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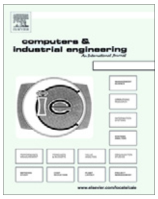

The robustness of scheduling policies in multi-product manufacturing systems with sequence-dependent setup times and finite buffers ☆

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ABSTRACT

In this paper, a continuous time Markov chain model is introduced to study multi-product manufacturing systems with sequence-dependent setup times and finite buffers under seven scheduling policies, i.e., cyclic, shortest queue, shortest processing time, shortest overall time (including setup time and processing times), longest queue, longest processing time, and longest overall time. In manufacturing environments, optimal solution may not be applicable due to uncertainty and variation in system parameters. Therefore, in this paper, in addition to comparing the system throughput under different policies, we introduce the notion of robustness of scheduling policies. Specifically, a policy that can deliver good and stable performance resilient to variations in system parameters (such as buffer sizes, processing rates, and setup times) is viewed as a "robust" policy. Numerical studies indicate that the cyclic and longest queue policies exhibit robustness in subject to parameter changes. This could provide production engineers a guideline in operation management.

1. Introduction

Modeling and analysis of manufacturing systems have attracted significant research attention during the last 50 years. Substantial effort has been devoted to performance evaluation, continuous improvement, customer demand satisfaction, etc. (see monographs by Viswanadham and Narahari (1992), Buzacott and Shantikumar (1993), Gershwin (1994), Zhou and Venkatesh (1999), Li and Meerkov (2009), and reviews by Dallery and Gershwin (1992), Papadopoulos and Heavey (1996), and Li et al. (2009)). In most of these studies, optimal solutions are often pursued to maximize throughput, reduce work-in-process, minimize cost, etc. Such optimal solutions are based on accurate information of system configuration, machine and buffer parameters, and quality statistics. However, in manufacturing environments, randomness is part of the nature. Many system parameters are either inaccurate, uncertain, or varying, due to lack of data, process complexity, environmental changes and economy oscillations, or to unreliability of the sensors (5–10% error is typical for the data collected on the factory floor). Clearly, "optimal" systems based on imprecise information may not be optimal anymore. Hence, in such scenarios, optimal solution may not be applicable. A good and robust one will be more desirable. Therefore, how to design and operate a robust production system, which is resilient with respect to the unpredictable randomness and uncertainties, is an important issue.

Although substantial research effort has been devoted to studying manufacturing systems, the problem of robust production systems is often neglected in the literature and practice. Only a few studies address the issues of data and estimation error, incompleteness of data, and design of repair and repaint systems (Feit and Wu, 2000; Kang and Gershwin, 2005; Li et al., 2005, 2007, 2008). In addition, robust design is typically studied from the statistical point of view (e.g., Moeeni et al., 1997; Saitou et al., 2002; Taguchi, 1987), rather than through analysis of the nature of production systems. Thus, robustness in production systems is not fully understood and requires an in-depth systematic investigation.

In another direction, in modern manufacturing systems, flexibility becomes more and more important. Many manufacturing systems are capable of making multiple products on the same production facility. For instance, in electronic industry, on the same production line, one may find CPU chips with multiple product families. Similar observations can be found for the production of LCD monitors with various sizes and colors, and GPS systems with different accessory functions. In such systems, setup times usually occur when a machine is switched between different products due to the needs of updating device mode, changing machine components, or re-allocating resources, such as human operators. Moreover, in many cases, the setup times are often

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sequence-dependent. In other words, the durations of setup times depend both on the previous product type and the current one. For example, the setup time between two "Product Family A" units might be different from that between a "Product Family B" unit and a "Product Family A" unit. In the latter case, the machine may need to adjust its processing temperature for the new product. In addition to setup times, finite buffers usually exist for various product types to reduce inventory and control product flow time. To coordinate the manufacturing of different products, various scheduling policies have been presented, intended to achieve the maximal production, smallest inventory, least changeover time, or the desired demand satisfaction, etc. Then, the question is, which scheduling policy may lead to a good and robust performance, independent of uncertainties or changes in system parameters (such as buffer capacities, setup times, product arrival, and processing times)? This leads to the issue of robust scheduling policy.

Again, even though multi-product manufacturing systems have received increasing research attentions in recent years (see, for instance, reviews by Buzacott and Yao (1986), Beach et al. (2000), Takagi (2000), Shi and Daniels (2003), and papers by Altiok and Shiue (2000), Krieg and Kuhn (2002), Krieg and Kuhn (2004), Li and Huang (2005), Ryan and Vorasayan (2005), Jang (2007), Colledani et al. (2008), Dasci and Karakul (2008), Gurgur and Altiok (2008), Satyam and Krishnamurthy (2008), Feng et al. (2011)), most of the papers ignore the issues of setup times or finite buffers, while only a few studies address both problems (Altiok and Shiue, 2000; Dasci and Karakul, 2008; Feng et al., 2011; Krieg and Kuhn, 2002; Krieg and Kuhn, 2004). Except Dasci and Karakul (2008) and Feng et al. (2011), sequence-dependent setup times are not investigated. To our best knowledge, there are no thorough analysis of different scheduling policies and concrete instructions of using these policies to promote system performance. The issues of robust scheduling policies have not been studied in the current literature. This paper is intended to contribute to this end.

