

Chapter 3

Distributed Maximally Permissive Nonblocking Control of Flexible Manufacturing Systems

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ABSTRACT

In recent years, a great deal of research has been focused on preventing deadlock in Flexible Manufacturing Systems. Policies based largely on Petri net models have been presented in the literature. Recently, a quite different approach has been developed based on supervisory control theory, and it has been adapted to solve the nonblocking maximally permissive control problem in various resource allocation systems, such as an Automatic Guided Vehicle system and a Production Cell. In this chapter, the authors obtain the corresponding control policy for a Flexible Manufacturing System, and from it derive an equivalent distributed control using the recent theory of supervisor localization.

1. INTRODUCTION

Manufacturing has undergone a fundamental shift from mass production markets to the diverse, quality oriented markets of today. With this shift, small batch manufacturing has become increasingly important, and manufacturing flexibility has emerged as a key competitive organization

feature. Technology-based attempts to achieve manufacturing flexibility include the Flexible Manufacturing System (FMS), a set of manufacturing machines serviced by an automated material handling system, all under computer control. An FMS is intended to combine the efficiency of highly automated mass production with job shop flexibility (Li, Zhou & Wu, 2008; Lawley, Reveliotis & Ferreira, 1997).

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In an FMS, different types of raw parts enter the system at ‘random’ times and are processed concurrently, sharing a limited number of resources such as machines, robots, buffers. A raw part follows a pre-established production sequence through a set of system resources. These sequences are executed concurrently, and therefore have to compete for resources. Such competition can cause deadlocks, resulting in production delays that are highly undesirable (Banaszak & Krogh, 1990; Fanti & Zhou, 2004; Viswanadham, Narahari & Johnson, 1990; Zhou & Venkatesh, 1998). Additionally, since the sizes of buffers are limited, we must ensure that buffers will not be subject to overflow or underflow.

Deadlocks in resource allocation systems are extensively investigated in the literature (Coffman, Elphick & Shoshani, 1971; Gold, 1978; Singhal, 1989). Petri nets (Murata, 1989) are a widely used mathematical tool for handling deadlock problems in the FMS (Commoner, 1972; D’souza & Khator, 1994; Fanti, Maione & Turchiano, 2000; Silva & Teruel, 1997; Zhou & DiCesare, 1993; Zhou & Venkatesh, 1998). The methods derived from a Petri net formalism for dealing with deadlocks either preclude the possibility of deadlock occurrence by preventing some necessary condition or detect and resolve a deadlock when it occurs. Generally, these methods are classified into three strategies: deadlock detection and recovery, deadlock avoidance, and deadlock prevention (Li, et al. 2008). (1) The deadlock detection and recovery approach permits the occurrence of deadlocks; when a deadlock occurs, it is detected, and then, the system is put back to a deadlock-free state, by simply reallocating the sources. (2) In deadlock avoidance, at each system state, an online control policy is used to make a correct decision to proceed among the feasible evolution; the main purpose of this approach is to keep the system away from deadlock states. (3) Deadlock prevention is considered to be a well-defined problem in discrete event systems literature, which is usually achieved by using an

offline computational mechanism to control the request for resources to ensure that deadlocks never occur; the goal of a deadlock prevention approach is to impose constraints on a system to prevent it from reaching deadlock states. In (Li, et al., 2008), the authors compare the different policies in terms of structural complexity, behavior permissiveness, and computational complexity.

Recently, based on the theory of decentralized and distributed control in the supervisory control of discrete-event systems (Wonham, 2012a; Feng, 2007; Cai, 2008), an approach through abstraction, coordination and localization has been applied to effectively solve various source allocation systems, such as Automatic Guided Vehicle systems and Production Cell (Feng, Cai & Wonham, 2009; Cai & Wonham, 2009a, 2009b, 2010a, 2010b). This approach constitutes a new design method for maximally permissive nonblocking control in FMS. Briefly, the initial control problem is the standard ‘Ramadge-Wonham’ (RW) problem (Ramadge & Wonham, 1987a, 1987b; Wonham, 2012a). Here the plant (DES to be controlled) is modeled as the synchronous product of several DES agents (plant components), say **AGENT**₁, **AGENT**₂, ..., that are independent, in the sense that their alphabets $\Sigma_1, \Sigma_2, \dots$, are pairwise disjoint. In a logical sense these agents are linked by specifications **SPEC**₁, **SPEC**₂, ..., each of which (typically) restricts the behavior of an appropriate subset of the **AGENT**_i and is therefore modeled over the union of the corresponding subfamily of the Σ_i . For each **SPEC**_j, a ‘decentralized’ supervisory controller **SUP**_j is computed in the same way as for a ‘monolithic’ supervisor (Ramadge & Wonham, 1987a); it guarantees optimal (i.e. maximally permissive) and nonblocking behavior of the relevant subfamily (the ‘control scope’ of **SPEC**_j) of the **AGENT**_i. In general it will turn out that the synchronous product of all the **SUP**_j is blocking (e.g. may cause deadlock in the overall controlled

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