Effectiveness of FASTag System for Toll Payment in India

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Abstract— Introduction of electronic toll collection (ETC) system, commonly called FASTag in India, aims to decrease service time, delay, and vehicular emissions. The present study attempted to evaluate the success of FASTag over manual toll collection (MTC) under mixed lane traffic while considering service time as a measure of effectiveness. The results showed that the service time for FASTag lane varies from 0.12 second (s) to 13.12 s while for MTC lane 2.36 s to 45.36 s. It is also observed that there is significant difference in service time with vehicle class in case of MTC and FASTag lane. Service time is minimum for a small car (SC) and maximum for the trailer when the vehicle passes through MTC lane. Further, the study revealed that with the use of FASTag lane, the average service time decreases by 77 percent. This ultimately reveals that a reduction in service time increases the throughput. The average increase in capacity is observed as about by 318 percent due to FASTag implementation. Further, the service time-based tollbooth equivalency factors (STEF) are developed in the present study for the conversion of the different vehicle class into a standard vehicle, i.e., standard car. The STEF value ranges between 0.89 and 1.43 for the MTC lane and from 0.78 to 1.06 for the FASTag lane. Thus, the present study output will be used to check the capacity, level-of-service and pollution level at toll plazas due to implementation of FASTag system.

Keywords— Toll plaza, FASTag, MTC, Service time

I. Introduction

India, being a developing nation, started projects under a public-private partnership (PPP) basis for highways development. Till December 2019, Manual Toll Collection (MTC) prevails for toll tax collection [1, 2]. But after December 2019, Electronic Toll Collection (ETC) system, commonly known as FASTag, becomes mandatory for payment of toll on National Highways (NH's) [3]. Only a single lane on each side is kept as an MTC lane. FASTag is a chip fitted on the vehicle that enables automatic deduction of the toll amount when the vehicle passes the zone of Radio Frequency Identification (RFID) located in the FASTag lane. FASTag has benefits to reduce travel time, delay, and vehicular emission. FASTag is a subsystem of intelligent transport systems (ITS) which is widely used in other nations like the United States, Europe, China, etc.

The most important aspect of the delay while the MTC lane is used is due to service time. Service time or transaction time is the time required for toll transactions, started when the vehicle arrives at the toll window and ends when it accelerates after paying the toll[1, 4]. The service time depends on various factors such as vehicle class, tollbooth operators and drivers behavior, leader-follower pair, the composition of traffic [1, 5–8] in terms of MTC lane (Fig. 1(a) shows the manual toll transaction).

(a)

(b)

Fig. 1. (a) MTC toll collection (b) RFID reader

But in the ETC system, the service time decreases and remains the same for most of the vehicle, which directly increases tollbooth capacity and thus throughput. Indian Roads Congress (IRC): SP: 84 [9] specifies the capacity of 1200 vehicles/hour through the ETC lane. The FASTag system is new in India, and hence its penetration rate is still very low. The FASTag system is in the preliminary stage, thus not yet fully developed. As in developed countries, the ETC vehicles move with constant speed from the ETC lane without halt [10], which is not India's case. The vehicle has to stop or take some time to scan the tag for toll deduction. Thus, the service time for the ETC system (FASTag) is defined as the time from when the vehicle enters the charging area until the boom opens (end of the transaction) [11]. This service time directly affects the capacity and also the traffic flow from FASTag lanes. Fig. 1 (b) shows the RFID scanner used for FASTag transactions. Thus, the present study aims to study the service time characteristics of the FASTag lanes under mixed traffic conditions. Moreover, the other objective is to compare the service time of the manual and FASTag lane.

