Service Time Prediction Models for Manual Toll Booth Operation under Mixed Traffic Conditions

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Abstract

The present study attempts to develop service time prediction models for different vehicle categories on toll plazas in India under mixed traffic conditions. Here service time is defined as the time required by a vehicle to pay toll and clear the toll booth. Service time includes the time elapsed in transaction of toll tax and time required by a vehicle to travel a distance equivalent to its own length. Field data are collected at fourteen different lanes at three toll plazas in different region of the country by the video recording method. All vehicles in the traffic stream are divided into seven categories. The service time values are obtained as low as 2.64 second (s) to as high as 58.76 s for small car and trailer respectively. This variation in service time is dependent on random arrival of vehicle at tollbooth and drivers and toll booth operator's personal attributes. Hence simultaneous equations are developed to relate service time of a vehicle type with the traffic volume and its composition. These equations are solved for some assumed values of traffic volume and traffic composition and effect on the service time of each vehicle type is explained. Accuracy of the service time values estimated through equations is checked by comparing the estimated value with those calculated directly from the field data. The service time models proposed in the present study may be useful for planners and managers for designing and evaluating the performance of toll plazas.

Keywords: Service Time, Mixed Traffic, Toll booth, Toll Plaza

1. Introduction

The rapid pace of urbanization observed in the last two decades in India has intensified the travel demand. Owing to the lack of government funding which is needed in the construction of highway infrastructure, most of the highway project is awarded on a Public Private Partnership (PPP) basis. In PPP projects,the concessioner designs, constructs and maintains a particular highway from his own investment and in line of that they are entitled to collect taxes in the form of toll from end users for a defined

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period. The length of time required by a vehicle to pay the toll tax and clear the toll booth is known as service time. The service time at a toll booth depends on the multitude factors such as vehicle class, toll rate, toll booth operators and driver's personal attributes (Wanisubut, 1989; Woo and Hoel, 1991; Zarrillo et al., 2002; Klodzinski and Al-Deek, 2002; Russo et al., 2010). For the collection of tax, toll plazas are built in India along the road network as per National Highway Fee Rules, 2008. The toll booths are built for dedicated lane so as to serve a specified category of vehicle to expedite the process of toll collection. In spite of this, it is observed that different vehicles encroach a lane irrespective of the type of vehicle for which the toll both has been assigned (Figure 1). This may lead to heterogeneous traffic in the same lane and it affects the toll booth operator's performance in terms of service time required to collect toll from different vehicle types. As the operator is required to perceive the arrival of the same vehicle in the lane, but due to the heterogeneity in traffic they have to collect the different toll amount which may result in the variability in service time and consequently the capacity of the toll booth decreases. In India, most of the toll plaza have the manualtoll collection system wheretoll is collected according to vehicle category at different toll rates and cash is received by the toll booth operator. Indian Road Congress (IRC-SP84- 2014) has specified the service time of not more than 10 seconds (s) per vehicle at peak flow irrespective of the vehicle type and method of payment. Hence there is a need to study the variation in service time in order to enhance the capacity of toll plaza. Several research have been conducted to study service time at the toll booth.

Figure 1:Mixed Traffic Present at Toll Plazas in India

Kepsutlu (1986) observed that the service time required for cash payment at toll plaza is 8 to 30 s. Woo and Hoel (1991) found that traffic demand at toll plaza increases as the service time decreases due to the fact that when toll collectors are under greater pressure from growing queue, they tend to process transactions faster. Kim (1993) intended to apply the queuing theory to developing a model that could explain the changes in a proper number of lanes at expressway tollgate depending on increase or decrease in traffic volume. The authors concluded that the exponential distribution was appropriate for service time distribution. Lin and Su (1994) observed that mean service time required for different vehicle categories varies according to vehicle type and their means of payment when exact change is rendered or when prepaid toll tickets are used. They have indicated that a lognormal distribution followed by service time at tollbooth.Kim (1995) intended to develop a model that examined the service characteristics of vehicles in the toll collection system and evaluated the lane operation at tollgate. In order to verify the service time distribution, the author classified the service time into toll collecting time, transit time and service preparation time. The author stated that the service time followed the Erlang distribution, instead of the exponential distribution verified by the previous studies. Parsula (1999) assumed different average service time values required for different type of payment at tollbooth. Dijk et al. (1999) from field observation showed that service time required for cash payment by cars, motorcycles and trucks are 7.5 s and 13.1 s respectively. The service time (processing time) is the most significant calibration parameter for any toll plaza simulation model (Klodzinski and Al-Deek, 2002; Gordon, 2004). Aycin (2006) considers average service times for automobile vehicle as 10.5 s, heavy vehicle as 19.6 s. and traffic mix condition as 11.5 s. Cho (2005) studied the arrival and travel characteristics of vehicles in Hi-Pass lane based on drivers' behavior of lane selection. By utilizing the results of such examination, the researcher developed the simulation model to design and operate toll plaza in consideration of the service characteristics by vehicle type, toll payment type and time slot, the traffic volume and the vehicle composition ratio. According to the analysis, the service time of vehicle followed the log-normal distribution. Oliveira and Cybis (2006) concluded that service time have a strong influence on the toll plaza operation. Service time per vehicle is greatly affected by the number of bills and/or coins that must be processed by the toll booth collector or Automated Coin Machine (ACM). Manual toll booths charging exact bill amounts tend to have higher capacities than ones that do not. Road Design Manual (2009) of the Korea Expressway for the design of toll gate consider service time followed exponential distribution.Lee et al. (2011) have studied characteristics at tollgate to improve the efficiency. The study found that service time followed the lognormal distribution. Many other researcher also used the microscopic simulation model such as TPSIM (Al-Deek et al., 1998; Klodzinski and Al-Deek, 2002), PARAMICS (Nezamuddin and Al-Deek, 2008), SHAKER (Zarrilo and Radwan, 2009), GENTOPS (Aysin, 2006), VISSIM (Niu and Zang, 2014; Chakroborty et al., 2016) etc. to study the operational characteristic at toll booth and its capacity calculation.

The review of literature presented above reveals that different researchers have studied service time and simulated the operation of toll plazas. Service time values reported in the literature vary according to vehicle category and type of payment adopted. Most of these studies were carried out in developed countries where traffic is homogenous and rules of priorities as well as lane discipline voluntarily followed. Previous studies proposed static service time values for different payment methods and vehicle class. However in India, due to mixed traffic condition (Figure 1) and varying the toll rate, a wide variation in service time is observed between different vehicle classes and also within the same vehicle class. Previously, no explicit attempt was made to model the dynamic nature of service time for different vehicle categories by considering vehicle composition and volume present in the traffic stream. Considering this aspect, the present study attempts to develop service time models for different vehicle classes which are functions of traffic composition and traffic volume through regression analysis.

2. Research Methodology

Service time is dependent on multitude of factors such as vehicle class, toll rate, drivers and toll booth operator's personal attributes. In a mixed traffic condition, due to the random arrival of vehicle at the toll booth and varying toll rates, service time is also dependent on the traffic volume and its composition. These two factors are sufficient to explain all variation in service time for a particular vehicle type. The composition accounts for any change in the traffic and the changing degree of damaging effect in service time at different volume level. Mathematically, for a traffic stream consisting of seven categories of vehicles (j, k, l, m, n, o, p), the service time of the vehicle type j is given by Eq. (1).

$$\mathrm{Log_e}[\mathrm{ST_j}] = a_1 * P_j + a_2 * P_k + a_3 * P_l + a_4 * P_m + a_5 * P_n + a_6 * P_o + a_7 * P_p + a_8 * N \qquad (1)$$

Where,
ST_j = Service time of vehicle category j (s)
P_j = Proportion of vehicle type j in traffic stream (Percentage)
N = Number of Vehicles served during an hour
a_1, a_2………… a_8 are regression Coefficients

Field data on 30-min classified traffic volume count and service time were collected on different toll plazas in India. These data are used to relate service time with traffic composition and volume as explained above. This equation was developed separately for each category of vehicles using the field data and as many equations are formed as the number of vehicle categories in the traffic stream. These equations are used to demonstrate the variation in service time for different categories of vehicles at toll booth with the change in traffic composition and volume.

