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Performance evaluation of a petrol station queuing system: A simulation-based design of experiments study

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ABSTRACT

The main goal of this paper was to develop an integrated simulation-design of experiments (DOE) model to optimize a petrol station queuing system and sales rate. Initially, the petrol station operating system was simulated using Witness 2014 simulation software©. Then, the responses of simulation were deployed as the input of DOE. Two-level full factorial experiments with center points were performed where the simulated model parameter studied were number of pump, number of cashier and inter arrival times (IATs). The response variables analyzed were queue length and sales rate. The obtained model from experimental design revealed that number of cashier and inter arrival time were significant in determining the queue length while all the factors and their interaction were significantly affecting the sales rate.

1. Introduction

Service industries recognized that improving and optimizing their service level is extremely required to increase the efficiency in competitive markets [1]. Customer satisfaction has been announced as one of the most significant parameters of making competitive advantage in service industries [2–5]. Many people use petrol stations' services in their daily life. Petrol companies can increase their profit through satisfying their customers. In this industry, competitive advantage can be translated into three perspectives of petrol quality and service speed as well as price. Since the quality and price are commonly comparable in majority of the markets, speed service and consequently queue length can be considered as the most influential factor on customer satisfaction and correspondingly the revenue [6].

Simulation modeling, mathematical programming and statistics can be considered as useful tools for all managers, researchers and practitioners to analyze dynamic systems without interrupting their operations [7–9]. In addition, simulation modeling of real world cases and its integration with DOE models is a challenge for many practitioners, managers, and researchers [10–14].

Since the DOE is an active statistical technique, its integration with simulation can be used to predict a model which can evaluate the effect of significant factors on queuing system. Proposing a simulation-DOE model for the aim of assessing petrol station queuing system and correspondingly sales rate can be beneficial because; (i) Making critical decisions is a serious challenge to top management in different service industries, (ii) Performance of service industry should be exactly assessed due to numerous restrictions in time, cost, labor and different sources of energy, and (iii) Using different tools to optimize processes deprived of interrupting the system operations and evaluate their influence before implementation [15–17].

Although the application of simulation in service industries has been discussed by many authors [18–22], only a very few attempts have been made to integrate it with design of experiments. Based on our best of knowledge, there is no integration on evaluating the performance of petrol station queue system.

This study contributes to integrate simulation modeling with DOE in order to analyze and optimize a petrol station performance. It introduces a new idea for using computer simulation and proposing different scenarios as the input of DOE. This approach provides a valuable contribution because it is impossible to stop the operating system or change the layout due to constraints of cost, time, labor and many other factors. The novelty of this study lies on integration of simulation and design of experiments in a petrol station which will lead to obtain a predictable model in order to optimize the best scenario for a petrol station considering two perspectives of queue length and sales rate.

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2. Literature review

Simulation has been practiced to numerous segments including services, manufacturing, healthcare, defense and public services [23–27]. It is known as one of the most proper commonly used approaches in the field of operations management [28–32]. The appropriateness, suitability and relevance of simulation methods is a significant issue to study in applied real-world applications, chiefly as there is a rising necessity to address the difficulties of the entire enterprise [19,33–36].

In any service organization, managers are mostly concerned about the customers and their profit simultaneously [13,37,38]. The important structures of a standard queuing system contain line structure, demand group, entrance and service procedures, and queue discipline [36,39,40]. The majority of existing studies in service industry focus on maximizing the customer satisfaction. The type and quality of demand or quantity of customers, serving priority, the tolerable queue length, the bearable waiting time are the major factors which can affect customer satisfaction. The waiting time and queue length are two important issues that play significant roles in customer insight about the service quality. Though, to have an optimal service configuration, both the customer satisfaction and enterprise revenue should be considered simultaneously. Consequently, numerous decisions should be evaluated to attain the best likely scenario which is tolerable from both the customer's and service provider's view point [41–44].

Different approaches have been applied to progress service quality and subsequently customer satisfaction in petrol service industry. Previously, Cornillier, Boctor [45] developed an exact algorithm for the petrol station replenishment problem. Moazzami et al. [9], focused on simulation, modeling and analysis of a petrol station where a petrol station behavior was simulated as one of the most significant sections of service industry.

