A Simulation-Based Optimization Framework for Improving Customer Waiting Time During Vehicle Inspection Process

Khibtiyah Ilyas[#1], Norazura Ahmad[#2], Norhaslinda Zainal Abidin[#3]
[#]*School of Quantitative Sciences, Universiti Utara Malaysia*
06010 Sintok, Kedah, Malaysia
[1]khibtiyahilyas@gmail.com
[2]norazura@uum.edu.my
[3]nhaslinda@uum.edu.my

***Abstract*— Issue of a customers' long waiting time is a common issue in the service industry. A Vehicle Inspection Centre (VIC) is one of the service industries that face this issue and has a significant impact on the quality of service. The management of VIC has been struggling in applying alternative solutions to reduce the customers waiting time, but the long waiting time still occurs. Therefore, the management requires an appropriate tool that contributes to improving customer waiting time problem and indirectly improving quality of service. A simulation-based optimisation framework is presented in this paper to mitigate the issue of long waiting time in order to assist the management. The preliminary result of the implementation of the framework on customers waiting time at VIC is also presented in this paper.**

***Keywords*—** *Customer waiting time, Quality of service, Service industry, Simulation-based optimisation, Vehicle inspection centre.*

1. Introduction

The purpose of Vehicle Inspection Centre (VIC) in Malaysia is to ensure the vehicles on the road are safe and free from mechanical and technical problems, to detect and prohibit illegally modified vehicles and control unhealthy environment due to the exhaust emission [1]. VIC undertakes mandatory inspections for commercial and private vehicles. Roughly, more than 500 vehicles are inspected every day and the target of key performance indexed (KPI) for each vehicle inspection is between 20-30 minutes. This duration is considered to be the customers waiting time.

Hence, as one of the service industries, VIC's customer has no exception but to face the problem of a long waiting time. Usually, the long waiting time is crucial during the festive months as shown in Table 1. Although the management of VIC has taken several actions to prevent this issue such as by initiating the appointment of vehicle inspection and appointed skilled of vehicle examiner (VE), the problem of a customer waiting for a long time is still occuring[2].

Table 1. Average customers' waiting time based on the type of inspection during festive months in 2016 at VIC.

Month	Festive	Average Customers' Waiting Time Per Month (hh:mm:ss)	
		Routine Inspection (Light 9002)	Re-Routine Inspection (Light 9004)
February	Chinese New Year	00 : 46 : 13	00 : 42 : 30
June	Hari Raya	00 : 34 : 07	01 : 58 : 57

Figure 1 illustrates the causes of customers' long waiting time at VIC. In this case study, customer arrivals, VE availability and maintenance of inspection machine are identified as critical elements contributing to the long waiting time. However, alternative actions have been applied to overcome these causes but the long waiting time still occurs. The alternative actions taken by VIC have been described in Table 2.

Table 2. Alternative actions taken by VIC.

Problem	Alternative Actions
Downtime and maintenance	• Sharing equipment • Swap inspection lane • Close inspection lane
VE availability	• Replace another VE to support
Arrival	• Scheduling the arrival per hour • Walk-in and re-inspection vehicle can enter the premise when inspection lane is free

