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A Systematic Review on Traffic Operations at Mainline Toll plazas

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ABSTRACT

Most of the projects across the world are built under the public-private partnership (PPP) module. In the highway sector, the highway projects are built by the concessioner, and in lieu of that, he generates revenue by collecting toll from road users. The toll plazas are built across the highways, which act as a bottleneck in highway facilities to collect tolls. Although the toll collection system has been improved over the period worldwide, the users are still experiencing an enormous delay at toll plazas that causes congestion, especially in developing countries like India. This congestion is caused due to various factors such as long service time, an inadequate number of windows, traffic volume, categories of toll rates, etc., which lead to delay, degradation of capacity, and level of service (LOS). All these factors have been analyzed by different researchers in their countries. The present paper gives a detailed literature review summarizing these studies on the different parameters related to toll plazas and proposes research gaps, from the perspective of developing countries. The challenges and methodology for evaluating various parameters are also discussed, and a way forward for future research is suggested.

Keywords: Toll Plaza; Toll Collection; Mixed traffic; capacity; level of service (LOS)

1 INTRODUCTION

Understanding traffic characteristics at toll plazas has a long historical perspective since the early 1950s. Many researchers have focused on the evaluation of various parameters affecting toll plaza performance, capacity, and Level of Service(LOS) during the last seven decades. The capacity of a section is the key term in the planning and designing of any traffic facility. It also acts as a tool to evaluate the operational conditions for the same facility. The main design element of a toll plaza is the number of toll lanes, which indirectly depends on the capacity analysis. Hence, the capacity aspect plays a vital role at the tollbooth as it provides the basis for deciding the number of toll lanes required during peak and off-peak hours to cater to the approach traffic volume at the toll plaza. Traffic in India and other developing countries is mixed in nature, and the same mixed traffic behavior is observed at toll plazas (here in the present study, the mixed traffic is devoted to the use of the same dedicated lane by various vehicle classes, causing the presence of mixed vehicle nature in a particular toll lane). The mixed nature of traffic affects toll plaza operations in terms of an increase in service time, and subsequently, users' waiting time in queue increases which ultimately leads to a decrease in toll plaza capacity[1–3]. The design guidelines for midblock sections, highways, intersections, pavements and traffic analysis are given properly and are followed for uniformity throughout the nation[4–6]. But the toll plazas are still designed as per the previous experience of the designer or a consultant. Therefore, design criteria for toll plazas vary from agency to agency. Further, due to mixed traffic conditions in toll lanes, the number of vehicles passing through a tollbooth in terms of vehicles/hour will not give the proper insight to field engineers on the operating efficiency of toll lanes to satisfy the approaching traffic demand. Hence, the concept of equivalency factors in the line of Passenger Car Units (PCU) for highways and intersections, is an important aspect to convert a mixed traffic flow into the homogenous equivalent.

The LOS is a quality measure that describes the performance state of traffic flow. These conditions are converted into operational parameters directly related to the user's perception of comfort and convenience when traveling through different traffic scenarios[7]. As there was no explicit procedure available for evaluating LOS at toll plazas, many researchers attempted to study LOS at toll plazas over the last few decades under various conditions in different parts of the world. But, due to the consideration of different measures of effectiveness such as volume to capacity (v/c) ratio[8,9], service time[10], delay[11], etc., the scales of levels of service for representing the performance of the toll plazas also depict a wide variation. Hence, capacity, equivalency factors, and LOS are the three important parameters considered in the present review paper.

This paper aims to present the current state of the art on the traffic flow characteristics at toll plazas and thus to identify the crucial gaps experienced by various researchers across the world that need to be explored further. The present study will provide the background for analyzing the traffic operations at toll plazas in both developed and developing countries based on available literature. Also, it will act as the framework for the researchers to focus on the critical gaps.

For better appreciation of the discussion in the paper, the terms related to toll plazas need to be explained and understood.

(1) Throughput: It is defined as the number of vehicles passing over a short period (usually for one hour) through the toll plaza[12].

(2) Service time: Service time is defined as the exact time required by a vehicle to pay the toll at the tollbooth, excluding the waiting time in queue[3,12].

(3) Service headway: Time difference of exit of two consecutive reference points in the same toll lane is called a service headway. This implies that headway at toll plaza includes inter-arrival and service times for a given vehicle[13].

(4) Clearance time: Time taken by the follower vehicle in the queue, to arrive at the tollbooth after the leader vehicle completes its transaction procedure and exits[14,15].

(5) Waiting time in the queue: The time difference between the instants when a vehicle joins the queue and enters the system for paying the toll fee[16].

2 METHODOLOGY

Kitchenham[17] defines a systematic literature review as "a means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest." The present study adopts the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) methodology for the systematic review. PRISMA is a set of reporting guidelines consisting checklist of twenty-seven items[18]. It was developed by the 29 review authors in 2009[19]. The PRISMA methodology was updated in 2020[20] and is used in the present study.

2.1 Information sources

As per the author's search, no literature review paper was available on the present topic, and hence the present study is not an advancement; instead, it will act as a base review paper in the field of toll plaza traffic operations. The articles from the peer-reviewed database such as Scopus, Transport Research International Documentation (TRID), Web of Science (WOS), and ScienceDirect were considered only to ensure the highest quality of research findings for incorporating in the present review. All the datasets were obtained in the Research Information Systems (.ris) format.

The initial search was conducted for the data up to November 2021. The data from 1954 to 2021 was retracted from different sources, and the inclusion and exclusion at each stage were carried out with the help of the EXCEL spreadsheet. For the initial data search, different key terms such as "toll plaza," "toll plazas," "capacity," "level of service" were used. The search was carried out with the use of different Boolean operators such as "toll plaza" OR "toll plazas," "toll plaza" OR "toll plazas" AND "capacity," "toll plaza" OR "toll plazas" AND "level of service" and "toll plazas" AND "level of service" AND "capacity" were used. The search keyword is applied only for TITLE, ABSTRACT, and KEYWORDS. These searches resulted in 1093, 370, 617, and 50 articles from Scopus, WOS, TRID, and ScienceDirect, respectively.

2.2 Screening Phase (Inclusion and Exclusion of the articles)

The main aim of the study is more focused towards the engineering point of view, and hence the first filter of exclusion, i.e., articles published in the medical sciences, radiology, etc., were excluded. No year filter was applied as a first of its kind review paper on toll plaza operations. Further, the second criterion for inclusion filter was applied, and thus the research articles, conference proceedings, and book chapters were included in the present study. Only the "ENGLISH" language documents were included. Finally, the studies relevant to the capacity and LOS were screened from the remaining articles using the Boolean operators.

2.3 Eligibility and exclusion of duplicate articles

Before the eligibility process, duplicate articles were removed using the spreadsheet. After removing the duplicates from all datasets, a total of 610 documents remained. Next to the eligible articles, the documents with full-text access were considered only. Then after, the manual screening of each document leads to the final documentation of about 59 articles. Additionally, the 15 articles were added carried out by bibliographic search that mostly includes the National Cooperative Highway Research Program (NCHRP) reports, Indian Roads

Congress (IRC) Codes, etc., on toll plaza operations. Finally, a total of 74 articles were considered for the analysis.

