Smart Computing and Systems Engineering, 2021
Department of Industrial Management, Faculty of Science, University of Kelaniya, Sri Lanka

Paper No: SE-14 **Systems Engineering**

Simulation analysis of an expressway toll plaza

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***Abstract* - Since the early civilizations, transportation has played a significant role, from fulfilling basic human needs to contributing towards major economic growths all over the world. With the advancement in technology, the demand for smooth and hassle-free transportation increased and it is particularly true for road transportation in Sri Lanka as well. As a result, the expressway road network was introduced to Sri Lanka in 2011. Although a toll is payable for the use of expressways, many vehicle users prefer to utilize the expressway due to the extensive amount of time saved. Time is of utmost importance for expressway users. Hence, long queues and waiting time at toll plazas where the toll payment is made should be minimized. This study is aimed at analyzing the performance at the Peliyagoda toll plaza of the Colombo-Katunayake expressway where the formation of long queues and long waiting time in queues can be observed during peak hours. Due to the high complexity of using the analytical approach in obtaining the performance measures, a simulation approach was used with Arena Simulation Software. Few setup improvements were identified, and each of the setups were simulated to obtain the performance measures. Based on the comparison of the results, recommendations and suggestions to improve the efficiency of the operations at the Peliyagoda toll plaza have been outlined.**

Keywords - expressway, M/M/1, queue simulation, queuing theory, toll plaza, waiting time

I. INTRODUCTION

Today, expressways around the world connect cities far and wide, and they are instrumental in saving time and operational costs. With advantages such as high speed, high vehicle volume, greater comfort and less fuel wastage, drivers tend to utilize expressways even if a toll is charged. By the end of the year 2019, the total length of expressways in Sri Lanka was 217.8 km [1]. It should be noted that while the expressways are advantageous to vehicle users, it is also a revenue generation model for the country. According to the Annual Report of the Central Bank of Sri Lanka, a revenue of Rs. 8.6 billion was generated from the expressway network in 2019 [1], compared to Rs. 8.4 billion in 2018 [2].

A tolling system situated at the exit point of an expressway charges a toll from each user based on the distance travelled and the vehicle category. The Peliyagoda toll plaza is situated towards the Southern end of the Colombo-Katunayake expressway. A majority of the vehicles that come to the Colombo city from Ja Ela, Katunayaka, Negombo and even from Chilaw and Puttalam areas, utilize the Colombo-Katunayake expressway, and make the toll payments at the Peliyagoda toll plaza to enter Colombo and its suburbs. With the introduction of the Outer Circular Highway, traffic flow from Southern parts of the country to Colombo also exit the expressway network from the Peliyagoda toll plaza. Moreover, vehicles that need to take the Colombo-Kandy Highway or go towards Wattala will need to make the toll payment at the Peliyagoda toll plaza. Currently, two types of toll collection methods are available at the Peliyagoda exit. They are: (1) the Manual Toll Collection (MTC) and (2) the Electronic Toll Collection (ETC). At MTC, a vehicle is required to stop at the gate and make the payment to the teller using cash. The teller then issues the ticket and balance (if any), and the toll gate barrier is opened for the vehicle to pass through. For a vehicle to utilize the ETC facility, it should be enrolled in the highway's information system as a user, and sufficient funds should be available in the user's account. Enrolled vehicles are given an e-tag to paste on the vehicle's windshield. The e-tag of a car approaching the ETC gate is scanned using an automatic vehicle identification technology, and the toll gate barrier is opened without requiring the vehicle to stop. Simultaneously, the toll is debited from the user's account. The toll plaza at Peliyagoda consists of five toll gates of which four are MTC and one is ETC.

The problem lies in the formation of long queues at the toll plaza during peak hours and its adverse effects on users and the environment. According to an analysis conducted by the Expressway Operation Maintenance and Management Division (EMO&MD), the current number of toll lanes are insufficient at the Peliyagoda exit (Figure 1). Due to the high rate of arrivals and the inadequate number of toll gates to serve them, queues are formed and long waiting times are encountered by the vehicle owners during peak hours.

The benefit of the time gained by taking the expressway could be lost to the users when long waiting times are encountered at the toll plaza. For example, delays in reaching offices, educational institutions, and other personal commitments can result in disciplinary actions, loss of the business and other personal losses. Furthermore, vehicles accelerating and decelerating to move slowly in queues and braking to bring the vehicle to a stop, cause wastage of fuel and emission of harmful pollutant gases such as CO, CO2, and NOx to the environment, that in turn, cause respiratory diseases in humans [3].

