

Chapter 11

A Critical–Siphon Approach to Fastest Deadlock Controller for S^3PR

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ABSTRACT

The authors developed a theory to show that exactly one monitor is required for the set of siphons in the family of 2-compound siphons and how to assign its initial markings. This avoids redundant monitors and the unnecessary associated computational burden. Neither reachability graph nor minimal siphon needs to be computed to achieve polynomial complexity—essential for large systems. This chapter redevelops the theory more formally and further applies this approach to two well-known S^3PR to obtain a controller full or near maximally permissive, where Weighted Control (WC) arcs are nevertheless necessary to keep the controlled model maximally permissive. However, optimal control for siphons involving WC arcs are still under research. As many as possible for simpler structures are desired to reduce WC arcs. In addition, fast computation is important for dynamic reconfiguration situations. The authors develop a single theorem to identify the condition where WC places cannot be replaced by Ordinary Control (OC) arcs, while others can be replaced.

1. INTRODUCTION

Flexible Manufacturing System (FMS) can adapt to swift changes of production requirements to provide various market segments with suitable customized products. Concurrent automated

processes share some costly resources such as robots, machines, and logistic systems to work on some raw parts to manufacture mixed type products. It is well-known in operating systems that highly sharing of limited resources can lead to complete system shut down due to deadlocks.

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Deadlock-freeness is essential for the automation of a Flexible Manufacturing System (FMS). Various deadlock resolution approaches (Cho *et al.* 1995; Hu *et al.* 2008; Iordache *et al.* 2001; Wysk *et al.* 1994; Visvanadham *et al.* 1990; Huang *et al.* 2006; Zhao *et al.* 2009) have been proposed to tackle deadlocks. Deadlock prevention has been popular to avoid deadlocks in FMS since it runs fast and statically to avoid run-time detection and computation.

In obtaining PN based monitors for deadlock prevention (or liveness enforcing) there are three main issues tackled within the literature: behavioral permissiveness, computational complexity, and structural complexity. *Behavioral complexity* is related to the performance in terms of the reachable good states. In the context of FMS the number of good states in a Petri net model of an FMS, which can be provided under the deadlock prevention or liveness-enforcing policies, has been regarded as a “quality measure.” In terms of the practical implementation of these policies, this quality measure implies high efficiency, throughput, and flexibility (Uzam *et al.*, 2007). The highest quality can be provided by the maximally permissive (optimal) control policies. *Computational complexity* is related to the computational cost paid in order to obtain a liveness-enforcing supervisor (LES) for a given deadlock prevention FMS problem. In this case it is desirable to obtain an answer for a given problem in the least time possible. *Structural complexity* means extra cost in system verification, validation, and implementation. It is related with two aspects of a LES: the number of monitors and the type of monitors. In the former, it is desirable to obtain the least number of monitors possible. In the latter, there are two types of monitors: ordinary and general. Ordinary monitors are the ones with no weighted arcs. General monitors are the ones with weighted arcs. It is obvious that ordinary monitors are preferable to general monitors due to verification, validation, and implementation issues.

Classical approaches either suffer from adding too many monitors (Ezpeleta *et al.*, 1995) (problematic siphons growing quickly with the size of the system) or reaching too few states (Li *et al.*, 2004, 2007). Recently, maximally permissive control policies (Chen *et al.* 2011, Huang *et al.* 2009, Li *et al.* 2008, Piroddi *et al.* 2008, 2009, Uzam *et al.* 2006) with little redundancy have emerged. They however suffer from either complete state enumeration—based on region theory (Uzam *et al.* 2006; Huang *et al.* 2009; Li *et al.* 2008) or the time consuming computation of a large number of inequalities associated with the concept of selective-siphons (Piroddi *et al.*, 2008, 2009). Both are NP-hard and take exponential amount of time.

The authors in (Shih *et al.*, 2009) propose to optimize the number of monitors (good states as well) if one adds monitors in the normal sequence of basic, compound, control, and other types of siphons. It is shown that among all 2-dependent siphons (depending on two component siphons), only one (called critical) siphon needs to be controlled by adding a monitor.

This greatly simplifies the synthesis as well as minimizes the number of monitors required while making the controlled net near maximally permissive. Furthermore, the computational burden is much less since there is no need to enumerate minimal siphons, nor to build the reachability graph. It requires neither iterations nor the removal of redundant monitors. In addition, no control arcs are weighted. It scales well with the initial markings and the size of the nets. However, theorems in (Shih *et al.*, 2009) are stated and proved based on non-formal concepts and symbols. Another approach that can handle large nets is the elementary-siphon one by Li *et al.* (2004); however, the number of reachable states is far fewer than those full or near maximally permissive ones.

This work redevelops the theorems more formally by defining some new symbols so as to be able to show that for all the emptiable siphons

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