II. Literature Review

The studies related to the ETC system and service time were reviewed, and some of them are discussed here. Edie [12] studied the delay at the toll plaza and found that the service time and backup affect the delay. Also, service time was found to be dependent on traffic volume and its composition, number of tollbooths, and tollbooth operator's behavior. Lennon [13] evaluated the electronic toll collection system (E-Z Pass) at the Tappan Zee Bridge in New York. The author observed that the ETC lanes (E-Z lanes) had a volume of 1,000 vehicles/hour compared to 450 vehicles/hour for other lanes. Lam [14] investigated the ETC system in Hong Kong and found that with the provision of an ETC lane (with dedicated AVI lane), the capacity increases 100 % (600 vehicles/hour to 1,200 vehicles/hour) as compared to a manual toll lane. An express AVI lane's capacity was 1,800 vehicles/hour, mixed AVI lane was 500 vehicles/hour, and the manual lane was 400 vehicles/hour. Al-Deek et al. [15] studied the improvements in traffic operations at the electronic toll collection plazas of the Orlando-Orange County Expressway Authority. The findings indicate that, for the dedicated E-PASS lane, the measured capacity has tripled, the service time has decreased by five seconds per vehicle. IRC [16] gives the service time as 10 seconds (s) irrespective of vehicle class. Jun-long [11] analyzed the ETC traffic flow and their characteristics and developed the different service level criteria based on the delay of ETC vehicles. Navandar et al. [4] found that the service time as the variable entity and thus developed a new factor called as Tollbooth Equivalency Factor (TEF) depending upon service time and clearance time. Similarly, service time prediction models were developed depending upon the traffic composition [2, 17].

From the above literature survey, it is found that the various studies were carried out on service time and capacity for both MTC and ETC but in developed countries and homogeneous conditions. Further, the IRC suggests the capacity and service time irrespective of the vehicle category. As the FASTag is implemented from the last eight months, the effectiveness of the FASTag system over the MTC system is not evaluated. Hence, the objective of the present study is oriented towards the evaluation of the vehicle category wise service time of both MTC and FASTag lane and thus compare the difference in both of them. Further, the capacity estimation and development of vehicle equivalency factor is carried out.

III. Methodology

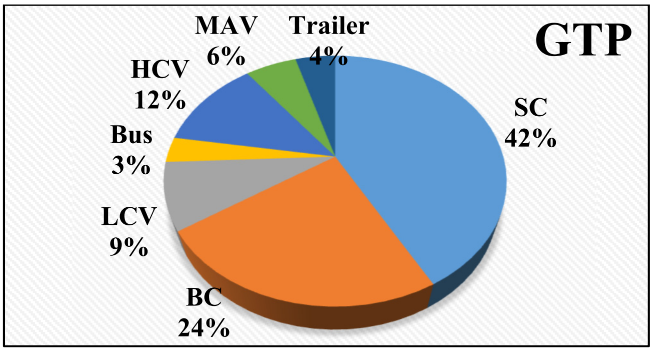
Traffic data were collected using videographic surveys at three toll plazas in India, namely, Ghoti Toll Plaza(GTP), Bokarwadi Toll Plaza(BTP), and Kambrej Toll Plaza(KATP). GTP is located near Nashik on National Highway (NH- 53), which connects Mumbai region. BTP is located near Aurangabad, Maharashtra on NH-222, and KATP is located near Surat, Gujarat. GTP is located in a rural region, and the other two are located in urban areas. The different toll plaza locations were taken to capture the diversity in traffic and humans' behavior. The videographic data were collected during January – March 2020. These months are intentionally taken as the FASTag was made mandatory in January 2020 for toll transactions on NHs in India.

Data were extracted for the service time for FASTag and MTC lane using AVIDEMUX software. The different locations were taken to capture the diversity in traffic characteristics. The data was extracted for seven vehicle categories as a small car (SC), big car (BC), light commercial vehicle (LCV), Bus, heavy commercial vehicle (HCV), multi-axle vehicle (MAV), and Trailer [4]. The average horizontal projected length for all vehicle class observed on the field was 3.72 m, 4.58 m, 5.00 m, 10.30 m, 7.20 m, 11.70 m, 15.60 m for SC, BC, LCV, Bus, HCV, MAV, and Trailer, respectively. Here small car includes all hatchback and sedan cars with engine capacity less than 1400 cc. and their average length is reported. The data was then analyzed using the statistical analysis for service time according to the vehicle class wise. Finally, the comparison is being made for the service time between the two methods.

