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Evaluating Maintenance Strategy using Discrete Event Simulation to Sustain Customer Waiting Time at Vehicle Inspection Centre

Azurah A.Samah, Khibtiyah Ilyas and Hairudin Abdul Majid
Department of Computer Science
Faculty of Computing
Universiti Teknologi Malaysia
81310, Skudai, Johor, Malaysia

Abstract

This research concerned on modeling the business process of vehicle inspection activities at a vehicle inspection centre (VIC) using discrete event simulation (DES) approach. The business processes and problem of lengthy customer waiting time that caused by machine breakdown at vehicle inspection centre were explored and investigated. A conceptual model of a VIC simulation model was developed and in parallel the data of inter-arrival time, service time and breakdown of vehicle inspection machine was collected, filtered, analyzed and modeled. It followed by the development of a computerized VIC simulation model. Experimental design was carried out to experiment factor that contributes most to sustain customer waiting time at acceptable range. Corresponding performance measures in terms of customer waiting time were analyzed and compared.

Keywords
Discrete Event Simulation, Maintenance Strategy, Customer Waiting Time, Vehicle Inspection Centre

1. Introduction

For service industry, such as Vehicle Inspection Centre (VIC), the problem of long waiting time for customers happen almost every day and some of the causes were operation disrupted by vehicle inspection machine breakdown, system breakdown, no electricity or lengthy service time. Based on observation, interview and raw data, we concluded that one of the problems of customer waiting time was machine breakdown. Briefly, vehicle inspection machines at the inspection lanes were operating continuously from 8.00 am until 5.00 pm excluding lunch hour. Frequently, machine breakdown occurred especially when the VIC receive high volume of customer. If a major breakdown occurs which requires major fixing works, it will disturb the services processes and the customer waiting time will be increased. Based on these problems, this research was carried out to sustain customer waiting time by experimenting, analyzing and proposing an appropriate maintenance strategy for vehicle inspection machines using discrete event simulation (DES) approach.

2. Literature Review

This topic we discussed a background of VIC and previous research that related to simulation and maintenance strategy to demonstrate our understanding on theoretical of research and give rationale information to solve problem on customer waiting time and maintenance strategy at VIC.

2.1 Background of Vehicle Inspection Centre

Vehicle Inspection Centre (VIC) was the vehicle inspection company that authorized by the Malaysian Government to undertake computerized vehicle inspections for all commercial vehicle. VIC was established to ensure the safety of vehicle such as mechanical problems, healthy environment in term of emission and avoid cut joint vehicles. VIC had 55 branches nationwide and one of the branches was VIC Wangsa Maju that located at Kuala Lumpur. At the VIC, various vehicle inspections were provided such as routine inspection (9002), re-inspection (9004), special inspection (9003), transferred-ownership inspection (9011) and initial inspection (9001). Generally, most vehicle inspections underwent computerized inspection excluded vehicle identification, above carriage and under carriage inspection that were done manually by vehicle examiner.

Physically, VIC Wangsa Maju has six inspection lanes. Specifically, there were two lanes for heavy vehicle and light vehicle and one lane each for express lane and special lane. In a single lane excepted special lane has a series of vehicle inspection machines that attached to the computer to form a computerized machine. These machines were located sequentially in the lane as shown in Figure 1 and Figure 2. However, for safety purpose at most four light vehicles and three heavy vehicles can be inspected in a lane. If more than the permitted number of vehicle put on a lane at any particular time, the vehicle may crash with one another since the vehicle inspection machines in a lane were very close to each other.