Expressway	Critical IC	Peak time	No of toll Lanes	Given Capacity of toll Lane Vehicles per hour		Actual Traffic per hour		Remarks
				ETC	MTC	ETC	MTC	
OCH, E02	Kadawatha	Morning	Entrance 3 - Exit- 5	N/A	360 (for Entry)	-	528	Entry Booth no-3
		Evening	Entrance 3 - Exit- 6			-	400	Entry Booth no-3
	Kottawa	Morning	Entrance 3 - Exit- 7	N/A	360 (for Entry)	-	337	Entry Booth no-5
		Evening	Entrance 3 - Exit- 7			-	395	Entry Booth no-5
CKE, E03	Peliyagoda	Morning	Exit 5 (MTC 4, ETC 1)	1100	240	453	286	Available no of Toll lanes are insufficient
		Evening				150	228	
	Ja Ela	Morning	Entrance 2 (MTC 1, ETC 1)	1100	360	253	415	Available no of Toll lanes are insufficient
		Evening	Exit 2 (MTC 1, ETC 1)		240	160	341	

Expressway	Critical IC	Peak	Peak days	Toll Plaza (Entrance/Exit)	Peak Time		Remarks
					From	To	
OCH, E02	Kadawatha	Morning	Monday	Entrance	7.00 a.m.	9.30 a.m	
		Evening	Friday	Entrance	4.00 p.m.	9.00 p.m	
	Kottawa	Morning	Monday	Entrance	7.00 a.m.	8.00 a.m	
		Evening	Friday	Entrance	5.00 p.m.	9.30 p.m	
CKE, E03	Peliyagoda	Morning	Monday	Exit Plaza	7.30 a.m.	9.30 p.m	Insufficient Lanes at Exit (available 5 lanes)
		Evening	Friday	Exit Plaza	4.30 p.m.	6.00 p.m	
	Ja Ela	Morning	Monday	D-Entrance Plaza	7.30 a.m.	9.30 p.m	Insufficient Lanes at Entrance & Exit (Peliyagoda - Ja Ela Section)
		Evening	Friday	A- Exit Plaza	4.30 a.m.	7.30 a.m	

N/A - Not Available

Fig. 1. Remarks from EMO&MD
Source: http://www.exway.rda.gov.lk/index.php?page=announcements/20190401

Queuing Theory can be used to analyze the formation of queues and delays caused due to long waiting times in a system. Some measures that can be derived include average waiting time in the queue, average time spent in the system and average number of customers in the queue.

In this paper, we apply queuing theory to analyze the toll payment system at the Peliyagoda toll plaza of the Colombo-Katunayake expressway in Sri Lanka. Due to the complexity of the system, applying analytical models is difficult. Thus, we develop a simulation model to calculate the performance measures of the system. In addition to the current system, we propose several simulation setups of alternative systems to improve the performance of the current system. The proposed systems are also analyzed using simulation. By analyzing the performance of the current system and proposing alternative setups, we provide recommendations to the expressway management's decision-making process to help reduce the congestion, especially during peak hours, and thereby achieving an efficient transportation system and minimizing environmental pollution.

II. Queuing Concepts

A queue is formed by a flow of customers from an infinite or finite population towards the service facility that lacks the capability to serve them all at a time [4]. The basic features of a queuing system can be stated as follows:

A. The arrival process

This is the way that customers arrive at the system. The arrival process can be classified in several ways such as single line or multiple lines, finite or infinite and single customer or customers that come in bulk. The arrivals are assumed to occur in a random pattern and are usually modelled using a suitable probability distribution such as the Poisson distribution. The average customer arrival rate, λ is an important parameter of the arrival process.

B. Service discipline

The serving process can be carried out according to four main principles such as, First-In-First-Out (FIFO), Last-In-First-Out (LIFO), Service for Random Order (SRO) and Priority Service (PS).

C. The service time distribution

The service time distribution is usually modelled as a uniform or exponential distribution. It is independent of the arrival process. The average customer service rate, μ is an important parameter that characterizes the service time distribution.

D. Service mechanism

This is the work on policy decided for service, and how the customers leave the system. The service mechanism can be classified in several ways according to the number and configuration of service facilities and the service pattern of the system. The service mechanism can be single channel-single stage, single channel-multiple stage, multiple channel-single stage or multiple channel-multiple stage (Fig. 2).

