OUSL Journal (2015)
Vol. 9, (pp. 19-40)

Future Impact of Current Toll-Gates on the Capacity of the 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

Abstract

The Southern Expressway plays a vital role in national road network in Sri Lanka. Vehicles on Expressways can travel at uniform speeds throughout their journey offering advantages on fuel consumption and reduced travel time. The expressways ensure a hassle free safe journey due to the minimum obstructions to the traffic.

At present, all the interchanges along the Southern Expressway operate with manually operated toll gates. The efficiency of current toll gates was studied for the existing exit ramp lengths and it investigated whether their current efficiencies are sufficient for higher vehicle volume of the future traffic. To investigate the current toll gate efficiency on the capacity of 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 of the Southern Expressway. 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 were found. Simultaneously the analysis was carried-out for a different number of gates.

Finally, maximum queue lengths and longest individual delays were compared with existing ramp lengths, and shortcomings were identified. By using suitable growth rates for the Southern

---

**Correspondence should be addressed to Prof. K.S. Weerasekera, Department of Civil Engineering, Faculty of Engineering Technology, The Open University of Sri Lanka, Nawala, Sri Lanka.*
(Email: kolitaw@gmail.com)

Expressway, future traffic conditions were predicted. Subsequently, by using the maximum vehicular queue lengths, individual delays that could occur in the future were computed. Hence, these values were used to analyze the effect of the capacity of Southern Expressway due to the present toll gate arrangement. Therefore, it was able to recommend suitable off ramp lengths considering queue lengths and deceleration lengths. Recommendations were also proposed for future improvements to the service rates at toll gates.

Keywords: Southern Expressway, Service time, Service rate, Toll gates, Maximum queue length, Exit ramp length

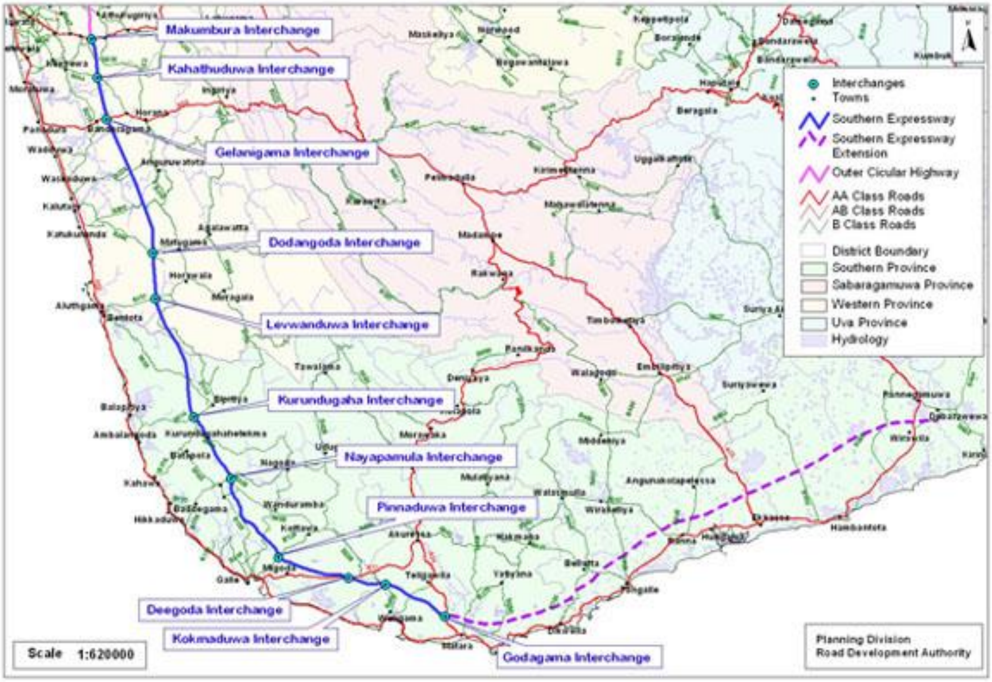
Introduction

The Southern Expressway is the first expressway to be built in Sri Lanka and it is an important link of the proposed expressway network. It traverses from Kottawa to Matara (126 km) and the construction of the section from Kottawa to Pinnaduwa (Galle) was completed and operates as a dual carriageway expressway with 4-lane facility when the study was conducted in 2013. Expressways have many advantages such as; reduced travel time, reduced traffic congestion, reduced transport delay costs, reduced fuel costs, attract private sector investors and thereby contribute to expand the job market and develop fisheries, agriculture, industries in the region, expand tourism presently confined to the coastal belt along Colombo-Galle-Matara, and enhance the value of land and property.

