Unpaced Merging Lines With Uneven Buffer Allocation

Sabry Shaaban*, Tom McNamara**, Viatcheslav Dmitriev**

* ESC La Rochelle, 17024, La Rochelle, France
(Tel: +33 05 46 51 77 00; e-mail: shabaab@esc-larochelle.fr).
** ESC Rennes School of Business, 35065, Rennes, France
(e-mail: tom.mcnamara@esc-rennes.com, viatcheslav.dmitriev@esc-rennes.com)

Abstract: As a common production practice in many developing economies and in reverse logistics, unbalanced merging assembly lines are a research area which is re-emerging in prominence. This paper aims to study the performance of reliable, un-paced merging assembly lines that are unbalanced in terms of their buffer storage sizes. Lines are simulated with different values of line length, mean buffer storage capacity and configuration of uneven buffer allocation. The best patterns in terms of generating higher throughput and lower average buffer level as compared to a balanced merging line are those where total available buffer capacity is allocated as evenly as possible between workstations and to concentrate more buffer capacity towards the end of the line, respectively.

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1. INTRODUCTION

Unbalanced and un-paced assembly lines are common in developing economies and also in reverse logistics and remanufacturing processes. Since many developed economy corporations outsource production to lesser developed economies, this research has global implications. In addition, particularly in reverse logistics and remanufacturing, demand and supply are upsized from those typically experienced in traditional manufacturing (Guide and van Wassenhove 2001, Fleischmann et al. 2001). Unlike traditional manufacturing, supply here is consistently inconsistent and cannot be expected to provide reliable volumes of standard quality source materials. In addition, unlike traditional manufacturing’s long planning processes, these assembly lines may be set in place for minimal time frames, to take advantage of short-term demand bursts, and then disassembled just as quickly to be reformed elsewhere, which increases process variability (Hudson et al. 2015). Given the explosive growth in remanufacturing and similar processes, this again reinforces the global implications of research on unbalanced and un-paced assembly lines.

Unpaced parallel merge lines are high volume stochastic serial queuing systems. With no form of mechanical pacing, workers along the line are free to work at their own pace. Provisions are usually made for keeping partly finished work-in-process (WIP) inventories between stations so that when work is completed at one station, the item is transferred to a storage location, or a buffer. Figure 1 illustrates a typical merging assembly line comprised of a series of parallel work stations and unequal capacity buffers, and a final merge or assembly station.

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

Merging lines unbalanced with respect to their buffer capacities are of great interest as technical considerations often restrict the amount of space available in the line, thereby making it difficult to allocate total buffer capacity evenly amongst individual buffers. How best to allocate buffer space in order to achieve the performance objectives desired is therefore a burgeoning area of research.

Simulation results from research into reliable lines where buffer space is allocated unevenly along the line (see for instance Conway et al. 1988), seem to show that not only can this buffer imbalance be managed in order to minimize its disadvantageous effects, but that performance can actually be enhanced in certain cases when compared to a corresponding balanced merging line with even buffer sizes through careful positioning of the buffers. However, studies of buffer imbalance effects on un-paced merging lines are scarce, and form the main focus of this paper.

This paper will first provide a review of the relevant literature, followed by a presentation of the motivation and objectives of the study. Subsequent sections discuss the methodology and experimental design, and provide the simulation results and analyses. The last two parts provide a summary of the results along with a discussion and some conclusions, with future research directions suggested.
2. LITERATURE REVIEW


However, the literature on buffer allocation in merging lines is rather scarce. Bhatnagar and Chandra (1994) used simulation to study the effect of variability on three-station assembly systems. Greater throughput improvements were possible from increasing the production rate of individual stations than from increasing the size of buffers.

Several years later, Powell and Pyke (1998) offered general guidelines regarding the efficient placement of buffers in unbalanced assembly systems having random processing times.

A study of optimal allocation of servers to tandem queueing networks with unbalanced mean service times (MTs), coefficients of variation (CVs) and buffer sizes (Futamura, 2000) showed that generally speaking, there is an interaction between the CV of the service time distribution and the number of servers at the stations and that the optimal configuration can be predicted.

Yuan and Liu (2005) investigated merging assembly systems with unequal buffers and exponential processing time distributions. They developed an analytical procedure which can be applied to intricate multi-stage manufacturing processes and probabilities for system events such as blocking, starving, stockouts and system availability.

Leung and Lai (2005) discussed strategies for installing parallel workstations to improve cycle times, compared to simple assembly systems. They concluded that off-line parallel systems work best in terms of reducing buffer requirements and reducing sensitivity to imbalance in terms of MT and CV compared to on-line and tunnel-gated systems.

Bulgak (2006) used a genetic algorithm and simulation approaches to yield maximum output, while optimizing buffer between workstations in split and merge unpaced assembly systems.

Abu Qudeiri et al. (2008) used a genetic algorithm to find the nearest optimal design for serial parallel production lines with unbalanced buffers with stations containing varied machine numbers and types at the workstations. They found that their algorithm was efficient and that its application to a parallel line system with 5 machines in each line improved design so that production efficiency rose from 80 to 85%.

Jia et al. (2014) studied the transient behaviour of assembly systems of merging serial lines that were comprised of Bernoulli machines (subject to failure) having finite buffers. Formulas were derived for the efficient measurement of throughput rate, work-in-process levels, and the probability that any one station will be blocked or starved. An analytical method was developed and applied to larger and more complex assembly systems with multiple feeder lines and multiple assembly/merge stations.

Given these few studies, the area of unpaced, unevenly-buffered merging assembly lines, is scanty researched. To contribute to this research area, we examine here the performance and operation of merging lines with unequal buffer sizes. Using simulation and statistical analysis, this study investigates if unbalancing merging line buffers could yield better results than from using a fixed buffer size all along the line. In addition, it examines how different design factors (line length, mean buffer capacity and pattern of buffer imbalance) influence merging line efficiency.

To our knowledge, there are no studies that observe the effects of various patterns of buffer allocation on throughput and average buffer level in un paced merge lines. It is hoped that the findings presented in this paper will contribute to a deeper understanding of how merging line design in terms of uneven buffer allocation can affect performance outcomes.

3. MOTIVATION AND OBJECTIVES

This paper focuses on merging assembly lines having one source of imbalance, caused by allowing buffer capacity to differ amongst stations, i.e. available total buffer capacity is distributed unevenly between workstations, while all stations along the line have the same MT and CV values.

Since there is a paucity of research on unevenly buffered merging assembly lines, this study contributes to the literature through a comprehensive and systematic investigation which fills some of the gaps left by the more general scope of previous research.

The research questions to be addressed are:
1) What is the influence of the pattern of buffer capacity imbalance on the performance of the merging lines simulated compared to that of an equivalent balanced line?
2) Which of the simulated patterns leads to the best performance?
3) What are the relative contributions of buffer imbalance pattern, line length and mean buffer capacity to performance?

4. METHODOLOGY AND EXPERIMENTAL DESIGN

Computer simulation was selected for this study for several reasons. Previous work has found that several limitations restrict the value of the queuing theory approach (both analytical and numerical) as it stands today (Altiparmak et al., 2002; Hillier and So, 1997). Firstly, it is known that as system size increases, the appropriate description and identification of its states needed to develop the necessary linear equations become very complex and difficult. The rapid rise of the number of system states with slight increases in line length and buffer size is one of the causes of this complexity. For example a line with three stations and no
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