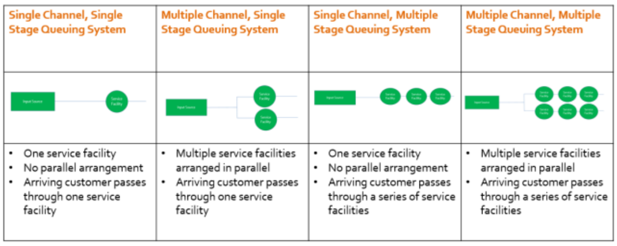


Fig. 2. Configuration of queuing systems

Queuing theory gives an understanding of the queuing system and ideas about what can be done to make it more efficient, easy to serve, and the number of users that can be served. The ultimate objective is to make intelligent decisions by understanding the underlying processes [5]. Although several analytical queuing models exist, modelling complex systems using these models might lead to too many simplifications which might in turn cause resulting models to be invalid. Simulation modelling can be utilized to understand the behaviour of complex queuing systems. A simulation provides the flexibility to experiment with certain parts of a decision problem and analyze the likely consequences of alternative decisions. Once the basic features of the queuing system are clearly defined and understood, the system can be simulated, and the required performance measures can be calculated.

III. Literature Review

Expressways were introduced to Sri Lanka in 2011, and it is being expanded to other parts of the country. Currently, there is hardly any published research work available for queue analysis at toll plazas in Sri Lankan expressways, but a substantial body of international research findings is available on this topic.

One of the latest research works available for the application of the queuing theory for a toll plaza is [6]. The main objective of their study was to examine the applicability of the queuing theory for a toll plaza in both directions. Their results showed that although the postulated Poisson distribution is the true population distribution to one direction, there is less degree of agreement to the other direction. They further showed that although most of the studies related to expressway queues are assumed to be operating under the steady-state condition, it is seldom true in nature.

Sihotang et al. [7] analyzed the performance measures of a toll plaza queuing system assuming arrivals and service times to be normally distributed. The data collected for this research were the total number of vehicles that arrived, and the total number of vehicles served for five weekdays at the toll gate Mukti Harjo. Using the data, they calculated the arrival rate and service rate, and used the Kolmogorov-Smirnov test and the Chi-Square test to determine the distribution of arrivals. Using Arena Software for Simulation of the system with varying number of servers, they concluded that the number of servers at the toll plaza is optimal and does not need to be changed.

A toll gate system in Salem, Bangalore was simulated by Shanmugasundaram & Punitha [8] for different vehicle categories such as car/jeep (F1), light commercial vehicles (F2), truck/bus (F3) and multi-axle vehicles (F4). The arrival and service distributions for each vehicle category were calculated using the collected data, and a simulation was conducted to compare various service mechanisms. Duhan et al. [9] analyzed a toll plaza system in North India to study the current traffic congestion situation and suggested possible solutions. With data on the volume of traffic on an hourly basis for a working day (Monday) and non working day (Sunday), they identified the peak and nonpeak hours. By focusing the experiments only for those hours, they suggested ways to reduce the waiting time in queues, such as increasing the number of toll booths, employing mobile toll collectors, and setting up smart machines to decrease the service time. They also suggested the option to install a red traffic light before 1km to the plaza, to enhance a smooth vehicle flow towards the booths.

Ceballos & Curtis [10] analyzed the queuing system at a parking exit toll plaza at airports. Although the study was not based on expressways, the approach to their analysis of a multi-server queuing model is noteworthy. In their study, both the application of the analytical queuing model and simulation were used, and measures of effectiveness from both methods were compared. They pointed out that although toll plazas are multi-queue multi-server systems, the analytical formulation of such systems is extremely complex. The workaround used was to model the system as a series of single-channel queuing systems in parallel, and a single-queue multiple-channel system. They showed that the analytical results greatly differ from the simulation results. However, not all research shows that the above conclusion is true. In a study done by Punitha [11] by using the simulation approach and analytical approach, she concluded that both methods give coinciding results. Her study was based on the traffic delay at a toll plaza, and she examined the performance measures for a single server queue with four types of vehicle categories. Each vehicle category was simulated, and performance measures for each were obtained accordingly.