In the Southern Expressway (between Kottawa and Galle) there are eight interchanges namely; Kottawa (Makumbura), Kahathuduwa, Gelanigama, Dodangoda, Welipanna, Kurundugahahatakma, Baddegama, and Pinnaduwa (Galle).

Problem Identification

With the increase in traffic in the future, the possible formation of traffic queues at entry or exit points during congested periods can cause a considerable time delay and may result in the reduction of highway performance. Southern Expressway has shortened the journey time from Galle to Colombo to one hour. At present, since manually operated toll gates are installed and with increased traffic, it is intended to observe whether their efficiency is adequate to handle higher vehicle volumes.



(Source: www:rda:gov:lk/supported/expressways/stdp:htlm)

Figure 1. Southern Expressway

At present, the traffic at the toll booths is not very heavy, but in future, with the increase of vehicles, the traffic at the booths could be a problem. Traffic delay in a toll plaza is caused by time taken due to the manual operated method adopted in paying user fee. Hence the long queues that could occur at exit ramps may cause safety threat to the vehicles travelling along the expressway if vehicles at toll booths heads-up along the exit ramps and enter the expressway. Therefore, in here, it studies the present toll gates operation and observes whether it could cope with future traffic needs at a meaningful level of service and investigates whether the capacity is adequate to meet this demand.

Aim of the Study

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 Southern Expressway. It consists of investigating the present condition in interchanges, and to develop recommendations for future implementation (including traffic engineering, geometric consideration and benefit evaluations). 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 a reduction in the capacity of the expressway.

Strategies

To achieve the aims of this project, 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 interchanges.
- Existing procedure of paying of user fee in toll gates and the toll gate operation was studied.
- Peak day/peak hour was identified for each interchange.
- The critical exit ramps of the expressway by considering exit ramp distances and traffic volume, were identified.
- 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, the effects of the capacity of Southern Expressway due to present toll gates in interchanges, were analyzed.
- Suitable off ramp lengths considering queue length and deceleration lengths were recommended and future improvements to the service rates at toll gates are suggested.

Methodology

Graph of Time *vs* Cumulative Vehicle at Ramp

Figure 2 illustrates the curve of Time vs. Cumulative Number of Vehicle and how it effects with service rate. The two curves shown in the Figure 2 is related arrival and service rates (Mannering and Washburn, 2004).

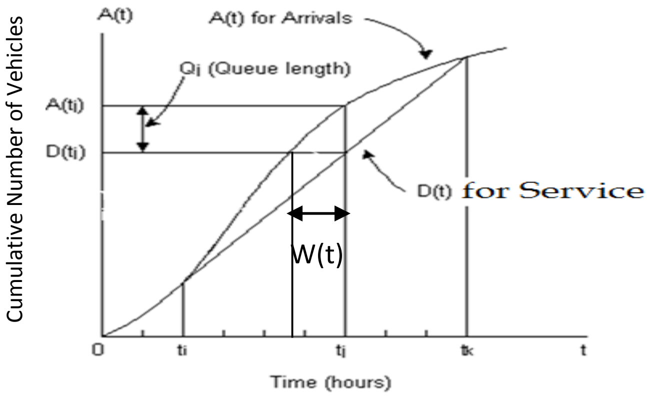


Figure 2. Graph of Cumulative Number of Vehicle vs. Time

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'

<u>Note</u>

- 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 entry of the vehicle into the toll booth until the exit of the vehicle from the toll booth.

Service rate **-** The number of vehicles serves in unit time

Field Data

The Southern Expressway consists of eight interchanges between Kottawa and Pinnaduwa including the two at the ends. They are of the following types:

Kottawa (Makumbura)	Grade separated
Kahathuduwa	Diamond (conventional)
Gelanigama	Partial cloverleaf
Dodangoda	Diamond (conventional)
Welipanna	Diamond (conventional)
Kurundugahahatakma	Partial cloverleaf (modified)
Baddegama	Diamond (conventional)
Pinnaduwa (Galle)	Mixed diamond- cloverleaf

(Source: RDA, www.rda.gov.lk/supported/expressways/stdp.htlm)

Adopted Procedure in Paying 'User Fee'

When a driver enters the expressway, a ticket is issued to him/her at the entry toll gate of the interchange. The ticket displays the type of the vehicle (vehicle category), date, time and name of the interchange which the vehicle entered. Driver has to handover the ticket to the exit toll gate, and he/she will be informed of the user fee. A receipt will be issued for the payment of the user fee.

