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Productivity Improvement at Motor Vehicle Inspection Station by using Taguchi Approach

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Abstract

Motor vehicle inspection (MVI) services and the measurement of exhaust emissions have become significantly important in recent years due to the increasing air pollution in large cities. A part of the urban air pollution is due to exhaust emission from motor vehicles and thus periodic inspections are enforced by law. In Turkey, the periodic inspection of motor vehicles has been performed by a privately owned company since early 2000's. The company largely contributes to traffic and vehicle safety in Turkish roads as well as air pollution via exhaust gas emission testing services.

The aim of this study is to optimize the daily throughput at the MVI station. All vehicles are admitted via a prearranged appointment procedure and each vehicle has to be inspected on the day of the appointment. A low admission rate will clearly result in lower inspection rate at the end of the day leading to a lower revenue whereas a high admission rate will certainly bring higher revenue at the expense of unwanted high waiting times or long delays at the queues. The main focus of this study, is to establish a balance between vehicle admission (appointment) rate and mean waiting times of the vehicles. A discrete-event simulation model is constructed by using the ARENA software which re-creates the inspection process and daily operations in the MVI station is simulated. Several vehicle admission (appointment schedules) policies, different processing sequences during the inspection have been considered. A Taguchi DOE framework is constructed to optimize the throughput at the MVS. Recommendations are offered to increase the throughput while keeping the waiting times at a reasonable level.

Keywords: Motor vehicle inspection, simulation, Taguchi approach

1. INTRODUCTION

Since the time service industry overpasses other industries (manufacturing, mining, agriculture etc.) in a country's economy, effective and efficient use of the service systems has been one of the most important issues in the management of these systems. Typically a service is produced upon demand since it is not possible to produce and store them. Moreover, the demand for a service is highly variable and depends on a number of factors such as price, brand name, level of advertising etc. Therefore, the demand needs to be estimated beforehand so that the service supplier can meet fully the demand on time. When these two significant factors come together under a service capacity limitation, development of queues becomes unavoidable. Usually, shorter queues are tolerable by the customer to some extent; on the other hand longer queues are not welcome. Therefore, a delicate balance between demand and delay is needed.

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Vehicle inspection is a procedure required by governments in many countries, in which a vehicle is inspected to ensure that it conforms to regulations governing safety, emissions, or both. Usually a vehicle is required to be inspected every two years depending on the status of the vehicle. In Turkey, the government decided to introduce vehicle inspection services following the European Union directives. In 2005, a privately owned company is given a monopoly on car inspection for 20 years. [1]

There are researches focusing on the operational problems at vehicle inspection stations. For instance, [2] used simulation to improve operational effectiveness at vehicle inspection centers in England. In particular, simulation is used to gain insights, model the interactions of operational activities and experiment with specific operational policies.

Stochastic multi-objective optimization approach is taken in [3] where two practical stochastic multi-objective programs are built subject to stochastic demand, varying velocity, and regional constraints considering the vehicle inspection station as a typical automotive service enterprise example. This approach is applied to a real-world location problem of a vehicle inspection station in Fushun, China.

Monte Carlo simulation is an objective and powerful method in capital budgeting analysis. Ref. [4] provides an application of Monte Carlo simulation in capital budgeting process for vehicle inspection station investment in Denizli, Turkey.

The Taguchi method is an experimental design technique seeking to minimize the effect of uncontrollable factors, using orthogonal arrays. It can also be designed as a set of plans showing the way data are collected through experiments. The Taguchi method has been frequently used together with simulation studies in literature. For example, [5] used Taguchi experimental design methodology with ARENA simulation to prove that experimental design is an utilizable method to be used effectively in the design of material handling–transfer systems and performance optimization of automation technologies. Other examples are, [6] analyzed the output of a dynamic simulation by using the Taguchi method to design a robust blood supply chain system at the national blood center in Iran. References [7], [8], [9] are other studies to figure out optimal levels of control factors affecting the performance of the system.

In this study, a discrete-event simulation model of a MVI station is constructed using the ARENA simulation software. A Taguchi DOE framework is constructed to optimize the throughput at the MVS. We considered four control factors: vehicle admission rate, vehicle calling frequency, number of technicians in the station and queueing discipline (LIFO, FIFO).

2. MATERIALS AND METHODS

2.1. Discrete-Event System Simulation

Discrete-event system simulation is the modeling of systems in which the state variable changes only at a discrete set of points in time. In simulation, models are run rather than solved which means an artificial history of the system is generated from the model assumptions and observations are collected to be analyzed and to estimate the true system performance measures. Real-world simulation models themselves as well as the data required are rather large. Therefore special simulation software is available to the practitioners [10]. One of the main advantages of simulation is that it allows experimentation on the model rather than the real world system which can sometimes be prohibitory.

