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Original article

Application of computer simulation experiment and response surface methodology for productivity improvement in a continuous production line: Case study

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ABSTRACT

This study focused solely on a paint manufacturing industry in Iran that will help managers to effectively manage their enterprise. The goal of this paper is to integrate simulation modeling along with response surface methodology (RSM) and design of experiments (DOE) in order to analyze and improve the productivity in a selected continuous paint manufacturing industry. Computer simulation is developed to propose different scenarios as the inputs of DOE. Based on the final results, the optimum productivity was achieved at the point of 93.5, that is relevant to the number of labor (B) = 26 and failure time of lifter (C) = 56.01 min. Moreover, the other two factors, A (service rate of delpak mixer) and D (number of permil) should be located at a low level. Quality and production managers, engineers as well as academicians can implement the results of the current study in other case studies. This approach can be generalized to other manufacturing systems to improve their productivity in a timely and cost-effective manner.

1. Introduction

In the manufacturing industry, managers and engineers are seeking to find methods in order to eliminate the common problems in production lines such as bottlenecks and waiting times. This is because all these kinds of problems impose an extra cost on companies (Zahraee et al., 2014b). In addition, manufacturing companies are striving to sustain their competitiveness by improving productivity, efficiency, and quality of products. It can be acquired by finding ways to deal with various industrial problems which have affected the productivity of manufacturing systems such as high lead time and Work in Progress (WIP) (Zahraee et al., 2014d). Moreover, some parameters, such as machine capacities and availability of resources have significant effects on aspects such as throughput, cycle time and average delay in a continuous production system. Some of them may have more considerable effects on the system performance compared to the others (Zahraee et al., 2014a). On the other hand, limitations of the use of one or two machines or resources can lead to bottlenecks that cause delays in the whole operation chain. Therefore, it is necessary to handle the bottlenecks in order to enhance the system performance by assessing different parameters that have considerable effects on it. In this regard, it is difficult to find the root of the problem if the production line is plagued with difficulty related to resource availability (Hatami et al., 2014). This can be achieved by finding a suitable and cost-effective way to improve productivity as well as to decrease the occurrences of bottlenecks (Jahangirian et al., 2010). In recent years, big efforts have been done to show the different bottleneck definitions, results and detection approaches. However, there is still no commonly accepted definition or detection method. This is principal because of the diversity of the bottlenecks in different application scenarios. This proves to create challenges and problems in implementing the theoretical results in real life applications. There are some investigations which suggest that approaches, such as DOE help engineers to deal with these problems by recognizing the important factors affecting system productivity (Zahraee et al., 2015a). By conducting experimental designs, engineers are able to predict how changes in input factors affect the responses of an experiment (Barton, 2013). Computer simulation is another suitable and popular approach for estimating the performance of complex systems with complicated processes, especially systems that involve

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random phenomena. Due to these reasons, simulation experiment plays a leading role in projects that are done within time and budget limits. This is because, in these projects, a considerable amount of effort is allocated for developing and validating the model. Hence, within a limited time or budget constraint, simulation will help decision makers to simulate projects in a cost-effective and timely manner (Sargent, 2005). According to a previous study (Hatami et al., 1990), the applications of experimental designs and simulation to improve productivity can lead to significant savings. Additionally, the result will be more credible and reliable as all possible combinations of factors are examined. Furthermore, it is easier to justify the recommendations because the verification runs have validated the result of the model (Hatami et al., 1990).

RSM is another novel statistical method, its combination with computer simulation and DOE can be applied to develop a model that can assess the impact of important factors on manufacturing system. Suggesting a simulation-RSM model for the goal of evaluating production line and productivity rate can be useful and advantageous because; (1) Making key decisions is a significant issue to top management in any manufacturing industries, (2) Productivity of manufacturing industry should be exactly evaluated because of major limitations in labor, time and cost, and (3) Applying different techniques to improve processes deprived of interrupting the operations of the system as well as to assess their effect before implementation (Kouritzin et al., 2014). So in this paper, computer simulation is developed to propose different scenarios as the inputs of DOE. This paper aims at presenting a new idea for using response surface methodology along with the computer simulation experiment to fill the gap in order to improve the productivity of a selected paint production line with a continuous and complex process in Iran's paint industry in a cost-effective and timely manner.

