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Combined Petri net modelling and AI based heuristic hybrid search for flexible manufacturing systems—part 1. Petri net modelling and heuristic search

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Abstract

This two-part paper presents modelling and scheduling approaches for flexible manufacturing systems (FMS) using Petri nets (PNs) and artificial intelligence (AI) based heuristic search methods. In part I, the description of FMS formulation that will be considered throughout the paper is presented. A new class of PNs, *Buffer-nets*, for defining FMS is proposed, which enhances the modelling techniques for manufacturing systems with features that are considered difficult to model. An input language for automatic synthesis of these nets is developed. A scheduling architecture, which integrates PN models and AI techniques, is proposed. Finally, the complexity issues of manufacturing systems are addressed.

Keywords: Petri nets; Artificial intelligence; FMS scheduling problem; Modelling

1. Introduction

An flexible manufacturing system (FMS) usually consists of several numerically controlled manufacturing machines, and automated material handling systems that transport work-pieces between machines and tool systems. In a facility with routing flexibility, each product can be manufactured via one of several available routes. A high-level control system must decide what resources are to be assigned to what product and at what time, so as to optimise some criteria, e.g. makespan, cost, etc. The purpose of scheduling is then to determine when to process which job by which resources so that production constraints are satisfied and production objectives are met.

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Many industry and research communities are now focusing on developing methods for quickly solving real-world scheduling problems—a challenge that maintains its momentum because no perfect solution has been found for all problems, due primarily to the complexity of FMS scheduling. The general FMS scheduling problem belongs to one of the NP hard combinatorial problems (Tzafestas & Triantafyllakis, 1993) for which the development of optimal polynomial algorithms is unlikely.

Scheduling of an FMS can be divided into two parts: representation and reasoning. We use a PN as a representation tool and an AI-based heuristic search method as a reasoning mechanism. We will present the PN modelling approach of manufacturing systems in Part I and in Part II will present several new scheduling algorithms which are based on the PN model presented here.

A PN (Murata, 1989; Peterson, 1981) is a mathematical formalism and a graph tool for the formal description of systems whose dynamics are characterised by concurrency, synchronisation, mutual exclusion, and conflict, which are typical features of distributed environments and FMS. PNs incorporate the notion of a distributed state of a system and a rule for a state change that allows them to capture both the static and the dynamic characteristics of real systems. As a mathematical formalism, we can set up a matrix equation to perform analysis. As a graph tool, it works like a flow chart and gives us a visualisation of a dynamic system. As a modelling paradigm, PNs allow a modular and hierarchically construction approach (Wang & Xie, 1996; Yu, Lloyd, Yusuf, & Balakrishnan, 1997) which can build up a PN from FMS specification languages or formal definitions (Arjona-Suarez & Lopez-Mellado, 1996; Camurri, Franchi, Gandolfo, & Zaccaria, 1993; Richard & Proust, 1998; Xue, Kieckhafer, & Choobineh, 1998). As a direct result, a preliminary version of a language for defining an FMS is presented in this paper.

PNs are currently being successfully employed to support many stages of the development of complex systems: rapid prototyping, formal specification, verification of correctness, performance evaluation, and documentation. These demonstrate that PNs represent a well-known, powerful and widely used analytical formalism.

There are various applications in the areas of system modelling and control using PNs as a simulation and analysis tool for different engineering systems, such as robots, processing plants and batch systems. Many of them are focusing on the simulation, verification and design of real systems (Zhou & Jeng, 1998).

The main reasons that support the claim that PNs are an ideal tool for modelling FMS are:

(a) They are capable of modelling the characteristics and natural constraints of FMS systematically;
(b) They can provide information about the FMS through mathematical analysis that can be used to guide the scheduling process.

Some researchers in this area have defined several PN classes (Proth, Wang, & Xie, 1997) for manufacturing systems by extending the PN modelling power (Konstans, Llyod, & Yu, 1998; Wang & Wu, 1998; Wang & Xie, 1996).

The paper is organised as follows: Section 2 describes the class of FMS which are studied in this paper. Section 3 first introduces PN concepts and briefly explains the automatic synthesis of a PN using the FMS modelling language (FmsML) developed by the authors. Then a new type of net—the *Buffer-nets* (*B-nets*) is proposed. Some properties of the *B-nets* are also presented. Section 4 represents scheduling as a search problem. The well-known A^* algorithm (Pearl, 1984) is adapted to the FMS scheduling problem. Conclusions are presented in Section 5.