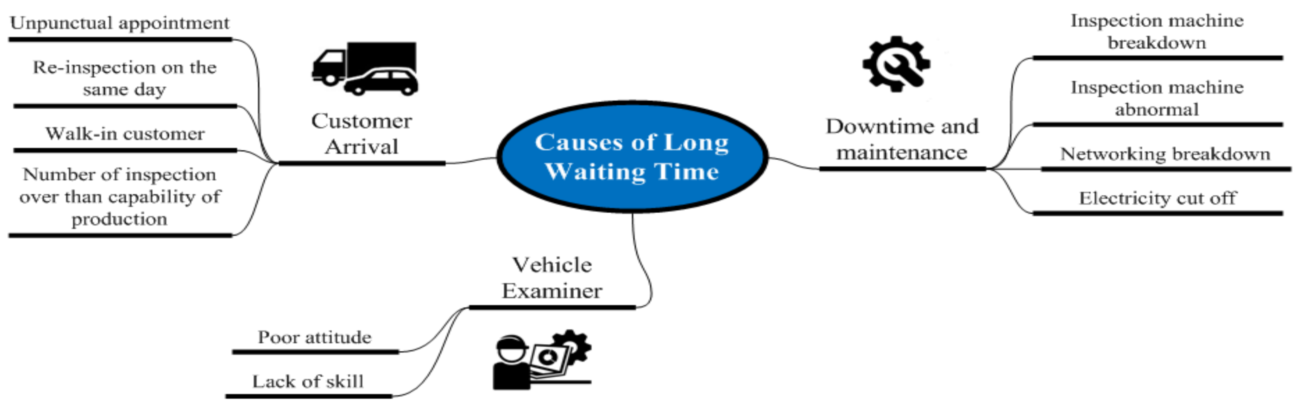


Figure 1. Causes of the factor that contribute to a long waiting time.

For these reasons, this study is carried out to determine appropriate strategies to improve the customer waiting time at an acceptable level during the vehicle inspection process. Hence, this paper proposed a simulation-based optimisation framework using discrete event simulation (DES) and integrates with system dynamics (SD) and genetic algorithm (GA) to mitigate the issue of a long waiting time at VIC. The preliminary result of DES also presented in this paper.

This paper is organised in five sections. Section 1 is the introduction as discussed beforehand. The remainders of the paper are as follows: Section 2 which offers a review of the recent literature on approaches for improving customers' waiting time. Section 3 presents a simulation-based optimisation methodology while Section 4 presented a preliminary result from DES output. Finally, some conclusions and further research perspectives are offered in Section 5.

2. Literature review

The waiting line or queue is a dominant traditional approach used to solve customers' waiting time problem [3]. Unfortunately, this approach becomes complicated when involving multi-server queuing system [4]. Recent years, researchers enhance a GI/G/n queue approach using a complex numerical approach that incorporated in optimisation model [5]. In addition, this approach is practically used in the software application to measure waiting time, inter-arrival time or service time distribution. The spreadsheet formula is used to estimate the standard deviation of waiting time using mathematical expression into Markov queues model. This model is applicable in appointment scheduling and waiting time strategy for operational level [5].

Besides the queuing approach, simulation modelling also has been widely used to solve waiting time problem. Simulation modelling is an approach that imitates the process or activities of a complex model and is capable of evaluating the impact of different scenarios [6, 7]. Discrete event simulation (DES) has been used frequently to study the behaviour of the complex system and to understand the interactions within the system [7]. Based on previous studies, DES approach is mostly used to explore and to figure out the problem of long waiting time at VIC [8–12]. Although DES is able to solve a complex problem in long waiting time based on time series data, unfortunately, DES is complicated to incorporate qualitative variables [13].

To support this limitation, a system dynamics (SD) provides a solution to incorporate qualitative and quantitative variables in a holistic picture [14]. For example, SD is a strategic tool that has been combined with DES to optimise the performance of the healthcare system [15]. However, one of the constraints in SD is the inappropriateness for individual analysis especially to estimate the service time or arrival time at a certain period in the VIC system.

Due to the limitation of applying standalone of the simulation method to determine an optimal output of waiting time, simulation-based optimisation is proposed [16, 17]. For instance, integration of DES and GA are used to find the optimal maintenance process of producing goods and improving the delay time in service delivery [16, 18]. Besides, simulation-based optimisation approach is also used to optimise the daily workload of staff and to decrease the long queue in call centre [19]. This integration approach also applied in appointment scheduling problem by optimising the appointment of a customer to improve the process of customer waiting time [20, 21].