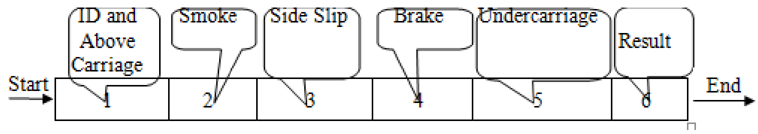

Figure 1: Sequences of vehicle inspection machine at the heavy lane

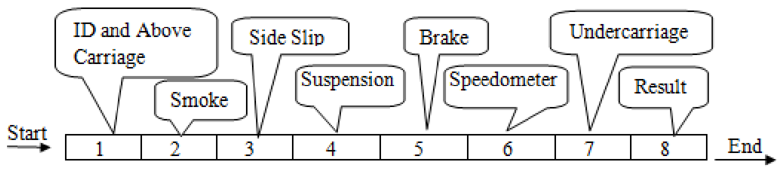

Figure 2: Sequences of vehicle inspection machine at the light lane and express lane

2.2 Research on Application of Simulation in Maintenance

Simulation was a modeling process that imitate the operation of a process in the real world without interrupt the real process and it was one of techniques that used as a tool to solve problem in various application areas such as manufacturing, logistics, communication networks, health care, service sector and military sector (Banks et al. 2010; Doomun and Jungum 2008; Law 2007 and Harrel et.al 2004). The literature in the context of maintenance modeling in service system was poorly covered compared to manufacturing system (Alabdulkarim et al. 2011). Boschian et.al (2009) carried out their research by applying discrete event simulation technique in optimizing maintenance policies. Duffuaa and Andijani (1999) developed a conceptual framework for airline industry that integrates maintenance operations and Duffuaa et al. (2001) came out with another study of conceptual model for maintenance in manufacturing systems that integrates with different modules. Aissani (2009) used combination of simulation and genetic algorithm to optimize the schedule of maintenance task of machines. The combination technique also have been carried out by Roux *et. al* (2008) to evaluate the strategy of maintenance performances for manufacturing systems while Oyarbide-Zubillaga *et. al* (2008) applied this technique to optimize of preventive maintenance in the manufacturing. Generally, decision-maker use simulation as a tool to evaluate proposed maintenance models against current maintenance model.

3. Methodology

In this research, we enhanced the simulation framework proposed by Banks *et.al.* (2010), Harrel *et.al* (2003) and Law (2011) to fit with our case study. Figure 3 shows a framework of study in determining maintenance strategies of vehicle inspection machine using discrete event simulation. The framework starts with problem identification phase and ended with documentation phase.

- **Problem Understanding and Identification**
  The problems of long waiting time and the consequences of these problems were identified through observations from one checkpoint to another checkpoint. Subsequently, a set of objectives was setting up to solve the problem.

- **Development of Conceptual Model**
  Sketches of vehicle inspection process and flow were developed. The locations, entities, processes and routings, downtime and arrival were identified and described in a simple model.

- **Data Collection**
  Data collection was performed in parallel with development of conceptual model. The required data which are inter-arrival time, service time and maintenance were collected, filtered, analyzed and modeled.

- **Construction of Simulation Model**
  A conceptual model and input data that had been developed and modeled were translated into a simulation model using ProModel. The development of simulation model starts with a simple model and gradually into a complicated Vehicle Inspection Centre model.

- **Validation and Verification**
  This validity process is carried out by subjective and objective test. Subjective test involves judgments of knowledgeable people such as Vehicle Inspection Centre manager, technicians, operation manager, and vehicle examiner, while objective test involves statistical test which comparing the model output to the performance of the actual system. If there is an inconsistency in the hypothesis test conducted for validation process, the improvement of the model will be refined either in data collection phase, conceptual model phase or simulation model development phase. This process will continue until the model output is consistent with the actual model.

- **Experimental Design**
  Experimental design refers to a systematic way to investigate which level of factor that contributes most to customer waiting time. A full-factorial is selected as a method to design an experiment.

- **Output Analysis**
  Replication method was implemented in the simulation run. Output of simulation model was collected and analyzed. Then, confidence interval 95% was used to compare proposed maintenance strategy and current maintenance strategy.

- **Documentation**
  Documentation was important as a reference in future. Documentation process was prepared in a report which is easy to understand, clear and concise.