Design of experiments (DOE) is a mathematical, statistical and systematic technique in order to determine the relationship between affecting process factors and the output of that process. In other words, it is utilized to find cause-and-effect and interaction between parameters where in one-factor-at-a-time approach not possible. Analysis of DOE results is essential to manage process inputs in order to optimize the process output [46–48].

Cheng and Kleiinen [49], established optimal DOE with simulation models of nearly saturated queues. The application of computer simulation have been suggested and executed to solve the problems of variation in incorporated manufacturing systems. Though, a simulation model merely acts as a device in investigating performance. Tsai [31], focused on assessment and optimization of joined manufacturing system operations with the aim of experimental design in computer simulation. The results show that this approach can consider the assessment and optimization of operating situations in multifaceted systems concurrently.

A comparison of experimental designs for simulation-based symbolic regression of manufacturing systems was provided by Can and Heavey [50]. The objective was to identify a robust sampling approach. In a very recent study, Li et al. [13] developed a Simulation-based experimental design and statistical modeling for lead time quotation. This work developed a simulation-based statistical method to offer high-quality and responsive forecast of a new job's flow time through the system, that reduces the ability of precisely quoting lead times in real time. The method incorporated analytical queuing analysis, design of experiments, and statistical modeling.

Previous studies on this field show that the simulation results can be used as an input to design of experiment. Simulation and DOE are some tools to analyze the behavior of a system. In this study the behavior of the petrol station queuing system was simulated and the model outputs were used as the raw data of DOE.

According to the previous literature, this is the first attempt to analyze a petrol station queuing system using an integrated simulation-DOE model. Trying to fill the gap in the literature, this paper proposes an integrated simulation-DOE model to analyze and optimize the queuing system of a petrol station by considering different scenarios, in order to assist managers to efficiently manage their enterprise.

3. Case study

The case study is located in Skudai, Johor, Malaysia. It consists of two main platforms. Each of these platforms comprises four fuel dispensers. Every fuel dispenser comprises two nozzles that pump two types of Octane 95 and Octane 97 fuels. There is also a supermarket in which customers do their shopping (if any) while refueling their cars. Two cashiers work in this station; one of them performs customers' payments for those who just do the refueling process. The other cashier performs the shopping related affairs as well as payments for the fuel. Customers have the chance of paying the fuel price (Octane 95 or 97) either by cash or with a credit card.

3.1. Petrol station layout and process mapping

The petrol station layout is shown in Fig. 1. 'D1–D8' indicates the number of pumps. Conceptual model is used to map the whole process. The whole process and inputs flow through the output is depicted in the process map as Fig. 2. The process commences with cars arrival to the station and chooses the desired pump among 8 available options. Their selection would be influenced by the least quantity of cars in the queue and distance to the counters if they cannot find an empty queue.

The next process is the payment task which involves paying money refers to desired fuel type (petrol 95 or 97). Once the cashier received the payment, the pump will be replenished exactly as the payment quantity (Octane 95 or 97). Refueling process starts once the drivers comeback to the selected pump and pick the desired nozzle (Octane 95 or 97). Afterward, the pump will refill the fuel tank equal to payment. Once the refueling process ended, drivers put the nozzle back and leave the system.

4. Model development

The problem in this case can be classified into two categories: first, it is related to the service level which petrol station provide to the customers and the second one, refers to the pumps and cashiers idle times. In addition, based on the observations, the IATs, fuel and payment choice varies depending on the time and the type of cars. This problem worsens in unusual times such as rush hours or holidays. Consequently, top managers may be dissatisfied with the efficiency of the petrol station due to its crowdedness or under capacity usage. In addition, managers have to pay for maintenance, cashiers and many other expenses which can be avoided by optimizing the petrol station queuing system.

4.1. Model assumption

Following assumptions are considered in simulation modeling:

- All customers have 4 choices to select from; petrol types (Octane 95 or 97) and payment method (by cash or credit card).
- No customer leaves the system after entering the Queue.
- Shopping from petrol station supermarket was considered in the system.
- There is no jockeying in the system (changing the Queue lines).
- The observation process (data collection) was completed in numerous days of the week and different hours of the day.
- Some fluctuations in the petrol rates were ignored.