In this study, a simulation model is constructed using ARENA software to simulate the operations of a MVI station. ARENA simulation model is shown in Figure 1.

2.2. The Taguchi Method

The Taguchi method is due to Dr. Genichi Taguchi who developed it after World War II in Japan. His most notable contributions lie in quality improvement, but in recent years, the basic concepts of the Taguchi method has been widely applied in solving optimization problems. Because the Taguchi method is a kind of fractional factorial DOE, the required simulation runs or the number of experiment at times can be reduced, compared to full factorial DOE. For example, if there are seven two-level factors in a design problem, only eight simulation runs have to be done in the Taguchi method. In DOE, however there are 2^7=128 simulation runs that have to be done. The main objective of the Taguchi method is to decrease the effect of noise factors as well as to determine the optimum level of the control factors by considering the Taguchi's robust design [6]. Using orthogonal arrays, simulations can be executed in a systematic way. From simulation results, the responses can be analyzed by level average analysis and signal-to-noise (S/N) ratio in the Taguchi method [11], [12].

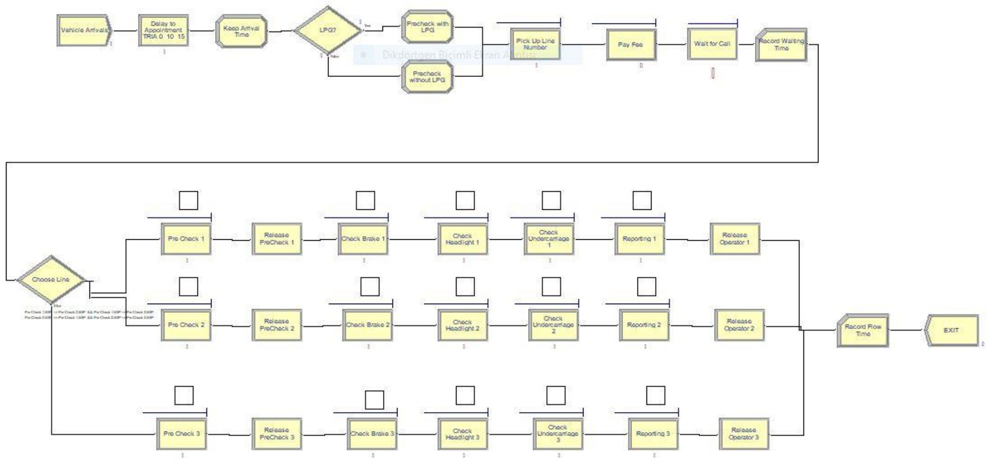

Figure 1. ARENA simulation model of the MVI station

2.2.1. Control Factors

The following control variables are considered:

Vehicle Admission Rate (A): Vehicles are admitted into the station on an appointment basis and this is the number of appointments allocated for each appointment time slot of length 15 min. This allows us to control the admission rate as a controllable factor. It is assumed that vehicles arrive early according to a triangular distribution along the 15 min interval.

Vehicle Calling Frequency (B): Arriving vehicles are called for inspection at regular intervals. This is the time between two consecutive calls of vehicles.

Number of Technicians (C): This is the number of technicians available at the station. All technicians are assumed to be available during the work day.

Queue Discipline (D): This queue discipline is used when a vehicle is called for inspection. A FIFO queue prioritizes early arrivals whereas a LIFO queue gives priority to relatively “late” comers who are in fact punctual and stick to their appointment time.

These controllable factors and their levels are shown in Table 1. The output response variables are mean flow time for the arriving cars and the throughput is measured as the percentage of the cars whose inspection is completed during the workday.

Table 1. Main factors and levels

	Main Factors			
	Vehicle Admission Rate (A)	**Vehicle Calling Frequency (B):**	**Number of Technicians (C):**	**Queueing Discipline (D):**
Low Level (1)	4	5	10	FIFO
High Level (2)	8	10	16	LIFO

2.2.2. Taguchi Orthogonal Array

The Taguchi orthogonal array is selected on the basis of the number of control parameters and their levels. Considering four parameters and two levels each, the orthogonal array L8 is selected.

3. RESULTS AND DISCUSSION

The simulation model is run as a terminating system simulation for a 9-hour working day, under the four controllable factors. Each experimental setup is run with 5 replications and the average values for response variables are recorded in Table 2.

