A discrete event simulation in an automotive service context

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Abstract

In recent years, simulation approach for illustrating the current situation and evaluating behavior of system under different condition is widely used especially in service sector. This paper has modeled an after-sale service shop with WITNESS simulation software. The aim of this work is to increase service rate while reducing the amount of waiting time in queues for the entire service shop which results in more customer satisfaction. Results of developed model were analyzed and the main cause of the problem has been identified that was large amount of time a customer should wait before Road Test station and the unbalance situation of Inspection Report Recording stations. The outcome of the simulation model has been validated and some modifications in the structure of the model to improve the system have been set. The result indicates that customer satisfaction has increased at the same time as improving service rate of the system.

Keywords: *Simulation, Queue Time, WITNESS, Waiting Time, Customer Satisfaction, Service Rate*

1. Introduction

Earliest and most numerous application of discrete event simulation have been in manufacturing sector [1], although it has expanded into service sector vigorously. Fulfilling the desired service rate which is characterized by small buffer sizes and optimized cycle times is the main context of discrete event simulation studies application in the service automotive industries. However simulation does not improve a given scenario by itself, instead it can model different feasible scenarios for the analysis and improvement of an existing system.

Similarly, this research work concentrates on improving the operation of an after-sale service automotive repair shop which provides the Periodic Service Inspection, Defect Detection and Road Test services. Additionally, this shop may have one or more number of stations for vehicle inspection report recording which operate in parallel with other stations. In each station the improvement was carried out in terms of reducing waiting time which will derive customer satisfaction.

While there are various tools available for analysis of repair and maintenance support system like TQM tools [2] optimization techniques, simulation is selected because simulation gives good insight of factors of interests [3]. Further simulation models can be run for numerous alternatives.

2. Literature

Simulation is considered as an important and powerful tool for process improvement [3]. Despite the primary prevalence of discrete event simulation in manufacturing sector of the economy [4], recently, simulation has become widespread in various service industries [5].

Indeed, various published results certify the value of simulation in the service sector. For example Mehmod and Jahanzaib [6] described the decision support system using simulation in the dynamic environment of vehicles repair and maintenance. Zottolo et al. [7] used discrete event simulation to determine the optimal strategies relative to target inventories of pending inquiries in a healthcare insurance provider. Gourgand et al. [8] conducted a comparative study on effectiveness of ARIS analysis tools and WITNESS software in a new hospital. Belkadi and Tanguy [9] modeled and simulated the ophthalmology service of Regional Military and University Hospital in order to study the utilization rate of rooms and doctors of ophthalmology service, and to increase its quality of service. Jenkis et al. [10] visited the issues related to validation and verification of simulation models in the light of case study being carried out in the health sector. Cuthbert et al. [11] worked on a demonstration to illustrate the impact of information in the context of complex engineering services. Pichitlamken et al. [12] used simulation to a telephone call center handling both inbound and outbound traffic. Palacis [13] improved the business processing of accounting transaction within supply chain in the timber industry using simulation. Nanthavanji et al. [14] described an application in which simulation was used to improve services provided by car park systems.

In addition, three applications of simulation in logistics military conflict developments within the U.S. Army Combined Arms Support Command were presented by Graves and Higgins [15]. In the work of Ramadass et al. [16] a bus maintenance facility could accommodate to peak traffic by process analysis of system through simulation modeling application. Simulation also used as Decision Support System (DSS) for automobile manufacturing supply chain simulation in the grids environment [17].

Simulation is a decent tool for illustrating the current situation of the system and evaluating behavior of system under different sets of condition in order to overcome the current difficulties that businesses deal with. The presented work is modeled in simulation which is explained in the upcoming section.

3. Conceptual framework

In accordance with the processes associated with the after-sale service automotive repair shop, the activities of the shop are divided into the following main processes: Customer Arrival, Periodic Service Inspection (PS Inspection), Defect Detection, Road Test and Inspection Report Recording (IR Recording).Figure 1 shows a schema of the resources and processes involved in this shop. Once customers enter the shop, type of needed repair is identified then customers might proceed to the Periodic Service Inspection or Defect Detection station based on their desired type of service. Customers' need on processing to Road Test station will be investigated by Defect Detection station. The Road Test station is operated by three workers that two of them just work in the first 60-minute of the shift. Before leaving the shop, customers are required to file their vehicle's inspection report by one of the Inspection Report Recording stations.

Customers arrive at the shop based on a rather fixed schedule and have one day periodicity. Nevertheless, if customers do not follow the schedule strictly, a stochastic pattern of anticipation for incoming customers will be introduced. Customers enter the shop using a single entry track and leave it using the same one.
The modelization of the resources and the operating policies we have assumed will be described below. The five aforementioned processes utilize unique resources, although in some cases like Inspection Report Recording resources might be shared by two of these main processes for further improvement.