3 RESULTS

About 74 studies considered in the present review were published from 1954 to 2021, dealing with the capacity and LOS related parameters on toll plazas. Considering the variability in the traffic conditions, about 52% of studies were carried out in the homogeneous traffic conditions mostly observed in the developed countries, while only 34% of the studies were focused on the mixed traffic issues.

The research on toll plaza operations started long back in 1954, with the first classical paper by Edie on manual toll operations. With motivation from this paper, various research was started in developed countries, but the research rate as observed from publications was very mere till 1996 (less than 10 percentile). Consequently, the researchers started to explore the benefits of electronic toll over manual toll, and hence the number of publications was seen to be a little higher till 2011. Later on, again, an increasing trend in research mostly for mixed traffic conditions is seen from the year 2018 to 2021 (30 percentile of the papers were published in these years). **Fig. 1** shows the cluster graph for the distribution of research for different countries around the globe, with the year, developed using VOSviewer software[21].

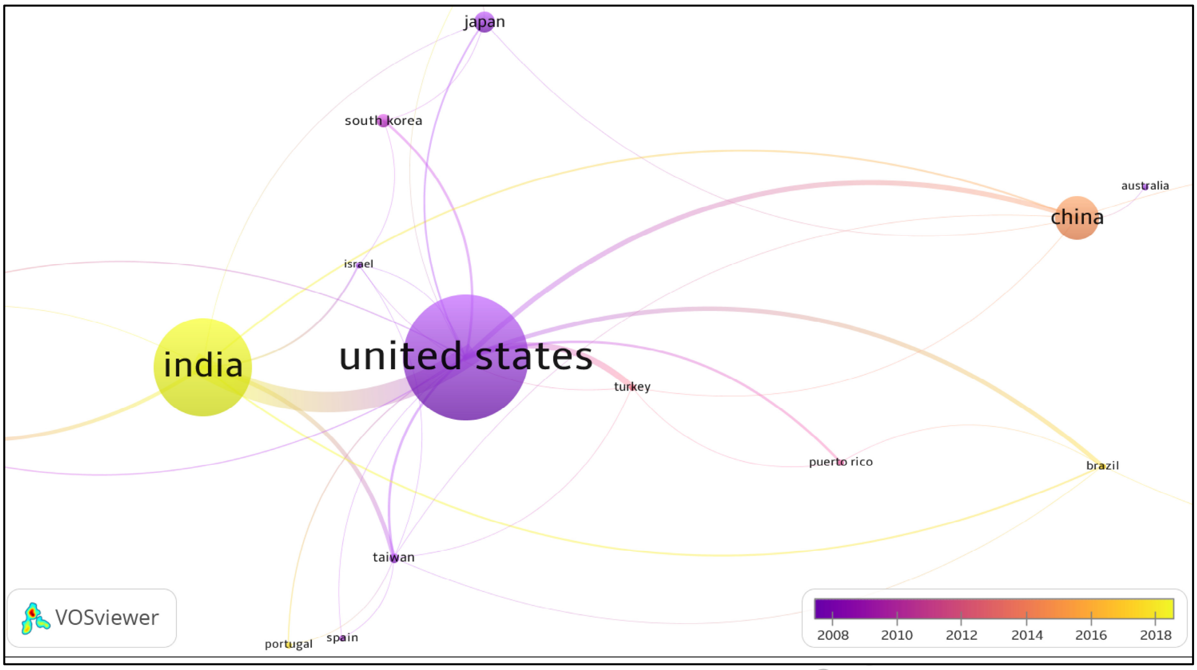

Fig. 1 Cluster graph showing the country-wise variation of research

It can be seen that the United States of America (USA) has a higher number of publications, followed by India and then China. About 36 % of the total considered publications were from the USA, and about 28 % were from India (**Fig. 1**). **Fig. 2** illustrates the author-wise distribution of publications considered for having a minimum of two articles. Total of 122 researchers contributed, considering the 74 publications. A total of 102 researchers have only a single publication. It can be seen that A. Dhamaniya is the most prolific researcher in the area of toll plaza traffic operations, with a total of 16 publications. He is followed by Y. Navandar (14 articles), D. Patel (9 articles), and Al-Deek (8 articles). Here, one point to note is that the Al-Deek was a pioneer in working on toll plaza operations and published much research before 2005, but on homogeneous traffic conditions.

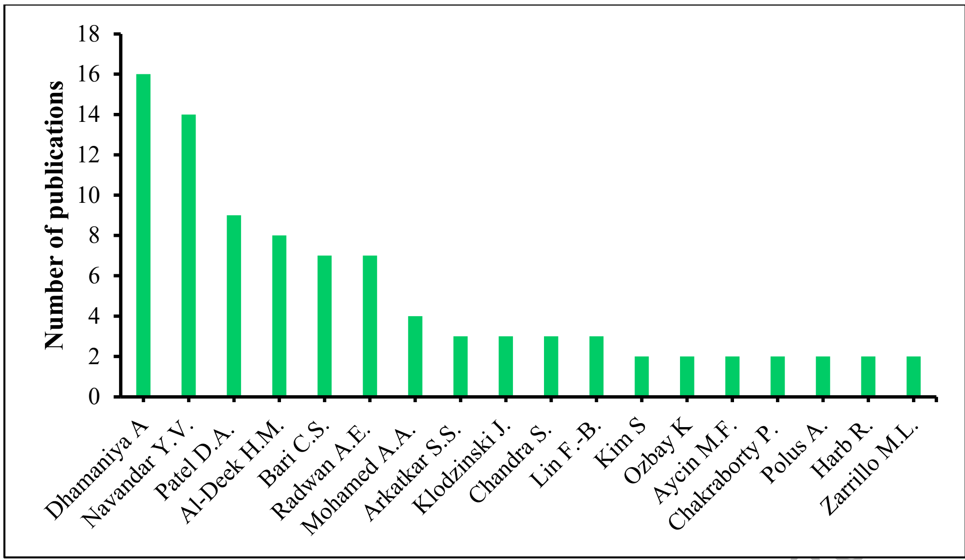

Fig. 2 Author wise distribution

4 PARAMETERS CONSIDERED IN THE LITERATURE

4.1 The capacity of the toll plaza

The capacity of any facility can be defined as the maximum number of persons or vehicles reasonably expected to traverse at a point or a uniform section of a lane or roadway during a given period under the prevailing roadway, traffic, and control conditions[7]. The capacity of a section is the key term in the planning and designing of any traffic facility. It also acts as a tool to evaluate the operational conditions for the same facility.

Edie[22] conducted preliminary work using empirical data to determine the number of tollbooths and toll collectors scheduled on the Lincoln tunnel based on the probabilistic analysis. This study portrayed methods for determining the relationship between traffic volumes, delay, and the number of tollbooths. Schaulfer [23] collected field data from fifty-four toll plazas in the United States. The author found that the optimal capacity is achieved when the eight queued vehicles are waiting to get served. According to survey results, the average capacity of the manual lane was found to be 416 vehicles per hour per lane (vphpl) for passenger cars traffic only which decreases upto 360 vphpl for mixed traffic (presence of less than 5 %

trucks or buses). On the other hand, for ETC lanes, the average capacity is 1154 vphpl for passenger cars and 1050 vphpl for mixed traffic (presence of less than 5 % trucks or buses). He found the capacity of express ETC lanes as 1500 vphpl for passenger car traffic only. Zarrillo[24] proposed equations for capacity estimation of toll plazas as shown in equation-(1).

$$C = J + K_{MTE} \tag{1}$$

Where, C = toll plaza capacity(vph), J = capacity of single service lanes(vph), K_{MTE} = capacity of mixed-use lanes(vph) calculated as per equation-(2),

$$K_{MTE} = N_{MTE} S_{MTE} = N_{MTE} \frac{100\ \%}{\frac{P_M}{S_M}+\frac{P_T}{S_T}+\frac{P_E}{S_E}} \tag{2}$$

Where, K = capacity of mixed-use lanes(vph), N = number of lanes for mixed-use, Si = vehicle processing rate for payment type-i(vph), Pi = percentage of vehicles utilizing payment method i.e., M for manual lane, T for mixed lane and E for ETC lane.

