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Reliability analysis of a flexible manufacturing cell

M. Savsar*

Department of Mechanical and Industrial Engineering, College of Engineering and Petroleum, Kuwait University, P.O. Box 5969, Safat 13060, Kuwait

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Abstract

In this study, mathematical models are developed to study and compare the operations of a fully reliable and an unreliable flexible manufacturing cell (FMC), each with a flexible machine, a loading/unloading robot, and a pallet handling system. The operation times, loading/unloading times, and material handling times by the pallet are assumed to be random. The operation of the reliable cell is compared to that of an unreliable cell with respect to utilization of the cell components, including the machine, robot, and pallet handling system. The unreliable cell is assumed to operate under random (machine and robot) failures with constant failure rates for the machine and the robot. The pallet handling system is assumed to be completely reliable. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Flexible manufacturing cell; Flexible manufacturing systems; Reliability analysis

1. Introduction

In recent years a great deal of attention has been given to the automation of manufacturing systems. In order to meet increased demand for customized products and to reduce production lot sizes, the industry has adapted new techniques and production concepts by introducing flexibility into the production machines so that a variety of products can be manufactured on the same equipment.

As indicated by Snader [1] and Chan and Bedworth [2], at present, the most feasible approach for automating the job shop process seems to be through flexible manufacturing cells (FMCs), which require lower investment, less risk, and also satisfy many of the benefits gained through flexible manufacturing systems (FMSs). While FMSs are very expensive and generally require investments in millions of dollars, FMCs are less costly, smaller and less complex systems. Therefore, for smaller companies with restricted capital resources, a gradual integration is initiated with limited investment in a small FMC, which facilitate subsequent integration into a larger system, a FMS. An FMC consists of a robot, one or more flexible machines including inspection, and an external material handling system such as an automated pallet for moving blanks and finished parts into and out of the cell. The robot is utilized for internal material handling which includes machine loading and unloading. The FMC is capable of doing different operations on a variety of parts, which usually form a part family with selection by a group technology approach. The cell performance depends on several operational and system characteristics, which include, part scheduling, robot, machine and pallet characteristics. Smith et al. [3] have presented a survey of the characteristics of US FMSs. Most of the research related to operational characteristics of FMCs are directed to the scheduling aspects. Scheduling algorithms are used to determine the sequence of parts, which are continuously introduced to the cell. Chan and Bedworth [2], Hitomi and Yoshimura [4], Seidman [5], and Hutchinson et al. [6] have developed models for static and dynamic scheduling in FMCs. However, system characteristics, such as configuration, design, and reliability of FMCs, have significant effects on its performance. Machining rate, pallet capacity, robot speed and pallet speed, are important system characteristics affecting FMC performance. Several models have been developed for FMSs and FMCs in relation to the effects of different parameters on system performance. Buzacott and Yao [7], Henneke and Choi [8], Sabuncuoglu and Hommertzheim [9], and Savsar and Cogun [10] have presented stochastic and simulation models for evaluating the performance of FMCs and FMSs with respect to system configuration and component speeds, such as machining rate, robot and pallet speeds. Koulamas [11] looked into the reliability and maintenance aspects and presented a stochastic model for an FMC, which operates under a stochastic environment with tool failure and replacement consideration. He developed a semi-Markov model to study the effects of tool failures on system performance.

* Tel.: +965-4811188; fax: +965-484-7131.
E-mail address: mehmet@kuc01.kiniv.edu.kw (M. Savsar).

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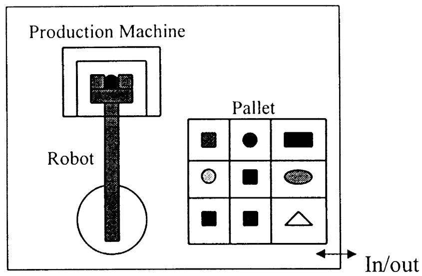

Fig. 1. A flexible manufacturing cell with a robot and a pallet.

Thus, with the exception of the study by Koulamas [11], previous researches have been mostly directed to the scheduling aspects of reliable FMC systems. Not much research has been done on the reliability aspects of such systems. Vineyard and Meredith [12] have looked into the effects of maintenance policies on FMS failures by studying some real systems using simulation. Their conclusion suggests that the FMSs experience four times more wear and tear during their useful life than the traditional machine tools. This is mainly because of the accelerated usage of the FMSs during their useful life. Past studies, such as Smith [3], indicate that while the FMS and FMC systems typically operate 70–80% of the time during their useful life, the traditional machine tools are only utilized 20% of the time during their useful life. Therefore, reliability analysis of flexible systems is extremely important in understanding and increasing the utilization and productivity of such systems.

In this study, we present a stochastic model to determine the performance of a FMC under random operational conditions, including random failures of cell components (machine tool and robot) in addition to random processing times, random machine loading and unloading times, and random pallet transfer times. Stochastic modeling is necessary due to different operational requirements of a variety of parts dynamically scheduled to enter into the cell. Further, production machine and robot failures are very important consideration in system performance. Stochastic models are presented to study and compare the utilization of the components of a reliable cell to that of an unreliable cell. In particular, utilization rates of the machine tool, the robot and the pallet handling system are formulated and compared under the fully reliable system and the unreliable system with specified component hazard rates and operational conditions.

2. Operation of the cell

The FMC considered in this study is illustrated in Fig. 1. An automated pallet handling system delivers n blanks consisting of different parts into the cell. The robot reaches to the pallet, grips a blank, moves to the machine and loads the blank. After the machining operation is completed, the robot reaches to the machine, grips the part, moves to the pallet and releases the part in its spot. Then, it picks up another blank, moves to the machine and loads it to the machine. This cycle of operations is continued until all n blanks are completed. The pallet then moves completed parts out of the cell and a new pallet with a set of n blanks is delivered to the cell automatically. Due to the introduction of different parts into the FMC and the characteristics of the system operation, processing times as well as the loading/unloading times are random, which present a complication in studying and modeling the cell performance. The problem is further complicated if random failures of the machine tool as well as the robot are incorporated into the model. In the following section, stochastic mathematical models are presented to study cell performance under the mentioned characteristics and operational conditions.

3. Stochastic models

Stochastic models are developed for the FMC discussed above and illustrated in Fig. 1. Processing times on the machine, robot loading and unloading times, pallet transfer times and the equipment up and down times are all assumed as random quantities that follow exponential distribution. Models are presented for the unreliable cell and the reliable cell with no failures. In order to model the FMC operation, the following system states are defined:

- $S_{ijk}(t)$ state of the FMC at time t
- $P_{ijk}(t)$ probability that the system will be in state $S_{ijk}(t)$
- i number of blanks in the FMC (on the pallet and on the machine or the robot gripper)
- j state of the production machine ($j = 0$ if the M/C is idle; $j = 1$ if the machine is operating on a part; and $j = d$ if the machine is down under repair)
- k state of the robot ($k = 1$ if the robot is loading/unloading the machine; $k = 0$ if the robot is not engaged in loading/unloading the machine; and $k = d$ if the robot is down under repair)

The following notation is used for the system parameters in the model.

- ι loading rate of the robot (parts/unit time)
- u unloading rate of the robot (parts/unit time)
- z combined loading/unloading rate of the robot (parts/unit time)
- ω pallet transfer rate (pallets/unit time)
- λ failure rate of the production machine ($1/\lambda$ = mean time between machine failures)
- μ repair rate of the production machine ($1/\mu$ = mean machine repair time)
- α failure rate of the robot
- β repair rate of the robot
- ν machining rate (or production rate) of the machine (parts/unit time)
- n pallet capacity (number of parts/pallet)