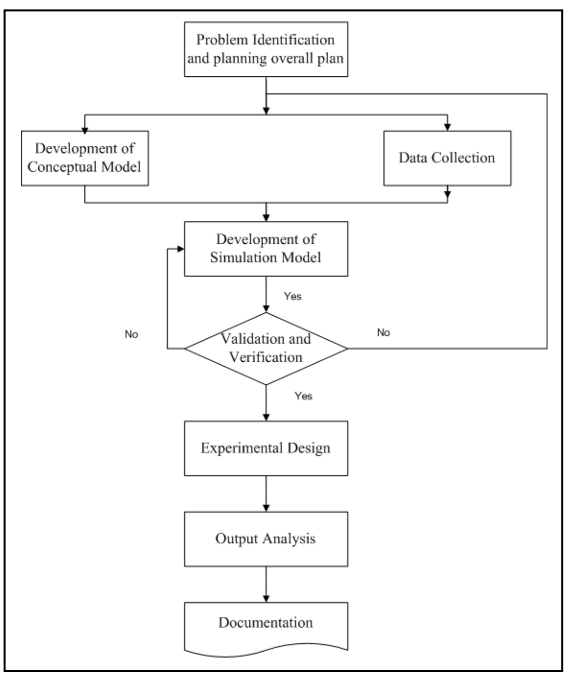

Figure 3: Framework of Study

4. Data Analysis and Input Modeling

The numerical data such as inter-arrival time, service time and downtimes were discussed. Data were categories into two categories which primary data for service time while secondary data for inter-arrival time and downtime. For data analysis, histogram was plotted to discover the frequency distribution of data and a particular shape or pattern to the distribution while test of independence which is scatter plot was plotted to determine the randomness of data.

4.1 Primary Data

Service time was recorded manually from one inspection point to another inspection point starting with identification and above carriage and ending with printing the result of inspection. The service times of 270 heavy vehicles and 234 light vehicles were collected at each inspection point. A statistical method which are mean, maximum, minimum and standard deviation were carried out to analyze the data. For randomness of data, the service time data at each point of inspection were scattered randomly without appeared slope trend line.

4.2 Secondary Data

The inter-arrival times of vehicles were collected based on types of inspection. Four types of inspection which are routine inspection (9002), re-inspection (9004), special inspection (9003) and transfer-ownerships inspection (9011) were concern based on most frequent volumes of vehicle underwent inspection.

The data of maintenance was collected from 3 January 2011 until 31 December 2011. Figure 4 presented a Pareto chart of numbers of breakdown based on vehicle inspection machine. The brake machine record 49 times breakdown and followed by suspension record 36 times breakdown, side slip machine records 22 times breakdown and smoke meter machine records 20 times breakdown. Other breakdowns were assumed as not critical machine to breakdown. Figure 5 presented a number of major breakdown based on inspection lanes. Heavy lane 2 (HV2) recorded 26 breakdowns of brake inspection machine while Light Lane 1 (LV1) recorded 26 breakdowns of suspensions inspection machine.

