Computers & Industrial Engineering 57 (2009) 61–72

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Multi-tier and multi-site collaborative production: Illustrated by a case example of TFT-LCD manufacturing

Wu-Lin Chen [a], Chin-Yin Huang [b,*], Yin-Chieh Lai [c]

[a] Department of Computer Science and Information Management, Providence University, Taichung, Taiwan
[b] Department of Industrial Engineering and Enterprise Information, Tunghai University, P.O. Box 985, Taichung 407, Taiwan
[c] i2 Technologies Taiwan, Inc., RM 1510, 15FL, NO. 333, Sec. 1 Keelung Road, Taipei 110, Taiwan

ARTICLE INFO

Article history:
Available online 6 September 2008

Keywords:
Distributed production planning
Factory Planner
Multi-agent system
Protocols
Supply network

ABSTRACT

To seek collaboration with other partner enterprises becomes an inevitable strategy in today's highly dynamic and complex business. Production planning over a collaborative network relies on resolving three challenges: (1) different objectives and autonomy of partner enterprises, (2) communication and coordination among the enterprises, and (3) planning over multiple tier enterprises and multiple local plants (sites) inside an enterprise.

To resolve the challenges, this paper proposes a distributed production planning system for a multi-tier and multi-site production system by combining agent technology with advanced planning and scheduling (APS) system. Two types of agents are designed: one for each tier enterprise (tier agent) and the other for each local plant (site agent) inside a tier enterprise. While a tier agent is responsible for finding a suitable plan for the demand orders by transmitting messages through designated protocols with its downstream and upstream tier agents, a site agent is designed for detailed production schedules for its local plant by interacting with its tier agent and its APS system. This paper has developed various protocols to integrate the partner tier and site agents to construct a distributed collaborative production system.

This paper takes TFT-LCD manufacturing as an illuminative example to demonstrate the feasibility of the proposed multi-tier and multi-site collaborative production. The results show the feasibility of synthesizing multiple production plans over multiple enterprises and multiple production sites. Within the planning system, each company maintains their autonomy of production decision. Besides, the supply network is reconfigurable because the participated companies only need to comply with the protocols without changing their local legacy production planning systems.

1. Introduction

Distributed collaborative production among dispersed yet cooperative partnered companies is considered an effective approach to grasp transient opportunities in a highly uncertain market without investing much in assets (Huang & Wu, 2003; Huang, Huang, & Liu, 2008). To support operations of such production relies on system architectures such as virtual enterprises, extended enterprises, or distributed production systems (Jagdev & Browne, 1998; Soares, Azevedo, & de Sousa, 2000; Jagdev & Thoben, 2001; Lima, Sousa, & Martins, 2006). Within a distributed collaborative production system, the participated companies should be autonomous and be able to rapidly form (reconfigure) a supply network with other companies to meet the dynamic market demands (Lima et al., 2006).

Though the aforementioned concept has been studied by approaches of agent technology in literature (e.g. Fox, Barbuceanu, & Teigen, 2000; Huang & Nof, 2000; Lu & Yih, 2001; Lima et al., 2006; Huang et al., 2008) it still needs an application to specify the required elements and to show how the concepts can be deployed and integrated within a production planning environment. Especially when each local company has its own legacy production planning system, to integrate those legacy systems into a reconfigurable multi-enterprise collaborative network with the respect of each legacy system's autonomy is not simple.

The objective of this research is to develop a reconfigurable distributed production system with a background of multi-tier and multi-site supply network. Additionally, this research intends to deploy the system into a multi-enterprise TFT-LCD manufacturing environment. Today, multi-tier is a standard structure for a supply network (Lambert & Cooper, 2000). Upstream and downstream companies are engaged in a multi-tier structure of a supply network. However, little research has explored further to integrate the dispersed resources on multi-sites of the engaged companies that actually execute production. Fig. 1 shows a structure of

* Corresponding author. Tel.: +886 4 23594319x141; fax: +886 4 23591756.
E-mail addresses: wlchen@pu.edu.tw (W.-L. Chena), huangcy@ie.thu.edu.tw (C.-Y. Huangb), anthony_lai@i2.com (Y.-C. Laic).

0360-8352/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cie.2008.08.012

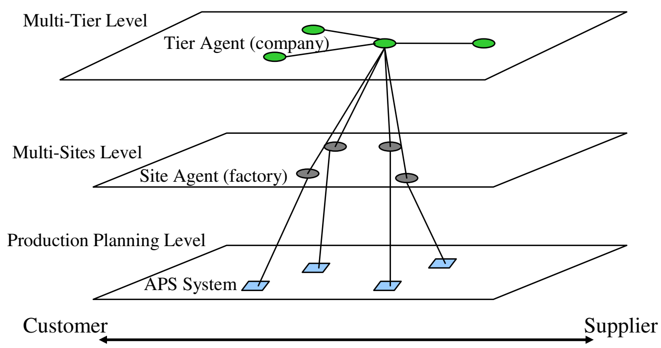

Fig. 1. Structure of multi-tier and multi-site production.

multi-tier and multi-site production planning. The multi-tier level indicates companies that are in different tiers of a supply network. The multi-site level indicates distributed factories (resources) under a single company. The production planning level indicates that each factory's production is guided by an Advanced Planning and Scheduling (APS) system. To make the structure reconfigurable relies on the ability to let companies and factories quickly connect on or disconnect from the supply network. This research develops various communication protocols, tier agents, and site agents to handle the issue of connection/disconnection, i.e. reconfiguration. Additionally, autonomy of local companies is designated to tier agents, site agents, and APS systems. It is noted that this research does not intend to develop further advanced scheduling methods. This research assumes that each of the participating companies has its local legacy production planning system to collaborate with other companies.