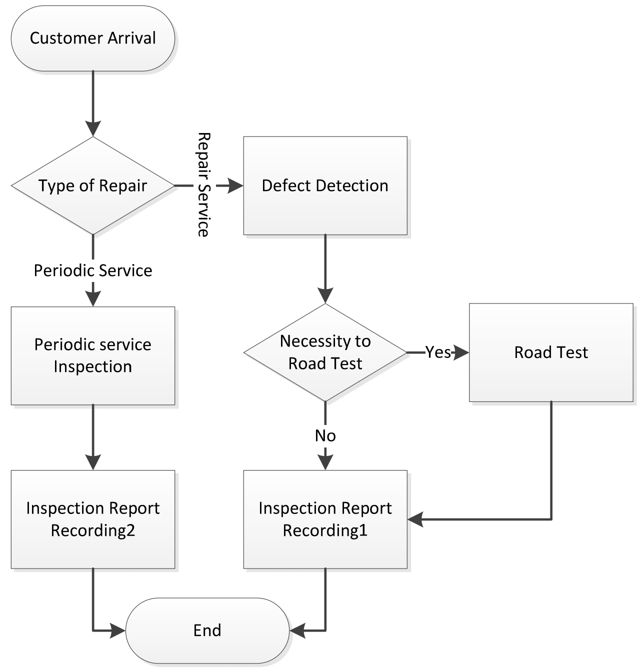

Fig. 1 Repair shop resources and processes schema

4. Data gathering and analysis

We have implemented the conceptual model described in the previous subsection using WITNESS software. The detailed model specification and available values that should be provided regarding each design parameter need to be established before model implementation. Further, Kochar [18] believed that the duration of the simulation model development may well depend on the amount of quantifiable data and quality that has been gathered. If data is not gathered accurately, they can be a major obstacle in trying to develop a precise model. Similarly for increasing the data collection accuracy, a form was attached to the customers' inspection report, and servers were asked to record the arrival and departure time of the customers in this form.

The data gathering process took two weeks (10 days) and the average number of customers who were served every day was approximately130. As mentioned in Section 3, the model is subdivided into five elements, which have its own specific input parameters. The input values for the involved parameters within each element are based on data collected during the study period. Table 1 is illustrated the probability distribution of each element's cycle time and customers inter arrival time which has been calculated using Input Analyzer tool of Arena software.

Table 1: Stations cycle time and entities inter arrival probability distributions

Stations Name	Cycle/Inter Arrival Time Distribution	P-Value	Square Error
Customers' Arrival	0.5 + 10 * BETA(0.439, 2.53)	0.067	0.0033
Defect Detection	1.5 + GAMM(2.13, 3.67)	0.163	0.0010
Road Test	TRIA(2.5, 5, 18.5)	0.622	0.0016
IR Recording1	0.5 + ERLA(0.795, 4)	0.685	0.0009
PS Inspection	TRIA(2.5, 5.5, 13.5)	0.27	0.0058
IR Recording2	NORM(3.21, 0.697)	0.053	0.0074

As it was illustrated in Table 1 both inter arrival time of customers and service times of operators have certain distributions of their own.

Table 2: Result of distribution fit for Defect Detection Station

Distribution Name	Square Error
Gamma	0.001
Erlang	0.001
Weibull	0.001
Beta	0.003
Lognormal	0.004
Normal	0.006
Triangular	0.060
Exponential	0.102
Uniform	0.139
Poisson	0.253

From Table 2, it was shown that the input variable of "Defect detection" station follows the Gamma distribution due to its minimum value of square error which is equal to 0.00102. The same procedure was used for determining the probability distribution of other stations' input variables.

5. Model Simulation

Witness software was used to develop the model. Fig. 2 shows the simulation model for this automotive repair shop. The initial model was replicated for six times and each replication run for 360 minutes for the entire shift in one day. During the first 60 minutes of system running, customers are not served since they arrive at the queue before the service shop is opened; therefore it makes the first minutes of the shop operating hours as pick time that leads to high queue time.

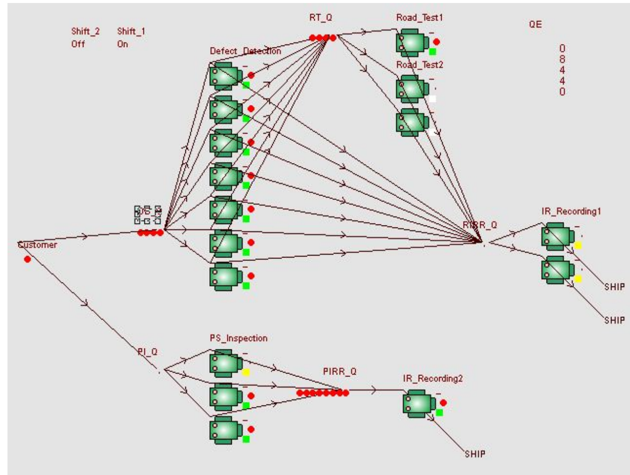

Fig. 2 Simulation Model

The simulation report is shown in Table 3. The table indicates the number of operations for each station; as well as the idle and busy time of the initial model.