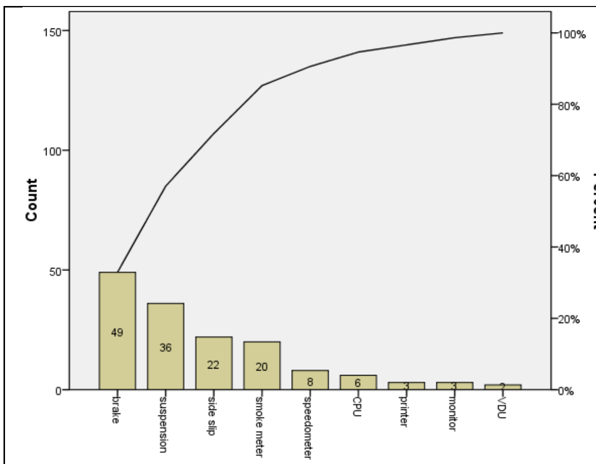

Figure 4: Pareto Chart of Breakdown of Inspection Machine

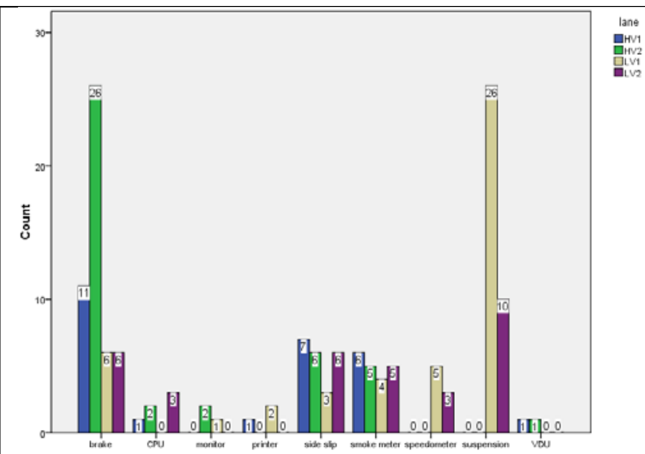

Figure 5: Bar chart of maintenance of inspection machine

4.3 Input Modeling

Input modeling was the phase of selecting statistical distribution for data before implement in the simulation model. There were three main steps to select and fitting the statistical distribution that has been suggested by Banks et.al (2011) as followed:

- Select one probability distribution
    - Exponential distribution was chose for interarrival time and service time

- o Weilbull distribution was chose for breakdown time
- Determine the parameters of the probability distributions
  - o $\beta = \lambda^{-1}$ and β was used for interarrival time and service time with probability density function

$$f(x) = \frac{1}{\beta}\exp\left(-\frac{[x-min]}{\beta}\right) \tag{1}$$

Min = minimum x value
β = scale parameter
Mean = min + β

  - o α, β was used for breakdown time

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x-min}{\beta}\right)^{\alpha-1}\exp\left(-\left(\frac{[x-min]}{\beta}\right)^{\alpha}\right) \tag{2}$$

Min = minimum x value
α = shape parameter > 0
β = scale parameter >0
Mean = min + $\boldsymbol{\alpha}\beta$
Variance = $\boldsymbol{\alpha}\beta^2$

$$\text{mode} = \begin{cases} \min + \beta(\alpha - 1) & if\ \alpha \geq 1 \\ \min & if\ \alpha < 1 \end{cases}$$

- Test the selected distribution using a goodness of the fit test.
  - o Kolmogorov-Smirnov (KS) test was used fit the data.

Stat::Fit software was used to model the data. Table 1 shows the result of input model for inter-arrival data, Table 2 shows the result of input model for service time at the light lane and Table 3 shows the result of input model for service time at the heavy lane

Table 1: Input model for inter-arrival data

Type of Arrival	Input for Model (minimum +β) minute
9002 Light	E(5.58)
9004 Light	E(5.71)
9002 Heavy	E(6.00)
9004 Heavy	E(6.48)
9003	E(3.46)
9011	E(2.98)

Table 2: Input model for service time data at light lane

Inspection Point	Input for Model (minimum +β) minute
Identification and Above Carriage	0.8+E(1.10)
Smoke Inspection	0.95+E(0.72)
Side Slip	1+E(0.84)
Suspension	1.52+E(0.31)
Brake Diesel Vehicle	0.73+E(0.6)
Brake Petrol and NGV Vehicle	0.75+E(0.36)
Speedometer	2.41+E(0.34)

Table 3: Input model for service time data at heavy lane

Inspection Point	Input for Model (minimum +β) minute
Identification and Above Carriage	1.12+E(2.73)
Smoke Inspection	0.5+E(0.34)
Side Slip	6.1+E(3.54)
Brake and Undercarriage	1.18+E(2.85)

For input model of maintenance, mean time between failures (MTBF) was used to measure the reliable of the inspection machine during operation while mean time to repair (MTTR) was used to measure the average time to repair a machine. The mathematical equation of MTBF and MTTR were follows below:

$$\text{MTBF}=\frac{\sum operation\ time}{n\ Breakdown} \tag{3}$$

$$\text{MTTR}=\frac{\sum Breakdown\ time}{n\ Breakdown} \tag{4}$$

The results of MTBF and MTTF for inspection machine at the VIC Wangsa Maju were shown in Table 4.