The rest of the paper is organized as follows: Section 2 presents literature regarding the background and techniques used in this research. Multi-tier and multi-site production planning relies on agents (tier agents and site agents) and protocols. Design of agents and protocols is presented in Section 3. An illustrative TFT-LCD manufacturing example is provided in Section 4. Finally, concluding remarks and future research are addressed in Section 5.

2. Related works

2.1. Multi-tier supply network and multi-enterprise collaboration

The concept of supply chain has been expanded to multi-tier supply networks (Christopher, 1998; Swaminathan, Smith, & Sadeh, 1998; Lambert & Cooper, 2000). Participated companies in a multi-tier supply network may be component suppliers or outsourcers who provide resource capacities. Several factories may locate in the same tier to add value for the product production/service. A company in a tier has to collaborate with upstream and downstream tier companies, so the whole supply network may deliver superior values to the customers (Christopher, 1998). Though each company in a supply network is demanded to view the performance of the whole supply network as its own performance, rare cases sustain the idea. Because of the uncertain market demands, companies in a multi-tier supply network usually act as autonomous contractors. Their appearances on a supply network are temporary. Therefore, their collaboration with other partners is conditional. How to quickly build a collaborative supply network with a low cost becomes an issue.

Nof, Morel, Monostori, Molina, and Filip (2006) specify a migration from local control to multi-enterprise collaboration. They also pinpoint e-work (including agents, protocols, networking, integration, etc.) as the essential tool to construct multi-enterprise collaboration.

2.2. Multi-site production planning

Bullinger, Faehnrich, and Laubscher (1997) specify the needs to collaborate multi-site resources to react to the constantly changing markets. They identify the needs of making plans to coordinate the interactions between production activities on multiple sites. There are two main questions to be resolved in multi-site production planning: "who does production?" and "by when the product must be produced? Guinet (2001)" Besides, Sauer Sauer (2006) regards the framework of multi-site production planning as two layers of planning: global scheduling and local scheduling. The first layer mainly focuses on planning intermediate products then deciding which site to produce. The second layer is for site planning to dispatch resources and machines for a certain manufacturing process.

2.3. Agent technologies in distributed production

Agent technologies have been applied in handling various production or manufacturing problems. For example, Jia, Ong, Fuh, Zhang, and Nee (2004) take the advantages of agent technologies and develop a fault-tolerable and re-configurable system for collaborative design and manufacturing. Since this research only concerns production plans of distributed factories, only agent technologies that are associated are reviewed.

Shaw Shaw (1987) develops one of the earliest studies to apply agent technologies in distributed production planning. Agents and protocols are the two most important factors for forming an agent-based production network (Huang & Nof, 2000). Agent technologies are suitable for distributed production planning, because of their two key characteristics: (1) autonomy and (2) loosely coupled connections through protocols. Both characteristics correspond with the autonomy and ability of reconfiguration for distributed production planning proposed by Lima et al. (2006).

Additionally, Peng et al.(1999) propose to integrate enterprise's information systems to transmit information and knowledge by communication and cooperation among multi-agents. Ferber Ferber (1999) proposes an agent-based production planning system. He suggests that a production planning agent can be aware of environmental changes, and be capable of executing operations based on these changes. Lu and Yih (2001)) design an agent-based collaboration production control framework. The mechanism of their work makes use of some production factors to generate scheduling and dispatching rules under the collaborative manufacturing environment.

Sauer (2006) considers that the features of multi-agents are to satisfy dynamic and distributed production systems and logistics networks. Furthermore, he enhances the organizational structure of a distributed production network and separates a supply chain into five tiers: enterprises, local plants, workstations, resource groups, and resources. He suggests that under the production planning phase, not a single tier planning needs to be considered but many tiers planning requires to be considered based on a certain order. Zhang, Anosike, Lim, and Akanle (2006) integrate agent-based technologies with e-manufacturing to make a dynamic integrated manufacturing system more responsive to the environment.

2.4. Advanced planning and scheduling

Advanced Production and Scheduling (APS) has been considered an effective approach to generate an optimal production plan by considering a wider range of constraints including availability of raw material, capacity of operators and machines, service level (in terms of meeting order due dates), safety stock level, cost, sale demand, etc. For example, Jia, Nee, Fuh, and Zhang (2003) proposed a modified genetic algorithm to schedule distributed production systems which consist of multiple factories, machines, and jobs