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Petri net based decision system modeling in real-time scheduling and control of flexible automotive manufacturing systems

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ABSTRACT

This paper presents the design and the implementation of a Petri net (PN) model for the control of a flexible manufacturing system (FMS). A flexible automotive manufacturing system used in this environment enables quick cell configuration, and the efficient operation of cells. In this paper, we attempt to propose a flexible automotive manufacturing approach for modeling and analysis of shop floor scheduling problem of FMSs using high-level PNs. Since PNs have emerged as the principal performance modeling tools for FMS, this paper provides an object-oriented Petri nets (OOPNs) approach to performance modeling and to implement efficient production control. In this study, we modeled the system as a timed marked graph (TMG), a well-known subclass of PNs, and we showed that the problem of performance evaluation can be reduced to a simple linear programming (LP) problem with $m - n + 1$ variables and n constraints, where m and n represent the number of places and transitions in the marked graph, respectively. The presented PN based method is illustrated by modeling a real-time scheduling and control for flexible automotive manufacturing system (FAMS) in Valeo Turkey.

1. Introduction

Flexible manufacturing systems (FMSs) represent an important recent development in manufacturing automation, on account of improved productivity, quality and resilience to demand fluctuations. An FMS consists of numerically controlled machining centers linked together by an automated material handling system, and can be quickly configured to produce multiple type of products. Flexibility in a manufacturing system provides various advantages such as increased productivity, reduced work-in-process inventory, reduced lead times, increased machine utilization, and reduced set-up costs.

Despite these productivity improvements, FMSs induce new management and control problems encountered through the design, planning, scheduling, and control (Saygin, Chen, & Singh, 2001). Scheduling and control problem of FMS differs considerably from the problems appeared in traditional flow shop and job-shop environments due to the different set of operating conditions (Sivagnanavelu, 2000). The main characteristics of an FMS include multi-layer resource sharing and routing flexibility of the jobs.

Due to the high complexity of automotive FMSs, some mathematical programming related methods such as integer programming, linear programming, and dynamic programming often lacks to describe the practical constraints, and dynamic features of complex scheduling problems, or lack of providing analytical solutions within a reasonable time. Besides, analytical methods usually require repetition as the status of the system changes, and assume that all the parts are ready at time zero, which is rarely the case in practice. On the other hand, classical scheduling techniques such as branch-and-bound and neighborhood search techniques cause substantial increase in state enumeration, and exponentially growing time in computation as the problem size increases.

Since a FMS is a capital intensive and complex system, the design and implementation of FMS should be carefully made. Recently, either existing techniques are improved or new scheduling approaches are developed to deal with the practical constraints of the real-world scheduling problems of automotive FMSs. These methods include the simulation based approaches, expert systems, Petri nets based methods, and hybrid methods (Lin & Lee, 1997). Petri nets (PNs) have been extended and applied to the problems including the scheduling of production systems by means of their modeling capabilities and formulation advantages (Zhou & DiCesare, 1993).

In this study, we propose a flexible automotive manufacturing approach for modeling and analysis of shop floor scheduling problem of FMSs using high-level PNs. To implement efficient production control, this paper provides an object-oriented Petri nets (OOPNs) approach to performance modeling. We modeled the

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system as a timed marked graph (TMG), a well-known subclass of PNs, and we showed that the problem of performance evaluation can be reduced to a simple linear programming (LP) problem with $m - n + 1$ variables and n constraints, where m and n represent the number of places and transitions in the marked graph, respectively.

This paper is organized as follows. In Section 2, the basic definitions and properties of FMS and PNs are given. The relationships between FMS and PNs and a literature survey on FMS and PNs are also presented in Section 2. In Section 3, object oriented design method is proposed to find static relationship among different objects of FMS. In Section 4, an application of PNs in solving a FMS related problem is introduced. The presented method is illustrated by modeling a real FMS cell and working process in Valeo Turkey. We have shown that the performance evaluation can be transformed into a simple linear programming problem in Section 5. Finally, conclusion is discussed in Section 6.

2. Main concepts

2.1. Flexible manufacturing system (FMS)

In the middle of the 1960s, market competition became more intense. During 1960 to 1970 *cost* was the primary concern. Later *quality* became a priority. As the market became more and more complex, *speed of delivery* became something customer also needed. A new strategy was formulated: *Customizability*. The companies have to adapt to the environment in which they operate, to be more *flexible* in their operations and to satisfy different market segments. Thus the innovation of FMS became related to the effort of gaining competitive advantage.