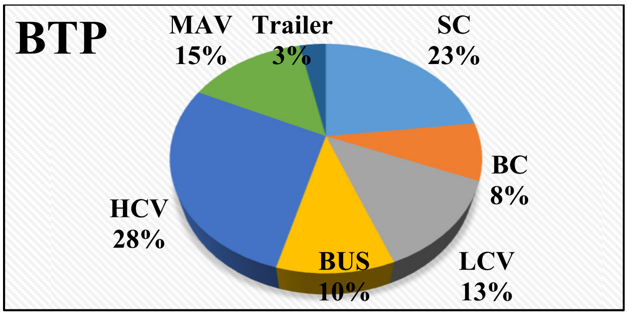
IV. Results

A. Traffic Composition

Fig. 2 shows the traffic composition for all three toll plazas. The results show that BTP has maximum HCV composition with 28% followed by SC 23% in traffic, while at DTP traffic consist most of SC with a percentage of 27%. Thus, the traffic variation is captured, and for generalized results, the data were combined for service time of both toll plazas for FASTag lane and MTC lane. The proportion of SC and BC together is up to 66% at the GTP. Traffic at KATP has mostly heavy vehicles, as this plaza is located on NH connecting Mumbai and Ahmedabad. As may be seen, a reasonable variation exists in traffic conditions at three toll plazas.



(a)



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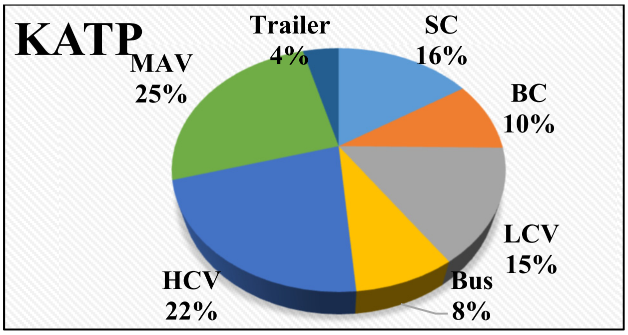


(c)

Fig. 2. Traffic Composition (a) GTP (b) BTP (c) KATP

B. Service time analysis for Manual lane

The actual time taken for toll transactions is considered as the service time, which is recorded from videographic data. Table I shows the descriptive statistics of service time for all data combined from three locations considering each class of the vehicle distinctly. The maximum sample size is for SC (641), and the minimum is for Trailers (63). SC's service time varies from 2.36s to 34.32s, and that for the trailer varies from 13.00s to 45.76s. This large variation in service time within the different vehicle classes is due to the traffic composition, vehicle type, leader-follower combination, drivers' and tollbooth attendant behavior [4, 17]. The maximum service time is observed for trailer because of the drivers' seat height, driver behavior, and acceleration characteristics of the trailer [1]. The driver's seat height for SC is at the tollbooth level, which helps in the easy transaction of toll and receipt, but for heavy vehicles such as Bus, MAV, HCV, and Trailer, the driver's seat is much above the tollbooth operator's window. It increases the service time required for these vehicles in the MTC lane.