Table 4 Results of MTBF and MTTR

Inspection Machine	MTBF	MTTR
Brake Heavy Lane 1	MTBF= $\frac{2413.75}{11}$ = 219.43 hours	MTTR = $\frac{22.55}{11}$ = 2.05 hours
	Input model: 20.25+W(0.85,170.57)	Input model: 0.5+W(0.39,0.68)
Brake Heavy Lane 2	MTBF= $\frac{2380.1}{24}$ = 99.17 hours	MTTR = $\frac{44.1}{24}$ = 1.84 hours
	Input model: 4.5+W(0.63,69.28)	Input model: 0.33+W(0.65,1.05)
Suspension Light Lane 1	MTBF= $\frac{2374}{10}$ = 237.4 hours	MTTR = $\frac{36}{10}$ = 3.6 hours
	Input model: W(0.49,128.97)	Input model: -0.77+W(2.55,4.94)

As tabulated in Table 4, we can summarized that the lifespan for that brake inspection machine at heavy lane 1 was 219.43 hours and required 2.05 hours to repair if breakdown occurs while heavy lane 2, the lifespan of brake inspection machine was 99.17 hours and the average time to repair the machine was 1.84 hours. The lifespan for suspension machine at the light lane 1 was 237.4 hours and required 3.6 hours to repair.

5. Development of VIC Conceptual Model and Simulation Model

In conceptual model, scope and model details were determine as show in Table 5.

Table 5: Scope and model details of VIC conceptual model

Component	Include/ Exclude	Justification	Details	Description
Entities: Vehicles	Include	Flow through service process	Quantity Inter-arrival Routing	Unlimited Distribution of inter-arrival time Route through specific queue
Activities: Main gate Register counter Inspection lane Exit gate	Include Include Include Include	Entrance for all vehicle Starting of waiting time Starting of service time Required service time at each point of inspection Routine maintenance Terminate process	Quantity Breakdown	1 vehicles at one time at the register counter 4 vehicles at one time at the light lane 3 vehicles at one time at the heavy lane Major breakdown at each lane Distribution of MTBF and MTTR
Queue: Queue Lane	Include	Location to vehicle before register.	Queuing discipline	First In First Out (FIFO)

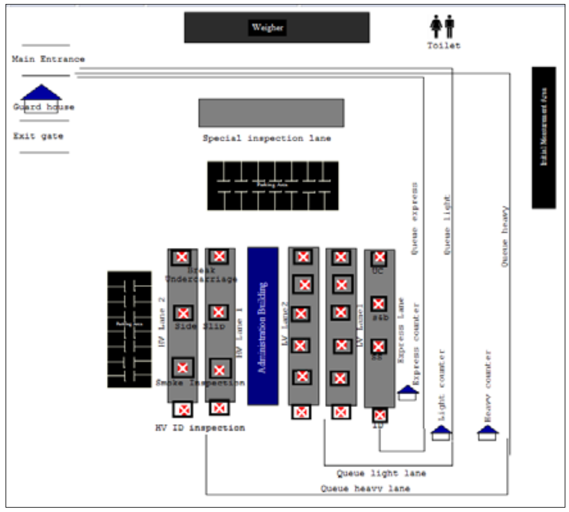

Figure 6: A snapshot of VIC Wangsa Maju simulation model

A VIC simulation model was developed using ProModel software starting from developed a simple model and gradually to complex model. The development of VIC simulation model was programmed from the arrival of entities at the main gate, then moved into inspection lane and finally exit at exit gate. Figure 6 represent a VIC simulation model. The details of model developments as describe in Table 6:

