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Asymmetrical buffer allocation in unpaced merging assembly lines

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A B S T R A C T

Asymmetrical merging assembly lines are a research area which is rising in prominence due to increasing use in reverse logistics, remanufacturing, and developing economies. This paper studies the performance of reliable, unpaced merging assembly lines with asymmetric buffer storage sizes. Lines are simulated with varying line lengths, mean buffer storage capacities and uneven buffer allocation configurations. Contrary to typical manufacturing expectations, results indicate that production line imbalances do not always result in detrimental performance. Higher throughput and lower average buffer levels, as compared to a balanced merging line, are found where total available buffer capacity is allocated as evenly as possible, and with a higher buffer capacity concentration towards the end of the line. This paper contributes to total production line knowledge by providing performance improvement methods for unpaced merging assembly lines with asymmetrical buffer allocation, and inexpensive or no cost managerial options to increase productivity and resource utilization, and decrease waste, in asymmetrical merging assembly lines.

1. Introduction

Due to their unique characteristics, reverse logistics and remanufacturing processes, as well as developing economies, commonly use asymmetrical and unpaced assembly lines. Research has indicated that production planning and control is an area of need of supply chain managerial skills development (Lorentz, Töyli, Solakivi, & Ojala, 2013) and that the implementation of lean production practices may result in greater uncertainty and variance (Marodin, Frank, Tortorella, & Saurin, 2016). With substantial global production taking place in lesser developed economies, this research has significant implications across industries. Also of increasing importance, supply and demand patterns in the growing industries of reverse logistics and remanufacturing differ significantly from those typically experienced in traditional manufacturing (Erol et al., 2010; Fleischmann, Beullens, Bloemhof-Ruwaard, & Wassenhove, 2001; Guide & Wassenhove, 2001), resulting in inconsistent supply patterns which are sometimes unable to meet consistent and quality source demand requirements. In addition, unpaced assembly lines may be quickly implemented to meet short-term needs, increasing process variability (Hudson, McNamara, & Shaaban, 2015). A combination of these unique characteristics reinforces the value of unbalanced and unpaced assembly line research.

Unpaced parallel merge lines are considered stochastic serial queuing systems with high volume. They involve no mechanical pacing; hence line workers are free to set their own pace. Work-in-process (WIP) inventories are commonly kept between stations so that partially finished items are transferred to a buffer or storage location. Fig. 1 illustrates a common merging assembly line which includes a series of parallel work stations and asymmetrical capacity buffers, leading to a merge or assembly station.

Merging lines with asymmetrical buffer capacities are an important research and practical topic since technical considerations often constrain available line space, resulting in uneven allocation of total buffer capacity across the line. Since this is a common experience, determining how to best to allocate asymmetrical buffer space to meet desired performance objectives contributes value to both research and industry.

Previous simulation research on reliable lines with unequal allocations of buffer space (Conway, Maxwell, McClain, & Thomas, 1988) suggests that buffer imbalance can be managed to (1) minimize its deleterious consequences, and (2) improve performance results under certain conditions, when compared to similar balanced lines. Despite this, research on asymmetrical buffer

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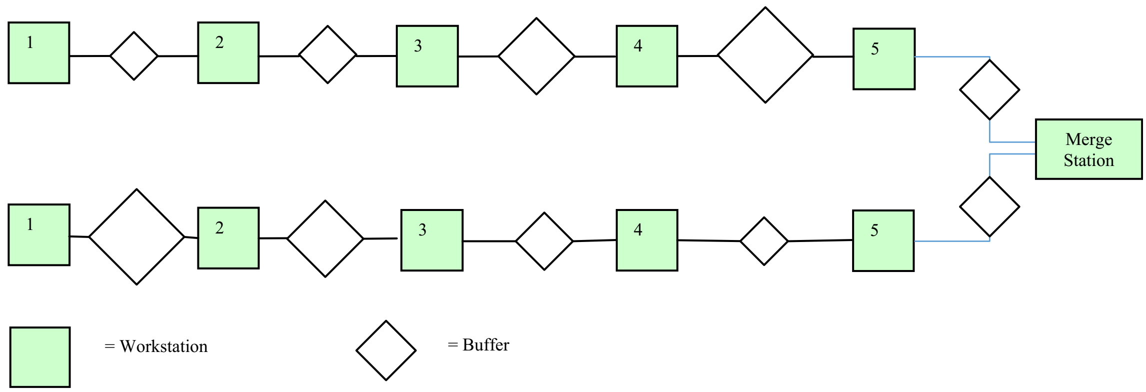

Fig. 1. An asymmetrical assembly line with 5 parallel stations, 4 *unequal* capacity parallel buffers, and a merge station.

effects on unpaced merging lines is scarce and provides a strategic gap which this paper attempts to fill.

