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A meta-model based simulation optimization using hybrid simulation-analytical modeling to increase the productivity in automotive industry

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Abstract

Simulation modeling is one of the most useful techniques to analyze and evaluate the dynamic behavior of the complex manufacturing systems. Combining the mathematical power of an analytical method and the modeling capability of simulation with optimization approach called hybrid simulation-analytical modeling has been presented rarely. In this study a production control model is developed for a paint shop department in an automotive company in Turkey. As a real case study, the optimum operating setting of a paint shop production line of automotive company is determined using hybrid simulation optimization approach. In the optimization stage of the study Design of Experiment (DoE) is used to identify critical variables of the system by fitting a polynomial to the experimental data in a multiple linear regression analysis. The meta-model is validated and shown that it provides good approximations to simulation results. Findings from hybrid simulation-analytical optimization approach give invaluable knowledge to the company for the re-designing and control of current manufacturing system to increase its productivity.

Keywords: Simulation optimization; Design of experiment; Multiple linear regression model; Paint shop production line; Automotive industry

1. Introduction

The existence of companies in today's automotive industry is the fastest growing sector in Turkey in both external trade and the share of the industry. Changing customer demands and today's global competence forces the Turkish automotive firms to be more productive with high level of quality. Due to today's highly competitive global economy, manufacturing companies must be able to adapt to its customers' needs and improve the quality of its products in order to survive [7]. They also have to use new technologies and production models to produce the products faster, cheaper, flexible, and more effectively [14].

It is known that traditional techniques are not appropriate for analysis of complex manufacturing systems such as the systems in automotive industry. Because of the complex stochastic characteristics of automotive production

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systems, simulation is used to easy understand and explain their behavior and the effects of design factors on the production system's performance [32,33]. On the other hand, simulation an alternative tool, overcomes the complexities of stochastic systems yielding probabilistic outputs [17]. However, the important drawback of simulation for practical applications is that it is computationally time consuming [7]. Therefore, an abstract model called meta-model is needed to replace the simulation model.

The principal aim of this study is to provide a systematic methodology to analyze the daily production control of a paint shop department in an automotive company. Controlling for production capacity at the factory level, requires answering what-if questions involving different scenarios for system attributes, product specifications, production targets and capital expansion. In this paper, we propose a production control model that improves of daily production rate of a paint shop department in an automotive company subject to controllable parameters.

The first objective of this study deals with determining more controllable and productive paint shop production system for an automotive company. This study also demonstrates how simulation modeling and the regression meta-modeling approach – as an objective function – can be used to design and optimize a multi-stage real automotive production system in detail. Hence, practitioners and engineers working in the automotive firms can do easily similar simulation optimization studies for their companies. The rest of the paper is organized as follows: In Section 2, a literature survey is presented. In Section 3, steps of the hybrid simulation optimization methodology are shown. In Section 4, a real case study application is illustrated. In Section 5, the conclusions are presented.

2. Literature

Simulation optimization has a wide application area in production and service systems for the re-design of an existing system or the development of a new system. In the literature there are various simulation optimization studies have been proposed [1–4,6–8,13,16,21,20,22–24,26,27,30,31]. For example, Dengiz and Akbay [6] proposed a regression meta-model to optimize batch sizes in a printed circuit board assembly line considering MRP and JIT models. Barton [1] reviewed different methods for choosing a functional form for the meta-model relationship such as polynomials, Taguchi models and generalized linear models. In Madu and Kuei [23], group screening and Taguchi methods were employed in the design of a multi-echelon maintenance float simulation. Additionally, Lin and Cochran [21] studied the dynamic performance of a hypothetical multi-station, multi-server assembly line. Kleijnen and Sargent [16] used a sequence of two-level fractional factorial designs to estimate a first-order meta-model that can be used to analyze and optimize the metal tube production process of Dutch companies. Sridharan and Babu [30] and Park et al. [27] presented a detailed simulation study on a typical FMS. Lin and Chiu [20] modeled a manufacturing cell with a fixed flow pattern considering dynamic effects of machine breakdowns and job changes [7].

In recent studies, Yang et al. [34] proposed a simulation-based methodology to map the mean of steady-state cycle time (CT) as a function of throughput (TH) and product mix (PM) for manufacturing systems. In their study, a new meta-modeling methodology, coupled with preliminary queuing analysis, is proposed for generating the CT–TH–PM response surface via sequential simulation experiments. The resulting their meta-modeling application is able to provide a CT estimate for any TH and any PM [33]. Ekren et al. [10] selected the best combination of numbers of lifts and vehicles from pre-defined scenarios that are the key components of the manufacturing system. In their studies, a simulation based experimental design is proposed for an Autonomous Vehicle Storage and Retrieval System (AVS/RS). They apply design of experiment (DoE) for a system with combination of lifts and vehicles and for various arrival rates. Kuo et al. [18] proposed a gray-based Taguchi method to solve the multi-response simulation problem. In their studies, the gray-based Taguchi method is based on the optimizing procedure of the Taguchi method, and adopts gray relational analysis (GRA) to transfer multi-response problems into single-response problems. Dengiz [5] used Taguchi design for optimization of the Printed Circuit Board (PCB) production line in an electronic company. Sandanayake et al. [29] presented a systematic modeling and simulation approach for JIT performance optimization. The main objectives of their studies are to obtain the meta-model as the abstraction of simulation model.

The first real case application of hybrid simulation-analytical model was introduced by Dengiz et al. [7]. In their study, they optimize the working conditions of diamond tool manufacturing system to obtain more productivity under considered constraints. To the authors' best knowledge; there are a few simulation optimization studies for automotive industry is available in the literature. For example, Wang et al. [32] analyzed the main parameters that affect the fuel consumption of Hybrid Electric Bus (HEB) and their respective levels. In their work, they discuss conducted orthogonal experiments to optimize the parameters of the hybrid propulsion system. Park et al. [28] proposed an approach that