Chapter 44
Modeling and Synthesis of Supply Chain Networks Using High-Level Petri Nets

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ABSTRACT

This chapter presents a systematic methodology for modeling and control of supply chain networks, especially focusing on formal representation and control synthesis aspects. A supply chain is represented as a discrete event dynamic system. The use of high-level Petri nets is proposed to formulate event related rules commonly seen in supply chains and analyze cause-effect relationships between events. Petri nets have been successfully introduced as an effective tool for describing control specifications and realizing the control in automated supply chain processes. The extended net representation of the productive task flows can provide more synthetic specifications for consistent management and control of supply chain systems by a top-down refinement methodology. Software implementation is described to simulate and control real supply chain processes.

INTRODUCTION

This chapter presents a systematic methodology for modeling and synthesis of supply chain networks, especially focusing on formal representation and control aspects. In the last two decades, manufacturing industry has experienced some notable changes from flexible manufacturing through lean manufacturing towards agile manufacturing, to seek to produce a high level of throughput with a minimum of inventory, lowering waste and enhancing productivity on the factory floor. The aim of Just-In-Time control is that in-process inventories have to be as small as possible, which means that at the exact time when a request is received by a machine, the required material and part has to be available in its input buffer, ready to be pushed. This kind of optimization can only result from a real-time synchronization between the operations in the manufacturing system (Suda, 1989). As production systems move toward more flexible for smaller batch sizes and shorter product cycles to cope with highly demanding customer

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orders, more advanced control systems are needed. To develop optimized architectures to control and supervise the production system by organizing the cooperation between facilities that are geographically distributed, the system architecture has changed from centralized processing to distributed processing in order to meet the requirements of lean and agile software development. In place of early process oriented approach, following the data-oriented approach, in 90s the object-oriented approach was highlighted. Supported by the feasibility of novel distributed control architectures (Duffee & Prabhu, 1996; Zamei et al., 1997), advanced large and complex production systems have a holonic or self-organizing and self-adaptive hierarchical structure like bionic systems. According to not only abilities of computers and networks but also needs from the business environment based on the Internet popularization, the service oriented architecture has been successfully applied to supply chain management, order entry system, etc. However, failures may occur due to an inadequate specification of services with particular real-time requirements in a supply chain. In this context, a formal approach is strongly required to treat the integration of distributed system components loosely coupled in a heterogeneous environment such as a supply chain network. (Komoda, 2006; Vollman et al., 2004; Yu et al., 2014; Zeng et al., 2014 ; Zhang et al., 2004).

Yasuda is the first that originated conceptual and synthetic researches towards realization of non-centralized systems (Yasuda & Mori, 1974). Non-centralized systems or center-less systems are featured as self-coordinated systems without any main agent or any centralized decision-making mechanism against unpredicted, emergency situations. In supply chains, because each facility has some decision making abilities with respect to input and output of productive items as an independent agent, non-deterministic decision or task selection for cooperation should be essentially taken into account. So, the supply chain management system is one of typical examples of non-centralized systems, which can be commonly found in biological organisms and societies, although, in real biological systems, non-centralized and centralized systems alternate with each other as the system evolves. In this context, web services protocol through Internet can afford to provide communication tools for non-centralized realization of supply chain systems.

This chapter discusses the specification problem for real-time monitoring and control of different productive processes involved with distributed supply chains, aiming at realizing non-centralized control. Petri nets are a modeling tool for describing information processing systems characterized as being concurrent, asynchronous and nondeterministic, based on discrete events and state change. Beside the mathematical formalism, it can simulate the dynamic behaviors of the system graphically through the flow of tokens. Thus, a Petri net approach can be applicable to obtain an easily understandable and systematic procedure. In the chapter, the specification task is based on the characterization of automated supply chain processes as a discrete event system, and then the use of high-level extended Petri nets based on composed condition-event nets is proposed to formulate event related cause-effect rules commonly seen in supply chains, aiming to synthesize strategic and tactical operations in the hierarchical distributed control of supply chains in order to react events in a real-time manner. Because Petri nets can provide a structural design methodology in production systems through a top-down and/or bottom-up relationship between abstract specification and practical implementation (Moreira & Basilio, 2014), (Yasuda, 2011), a unified Petri net based methodology is proposed to design and implement distributed control software corresponding to the hierarchical structure of the overall supply chain system. Software implementations are also described to simulate and control real supply chain processes.