The remainder of this paper is structured as follows. A brief literature review is followed by a presentation of the research questions. Subsequent sections discuss the methodology and design details, and describe the results and analyses. The paper ends with a discussion of implications and conclusions, with future research directions suggested.

2. Literature review

Literature on buffers first began following the post-World War II economic expansion and parallels the growth and evolutionary development of manufacturing. One of the earliest reported investigations on buffers was carried out by Koenigsberg (1959), who discussed basic production line problems and internal storage characteristics. Later, Buzacott (1967) arrived at an analytic method for determining the throughput and buffer management of a two-station production system (i.e. automatic transfer line). Gershwin (1987) than derived a decomposition method for buffering lines with unreliable machines, with Dallery, David, and Xie (1988) formulating an analytical method capable of evaluating systems with more than two stations.

Various aspects of the efficient allocation of buffers in automated and transfer lines have also been addressed and further refined over time. Ho, Eyler, and Chien (1983) derived a novel method for optimizing transfer line performance in which the "history" of the production line is incorporated into the computations. Altiok and Perros (1986) developed a decomposition method capable of analysing merging queues subject to blocking. Jafari and Shanthikumar (1989) framed the BAP for automated transfer lines in terms of a dynamic programming method and provided an efficient heuristic, while Bulgak and Sanders (1991) arrived at a hybrid analytic solution for the optimization of asynchronous assembly systems. Gershwin and Schor (2000) studied both the Primal (minimum buffers needed to achieve a given rate of production) and the Dual problem (maximum production rate for a given total number of buffers) for lines subject to failure. Shi and Gershwin (2009) later derived an efficient algorithm with regard to the optimization of buffer placement (subject to profit maximization). Papadopoulos, O'Kelly, and Tsadiras (2013) evaluated algorithmic search techniques for the efficient allocation of buffers by employing a Markovian as well as a decomposition method, but lines subject to failure were not expressly addressed. Recently, Shi and Gershwin (2016) studied unreliable lines having deterministic processing times. Kouikoglou and Phillis (1997) also investigated buffer allocation in unreliable continuous flow systems, while the buffering of job-shop fabrication systems has been studied by Huang, Chang, and Chou (2002) and Toba (2005). Detailed analyses of closed loop production systems were also carried out by Paik, Kim, and Cho (2002) and Zhang (2006).

Utilizing more advanced analytical techniques, studies have also applied mathematical programming to production systems that are modelled as discrete event systems (DES) to arrive at efficient buffer allocation solutions (Alfieri & Matta, 2012; Matta, 2008; Weiss & Stolletz, 2013). Comprehensive investigations into mathematical models as they relate to the effective use of buffers were also carried out by researchers such as Dallery and Gershwin (1992), Buzacott and Shanthikumar (1993), Papadopoulos and Heavey (1996) and Papadopoulos, Heavey, and Browne (1993), Papadopoulos, O'Kelly, Vidalis, and Spinellis (2009).

More specific and detailed reviews of buffer studies applying heuristic methods to the allocation of buffers provide a complementary stream of research. In this area, Buzacott and Hanifin (1978) reviewed and analysed the literature on predictive models for the performance of transfer lines with various levels of buffers. More recently, Sabuncuoglu, Erel, and Gocgun (2006), developed an efficient heuristic for the optimization of buffer usage in reliable unbalanced unpaced serial production lines and provided an extensive review of investigations into the BAP. Altiparmak, Dengiz, and Bulgak (2007) analysed buffering problems in assembly systems and transfer lines, while Vergara and Kim (2009) categorized buffer studies in terms of design rules and optimization algorithms, as well as the formulation of network structures arrived at through simulation. A detailed review of buffer investigations as they relate to "search" algorithms, "evaluation" algorithms, and meta-heuristic solutions was provided by Demir, Tunali, and Løkketangen (2011). This was followed up by an even more extensive review of the BAP in terms of both reliable and unreliable production systems in Demir, Tunali, and Eliiyi (2014).

Hence, it can be seen that there is a significant body of literature on the topic of buffer allocation and performance effects in *single*, *unparallel* production lines, but despite this body of literature, literature on buffer allocation in *merging* lines is sparse in comparison, and even less exists on asymmetrical buffer allocation in merging lines.

Some of this work began in the early 1990s, where Bhatnagar and Chandra (1994) studied the effect of variability on three-station assembly systems via simulation, and found that larger throughput improvements resulted from increasing individual station production rates than from increasing buffer sizes. Following their work, Powell and Pyke (1998) presented general strategies on the efficient placement of buffers in unbalanced assembly systems with random processing times. Futamura (2000) later studied optimal server allocation to tandem queueing networks with unbalanced mean service times (MTs), coefficients of variation (CVs) and buffer sizes and showed that (1) optimal configurations