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

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Abstract

This two-part paper presents modelling and scheduling approaches of flexible manufacturing systems using Petri nets (PNs) and artificial intelligence (AI)-based heuristic search methods. In Part I, PN-based modelling approaches and basic AI-based heuristic search algorithms were presented. In Part II, a new heuristic function that exploits PN information is proposed. Heuristic information obtained from the PN model is used to dramatically reduce the search space. This heuristic is derived from a new concept, the resource cost reachability matrix, which builds on the properties of *B-nets* proposed in Part I. Two hybrid search algorithms, (1) an approach to model dispatching rules using analysis information provided by the PN simulation and (2) an approach of the modified *stage-search* algorithm, are proposed to reduce the complexity of large systems. A random problem generator is developed to test the proposed methods. The experimental results show promising results.

Keywords: Petri net modelling; Heuristic search; Resource cost reachability matrix; Hybrid search; Stage search

1. Introduction

The increasing automation and complexity of manufacturing systems has highlighted the need for the development of improved scheduling and planning techniques for flexible manufacturing systems (FMS). The successful development of realistic scheduling and planning techniques for FMS could have a significant impact on the manufacturing industry.

Production scheduling is concerned with the effective allocation of resources over time. The purpose of scheduling is to determine when to process which job by which resources so that production constraints are

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satisfied and production objectives are met. On-line scheduling is the automatic rescheduling of the system in response to, either disturbances in the plant operation mode, or to changes in product demand. The objective of this paper is to make a contribution to the solution of the scheduling problem through the combination of Petri net (PN) modelling and artificial intelligence (AI)-based heuristic search techniques.

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, 1998) 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. Recent advances in AI have created significant new opportunities in manufacturing system scheduling. From the AI standpoint, scheduling could be considered as a search with constraints through a problem space, to generate automatically a schedule with required performance. The NP hard nature of the problem has led to a move from systematic and deterministic methods to local, random and optimisation methods such as genetics algorithms, simulated annealing and *Tabu* search.

Combining PN modelling with AI-based search methods to perform scheduling both in cyclic and non-cyclic manufacturing systems has already begun. The use of conflict resolution rules or dispatching rules, whenever a conflict arises in the systems modelled using PNs, was studied by Camurri, Franchi, Gandolfo, and Zaccaria (1993), Huang and Chang (1992), and Takamura and Hatono (1991). The search problem using a branch and bound approach was studied by Chen, Yu, and Zhang (1993) and Lloyd, Yu, and Konstas (1995). The beam search as a scheduling conflict solution method was applied by Shih and Sekiguchi (1991). The truncation of the PN model and branch and bound search for partial scheduling was considered by Chen and Luh (1993), Chen, Luh, and Shen (1994), and Shen, Chen, and Luh (1992). A linear programming approach to schedule systems modelled using PNs was presented by Onaga, Silva, and Watanebe (1991). The constraint logic programming to solve scheduling problems modelled by PNs was used by Richard and Proust (1998). The A^* algorithm with several heuristic functions which aim to find a first near optimum solution was applied by Lee and Dicesare (1994). A modified heuristic function was proposed by Jeng and Chen (1998), and Jeng, Chen, and Lin (1996) that is the solution to the PN state equation using the A^* search algorithm by using the pruning techniques. A hybrid heuristic search between *Best First* and *Backtracking* to enhance the search efficiency was proposed by Xiong and Zhou (1998). The scheduling approaches of continuous and cyclic manufacturing systems using the PN's *T-invariant* were studied by Chen et al. (1994) and Proth and Sauer (1998).

Although these studies represent an effort to combine the PN modelling power with the AI systematic heuristic search, there are few applications using PN properties to guide a search. A specific use of PN information to guide the search process was studied by Jeng et al. (1996). The aim of the paper is to reduce the scope of evaluation of the A^* algorithm which will eventually allow application of a more exhaustive local search and to enhance the power of the heuristic information. We focus both on the improvement of the algorithm and on presenting a heuristic function based on PN analysis that makes the pure A^* algorithm admissible.

The paper is organised as follows. A new heuristic function is presented in Section 2. Its properties are formally demonstrated by experiment. Techniques to reduce the search effort based on the PN model and