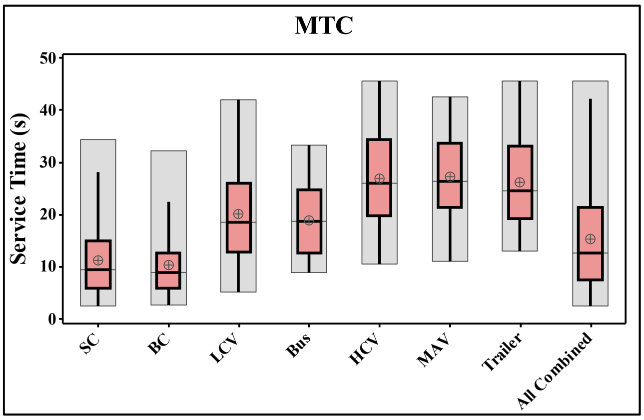


Fig. 3. Box plot of service time for MTC lane

TABLE I. DESCRIPTIVE STATISTICS OF SERVICE TIME FOR MANUAL LANE

Vehicle Class	Sample Size	Minimum (s)	Maximum (s)	15th Percentile (s)	50th Percentile (s)	85th Percentile (s)	Standard Deviation (s)
SC	641	2.36	34.32	4.68	9.36	18.20	6.61
BC	359	2.48	32.24	4.68	8.80	16.12	6.26
LCV	120	5.04	42.12	10.92	18.46	30.68	9.42
Bus	44	8.84	33.28	10.67	18.72	27.18	6.90
HCV	173	10.40	45.76	17.16	26.00	36.92	8.92
MAV	74	10.92	42.64	18.68	26.26	37.14	8.14
Trailer	63	13.00	45.76	18.2	24.48	38.22	8.83
All Combined	1474	2.36	45.76	5.72	12.48	26.00	9.86

Further, one-way analysis of variance test (ANOVA) is carried out to check whether the service time values are statistically significant within the different classes. For the ANOVA test, the null hypothesis (H_0) is assumed that the means of the service time of the different classes of vehicles is the same. The alternate hypothesis (H_1) is assumed that the mean service times of different vehicle classes are different. The test is carried at a 5 % level of significance. The results showed that the F-value (205.45) is higher than the F-critical value (2.10), which means the service time values are statistically different, and the null hypothesis is rejected.

Fig.3 shows the box plot for service time variation of MTC for each class of vehicle. Further, it is observed that the CDF of each vehicle class for the MTC lane is very steep, showing less variation in service time. This variation may be due to the variation in drivers' and tollbooth operator's behavior, toll rate, and traffic composition at a particular location.

C. Service time analysis for FASTag lane

The service time for the ETC system (FASTag) is defined as the time from when the vehicle enters the charging area until the boom opens (end of the transaction)[11]. Table II shows the descriptive statistics of service time for the FASTag lane. Most of the HCVs (281) and MAVs (241) are equipped with FASTag and are using the FASTag lane. The results show that the service time is minimum for LCV (0.12s) and maximum for HCV (13.12s). The large variation in service time is due to the very recent introduction of this technology on Indian Highways, and drivers are not familiar with the system. The 15^{th} percentile value of service time for HCV is 1.44s, which is the lowest among all vehicle classes. The average service time value is the lowest for the Bus category. Lower service time for large-sized vehicles is due to the RFID reader's height, which is very suitable for reading the FASTag of these vehicles such as Bus, HCV, MAVs, and Trailers. Further, the maximum service time is observed for

HCVs, because most of the time, due to the wrong placement of the tag on the vehicle window screen or dirty screen (screen having dust), the tag is not appropriately read by the scanner. Most of the time, it was observed in the field that an extra attendant is required to scan the tag of these vehicles, which increases the service time (Fig. 4).