Aycin[25] developed a methodology for determining toll plaza capacity by considering the approach roadway conditions and traffic demand characteristics. This methodology appears to be suitable for manual calculation and is suggested to improve users' understanding of toll plaza operation. The author proposed equations-(3 to 6) for capacity estimation considering different tollbooths payment options.

$$C_{ETC} = 3600 \frac{V_{ETC}}{S} \tag{3}$$

$$C_{cash} = \frac{3600}{\text{service time + moveup time}} \tag{4}$$

$$C_{cash\text{-}ETC} = \frac{3600}{\sum_j \triangle tjPj} \tag{5}$$

$$C_{plaza} = N_{cash} x C_{cash} + N_{ETC} x\ C_{ETC} + N_{cash\text{-}ETC}\ x\ C_{cash\text{-}ETC} \tag{6}$$

where, C_i = Capacity of tollbooth for payment type i(vph); V_{ETC}= Average ETC vehicle speed(feet/s); S = Average distance headway(feet/veh); Δt_j= Transaction time of pair-j; P_j=

Probability of possible leader-follower pairs given the percentage of ETC vehicle using the mixed lane.

Li[26] carried out the capacity analysis of the ETC lanes and developed the equation (7) depending upon the service time.

$$C = \frac{3600}{T_S + T_G \, x \, k} \tag{7}$$

Where, C =ETC lane capacity; T_S = standard car service time; T_G = standard car leaving time; k = standard car adjustment coefficient (taken as 0.7)

IRC[27] suggests the capacity of 240vph for manual and automated tollbooths and 1200vph for ETC lanes. Navandar et al.[28] determined the capacity of the MTC lanes operating under mixed traffic conditions in tollbooth equivalency factors (TEFs). The latest study by Bari et al.[29] studied the capacity of ETC lanes in Indian mixed traffic conditions. Table 1 describes the Strobe list table showing the different parameters considered in the different literature for capacity analysis.

Table 1 Literature related to capacity

Sr. No.	Researcher	Parameter										Country
		TOL	ST	SH	CT	D	SIM	Q	DIS	PCU	HO/HT	
1.	Edie[22]	M	X			X			X		HO	USA
2.	Al-Deek et al.[30]	M,E	X	X	X	X			X		Any	USA
3.	Polus and Reshetnik[31]	M, E									HO	USA
4.	Al-Deek et al.[32]	M,E	X	X	X	X			X		Any	USA
5.	Polus[33]	M, A, E	X			X	X				HO	USA
6.	Boronico and Siegel[34]	M	X			X					HO	USA
7.	McDonald and Stammer[35]	M, A, E	X								HO	USA
8.	Astarita et al.[36]	M, A, E	X			X	X				HO	Canada
9.	Perry and Gupta[37]	M, E	X			X	X				HO	USA
10.	Al-Deek[38]	M, A, E	X			X	X		X		HO	USA
11.	Lin[39]	M				X	X				HO	Taiwan
12.	Klodzinski and Al-Deek[40]	M, A, E	X			X	X		X		HO	USA
13.	Zarrillo et al.[41]	M, A, E					X				HO	USA
14.	Al-Deek et al.[42]	M, A, E	X			X	X		X		HO	USA
15.	Aycin[25]	M, E	X	X	X	X					HO	USA
16.	Upchurch[43]	M	X	X	X						HT	USA
17.	Zarrillo and Radwan[44]	M, E						X			HO	USA
18.	Kim[45]	M, A, E				X	X	X			HO	Korea
19.	Shitama et al.[46]	M, E	X	X		X	X		X		HO	Japan
20.	Kim[47]	M, E					X				Any	USA
21.	Gugol et al.[48]	E	X			X	X	X			HT	Philippines’
22.	Li[26]	E	X				X				HO	China
23.	IRC[4,27]	M, E	X	X							Any	India
24.	Bains et al.[49]	M	X				X				HO	India
25.	Wang[50]	M	X			X		X			HO	China
26.	Zhang et al.[51]	E					X				HO	China
27.	Navandar et al.[28]	M	X	X	X				X	X	HT	India
28.	Talavirya and Laskin[52]	M, E	X				X	X	X		HO	St. Petersburg
29.	Bari et al.[29]	M, E	X							X	HT	India

TOL = Type of lane, M= MTC lane, A= Automatic Coin Machine (ACM) lane, E = ETC lane ST= Service time, SH = Service headway, CT = Clearance time, D = Delay, SIM = Simulation, Q = Queuing, DIS = Distribution, PCU = Passenger car unit, HO = Homogeneous traffic, HT = Heterogeneous traffic

From the above description, it can be seen that there is no single method that is universally accepted for capacity estimation at toll plazas, but various researchers tried different methods according to the field conditions. Most of the methods used the service headway or the service time as the parameter for the capacity estimation. The equation given by Aycin[25] consists of speed, service time, and clearance time, which can be a good estimator of the capacity of toll plazas. Further, Aycin[25] has given the capacity estimation formulas for different combinations of leader-follower pairs of MTC and ETC vehicles. So, one can apply the equation for getting the capacity but for traffic consisting of only passenger cars and heavy vehicles. Limited studies are for mixed traffic conditions, and hence, there is a need to think about the capacity estimation for it.

4.2 Level of Service at the toll plaza

LOS is a quality measure that describes the performance state of traffic flow. These conditions are converted into operational parameters directly related to the user's perception of comfort and convenience when traveling through different traffic scenarios[7]. As there was no explicit procedure available for evaluating LOS at toll plazas, many researchers attempted to study LOS at toll plazas over the last few decades under various conditions in different parts of the world. But, due to the consideration of different measures of effectiveness (**Fig. 3**), the scales of levels of service for representing the performance of the toll plazas also depict a wide variation. As seen from **Fig. 3**, researchers have taken V/C ratio[8,9], mean queue length per booth[53–56], mean waiting time per vehicle per tollbooth[10,57,58], mean waiting time for the entire toll plaza[33], maximum queue length per tollbooth[58], average travel delay[59], average speed of ETC vehicle[60], and service time and service time per equivalent unit[3,10].

