

Chapter 16

Solving Siphons with the Minimal Cardinality for Deadlock Control

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ABSTRACT

By modifying the objective function and adding new constraints to a Mixed Integer Programming (MIP) method proposed by Park and Reveliotis, this chapter presents a Revised MIP (RMIP) method to directly solve siphons, called smart siphons, with the minimal cardinality as well as the minimal number of resource places. Accordingly, a proper Control Place (CP) is added for each smart siphon in order to achieve the desired control. Both efficiency and practicality of this method are proved through a theoretical proof and several examples.

1. INTRODUCTION

Due to the competition of shared resources in a flexible manufacturing system (FMS), deadlock problems occur frequently (Chao, 2006; Piroddi *et al.*, 2009), which are a highly undesirable situation, leading to unnecessary costs. One way of dealing with deadlock problems is to model an FMS with Petri nets (Murata, 1989; Li & Zhou, 2009). As a particular Petri net structural object, siphons play an important role in solving deadlock problems in Petri nets, resulting in many deadlock prevention policies using siphon control (Ezpeleta

et al., 1995; Li & Zhou, 2004; Huang *et al.*, 2006; Uzam *et al.*, 2007). These siphon-based control methods mainly consists of two phases. The first is about siphon computation and the second adds a CP to each computed siphon in order to achieve the desired control.

It is well known that the number of Strict Minimal Siphons (SMSs) in a Petri net grows quickly with respect to its size. A deadlock prevention policy using a complete siphon enumeration such as E-policy and L-policy, is time-consuming, where E-policy and L-policy are referred to the DPP in (Ezpeleta *et al.*, 1995) and

(Li & Zhou, 2004), respectively. Moreover, E-policy introduces too many additional CPs when the number of such siphons is large, leading to a much more structurally complex Petri net supervisor than the plant net model, which is impractical for large-sized systems. For this, Li and Zhou (Li & Zhou, 2004) propose the concept of elementary siphons that are a special class of SMSs and indicate that only a part of computed SMSs need to be controlled. Hence, a DPP using a partial siphon enumeration such as C-policy, H-policy, and P-policy, focuses on solving those siphons that contribute to deadlocks and then add CPs for them, which relatively reduces computational time and obtains a live controlled system with a simple structure. Note that the policies in (Chao,2009) (Huang *et al.*, 2006) and (Piroddi *et al.*, 2009) are denoted as C-policy, H-policy, and P-policy, respectively. The C-policy has an advantage over the others since it can directly compute a minimal siphon, which eliminates an extra step to derive a minimal siphon from a maximal unmarked siphon computed by the MIP method in (Chu & Xie, 1997). However, an MIP method in C-policy (Chao,2009) that is obtained by revising the MIP method in (Chu & Xie, 1997) suffers from a number of problems. It is only suitable for Ordinary Petri Nets (OPNs). In addition, since a PN system that models a practical FMS such as S^2 PR (a simple sequential process with resources), S^3 PR (systems of simple sequential processes with resources) (Ezpeleta *et al.*, 1995), L- S^3 PR (Linear S^3 PR), ES 3 PR (Extended S^3 PR) (Huang *et al.*, 2006) and S^4 R (system of sequential systems with shared resources) (Li & Zhou, 2009) is self-loop free and contains one or more strongly connected state machines, the number of places in the PN is at least two. As a result, a new added constraint $\sum_{p \in P} \nu_p < |P|$ ($|P|$ denotes the total

number of places in a Petri net) is not accurate to solve the revised MIP problem in (Chao,2009).

Partially motivated by the revised MIP method in (Chao,2009) this paper develops an RMIP method to directly solve siphons, called smart siphons, with the minimal cardinality as well as the minimal number of resource places. In other words, by modifying the objective function and adding new constraints to an MIP method in (Park & Reveliotis, 2001) a feasible solution of the RMIP can be obtained, which corresponds to a smart siphon under a certain reachable marking M . Accordingly, a proper CP (Li *et al.*, 2011) is added for the smart siphon such that it can be max-controlled (Barkaou & Peyre, 1996). The siphon-based control (ISC) process proceeds until no feasible solution (NFS) of the RMIP is declared, implying that no smart siphons can be found in the resulting net system and the finally controlled system is live. From (Chao,2006) and (Li & Zhou, 2008), any siphon that has more resource places can be composed by those containing less ones. As a result, a small number of smart siphons can be found in the ISC process due to smart siphons containing the minimal number of resource places, leading to a small number of additional CPs and a liveness-enforcing supervisor with a simple structure.

The rest of this work is organized as follows. Section 2 reviews preliminaries of Petri nets that are used throughout this paper. In Section 3, by modifying the objective function and adding new constraints to an MIP method in (Park & Reveliotis, 2001), we present an RMIP method to directly solve smart siphons. An ISC approach using the proposed RMIP method is developed in Section 4. In Section 5, a case study shows its applications to deadlock prevention in FMS. Finally, the last section concludes this paper.

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