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Performance measurement and lumped parameter modeling of single server flow lines subject to blocking: An effective process time approach

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Abstract

The present paper extends the so-called effective process time (EPT) approach to single server flow lines with finite buffers and blocking. The power of the EPT-approach is that it quantifies variability in workstation process times without the need to identify each of the contributing disturbances, and that it directly provides an algorithm for the actual computation of EPTs. It is shown that EPT-realizations can be simply obtained from arrival and departure times of lots, by using sample path equations. The measured EPTs can be used for bottleneck analysis and for lumped parameter modeling. Simulation experiments show that for lumped parameter modeling of flow lines with finite buffers, in addition to the mean and variance, offset is also a relevant parameter of the process time distribution. A case from the automotive industry illustrates the approach.

Keywords: Blocking; Discrete event simulation; Finite buffer capacity; Lumped parameter modeling; Performance analysis; Queuing

1. Introduction

Single server workstations with finite buffer sizes in a tandem flow line are an important class of manufacturing systems. Examples of such flow lines are semi-synchronous lines and assembly lines, as e.g. encountered in the automotive industry.

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The performance of a flow line is commonly expressed in terms of throughput and flow time. Both performance indicators are influenced by blocking. The finite capacity of the buffers in the single server flow lines considered in this paper introduces blocking in the line.

Blocking causes suspension of service to a lot (which implies loss of production capacity) since a finished lot cannot be sent on due to a saturated downstream buffer. Starvation refers to the situation where processing of the next lot is suspended due to an empty upstream buffer.

Variability in process times is the main reason that blocking and starvation occur. The variability of process times can be traced to several common sources. First of all, natural process times are variable due to differences in product types, machine states at product entry, operator behavior etcetera. Furthermore, disturbances such as setups, preventive maintenance, machine failures and absence of operators occur. These disturbances cause loss of production capacity effectively available at the workstation and increase the variability of process times, which in turn decreases the throughput. Subsequent workstations affect one another more prominently as the variability of process times increases. Variability of process times on workstation j can cause starvation on workstation $j+1$. Furthermore, in a flow line with finite buffers, variability of process times on workstation j can cause blocking on workstation $j-1$.

Obviously, for performance analysis of a finitely buffered flow line, an analysis tool that quantifies both the production losses and the level of variability of process times is required. A commonly applied performance analysis metric is the overall equipment efficiency, OEE. However, OEE can only be used for quantifying production losses. Therefore an alternative analysis tool will be used in this paper.

Hopp and Spearman (2001) introduced this alternative concept to account for irregularities in process times of workstations. The alternative concept, effective process time (EPT), is defined as the total time seen by a lot at a workstation from a logistical point of view. Here, total time indicates the total time that the lot has effectively consumed production capacity of the workstation. EPT is based on the notion that, from a logistical perspective, a workstation does not care whether production capacity is claimed since the server is processing the lot or whether production capacity is claimed by other influences. These other influences are included in the EPT of the workstation.

Hopp and Spearman's notion of including processing disturbances in the effective process times is not new, see e.g. the work of Chen and Chen (1990), Dallery and Gershwin (1992) and Buzacott and Shanthikumar (1993). The aforementioned authors all assume, or measure, distributions for the various processing disturbances and combine these into one single distribution. However, from industrial practice, it is often hard, if not impossible, to identify and quantify all individual disturbances, see e.g. the work of Pierce (1994), McMullen and Frazier (1998), Hsieh (2002) and Mendes et al. (2005).

Starting from the concept of EPT, Jacobs, Etman, van Campen, and Rooda (2001) and Jacobs, Etman, van Campen, and Rooda (2003) presented a method to translate lot arrivals and lot departures at an infinitely buffered workstation into an EPT-distribution. The workstation process times and the disturbances from the factory floor are aggregated into a single distribution without the need to quantify the individual factors. In automated manufacturing environments, arrival and departure data are often available.

The obtained EPT-distributions can be used for performance analysis and optimization. Based on the characteristic parameters of the EPT-distributions, i.e. the mean effective process time t_e and the coefficient of variation c_e, a bottleneck analysis can be performed, after which an approximating model can be used to predict the changes in system performance. Two types of models may be distinguished: analytical queueing models and (discrete event) simulation models. Analytical queueing models are fast to evaluate, usually based on assumptions such as Markovian process times and Markovian times between failure and times to repair, see e.g. Chen and Chen (1990), Dallery and Gershwin (1992), Buzacott and Shanthikumar (1993), Gershwin (1994), Jeong and Kim (2000), Hopp, Spearman, Chayet, Donohue, and Gel (2002), Li, Alden, and Rabaey (2005), Diamantidis, Papadopoulos, and Heavey (2007) and Van Vuuren (2007). Analytical models typically require the first two moments of the process times, for which t_e and c_e can be used. Alternatively, simulation models may be used (Banks, 1999; Law & Kelton, 2000). The EPT-distributions may be directly used as input to the simulation model, either by fitting an appropriate distribution function or by using the EPT-distribution as an empirical distribution.

This paper aims to generalize the EPT-approach for application to single server flow lines subject to blocking. That is, the paper considers finite buffers rather than infinite ones. Workstations can no longer be ana-