First of all, FMS is a manufacturing technology. Secondly, FMS is a philosophy and "system" is the key word. Philosophically, FMS incorporates a system view of manufacturing. The new word for today's manufacturer is "agility". An agile manufacturer is one who is the fastest to the market, operates with the lowest total cost and has the greatest ability to "delight" its customers. FMS is simply one way that manufacturers are able to achieve this agility. An MIT study on competitiveness pointed out that American companies spent twice as much on product innovation as they did on process innovation. We need to keep in mind what Peter Drucker said: "We must become managers of technology not merely users of technology".

2.2. Literature survey on the analysis of FMS

The analysis of FMS for design and control is complex. The basic structure of the FMS control hierarchy has been defined by Buzacott and Yao (1986). In the literature, to deal with design complexity of FMS, a number of analytical techniques are available. The simulation of FMS is a field of research for many people. Bruccoleri et al. (2003) and Shnits et al. (2004) suggested the simulation as a decision support tool for defining the configuration and the control of an FMS. Chan, Bhagwat, and Wadhwa (2007) presented a simulation study using Taguchi's method analysis of physical and operating parameters of the flexible manufacturing system along with flexibility. Jain, Sandhya Maheshwari, and Baghel (2008) developed queuing model for the performance prediction of flexible manufacturing systems (FMSs). Kumar, Tiwari, and Shankar (2003) used an ant colony optimization approach for scheduling of FMS for a given level of flexibility. Wang and Yen (2001) considered the transportation times in automated material handling system for simulation study of dispatching rule performance. An iterative method has been suggested using mean value analysis (MVA). Wong, Loh, and Hu (1995) controlled the efficiency and productivity of the FMS using the performance of the scheduling and real-time dispatching of the system.

Mathematical modeling plays a vital role in the design, planning and operation of flexible manufacturing systems (FMSs). In the paper of Viswanadham, Narahari, and Johnson (1992), attention is focused on stochastic modeling of FMSs using Markov chains, queuing networks, and stochastic Petri nets. The paper of El-Sayed, Younis, and Magdi (1989) focuses on the loading problem in FMS with variable production ratios. Savsar and Aldaihani (2008) developed a simulation model to investigate the FMS performance while minimizing the workload unbalance. In this study, a stochastic model is developed to analyze performance measures of a flexible manufacturing cell (FMC) under different operational conditions, including machine failures and repairs. Bigand, Korbaa, and Bourey (2004) present a work to create an information system able to integrate different viewpoints concerning the design and the control of a FMS. The proposed approach tackles the problem from the information system point of view. Gamila and Motavalli (2003) developed a mathematical model to select machines and assign operations and the required tools to machines in order to minimize the summation of maximum completion time, material handling time, and total processing time. They formulate loading and routing, two of the most important FMS planning problems, as a 0–1 mixed integer programming problem. Buzacott (1985) outlined and illustrated the basic approaches to the development of such models will be outlined and illustrated with examples pertaining to FMS. The objective of Aized's (2009) study is to model and maximize performance of an integrated Automated Guided Vehicle System (AGVS) with multi-line FMS. The system is modeled using colored Petri net method (CPN).

Since FMS is a technology, well adjusted to the environmental needs, we have to manage it successfully. Today flexibility means to produce reasonably priced customized products of high quality that can be quickly delivered to customers. Different approaches to flexibility and their meanings are shown Table 1.

While variations abound in what specifically constitutes flexibility, there is a general consensus about the core elements. There are three levels of manufacturing flexibility:

Basic flexibilities

- Machine flexibility: the ease with which a machine can process various operations.
- Material handling flexibility: a measure of the ease with which different part types can be transported and properly positioned at the various machine tools in a system.

Table 1
Approaches to flexibility and their meanings.

Approach	Flexibility meaning
Manufacturing	The capability of producing different parts without major retooling
	A measure of how fast the company converts its process (es) from making an old line of products to produce a new product
	The ability to change a production schedule, to modify a part, or to handle multiple parts
Operational	The ability to efficiently produce highly customized and unique products
Customer	The ability to exploit various dimension of speed of delivery
Strategic	The ability of a company to offer a wide variety of products to its customers
Capacity	The ability to rapidly increase or decrease production levels or to shift capacity quickly from one product or service to another