Antil [12] studied the traffic congestion at a Delhi toll plaza with a high arrival rate of vehicles. His analysis was limited to the busiest hour of the day for a working day (Monday) and non working day (Sunday). For the server that serves the incoming traffic, he used the single-channel single-stage queuing model and compared the resulting performance measures. In addition to that, he also calculated the cost of waiting per customer based on the assumption that fuel of Rs 4 per minute was wasted while waiting in the queue. He suggested that the toll plaza needed more toll gates and modern technology to improve the service times.

IV. FORMAL DEFINITION OF THE PROBLEM STATEMENT

The Peliyagoda toll plaza is the service facility of our queuing system. The vehicles are the arriving units, and the toll gates are the servers or channels. The toll plaza has 5 toll gates, i.e., the queuing system under study has 5 servers. Out of the 5 servers, the 4 MTC servers are assumed to have the same service rates whereas the ETC server has a different service rate. Once served, the units exit the system. Therefore, there is only one stage of service and the system is a single-stage multiple-channel multiple-queue system. There is no limit to the number of arriving units. There are no predefined queuing formulas to analyze such systems due to their complexity. Thus, we resort to a simulation-based approach to analyze this system.

A. Data and data description

Raw data is collected from the EOM&MD with due permission from the Sri Lanka Road Development Authority (RDA). Data is collected based on the number of vehicles that exited through the Peliyagoda toll plaza for one hour time intervals during each day for a one-week period in the year 2019 when no holidays or other external factors affected the traffic inflow to Colombo or its suburbs. Figure 3 depicts the number of vehicle arrivals at the Peliyagoda toll plaza during each hour within the time considered. Table I, further summarizes the total number of vehicles that exited through each lane.

According to Figure 3 and Table I, the number of vehicle arrivals during the period of 6 am to 9 am is the highest compared to other time intervals and vehicle arrivals on weekdays are higher than the vehicle arrivals during the weekend. Thus, the weekend is disregarded, and the study is carried out for weekdays for the period 6 am – 9 am which can be considered as the peak hour period in the morning.

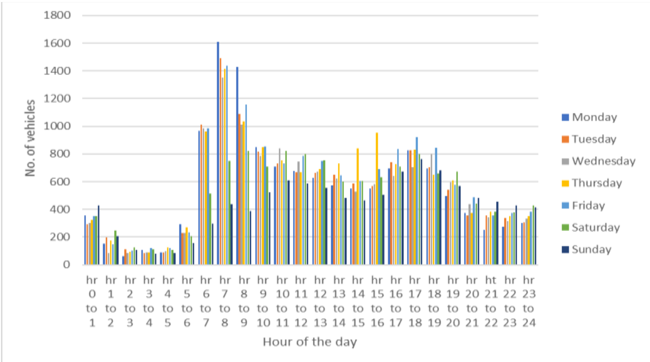


Fig. 3. Number of vehicles that exited from Peliyagoda toll plaza during each hour within a week in 2019

TABLE I. DATA ON THE TOTAL NUMBER OF VEHICLE ARRIVALS AT EACH GATE

Day	Total number of vehicles that exited through each lane					Total
	Gate 1 - ETC	Gate 2 - MTC	Gate 3 - MTC	Gate 4 - MTC	Gate 5 - MTC	
7.10.2019 (Monday)	2585	3108	3244	2590	1980	13507
8.10.2019 (Tuesday)	2690	3138	3289	2430	1896	13443
9.10.2019 (Wednesday)	2634	2967	3049	2618	1919	13187
10.10.2019 (Thursday)	2677	3389	3325	2653	2208	14252
11.10.2019 (Friday)	2752	3219	3448	2761	2309	14489
12.10.2019 (Saturday)	174	3158	3231	2583	1891	12617
13.10.2019 (Sunday)	1142	2828	2903	2105	1396	10374

In addition to the data collected on vehicle arrivals, data on service rates were also gathered by interviewing an official at the EOM&MD. According to experts, the average number of tickets that can be issued by a teller at the MTC gate is 210 per hour and the maximum number ever reached is 295 per hour. The ETC gate on the other hand has never been saturated since its installation, and on average, 453 vehicle arrivals per hour are observed during the morning. These expert opinions are used in calculating service rates, as direct observation at the facility was not possible because of the restrictions imposed due to the COVID-19 situation in the country during the considered period.

V. Simulation Experiment

The queuing system under study is first analyzed based on the number of lanes and queue formation.