Due to the manual transaction, the operator has to monitor the entrance ticket details. Also, the user takes time to pay for the usage. Therefore, it takes time at exit toll gates compared with other advanced tolling methods. It was especially experienced when paying of fines for over speeding or any other negligence of road rules, causing further delay at exit gates.

Present Condition of Entry and Exit Gates

It is not the same number of entry and exit gates that have been constructed in each interchange for the two directions. At present, only a few gates are operating due to lack of traffic. The gate details and exit ramp lengths are tabulated in Table 1.

Table 1. Number of entry and exit gates and exit ramp lengths of interchanges

Interchange	Number of toll gates (total in both direction)				Exit Ramp	Exit Ramp length (m)
	Constructed		Currently operating			
	Entry	Exit	Entry	Exit		
Kottawa (Makumbura)	05	08	02	03	Ramp 1 – From Galle	197
Kahathuduwa	04	04	02	02	Ramp 1 – From Galle	106
					Ramp 2 - From Colombo	96
Gelanigama	04	04	02	02	Ramp 1 – From Galle	181
					Ramp 2 - From Colombo	187
Dodangoda	04	04	02	02	Ramp 1 – From Galle	93
					Ramp 2 - From Colombo	134
Welipanna	04	04	02	02	Ramp 1 – From Galle	73
					Ramp 2 - From Colombo	69
Kurundugaha hatakma	04	04	02	02	Ramp 1 – From Galle	45
					Ramp 2 - From Colombo	134
Baddegama	04	04	02	02	Ramp 1 – From Galle	154
					Ramp 2 - From Colombo	90
Pinnaduwa (Galle)	02	02	01	02	Ramp 1 – From Galle	378

(Source: Expressway Operation Maintenance and Management Division - RDA)

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 seventeen exit ramps between Kottawa and Pinnaduwa, critical exit ramps were identified using 'weight factor' as described below.

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

$$\text{Weight factor} = \frac{\text{Peak hour volume (veh/hr)}}{\text{Ramp length (m)}}$$

Table 2. 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 2, seven critical exit ramps were selected to conduct the detailed surveys. Exit ramps consisting 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 (see Table 2).

Selection of field survey days (as per data collected from RDA)

Prior to conducting traffic survey at the interchanges, probable peak days and peak hours for exit ramps were identified according to collected data from Expressway Operation Management and

Maintenance division of RDA. These traffic survey days and time periods are as shown in Table 3.

Table 3. The peak hour ranges for each critical exit ramps

Interchange	Day	Date	Time period (hrs)
Kottawa	Monday (Poya day)	25.03.2013-26.03.2013	16:00-06:00
Kahathuduwa	Sunday	07.04.2013	17:00-21:00
Galenigama	Sunday	21.04.2013	16:00-19:00
Dodangoda	Sunday	21.04.2013	11:00-17:00
Welipanna	Sunday	28.04.2013	11:00-17:00
Kurundugahahetakma	Sunday	28.04.2013	13:00-17:00
Pinnaduwa	Saturday	04.05.2013	09:00-17:00

Present Condition of Toll Gates Considering Average Service Time

Separate surveys were conducted for each and every gate operating in critical exit ramps. The survey durations are as indicated in Table 3. The purpose of the survey was to obtain the average service time in each toll gate according to the exit ramps.

Table 4. 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	
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**

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 was 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 4.

Average Length for Vehicle Categories

Traffic on interchanges is mixed in nature. Therefore, several categories (according to Southern Expressway Operation Maintenance and Management division) were selected to calculate queue lengths. Average lengths of vehicles are as shown in Table 5.

Table 5. Average vehicle length

Vehicle category	Description	Average length (m)
A	Car, utility vehicles, light good vehicles	4.92
B	Medium/ large buses, larger lorries/ trucks	10.9
C	3 Axels vehicle	12.5
D	More than 3 Axels vehicle	16

(*Source: Washington States Department of Transportation, 2011)*

Four wheel drive jeeps, small trucks with design on a car frame and vans come under utility vehicles and light good vehicles.

The average length of car (4.92 m) was selected for all the vehicles included in category 'A'. It was selected based on the highest composition according to field survey data. The average length of a large bus (10.9 m) was selected for all the vehicles included in category 'B'. It was selected based on the highest composition according to field survey data.

Traffic Volume Data up to 2080 Using Trend Curves

Trend curves were drawn up to year 2080 according to predicted vehicle growth rates for Southern Expressway from RDA. The obtained values are given in Table 6.