Table 3: Report of simulation model

Station Name	No. of Operations	% Idle	% Busy
Defect Detection1	11	56.3	43.7
Defect Detection2	12	61.3	38.7
Defect Detection3	12	60.4	39.6
Defect Detection4	11	60.5	39.5
Defect Detection5	12	61.4	38.6
Defect Detection6	15	65.2	34.8
Defect Detection7	12	59.8	40.2
PS Inspection1	18	62.5	37.5
PS Inspection2	14	67.0	33.0
PS Inspection3	13	66.9	33.1
IR Recording2	45	49.1	50.9
IR Recording1,1	41	82.2	17.8
IR Recording1,2	43	80.4	19.6
Road Test1	4	49.1	65.5
Road Test2	3	62.5	37.5
Road Test3	31	11.8	88.2

According to the first report in Table 3, Inspection Report Recording1 has assigned higher percentage of idle time while Table 4 shows the amount of waiting time in Inspection Report Recording 2 queue is considerably high (8.9 min) which necessitates balancing of these two stations. Also, average time is spent in Road Test queue has quite high amount (14.4 min) which may lead the customer satisfaction to be decreased.

Table 4: Report of simulation model

Queue Name	Max Length of Queue	Ave NO. in Queue	Ave Time in Queue
Defect Detection	20.0	2.8	12.7
PS Inspection	10.5	1.5	12.2
Road Test	5.3	1.2	14.4
IR Recording2	6.5	1.1	8.9
IR Recording1	2.2	0.0	0.1

6. Model verification

To check the simulation model, components of the model were verified by comparing the number of calculated customers that were served with the number of customers created by simulation. For example, Road Test3 station was selected to show the outcome of the verification. The automotive repair shop works for one shift in the whole day and its working time is 300 minutes. In considering busy time and Mean of distribution of this station which are %88.2 and 8.67minutes respectively, Eq. (1) is used to illustrate the number of customers served (30.54) is approximately equal to the number of customers obtained by simulation (31). The difference ratio between these two numbers is less than % 0.01 which is negligible.

Number of customers served = (0.882*300)/ 8.67= 30.54 (1)

7. Validation

Validation can be considered as the procedure of determining the similarity of a model to a real system. Further, it gives enough confidence that the simulation model is able to mimic the real system.

The procedure of validation in this model consists of two steps. The first step is comparing the number of customers served from Defect Detection and Periodic Service Inspection stations of the simulation and actual output of these two stations. And the second step is validation with Mann-Whitney test.

First step: According to gathered data during two weeks (10 days), the average number of customers served in Defect Detection and PS Inspection stations are 78.6 and 42.5 respectively. Acquired data from the simulation model for these two stations are 89.5 and 45.5 respectively. Therefore there is no significant difference between simulation and actual output of these two stations.

Second step: SPSS software was used to conduct the Mann-Whitney test. So, the following hypotheses were applied to determine the adaptation between the represented model and real system.

H_0: the average number of customer served in actual process for Defect Detection station ($\mu_1 = 78.6$) is equal to the average number of customer served in simulation model ($\mu_2 = 89.5$)
H_1: μ_1 is not equal to μ_2

H_0: the average number of customer served in actual process for PS Inspection station ($\mu_1 = 42.5$) is equal to the average number of customer served in simulation model ($\mu_2 = 45.5$).
H_1: μ_1 is not equal to μ_2

α which is confidence level was chosen 0.05. According to Table 5, the P-value result of Mann-Whitney test for each of these two stations is more than 0.05; which means that null hypotheses (H_0) are not rejected. Therefore, the simulation model is valid.

Table 5: Mann-Whitney test statistics result

	Defect_ Detection	PS_ Inspection
Mann-Whitney U	28.500	27.000
Wilcoxon W	83.500	82.000
Z	-1.631	-1.744
Asymp. Sig. (2-tailed)	.103	.081
Exact Sig. [2*(1-tailed Sig.)]	.105[a]	.089[a]

8. Number of replications

In this section, the amount of replications to produce a satisfactory level of precision was calculated.

Number of replications = ($t_{\alpha/2, n-1}$ * S) / (h*μ) (2)

Where;

$t_{\alpha/2, n-1}$: t-value

S: Standard deviation of average of the number of customers in the whole process (Ave WIP).

