

Chapter 15

Deadlock Prevention for Automated Manufacturing Systems with Uncontrollable and Unobservable Transitions: A Petri Net Approach

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ABSTRACT

Many deadlock prevention policies on the basis of Petri nets dealing with deadlock problems in flexible manufacturing systems exist. However, most of them do not consider uncontrollable and unobservable transitions. This chapter solves deadlock problems in Petri nets with uncontrollable and unobservable transitions. A sufficient condition is developed to decide whether an existing deadlock prevention policy is still applicable in a Petri net with uncontrollable and unobservable transitions, when the policy itself is developed under the assumption that all the transitions are controllable and observable. Moreover, the author develops a deadlock prevention policy to design liveness-enforcing supervisors for a class of Petri nets with partial observability and controllability of transitions. Furthermore, a sufficient condition to decide the existence of a monitor to enforce a liveness constraint is developed.

1. BACKGROUND

There are many policies to design liveness-enforcing supervisor for Flexible Manufacturing Systems (FMS) that are modeled with Petri nets. However, most of them are developed under the assumption that all the transitions are control-

lable and observable. Only a minority of these policies focus on Petri nets with uncontrollable and unobservable transitions. An uncontrollable transition describes a transition that cannot be disabled by a supervisor while an unobservable transition means that its firing cannot be directly measured or detected.

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A class of specifications called Generalized Mutual Exclusion Constraints (GMEC) (Giua et al., 1992; Giua et al., 1993) is defined to design monitors in Petri nets with uncontrollable transitions. In (Basile et al., 1996), monitors are derived from GMEC for a Petri net with uncontrollable transitions. Constraint transformation is necessary if a constraint is uncontrollable (Basile et al., 1996). Iordache et al. propose a deadlock prevention policy based on Supervision Based on Place Invariants (SBPI) (Moody et al., 1995; Moody et al., 2000; Yamalidou et al., 1996) to design supervisors for Petri nets with uncontrollable and unobservable transitions in (Iordache et al., 2002). However, the above policies avoid arcs from monitors to uncontrollable transitions, which will lead to the prohibition of legal behavior.

Monitors are designed to enforce linear constraints of a lived marked graph with uncontrollable and unobservable transitions (Darondeau & Xie, 2003). Constraints are given based on firing vectors. However, the work in (Darondeau & Xie, 2003) cannot be used to preserve liveness.

The theory of regions is adopted to control Petri nets with uncontrollable transitions (Ghaffari et al. 2003)) such that a controlled system with a maximally permissive supervisor is usually obtained. Uzam shows that it is possible to derive an optimal supervisor from a GMEC in Petri nets with uncontrollable transitions (Uzam, 2003). He also shows that it may be legal that there are arcs from monitors to uncontrollable transitions. However, the methods in (Ghaffari et al. 2003) and (Uzam, 2003) do not take unobservable transitions into account. This chapter focuses on deadlock prevention policies of FMS, which aims to deal with deadlocks in Petri nets with uncontrollable and unobservable transitions. Section 3 provides a policy to evaluate the applicability of existing approaches when there are uncontrollable and unobservable transitions. We propose a sufficient condition to decide whether a policy is still applicable to a Petri net. Section 4 provides a policy to

design a liveness-enforcing supervisor for a class of Petri nets with uncontrollable and unobservable transitions. Liveness constraints can be derived from all the emptiable minimal siphons. Monitors are directly designed without constraint transformation based on SBPI. A sufficient condition is developed to decide the existence of a monitor enforcing a constraint.

2. UNCONTROLLABLE AND UNOBSERVABLE TRANSITIONS

Uncontrollable transitions are first proposed in automata (Ramadge & Wonham, 1989). Later, they are introduced into Petri nets (Giua et al., 1992). In this section, we give the definitions of uncontrollable and unobservable transitions.

Definition 1 (Moody, & Antsaklis, 1998): A plant transition is said to be uncontrollable if its firing cannot be inhibited by an external action.

Definition 2 (Moody, & Antsaklis, 1998): A plant transition is said to be unobservable if its firing cannot be directly detected or measured.

“A plant transition” denotes a transition in a plant Petri net. “Its firing cannot be inhibited by an external action” means that the transition cannot be disabled by a supervisor. Transitions in a Petri net can be divided into three subsets $T = T_c \cup T_{ouc} \cup T_{uo}$, where T_c denotes the set of controllable transitions, T_{ouc} is the set of observable but uncontrollable transitions, and T_{uo} denotes the set of unobservable transitions. Since a controllable transition is also observable, $T_o = T_c \cup T_{ouc}$ is the set of observable transitions (Qin et al., 2012). Note that a Petri net controller cannot have any connection to an unobservable transition. Thus, all unobservable transitions are also implicitly uncontrollable (Moody, & Antsaklis, 1998). $T_{uc} = T_{ouc} \cup T_{uo}$ is the

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