Table 6. Predicted vehicle growth

Interchange	Vehicle category	Predicted vehicle growth (%)													
		2017	2022	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080
Kottawa, Kahathuduwa, Galanigama	Car, utility vehicles, light good vehicles (A)	6.3	5.1	3.6	4.1	3.95	3.8	3.7	3.6	3.5	3.45	3.4	3.3	3.25	3.2
	M/L buses, L lorries/ trucks (B)	2.9	2.3	2.1	2.21	2.19	2.12	2.11	2.1	2.0	2.04	2.01	2	1.99	1.95
	3 Axels vehicle (C)	2.9	2.3	2.1	2.05	1.93	1.8	1.7	1.6	1.5	2.06	1.32	1.22	1.15	1.11
	More than 3 Axels vehicle (D)	6.3	6.5	3.8	4.21	3.82	3.5	3.25	2.95	2.7	2.5	2.25	2.05	1.86	1.7
Dodangoda Welipanna, Kurundugahahatakma, Baddegama Pinnaduwa	Car, utility veh., light good veh. (A)	11.2	9.8	6.8	8.2	8.1	8	7.9	7.8	7.8	7.7	7.6	7.58	7.56	7.5
	M/L buses, L lorries/ trucks (B)	5.2	4.5	3.9	4.41	4.46	4.5	4.51	4.52	4.5	4.55	4.58	4.59	4.59	4.6
	3 Axels vehicle (C)	11.3	12.5	7.3	9	8.6	8.3	8.1	7.9	2.6	7.3	7.1	6.9	6.65	6.4
	More than 3 Axels vehicle (D)	11.3	12.5	7.3	8.9	8.6	8.3	8.1	7.8	7.6	7.4	7.1	6.9	6.7	6.45

Data Analysis

Traffic Volume Forecast of Southern Expressway

Traffic volume forecast data were used to calculate the annual traffic growth rates for vehicle categories. And the equation which was used to calculate the future traffic demand was stated below (Mannering and Kilareski, 1998).

$(\text{Peak hour volume})_{\text{future}} = (\text{Peak hour volume})_{\text{present}} \times (1+g)^n$
g = Annual growth rate
n = Number of year

Above equation and relevant annual traffic growth rates were used to calculate the peak hour volume in coming years.

Example: Sample calculation for Kottawa interchange at 2017 (*i.e.* 4 years from 2013)

$$(\text{Peak hour volume})_{2017} = (\text{Peak hour volume})_{2013} \times (1+g)^n$$
$$(\text{Peak hour volume})_{2017} = 554 \times (1+0.063)^4 = 704 \text{ veh/hr}$$

Calculated vehicle growth over the years for Kottawa interchange is tabulated below in Table 7. The same procedure was followed to calculate vehicle growth for other interchanges as well.

Table 7. Vehicle growth at Kottawa interchange over the years

Time	Cumulative Number of Vehicles														
	Pres	2017	2022	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080
16:00-16:05	25	32	41	45	55	66	80	96	114	135	160	189	222	260	304
16:05-16:10	51	64	82	91	111	134	160	191	228	269	318	375	440	515	602
16:10-16:15	80	101	129	143	174	211	253	303	360	427	504	595	698	818	956
16:15-16:20	119	151	192	213	260	314	377	451	537	636	752	887	1041	1220	1425
16:20-16:25	163	207	263	292	356	431	517	619	737	873	1033	1218	1430	1676	1958
16:25-16:30	215	273	348	386	470	569	684	818	974	1154	1365	1611	1892	2216	2591
16:30-16:35	263	334	425	472	575	696	836	1000	1190	1410	1669	1968	2311	2708	3166
16:35-16:40	311	395	504	559	681	824	991	1185	1411	1673	1979	2335	2743	3214	3757
16:40-16:45	371	471	601	667	813	984	1183	1415	1686	1998	2365	2791	3278	3841	4491
16:45-16:50	429	545	696	772	941	1140	1370	1640	1954	2316	2741	3235	3801	4454	5208
16:50-16:55	494	628	802	890	1085	1314	1580	1892	2254	2673	3163	3734	4387	5142	6013
16:55-17:00	554	704	900	999	1219	1476	1776	2126	2533	3005	3557	4199	4934	5783	6764
17:00-17:05	624	793	1014	1126	1373	1663	2001	2395	2854	3386	4007	4731	5559	6517	7622

In order to identify the efficiency of current toll gates for present and future conditions, the following study methodology was adopted.

- Service rate when operating a different number of toll gates. (Service rate denotes the rate at which vehicles are being served in a system. In here service rate depends on the number of toll booths and average service time.)