Hence, from the reviews made in waiting time problems, it is found that the simulation-based approach is an appropriate approach to apply in VIC case study. The aim of this study is to optimise the factor contributing to the customers' long waiting time. Therefore, a proposed simulation-based optimisation framework that conducted in this study is developed which is discussed in the following section.

3. Methodology

This paper proposed a simulation-based optimisation framework that enables to improve customer waiting time during vehicle inspection process as illustrates in Figure 2.

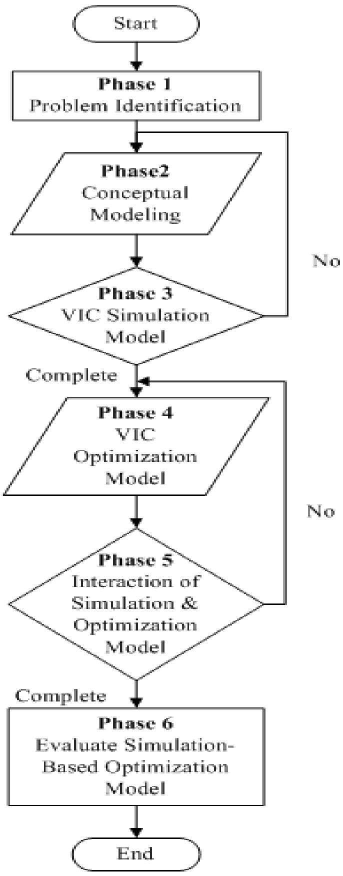


Figure 2. Overview simulation-based optimisation framework.

Referring to Figure 2, Phase 1 is an initial phase which is to identify the problem of the case study. The process continues in Phase 2 with the development of conceptual model where the information data obtained in Phase 1 are processed into the conceptual model. The results of this phase are to be used in Phase 3 which is the development of VIC simulation model.

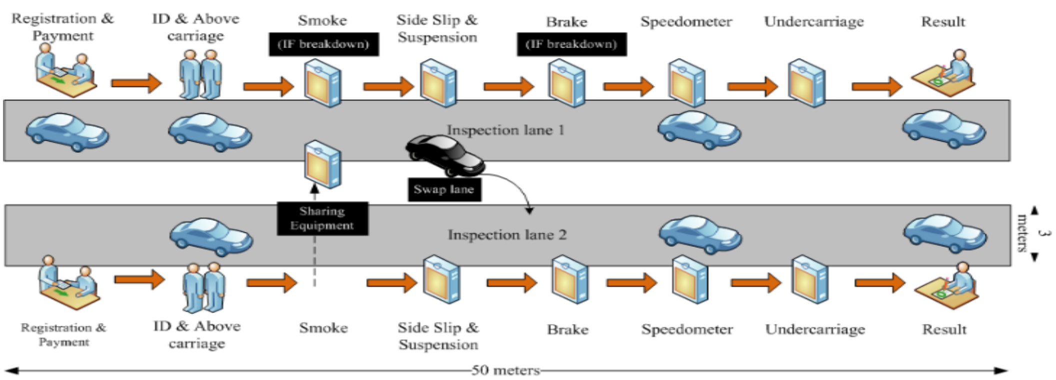
In Phase 3, the abstracting information from Phase 2 is translated into simulation models. After completing the development of simulation models, the verification and validation (V&V) process are carried out. If the V&V processes are inaccurate; Phase 2 will be reviewed. Otherwise, Phase 4 is able to proceed by developing the VIC optimisation model.

Then, Phase 5 is continued by integrating the VIC simulation models (Phase 3) and VIC optimisation model (Phase 4). After that, the V&V process is carried out to obtain the accuracy of the interaction models. If the processes are inaccurate, then Phase 4 will be reviewed. Otherwise, Phase 6 can be carried out by analysing the output of VIC simulation-based optimisation to propose an appropriate solution to VIC to improve the customers' waiting time. Hence, to get a clearer picture of each phase, the descriptions of detailed processes are discussed as follows.

