Application of Queueing Theory towards Improved Traffic Management in Southern Expressway of Sri Lanka

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Abstract— *A good road network of a country is always a sign of healthy transportation. Further, it is linked with developed traffic management. Unfortunately, the level of the traffic management of Sri Lanka does not comply the satisfaction level of general public. Queues are being generated everywhere during day today transportation. When it comes to the topic of queue, Queues could be seen at anywhere such as super market, banks, and whilst traveling etc. Understanding of queueing theory is the prime way of finding solutions for queues. This paper targets the problem of having queues in road networks and a solution towards a better traffic management. Further this paper proposes a solution to avoid queues and monitor over speeding vehicles whilst suggesting the application to the southern expressway at very first as a pilot project and expand to the rest of road networks step by step. Automatic Number Plate Recognition is proposed as the technical solution to rectify the identified problem. The proposed traffic management system consists with ANPR toll gate system and ANPR based monitoring system in southern expressway. Main components of the proposed system will be a set of ANPR cameras, A fibre optic network, Centralized database and system software. With the proposed system is expected to improve the service rate of an entry toll gate of the expressway by 300%, and exit by 200%. Moreover, it is expected to generate less conjunctions during an accident. Proposed system could be enhanced toward other road with the success.*

Keywords— **Queueing Theory, ANPR Solutions, Traffic Management, Southern Expressway, Sri Lanka**

I. INTRODUCTION

In any country, road networks are being used to utilize for transportation. As well as a good road network, a good traffic management too, plays a vital role of saving people's time, ultimately improve the economy by saving the effective time of the work force of the country. However, when it comes to Sri Lanka, it is generally known, traffic management is not in a level that general public can be satisfied. Especially before and after office hours it is worst in most cities and urban areas. Author has experienced a long-waited queue for 20 minutes to exit in Kadawatha interchange of Expressway where the total travel time from Kottawa to Kadawatha lies around 11 minutes, where total travel time lead nearly 20 minutes.

A queue is formed at any place when a customer (A human being or a physical entity) that require a service is made to wait due to the fact that the number of customers exceeds the number of service facilities or when service facilities do not work efficiently and take more time than prescribed to serve a customer(Sharma, 2009). A Queue can be experienced anywhere in our lives, as in a Bank, a supermarket, a fuel station, a Bus stop, while traveling etc. Simply a queue can be defined as the gap between a service time of the process and the arrival rate of the process. Queueing Theory is a mathematical solution to handle the queue effectively.

A. Problem Statement and Aim

Even though Sri Lanka's Expressway is considered better than normal road network with regard to time waste and safety, it is popularly known that very long queues are being generated during some occasions. These queues are being generated within highways following a disruption such as severe weather conditions and accidents. And also, they are being generated often within interchanges during long weekends and daily before and after office hours in some interchanges like Kadawatha, Kaduwela, and Kottawa.

The aim of this paper is to provide a technical solution in order to improve the traffic management of Sri Lankan road networks as an application of queuing theory. Further this paper proposes a solution to avoid queues and monitor over speeding vehicles whilst suggesting the application to the southern expressway at very first as a pilot project and expand to the rest of road networks step by step. Automatic Number Plate Recognition (ANPR) is proposed as the technical solution to rectify the identified problem. ANPR is being already used in many countries in order to monitor traffic violations. However the proposed solution will not be just an ANPR solution. It will be an ANPR based application combined with results obtained from queueing analysis.

With the proposed ANPR based traffic management system it is expected to increase the efficiency at entry toll gates of expressway interchanges by 300%, and increase the efficiency at exit toll gates of expressway interchanges by 200%. Further it is expected to produce disciplined drivers via continuous monitoring and reduce accidents in the expressway.