Structural elements	Operational elements
o **Entities** ▪ **Light 9003** ▪ **Light 9011** ▪ **Light 9002** ▪ **Light 9004** ▪ **Heavy 9002** ▪ **Heavy 9004** o **Arrival** ▪ **All entities were arrived at the main entrance.** ▪ **No arrival cycle over a running time were declared.** o **Location** ▪ **Location has capacity value, units and rule such as highest priority or First in First out (FIFO).**	o **Processing and Routing** ▪ **Processing was defined as a condition of entities when it arrived at the location and how many time is required if the process occurs. The input modelings of service time were programmed in this part.** ▪ **Routing was defined as a location of entities should have after completed the process at the location.** o **Downtime and Maintenance** ▪ **Promodel software allows developer to assign downtime at location by setting the downtime at the DTs field in the location table.** ▪ **The distribution of the MTBF that has been analyzed was translated into a frequency field in the clock time table while a distribution of MTTR was assigned into a Logic field in the same table.**

6. Verification and Validation of Model

VIC simulation model was verified and validate to ensure an accurate VIC simulation model was developed reflect to the real scenario.

6.1 Verification of VIC Simulation Model

VIC simulation model was verified to assure that it reflects accurately to the conceptual model and checking the reasonable output model by running using a distribution of input parameters. The detail steps were described as follows:

- Checking the flow of VIC simulation model with expertise (VIC Operation Officer)
- Checking each processing or code of model was running and functioning as determined in conceptual model.
- Observing the model outputs produce variety of output statistic by testing variety of input parameter.
- Verify that animation is reflecting to actual system.
- Identify the debugging of VIC model.

6.2 Validation of VIC Simulation Model

The validation activities were carried by subjective test which involve VIC branch manager and technician making judgment of the business process of simulation model while objective test was carried out by comparing the output of simulation model with result of real system using statistical method. In objective test, *t*-test was used to validate the result of the VIC simulation model. If $|t_0| > t_{\alpha/2,K-1}$, we reject H_0 while $|t_0| \leq t_{\alpha/2,K-1}$, we accept H_0. The model was executed 24 replications and the result of mean is 33.67 minutes while the mean of real system is 35.07 minutes. Then, the standard deviation is 5.2108 and alpha value is 0.05. The t-test result shows $|t| = 1.3163 < t_{0.025,23} = 2.07$, we accept H_0 and conclude that VIC model was tentatively valid.

7. Output Analysis

The average waiting time of customer was selected as performance measure while the vehicle undergoes routine inspection (9002) and re-inspection (9004) were selected as entities. This performance measure was obtained through the output of simulation model by execute model with 24 replications.

7.1 Experiment Using Full-Factorial Design

A full-factorial design at two levels was applied to select level of factor that contribute most to customer waiting time at acceptable range. Three factors which are interarrival time (Factor A), service time (Factor B) and maintenance (Factor C) were selected as a factor that contribute to customer waiting time. Lower level (-1) is assigned for current model and higher level (+1) for proposed model. The value of higher levels for each factor is based on knowledge and experience of VIC management team. Table 6 shows an input value for level of factors.

Table 6 Level of factors

Levels	Factors		
	A Interarrival Time	B Service Time of Undercarriage and Inspection Result	C Maintenance Strategy
-1 (current system)	Heavy9002: E(6.0) minutes Heavy9004: E(6.48) minutes Light9002: E(5.58) minutes Light9004: E(5.71) minutes	Heavy Vehicle: 1.12+E(2.73) minutes Light vehicle: 0.8+(E1.10) minutes	Corrective Maintenance Brake H1: 20.25+W(0.85,170.57) hr BrakeH2: 4.5+W(0.63,69.28) hours SuspensionL2: W(0.49,128.97)
+1 (proposed system)	Heavy 9002 T(2,5,10) minutes Heavy 9004: T(5,10,15) minutes Light9002 and Light9004: T(3,5,7) minutes.	Heavy vehicle: T(3,5,10) minutes Light vehicle: T(1,3,5) minutes	Clock-based maintenance Brake H1: 8.9+W(1.35,175) hours, BrakeH2: 0.1+W(0.625,72.1) hours SuspensionL2: 16+W(0.564,114) hours

With three inputs factor that have been declared, 8 design points were assign based on full factorial design, $2^k = 2^3 = 8$ as tabulated in Table 7.

