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Performance analysis of unreliable manufacturing systems with uncertain parameter estimates

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Abstract

Traditional systems engineering methods for the performance evaluation of manufacturing systems assume that machine reliability parameters (Mean Time to Failure and Mean Time to Repair) are precisely known. However, in practical situations, these parameters are either estimated from real life data or based on experts' knowledge. In both cases, they are subject to uncertainty. This paper proposes for the first time an approach for the performance evaluation of unreliable manufacturing systems that considers uncertain machine parameter estimates. The proposed method is based on the combined use of Bayesian estimation, probability density function discretization and existing decomposition-based techniques for analyzing manufacturing lines composed of unreliable machines and capacitated buffers. Numerical results show that neglecting uncertainty in the input parameter estimates generates consistent errors in the output performance measure estimates, thus making the consequent system design and operation decisions sub-performing. An industrial case is proposed to show the benefits of this method in real production settings.

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1. Introduction

Uncertainty and complexity highly influence the design, management and operation of manufacturing systems, by posing serious challenges towards the achievement of their target performance. As a matter of fact, uncertainty analysis and robust system performance measurement are crucial activities for manufacturing competitiveness. Indeed, several important system design decisions are dependent on the ability to carry on a significant analysis of the system performance in presence of uncertainty. Uncertainty in system design/re-design phases may be either generated internally or externally to the system; internal uncertainty is related to imprecise characterization of the events that affect the technical efficiency of the resources in the system, i.e. breakdowns and disturbances; external uncertainty is related to the difficulty in prediction of the system design requirements, mainly due to the market volatility and turbulence. In this paper, we will focus on the first source of uncertainty, i.e. internal uncertainty.

From a practical point of view, a systematic approach towards uncertainty is an essential step to support both the "green field" design and the re-configuration phases. During the "green field" design phase, the technical efficiencies of the resources/machines that shall compose the manufacturing system are considered as nominal values, provided by the equipment/sensor producers. However, when installed and integrated in the system, these resources typically prove to perform differently from what expected, due to the specific operational conditions and control system settings. Therefore, in order to capture this deviation in the "green field" design phase and to generate a robust system configuration, uncertainty should be associated to the resource efficiency estimates, used as input parameters of the design process. On the contrary, in the system operational phase, the technical efficiency of the machines can be estimated by using historical data, i.e. the machines' operational records, typically stored in the company production monitoring system database. In this case, estimates are subjected to uncertainty due to the specific sampling plan adopted.

Embedding uncertainty in the system performance evaluation and design process is of paramount importance for generating system configurations that are robust to input parameter estimation uncertainty. Moreover, it makes it possible to know how the level of uncertainty associated to each input parameter impacts the resulting uncertainty in the output performance measure, and to refine the level of confidence of the input parameters accordingly. For example, if the system is already existing, the sampling plan can be adaptively modified to gather more data about the most critical resources in the system (bottlenecks) and to decrease the monitoring effort for less critical resources, thus providing data management policies that are functional to the achievement of a desired level of confidence in the output system performance estimation.

In spite of the industrial relevance of this problem, in the literature Manufacturing System Engineering approaches, including both simulation and analytical methods [1] never considered this problem. Traditionally, the reliability of machines is modeled through the characterization of the Mean Time to Failure (MTTF) and the Mean Time to Repair (MTTR) of each failure mode affecting the machine production. Although these are assumed to be the mean of statistical distributions (typically exponential or geometric distributions), their value is considered as known deterministically. However, if they are gathered by using a sample size of 5 instead of 1000 failure observations, the resulting level of confidence on the mean value is different. Traditionally, the considered performance measures are the average throughput and the average inventory levels of the system. Again, these are considered to be precise estimates, although they are strongly affected by the input parameters' uncertainty. Important issues in using estimated reliability parameters for performance evaluation are discussed in [2-4]. The growing use of online data collection systems for manufacturing systems and the potential of integrating data collection to performance evaluation is also pointed out in literature [5]. This further motivates our research.

This paper proposes an approach to analyze the performance of multistage manufacturing systems composed of unreliable machines and capacitated buffers when machine failure and repair parameters are known with uncertainty.

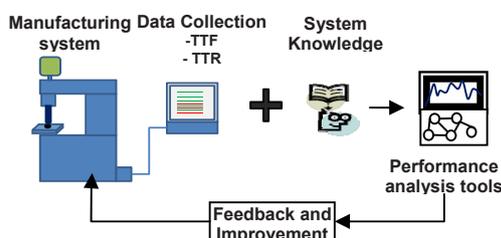


Fig. 1. Integrated data collection and performance evaluation.

The proposed method is based on the integration of Bayesian estimation, probability density function partitioning and approximate analytical models for the system performance evaluation. Therefore, the proposed performance evaluation approach is designed to support system design/re-design under uncertainty. The two major research questions that this paper aims at answering can be formulated as follows: “What is the error in the estimation of the system throughput observed if only the expected values of the estimated input parameters are considered, i.e. uncertainty is neglected?”, and “What system design decisions can be significantly affected by this error?”. The preliminary results reported in this paper will show that internal uncertainty modifies the performance evaluation results and can affect the subsequent system design decisions. Although the proposed approach is general and can be in principle applied to any manufacturing system layout for which approximate analytical methods are available, in this paper we will focus on serial manufacturing lines.

2. System Description

The modelled serial production line is composed of K unreliable machines separated by $K-1$ limited capacity buffers, as represented in Fig 2. The machines (squares) perform operations on parts flowing in the system. Buffers (circles) have the role of decoupling the machines in the system. They can be either inventory storages or automated material handling systems that transport semi-finished materials between machines. The i -th machine and buffer are denoted with M_i and B_i (with $i=1, \dots, K-1, K$) respectively: B_i has capacity equal to N_i and it contains only pieces already worked by M_i . A generic M_i is blocked if the downstream B_i is full. A generic M_i is starved if the upstream dedicated buffer B_{i-1} is empty. The first machine is never starved, meaning that there is continuous supply of raw parts at machine M_1 , and the last machine is never blocked, meaning that there is always place to store finished products.

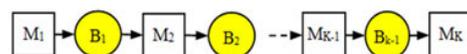


Fig. 2. Representation of serial manufacturing line

3. Modeling Assumption

The detailed list of modelling assumptions follows:

- A discrete material flow model is considered.
- Machine processing times are deterministic and equal for all the machines in the system. The time unit is scaled to the processing time.
- Machine M_i can fail in F_i independent failure modes.
- Times to Failure ($TTF_{i,j}$) and Times to Repair ($TTR_{i,j}$) are geometrically distributed.
- Failures are Operational Dependent Failures (ODF).

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