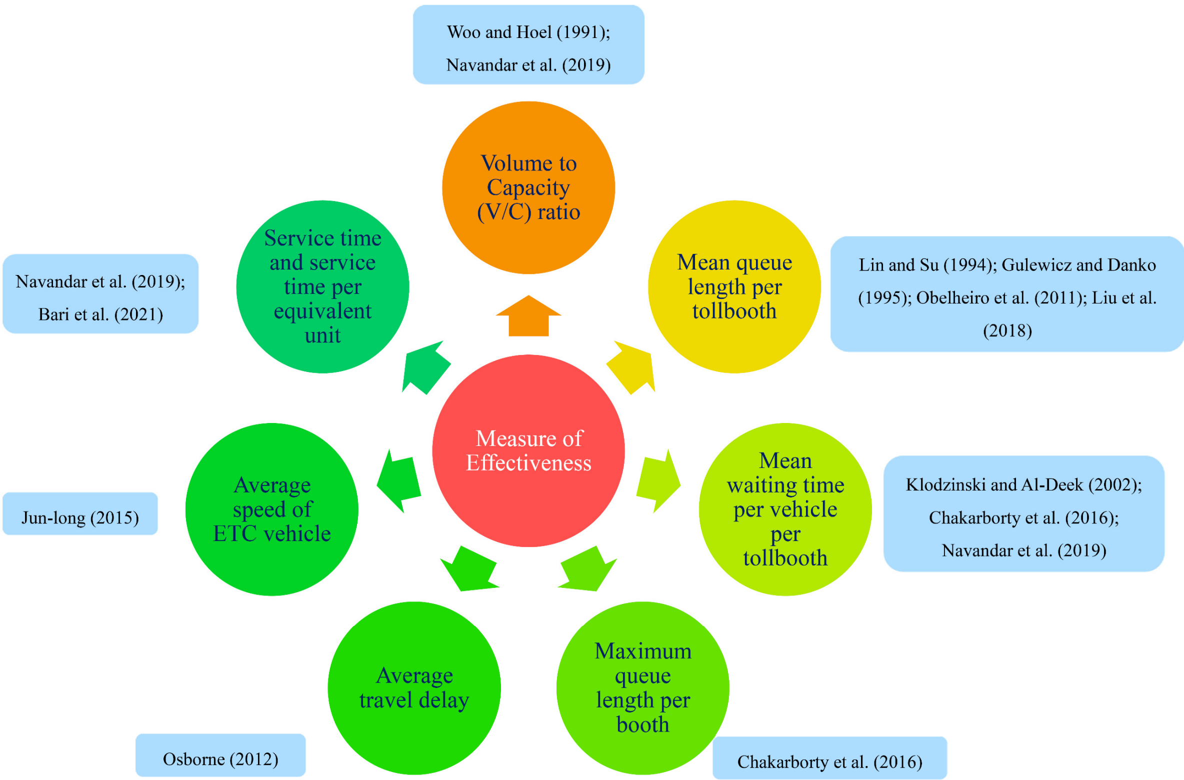

Fig. 3 Different MOEs for LOS estimation reported in the literature

Study carried out by Klodzinski and Al-Deek[57], considered 85th percentile individual delay at toll plazas as MOE for defining LOS thresholds. Obelheiro et al.[56] proposed the different LOS criteria in context with the users' perception. They evaluated LOS for toll plazas located in Brazil using field and VISSIM simulated data. The average queue length and the percentage of trucks present in the queue were taken as LOS indices. The queue length at the tollbooth was found to be the most influencing factor for users' perceived level of service. Further, the LOS thresholds were compared with the users' perceived service time and delay. Navandar et al.[10] revealed the LOS thresholds based on service time, service headway, and waiting time in the queue. In another study, Navandar et al.[61] provided the LOS thresholds under mixed traffic conditions using an ordered probit model for MTC. Authors found that the humps at the tollbooth were one of the most influencing factors affecting LOS. **Table 2** illustrates the different studies primarily focused on LOS at toll plazas.

Table 2 Literature studies for LOS at toll plazas

Sr. No.	Researcher	Parameter						Country
		TOL	ST	D	SIM	DIS	HO/HT	
1.	Klodzinski and Al-Deek[57]	M, A, E		X	X	X	HO	USA
2.	Obelheiro et al.[56]	M			X		HT	Brazil
3.	Inacio et al.[62]	M	X		X		HT	Brazil
4.	Navandar et al.[61,63]	M					HT	India
5.	Navandar et al.[10]	M		X			HT	India
6.	Bari et al.[3]	M	X			X	HT	India

Similar to the capacity analysis, it is observed that the LOS thresholds are not fixed for toll plazas and are not given in the referred guidelines such as HCM [64] and Indo-HCM [5]. Different researchers used different parameters for determining LOS, such as delay, service time, service headway, V/C ratio, average queue length, etc. The service time, service headway, and V/C ratio are point measures, but, on the other hand, delay and queue length is space measure, and hence, it can be seen that the delay is used by various researchers for determining LOS. This delay-based LOS can be related to the LOS thresholds developed for other facilities like intersections. The delay gives the level of incomfort and inconvenience to the users due to toll plaza, and thus, it can be a good measure for determining the LOS than any other parameter.

4.3 Combined study of capacity and LOS

The present section discusses the studies related to capacity and LOS combined. The study conducted by Woo and Hoel[8] found that the capacity varies from 600 to 750 passenger cars per hour, depending on the type of toll collection method and traffic composition. For example, with a higher truck proportion, service time was found to be more, thus decreasing the service volume, whereas, for small-sized vehicles, it's vice versa. It was observed that demand volume has significant effects on toll plaza capacities. Equation-(8) was proposed for estimating capacity of entire toll plaza

$$C = \sum_1^j n_j C_j = n_1 \frac{3600}{ti1} + n_2 \frac{3600}{ti2} + \cdots + n_j \frac{3600}{tij} = \sum_1^j n_j \frac{3600}{t1j} \quad (8)$$

Where,

C = Capacity of toll plaza (vehicles/hour) (vph)

n_j= Tollbooth with collection type-j

C_j = Capacity of toll booth with collection type-j(vph)

t_{ij}= Service time for vehicle type i and toll collection type-j(s)

The authors statistically correlated the V/C ratio to the density in the arrival and departure areas of the plazas and concluded that the V/C ratio could be estimated from the density values. The average density was chosen as a performance indicator for the LOS.

Lin and Su[54] used mean queue length at the tollbooths and meantime in the system as the measure of effectiveness for defining LOS. The delay based LOS values given by Highway Capacity Manual for Taiwan Area[65] at intersections were used for defining the LOS based on the meantime in the system. They reported that the performance of a toll gate can be significantly affected by several factors such as service capacity, vehicle's arrival pattern, number of available gates, and drivers' behavior.

Al-Deek et al.[30] suggested the theoretical measurement of capacity based on intervehicle time as shown in the equation-(9)

$$\text{Capacity} = 3600/T_i \quad (9)$$

where T_i = intervehicle time measured during a peak 20-minute of the period.

The evaluation results showed that there was an increase in maximum throughput by 154% for dedicated AVI lanes. Simulation-based capacity estimation attempt was taken by Osborne[59] in FREEPLAN. The developed equations are illustrated as equation-(10).

$$Cap = \frac{3643.564\ x\ N}{\bar{t}_{process}} - 1.313\ x\ PctTrucks \quad (10)$$

where, Cap = the maximum number of vehicles a toll plaza can discharge per hour (veh/h), $\bar{t}_{process}$ = average processing time for the plaza (s), N = number of open toll lanes, PctTrucks = the percentage of trucks present.

