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Queueing network model for a single-operator machine interference problem with external operations

Taho Yang a,*, Rong-Shean Lee b, Mu-Chen Chen c, Pangwei Chen a

a Institute of Manufacturing Engineering, National Cheng Kung University, 1 University Road, Tainan 701, Taiwan
b Department of Mechanical Engineering, National Cheng Kung University, Tainan 701, Taiwan
c Department of Business Management, National Taipei University of Technology, Taipei 106, Taiwan

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Abstract

Machine interference is a significant problem in many manufacturing systems. Prior research shows that machine interference may be as high as 10% of machine time. This paper proposes a queueing network model for a single-operator, machine interference problem with external operations, i.e., those tasks that can be completed while the machine is running. The interactions for part/machine and machine/operator are modeled as an open and a closed queueing network, respectively. In the open network, part inter-arrival time follows an exponential distribution. In both networks, service times follow a general distribution that is characterized by their first two moments. An iterative procedure is developed to solve the proposed model. Solution quality is justified by an industry-based case study. Data were collected from the integrated circuit (IC) ink-marking machines of a leading IC packaging company in Taiwan that allowed the construction of an experimental design for computational tests that encompassed a wide range of production scenarios. Empirical results show promise for the proposed methodology in helping to solve industrial problems. Model limitations as well as future research opportunities are discussed.

Keywords: Queueing network; Machine interference; Two-moment approximation

1. Introduction

Machine interference is a significant problem in many manufacturing systems. It occurs when a machine stops and will not resume production until it is rectified (attended) by the technician (operator) (Stecke and Aronson, 1985). When an operator attends more than one machine, there is machine interference. The more the number of machines that an operator attends, the greater the machine interference will be. Thus, there is often a trade-off between the operator staffing level and the magnitude of machine interference. Industrial investigations show that machine interference may, in some cases, be as high as 10% of machine time (Tefen, 1997). This problem is particularly critical when a system has a throughput...
constraint and the purchase of a new tool is a costly decision.

For a practical perspective, machine interference problems cannot merely consider the relationship between machines and the operator. Other factors such as the existence of external operations, part arrival rate, and machine failures also impact the level of machine interference.

Operator attendance to a machine can be either internal or external operations. Internal operations are those tasks that take place when a machine is stopped. External operations are those tasks that can be completed while a machine is running. For instance, loading and unloading operations can often be performed while a machine is running (Hopp and Spearman, 2000). Similarly, production paperwork could be performed when the machine is running or stops for external and internal operations, respectively. It is a good practice to try and convert internal operations to external ones.

Part arrival rate is another factor that impacts on the occurrence of the machine interference. Thus, the machine interference problem should consider interactions between parts and machines, and between machines and the operator. In addition, machine failure, repaired by a technician, does not require operator attendance, but it has an impact on the request frequency for operator services. Thus, it is one of the factors that impacts on the machine interference.

A simulation approach can solve the proposed machine interference problem. It can provide detailed analysis results; however, it is often time consuming (Law and Kelton, 1991). In this paper, we examine an alternative method. Our objective is to develop a simple yet accurate queueing network model for a single-operator, machine interference problem with external operations. The existence of external operations is modeled by the introduction of pseudo-machines into the network. The machine repair time is explicitly considered. The interactions between parts and machines and between machines and the operator are modeled as an open and a closed network, respectively. In the open network, part inter-arrival times follow an exponential distribution. In both networks, service times follow a general distribution that is characterized by their first two moments. In the closed network, the machine successive inter-arrival times follow a general distribution and are independent. An iterative procedure is developed to solve the proposed model.

This research seeks to answer the following questions for a manufacturing system. Can the required customer demands be met under the current system configuration? What are the utilization levels of the machines and of the operator? What is the level of the machine interference? The calculations of these system performance measures are important for the design and analysis of a manufacturing system.

An industry-based case study is adopted to illustrate the proposed methodology. The case study company, Siliconware Precision Industry Ltd. (SPIL), is one of the leading IC packaging companies in Taiwan. Its annual sales are consistently one of the top five companies in the world during the past seven years. Its ink-marking machines often encounter the proposed machine interference problem, which initiated this research. The empirical data were collected from SPIL’s ink-marking machines and were used in constructing the experimental design.

The remainder of this paper is organized as follows. Section 2 reviews the literature pertinent to the proposed problem. The details of the proposed approach are discussed in Section 3. Section 4 contains empirical illustrations of the proposed approach. Conclusions and suggestions for future research are given in Section 5.

2. Literature review

Much prior research aimed at developing analytical approaches for modeling the machine interference problem, e.g., Stecke and Aronson (1985). Among those analytical approaches, queueing theory-based models are particularly important in solving the machine interference problems (Suri and Diehl, 1987). Queueing theory has been extensively adopted to solve a variety of performance analysis problems of manufacturing systems (Govil and Fu, 1999; Altıok, 1989).

The basic M/M/m queueing network can model the interactions between machines and operators