As indicated in Banks (2010), service rate when operating of different number of toll gates;

Service rate = [1 vehicle × 60 × No. of toll booths × Time interval for arrival rate (veh/min)] / Average service time

- According to the queuing analysis graph of time vs. cumulative number of vehicles, following terms are indicated.
  - Number of vehicle in queue
  - Individual delay time

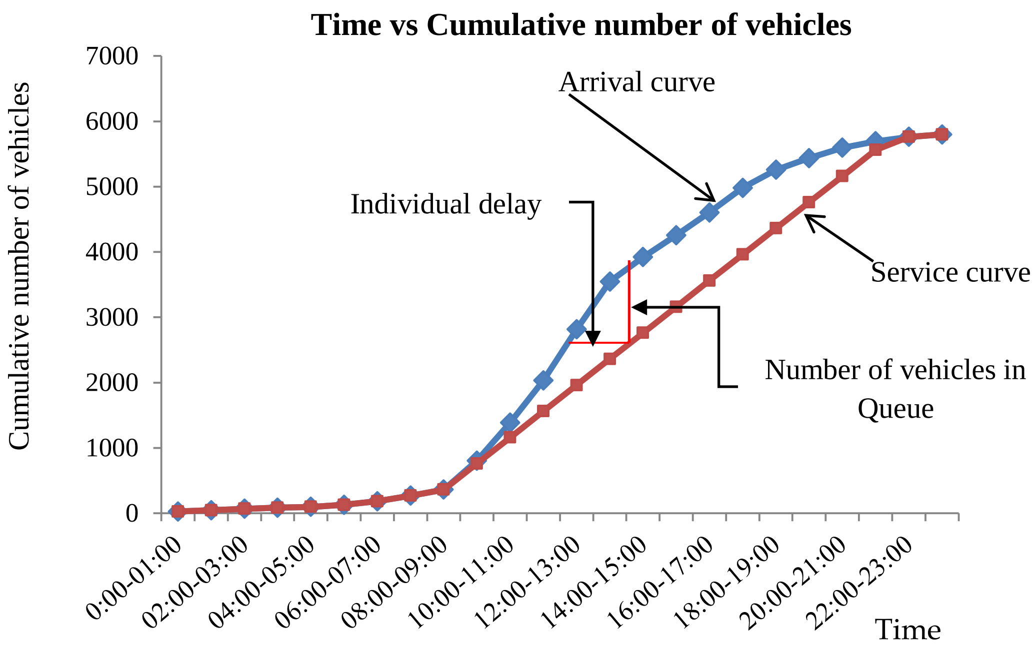


Figure 3. Graph of time vs. cumulative number of vehicles

Critical exit ramps were evaluated to see whether they could handle the present traffic flow according to the traffic survey results. Figure 3 illustrates variation of time vs. cumulative number of vehicles at Pinnaduwa. In here, these two curves represent arrival curve and service curve. Arrival curve was plotted according to the 5 minutes time interval during the peak hours at each exit ramp. Service rates were calculated for different number of toll gates when operating at exit ramps. Service curve was plotted according to the number of toll gates in operating. Vertical length between these two curves indicates the number of vehicles in queue and horizontal difference indicates individual delay.

Service Rate, When Operating Different Number of Toll Gates for 5 Minute Arrival Rate

Service rate = [1vehicle × 60 × No. of toll booths × Time interval for arrival rate (veh/min)] / Average service time

Sample calculation for service rate when operating one toll gate only;

Service rate = [1 × 60 s × 1 × 5 s] / 18 s/veh
= 16.67 veh/5 min

Service rate increases due to the number of gates operating in exit ramps. Table 8 shows service rates for 5 minutes time duration for a different number of toll gates.

Kottawa interchange has the most number of exit gates. It has eight exit gates. It is observed that more vehicles can be served when the number of toll gates increase. When operating one gate, seventeen vehicles can be served in 5 minutes. As observed in Table 8 with the increase of number of gates, number of vehicles served in exit ramps too increases.

Table 8. Service rates

Number of toll gates	Service rate (veh / 5 min)
1	16.67
2	33.33
3	50
4	66.67
5	83.33
6	100
7	116.67
8	133.33

Analysis of Maximum Queue Length and Individual Delay Time Up to Year 2080 when Operated Different Number of Toll Gates

Sample 1 - Maximum queue length and maximum individual delay at Kottawa interchange

Survey data were used to obtain the cumulative number of vehicles. Arrival curve was obtained when plotting cumulative number of vehicles against time. Service curves were also plotted according to the number of gates in service and it varies with time. For the purpose of identification of future traffic, arrival curves were also plotted according to predicted vehicle growth.