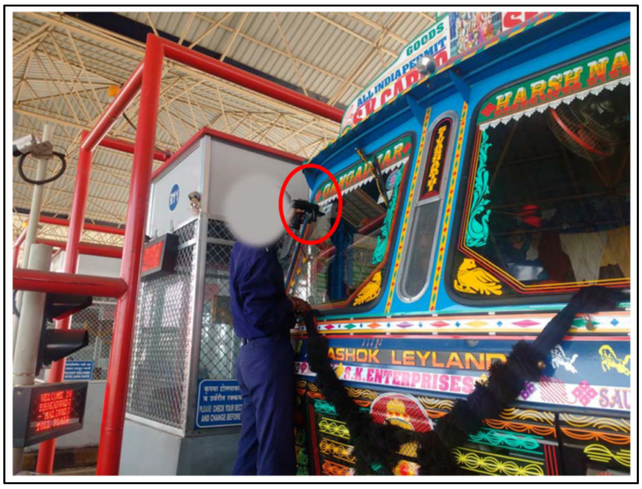


Fig. 4. Scanning of FASTag by an attendant at a toll plaza

TABLE II. DESCRIPTIVE STATISTICS OF SERVICE TIME FOR FASTag LANE

Vehicle Class	Sample Size	Minimum (s)	Maximum (s)	15th Percentile (s)	50th Percentile (s)	85th Percentile (s)	Standard Deviation (s)
SC	198	0.76	11.20	1.56	3.04	6.58	2.36
BC	94	0.84	8.08	1.56	2.66	5.21	1.68
LCV	166	0.12	12.60	1.52	2.82	7.00	2.96
Bus	111	0.52	8.32	1.52	2.56	5.14	1.83
HCV	281	0.28	13.12	1.44	2.80	6.64	2.88
MAV	248	0.52	11.88	1.56	2.86	6.03	2.38
Trailer	42	1.04	11.96	1.88	3.94	7.00	2.53
All Combined	1140	0.12	13.12	1.56	2.84	6.21	2.53

Further, one-way analysis of variance test (ANOVA) is carried out to check whether the service time values are statistically significant within the different classes. For the ANOVA test, the null hypothesis (H_0) is assumed that the means of the service time of the different classes of vehicles is the same. The alternate hypothesis (H_1) is assumed that the mean service times of different vehicle classes are different. The test is carried at a 5 % level of significance. The results showed that the F-value (2.56) is higher than the F-critical value (2.10), which means the service time values are statistically different, and the null hypothesis is rejected.

Fig. 5 shows the box plots of service time for different vehicle classes in the FASTag lane. The box plots show that the variation of service time is lower for Bus as compared to other types of vehicles, but the minimum for LCV followed by HCV. Table II and Fig. 5 show that 15th, 50^{th,} and 85th percentile service time for all combined data is 1.56s, 2.84s, and 6.21s, respectively.

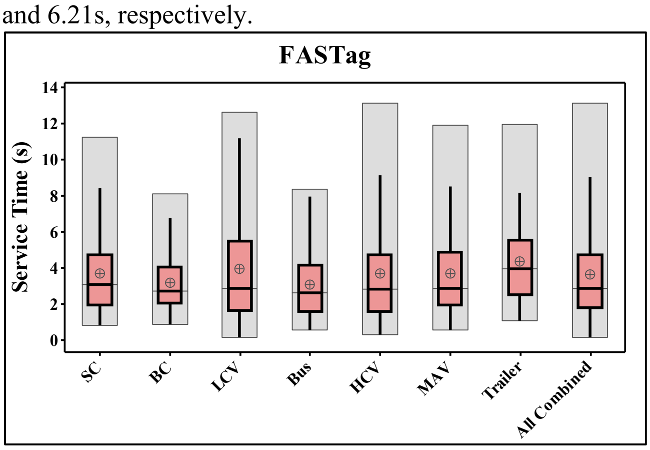
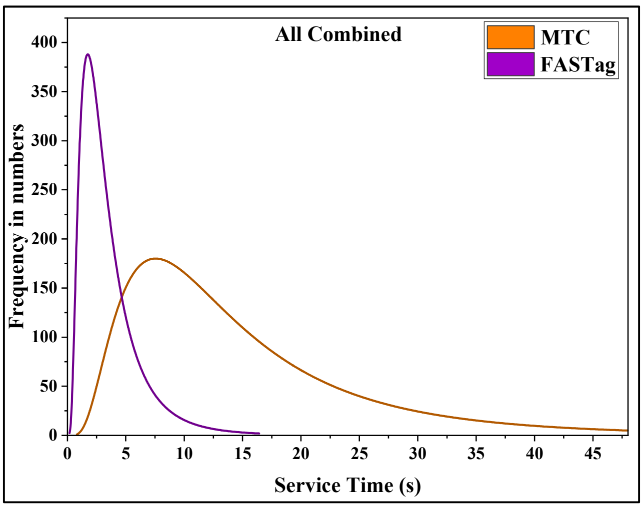