3.1 Phase 1: Problem identification

VIC operation is characterised as a complex system where the problem is associated with the long waiting time of which is usually hard to visualise in the human mind. Understanding clearly the VIC operational process is crucial in order to obtain a proper decision and providing an appropriate solution. Therefore, it is essential to formulate the vehicle inspection problem that related to long waiting time from all perspective.

At VIC, the vehicle inspection lane measures approximately 50 metres length and three metres wide (50 m x 3 m). Each vehicle inspection lane has a series of vehicle inspection machines that are connected to the



computer. For safety reasons, a maximum of four lights vehicles is allowed in a lane at any particular time. Figure 3 shows the vehicle inspection process at VIC. Vehicle inspection starts with vehicle registration and payment and ends with the printing inspection result. If any vehicle inspection breakdown, an alternative strategy will be taken as described in Table 2. For example, when the smoke inspection machine breakdown, the inspection machine from the next inspection lane will be shared. If the brake inspection machine is broken down, the vehicle inspection at that checkpoint will be swapped to the next inspection lane or the inspection lane will be closed for all vehicle inspections.

The data collection part focused on collecting relevant information related to the vehicle inspection processes. The processes of qualitative data have been obtained through the interviews with expertise (e.g. branch and operation manager), site visit and observation while quantitative data are obtained via the VIC database. Through these processes, problems of customer waiting time are identified. In consequence, based on collected data, it was found that the three factors contributing to the long waiting time are the arrival of vehicles, maintenance and VE performance. Then all related information is interpreted in a conceptual model and analyse in Phase 2.

3.2 Phase 2: Conceptual model

The data collection in Phase 1 provides the complete information that gets insight an issue. Then, the information is interpreted into a conceptual model which the elements of inputs, outputs, model contents, assumptions, and simplifications of the vehicle inspection processes are assigned before translated into a VIC simulation model. Then, the flows of vehicle inspection processes are mapped using the process flow chart. At VIC, while the vehicle inspection process is computerised; the vehicle examiner (VE) and staff are still required throughout the process. Staffs are responsible for the registration and payment while the VE is responsible for driving a vehicle at each checkpoint and carried out inspection (e.g. press the oil pedal for smoke inspection and press the brake pedal for brake inspection).

In order to analyse the qualitative data of VE availability, a causal loop diagram of system dynamics is developed. The availability of VE in this system refers to the number of VE in one lane. If the number of VE is decreased, productivity also decreases. Additionally, if the working phase of VE is an increase or constants, the waiting time of the customer will decrease. On the other hand, several procedures are required to analyse the quantitative data. The data consists of the type of inspection, type of downtime and services at inspection lane. Then, each data input is fitted into the probability distribution before used in the VIC simulation model.

To emphasise, Phase 2 is a critical phase of the DES model and therefore must be identified clearly. If one element is incorrect, the possibility of generating a wrong output of the simulation is high.

3.3 Phase 3: VIC simulation models

Before the VIC model is developed, the first step is to translate the causal loop diagram to stock-flow diagram. Then the process continued with the development of VIC's operational process using DES approach. All elements that are designed in the conceptual model and the obtained data are transformed into the VIC model. The construction of the VIC simulation model began with a simple model that eventually grew into a complex VIC simulation model that mimics the real process of VIC operation. To determine the accuracy and reliability of the VIC simulation model, the validation and verification (V&V) process are performed.

3.4 Phase 4: VIC optimisation models

In this phase, the purpose of applying the optimisation model is to optimise the variables of inter-arrival time, maintenance time and VE performance. These variables are selected based on the critical factors that contribute to the customers' long waiting time. The VIC optimisation model is developed using the GA approach. The optimisation results will be placed in Microsoft Excel that to be used in the VIC simulation-based optimisation model. The GA processes are as follow [22]:

- **Initialisation:** Generate random chromosome from fitted data distribution; inter-arrival, maintenance and VE performance (of size P) at random from fitted data distribution.
- **Fitness:** Evaluate the fitness value of each variable (maximise and minimise).
- **Selection:** A "good" fitness value (low) will be allowed to contribute the genetic material to the next generation and use tournament selection with probability p_t to select P −E parents.
- **Crossover:** A random crossover point is chosen between the first and last densities. Then, the densities after the crossover point are swapped between the two parents, creating two offspring individuals and renormalise.
- **Mutation:** Adding a small random value randomly chosen density in each newly created offspring individual and renormalise.