3. Data Collection

Field data for this study were collected at three toll plazas located in northern and western part of India; Ghoti toll plaza is located on National Highway-3 (NH-3) near Nasik (Maharashtra), Gurgaon-Faridabad toll plaza located on commuter route and Kerki toll plaza at NH-8 in the National Capital Region (NCR). The details of the selected toll plazas and traffic survey schedules are given in Table 1.

Table 1: Study Locations and Survey Details

Sr. No.	*Name of Toll Plaza*	*City*	*State*	*Date and Day*	*Timing*	*Number of Lane*
1	Ghoti Toll Plaza (GTP)	Nasik	Maharashtra	09/3/2016 to 12/3/2016 (Thursday to Sunday)	9AM to 12.30PM and 3 to 6.30 PM	6
2	Kerki Toll Plaza (KTP)	New Delhi	Delhi	24/5/2016 (Tuesday)	9AM to 12.30PM and 3 to 6.30 PM	6
3	Gurgaon-Faridabad Toll Plaza (GFTP)	New Delhi	Delhi	26/5/2016 (Thursday)	9AM to 12.30PM and 3 to 6.30 PM	2

Data were extracted for six lanes at the Ghoti toll plaza, two lane for Gurgaon-Faridabad toll plaza and six lanes at Kerki toll plaza by replaying the video on a large screen monitor in the laboratory. In order to achieve the desired degree of precision, the time was noted up to two decimals of seconds by using Avideux 2.6 software. In a spreadsheet, data like lane number, vehicle class, their entry and exit time at the toll booth (exactly at the toll window for the transaction) were entered. Service time is calculated by subtracting exit and entry time of the vehicle at a particular toll booth. All vehicles arrived at the toll booth are divided into seven classes and the horizontal projected lengths taken from field measurement for different category of vehicles as shown in Table 2.

Table 2:Vehicle Class and their Sizes

Sr. No.	*Vehicle Class*	*Vehicle Included*	*Length (m)*
1	Small Car (SC)	Car	3.72
2	Big Car (BC)	Big Utility Vehicle	4.58
3	Light Commercial Vehicle (LCV)	Light Motor Vehicle	5.00
4	Bus	Standard Bus	10.30
5	Heavy Commercial Vehicle (HCV)	2 to 3 Axle Truck	7.20
6	Multi Axle Vehicle (MAV)	4 to 6 Axle Truck	11.70
7	Trailer	More than 7 Axle Truck	15.60

Here small car includes all hatchback and sedan cars with engine capacity is less than 1400cc. and their average length is reported. Big car includes all SUV and XUV and their average length is considered. All other vehicle categories are standard as reported in Table 2.

4. Analysis of Field Data

It was observed that lanes 1, 2 and 4 were assigned only for car traffic at Ghoti toll plaza. However, other vehicle categories were also present in these lanes, whereas at Gurgaon-Faridabad toll booths, mostly car traffic was present. The combined share of small and big car was observed as 99 percent at the Gurgaon-Faridabad toll plaza and hence the traffic condition can be assumed to be homogenous. However in the case of the Kerki toll plaza, mixed traffic was observed on all six lanes. Traffic in Electronic Toll Collection (ETC) lanes is not considered here because vehicle in India are not equipped with ETC system. The proportional share of the different categories of vehicles at the toll booth as shown in Table 3.

Table 3: Traffic Composition Observed in Field

Sr No.	***Lane Number***	***Composition (in Percentage)***						
		SC	***BC***	***LCV***	***Bus***	***HCV***	***MAV***	***Trailer***
Ghoti Toll Plaza (NH-3)								
1	Lane No.1	42.44	27.73	6.72	2.94	17.65	0.42	2.10
2	Lane No.2	31.51	26.03	7.31	3.20	22.37	1.83	7.76
3	Lane No.3	40.69	15.86	10.34	3.45	22.07	4.14	3.45
4	Lane No.4	62.26	32.08	3.30	N.P.*	0.94	0.47	0.94
5	Lane No.5	41.28	25.74	7.59	2.49	9.96	7.59	5.34
6	Lane No.6	41.02	25.03	9.14	3.16	9.58	7.07	5.01
Gurgaon Faridabad Toll Plaza								
7	Lane No.2	92.86	6.30	0.84	N.P.*	N.P.*	N.P.*	N.P.*
8	Lane No.3	93.37	5.42	1.30	N.P.*	N.P.*	N.P.*	N.P.*
Kerki Toll Plaza (NH-8)								
9	Lane No.1	48.91	26.21	9.48	4.03	6.45	1.81	3.83
10	Lane No.3	36.84	22.93	19.17	3.76	10.53	3.38	3.38
11	Lane No.4	48.54	19.09	15.21	1.29	10.03	1.94	3.88
12	Lane No.5	48.21	21.50	14.01	0.33	9.77	3.26	2.93
13	Lane No.6	38.34	15.67	7.42	1.69	26.17	8.68	2.11
14	Lane No.7	39.33	10.53	14.39	2.28	23.19	6.69	3.57

(Note: N.P.*- Not Present in the traffic mix)

4.1 Service Time Analysis

Service time is the time spent by a vehicle at toll booth for paying toll. Table 4 includes vehicle class wise descriptive analysis for service time at tollbooth. It may be observed from the Table 4 that number of small car samples were found to be higher, followed by big car and other remaining categories of vehicle. It has been observed that service time is varying in a wide range for all categories of vehicle and even within same vehicle class. In order to capture this variation in service time, the cumulative distribution plot has been drawn from the extracted data as shown in Figure 2. Mean service time for small cars is 11.14 s. whereas for bus and trailer 24.90 s and 32.37 s respectively. The minimum and maximum service time for LCV is observed as 4.16 s and 47.32 s respectively. The field observation showed that service time of a vehicle at toll booth is not a constant value, but varies in a wide range as shown in Figure 3. The observed value shows that under mixed traffic condition, the service time is more than 10 s whereas the value specified by IRC (SP-84-2014) is not more than 10 s irrespective to payment method. This variation may be due to mixed traffic conditions, the varying toll rate for different vehicle classes and the random arrival of vehicles at the same toll booth. Further, the exact change of the toll amount given by driver and efficiency of driver and toll booth operator may also lead to this effect on variation in service time.

Table 4: Statistical Analysis of collected Service Time Data

Vehicle Type	*Sample Size*	*Mean of service time (s)*	*Minimum value (s)*	*Maximum value (s)*	*Standard deviation*
SC	3363	11.14	2.60	42.64	6.77
BC	1338	12.91	2.60	39.52	7.46
LCV	641	19.90	4.16	47.32	8.44
BUS	128	24.90	8.84	50.96	9.70
HCV	966	25.63	7.80	58.76	9.37
MAV	326	28.74	7.80	52.00	10.24
Trailer	198	32.37	8.84	58.76	12.64

Field observed service time values compared with previous studies (see Table 5). Previous studies shows that lower service time values as compared to present study. Also vehicle class wise service time analysis estimated in present work shows that there is a wide variation in service time. This may be due to varying toll rate, vehicle characteristics, drivers and toll booth operators' personal attributes.