2. Computer simulation and design of experiments applications

Computer simulation is one of the most effective approaches that can be used to deal with the operational difficulties to increase productivity in different fields, such as production line (Zahraee et al., 2014a), port and transportation industry (Shahpanah et al., 2014), supply chain management (Golroudbary and Zahraee, 2015), healthcare system (Zahraee et al., 2015b) as well as construction industry (Zahraee et al., 2014c), all of which are not easy to model. Computer simulation has a significant effect on financial and operational parameters by saving monetary cost of investment, decreasing process cycle time, increasing resource utilization and enhancing throughput (Zahraee et al., 2014a). Moreover, Tsai (2002) claimed that computer simulation plays a vital role in solving the problems related to the integrated manufacturing systems as well as analyzing, designing and scheduling the production systems instead of applying complicated mathematical model equations. Benefits of simulation modeling are (Kikolski, 2017):

- to organize a type of system with experiments implemented on the investigated model.
- to deal with large and complicated decisional issues that cannot be handled with the application of other approaches.
- to prepare decisions quickly as a result of analyzing the impact of experiments carried out for many periods.
- to find an answer to the "what-if...?" questions – simulation experiments help to assess different decisional alternative scenarios.
- to analyze correlations of the effects of factors of a model that can affect the decision selected in different conditions.

There are many companies whose manufacturing systems are subjected to a stochastic behavior (e.g. random arrival of orders) and where frequent changes occur, for example due to fluctuation in the customers' demands. For such types of systems, the starting time and completion times of jobs can be unpredictable (Ferjani et al., 2017).

DOE is a statistical approach that can create a correlation between the significant parameters and the response of a process (Sadeghifam et al., 2015). The adoption of DOE helps to manage the process inputs for optimizing the output of a process (Steibel et al., 2009; Tack and Vandebroek, 2002), hence, several investigations had used DOE and computer simulation to predict a system's behavior. In this light, thanks to a large number of input factors and the high cost of experiments, computer simulation can be a useful and powerful tool for doing experimental tests in cost-effective and reliable conditions (Wang and Halpin, 2004; Ebrahimy et al., 2011; Hassan and Gruber, 2008). Tsai (2002) used DOE, along with computer simulation to assess and optimize the operation of a joined manufacturing system. In another research, Baesler et al., (2004) developed a computer simulation model of sawmill factory in Chile to enhance the productivity of the wood industry by decreasing bottlenecks. Consequently, a DOE experiment was conducted to present the minimum number of physical resources and human that are essential to satisfy the demands. The final results showed that by using this combined approach, productivity was improved by 25%. Furthermore, Nazzal et al. (2006) selected a semiconductor company as a case study to accommodate an easier decision-making process by combining DOE, computer simulation, and economic analysis. Meanwhile, Zahraee et al. (2014d) applied DOE and simulation to find the optimal set of parameters that have a considerable influence on the process productivity in the paint industry. Hatami et al. (2014) assessed the importance of different parameters on a production line using simulation and DOE to improve productivity. Final results showed that the number of workers and failure time of lifter machines have the most considerable impact on performance (Hatami et al., 2014). In another study, the statistical Taguchi method and computer simulation were combined to investigate the impacts of main and uncontrollable parameters on the overall production output in the paint factory. It was cited that the optimum value of productivity will be obtained when the values of main variables, like the service rate of the delpak machine, number of labor, inspection time and number of permil, were equal to UNIF (30, 40), 14, 120 and 5, respectively (Zahraee et al., 2015a). Based on these investigations, the technique has improved the productivity of manufacturing processes and reduced trials and errors to find the best solution (Montevechi et al., 2007). Dengiz et al. (2016) showed how the combination of regression meta-modeling techniques and simulation modeling can be applied to design and improve a real automotive manufacturing system.

Previous investigations in this area indicated that to analyze a system, the simulation outputs can be applied as inputs to the experimental design. Compared to other recent research, this paper presents a novel approach as it implements the response surface methodology to fill the gap, as well as to deal with the bottleneck problems related to the Iran's paint industry which has never been done before.

3. Material and methods

3.1. Case study

For the case study in this research, a paint factory that has a continuous and complex process was selected. This company is one of the primary and most reputable industrial and construction

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