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A heuristic algorithm for the buffer allocation in unreliable unbalanced production lines ☆

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Abstract

In this work we investigate the buffer allocation problem (BAP) in short unbalanced production lines consisting of up to six machines that are subject to breakdowns. Times to failure are assumed exponential whereas service and repair times are allowed to follow any Erlang-k distribution (with $k \geq 1$). An algorithm that is based on the sectioning (segmentation) approach was developed which solves the BAP. This, in conjunction with a method not previously reported that determines a "good" initial solution for the buffer allocation constitutes the main contribution of the present work. The accuracy of the proposed heuristic algorithm is remarkably good and its convergence is fast making it a promising tool that can be implemented in conjunction with a fast decomposition method to solve the BAP in large production lines. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction and literature review

Over the years a large amount of research has been devoted to the analysis of production lines. Much of this research has concerned the design of these manufacturing systems when there is considerable inherent variability in the processing times at the various stations, a common situation with human operators/assemblers. The literature on the modeling of production lines is vast, allowing us to review only the most directly relevant studies here. For a systematic classification of the relevant works on the stochastic modeling of these and other types of manufacturing systems (e.g. transfer lines, flexible manufacturing systems (FMS) and flexible assembly systems (FAS)), the interested reader is addressed to a review paper by Papadopoulos and Heavey (1996) and some recently published books, such as

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Altiok (1997), Askin and Standridge (1993), Buzacott and Shanthikumar (1993), Gershwin (1994), Papadopoulos, Heavey and Browne (1993) and Viswanadham and Narahari (1992). Two significant papers with efficient numerical procedures are those by Heavey, Papadopoulos and Browne (1993) and Hillier and Boling (1967) for short lines and Dallery and Frein (1993) for longer lines. The former make use of the traditional Markovian state model whereas the latter apply decomposition methods to calculate the various performance measures of the production systems.

One of the key questions that the designers face in a serial production line is the buffer allocation problem (BAP), i.e. how much buffer storage to allow and where to place it within the line. This is an important question because buffers can have a great impact on the efficiency of the production line. They compensate for the blocking and the starving of the line's stations. Unfortunately, buffer storage is expensive both due to its direct cost and due to the increase of the work-in-process (WIP) inventories. Moreover, the requirement to limit the buffer storage can also be a result of space limitations in the shop floor.

In Papadopoulos et al. (1993) both evaluative and generative (optimization) models are given for modeling the various types of manufacturing systems. The former are concerned with the evaluation of the various performance measures of the systems whereas the latter try to optimize these measures by determining the optimal values of the decision variables involved. This work falls into the second category. The literature on this problem again is vast. A systematic classification of the research work in this area is given in Papadopoulos et al. (1993) and Singh and MacGregor Smith (1997). The works are splitted according to the method used to solve the BAP. To our knowledge, three are the basic optimization methods:

1. *Search methods*. Traditional search methods such as the Hooke–Jeeves method have been applied as well as various heuristic methods. Some representative papers falling into this category are Altiok and Stidham (1983), Hillier and So (1991a,b), MacGregor Smith and Daskalaki (1988) and Seong, Chang and Hong (1995).
2. *Dynamic programming methods*. Several authors have employed the dynamic programming method for solving the BAP problem (see Jafari and Shanthikumar (1989), Kubat and Sumita, (1985) and Yamashita and Altiok (1997), among others). However, this method was employed in the case of a production line with synchronous transfer as defined in Papadopoulos et al. (1993), among others, where the steady-state throughput can be approximated in a closed and recursive form. Unfortunately, the dynamic programming method is not applicable to our case as this method needs a recursive formula for the throughput function and this is not possible for asynchronous transfer lines.
3. *Simulation methods*. These methods are evaluative rather than optimization methods. However, some authors have conducted extended simulation experiments to derive some design rules for the BAP (see for example Conway, Maxwell, McClain and Thomas 1988). Also, Ho, Eyler and Chien (1979) applied perturbation analysis in conjunction with simulation. These methods are not so efficient as simulation is time consuming and cannot be applied as an evaluation tool in conjunction with any search method.

Another classification of the research work relevant to the BAP is based on whether the lines under study are balanced or unbalanced. A line is called balanced (or unbalanced) if the mean processing times at each station are equal (or unequal). Powell (1994) provided a literature review according to this scheme.