Table 5: Comparison of Field Observed Service Time Values with Literature

Author	*Toll Collection Type and Average Service Time Findings*
Kepsutlu (1986)	Cash payment = 8 to 30 s
Lin and Su (1994)	1.Exact change or Prepaid toll ticket = 2.05 s 2.Small vehicle required change = 4.86 s 3.Heavy single unit truck = 3.87 s 4.Tractor, Trailer and Buses = 4.42 s
Pursula (1999)	1.E-Z pass = 3.8 s 2.Token only = 7.5 s 3.Token and manual = 10 s 4. Manual only = 20 s
Dijk *et al.* (1999)	Cash Payment 1.Car = 7.5 s 2.Motorcycle = 7.5 s 3.Truck = 13.1 s
Aycin (2006)	1.Automobile vehicle = 10.5 s 2.Heavy vehicle = 19.6 s 3. Traffic_{mix} = 11.5 s
Russo *et al.* (2010)	1.Car (Manual) = 5.8 s 2.Truck (Manual) = 11 s 3.Automated Coin Machine = 5.56 s
Field observed service time values in the present study	For manual toll collection 1.SC = 11.14 s 2.BC =12.91 s

	3.LCV = 19.90 s
	4.Bus = 24.90 s
	5.HCV = 25.63 s
	6.MAV = 28.74 s
	7.Trailer = 32.37 s

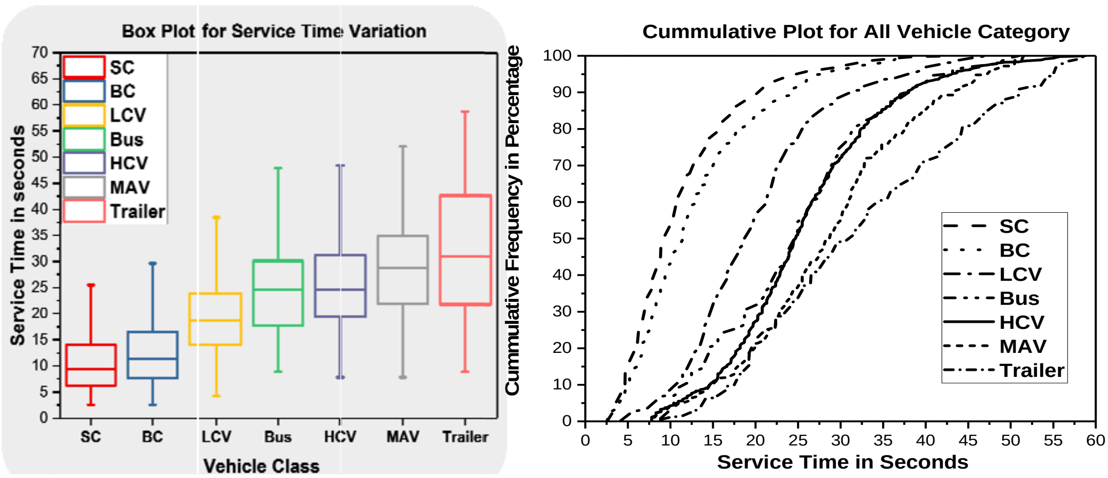


Figure 2(a): Box Plot Figure: 2(b). Cumulative Frequency Curve

Figure 2: Service Time Variation for Different Vehicle Class

It may be obtained from Figure 2(b) that around 60 percent of SC and 45 percent of BC clear the toll booth is less than 10 s time as specified by IRC (SP-84-2014) whereas other vehicles taken more than the specified time to clear the toll booth. This may lead to reduce the capacity of toll booth as specified by IRC (240veh/hr/lane).

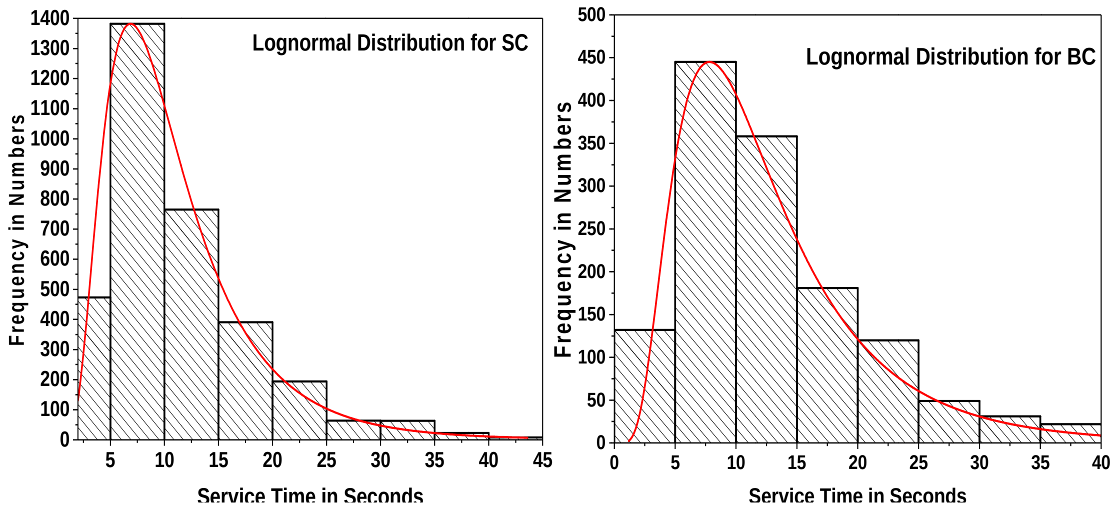


Figure: 3(a) Lognormal Distribution for SC Figure: 3(b) Lognormal Distribution for BC

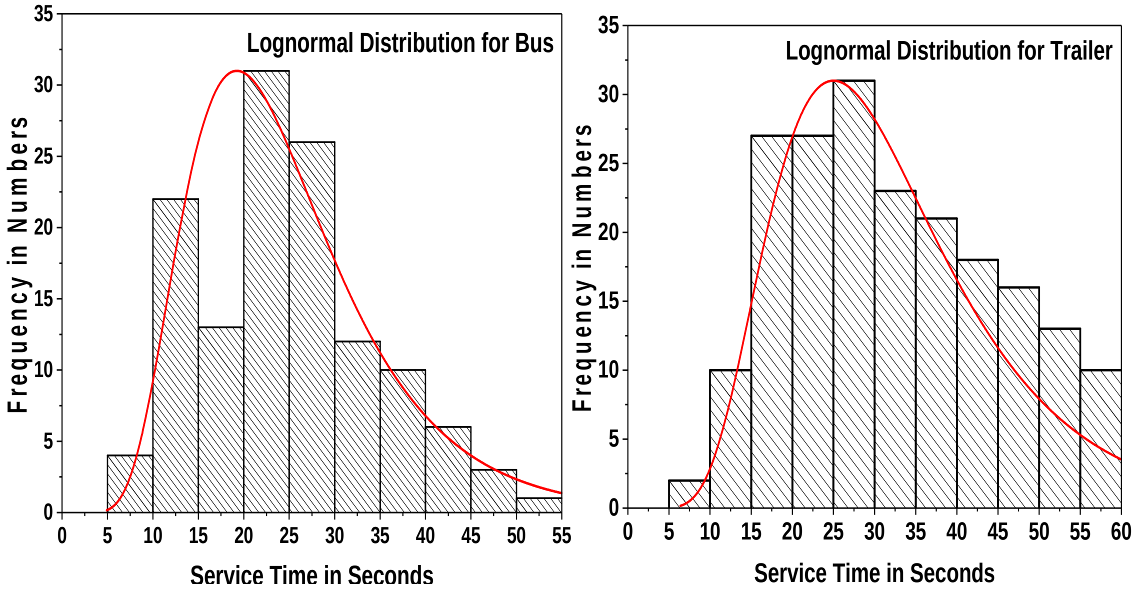


Figure: 3(c) Lognormal Distribution for BusFigure: 3(d) Lognormal Distribution for Trailer

Figure 3:Lognormal Distribution for Different Vehicle Categories

The empirical service time distribution for each individual vehicle class fitted with lognormal, Inverse Gaussian and General Extreme Value (GEV) hypothesized distribution and K-S tests are performed in order to determine the goodness of fit. A smaller K-S statistics value indicates a superior goodness of fit and the decision to reject the null hypothesis is made by comparing the p-value with the significance levelα (at the 5% level of significance). The null hypothesis is that the data follow the specified distribution. The K-S value considering individual vehicle class estimated for selected distribution. Comparing this value with each other than selecting the appropriate distribution for each case which one is having less K-S value compared to other distributions. All vehicle categories shows that lognormal distribution fitted very well fits (Figure 3).

Present study considered seven different vehicle categories. Due to mixed traffic condition present at tollbooth there is total forty-nine pairwise combinations observed in the field. The Figure 4(a) shows that frequency distribution curve for LCV as follower and BC, LCV, HCV and MAV as leader combination. It may be seen from curve (see Figure 4(a) and (b)) that a wide service time variation present in the field according to leader-follower pairwise combinations. This may be due to tollbooth operator required to adjust himself according to toll rate variation based on vehicle type. Figure 4(b) shows that all combinations of LCV as leader or follower and there average service time value. Service time depends on traffic composition present at tollbooth can be explained on the basis of Figure 4(a) and (b). Hence, traffic composition consider independent variable for developing service time prediction models (Eq. 1).