μ: Mean of average of the number of customers in the whole process (Ave WIP).

h: Allowable error

S and μ were calculated for six runs. Allowable error and confidence level were considered 0.05 and 95%

respectively. Table 6 shows the outcome of the model for six runs.

Table 6: Outcome of running model

No. of runs	1	2	3	4	5	6
Ave. WIP	18.4	14.5	12.9	10.4	12.9	8.9

Therefore, based on the Eq. (2) the number of replications is equal to:

$(2.571*3.3) / (0.05*13) = 13.004 \sim 13$

9. Improvement

Since this study is aimed to increase customer satisfaction, the system can be improved by reducing waiting time and average time spent in the queue by each customer. Fig. 3 shows the model after modification.
By combining two stations of Inspection Report Recording1 and 2 which are located after Road Test and Periodic Service Inspection, the system can operate more efficiently.

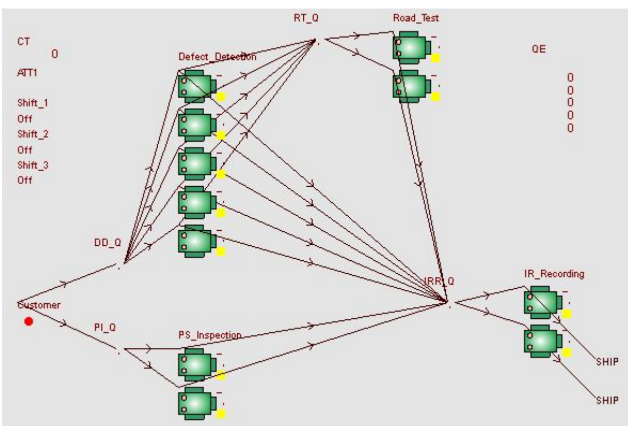

Fig. 3 Simulation of Model Improved

Based on the report of improved model in Table 7, after merging two last stations average time was spent in the queue would considerably decrease to 0.1 min. On the other hand, Road Test station just has one permanent worker for the whole shift which leads to high amount of average time in the queue for this station. Hence, in improved system, the number of the workers of Defect Detection station has been reduced while the number of permanent workers in Road Test station increases to two workers for the whole shift. This caused the peak of the customers gathered before opening the service shop to be coped with.

Table 7: Report of improved simulation model

Queue Name	Max Length of Queue	Ave NO. in Queue	Ave Time in Queue
Defect Detection	20.1	2.6	11.7
PS Inspection	10.4	1.6	13.6
Road Test	3.0	0.2	2.8
IR recording	2.1	0.0	0.1

As can be seen from Table 8 which compares average number of customers in the whole process (Ave WIP) and average time spend (Ave time) in the queue of both models (initial and improved model), there is a reduction in the amount of time spent in queues for all stations. Moreover, Work in process (the number of customers in the whole process) in the system has decreased. Besides, Table 8 also depicts the percentage of improvement for all thirteen replications that is an indication of positive effect of applied changes on system performance which results in higher customer satisfaction and service rate.

Table 8: Report of improved simulation model

No. of replications	Initial		Improved		Improved %	
	Ave. WIP	Ave. Time	Ave. WIP	Ave. Time	Ave. WIP	Ave. Time
1	7.5	22.5	6.8	17.3	10%	30%
2	16.4	49.1	8.7	22.2	87%	122%
3	10.9	32.7	7.7	19.7	41%	66%
4	11.1	33.2	7.4	18.9	49%	76%
5	11.2	33.7	7.1	17.9	59%	88%
6	10.0	30.1	6.7	17.1	49%	76%
7	9.4	28.2	7.2	18.3	30%	53%
8	13.0	38.9	8.0	20.4	61%	90%
9	12.3	36.8	8.8	22.2	40%	65%
10	10.8	32.5	7.0	17.8	54%	83%
11	11.2	33.5	7.4	18.7	51%	79%
12	10.9	32.8	6.5	16.6	67%	98%
13	10.8	32.4	7.3	18.4	49%	76%

10. Conclusion

This case study demonstrated the modeling approach using simulation output analysis designed by WITNESS software for an after-sale service automotive repair shop. The current system was running with a large amount of queuing time especially before the road test station that makes it incapable of meeting the customer needs appropriately and consequently result in reducing customer satisfaction. After merging two last stations and modifying the number of workers in Defect Detection and Road Test station, the system was simulated again and the outcomes indicated salient improvements without system interruption. In the future, several research topics can amplify this work by comparing the outcomes of this study with other simulation software such as SHOW FLOW, ARENA etc.

In addition, it may be of benefit to optimize the number of servers in each station by using Design Of Experiment (DOE) approach which sets reduction in the number of servers and waiting time as the system goal.

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