Operations status and bottleneck analysis and improvement of a batch process manufacturing line using discrete event simulation

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Abstract

There are many product and process variations in the production systems of batch processing. Planning and executing such manufacturing operations can be a significant and challenging task. Discrete Event Simulation is an effective tool to analyze the moderate complex product and process variations and predict the operations status and bottlenecks of an existing manufacturing system, which is critical to the operation planning, execution, and improvement. This study simulates the first process stage of tire manufacturing in batch process involving product variation and process variants. The study analyses the operations status, bottlenecks, and the interdependence of the manufacturing activities between machines. In the simulation modeling and analysis, the efficiency of machines, reliability, quality, and setup time are considered. The simulation identifies the operation bottlenecks and WIP status, and proposes process changes for improved production efficiency. The simulation study helps schedule operations to reveal the requirement/necessity of changes or addition of the buffer based on buffer status analysis. The model can also verify the changes of machines for throughput improvement.

Keywords: batch processing; discrete event simulation; bottleneck; buffer analysis; throughput improvement

1. Introduction

Batch processing is widely used in a high-volume production environment. Batch processing is planned and executed with considerations of various product specifications and manufacturing processes to meet customer
requirements. Compared with the repetitive processes in a high-volume production, the batch processing has more variables and complex impacts on manufacturing operations. Therefore, to achieve optimal operational productivity is challenging for the planning and execution of batch processes.

Discrete Event Simulation (DES) is an effective tool to analyze complex manufacturing operations with product and process variability. In addition, DES has advantages for performing analysis to any future scenarios for improved process time and efficiency. For example, DES has been used for the efficacy of introducing new processes or equipment in an existing factory and measuring the interoperability. As a tool, DES is used for imparting the data available with most of influential variables in the model, the product mix, at different stages and sequences in this study.

1.1. Literature Review

The line configuration for implementing lean manufacturing in high volume production encompass the use of pull systems (i.e., JIT, low inventories, short setup times, and make-to-order), emphasis on immediate resolution of quality problems, cultivation of multi-skilled workers, and use of worker teams [1]. The systems versatility for futuristic or newly-established production setups needs to be studied based on the design viewpoint of the production layout designer which would indicate the follow-up processes need to be taken in time for example change in layout, stand by machine setup and routing, repair arrangements and troubleshooting setups and resuming production. There are also studies in complex manufacturing environment, such as shipyard, that are complicated to be resolved by mathematical analysis and simulation methods have proven better for analysis and understanding their behaviors [2].

The Little’s Law predicts material stagnation due to work-in-process (WIP) or machine failures leading to long process time. The theory of constraints focus on the rigid bottleneck that causes the main inventory of the system. The buffer line must be set up for the production to have smooth flow and keep pulling in the orders. There is analytical equation available for buffer level calculation of the system with coefficient of variation and serial line machines [3]. For a new or trial-run system, the analysis on the pre-optimized production plans or existing production plans using multi objective criteria has also been studied in the basis of cost and bottleneck [4]. Their study show that an optimization-based mathematical model is used with the material flow simulation. These models also suggest that the subroutine models can be built in order to set objective parameters in the existing visual model templates for optimization. The visual model templates being modeled correctly allows a good platform to analyze the variation happening in the environment and be used for simulation-based forecasting and scheduling [5].

The use of analytical methods for different line configurations have been discussed [2, 3, 6]. For efficiency, several criteria taken into consideration for lean enterprise auditing as in WIP, buffer status, bottlenecks identification and are considered for improvement, such as smallest buffer capacity with multiple units sufficient to ensure production rate. Analyzing the serial production machines with re-entrant lines through the aggregated models with forward and backward aggregation are developed and compared with simulations [2].

Computer simulation is considered an indispensable method of problem solving [7] in different application contexts, outstandingly necessary in the cases of testing of a complex system and design of a new system [8, 9]. The simulation modeling approach can consider all decision variables and systems parameters, such as capacity and machine’s speed of operation that affect the performance measures of the system such as production rate serve as input [10, 11]. In all cases the system and inputs must be learned upon time for any high-volume production runs alike initial inventory and minimum runtime. Most of the DES software has the capability to add routines such as bottleneck detection methods that increases its potential [12].

The papers studied basic serial and parallel process lines with different efficiency, which provides a good platform for the study of DES for different applications like shipyard and automotive manufacturing. The studies established general guidelines for modeling, such as distribution selection, implementation of effective time for processing and warm up times [13]. The bottleneck identification methods and their algorithm gives an insight in how to interpret the results from the software. With these ideas and studies with essential parameters, the DES can be applied to different manufacturing environment, for example complex batch processing. All the research and literature provide a good foundation on a special study on multiple product and process variables in a batch process model.
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