A study from China by Jun-long[60] focused on the analysis of ETC traffic flow and their characteristics and developed the basic capacity formula of an ETC channel as given by Equation (11).

$$c_b = k\frac{3600}{t0} = k\frac{1000Vo}{lo} = k\frac{1000Vo}{\frac{Vo}{3.6}+\frac{Vo}{254\emptyset}+lv+lsv} \qquad (11)$$

Where, l_v= Average vehicle length (generally 6 meters); l_{sv}= Safe distance between the vehicle (2m); Ø = Longitudinal adhesion coefficient between tier and road adhesion coefficient; C_b = Basic traffic capacity of the road; V_0 = Driving speed; t_0 = Minimum headway; l_0 = Smallest front spacing; k = Influence coefficient. He developed the different service level criteria on the basis of delay faced by ETC vehicles.

Capacity and LOS of the toll plaza operating under mixed traffic conditions are examined by Liu et al.[53] in China. The LOS for toll lanes is defined based on average queue length and V/C ratio. Navandar et al.[9] studied the capacity and LOS for manual tollbooths operating under mixed traffic conditions by considering the V/C ratio. **Table 3** shows the parameters considered by different researchers for the combined study of capacity and LOS at toll plazas.

Table 3 Literature studies for combined capacity and LOS at toll plazas

Sr. No.	Researcher	Parameter								Country
		TOL	**ST**	**SH**	**CT**	**D**	**SIM**	**PCU**	**HO/HT**	
1.	Woo and Hoel[8]	M,A	X						HO	Virginia
2.	Lin and Su[54]	M	X				X		HO	Taiwan
3.	Osborne[59]	M, A, E				X	X		HO	USA
4.	Zhong et al.[66]	M, E				X	X		HT	China
5.	Jun-long[60]	E	X	X					HO	China
6.	Liu et al.[53]	M, E		X	X			X	HO	China
7.	Navandar et al.[9]	M	X	X		X		X	HT	India

Considering the different methods available for capacity determination, the method by Jun-long[60] was found to be more complex as it involves various parameters. On the other hand, the method suggested by Osborne[59] is simple and easy to apply in traffic conditions having only cars and trucks. Further, the LOS estimation is carried out by various methods for toll facilities, and hence, there is a need to study it meticulously to come up with acceptable LOS standards.

4.4 Equivalency factor

The equivalency factor has been least studied till now as most of the available studies are from developed countries with homogeneous traffic conditions. However, in developing countries like India, the traffic is heterogeneous in the toll lane, which significantly affects the traffic operations, and therefore the necessity of an equivalency factor is felt. Woo and Hoel[8] developed the vehicle equivalent factor depending upon the service headway. Liu et al.[53] developed the PCU based on average intervehicle time for vehicles in pairs. Navandar et al.[28] projected the new concept of tollbooth equivalency factor (TEF) based on service time and clearance time for manually operated tollbooths. The TEF is used to convert all vehicle classes in terms of SC. The equation (12) is used to calculate TEF.

$$\mathrm{TEF}_i = \frac{{ST_i}/{ST_c}}{{CT_c}/{CT_i}} \quad (12)$$

Where, ST_i and ST_c= service time for vehicle type-*i* and standard car, respectively; CT_c and CT_i= 85th percentile clearance time of the standard car and vehicle type-*i,* respectively.

Table 4 shows the comparison of equivalency factors for different vehicle classes as reported in the literature. It is found that the values obtained by Liu et al.[53] are lower than that of other studies. The values of equivalency factors in the mixed traffic conditions[28,29] are found to be higher than the values given for homogenous traffic conditions[8,53] due to an increase in service time and clearance time.

Table 4 Comparison of the equivalency factors from the previous studies

Study	Parameters used	Type of lane	Vehicle Class				
			Light Commercial Vehicles (LCV)	Bus	Heavy Commercial Vehicles (HCV)	Multi Axle Vehicles (MAV)	Trailer
Woo and Hoel [8]	Service headway	MTC	----	----	2.39-2.91	----	---
Liu et al. [53]	Service headway	MTC	---	---	1.03-1.27	---	---
Navandar et al. [28]	Service time and clearance time	MTC	1.28-2.63	1.38-3.91	1.84-4.97	2.32-7.66	2.94-5.35
Bari et al.[29]	Service time	MTC	1.69	1.49	2.03	2.04	2.10
Bari et al.[29]	Service time	ETC	1.06	0.78	1.01	0.92	1.06

As observed, very few studies were reported for finding out the equivalency factors at toll plazas as most of the studies considered only passenger car traffic or only a few percentages of heavy vehicles. But, in developing countries like India, Sri Lanka, China, etc., the traffic consists of different vehicle classes, and thus to encounter their effect on any facility, the equivalency factors should be developed. Further, the developed equivalency factors are for MTC lanes, and thus there is a need to develop the same factors for vehicles using ETC lanes. The latest study by Bari et al.[29], proposed the average values of the vehicle class-wise equivalency factor for the ETC lane. As these developed equivalency factors do not cover the effect of traffic volume and traffic composition, there is a necessity to develop the same factors that encounter the effect of traffic volume and traffic composition.

5 CRITICAL OBSERVATIONS

The knowledge of the capacity of the toll facility will help to estimate the required number of toll lanes based on approach volume and traffic composition. Further, the LOS thresholds can provide the basis for performance evaluation of the toll facility by considering the service time, delay, etc. The main aim of the present study is to explore the capacity and LOS estimation methods and the gaps that need to be further reviewed in the near future. Based on the above review, the following important findings can be made.

1. Service time is one of the most important parameters for the evaluation of the efficiency of the system. Lesser the service time, more will be the capacity. Service time for MTC lanes is found to vary with the vehicle classes, traffic composition, leader-follower pair, location, toll rate, drivers' seat height, drivers' and tollbooth operator behaviour, type of payment[8]. The service time is found to be different under homogeneous traffic conditions and mixed traffic conditions.