The main contribution of this paper is in studying the robustness of scheduling policies in a multi-product system with sequence-dependent setup times and finite buffers. Seven different scheduling policies, which can be easily implemented in practice, are considered. These policies are: cyclic, shortest queue (SQ), shortest processing time (SPT), shortest overall time (SOT, including setup time and processing times), longest queue (LQ), longest processing time (LPT), and longest overall time (LOT). A continuous-time Markovian model is constructed, and the system performances under different policies have been compared to discover which policy can exhibit a relatively good performance under different scenarios. Such a policy is referred to as a "robust" scheduling policy. It has been observed that cyclic and LQ policies can be viewed as robust scheduling policies.

The remainder of the paper is organized as follows: Section 2 reviews the related literature. Section 3 describes the system and formulates the problem. Performance evaluation is introduced in Section 4 and discussions on policy robustness are presented in Section 5. Finally, conclusions are given in Section 6. The proofs are provided in Appendix A.

2. Literature review

Although substantial research effort has been devoted to manufacturing systems analysis, the problem of robust performance has not been systematically studied in the literature. Only a few publications address some related issues, such as data and estimation error, incompleteness of data, and the design of repair systems. Specifically, Kang and Gershwin (2005) analyze the impact of inaccurate information in inventory systems. It shows that even a small probability of stock loss can lead to disruption of replenishment process and severe out-of-stock. Feit and Wu (2000) consider transfer line design with uncertain machine performance information. An analytical procedure is developed to reduce uncertainty through identifying the most critical information for overall design performance. Li et al. (2005) present a simple approximation approach to estimate the reliability data of feeder lines when such information is not available. It is shown that such an approach can help improve the accuracy of throughput estimation. Li et al. (2007) and Li et al. (2008) investigate the design of repair and rework systems in automotive paint shop to ensure a robust paint quality. In another direction, robust design has been studied from the statistical quality control point of view (see, for instance, Moeeni et al., 1997; Saitou et al., 2002; Taguchi, 1987), rather than through analysis of the nature of manufacturing systems. The issues related to multiple products are not addressed.

Multi-product manufacturing systems have received much research attention during the last few decades, see monographs by Viswanadham and Narahari (1992), Buzacott and Shantikumar (1993) and Zhou and Venkatesh (1999). In addition, several reviews have been published to summarize the development in this area. For example, Buzacott and Yao (1986) review the research work of analytical models of manufacturing systems developed by different groups in the world, and assess the strengths and weaknesses of each model. Beach et al. (2000) introduce an extensive review of literature to study the concepts of manufacturing flexibility, such as flexibility definition, measurement, and types of flexibility. Takagi (2000) summarizes the origin, basic model, applications and recent surveys of polling models, which have multiple product types and limited non-dedicated machines (servers). Shi and Daniels (2003) survey the existing literature on manufacturing flexibility and provide guiding principles in an e-business environment.

In recent years, multi-product systems have attracted more research interests. Ryan and Vorasayan (2005) study a multi-product CONWIP system. A multiple-chain multiple-class closed queuing network model of the system is developed, and non-linear programming is used to evaluate system performance and optimize kanban assignment. Satyam and Krishnamurthy (2008) also consider a multi-product CONWIP system, but the performance analysis is carried out with a parametric decomposition approach. Jang (2007) studies a multi-product system with finite buffers, constant processing rates and unreliable machines, without setup times. Gurgur and Altiok (2008) address multi-stage multi-product systems, where a two-card kanban control policy is adopted. An approximation algorithm is proposed to evaluate inventory and service levels for each product. A recursive method is introduced by Li and Huang (2005) to analyze a split and merge system with multi-products. However, setup times are not included. Only limited studies have been discovered in the current literature addressing both setup times and finite buffers. Altiok and Shiue (2000) consider a system with one machine, multiple products and a continuous-review (R, r) policy for each product. A sequence-independent setup time occurs when the machine switches to a new product type. Krieg and Kuhn (2002) and Krieg and Kuhn (2004) study systems with sequence-independent setup times, and with cyclic policy and kanbans. Dasci and Karakul (2008) analyze a two-product polling model with finite buffers and setups using an iterative method. Feng et al. (2011) evaluate the performance of a system with finite buffers, sequence-dependent setup times and cyclic policy. Closed-form solutions are derived and system properties are discussed. Among these works, only Dasci and Karakul (2008) and Feng et al. (2011) investigate the system with both sequence-dependent setups and finite buffers. Needless to say, robustness has not been addressed in all these studies.

Despite all these efforts above, multi-product systems with finite buffers, sequence-dependent setup times and different