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Performance analysis in a re-entrant operation with combinational routing and yield probabilities

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Abstract

Queuing networks arising from multistage processes with probabilistic re-entrant lines are common in manufacturing environments. Probabilistic re-entrant operation is defined as lots entering the operation with different repeated cycle requirements. This paper extends our work [S. Kumar, M.K. Omar, Stochastic re-entrant line modeling for an environmental stress testing in a semiconductor assembly industry, Appl. Math. Comput. 173 (2006) 603–615.] and proposes a modified analytical method based on the mean value analysis (MVA) technique and considering a probabilistic re-entrant line with yield loss probabilities. Introducing probabilities consideration into the MVA approach will substantially increase the complexity of the modeling and results analysis. However, the contribution of this paper is the introduction of a solution methodology that can overcome such complexity and allow operational managers to compute performance measures such as total cycle time and the mean throughput.

Moreover, our paper presents numerical tests under various probabilistic re-entrant and yield conditions to show the performance of the proposed approach compared with results obtained from a simulation model developed by the authors.

Keywords: Probabilistic re-entrant; Mean value analysis; Total cycle time; Mean throughput; Combinational routing probability; Yield loss

1. Introduction

The ability to assess accurately the performance of an operation in a supporting manufacturing environment would be an asset for the manufacturing itself. Any improvement in the performance would contribute a significant amount in terms of efficiency and cost savings. This research work is concerned with performance measure such as cycle time and throughput in a queuing network problem. A queuing network is a common phenomenon in manufacturing production lines in which servers, namely machines and humans are placed in line arrangements. Various types of queuing networks are used in manufacturing environments and thus, numerous studies have been conducted to model these networks.

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This paper considers a queuing problem arising from an environmental stress testing (EST) operation flow in back-end operation in the semiconductor industry. This operation is a five-stage process with probabilistic re-entrant lines. Lots entering the operation have different repeated cycle requirements and this make the re-entrant probabilistic in nature. It is unlike deterministic re-entrant flow where lots will have fixed cycle needs. This re-entrant process is subjected to certain probabilities and as a result, lots are re-entered into the previous stages, and therefore continue to be processed for second and subsequent cycles.

The EST operation is not part of the main production line, but performed separately in a laboratory environment on defect suspected lots. It is an operation that uses heat profile to screen lots that have potential heat related defects. In such industrial environment, the operational manager has to deal with N lots of products that required to go through different testing cycles and subjected to yield loss. This paper explores the problem and introduces a unique approach that extends the MVA approach to determine the total cycle time to and subsequently compute the mean throughput.

This paper is organized as follows. The literature review is presented in Section 2. Problem description and model formulation is presented in Section 3 and summary of the algorithm is presented in Section 4. Our computational experience, results and discussions are presented in Section 5. Finally, the conclusions are presented in Section 6.

2. Literature review

Re-entrant lines are a class of non-traditional queuing networks in which lots visit the same machine several times at different stages of processing before leaving the system. One good example of the re-entrant manufacturing system is the semiconductor manufacturing process in which several layers of circuits are fabricated on a wafer through re-entrant processing routes. Another good example is the EST process described in this research. Interested readers in re-entrant lines and queuing systems are referred to the comprehensive details provided by Kumar [1,2].

The MVA is an iterative method for analyzing a system in a steady state based on two principles: arrival theorem [3] and Little's law [4]. Narahari and Khan [5] proposed the first application of MVA approach to a re-entrant line with single class and single job machine. The main contribution in their paper is a proposal of an efficient approximate technique based on MVA approach to compute the performance of the re-entrant lines employing on-preemptive fixed buffer priorities and fixed WIP input release policy. The model was developed and the performance measures computed are the mean steady state cycle time and mean steady state throughput rate for a given work in progress fixed system. The performance of their developed model was verified through a simulation model. They have found that the model provides quite an accurate performance measures.

However, in their method, materials flowing through the system have deterministic routes. In addition to this, the number of lots tested in their system is below 40. Increasing the number of lots in the system would create larger errors and therefore, a correction factor was introduced to solve the problem.

In another research work, Narahari and Khan [6] considered re-entrant manufacturing systems with inspection stations placed at various stages. At the end of the inspection activities, there were three possible outcomes: accept, reject or rework. Thus, the system has a re-entrant line with probabilistic conditions. They formulated an approximate analytical technique based on MVA approach to compute mean steady state cycle times and throughput rates. The method clearly models scheduling policies used in re-entrant lines for rapid performance analysis. Thus, the method is able to determine the minimum number of inspection stations and the optimal location to maximize throughput. The shortcoming of their method is that the rejection rate has to be small (reported in the numerical example to be 0.05). Since there was nothing mentioned about the range of the rejects, the method might not be able to handle large rejection rate coming from the inspection station, as it would create instability in the system.

Park et al. [7] extended the work of Narahari and Khan [5] and proposed an approximate method for analyzing the performance of a re-entrant line using the MVA approach. The extended work includes multi class jobs, and in addition to that, the re-entrant lines consist of both single job machines and batch machines. The multiclass jobs were assumed to flow through pre-determined routes and the routes may be different for different classes of jobs. It is worth noting that in most of re-entrant lines studies done previously, the cycle time