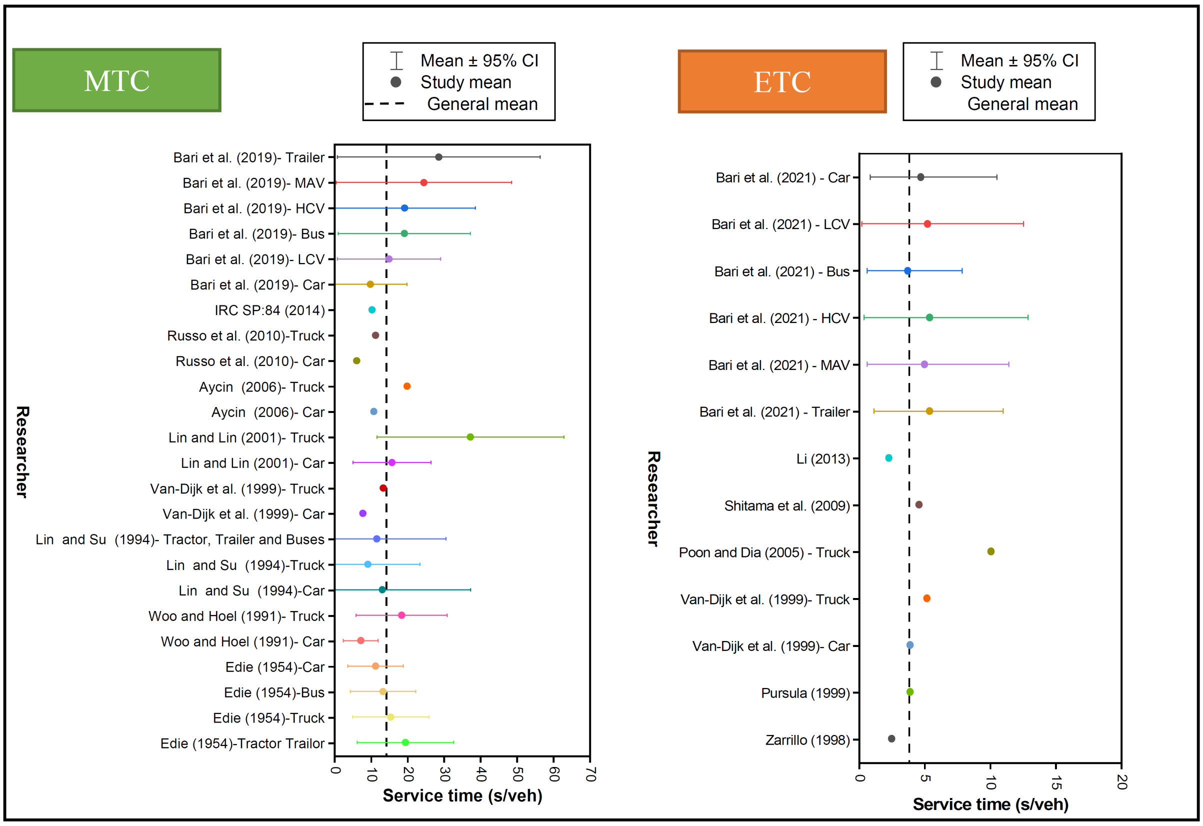

Fig. 4 Service time in different studies for different toll collection systems

The comparison of service time found in different studies is shown in **Fig. 4.** For MTC, the service time shows a variation from 2.05s to 35.56s for passenger cars. The average service time for the MTC system considering all vehicle classes, is found to be 14.15s, having a standard deviation of 8.11s. The higher standard deviation of the MTC values is observed due to the presence of higher service time values of the commercial vehicles and mixed traffic conditions. ETC service time was found to vary from 0s to a maximum of 10.44s for passenger cars. The average value of the ETC service time is 3.81s with a standard deviation of 2.05s (**Fig. 4**).

2. Various researchers deal with the capacity estimation of tollbooths for MTC and ETC lanes. The capacity is calculated by taking various measures of effectiveness, such as service time or saturation headway. The capacity of the manual lane was found to vary from 240vph[27] to 705vph[8], while for the ACM lane, it ranges from 425vph to 687vph[23]. Mostly for the ETC system, the capacity of mixed AVI lane is 700vph, dedicated AVI lane is 1200vph, and express AVI lane is 1800vph. The variation in capacity is observed due to the service time and service headway variations. The various capacities obtained by different researchers are illustrated graphically in **Fig. 5**. It can be concluded from **Fig. 5** that the average capacity of the MTC lane is 398 ± 142 veh/h/lane, for the ACM lane it is about 557 ± 148 veh/h/lane and for ETC it shows the value of 1050 ± 412 veh/h/lane.

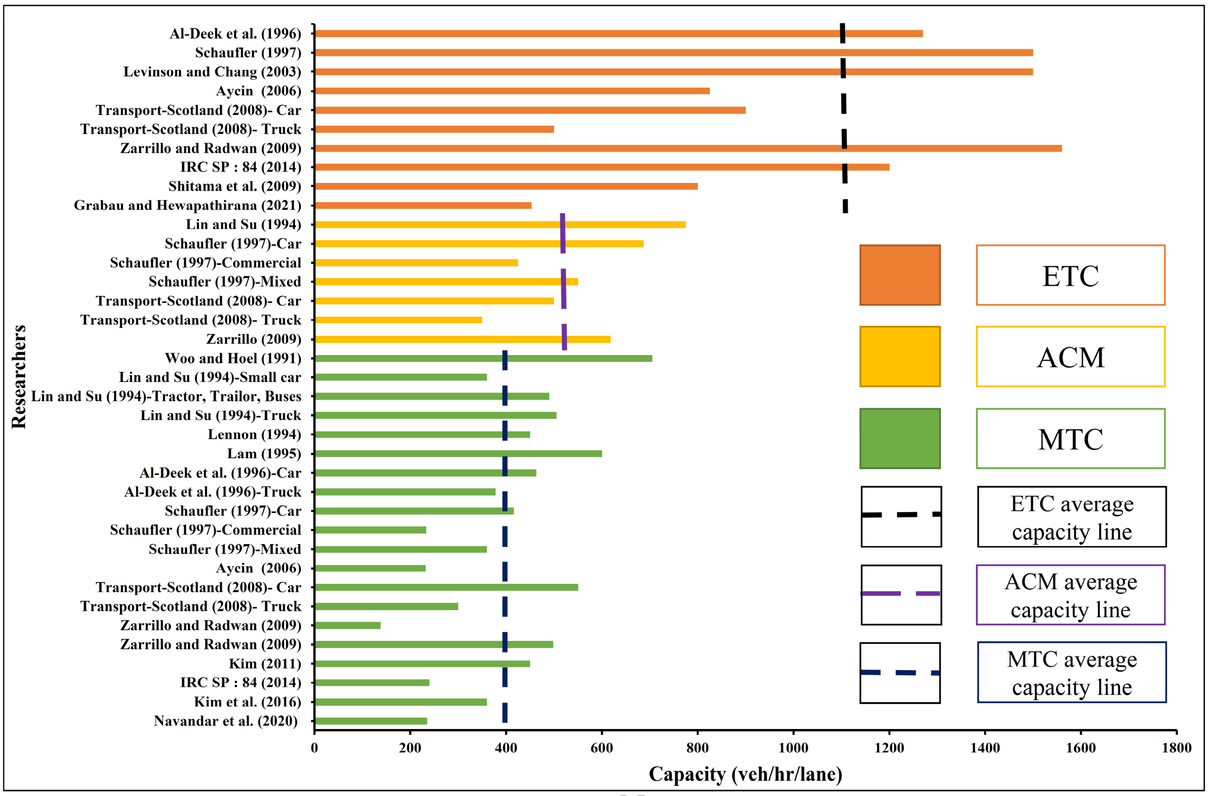

Fig. 5 Capacity from literature for a different type of toll collection systems

3. Level of service of toll plaza facilities is of great interest to various researchers with different measures of effectiveness (MOE's), as discussed in **Fig. 3**. Many of them focussed LOS on the basis of delay or waiting time in the queue. On comparison of homogeneous traffic conditions with the mixed traffic using MOE of waiting time in the queue, it is found that for LOS A, the minimum waiting time for the homogeneous condition is about 15s and that for mixed traffic, it is about 45s (**Table 5**). It is thus concluded that the LOS standards are not fixed and may vary on traffic conditions and operations.