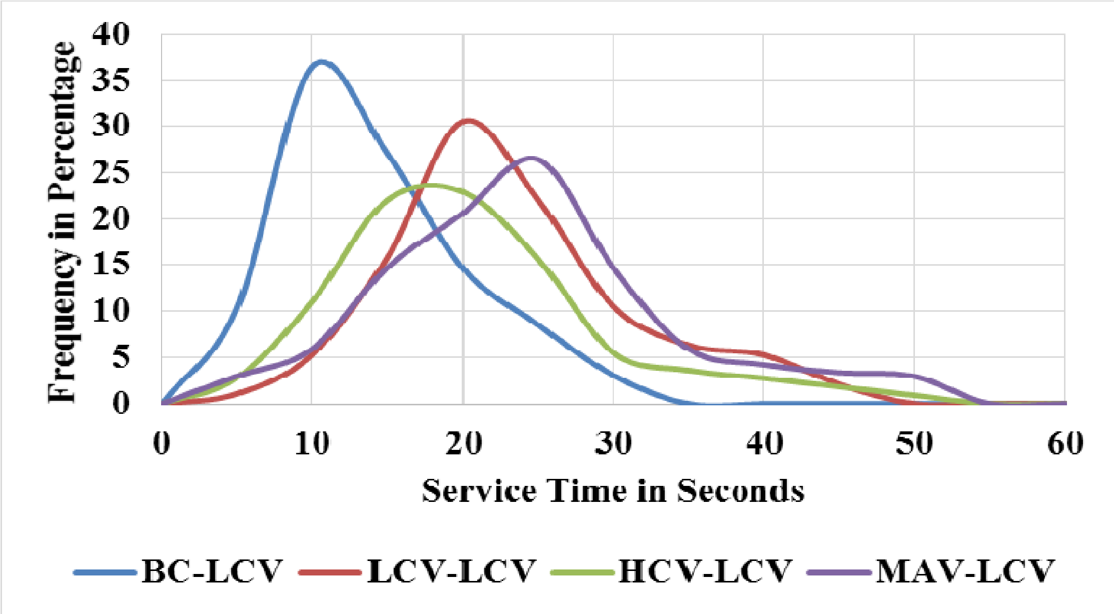


Figure: 4(a) Frequency Distribution Curve for Different Pairwise Leader-Follower Combinations

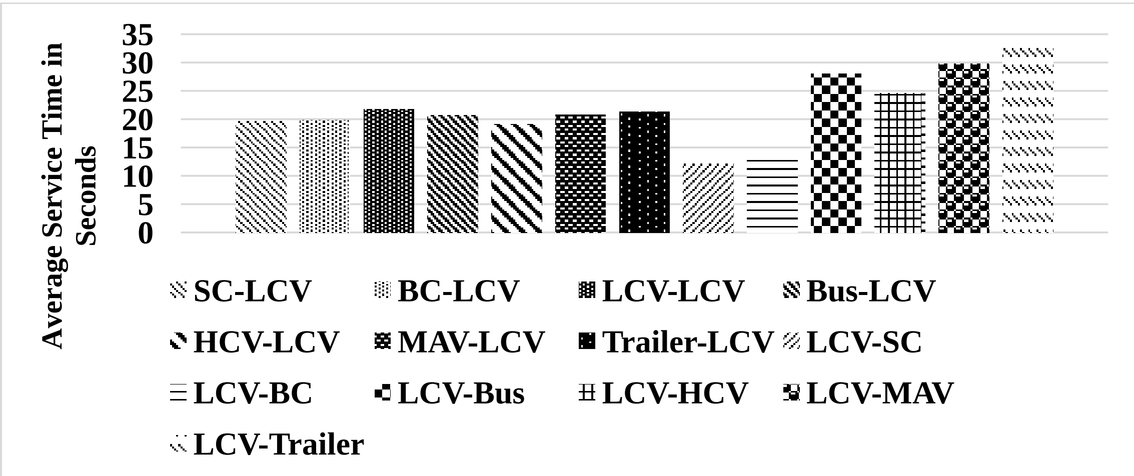


Figure: 4(b) Average Service Time for LCV Different Pairwise Leader-Follower Combinations

Figure: 4 Service Time Analysis for Different Pairwise Leader-Follower Combinations

5. Development of Service Time Prediction Model

Recorded film was replayed on a large screen monitor and classified traffic volume count data were conducted. Service time and volume were extracted for different vehicle categories for every 30 minutes count period. To capture the interaction among all vehicle classes and the fluctuations in their service times due to traffic composition and flow this 30-min classified traffic volume and compositional share in that count period has been used to develop the simultaneous equation for service time at toll booth as given in Eq. (1).

Average service time of a vehicle type will be influenced to the different extents by the vehicle of different categories and therefore coefficients a1 to a8 are expected to be substantially different when service time of individual type of vehicle is modeled. Arrival of all vehicle at toll booth is independent to the arrival of next vehicle and hence traffic composition and volume may be considered as independent variable in order to predict service time of a vehicle type. A correlation matrix is generated between independent variables as given in Table 6 and it is found that none of the independent variable is highly correlated with other independent variable. Regression coefficients a1, a2………a8 as estimated from field data are given in the Eq. (2) to (8). A total 559 data points each of 30-minute count period was extracted from field data used to develop these equations. The values given in parenthesis are the t-values of coefficients.

$$\mathrm{Log_e}[\mathrm{ST_{sc}}] = 3.55 * \mathrm{P_{sc}} + 4.04 * \mathrm{P_{bc}} + 5.69 * \mathrm{P_{lcv}} + 4.52 * \mathrm{P_{bus}} + 2.49 * \mathrm{P_{hcv}} + 2.73 * \mathrm{P_{mav}} + 3.84 * \mathrm{P_{trailer}} - 9 * \mathrm{N} \quad (2)$$

(37.03) (29.72) (17.84) (4.05) (19.56) (11.37) (16.30) (16.29) R^2= 0.91

$$\mathrm{Log_e}[\mathrm{ST_{bc}}] = 3.26 * \mathrm{P_{sc}} + 3.71 * \mathrm{P_{bc}} + 5.07 * \mathrm{P_{lcv}} + 4.57 * \mathrm{P_{bus}} + 3.55 * \mathrm{P_{hcv}} + 4.37 * \mathrm{P_{mav}} + 3.25 * \mathrm{P_{trailer}} - 7.3 * \mathrm{N} \quad (3)$$

(13.62) (10.92) (6.35) (2.64) (11.12) (7.27) (5.52) (5.24) R^2 =0.88

$$\mathrm{Log_e}[\mathrm{ST_{lcv}}] = 4.7 * \mathrm{P_{sc}} + 4.2 * \mathrm{P_{bc}} + 5.2 * \mathrm{P_{lcv}} + 2 * \mathrm{P_{bus}} + 1.60 * \mathrm{P_{hcv}} + 1.11 * \mathrm{P_{mav}} + 2.30 * \mathrm{P_{trailer}} - 6.4 * \mathrm{N} \quad (4)$$

(17.35) (11.01) (5.81) (2.65) (4.53) (2.66) (3.55) (4.02) R^2 = 0.90

$$\mathrm{Log_e}[\mathrm{ST_{bus}}] = 4.3 * \mathrm{P_{sc}} + 3.7 * \mathrm{P_{bc}} + 3.1 * \mathrm{P_{lcv}} + 3.6 * \mathrm{P_{bus}} + 3.1 * \mathrm{P_{hcv}} + 2.90 * \mathrm{P_{mav}} + 3.8 * \mathrm{P_{trailer}} - 4.4 * \mathrm{N} \quad (5)$$

(22.08) (13.21) (4.81) (2.54) (12.05) (5.81) (7.78) (3.81) R^2 = 0.84

$$\mathrm{Log_e}[\mathrm{ST_{hcv}}] = 4.2 * \mathrm{P_{sc}} + 3.8 * \mathrm{P_{bc}} + 3.1 * \mathrm{P_{lcv}} + 1.11 * \mathrm{P_{bus}} + 3.4 * \mathrm{P_{hcv}} + 4.0 * \mathrm{P_{mav}} + 3.6 * \mathrm{P_{trailer}} - 3.4 * \mathrm{N} \quad (6)$$