Table 2. Results of experiments for the L8 design

Experiment #	Vehicle Admission Rate (A)	Vehicle Calling Frequency (B)	Number of Technicians (C)	Queueing Discipline (D)	Mean Flow Time (min)	Throughput Rate	Mean Delay in Queue (min)
1	4	5	10	FIFO	52.7	99	8.8
2	4	5	16	LIFO	64.4	95	8.9
3	4	10	10	LIFO	36.9	100	11.9
4	4	10	16	FIFO	37.2	100	12.4
5	8	5	10	LIFO	51.6	66	25.4
6	8	5	16	FIFO	117.0	72	24.8
7	8	10	10	FIFO	124.3	69	28.5
8	8	10	16	LIFO	66.3	70	27.4

Because the objective is to maximize the throughput, the calculation of SNR values is based on Larger - The - Better (LTB) option. For LTB, the SNR is given by the following equation:

$$SNR(LTB) = -10 * \log\left[\frac{1}{n} * \sum_i \frac{1}{{y_i}^2}\right] \quad (1)$$

where n is the number replication of the experiment and y_i's are the individual observation values of the response variable.

Larger SNR values imply that strong signals and little noise (interference) exist during the experiment. Therefore, for a robust design larger SNR values are desired in the Taguchi Method. After the SNR calculations, the level average analysis can be performed to obtain the optimum solution [12].

The main effects plots for means and SNR are obtained using MINITAB and are given in Figure 2. For a robust design Vehicle Admission Rate (A) should be set at 4 arrivals/15 min. and Queueing Discipline (D) should be set FIFO whereas Vehicle Calling Frequency (B) should be set at 10 minutes and 16 technicians (C) should be available at the inspection station. On the other hand, to maximize the throughput A1-B2-C2-D1 setting should be used. Note that this particular setting is already experimented at experiment #4 which achieves the highest score. Furthermore, we also notice a large gap in factor (A) on both plots in Figure 2, which means that Vehicle Admission Rate (A) is the single main factor affecting the mean responses as well as the SNR values. The control factors are ranked for SNR values in Table 3, and for means in Table 4. Similarly, control factor (A) is ranked first on both tables.

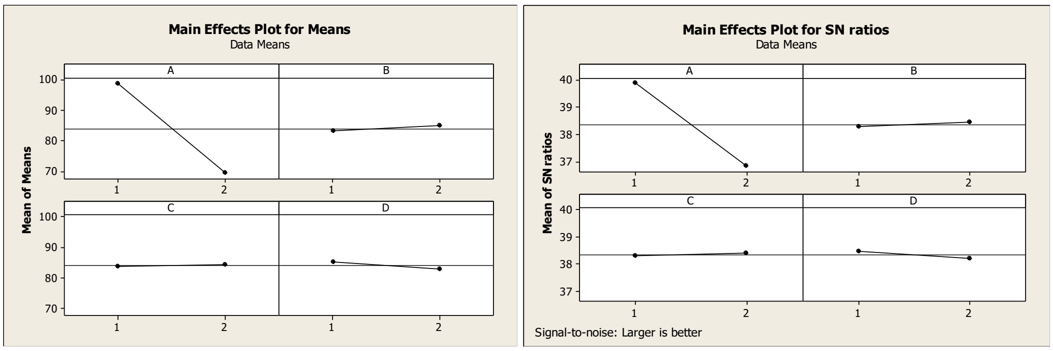

Figure 2. Main effects plots for the mean and SNR

Table 3. Response Table for SNR (larger is Better)

Level	Vehicle Admission Rate (A)	Vehicle Calling Frequency (B):	Number of Technicians (C):	Queueing Discipline (D):
1	39.87	38.25	38.27	38.46
2	36.80	38.42	38.40	38.21
Delta	3.06	0.17	0.13	0.25
Rank	1	3	4	2

Table 4. Response Table for means

Level	Vehicle Admission Rate (A)	Vehicle Calling Frequency (B):	Number of Technicians (C):	Queueing Discipline (D):
1	98.50	83.00	83.50	85.00
2	69.25	84.75	84.25	82.75
Delta	29.25	1.75	0.75	2.25
Rank	1	3	4	2

4. CONCLUSIONS

In this paper, Taguchi DOE framework is used to optimize the throughput at the MVI station. Experiments are performed via simulation model constructed using ARENA software. We considered four control factors: vehicle admission rate (A), vehicle calling frequency (B), number of technicians in the station (C) and queue discipline (D). To achieve a robust design it is shown that the main factor levels should be set as A1–B2–C2–D1. This means that vehicle admission rate (A) should be set at 4 arrivals per 15 min period, vehicles should be called (B) every 10 minutes, 16 technicians should be available (C) and the queue discipline at the inspection queues should be set to FIFO.

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