Kottawa Interchange–Exit Ramp (exit of vehicles arriving from Galle)–When one gate is operating

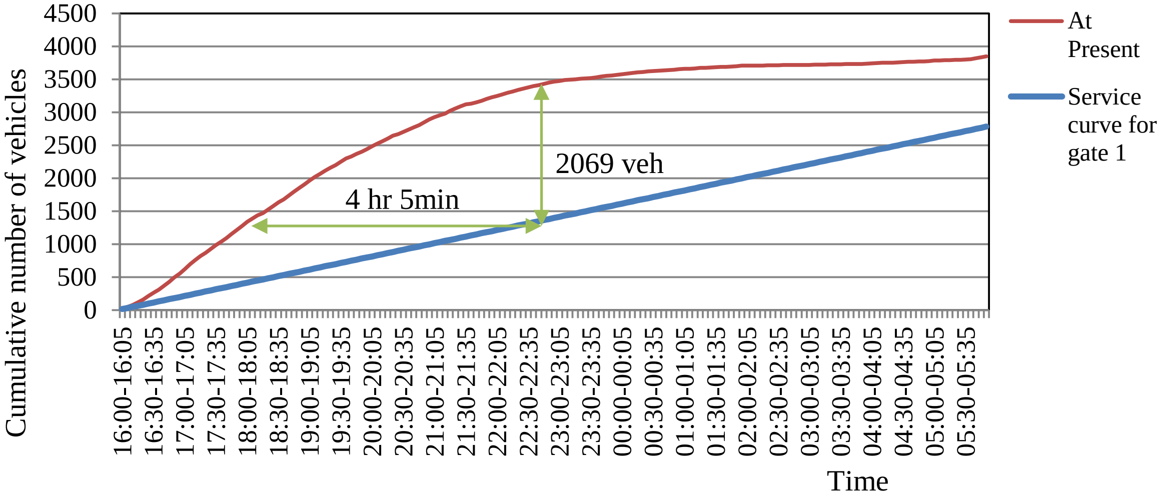


Figure 4. The graph of time vs. cumulative number of vehicles when only one gate is on operation at Kottawa Interchange

The total length of the queue at a specified time, expressed by the number of vehicles, is given for the particular exit ramp from the vertical length between arrival and departure curves. It shows the longest vehicle queue at manual system when only one gate is in operation. The longest vehicle queue occurs at time 22:50 hrs consisting of 2069 vehicles.

Sample Calculation for Present Condition When Only One Gate is on Operation at Kottawa Interchange

For the calculation of maximum longest queue for that particular exit ramp, average vehicle length according to the anticipated vehicle composition was found. One meter gap in between two successive vehicles was assumed.

Maximum no. of vehicle in queue at present = 2069 veh

Average vehicle length = ∑(Percentage composition for vehicle category × Average length of vehicle category)

Average vehicle length = (92.43% × Average length of category A) + (4.91% x Average length of category B) + (1.56% × Average length of category C) + (1.1% × Average length of category D)
= (92.43% × 4.92 m) + (4.91% × 10.9 m) + (1.56% × 12.5 m) + (1.1% × 16 m)
= 5.45 m

Gap between two successive vehicles = 1 m
Maximum queue length at present = Maximum No. of vehicle in queue at present × (Average vehicle length + Gap between successive vehicle)
= 2069 × (5.45 + 1) m
= 13345 m
Longest individual delay = 4 hr 5 min

At present it was found that 13345 m queue length is the longest queue length if only one gate at Kottawa exit ramp is in operation. When the operating gates are increased the queue length will decrease proportionally. Since critical exit ramp length of Kottawa interchange is only 197 m, it will be insufficient even with more gates operating at present service rates.

The same procedure was followed in obtaining maximum queue length and longest individual delay for each interchange when operating at different number of toll gates up to 2080 for critical exit ramps at interchanges.

Deceleration Lane Length

Exit ramp design based on the assumption that vehicles exiting from a freeway have adequate space to decelerate to the ramp's limiting design speed feature (typically a horizontal curve) after clearing the through traffic lane. The length provided between the freeway departure point and the ramp's limiting design speed feature should be at least as long as the distance needed to accomplish the appropriate deceleration which is governed by the speed of traffic on the through lane and the speed to be attained on the ramp.