(20.29) (13.06) (4.44) (2.45) (12.28) (7.77) (7.14) (2.81) R^2 = 0.90

$$\mathrm{Log_e}[\mathrm{ST_{mav}}] = 4.0 * \mathrm{P_{sc}} + 4.0 * \mathrm{P_{bc}} + 3.2 * \mathrm{P_{lcv}} + 1.21 * \mathrm{P_{bus}} + 3.70 * \mathrm{P_{hcv}} + 4.3 * \mathrm{P_{mav}} + 3.9 * \mathrm{P_{trailer}} - 2.8 * \mathrm{N} \quad (7)$$

(21.12) (14.98) (5.17) (2.55) (14.84) (9.07) (8.47) (2.55) R^2 = 0.91

$$\mathrm{Log_e}[\mathrm{ST_{trailer}}] = 4.1 * \mathrm{P_{sc}} + 4.2 * \mathrm{P_{bc}} + 3.5 * \mathrm{P_{lcv}} + 2.7 * \mathrm{P_{bus}} + 3.9 * \mathrm{P_{hcv}} + 5.11 * \mathrm{P_{mav}} + 3.4 * \mathrm{P_{trailer}} - 4.0 * \mathrm{N} \quad (8)$$

(15.47) (11.11) (3.92) (2.88) (11.11) (7.60) (5.21) (2.61) R^2 = 0.89

The t-values of the coefficients are more than the critical value of 1.96 at the 98 percent level of confidence and hence all the coefficients are significant. Signs of all coefficients are also logical as an increase in the proportion of any vehicle class would affect the service time of other vehicles. An increase in traffic volume leads to a significant reduction in the service time. Higher R-square values also indicate the good strength of the model in predicting the service time.

Table 6: Correlation Matrix between Independent Variables

Independent Variables	P_{sc}	P_{bc}	P_{lcv}	P_{bus}	P_{hcv}	P_{mav}	$P_{trailer}$	N
$\mathbf{P_{sc}}$	1.00	-0.19	-0.25	-0.06	-0.33	-0.28	-0.30	0.24

P_{bc}	-0.19	1.00	-0.33	0.26	-0.35	-0.24	0.12	-0.32
P_{lcv}	-0.25	-0.33	1.00	0.22	0.11	-0.26	-0.13	0.02
P_{bus}	-0.06	0.26	0.22	1.00	-0.43	-0.35	-0.07	-0.04
P_{hcv}	-0.33	-0.35	0.11	-0.43	1.00	0.32	-0.17	0.37
P_{mav}	-0.28	-0.24	-0.26	-0.35	0.32	1.00	0.17	-0.04
$P_{trailer}$	-0.30	0.12	-0.13	-0.07	-0.17	0.17	1.00	-0.33
N	0.24	-0.32	0.02	-0.04	0.37	-0.04	-0.33	1.00

6. Sensitivity Analysis

The service time models developed in this study can be solved for any composition and traffic volume at the toll booth, and estimated service time can be used in planning of toll plazas and to check toll booth's efficiency. In a mixed traffic situation, traffic volume, in terms of 'vehicle per hour', may vary widely depending upon the traffic mix. The same proportional composition of traffic stream may occur at different values of total volume at toll booth. Also, the different proportional composition may occur at same traffic volume. Therefore, it will be interesting to see the variation in service time of individual vehicle with traffic composition keeping total volume at some predetermined fixed value and vice-a-versa.

6.1 Variation in Service Time with Traffic Volume and Composition

The effect of traffic volume on the service time of individual vehicle can be studied by solving developed equations (Eq. 2 to 8) at different volume levels keeping predefined proportion of each type of vehicle. Traffic volume observed in the field was in the range of 80 to 240 veh/hr. Therefore, Eq. (2) to (8) were solved for traffic volume varying from 100 to 250 veh/hr an incremental of 50 veh/hr. The proportional composition of traffic stream was used according to the field observations. A number of curves can be generated to show the complete variation in service time of a vehicle type with both traffic composition and volume. Figure 5(a) to (f) show such curves for SC, BC, LCV, Bus, HCV and Trailer. The trend shows that as a smaller sized vehicle class (SC, BC and LCV) proportion increases in the traffic stream with respect to larger size vehicles such as Bus, HCV and MAV there service time also increases. This results depicts that impact of larger sized vehicles on service time of a smaller size vehicle is more. It may be due to the random arrival of the vehicle and mixed traffic condition. As the proportion of particular vehicle class increases in the traffic stream and due to the random arrival of vehicles in the toll booth operator required to adjust himself, according to the change in toll rates from previous vehicles to the next vehicle. An increase in traffic volume leads to a significant reduction in the service time depicts from Figure 5. This may be because vehicles of a formation of queue that might put pressure on toll booth operator to make faster transaction in order to clear the queue before reaching delay to a significant value. These results are in conformity with the finding of Woo and Hoel (1991). The result is logically correct also because the maximum volume from toll booth will pass only when service time is low.