A. *Calculating the arrival rate (λ) and obtaining the distribution of arrivals*

For each lane, we consider the number of vehicle arrivals per hour for the selected period of 6 am – 9 am during the five weekdays. Thus, for each server we have 15 data points and calculate the average vehicle arrival rate, λ.

$$\lambda = \text{total vehicle arrivals per hour} / 15 \qquad (1)$$

Graphical analysis shows that the arrival of vehicles at each lane is random. We conduct a Kolmogorov-Smirnov (K-S) test at 0.01 significance level to statistically confirm if the distribution of vehicle arrival per hour at each server follows a Poisson Distribution. Our results are summarized in Table II.

The K-S critical value at 0.01 significance level and 15 degrees of freedom is 0.404. From Table II, the K-S test statistics calculated for all five lanes are less than 0.404 and the vehicle arrivals can be assumed to follow a Poisson distribution with the respective arrival rate λ.

B. *Calculating the service rate μ and obtaining the distribution of service times*

The service rates for all lanes are obtained based on expert opinion as mentioned in Section III.A. At MTC lanes, a minimum of 210 vehicles on average can be served per hour. Therefore, the service rate μ is considered as 1/210 hours per vehicle. At the ETC lane, there is 453 actual traffic per hour observed in the morning. Taking this information into account, the service rate μ at ETC lane is considered as 1/453 hours per vehicle. The service times are assumed to follow an exponential distribution.

Due to the complexity of the system under study, traditional queuing theory equations cannot be used to calculate the performance measures of the system. Therefore, a simulation is performed using the Arena simulation software.

TABLE II. Vehicle Arrival Rates and K-S Test Statistic Results

	Server 1 - ETC	Server 2 - MTC	Server 3 - MTC	Server 4 - MTC	Server 5 - MTC
λ	370.5	205.8	207.8	203.5	194.2
K-S test statistic	0.4690	0.235	0.2444	0.327	0.389

C. *Simulation setup*

In addition to the current system setup, four other setups are proposed and simulated to improve the performance measures of the current system. Finally, the recommendations are presented. The five identified setups are summarized in Table III. Scheme B suggests adding more manual servers to the system, schemes C and D incorporate the use of new technology and adding more electronic servers, and scheme E incorporates both.

For each scheme, servers in each lane are simulated individually for a three hour period. The number of arrivals is generated using a Poisson distribution, and the service times are generated using an exponential distribution. Hence, each lane is separately modelled as a single server single stage queuing model. The relevant parameters for each simulation is provided in Table IV.

D. *Performance measures of the Queuing System*

The following performance measures were obtained from Arena Simulation Software for comparing the current system with the proposed system.

a. Average waiting time in queue
b. Average number of units in queue
c. Average time a customer spends in the system
d. Maximum time a unit spends in the system
e. Average number of units in the system
f. Server utilization

VI. Results and Discussion

The five identified schemes are stimulated repeatedly using Arena Simulation Software and performance measures are recorded. Finally, the overall performance of each scheme is obtained by calculating the average values of the performance measures from each simulation run. Table V and Figure 9 summarize and compare the performance for each scheme.

Considering the average values for Scheme A, a vehicle has to wait 2.3 minutes in the queue and nearly 3 minutes in the system before leaving after service. The maximum waiting time a unit may have to spend in the system is as high as 8.84 minutes. The utilization factor for Scheme A shows that 93.2% arriving customers have to wait for service. These measures highlight that the current setup should be made efficient. Performance measures of Schemes B, C, D and E show that waiting time can be reduced by implementing one of them, but it is important to note the changes that should be adopted along with the implementations of those schemes.

TABLE III. Summary of the Simulation Setup

Scheme	No. of MTC servers	No. of ETC servers	Total no. of servers
A – current system	4	1	5
B	5	1	6
C	3	2	5
D	2	3	5
E	5	2	7

Schemes B and E have the lowest waiting time and number of waiting units, in comparison to other schemes. The waiting times are 25.8 seconds and 19.8 seconds, respectively. The number of waiting units is approximately 1 for both schemes. Less than 1 minute waiting time and 1 unit waiting in queue are positive performance measures.

However, in order to implement either one of these schemes, extra space is required at the toll plaza as both schemes require additional toll gates. If space is available for two extra toll gates, Scheme D is the best option whereas Scheme B can be adopted if space is limited for one extra toll gate only. Both schemes can meet the current demand at the Peliyagoda toll plaza, and increase the efficiency, and therefore no effort is needed to promote the use of ETC among customers.