Table 5 Different LOS thresholds given in the literature

Authors	Country	Criteria	Level of Service					
			A	B	C	D	E	F
[65]	Taiwan	Average stopped delay (s/veh)	<15	15 - 30	30 - 45	45 - 60	60 - 80	>80
[8]	Virginia	V/C Ratio	< 0.24	0.24 - 0.40	0.40 - 0.57	0.57 - 0.74	0.74 - 1.00	Not Applicable
[8]	Virginia	Density (passenger car/mile/lane)	< 12	12 - 20	20 - 30	30 - 42	42 - 67	> 67
[54]	Taiwan	Average queue length in vehicles	< 1	1 - 2	2 - 3	3 - 6	6 - 10	>10
[54]	Taiwan	Average time in system (s/veh)	< 15	15 - 30	30 - 45	45 - 60	60 - 80	> 80
[57]	USA	85^{th} percentile delay (s/veh)	< 14	14 - 28	28 - 49	49 - 77	77 - 112	>112
[56]	Brazil	Queue length (m)	≤ 3	3 - 11	11 - 27	27 - 58	58 - 134	> 134
[59]	USA	Average travel delay (s/veh)	≤ 32	32 - 36	36 - 42	42 - 50	50 - 60	> 60
[60]	China	Average delay (s)	< 1.80	1.80 – 3.60	3.60 – 7.20	7.20 – 18	> 18	Not Applicable
[60]	China	Average speed (km/h)	20-30	15-20	10-15	5-10	< 5	Not Applicable
[60]	China	Service traffic volume (PCU/h)	300	450	700	900	1000	Not Applicable
[10]	India	Waiting time in queue (s/veh)	< 45	45 - 77	77 - 113	113 - 154	154 - 202	> 202
[10]	India	Service time (s/veh)	< 7	7 - 12	12 - 17	17 - 23	23 - 30	> 30
[10]	India	Service headway (s/veh)	< 13	13 - 18	18 - 25	25 - 33	33 - 43	> 43
[3]	India	Normalized service time (s/TEFs)	< 4	4 – 8	8 – 12	12 – 17	17 – 25	> 25

4. Equivalency factors for vehicles at toll plazas are studied based on service headway, service time, and clearance time. The ETC equivalency factors are lower than that of MTC lane equivalency factors.

6 FUTURE DIRECTIONS

Following directions are proposed for further research to fill the gaps in the literature on operations and design of toll plazas.

1. The service time characteristics for ETC lanes under mixed traffic conditions are not studied yet. In most of the developing countries, where the ETC system has been deployed in the last couple of years, the penetration rates are lower. The service time of ETC depends on the ability of the sensors to respond to the tag (like EZ Pass, M-Tag,

FASTag, etc.), which further depends upon the position of the receiver and speed of the vehicles passing through the lane. The effect of the boom-barrier on the service time is also not precisely evaluated in mixed traffic conditions.

2. Service headway is the basis of capacity estimation for most of the studies. These are focused on the homogeneous traffic conditions or where the traffic consists of two classes of vehicles only (passenger cars and trucks). But in many developing nations, the traffic conditions are mixed in nature; having more than two classes of vehicles in different proportions in the traffic stream creates heterogeneity in the service time and service headway properties due to different leader-follower pairs. Researchers give very little attention to the service headway distribution under mixed traffic conditions for ETC lanes and hybrid lanes (MTC plus ETC vehicles allowed in a single lane).
3. Different researchers suggest different capacities for various types of lanes depending upon the service time and service headway. Most of the studies derived capacities in homogenous traffic conditions. Hence, there is a need to develop the capacity equation considering the different proportions of the vehicle class in the traffic stream at the toll plaza so that it can quantify the effect of different leader-follower pairs for ETC lanes. Further, the applicability of the concept of stochastic capacity or the capacity as the function of breakdown probability can be evaluated by taking the possible uncertainty in the datasets.
4. Driving simulators should be used in the study that can capture the human and psychological factors of a driver. Further, most of the simulation models assumed the distribution of service time and service headway from the literature for homogeneous traffic conditions. It is suggested to study the distribution pattern of service time and

service headway for mixed traffic conditions before using it into the model mostly for ETC lanes.

5. LOS criteria are mostly given based on the field values of the delay with hardly any emphasis on the users' perception. It should be considered in future studies. The comparison between users' perceived and defined thresholds gives the ground truth of LOS. Based on the delay and queue length for mixed traffic conditions, warrants for operation of ETC lanes based on upcoming traffic volume and traffic composition can be studied in the future.
6. Equivalency factors are the basis of the conversion of mixed traffic into homogeneous traffic. But all the studies have either considered the vehicles as it is or taken PCU from HCM to convert them into an equivalent number of cars. Traffic behavior at toll plazas is different from other sections of the road, and therefore, comprehensive research is needed to develop PCU factors for different categories of vehicles at toll plazas. Further, the equivalency factors are mostly developed on the basis of point measures such as service time, service headway, etc., and thus an effort should be taken to incorporate delay for developing toll equivalency factors as developed for signalized intersection[67].

Apart from this, efforts should be taken for data collection methodology by using drones, Wi-Fi / Bluetooth sensors, etc. Use of trajectory data should be made for precise analysis of micro parameters at toll plazas. Drivers' perception, tollbooth attendants, and toll plaza manager's perception should also be studied to increase the efficiency of the toll facility. Acceleration and deceleration-based geometric design are required to enhance safety. Emission studies should be focused on mixed traffic conditions and measures to mitigate them. Moreover, the study of high occupancy toll lanes(HOV), willingness to pay(WTP) for ETC lanes or HOV lanes, freight corridors, congestion pricing strategies should be taken into consideration[68]. Now the world is moving toward connected and autonomous vehicles (CAVs), and most of the researchers have studied the challenges and the opportunities related to them[69,70]. The main aspect of switching towards the CAVs is the drivers' willingness to pay and to use for it[71]. Thus, the research is needed to set the optimum toll rates based upon the drivers' willingness to pay and the percentage of mixed traffic of human-driven vehicles and CAVs[72]. Moreover, the effect on various traffic operations, such as lane preference to the CAVs, toll rates, lane choice mechanism for CAVS, etc., with an increase in CAVS penetration required more focus for future studies[73,74].

7 CONTRIBUTION OF THE PRESENT STUDY

The study deals with the traffic operation at Toll Plazas with a comprehensive literature review. Capacity and level of service parameters have been focused on in the manuscript. The traffic operation in developing countries is entirely different than that in developed countries on any facility. The parameters related to capacity like service headway and with LOS like the total delay are different in different traffic operations. In this context, there is very limited study on traffic operation at toll plazas in developing countries like India. It is found (**Fig. 1**) that in the recent past, there has been number of studies progressives from India, and therefore this topic is of keen interest for researchers in India in recent time. There are very few studies on equivalency factors, pair-wise vehicle leader-follower vehicle and their behaviour etc., that can be taken up by the researchers in future availing the benefits from the current study. Also, the researchers may focus on the research gap provided in the current study for study in the future.

As far as the applicability part is concerned, the capacity is measured in veh/hr considering the constant service headway for any vehicle class[4], and the same has been used in the design of toll plazas. Whereas the present work suggests that it is varying with leader-follower class and also within the same vehicle class, and therefore researchers have proposed the equivalency factor. In order to operate the toll lane capacity in equivalent vehicle class/hr will give better insight to the concessionaire to operate the number of lanes for approaching traffic at a different time of the day. Also, the concessionaire may get the Level of Service operation in mixed traffic conditions, and the management may be able to take the appropriate decision to maintain the designated LOS class.

Thus, the comprehensive review presented in this study is not only useful for the researchers but also gives operational insight to the field engineers/concessionaires.

