EFFECT OF MANUAL TOLL COLLECTION ON CAPACITY OF SOUTHERN EXPRESSWAY

M. L. G. D. Kumari, P. G. D. Priyadarshana and K. S. Weerasekera*

Department of Civil Engineering, The Open University of Sri Lanka

AIM OF THE STUDY

The aim of this study is to firstly investigate the efficiency of manually operated toll gates along the Southern Expressway and secondly to observe the impact on the capacity of interchanges which may finally limit the expressway potential in the future.

Objectives

The objective of this study is to investigate the impact of toll gates efficiency on the capacity of the Southern Expressway. It consists of investigating the present condition in interchanges, and to develop recommendations for future implementation. These objectives entail the following.

– Identify the critical interchanges in the road from Kottawa to Galle exit.
– Find any inefficiency at toll gates when operated manually.
– Study ramp sufficiency and head-up length with future traffic.
– Check the off ramp length according to deceleration length with possible formation queues in critical exit ramps.
– If there are delays at toll booths to investigate whether it will affect the free flow of the Southern Expressway.

Propose suitable tolling systems to cope with the future traffic needs if there are any delays due to toll gates causing reductions in the capacity of the expressway.

Strategies

To achieve the aims of this project, the following strategies and principles were used:

– The layout arrangements of interchanges were studied in detail.
– The number of entrance and exit gates was identified for all interchanges.
– The exit ramp lengths were measured and the geometry of the intersection was studied for all the interchanges.
– The existing procedure of paying of user fee at toll gates and the toll gate operation was studied.
– Peak day/peak hour was identified for each interchange.
– Identified the critical exit ramps of the expressway by considering exit ramp distances and traffic volume.
– After identifying the peak days, traffic studies were conducted to obtain arrival rate and service rate for critical exit ramps in each interchange.
– The graphs which indicate the arrival curve and service curve at different toll gates were plotted according to the survey data.
– The longest individual delay and maximum queue were identified using above graphs for each critical exit ramps.
– By using the above graphs and collected data analyzed the effects of the capacity of Southern Expressway due to present toll gates in interchanges.
– Recommended suitable off ramp lengths considering queue length and deceleration lengths and recommended future improvements to the service rates at toll gates.

* *Corresponding author: Email -* ***kolitaw@gmail.com***

METHODOLOGY

Graph of Time vs. Cumulative Vehicle at Ramp

Figure 1 illustrates curve of Time vs. Cumulative Number of Vehicle and how it affects service rate. The two curves shown in the Figure 1 are related arrival and service rates.

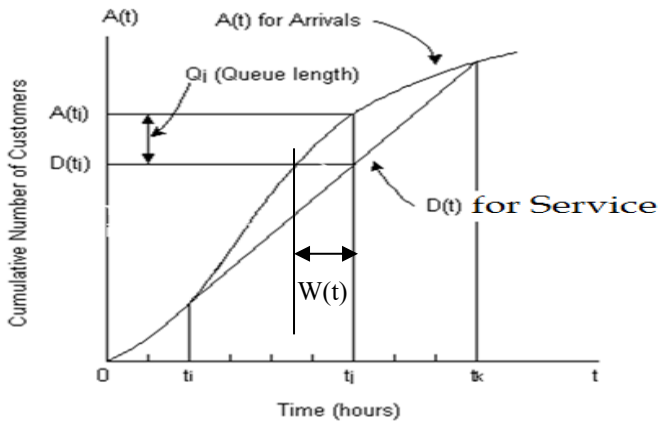

Figure 1. - Graph of Cumulative Number of Vehicle vs. Time

Area between A(t) and D(t) represents the total delay, or summation of delay to all vehicles.

- Q(t) – Vertical distance between A(t) and D(t) at any time t, represents the numbers of vehicles in queue at that time (t)
- Slope of D(t) in the 'departure rate'
- Slope of A(t) in the 'arrival rate'

Note

- The departure rate cannot exceed the service rate or capacity of the service provider. Hence it has to be less.
- Cumulative departure can never exceed cumulative arrivals. Hence D(t) can never be above A(t) in the queuing diagram.
- When queue is present the 'departure rate' will equal the 'service rate'.
- The queue first forms when the 'arrival rate' first exceeds the service rates.
- W(t) Horizontal distance between A(t) and D(t) represents the delay to vehicle arriving at time t.

Service time - Service time of collection payment is the time between the vehicles entering the toll booth until the vehicle leaves the toll booth.

Service rate - The number of vehicles serves in unit time

Data collection and analysis

To investigate current toll gate efficiency on the capacity of the Southern Expressway the necessary data were collected from relevant organizations. From the collected data, peak days and peak hours were identified for each and every exit ramp. By considering the peak hours, critical exit ramps were identified. After identifying critical exit ramps of the interchanges, traffic studies were conducted to obtain arrival and service rates in peak hours during the peak days. Then after analyzing survey data maximum queue lengths and longest individual delays for critical exit ramps along the Southern Expressway was found. Simultaneously the analysis was conducted for a different number of gates.