If space is not available to install more gates, the option is to adopt either Scheme C or D. The waiting time in both schemes is more than 1 minute. Although the number of waiting units are 5 and 6 respectively, it is an improvement from the current setup where the queue length can be as high as 8.

TABLE IV. SIMULATION SETUP

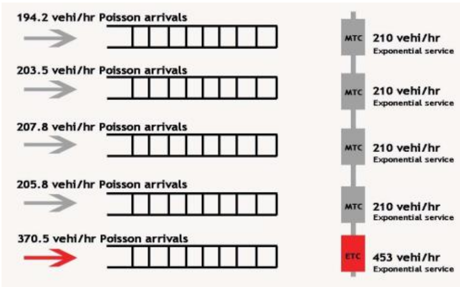
<table>
<tr><th>Scheme</th><th>Figure with parameter description of setup</th></tr>
<tr><td>A</td><td>

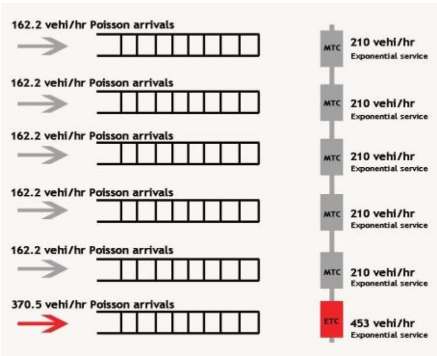
Fig 4. Scheme A setup</td></tr>
<tr><td>B</td><td>

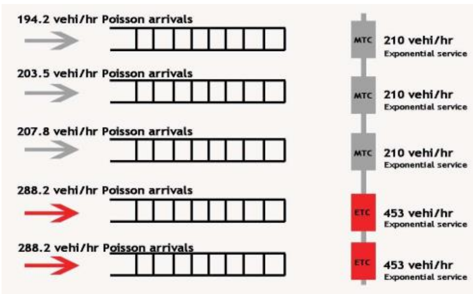
Fig. 5. Scheme B setup</td></tr>
<tr><td>C</td><td>

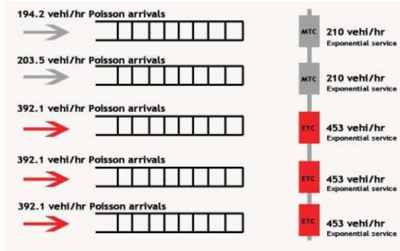
Fig. 6. Scheme C setup</td></tr>
<tr><td>D</td><td>

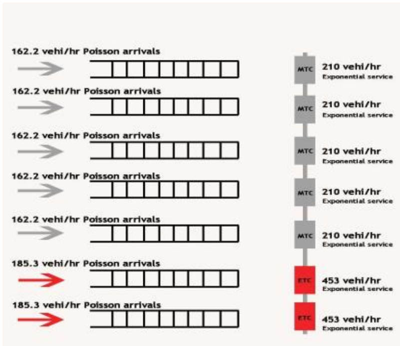
Fig.7. Scheme D setup</td></tr>
<tr><td>E</td><td>

Fig.8. Scheme E setup</td></tr>
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TABLE V. SUMMARY OF PERFORMANCE MEASURES FOR EACH SCHEME

Scheme	Avg. waiting time in queue (mins)	Avg. number of units in queue	Avg. time a unit spends in the system (mins)	Max.time a unit spends in the system (mins)	Avg. number of units in the system	Toll gate utilization
A	2.31	8.37 ≈ 8	2.56	8.84	9.30 ≈	93.2%
B	0.43	1.39 ≈	0.69	3.05	2.18 ≈	78%
C	1.64	5.87 ≈	1.86	6.41	6.71 ≈	83.89%
D	1.13	4.8 ≈	1.32	4.71	5.72 ≈	91.47%
E	0.33	0.9 ≈	0.57	2.48	1.62 ≈	68%

Scheme C replaces one of the existing MTC gates, and Scheme D replaces two of the existing MTC gates with ETC gates. In addition to this, an effort is needed to enroll more vehicles in the ETC programme. Based on the arrival rates used in the simulation of these schemes, the minimum number of vehicles that should be converted to ETC when adopting the schemes are:

- Scheme C – 618 vehicles
- Scheme D – 1241 vehicles

Reference [13] in their study on ETC systems in Sri Lanka suggested that having only one ETC gate at the toll plaza does not attract more customers to use it and that the RDA should take measures such as launching a sound marketing campaign to attract more customers to use ETC. Currently, the ETC payments are given a discount which is a positive move towards achieving this objective. In addition to the customer benefits, the authorities will also yield benefits by ETC gates such as, reduction in cash handling and hence less use of paper to help environmental conservation and reduction in staffing.