Calculation of Minimum Deceleration Lane Length for Exit Ramps

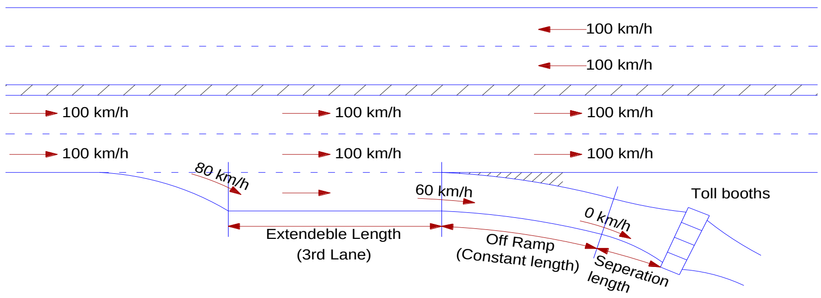


Figure 5. Deceleration lane of off ramp

Lower limit of highway design speed = 80 kmph
Design speed of off ramps = 60 kmph

The recommended minimum deceleration lane length for an off ramp is 255 ft (77.7 m) when vehicle travels at 80 kmph to become 60 kmph and once it reaches that speed the vehicle needs further 300 ft (91.4 m) lane length to stop the vehicle. Those values are clearly indicated in Table 9 considering highway design speed of the Southern Expressway.

Also it needs to provide deceleration lane length to the end of the anticipated queue at the off ramps. In here minimum deceleration length was considered as per Washington State Department of Transportation (WSDOT) Design manual 2011.

Table 9. Minimum Deceleration Lane Length

Highway Design Speed (mph)	Highway Design Speed (kmph)	Minimum deceleration lane length (ft) for ramp design speed (mph)											
		0	15	20	25	30	35	37.5	40	45	50	60	70
30	48	235	200	170	140								
35	56	280	250	210	185	150							
37.5	60	300											
40	64	320	295	265	235	185	155						
45	72	385	350	325	295	250	220		155				
50	80	435	405	385	355	315	285	255	225	175			
55	88	480	455	440	410	380	350		285	235	180		
60	96	530	500	480	460	430	405		350	300	240		
65	104	570	540	520	500	470	440		390	340	280	185	
70	112	615	590	570	550	520	490		440	390	340	240	
80	128	735	710	690	670	640	610		555	510	465	360	265
		0	24	32	40	48	56	60	64	72	80	96	112
		Minimum deceleration lane length (ft) for ramp design speed (kmph)											

(Source: WSDOT Design Manual 2011 – Chapter 1360)

Minimum deceleration lane length to achieve 60 km/h (ramp design speed), when vehicle travels lower highway design speed of 80 km/h for exit ramps is;

Minimum deceleration lane length = 255 ft (78 m)

Minimum deceleration lane length, once the vehicle achieves 60 km/h (i.e. ramp design speed) to stop the vehicle.

Minimum deceleration lane length = 300 ft

Total Minimum deceleration lane length = 255 ft + 300 ft

= 555 ft (170 m)

Therefore, total minimum deceleration lane length should be 170 m for all exit ramps.

The calculated minimum deceleration lane length for an off ramp is 170 meters. Exsisting ramp length of Kahathuduwa ramp 1 (from Galle) and ramp 2 (from Colombo), Dodangoga ramp 1 (from Galle) and ramp 2 (from Colombo), Welipanna ramp 1 (from Galle) and ramp 2 (from Colombo), Kurundugahahatakma ramp 1 (from Galle) and ramp 2 (from Colombo), Baddegama ramp 1 (from Galle) and ramp 2 (from Colombo) are respectively 106m, 96m, 93m, 134m, 73m, 69m, 45m, 134m, 154m, and 90m. Therefore, Table 10 highlights the exit ramps which do not satisfy the minimum deceleration lane length of 170 meter requirement according to WSDOT design Manual 2011.

Table 10. Comparison of minimum deceleration lane length and existing exit ramp lengths

Interchange	Exit ramps	Ramp length (m)	Minimum deceleration lane length
Kottawa	Ramp 1 – From Galle	197	(Satisfy)
Kahathuduwa	Ramp 1 – From Galle	**106**	(Do not satisfy)
	Ramp 2 - From Colombo	**96**	(Do not satisfy)
Galenigama	Ramp 1 – From Galle	181	(Satisfy)
	Ramp 2 - From Colombo	187	(Satisfy)
Dodangoda	Ramp 1 – From Galle	**93**	(Do not satisfy)
	Ramp 2 - From Colombo	**134**	(Do not satisfy)
Welipanna	Ramp 1 – From Galle	**73**	(Do not satisfy)
	Ramp 2 - From Colombo	**69**	(Do not satisfy)
Kurundugahahathakma	Ramp 1 – From Galle	**45**	(Do not satisfy)
	Ramp 2 - From Colombo	**134**	(Do not satisfy)
Baddegama	Ramp 1 – From Galle	**154**	(Do not satisfy)
	Ramp 2 - From Colombo	**90**	(Satisfy)
Pinnaduwa	Ramp 1 –From Colombo	378	