II. Literature Review

A. *Queueing theory and its applications*

In general, Queueing systems can be characterized by input process, service time distribution, Number of servers or channels, and buffer size (waiting room) (Zukerman, 2020). In addition to that queue discipline also play a significant role. Best example that we can get an idea of the behaviour of queue is a supermarket. Customers at the cashier is served as first come first serve basis. If the cashier takes 1 minute for example to serve a customer, next customers who reach the counter have to wait in sequence, until the previous customer is cleared. The Queue may increase when customers reach at the cashier counter in higher rate. The queue may become unpleasant when customers don't behave disciplined. Simply there are 2 main actions that can be taken to reduce the queue.

1. Speed up the serving process.
2. Slow down the Arrival Rate.

Speed up the serving process can be gained by establishing parallel servers and enhancing serving rate. Methods can be handled with technical processes. With regards to above super market example. It could be several cashiers working at the same times as well as serving time to a particular customer could be reduced by several seconds by using various techniques. The second point i.e. delaying the Arrival Rate is somewhat tricky where it may be technical or non-technical. Some super markets provide portable scanners or mobile applications so that customers can scan the barcode themselves in order to speed up the checkout process at the cashier counter. Further, some institutes such as banks and hospitals provide free Wi-Fi and free coffee for the customers so that they spend their waiting time comfortably.

The entire structure of queuing systems is usually presented as measuring efficiency and effectiveness of a system in terms of the number of customers in the system and in queues, the average time customers spend in the system and the probability of the system being busy or idle (Stevenson, 2009). The basic components of a queueing system are shown in figure 1.

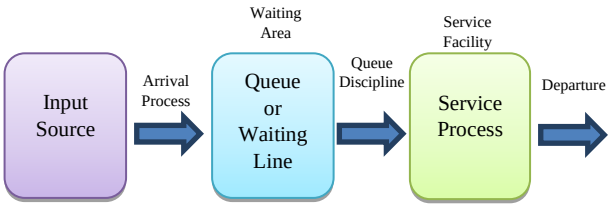

Figure1. Components of a Queuing System

Source: (Sharma, 2009)

1)The Basic Queueing Model: Queueing model can be illustrated by exponential and Poisson probability distribution mathematical functions(Winston, 1991). The exponentialdistribution with parameter λ is given by $\lambda e^{-\lambda t}$ for $t \geqslant 0$. If T is a randomvariable which represents interarrival times with the exponential distribution, then $P(T \leqslant t) = 1 - e^{-\lambda t}$ and $P(T > t) = e^{-\lambda t}$. This distribution lends itself well to modelling customer interarrival times or service times for a number of reasons. The first is the fact that the exponentialfunction is a strictly decreasing function of t. This denotes that after an arrival hashappened, the waiting time until the next arrival is more likely to besmall than large. Another important behaviour of the exponential distribution isknown as the no-memory property. The no-memory property suggests thatthe time until the next arrival will not depend on how much time has alreadypassed. This makes a sense for a model where we're measuring customerarrivals because the customers' actions are clearly independent of one another(Berry, 2006).

2) Little's Queuing Formula: It is useful todetermine variouswaiting times and queue sizes for particular components of the system in order toanalysehow the system should be run. In Little's formula, It is defined as $L=\lambda W$, $L_q=\lambda W_q$,$L_s=\lambda W_s$where; L =average number of customers in the queue at any given time; Further, L can be divided as L_q, average number of customers waiting in the queue, and L_s,the average number ofcustomers in service; λ=the arrival rate into the system; and, W = average time a customer spends in the queuing system, W could be further divided into W_q, average amount of time spent in the queue itself and W_s, average amount of time spent in the service. In this scenario $L= L_q+L_s$ and $W=W_q+W_s$(Bertsimas, Nakazato, 1993).