3.5 Phase 5: Interaction of VIC simulation and optimisation models

In this phase, the outputs from the optimisation model are integrated into the VIC simulation model. During execution of the VIC simulation model, the input data of inter-arrival time, maintenance time and VE performance from GA output will be retrieved. Then, this integrated model will be executed based on a design of experiment (DOE). The purpose of DOE is to manage process inputs in order to optimise the output. Here, a full factorial design with two levels that encompass three factors contributing to the customers' long waiting time was used to explore the significant effect of parameters on customer waiting time. A low level (-1) is assigned based on the historical data of these factors, while the high level (+1) is assigned based on the optimisation input data of these factors. Thus, it forms eight scenarios (2^3) as listed in Table 3.

Table 3. Scenarios of experimental design [Source: Law [22]].

Scenario	Inter-arrival Time	VE performance	Maintenance Strategy
1	-1	-1	-1
2	-1	-1	+1
3	-1	+1	-1
4	-1	+1	+1
5	+1	-1	-1
6	+1	-1	+1
7	+1	+1	-1
8	+1	+1	+1

3.6 Phase 6: Evaluating simulation based optimisation

The outputs from the eight scenarios will be compared and analysed to find the best scenario to improve the customer waiting time. The main effect plots will generate each scenario to illustrate the shorter customers' waiting time. Then, 95% confidence interval is used to compare the efficiency of the selected proposed model to the current model.

4. Preliminary result

This section discusses the preliminary result based on the execution of the VIC simulation-based optimisation model for eight scenarios. There are two types of inspection which are considered in the model; routine inspection (9002) and re-inspection (9004). The preliminary results of these eight scenarios are presented in Table 4.

Referring to Table 4, S8 optimises the inter-arrival time, maintenance time and VE performance achieve VIC's KPI target which is between 20-30 minutes per inspection. Comparison of customer waiting time for the proposed model (S8) with current VIC model (S1) for the 9002 inspection is reduced by 73.35% while for 9004 inspection is 59.10%. Thus, these preliminary results prove that the proposed framework of this study has assisted in mitigating the issue of a long customers' waiting time during vehicle inspection process at VIC.

5. Conclusion and future work

In this paper, the issue of long waiting time for the customers during the vehicle inspection process at VIC is highlighted. Thus, a framework of VIC simulation-based optimisation is proposed to improve the long waiting time. This framework involves DES and SD to simulate the operational processes of the vehicle inspection system to determine the contributing factors to the long waiting time and impact on the operational procedures. A GA approach is evolved to obtain the optimum value of waiting time in achieving the KPI waiting time of 20-30 minutes for vehicle inspection.

Furthermore, this paper provides a preliminary result of the VIC simulation-based optimising model. The results indicate that these optimal factors reduce the average waiting time at VIC. Finally, by using this framework, VIC management is able to investigate and plan the new

Table 4 Preliminary result of VIC simulation-based optimisation model.

Scenarios	S1	S2	S3	S4	S5	S6	S7	S8
9002 (minute)	48.95	43.90	23.21	23.35	23.72	23.33	13.68	13.05
9004 (minute)	45.72	39.67	19.57	19.67	19.49	19.12	19.05	18.70

Note: S1 is the current VIC model.
S2-S7 is the expected scenario set by the DOE.

strategy in future. Moreover, the framework can also be used by another branch of VIC. For future work, the VIC simulation-based optimisation model will be completely developed by including other resources and attributes (other types of vehicle inspection).

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