Table 7: 8 Design Point of Experiment

Design Point	A	B	C
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

7.2 Simulation Runs and Results

Figure 8 shows bar chart of customer waiting time for eight design points of experiment.

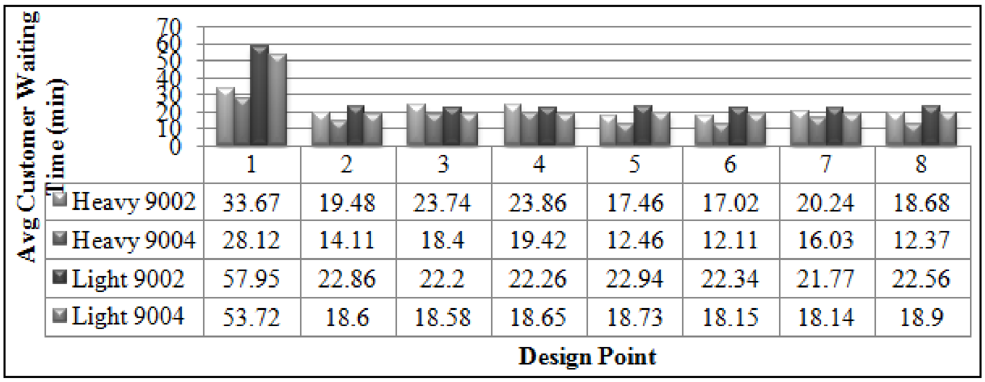

Figure 8: Bar Chart of Average Customer Waiting Time

In this research, we assigned an acceptable range of average customer waiting time is 30 minutes or less. It is supported by Rohdeler (2007) and information from VIC's customers about the satisfactory of average waiting time. Based on Figure 8, an average customer waiting time for all design points except design point 1 was less than 30 minutes. We conclude that if VIC controls or applied at least one of the proposed value into the real system either control inter-arrival time of vehicle or sustain service time at inspection lane or applied clock-based maintenance, it can influence and sustain the customer waiting at acceptable range.

7.3 Main Effects Plot

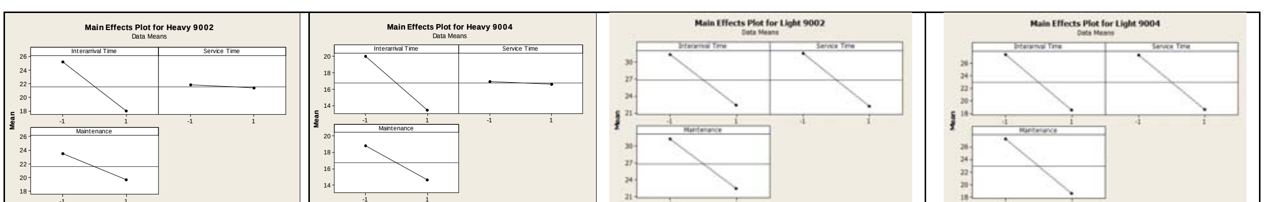

Figure 9(a) Figure 9(b) Figure 9(c) Figure 9(d)

Figure 9 Main Effect Plot for type of inspection

We plotted the effects of three factors on average customer waiting time for each type of inspection using main effect plots. Figure 9(a) refers to routine inspection for heavy vehicle, Figure 9(b) refers to re-inspection for heavy vehicle, Figure 9(c) refers to re-inspection for light vehicle and Figure 9(d) refers to re-inspection for light vehicle. For Figure 9(a) and Figure 9(b), the most contribute to average customer waiting time was inter-arrival time of vehicle while service time contribute little effect to average customer waiting time. Therefore, it support the simulation output for design point 6 (refers Figure 8) which the changes of inter-arrival time and maintenance strategy can sustain the customer waiting time at acceptable level. For Figure 9(c) and Figure 9(d), the factor that contributes most to average customer waiting time was service time. As conclusion, in general the factor that contributes most to average customer waiting time for heavy and light vehicle was maintenance strategy. It is proves that Experiment 6 which applying proposed routine maintenance can decrease the customer waiting time at acceptable range.