Fig. 5. Box plot of service time for FASTag

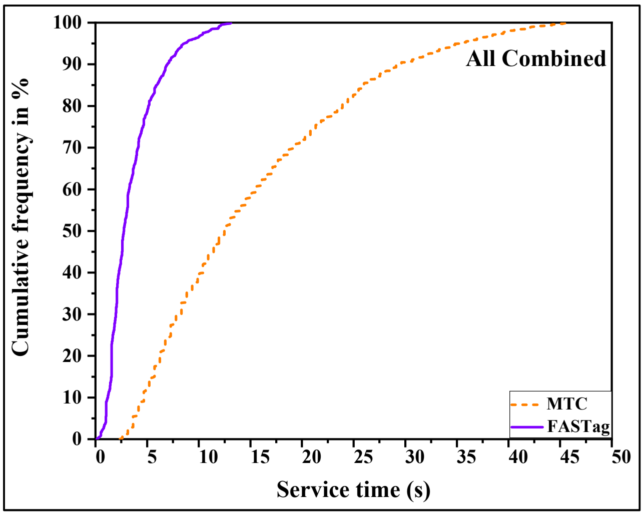
Thus, the service time required for a vehicle in the FASTag lane depends upon the RFID scanner's response, which is affected by the location of FASTag on the screen of the vehicle. The tollbooth operators and drivers' behavior do not matter here.

D. Comparison of service time for MTC and FASTag lane

For comparing the service time required for vehicles to pass from the MTC lane and FASTag lane, the probability density function (PDF) and CDF were plotted for all combined data. The combined data gives the actual picture of the mixed traffic condition observed in the field. Fig. 6 shows the PDF and CDF for comparison of service time between the two lanes.



(a)



(b)
Fig. 6. Comparison of service time for FASTag and MTC lane

As may be seen, the MTC lane service time graph is ahead of the FASTag lane service time graph. It means the average service time for the MTC lane is more than that of the FASTag lane. The service time for the FASTag lane varies from 0.12s to 13.12s, while for the MTC lane, it varies between 2.36s and 45.76s. The mean service time for the FASTag lane is 2.84s, while for the MTC lane, it is 12.48 s, which shows the reduction of service time by 77 percent for the FASTag lane. Considering different vehicle classes, the service time shows a drastic reduction for heavy vehicles (Table I and Table II). The reduction of the 50th percentile service time is maximum for HCV (89 percent). While MAV shows the maximum reduction of 83 percent in 85th percentile service time. Moreover, the maximum service time decreases from 45.76s to 13.12s. Compared with the literature values [5, 17–19], the service time for both MTC and FASTag lane was higher in the present study. These variations may be attributed to the diverse vehicle categories present in Indian and the mixed traffic conditions present in the dedicated lanes. The secondary factors affecting service time are toll rates, the drivers' and tollbooth operators' behavior.

Reduction in service time means there will be an increase in the throughput from the FASTag lane. For the service capacity estimation, equation (1) is used.

$$\text{Service Capacity} = \frac{3600}{Service\ time} \quad (1)$$

Table III illustrates the estimated service capacity for both the lanes using 85th percentile service time. Here, 85th percentile service time is taken to cater to the 85 percent of the users' service time. The results show that the capacity ranges between 94 and 223 vehicles per hour (vph) for the MTC lane, and for the FASTag lane, it varies from 515 to 700 vph. Further, for all combined data, i.e., representation of the mixed traffic conditions, the capacity obtained for the MTC lane is 138 vph and for the FASTag lane as 580vph. Thus, it shows that the capacity increases due to the implementation of the FASTag. In comparison with the IRC [9], the capacity for both the lane, i.e., MTC and FASTag lane, was found to be lower by 26% and 48%, respectively. On average, the service capacity was enhanced by 318 percent due to FASTag use.