Table 11. Results and Proposals

Interchange	Direction	Failure reason at year			Proposals
		Longest individual delay at year	Maximum queue length	Minimum deceleration length (169.04m according to WSDOT)	
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 not enough	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 not enough	Ramp length has to improve from now
	Ramp 2 - From Colombo	2040	2040		
Welipanna	Ramp 1 – From Galle			Existing ramp length not enough	Ramp length has to improve from now
	Ramp 2 - From Colombo	2045	2045		
Kurundugahahatakma	Ramp 1 – From Galle	2060	2050	Existing ramp length not enough	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

Conclusions and Recommendation

Southern Expressway will be directly influenced by additional traffic that would generate due to the anticipated rapid development of the Southern part of Sri Lanka. As seen from the study results, even at present, Kottawa and Pinnaduwa interchanges do not operate satisfactorily during long weekends and festive seasons. This study checked the effect of current toll gates on the free flow of the Southern Expressway. In fact, this study was conducted before commissioning the stretch from Pinnaduwa to Matara, and it is anticipated that the Pinnaduwa exit conditions will improve once the new stretch starts to operate.

It could be observed how each interchange dealt with maximum queue length, individual delay and minimum deceleration lane length. Table 11 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 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. As an example, proposed layout plan for Kurundugahahatakma interchange shown in Figure 5. Table 11 shows that queue lengths will exceed the critical exit ramps in years 2034, 2075, 2050, 2040, 2045, 2050 and 2030 for the Kottawa (from Galle), Kahathuduwa (from Galle), Galenigama (from Galle), Dodangoda (from Colombo), Welipanna (from Colombo), Kurundugahahatakma (from Galle) and Pinnaduwa (from Colombo) interchanges respectively. Due to the spillback of the traffic queues from off ramps, capacity reduction of expressway is visible by bottlenecking the expressway.

The maximum individual delay of 10 minute duration exceeded in years 2035, 2075, 2060, 2040, 2045, 2060, 2030 for the Kottawa (from Galle), Kahathuduwa (from Galle), Galenigama (from Galle), Dodangoda (from Colombo), Welipanna (from Colombo), Kurundugahahatakma (from Galle) and Pinnaduwa (from Colombo) interchanges respectively.

Hence, the capacity of the Southern Expressway will get affected due to the inadequacy at toll gates unless the number of toll gates is increased or the efficiency of the toll collecting systems is improved, thus improving the efficiency of the toll gates which is more practical. Due to the operational procedure of electronic toll collection systems such as; automatic coin machines, touch and go systems, systems operated through transponders *etc.* the queue length and individual delay can be reduced. The service rates and operational procedure for above mentioned systems are indicated in Table 12. The last column of Table 12 presents the study proposals for toll gates.

Table 12. Comparison of toll collection systems

Toll collection system	Service time (s)	Operational procedure
Manual toll collection system	18	Cash toll is received by the collector. The collector, who also dispenses change, may accept and sell scrip, tickets, coupons, making an entry of the vehicle in the system and issuing receipt to the patron. The processing time is highest, due to manual intervention
Automated coin machine	5.20	These machines accept both coins and tokens issued by the operating agency. Depending on the toll rate, the use of automated coin or token collection instead of manual collection reduces transaction and processing time as well as the operating cost.
Touch and go system	3.50	The drivers are provided with a prepaid or postpaid card in which the driver and vehicle details are been stored. And the driver comes to the entrance has the card and the machine reads the card information and sends it to the network. And the gate is then opened. Also at the exit, when the driver touches the machine with the card, the machine takes necessary action to deduct the required amount of money.
Electronic toll collection system	1.12	Most systems use the radio frequency transmitter and the transponder in the vehicle for identification for the billing process of electronic toll collection. It is mostly dealt by banks, and the billing process can follow a post-pay over a prepaid model.

(Source: www.researchgate.net)

Therefore, one of the tolling systems above described can be introduced to minimize the queue length and individual delay.

References

Banks, J. H. (2010), "*Introduction to Transportation Engineering*", 2nd Edition, Tata McGraw-Hill, New Delhi, India.

Mannering, F. L. and Washburn, S. S. (2004), '*Principles of Highway Engineering and Traffic Analysis*', 3rd edition, John Viley & Sons, Inc, USA.

Mannaring, F. L. and Kilareski, W. P. (1998) "*Principals of Highway Engineering and Traffic Analysis*", 2nd Edition

Washington State Department of Transportation (2011), *Design Manual*, Washington, US.

www.rda.gov.lk/supported/expressways/stdp.htlm

www.researchgate.net

Received: 5-4-2015 Revised: 14-9-2015 Accepted: 15-9-2015