7.4 Comparing Maintenance Strategies System With Current System

For comparison of the model, we considered on heavy vehicle. Table 8 shows the percentage of average waiting time decrease for proposed maintenance strategy which is 49.45% for Heavy 9002 while Heavy 9004 is 57.33%.

Table 8 Percentage decrease of customer waiting time of proposed model

Elements	**Heavy 9002**	**Heavy 9004**
Average waiting time (current)	33.67 min	28.12 min
Average waiting time (proposed)	17.02 min	12.11min
Difference	16.65 min	16.12 min
Percentage	49.45%	57.33%

Comparison of two model design using confident interval method is used to evaluate proposed maintenance strategy model with current maintenance strategy model. As hypothesis, if the confident interval for $\theta_1 - \theta_2 < 0$, then the current maintenance strategy model is better than proposed maintenance strategy model. If the confident interval for $\theta_1 - \theta_2 > 0$ the proposed maintenance strategy model is, better than current maintenance strategy model. If the confident interval for $\theta_1 - \theta_2$ contain zero, then no evidence shows that both model better than each other.

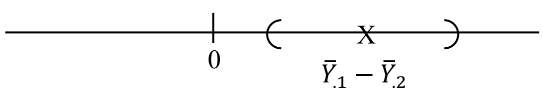

Figure 10: Confident Interval Result for Comparing Model

The result shows it is totally right of zero, $\theta_1 - \theta_2 > 0$ $(14.4561 \leq \theta_1 - \theta_2 \leq 18.8439)$ which there is strong evidence that proposed maintenance strategy model was better than current maintenance strategy model.

8. Conclusion

As conclusion, discrete event simulation approach was used to experiment the problem of lengthy customer waiting time at VIC. The business processes and VIC activities was developed using ProModel software to a clear picture of processes and experiment the problem. Three factors that contribute most to customer waiting time which are service time at undercarriage inspection, interarrival time and maintenance strategy were identified and experimented. A full-factorial design was used to design the experiment and running in the VIC simulation model with 24 replications. The simulation output which is average customer waiting time was collected, analyzed and compared using main effect plot. As a result, we found that maintenance strategy was one of the factors that contribute to customer waiting time and by applying proposed clock-based maintenance strategy into vehicle inspection machine, the customer waiting time can be sustain at acceptable range which is less than 30 minutes. Future research will be enhanced into combination of clock-based and used based maintenance to sustain the customer waiting time.

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Biography

Khibtiyah Ilyas has received the Dip and B.Sc. degree from University of Technology Malaysia in 2007 and 2009 respectively. Currently she is a Master student in Faculty of Comp. Science and Information System, University of Technology Malaysia. Her researches interests are in operational research, simulation and also in mathematical modelling.

Azurah A.Samah has received the Diploma and B.Sc. degree from University of Technology Malaysia in 1991and 1993 respectively. In 1996, she obtained her M.Sc. from the University of Southampton, UK and recently in 2010, she received her PhD from University of Salford, UK. Currently she is a lecturer in Faculty of Comp. Science and Information System, University of Technology Malaysia. Her research interests encompass Operational and Simulation Modeling, Soft Computing Techniques and Image Processing.

Hairudin Abdul Majid has received the Dip and B.Sc. degree from University of Technology Malaysia in 1993 and 1995 respectively. In 1998, he obtained his M.Sc. from the University of Salford, UK. Currently he is a lecturer in Faculty of Comp. Science and Information System, University of Technology Malaysia. His research interests focused on Operations Management and Warranty, Maintenance and Image Processing.