B. *Automatic Number Plate Recognition (ANPR) Solutions*

Automatic Number Plate Recognition (ANPR) system is a set of cameras which is connected to a database via a dedicated network (mostly uses optical fibre networks). Theses cameras are equipped inbuilt with image processing algorithm so that system itself scan the number plate of a vehicle, extract the text from the image, and feed to the database. ANPR technology is already considered as an incredibly useful technology across the world with uses varying from Traffic Management, Car Park and private land vehicle identification and fuel retail management through to motor trafficcontrol and intelligence purposes. (Mike Rhead, Soodamani Ramalingam, 2013) There has been a strong increase in competition for the government sector ANPR market that incorporates Policing, local and national authorities Government agencies specially within countries such as United Kingdom, United States, Japan etc.Number plate detections algorithms need to be aligned with several factors that may be vary with the country. They are number plate size, Locations of the number plate, Colour of the number plate and characters. In Sri Lanka, these

factors could not be affected significantly as vehicles' number plates are issued by the department of Motor Traffic where all vehicle will have same sized, same coloured, same font character number plates.However,there may be few exceptional cases such as old number plates with Character 'Sri'. Conventional ANPR system works as shown in Figure 2.

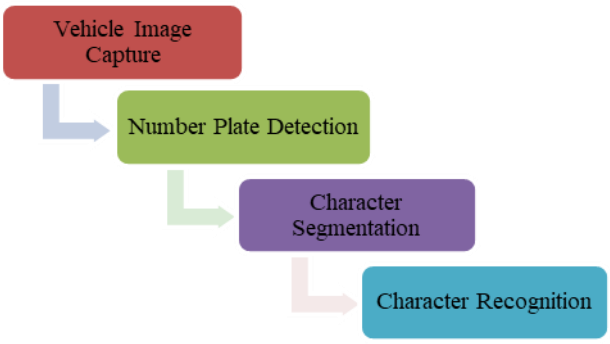

Figure2. Components of a Conventional ANPR System

Source: (Chirag Patel, 2013)

One of the most popular application of ANPR is car park management where we can understand the operation of ANPR solution in a simple way. When a vehicle enters the car park, ANPR camera scan the vehicle number plate and feed to the database with date and time. Again, number plate is scanned at the exit, fed to the database. ANPR software which is connected to the database calculate the price for the time duration spend in car park and open the payment method for the customer. Often it is card payment and exit would be opened once payment is success full.

C. Southern Expressway of Sri Lanka

Southern Expressway (E01) of Sri Lanka was the first ever highway which was added to the Sri Lanka's road network. Initially it was from Kottawa to Galle and extended to Mattala later. Total distance of expressway 222 km and it consists with 19 interchanges from Kottawa to Mattala. Average daily traffic volume in Southern Express way and Outer Circular way was 65,246 and it was around 8% increase than 2018. The toll revenue of Southern Express way and Outer Circular in 2019 was Rs.6192.18 Million(Ministry of Roads and Highways , 2019).

III. Proposed Methodology as a Pilot Project to the Southern Express way

Proposed system is mainly consisting with two sub systems i.e. ANPR based toll system and ANPR based monitoring system. Each sub system consists with ANPR cameras, Fibre optic Network, Database and associated software.

A. ANPR Based Toll System

The aim of having ANPR based toll system is to manage the traffic at expressway interchanges by enhancing efficiency at toll gates (both entry and exits). Main objectives of the system are reducing the average service time up to 5 seconds at entry and 10 seconds at exit approx.; and reducing the time spent in queue for the toll service at entry and exit. The proposed system will work as figure3.

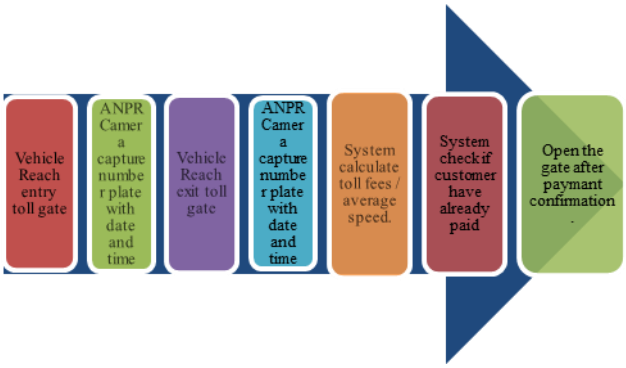

Figure 3: How the proposed Toll system works

1) How the system works at entry: ANPR cameras scan the vehicle's number plate, and image processing software in the system converts the number plate image to a text input. i.e. vehicle's registration plate is fed to the system with the date and time.A receipt at the entry will not be required like the existing toll system.

