

# Chapter 23

## Petri Net Model Based Design and Control of Robotic Manufacturing Cells

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### ABSTRACT

*The methods of modeling and control of discrete event robotic manufacturing cells using Petri nets are considered, and a methodology of decomposition and coordination is presented for hierarchical and distributed control. Based on task specification, a conceptual Petri net model is transformed into the detailed Petri net model, and then decomposed into constituent local Petri net based controller tasks. The local controllers are coordinated by the coordinator through communication between the coordinator and the controllers. Simulation and implementation of the control system for a robotic workcell are described. By the proposed method, modeling, simulation, and control of large and complex manufacturing systems can be performed consistently using Petri nets.*

### INTRODUCTION

Manufacturing systems, where the materials which are handled are mainly composed of discrete entities, for example parts that are machined and/or assembled, are called discrete manufacturing systems. Due to its complexity, manufacturing system control is commonly decomposed into a hierarchy of abstraction levels: planning, sched-

uling, coordination and local control. Each level operates on a certain time horizon. The planning level determines at which time each product will be introduced in the manufacturing system. The scheduling level produces a sequence of times for the execution of each operation on each machine or a total ordering of all the operations. The coordination level updates the state representation of the manufacturing system in real-time, supervises it and makes real-time decisions. The local control level implements the real-time

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control of machines and devices etc., interacting directly with the sensors and actuators. All the emergency procedures are implemented at this level, so real-time constraints may be very hard. At each level, any modeling has to be based on the concepts of discrete events and states, where an event corresponds to a state change (Martinez, 1986), (Silva, 1990).

A flexible manufacturing system is formed of a set of flexible machines, an automatic transport system, and a sophisticated decision making system to decide at each instant what has to be done and on which machine. A manufacturing cell is an elementary manufacturing system consisting of some flexible machines (machine tools, assembly devices, or any complex devices dedicated to complex manufacturing operations), some local storage facilities for tools and parts and some handling devices such as robots in order to transfer parts and tools. Elementary manufacturing cells are called workstations. At the local control level of manufacturing cells many different kinds of machines can be controlled, and specific languages for different application domains are provided; for example, block diagrams for continuous process control and special purpose languages for CNC or robot programming. For common sequential control, special purpose real-time computers named Programmable Logic Controllers (PLCs) are used. PLCs are replacements for relays, but they incorporate many additional and complex functions, such as supervisory and alarm functions and start-up and shut-down operations, approaching the functionalities of general purpose process computers. The most frequent programming languages are based on ladder or logic diagrams and boolean algebra. However, when the local control is of greater complexity, the above kinds of languages may not be well adapted. The development of industrial techniques makes a sequential control system for manufacturing cells more large and complicated one, in which some subsystems operate concurrently and cooperatively. Conventional representation methods based on flowcharts, time

diagrams, state machine diagrams, etc. cannot be used for such systems.

To realize control systems for flexible manufacturing cells, it is necessary to provide effective tools for describing process specifications and developing control algorithms in a clear and consistent manner. In the area of real-time control of discrete event manufacturing cells the main problems that the system designer has to deal with are concurrency, synchronization, and resource sharing problems. For this class of problems, Petri nets have intrinsic favorable qualities and it is very easy to model sequences, choices between alternatives, rendezvous and concurrent activities by means of Petri nets (Reisig, 1985). When using Petri nets, events are associated with transitions. Activities are associated to the firing of transitions and to the markings of places which represent the states of the system. The network model can describe the execution order of sequential and parallel tasks directly without ambiguity (Murata, et al. 1986), (Crockett, et al. 1987). Moreover, the formalism allowing a validation of the main properties of the Petri net control structure (liveness, boundedness, etc.) guarantees that the control system will not fall immediately in a deadlocked situation. In the field of flexible manufacturing cells, the last aspect is essential because the sequences of control are complex and change very often. Furthermore, a real-time implementation of the Petri net specification by software called a token player can avoid implementation errors, because the specification is directly executed by the token player and the implementation of these control sequences preserves the properties of the model (Bruno, 1986). In this approach, the Petri net model is stored in a database and the token player updates the state of the database according to the operation rules of the model. For control purposes, this solution is very well suited to the need of flexibility, because, when the control sequences change, only the database needs to be changed (Silva, et al. 1982), (Valette, et al. 1983).

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