Chapter 13
Design of Optimized Petri Net Supervisors for Flexible Manufacture Systems Based on Elementary Siphons

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ABSTRACT

This chapter focuses on the deadlock prevention problems in Flexible Manufacturing Systems (FMS), and the major target is to design more excellent controllers that lead to a more permissive supervisor by adding a smaller number of monitors and arcs than the existing ones in the literature for the design of liveness-enforcing Petri net supervisors. The authors distinguish siphons in a Petri net model by elementary and dependent ones. For each elementary siphon, a monitor is added to the plant model such that it is invariant-controlled without generating emptiable control-induced siphons, and the controllability of a dependent siphon is ensured by changing the control depth variables of its related elementary siphons. Hence, a structurally simple Petri net supervisor is achieved. Based on the previous work, this chapter explores two optimized deadlock prevention approaches based on elementary siphons that can achieve the same control purpose and have more excellent performance.

1. INTRODUCTION

Two deadlock prevention policys are proposed in this chapter based on the structural analysis of Petri nets for some representative classes of Petri nets, where deadlocks are related to the unmarked siphons. In policy 1, the problem that the competition for limited resources can produce deadlocks in a Resource Allocation System (RAS) is investigated. The deadlock avoidance policy of Conjunctive/Disjunctive Resources Upstream Neighborhood is incorporated into the elementary siphon-based deadlock prevention policy to achieve better control performance for a class of Petri nets, called System of Simple Sequential Processes with Resources (S^3PR). The proposed

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policy 1 can allocate the tokens in the control places reasonably to guarantee the absence of deadlock states, and a monitor is added to each elementary siphon to ensure that all elementary siphons in the S^3PR net are invariant-controlled. In policy 2, by rearranging the positions of output arcs of added monitors, an optimized deadlock prevention policy based on elementary siphons is proposed for a class of Petri nets, called System of Simple Sequential Processes with Multiple Resources (S^3PMR). Monitors are only added to elementary ones such that no emptiable control-induced siphons are generated and all siphons in it are invariant-controlled to obtain a more permissive liveness-enforcing supervisor. The proposed policy 2 ensures the max-controlled property of the controlled system. Hence, two deadlock-free liveness-enforcing supervisors with simple structure and more permissive behavior are obtained. The deadlock prevention policys proposed in this chapter can usually lead to a highly permissive supervisor by adding a small number of monitors and arcs.

The rest of this paper is organized as follows. Section 2 reviews the preliminaries of Petri nets that are used throughout this chapter. Two deadlock control policys are proposed in Section 3, section 3 also introduces manufacturing examples to illustrate the applications of the proposed policys. Finally, the last section concludes this chapter.

2. PRELIMINARIES

2.1. Petri Nets

The following theories are from (Ezpeleta, Colom & Martinez, 1995; Banaszak & Krogh, 1990; Barkaoui & Pradat-Peyre, 1996; Chu & Xie, 1997; Hsien & Chang, 1994; Zhou, Dicesare & Desrochers, 1992; Zhou & Dicesare, 1991; and Zhou, Dicesare & Rudolph, 1992).

A Petri net is a four-tuple $N=(P, T, F, W)$ where P and T are finite and non-empty. P is the set of places and T is the set of transitions with $P\cup T\neq\Phi$; and $P\cap T=\Phi$. $F\subseteq(P\times T)\cup(T\times P)$ is called the flow relation or the set of directed arcs. $W:F\rightarrow N$ is a mapping that assigns a weight to any arc, where N=$\{0, 1, 2, \ldots\}$. $N=(P, T, F, W)$ is ordinary, denoted as $N=(P, T, F)$, if $\forall f\in F$, $W(f)=1$. Unless otherwise stated, we consider only ordinary Petri nets in this chapter. Incidence matrix (N) of net N is a $|P|\times|T|$ integer matrix and $(N)(p, t)=W(t, p)-W(p, t)$. The preset of a node $x\in P\times T$ is defined as $^\bullet x=\{y\in P\cup T|(y, x)\in F\}$. While the postset of a node $x\in P\cup T$ is defined as $x^\bullet=\{y\in P\cup T|(x, y)\in F\}$. This notation can be extended to a set of nodes as follows: given $X\subseteq P\cup T$, $^\bullet X=\cup_{x\in X}{}^\bullet x$ and $X^\bullet=\cup_{x\in X} x^\bullet$. A marking is a mapping $W:F\rightarrow$ N.

The pair (N, M_0) is called a marked Petri net or a net system. The set of markings reachable from M in N is denoted as $R(N, M)$. (N, M_0) is bounded if $\exists\, k\in$N, $\forall M\in R(N, M_0)$, $\forall\, p\in P$, $M(p)\leq k$ holds. A transition $t\in T$ is enabled under M, denoted by $M(t\rangle$, if $\forall p\in{}^\bullet t$: $M(p)\geq 1$. A transition $t\in T$ is live under M_0 if $\forall M\in R(N, M_0)$, $\exists$ M$'\in R(N, M)$, M$'$(t> holds. (N, M_0) is deadlock-free if $\forall\, M\in R(N, M_0)$, $\exists\, t\in T$, $M(t\rangle$ holds. (N, M_0) is live if $\forall\, t\in T$, t is live under M_0.

A string $x_1, x_2, \ldots, x_n$ is called a path of N if and only if $\forall\, i\in\{1,2,..., n-1\}: x_{i+1}\in x_i^\bullet$, where $\forall\, x\in\{x_1, x_2, \ldots, x_n\}$, $x\in P\cup T$. A simple path from x_1 to x_n is denoted by $SP(x_1, x_n)$. Petri net N is called a state machine if $\forall\, t\in T$, $|{}^\bullet t|=|t^\bullet|=1$. A state machine component $N' = (P', T', F', W')$ of a Petri net $N=(P, T, F, W)$ is a state machine and is a subnet of N consisting of places in P', their presets and postsets, and related arcs. A Petri net is said to be state machine decomposable if it is covered by state machine components.

A nonempty set $S\subseteq P$ is a siphon if $^\bullet S\subseteq S^\bullet$ holds. A siphon is minimal if there is no siphon contained in S as a proper subset. A minimal siphon S is called a strict minimal siphon if $^\bullet S\subset S^\bullet$.