Calculation of weight factors for each exit ramps of interchanges

The study requires correctly identifying critical exit ramps since delays occur at exit ramps. Therefore out of 14 exit ramps between Kottawa and Pinnaduwa, critical exit ramps were

identified using 'weight factors'. The method adopted for computation of 'weight factor' was based on ramp length, and peak hour volume. Then the weight factor was obtained by dividing the peak hour volume of each exit ramp by the measured ramp length. By observing traffic data during a period of one week, peak hour volumes for each interchange were identified. The number of toll gates were considered when queue length exceeded the off ramp length.

Table 1. The weight factors for each interchange

Interchange	Exit Ramps	Peak hour volume (veh/hr)	Ramp Distance (m)	Weight factor (veh/m/hr)
Kottawa	Ramp 1 – From Galle	683	197	**3.47**
Kahathuduwa	Ramp 1 – From Galle	75	106	**0.71**
	Ramp 2 - From Colombo	16	96	0.17
Galanigama	Ramp 1 – From Galle	94	181	**0.52**
	Ramp 2 - From Colombo	60	187	0.32
Dodangoda	Ramp 1 – From Galle	41	93	0.44
	Ramp 2 - From Colombo	74	134	**0.55**
Welipanna	Ramp 1 – From Galle	23	73	0.31
	Ramp 2 - From Colombo	58	69	**0.83**
Kurundugahahathakma	Ramp 1 – From Galle	24	45	**0.53**
	Ramp 2 - From Colombo	55	134	0.41
Baddegama	Ramp 1 – From Galle	9	154	0.06
	Ramp 2 - From Colombo	43	90	0.48
Pinnaduwa	Ramp 1 - From Colombo	257	378	**0.68**

Selection of critical exit ramps

According to the weight factors, shown in Table 1 seven critical exit ramps were selected to conduct the detailed surveys. Exit ramps consisted of weight factors above 0.5 were considered as critical exit ramps. This was to limit the number of ramps to be studied, rather than studying all the ramps. Hence at-least one exit ramp was selected from all the interchanges except Baddegama.

Present condition of toll gates considering average service time

Separate surveys were conducted for each and every gate operated in critical exit ramps. The purpose of the survey was to obtain the average service time in each toll gate according to the exit ramps. Time at the commencement of service and departure for each vehicle was recorded. The difference of departure time and service commencing time for each vehicle were used to calculate service time. Service time was calculated separately for each interchange, then considering all the interchanges the average service time for current tolling system (manual operation method) was computed and tabulated in Table 2.

Table 2. The average service time for each gate

Interchange	Exit gate No.	Average service time for each gate (seconds)	Average service time for each interchange (seconds)
Kottawa	1	15.83	17.86
	2	16.37	
	3	22.07	
	4	18.28	
	5	16.77	
Kahathuduwa	1	25.45	25.45
Galanigama	1	17.13	17.13
Dodangoda	1	19.09	19.09
Welipanna	1	19.00	19.00
Kurundugahahatakma	1	15.75	15.75
Pinnaduwa	1	15.46	15.42
	2	15.38	
Average service time (seconds)			**18**

RESULTS

Minimum deceleration lane length for exit ramps

Table 3. Results and Proposals

Interchange	Direction	Failure reason at year			Proposals
		Longest individual delay at year	Maximum queue length	Minimum deceleration length (170 m)	
Kottawa	Ramp 1 – From Galle	2035	2034	2034 exceeded	At year 2034 ramp length has to improve / Service rate has to improve
Kahathuduwa	Ramp 1 – From Galle	2075	2075	Existing ramp length inadequate	Ramp length has to improve from now
	Ramp 2 - From Colombo				
Galanigama	Ramp 1 – From Galle	2060	2050	2050 exceeded	At year 2050 ramp length has to improve / Service rate has to improve
	Ramp 2 - From Colombo				
Dodangoda	Ramp 1 – From Galle			Existing ramp length inadequate	Ramp length has to improve from now
	Ramp 2 - From Colombo	2040	2040		
Welipanna	Ramp 1 – From Galle			Existing ramp length inadequate	Ramp length has to improve from now
	Ramp 2 - From Colombo	2045	2045		
Kurundugahahatakma	Ramp 1 – From Galle	2060	2050	Existing ramp length inadequate	Ramp length has to improve from now
	Ramp 2 - From Colombo				
Pinnaduwa	Ramp 2 - From Colombo	2030	2030	2030 exceeded	At year 2030 ramp length has to improve / Service rate has to improve

DISCUSSION AND CONCLUSIONS

It was observed how each interchange dealt with maximum queue length, individual delay and minimum deceleration lane length. Table 3 indicates the years when exit ramp lengths will become insufficient for each interchange. Critical exit ramps of Kottawa (from Galle), Galenigama (from Galle), and Pinnaduwa (from Colombo) interchanges could cater to the traffic up to years 2034, 2050 and 2030 respectively. Kahathuduwa (from Galle), Dodangoda (from Colombo), Welipanna (from Colombo) and Kurundugahahatakma (from Galle) existing ramp lengths were selected based on without considering deceleration lane lengths. There is a tendency that vehicles begin to decelerate on the lane on expressway in advance of the off ramp lengths. This can affect the efficient and safe movements of traffic on the expressway. Therefore it has to introduce an additional lane to allow for adequate ramp deceleration distances without disturbing the expressway through traffic.

Hence the capacity of Southern Expressway will get affected due to inadequacies at tolling stations unless the number of toll gates are increased or the efficiency of the toll collecting systems is improved by introducing advanced schemes such as electronic toll collection systems.