and seasonal forecasting model, etc. the system can easily and visually shows forecasting result using diagram, such as Figure 13 is a forecasting result diagram.

Figure 14 is the interface of APO SNP result. In the module of SNP, the system can visually show the plan result of procurement for different suppliers. Figure 15 is the result of detail scheduling generated by APO of the production planning system.

5.6 Efficiency improvement after implementing integrated PPC system at Coats company

Since the implementation of integrated PPC system at Coats, new competition advantage and efficiency has been improved. Notable effects can be summarized as followings:

(1) Optimization of the relationship between supply and demand: because of the reengineering of supply-chain structure, the roles of different operation units at the entire supply chain become clearer; the relationship between supply and demand becomes more balancing. Consequently, coordination ability of entire supply chain has increased, and the operations cost has decreased.

(2) Inventory reduction of entire supply chain: the application of APO system has effectively solved the problem of production bottleneck, increased the accuracy of demand forecasting, and decreased the unnecessary inventory, so the inventory cost has been cut down by 20 percent.

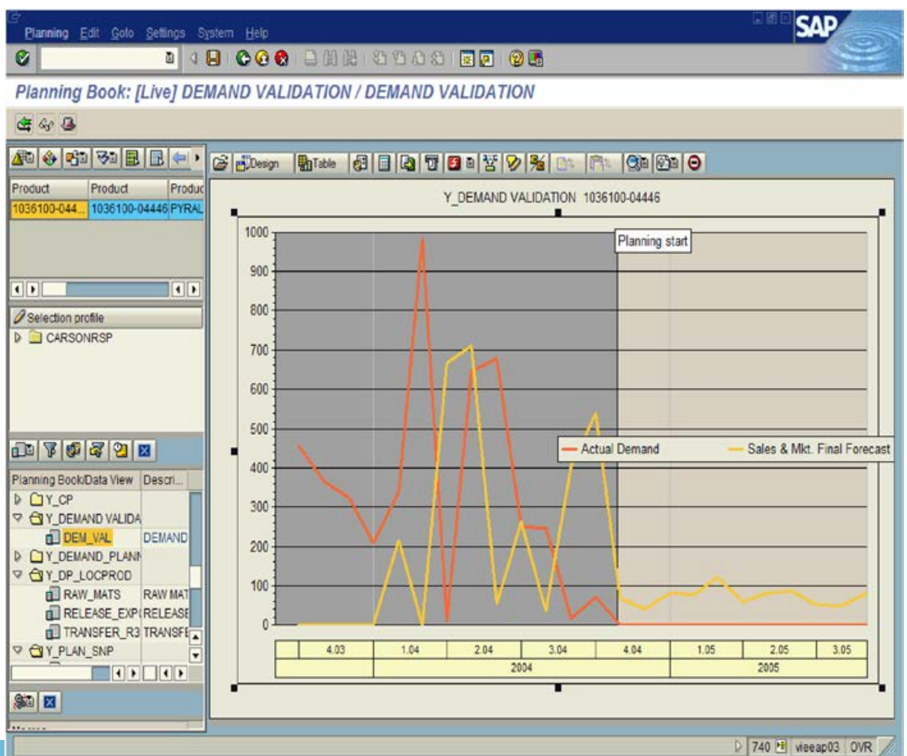


Figure 13.
Sale forecasting interface