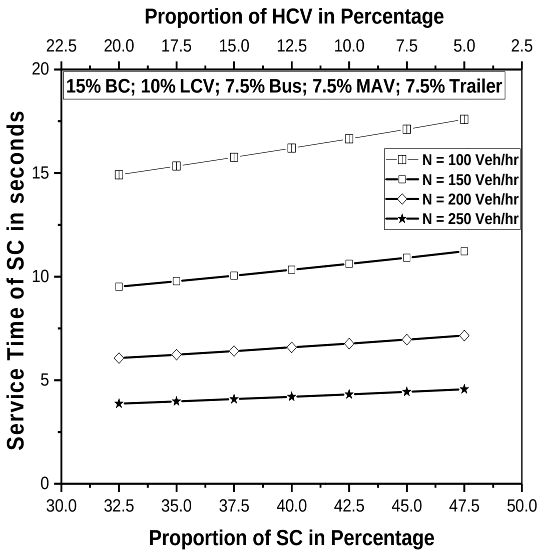


Figure: 5(a) Service Time Variation for SC with Volume

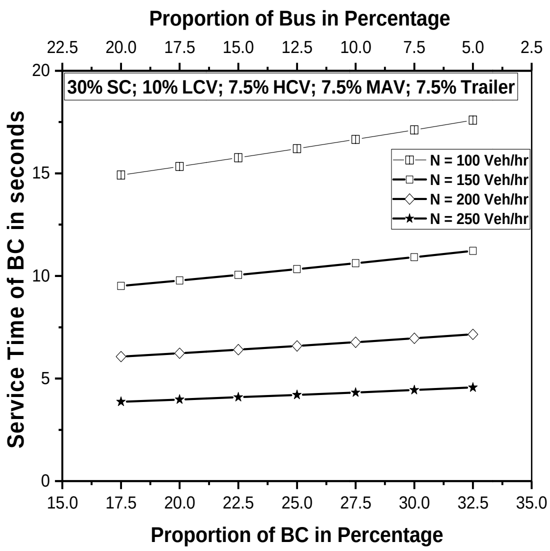


Figure: 5(b) Service Time Variation for BC with Volume

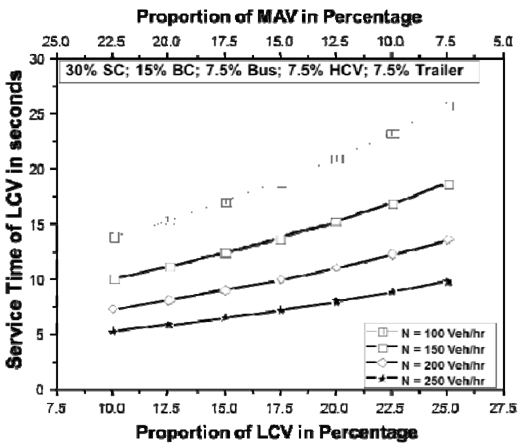


Figure: 5(c) Service Time Variation for LCV with Volume

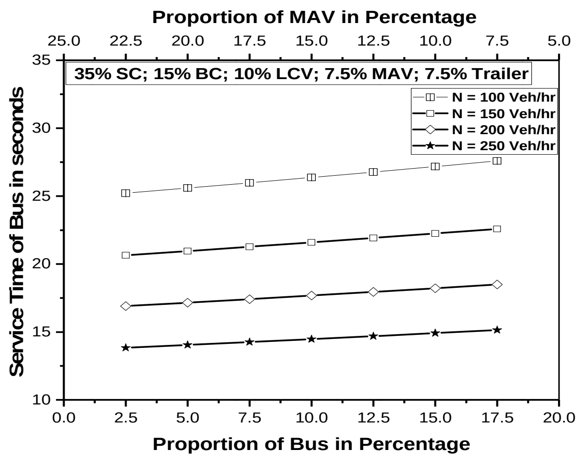
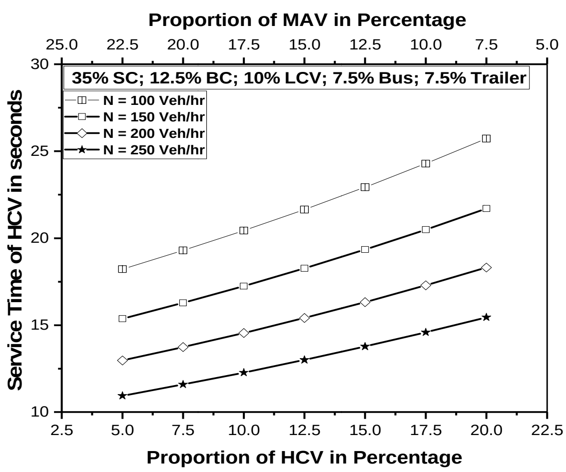


Figure: 5(d) Service Time Variation for Bus with Volume



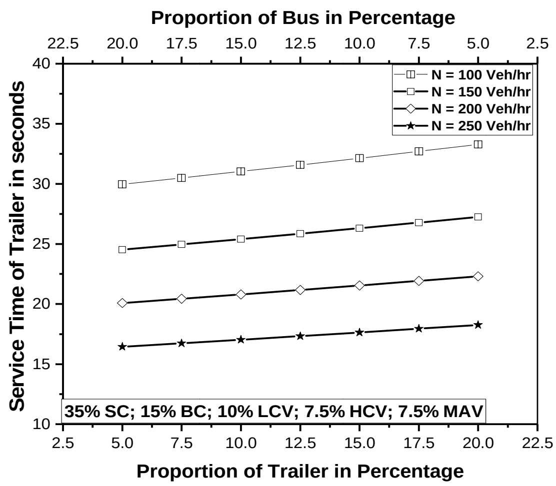


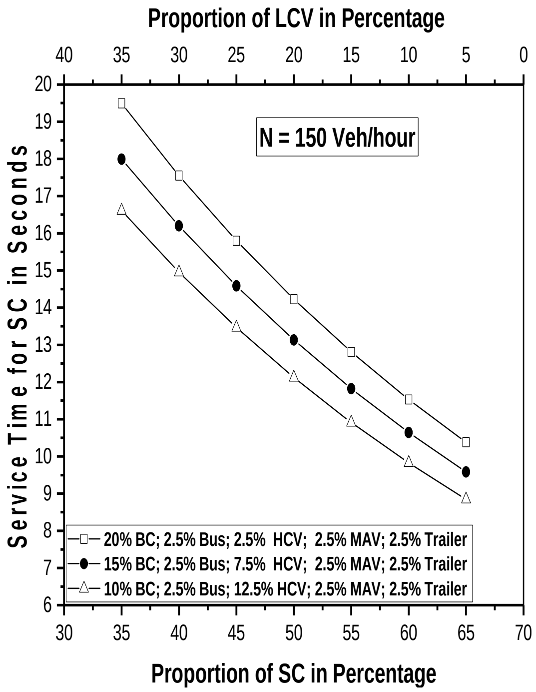
Figure: 5(e) Service Time Variation for HCV with Volume Figure: 5(f) Service Time Variation for Trailer withVolume

Figure 5: Variation in Service Time of Different Vehicle Class with Traffic Volume

6.2 Variation in service time with traffic composition

Traffic composition of a stream may change with traffic volume or at the same volume level from one count period to another. The observed traffic volume in the field data was ranging from 80 to 240 veh/hr. Therefore, equations were solved for a predefined volume (150 veh/hr) and by varying the proportions of different types of vehicle. Figure. 6 shows the variation in service time of SC, BC, Bus and Trailer with composition of the traffic stream.

As the proportion of SC in traffic stream increases, the service time decreases for SC and BC, whereas it increases for Bus, Trailer as shown in Figure 6. It is clear from curves that the increase in the proportion of smaller sized vehicles at tollbooth reduces their service time. As small vehicles in traffic stream increases homogenous condition occurs at the same time acceleration capabilities of such vehicles are high and hence they clear the toll booth in a lesser time which will reduce service time. Service time of larger sized vehicle increases as a proportion of smaller sized vehicle increases at tollbooth. It can be explained on the basis of random arrival of vehicles, varying toll rate, driver's personal attributes and vehicle acceleration capabilities. As a small vehicle like SC and BC clear the toll booth and next heavy vehicle arrives the toll booth; toll booth operator find less time to adjust himself in order to tender the different toll rates. Furthers the heavy vehicle having less acceleration capabilities they required more time to clear the toll booth. Again the large vehicle length require more time to clear the toll booth.



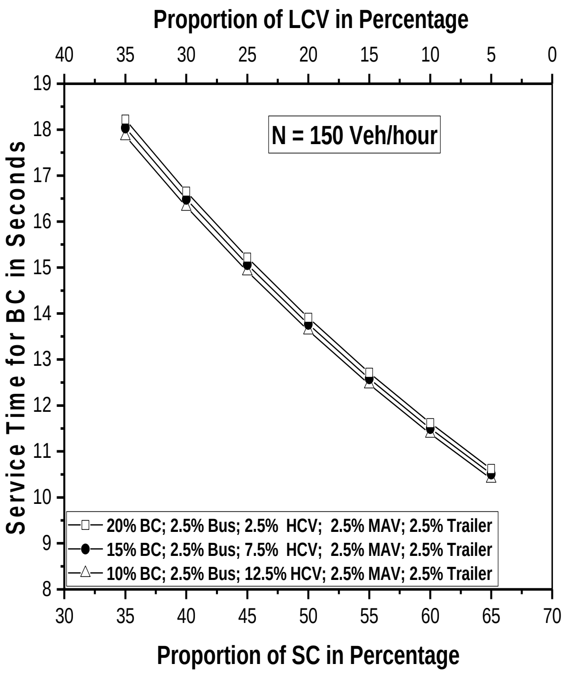
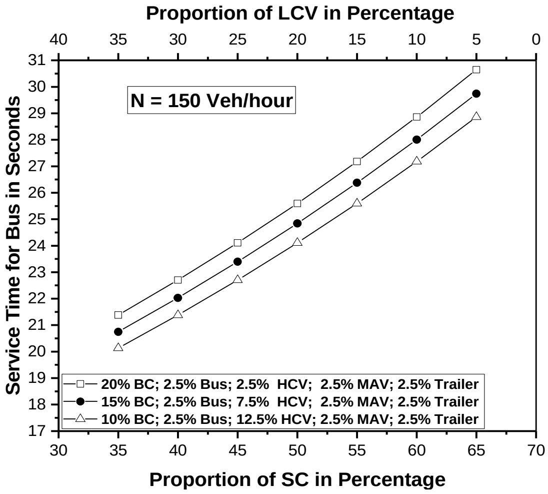


Figure: 6(a) Service Time Variation for SC with Composition Figure: 6(b) Service Time Variation for BC with Composition