2) How the system works at exit: ANPR cameras capture the vehicle's number plate and feed to the system with the date and time at the exit same as at the entry, Calculate the toll fee based on entry and exit point, calculate average speed based on the time duration, opens the payment gateway, identify whether customer has already paid or not, open the barrier if paid or Open the barrier after payment.

In this sub system customers could be categorised into two parties as prepaid customers and pay as you go customers. Prepaid customers will be regular vehicles which travel daily or very often where they can plan their journeys early, pay via a website or a mobile app. Moreover, they could be offered monthly, weekly seasons via the web portal. Even a non-regular customer can purchase a planned journey via the same web portal. Or else customers can pre authorise their debit/credit cards, bank accounts to make payment whenever they use expressway. Pay as you go customers are similar to existing users of express way i.e they pay at the exit. In addition to the present system, they would be offered a card payment opportunity.With this proposed system separate electronic toll control (ETC) will not be required. Instead, all toll gate will act as manual / electronic hybrid toll control gates.

3) Average Speed Check by the system: Even though the main objective of the sub system is to improve the queueing

at entry and exits, proposed sub system will support the police the vehicles by calculating average speed of the journey with the distance and the time duration between entry and exit. Moreover, Spot fine could be added to the toll fee if average speed is greater than 100 km/h or details of vehicle could be forwarded to relevant authorities for legal actions. However, existing motor traffic control act may have to revise with the proposed system in order to act against over speeding vehicles. ANPR cameras will act as evidences too when there is a legal activity take place.

B. ANPR based monitoring system

ANPR based monitoring system will be the next sub system of the proposed traffic improvement system. The aim of this sub system is to manage traffic whilst travelling in expressway. The Main objectives are monitor and handle the queue in expressway specially incidents such as natural disaster and accidents; and monitor the over speeding vehicles.

Figure 4. Proposed Camera Installationsalong the Expressway

Source: Ministry of Roads and Highways

1) How the ANPR based monitoring subsystem works: Along the express way, there will be 10 ANPR cameras will be installed. The distance between each camera location will be 20 km approximately. Each camera will be connected to the system with an optical fibre network which is installed along the expressway. For easy understanding camera locations will be numbered from 1 to 10 where number 1 will be nearest to kottawa interchange and number 10 will be nearest to Mattala interchange as shown in figure 4. Let's assume a hypothetical situation to understand the proposed system's work pattern: a vehicle enters to the expressway from Kottawa and travel to Mattala. The vehicle will be monitored by ANPR camera at each camera locations. Vehicle's Number plate will be captured by ANPR camera and stored in the database.

Average speed of the vehicle between each adjacent camera locations will be monitored. As shown in Figure 5,Two main functions will be taken place using these data. First, any over speeding durations will be identified using the distance between two cameras and time of travel. Spot fine could be added to the toll fee if average speed is greater than 100 km/h or details of vehicle could be forwarded to relevant authorities for legal actions same as

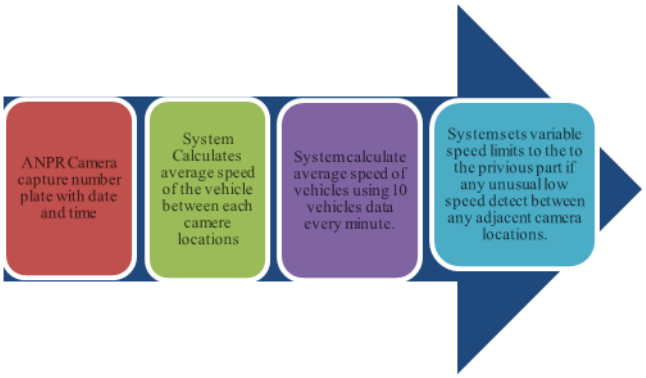

Figure 5: How the proposed Monitoring sub system

average speed check using entry and exit interchange cameras. However, Details of cameras which is located either side of service area should not be calculated as waiting times in service area will be added to the calculations and it may lead to errors in calculations.