However, high installation costs should be borne for ETC gates than for MTC gates. Hence, it is important to take the cost factor into conducting an economic analysis.

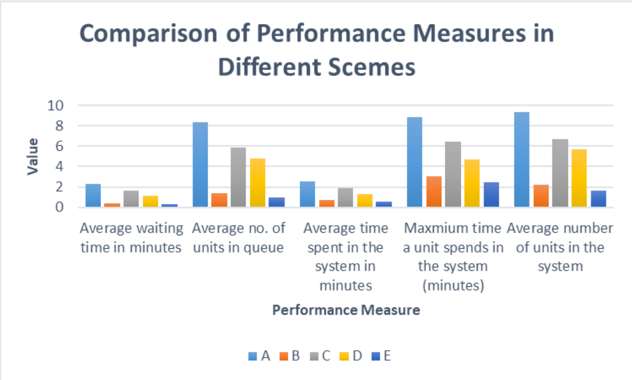

Fig. 9. Performance measures calculated for each simulation setup

In addition to the adoption of a better setup scheme at the toll plaza, the authorities could also take measures to improve the service times at the toll plaza such as encouraging customers to use exact change and adopting exact values for toll [14].

VII. CONCLUSION AND FUTURE WORK

The objective of this study is to analyze the performance of the queuing system at Peliyagoda toll plaza of the Colombo-Katunayake expressway. Using the data collected, the current setup and other four possible setups are simulated with the objective of comparing their performance measures. In the current setup, a vehicle spends 3 minutes on average in the system and the average number of vehicles in a toll gate queue is 8. Clearly this causes a high traffic congestion at the toll plaza. According to the Ministry of Transport in Sri Lanka [15], the vehicle population in the country will gradually increase in the future. Moreover, the number of users utilizing the expressway on a daily basis will increase as a result of the expansion schemes of expressways. Therefore, it is vital that steps are taken to increase the service efficiency of the toll plaza. Based on the results of the four proposed alternative setups for the system, our recommendations are presented in Table VI for the RDA to utilize when making decisions for the improvement of the current system.

One of the major limitations of the study is the unavailability of reliable data for calculating service times due to COVID-related travel restrictions imposed in the country during the data collection period. Therefore, estimated values were obtained using expert opinion as service rates of MTC and ETC gates respectively. More reliable estimates of the performance measures may be obtained if data through observation are used in the simulations. Although the system under study is a multiple-queue multiple-channel queuing system, the simulations are conducted individually for each queue as a series of multiple single-channel queuing systems. As Ceballos & Curtis [10] pointed out, this approach segregates the system into multiple sub-systems and is averse to change as it does not account for users to select the shortest-queue and no queue jumping is allowed.

TABLE VI. RECOMMENDATIONS

Factors to consider	Setup improvement
Space available to add more servers	Add one manual toll gate
No space for more toll gates but cost can be borne for new technology	Convert one or two existing MTC gates to ETC. Subsequently attracting more customers to enroll in the ETC usage is necessary.
Both space and cost for new technology available	Add one MTC gate and one ETC gate

This behaviour is different from normal behaviour at toll plazas where vehicles choose the shortest queue and changing lanes is allowed in some cases. Thus, although a highly complex setup, it might be beneficial to conduct the simulation as a multiple queue multiple-server queuing system. Such a simulation design phase may require careful planning to consider different characteristics of such a system.

The results of the analysis of this study show that adding more servers improves the performance of the system. However, it also increases the service cost. As future work, an economic analysis could be done to find the optimum number of servers that will simultaneously minimize the service cost and the cost incurred due to delays in queues.

In summary, this study performs a simulation-based analysis of the performance of operations at the Peliyagoda expressway toll plaza. Recommendations are drawn based on the results of the simulated setups and their performance measures. Furthermore, possible future work has been stipulated which can add more value in the direction of this study.

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