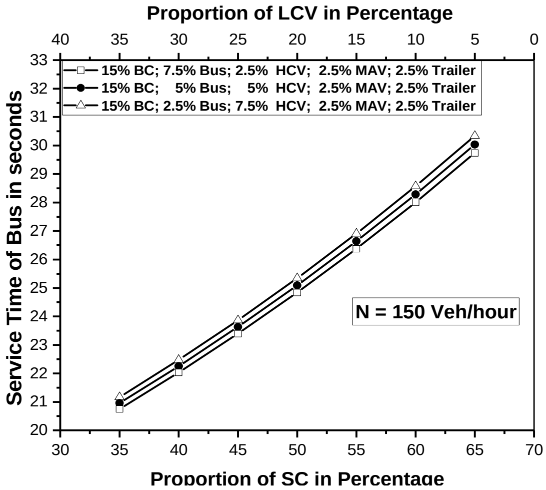
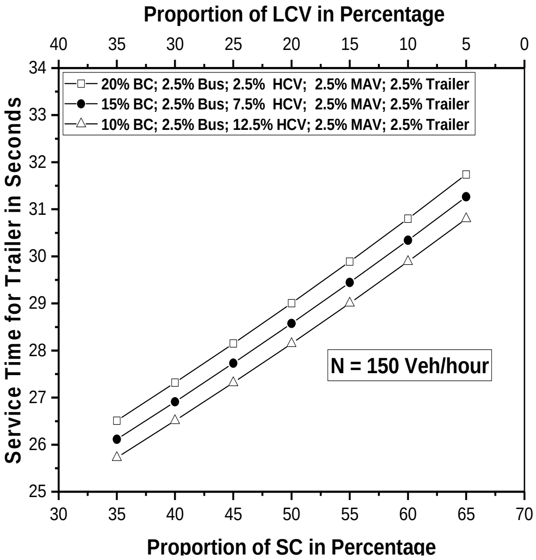


Figure: 6(c) Service Time Variation for Bus with Composition Figure: 6(d) Service Time Variation for Bus withComposition



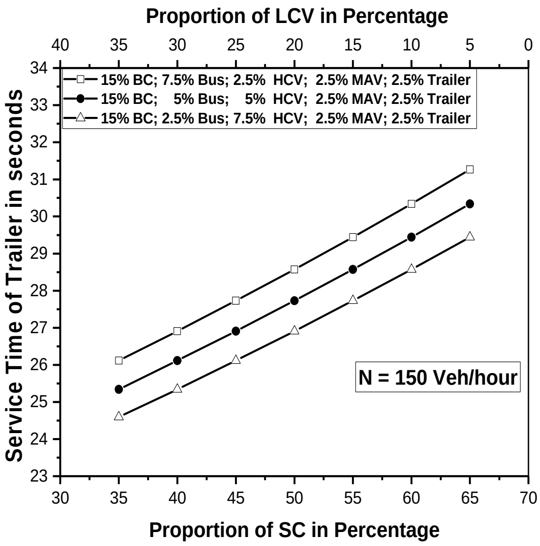


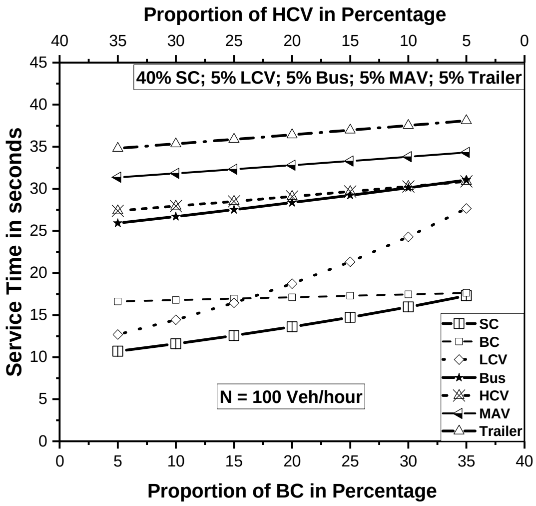
Figure: 6(e) Service Time Variation for Trailer with Volume Figure: 6(f) Service Time Variation for Trailer with Volume

Figure:6 Variation in Service Time with Traffic Composition

6.3 Variation in service time with traffic Volume

Traffic volume observed in field was in the range of 80 veh/hr to 240 veh/hr. Therefore Eq. (2) to (8) were solved for traffic volume 100, 150 and 200 veh/hr. The proportional composition of traffic stream was kept fixed with SC, LCV, Bus, MAV and Trailer as 40%, 5%, 5%, 5%, 5% respectively.

As may be seen from Figure 7, service time reduces for all vehicle categories as flow increases. The proportion of HCV increase in the traffic stream, service time for Bus, HCV, MAV and Trailer reduces. This may explain that the impact of larger sized vehicles such as Bus, HCV, MAV and Trailer on the service time of larger size vehicle is less as compared to smaller sized vehicles such as SC, BC and LCV. Also, as the proportion of BC in the traffic stream reduces, service time for LCV also reduces. This reduction in service time of LCV is steeper, while for all other vehicle classes, this reduction in service time is relatively flatter as shown in Figure 7. As a proportion of BC increases in the traffic, their service time reduces whereas service time for SC increases. Similarly, as the proportion of HCV increases in the traffic stream, service time of larger sized vehicle such as Bus, HCV, MAV and Trailer reduces. This may because a larger sized vehicle take more time to clear toll booth after making payment as compared with smaller sized vehicle. Due to higher clearance time, toll booth operator get the opportunity to adjust himself for the next vehicle. Hence service time is reduced in case of larger sized vehicle followed by larger size vehicles and vice-versa scenario observed in case of the small size vehicle followed by small size vehicle. Similar results are observed from curves also where service time difference between MAV and Trailer is more at lower volume levels, but as volume increases, this difference reduces.



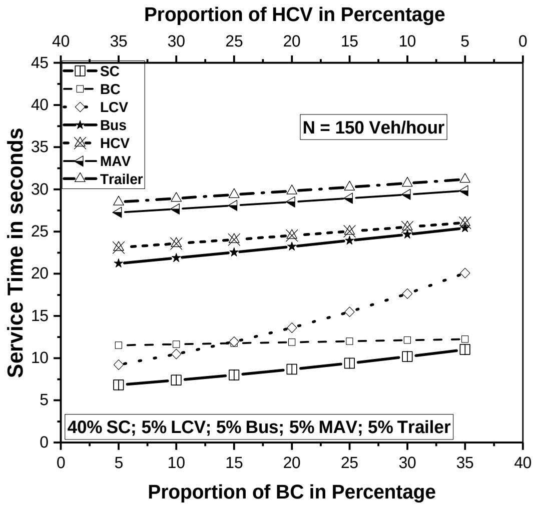
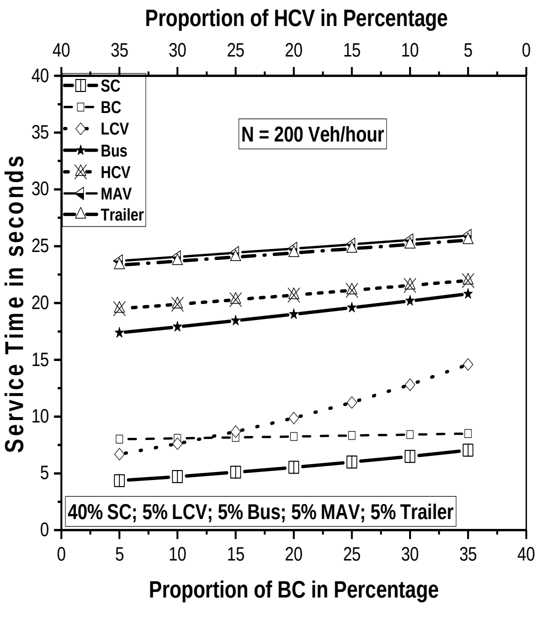


Figure: 7(a). Service Time Variation for volume at 100 Figure: 7(b). Service Time Variation for Volume at 150



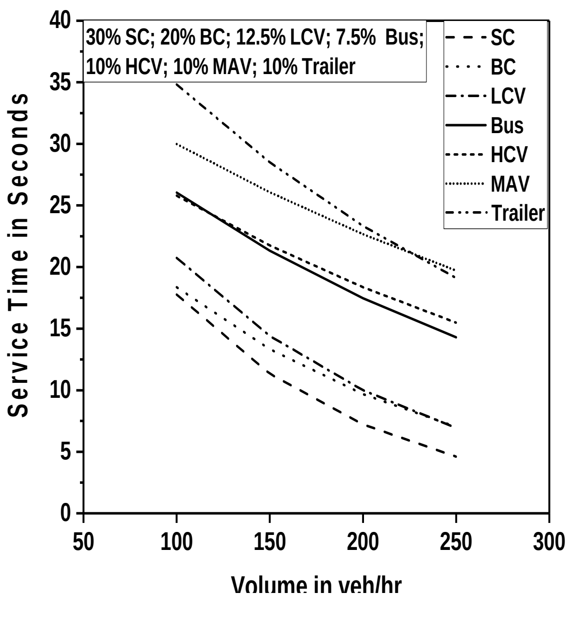


Figure: 7(c) Service Time Variation Volume at 200 Figure: 7(d) Service Time Variation with Different Volume level

Figure: 7 Variation in Service Time with Composition and Volume

Eq.(2) to (8) were solved for traffic volumes of 100, 150, 200 and 250 veh/hr/lane. The proportional composition of traffic stream was kept fixed with SC, BC, LCV, Bus, HCV, MAV and Trailer as 30%, 20%, 12.5%, 7.5%, 10%, 10% and 10% respectively. The curve was generated to show the variation in service time with traffic volume. Figure7 (d) shows such a graph for variation in service time of different types of vehicles with traffic volume at tollbooth.