This average speed check rather than a spot check will be more accurate since there will be more than one check to a particular vehicle and vehicles will be given an opportunity for quick accelerations for a very short period when it is really required such as over taking a heavy vehicle.

Secondly, System will take data of average speed of each vehicle between each adjacent camera locations. System will calculate the average speed of vehicles between camera locations all the time. This calculation may take from 10 vehicles for examples between a particular two locations at any given minute. System will identify any unusual low average speed due to an accident or natural disaster etc. System will have the ability to slow the arrival rate of vehicles towards the incident by setting temporary variable speed limits. i.e delaying the arrival rate to the service.

2) Slow down the Arrival Rate: Let's assume a hypothetical situation of an accident between number 4 and number 5 camera locations in the Kottawa to Mattala Track. Vehicles are blocked and being cleared very slowly and system calculates the average speed as 30 km/h. In order to slow the arrivals to the incident place, System sets variable speeds as 40 km/h between camera locations 3 and 4; 60 km/h between camera locations 2 and 3 and 80 km/h between camera locations 1 and 2. These variable speed limits would be shown to the vehicles using overhead LED displays along the expressway. Similar variable speed sets are being already used in smart motorways in countries such as United Kingdom. See Figure 6.

Figure 6: Variable Speed Limit Display in a Motorway in United Kingdom

Source: https://www.transportfocus.org.uk

Slowing the arrival of vehicles will mainly support two ways i.e. there will not be conjunctions in accident sites and there will not be unexpected repetitive accidents due to sudden emergency breaks. Ultimately the conjunction will be easily rectified.

These types of variable speed limits could be used in temporary work sites when there is an emergency repair in expressway. Further it would help the safety of labours of the constructions site.

IV. Expected Results and Discussion

A. *Expected Results*

The results of the proposed traffic management system are expected in several ways as there will be two sub systems. When the ANPR based toll system is considered, again there would be two separate gains at the entry and exits.According the annual performance report by Ministry of Roads and Highways, average daily traffic of the southern expressway and outer circular way in 2019 was 65,246. Based on that statistics, we could assume that at average of 45 vehicles use the expressway in a minute. i.e. 45 vehicles approx. should use an entry or exit toll gate in an average minute. Actual number of toll gate users may vary with the time such as before and after office hours as well as the location such as busy toll gates like Kaduwela, Kadawatha and Kottawa.

1) Expected Results at the Entry: With the existing system generally, it takes around 15 seconds for 1 vehicle to reach the toll gate and get the receipt. Hypothetically the service rate of 1 toll gate could be taken as 4 per minute. When an interchange with 4 toll gates are considered, it will become 16 per minute. However, based on statistics discussed in previous paragraph, if 45 vehicle arrivals occur in an interchange, 29 vehicles would be in the queue at a given minute assuming previous queue has been cleared. With the proposed ANPR based Toll system, it is expected to reduce the service time of a toll gate up to 5 seconds reaching the efficiency by 300%, where the service rate would be increased as 12 per minute. For a 4-toll gate interchange it would be 48 vehicles per minute where there would be 0 vehicles in waiting line.

2)Expected Results at the Exit: With the existing method of the exit of the expressway, generally, it takes around 20 – 30 seconds to scan the receipt, accept the toll fee, and to open the toll barrier. Sometimes it may drag more than 30 seconds with the difficulties of changing money. If it is considered as 20 seconds, the service rate of a toll gate is 3 per minute where 4-toll gate interchange has a service rate of 12 vehicles per minute. According to the same statistics which is discussed in previous paragraph, there would be 33 vehicles in waiting line at a given minute assuming previous queue has been cleared. With the proposed ANPR based Toll system at the exit, it is expected to reduce the service time of a toll gate up to 10 seconds reaching the efficiency by 200%, where the service rate would be increased as 6 vehicles per minute. For a 4-toll gate interchange it would be 24 vehicles per minute where there would be 23 vehicles in waiting line. With the increasement of popularity among general public, it is expected to increase the service rate up to by 300%. This could be gained by increasing the number of prepaid customers. Because the prepaid customer would have lesser service time around 5 seconds.