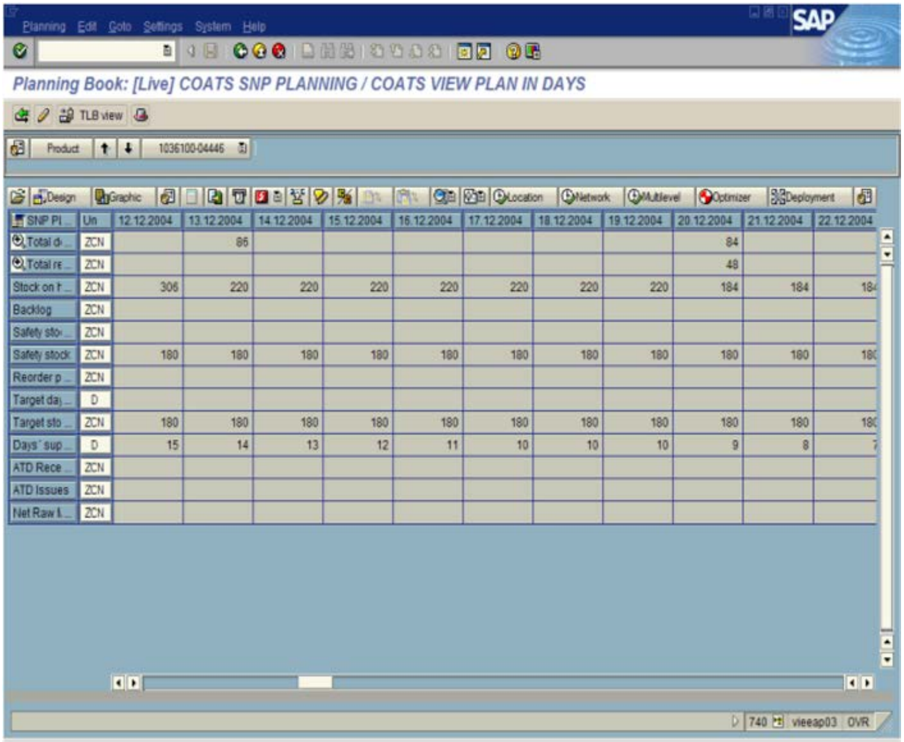


Figure 14.
Supply network planning generated

(3) Improvement of customer satisfaction degree: the application of APO system has speeded up the responsiveness to customer order, and the application of ATP/GATP has improved the commitment of order delivery and increased the customer order fill rate (COFR). Consequently, the market competition ability of the company has been enhanced.

(4) Optimization of production process and shortening of cycle time. The application of PPDS not only has reduced the work of planners at Coats, but also has made the plan more accurate and reduced the waiting time in production process, as result, 50 percent cycle time has been reduced.

5.7 Findings and implications of case study

Based on the case study of Coats, we summarize propositions which integrate our findings and implications. These propositions describe the relationships among IT support ability, OEM-CMs collaboration level, quality of collaborative planning and OEM operations performance:

P1. IT support ability of OEM-driven networked manufacturing has positive relationship with the OEM-CMs collaboration level, that is to say, IT support can strengthen the relationships between OEM and CMs.

This proposition is verified by our case study. The experience of Coats shows that with the support of information technologies, the relationships between Coats and suppliers