As may be seen from Figure 7 (d), service time of all vehicle categories decreases with increase in traffic volume. For a particular tollbooth, increase in traffic volume will cause reduction in service time, but the extent of reduction will be different for different type of vehicles. There is a steep reduction in service time of Trailer, MAV, Bus and HCV with increase in traffic volume, whereas TEF of BC and LCV are even flatter.

Although these curves can be developed by solving service time models for every small change in traffic composition and traffic volume, interpretation of this curve will be extremely difficult as all such charts will have the limitation of showing the change in service time of a particular type of vehicle keeping proportion of remaining vehicles unaltered. To circumvent this problem, equations were solved separately for the different range of traffic composition and traffic volume that was observed in the field, and the corresponding service time values were calculated. Table 7 provides the service time for different types of vehicle at different ranges of traffic volume and composition. The service time values are less for smaller sized vehicle and higher for larger vehicles. This may be because of the less toll amount, drivers behavioral attributes and acceleration capabilities in the case of smaller sized vehicle compared to larger sized vehicles. All vehicle category show that an increase in their proportion in the traffic stream results in the reduction of service time for that particular vehicle class, except for HCV and MAV. However, an increase in the traffic volume reduces service time of all vehicle categories. Field observation also shows that when service time reduces, then only volume increases at a particular toll booth. The service time values as given in Table 7 are suggested for use by field engineers and planners.

Table 7: Service Time of Vehicle at Tollbooth

Type of Vehicle	***Percent share of vehicle in traffic stream***	***Traffic Volume (Vehicle/hour/booth)***			
		< 100	***100 to 150***	***150 to 200***	***>200***
		Average service time of a vehicle type			
SC	**< 30**	18.91	12.06	7.69	6.42
	30 to 50	16.44	10.48	6.68	5.58
	50 to 70	14.87	9.48	6.04	5.05
	>70	14.51	9.25	5.90	4.92
BC	**< 5**	20.03	13.90	10.53	6.70
	5 to 15	18.96	13.16	9.13	6.34
	15 to 25	20.95	14.54	10.09	7.01
	>25	21.81	15.14	10.51	7.29
LCV	**< 5**	22.76	16.52	12	8.71
	5 to 10	25.40	18.44	13.39	9.72
	10 to 15	28.07	20.38	14.88	10.75
	>15	14.99	10.88	7.90	5.74
Bus	**< 5**	28.71	23.51	19.24	15.76

	5 to 15	31.26	25.59	20.95	17.15
	15 to 25	30.11	24.65	20.18	18.63
	>25	22.93	18.77	15.37	14.18
HCV	**< 5**	26.04	21.97	18.54	17.32
	5 to 15	25.72	21.70	18.31	17.10
	15 to 25	23.10	19.49	16.44	15.36
	>25	24.16	20.38	17.20	16.07
MAV	**< 5**	28.10	24.43	19.22	20.08
	5 to 15	29.61	25.74	22.38	21.16
	15 to 25	29.40	25.55	22.22	21.01
	>25	33.47	29.10	25.29	23.92
Trailer	**< 5**	35.16	28.78	23.57	21.75
	5 to 15	34.29	28.07	22.98	21.22
	15 to 25	31.65	25.91	21.22	19.58
	>25	30.41	24.90	20.38	18.82

7. Validation of Estimated Service Time Values

In order to check the accuracy of service time prediction models developed in this study, the field data kept aside for model validation is used to compare with model predicted values. The service time for different categories of vehicles are estimated using field observed traffic proportion using the developed models given in Eq. (2) to (8). The service time of different vehicle class observed from field is compared with the model predicted values. Further a paired t-test was conducted as a measure of statistical validation between observed service time and predicted service time. It is found that the value of t-statistics, calculated based on observed data is (to) is 0.53. The critical value of t-statistics, for 5 percent significance level at 69 degree of freedom, obtained from standard t-distribution is 1.99. Hence there is no significant difference between observed and predicted value. The predicted service time are plotted against the observed service time of individual vehicles in Figure 8. It can be seen that service time values of different categories of vehicles truly lie on a 45 degree line and hence there is a good fit between two sets of service time values.

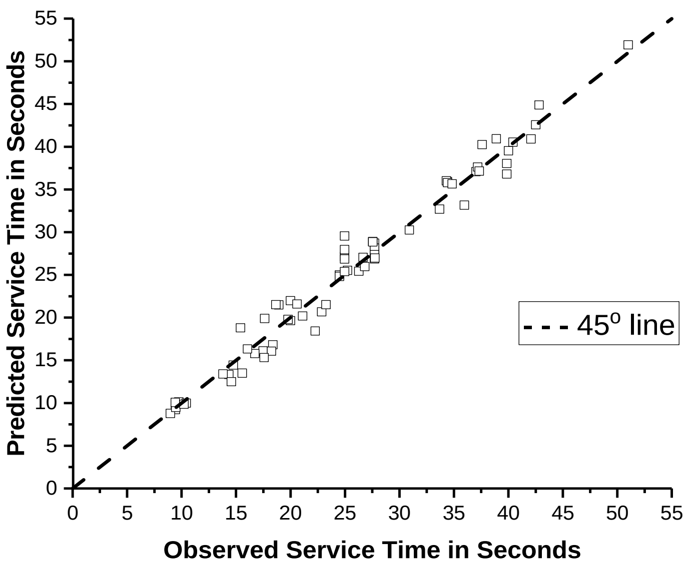


Figure:8 Observed and Predicted Service Time Comparison

8. Conclusion

The present study proposed service time prediction model may be used to predict service time of individual category of vehicle to study the various heterogeneous traffic scenarios that occur at toll booths. In the present work, the model was used to check the sensitivity of service time with traffic compositions and volume. Various traffic scenarios are generated and variation in service time of individual vehicle is presented graphically. The service time of a vehicle is influenced by both traffic composition and volume at toll booth. Models are developed to relate service time with traffic volume and its composition. These models are then solved for varying composition of the traffic stream at fixed values of traffic volume and for varying volume level at fixed traffic composition. The variation in service time for different types of vehicle is demonstrated graphically with traffic volume and traffic composition. It is observed that service time of a vehicle type decreases with increase in traffic volume. It may be due to the increase in queue length built up pressure on the toll booth operator to make faster transactions. Increase in the number of larger sized vehicle such as Bus, HCV and MAV in traffic stream decreases the service time for larger sized vehicle. This may be because of the additional clearance time required for larger vehicle and due to this toll booth operator get time to adjust himself for the next vehicle. As the proportion of SC in traffic stream increases, service time for smaller size vehicle reduces, whereas it increases for larger size vehicle.

Accuracy of the proposed model is checked by comparing the field data kept aside for model validation with service time obtained from equations. The two sets of service time values are found to be quite similar. The t-test also indicated there was no significant differences between predicted and observed service time values.

The present study provides a methodology for estimation of service time. Service time of individual type of vehicle can be estimated from the equations developed in present work. Traffic volume and its compositions vary widely on different toll booth and therefore, the equations are expected to be quite general in nature and can be used to derive service time of different categories of vehicles. However, these equations are applicable to traffic situation with vehicle categories as observed in these toll plazas only. Another contribution of this research is proposed dynamic service time values for different volume and traffic composition. These can be readily used by field engineers and planners for the design and management of toll plazas. It will reduce time and cost incurred in collecting field data required for the planning of the toll plaza and to check the efficiency of toll booths.

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