*3)Expected Results whilst travelling on Highway:*Expected results from ANPR based Monitoring system is more biased towards to the quality of the traffic management. It would become useful specially during a hazardous situation such as an accident, a natural disaster, or during a decreased visibility session like heavy rain etc. Further, this system will help the police to identify and monitor the over speeding vehicles very easily. When it comes to policing the vehicles, it would always easy when drivers have to deal with an automated system. With the existing traffic control methods sometimes, people tend to challenge the police or try to negotiate which results a deviation from a common law to every citizen. With the proposed system on the other hand, people will not have a chance to challenge an automated system.

B. Challenges

With no doubts there would be many more challenges when implementing such a system. Most significant challenges will be the Capital Cost, Payment Authorisation System and Legal Background.

1) Capital Cost: The main components of the proposed system will be the number of ANPR cameras, long distance Optical Fibre Network, System software and Database Server Equipment with Network Array Storages. Basically approximately 4 cameras will be required at each location. So,116 ANPR cameras will be required at the initial stage for the pilot project considering 19 interchanges and 10 monitoring nodes. Further, large-scale high-performance Database management system such as Oracle will be required in order to handle a traffic volume such as 65000 average daily. Again,it would add a considerable amount of Capital cost.

2) Payment Authorisation Methods: In order to have more success rate, number of prepaid customers should be increased and get more popular day by day. Hence web-based payment methods should be made easy and trusted. However, most of people in Sri Lanka are still bit reluctant to make card payments and web based online payments via Credit/Debit cards. Hence separate awareness campaign may be required in order to make people aware regarding payment methods. It is understood that each and every customer would not have a credit card. Hence introduction of several payment methods will be useful. Online payment via Debit card, Deduction from Bank account, QR payment methods, Easy cash, Separate smart travel card, and Adding payment to the Mobile bill are some of the payment methods that can be used with the corporation of relevant third parties.

3) Legal Background: Existing motor transport acts, legal framework, and spot fine methods may have to revise in order to support the proposed ANPR monitoring system. ANPR camera images and records would be act as witnesses when it comes to legal matters.

C. Future Enhancements

The proposed traffic management system could be easily expanded to the outer circular expressway, Katunayake expressway, Central expressway and proposed Ruwanpura expressway with the success and popularity. Even though ANPR based toll system is limited to expressways, proposed monitoring system can be used in other roads in order to monitor the violations of traffic rules. In future, this ANPR based monitoring system could be used to identify the vehicles which have not been insured, vehicles with expired emission reports, vehicles with expired revenue license and vehicles involved with illegal activities etc. provided that all insurance details, Revenue licence details, Emission test details and Details from police are linked to a Central Database.

V. CONCLUSION

As it was discussed in this paper, the existing level of traffic management or traffic discipline of Sri Lanka are not in a satisfied level according the view of the general public. Queues are being generated due to various reasons in road network and it has been spread to the entrances and exits of the expressway interchanges. In order to understand the nature of this traffic in the country,queueing model could be used. The concept of basic queueing model can be used to identify the nature of any queue such as banks, bus stops, fuel stations and hospitals etc.

Considering the easiness of approaching to a solution, Southern Expressway as a pilot project has been selected by the author in order to propose an improved traffic management to the country. The proposed system can be enhanced to other expressways and other road networks with the success rate of the project.

The concept and theory of identifying the problem is queueing theory and the solution to the problem and proposed improved traffic management system is based on ANPR solutions. ANPR solution are already being used in most countries in car parks, shopping malls as well as motorways. But they are being used not to analyse the traffic but to capture the traffic violations basically.

This paper provides a combination of queueing model analysis and ANPR based solution where the traffic management of Sri Lanka could be technology based one in future and with the success of the proposed project, the country will set an example of traffic management to the South Asian Region.

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