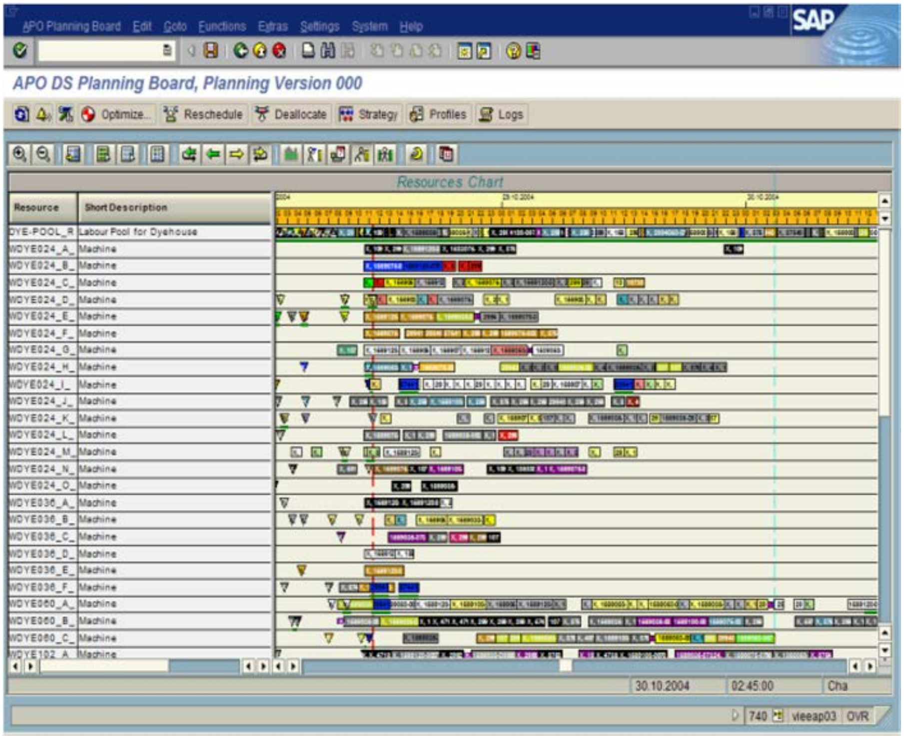


Figure 15. Production planning and detail scheduling

have been largely improved. This proposition also can be evidenced by other research literature. Narasimhan and Nair (2005) empirically show that information sharing can benefit the strategic alliance formation of supply chain. Similarly, Cheng (2011) also empirically shows that there is a connection between inter-organization relationships and information sharing. So, Coats experience and theories support our viewpoint, i.e. the higher IT support ability of OEM-driven networked manufacturing, the better the relationships between OEM and its collaborators (e.g. CMs):

P2. Transparent information and real-time information sharing are prerequisites of collaborative production planning in OEM-driven networked manufacturing system.

This proposition is observable in our case study. In Coats, all SOPs are made through online discussion and communication by information systems with partners (suppliers and different manufacturing units around the world). Without information sharing, it is impossible for Coats to implement the production plans and control the activities in so dispersed plants and distribution channels. Other literatures also support our proposition. Webster *et al.* (2000) emphasize the importance of decision support systems in scheduling of outsourcing manufacturing. Similarly, Mourtzis (2011) also stresses the necessity of facilitating information sharing to support cooperative planning of extended manufacturing enterprise. So, Coats experience and theories support our viewpoint, i.e. in order to make collaborative production planning in

OEM-driven networked manufacturing system, transparent information and real-time information sharing are necessary:

P3. The quality level of collaborative planning made by OEM with its CMs positively impacts OEM operations performance.

This proposition is also observable in our case study. During our interview with the production manager and information engineers in Coats, they often told us the contribution of collaborative planning to the business success of Coats. The production manager pointed out that the advantages of Coats are global production capacity, logistics, excellent quality and low cost. But all these advantages are achieved by collaborative planning. Our viewpoint can be supported by other researches. McCarthy and Golocic (2002) through case study show that implementing collaborative forecasting with partners in supply chain can yield substantial improvement in company and supply-chain performance. Hadaya and Cassivi (2007) also empirically show that joint collaboration planning actions possibly and significantly impact the company flexibility. So, Coats experience and theories support our proposed viewpoint, i.e. the higher the quality level of collaborative planning made by OEM with its CMs, the better the OEM operations performance.

6. Conclusions

In nowadays information era, productivity improvement is strongly dependent on the utilization of IT. It is impossible to effectively operate the networked manufacturing systems without IT supporting, especially the global manufacturing supply-chain systems. This paper discusses the integrated PPC technologies applied in OEM-driven networked manufacturing system. Basic principle and technologies of integrated PPC are first discussed and then one application case in an international OEM manufacturing company is demonstrated.

Our study contributes to a better understanding of IT support the operation of OEM-driven networked manufacturing. First, an integration framework of integrated PPC system is proposed. The framework extends the traditional MRP, adds more functions for connecting internal and external units of the manufacturing firm, such as demand information coordination platform, production coordination center, order tracking system, etc. Second, a multi-layer coordination idea is built in the framework, i.e. demand information coordination layer, production planning coordination layer and production control coordination layer. Through this multi-layer coordination integration idea, PPC are closely integrated together. Third, new production control strategies are proposed, such RFID-based order tracking and information sharing system, multi-echelon coordination control mechanism. These new thoughts of production control largely enhance the synchronization of inter-organizational operations of OEM supply chain. Fourth, experience implications learned from a case study have been formed into several propositions, which will be helpful for theory development and practice.

The light that this study sheds on the implications of IT support the operation of OEM-driven networked manufacturing fosters the notion that it is valuable to develop and apply integrated PPC system. Both theory and case study show that firms should pay more attention to information sharing and communication with partners and utilize advanced information technologies to synchronize the operations of partners.

The future research can follow different directions. First, a questionnaire collection method can be used to examine more other OEM companies and test the propositions summarized from the case study in Section 5. Second, the framework model proposed in this paper can be refined to be more detail and concrete, and more application methods of these technologies can be extended. Third, discussion on the application strategies of other new technologies, such as cloud computation and Web2.0 technologies in OEM supply chain will be a challenge direction.

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