TABLE III. CAPACITY CALCULATION FOR MTC AND FASTag LANE

Vehicle Class	MTC		FASTag		Toll Equivalency Factor		% Increase in Capacity due to implantation of FASTag
	Service time (s)	Capacity (vph)	Service time (s)	Capacity (vph)	MTC	FASTag	
SC	18.20	198	6.58	547	1.00	1.00	176.43
BC	16.12	223	5.21	692	0.89	0.79	209.64
LCV	30.68	117	7.00	514	1.69	1.06	338.29
Bus	27.18	132	5.14	700	1.49	0.78	428.79
HCV	36.92	98	6.64	542	2.03	1.01	456.02
MAV	37.14	97	6.03	597	2.04	0.92	515.45
Trailer	38.22	94	7.00	515	2.10	1.06	446.31
All Combined	26.00	138	6.21	580	1.43	0.94	318.95

Further, in the present study, the Service time-based Toll Equivalency Factors (STEF) are developed in line with the Woo and Hoel [18] for mixed traffic conditions. The STEF is calculated as the ratio of service time of the ith category of vehicle to the service time of the small car. The STEF found to vary between 0.89 and 1.43 for the MTC lane, with a minimum for BC and maximum for the trailer. On the other hand, the STEF ranges from 0.78 to 1.06 for the FASTag lane. The variation in the STEF factor is due to the service time variation. Also, as discussed in the above section, the FASTag service time is lower than the MTC lane, the STEF factors are lower for the FASTag lane. These factors will be used for converting the vehicles into the equivalent unit for capacity estimation. In comparison with Woo and Hoel [18], the STEF factors developed in the present study are found to be lower. These can be correlated with the traffic conditions considered for both the studies. The study carried by Woo and Hoel [18] in 1991 was carried in homogeneous conditions with traffic consisting of only car and truck. But, in the present study, seven different vehicle classes are considered, and also the mixed nature is observed in the dedicated lane, which was not in the case of Woo and Hoel [18]. Thus, the developed factors can be used for calculations of capacity in mixed traffic conditions.

V. Conclusion

The present study was carried out for service time comparison between the manual lane and FASTag lane in order to access the effectiveness of newly adopted FASTag system in India. The service time is a key performance parameter for toll plaza. The videographic data were collected at three different toll plazas in India's western part to capture diversity in traffic characteristics. The study shows that the number of factors such as toll rate, vehicle class, traffic composition, etc. are influencing the service time in the MTC lane case is reduced in the case of the FASTag lane; hence, it reduces the service time. Further, the average 50th percentile service time for FASTag lane was minimum for Bus 2.56 s and maximum for Trailer 3.94 s. It purely depends upon the RFID scanner's response, which gets affected by the location of FASTag on the screen of vehicles. 50th percentile service time for MTC lane is minimum for BC 8.80 s and maximum for MAV 26.26 s. This shows that the service time increases with an increase in vehicle length. Service time for MTC lane is affected by a number of factors such as drivers' seat height, toll rate, vehicle class, drivers, and tollbooth operators' behavior. Finally, the comparative analysis between the FASTag lane and MTC lane is carried out. The results showed a reduction of service time of 77 percent due to the FASTag system's implementation.

The service capacity is found to be enhanced by 318 percent due to FASTag implementation. Further, the service time-based toll equivalency factors are developed in the present study to convert the vehicles into a common unit. The STEF value ranges between 0.89 and 1.43 for the MTC lane and from 0.78 to 1.06 for the FASTag lane.

The present study will be used to calculate the capacity of different toll lanes, which is an essential parameter for designers to design the number of toll lanes required at toll plazas. Further, it will be used for estimation of the level of service and thus change in emission level at toll plazas.

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