8 CONCLUSIONS

This paper presents a comprehensive review of the operational parameters of the toll plazas under homogeneous and mixed traffic conditions. Authors tried to focus on important parameters such as capacity, level of service, and equivalency factors for detailed review and proposed research gaps for the potential researchers especially in the prospect of developing countries. An effort has been made to bring out the limitations of the studies and to open up new avenues for research for further studies. It is noted that most of the studies are carried out in homogeneous traffic conditions, and there is a need to work out the capacity estimation and LOS for mixed traffic conditions. Further, to deal with the mixed nature of traffic, more emphasis should be given to the development of volume and traffic composition-based equivalency factors. Further to the application part, the researcher may focus more on developing the equivalency factors and present the capacity in terms of equivalent vehicle class. The LOS may also be linked with the field observed parameter like approach volume in order to give inferences to the field engineers/concessionaires to maintain the desired LOS.

Attempting such studies by potential researchers will certainly give meaningful insight into the societal contribution.

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REFERENCES

1. Bari, C., Navandar, Y., and Dhamaniya, A., Service Time Variation Analysis at Manually Operated Toll Plazas under Mixed Traffic conditions in India. *J. East. Asia Soc. Transp. Stud.*, 2019, **13**, 331–350.
2. Bodas, T., Ganesh, A., and Manjunath, D., Pigouvian Tolls and Welfare Optimality with Parallel Servers and Heterogeneous Customers. *J. Indian Inst. Sci.*, 2021, **xxx**.
3. Bari, C. S., Chandra, S., Dhamaniya, A., Arkatkar, S., and Navandar, Y. V, Service time variability at manual operated tollbooths under mixed traffic environment : Towards level-of-service thresholds. *Transp. Policy*, 2021, **106**, 11–24.
4. Indian Roads Congress (IRC): SP: 84, Manual of Specifications and Standards for Four Laning of Highways (Second Revision). 2019, pp. 1–219.
5. Indo-HCM, *Indian Highway Capacity Manual (Indo-HCM) CSIR-Central Road Res. Institute, New Delhi*, New Delhi, 2017.
6. IRC-65, Recommendation practice for traffic rotaries. *Indian Road Congr. New Delhi*, 1976.
7. HCM, Highway Capacity Manual. *Transp. Res. Board, Natl. Res. Counc. Washington, D. C, 2010*, 2010, 1–1207.
8. Woo, H. T. and Hoel, L. A., Toll Plaza Capacity and Level of Service. *Transp. Res. Rec. J. Transp. Res. Board, Washington, D.C.*, 1991, **1320**, 119–127.
9. Navandar, Y. V., Dhamaniya, A., and Patel, D. A., A Quick Method for Estimation of Level of Service at Manually Operated Tollbooths under Mixed Traffic Conditions. *Transp. Res. Procedia*, 2020, **48**, 3107–3120.
10. Navandar, Y. V., Bari, C., Dhamaniya, A., and Patel, D. A., Analysis of Level of Service for Manually Operated Tollbooths under Mixed Traffic Scenario. *J. East. Asia Soc. Transp. Stud.*, 2019, **13**, 1648–1663.
11. Klodzinski, J., Al-deek, H. M., and Asce, M., New Methodology for Defining Level of Service at Toll Plazas. 2002, **128**, 173–181.
12. Russo, C., Harb, R., and Radwan, E., Calibration and Verification of SHAKER, a Deterministic Toll Plaza Simulation Model. *J. Transp. Eng. ASCE*, 2010, **136**, 85–92.
13. Navandar, Y. V., Bari, C. S., Dhamaniya, A., Arkatkar, S., and Patel, D. A., Investigation on the Determinants of Service Headway Variability at Tollbooths Under Mixed Traffic Scenario in Emerging Countries. *Curr. Sci.*, 2021, **121**, 148–160.

14. Deshmukh, M., Navandar, Y. V, and Dhamaniya, A., Statistical Distribution Analysis of Clearance Time at Manually Operated Toll Plazas under Mixed Traffic Conditions. *Proc. East. Asia Soc. Transp. Stud.*, 2019, **12**.
15. Lin, F. B. and Lin, M. W., Modeling traffic delays at northern New York border crossings. *J. Transp. Eng. ASCE*, 2001, **127**, 540–545.
16. Busam, A. K., Optimization of Waiting Time at Toll Plazas. Florida International University, 2005.
17. Kitchenham, B., *Procedures for Performing Systematic Reviews Jt. Tech. Rep.*, 2004.
18. Moher, D., Liberati, A., Tetzlaff, J., and Altman, D. G., Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ*, 2009, **339**, 332–336.
19. Liberati, A., Altman, D. G., Tetzlaff, J., et al., The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *BMJ*, 2009, **339**, 1–27.
20. Page, M. J., McKenzie, J. E., Bossuyt, P. M., et al., The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Syst. Rev.*, 2021, **88**, 1–11.
21. VOSviewer - Visualizing scientific landscapes.
22. Edie, L. C., Traffic Delay at Toll Booths. *J. Oper. Res. Soc. Am.*, 1954, **2**, 107–138.
23. Schaufler, A. E., National Cooperative Highway Research Program (NCHRP) Synthesis 240- Toll Plaza Design. *Transp. Res. Board, Washington, D.C.*, 1997, 1–113.
24. Zarrillo, M. L., Capacity Calculation for Two Toll Facilities: Two Experiences in ETC Implementation. *79th Annu. Meet. Transp. Res. Board*, 2000, 1–11.
25. Aycin, M. F., A Simple Methodology for Evaluating Toll Plaza Operations. *85th Transp. Res. Board Annu. Meet. Washington, D.C.*, 2006, 1–25.
26. Li, Y., The Analysis of Highway Toll Station ETC Lane Capacity. *ICTE*, 2013, 966–972.
27. Indian Roads Congress (IRC) SP:84, *Manual of Specifications and Standards for Four Laning of Highways through Public Private Partnership* 2014.
28. Navandar, Y. V., Dhamaniya, A., Patel, D. A., and Chandra, S., Traffic Flow Analysis at Manual Tollbooth Operation under Mixed Traffic Conditions. *J. Transp. Eng. Part A Syst. ASCE*, 2019, **145**, 1–17.
29. Bari, C. S., Kumawat, A., and Dhamaniya, A., Effectiveness of FASTag System for Toll Payment in India. *Present. 7th Int. IEEE Conf. Model. Technol. Intell. Transp. Syst. 16-17 June*, 2021, 1–6.
30. Al-Deek, H. M., Radwan, A. E., Mohammed, A. A., and Klodzinski, J. G., Evaluating the Improvements in Traffic Operations at a Real-Life Toll Plaza with Electronic Toll Collection. *ITS J. - Intell. Transp. Syst.*, 1996, **3**, 37–41.
31. Polus, A. and Reshetnik, I., A new concept and a manual for toll plaza planning. *Can. J. Civ. Eng.*, 1997, **24**, 532–538.
32. Al-Deek, H. M., Mohamed, A. A., and Radwan, A. E., Operational Benefits of Electronic Toll Collection:Case Study. *J. Transp. Eng.*, 1997, **123**, 467–477.
33. Polus, A., Methodology and Simulation for Toll Plaza Analysis. *Road Transp. Res.*, 1996, **5**, 44–68.
34. Boronico, J. S. and Siegel, P. H., Capacity Planning for Toll Roadways Incorporating Consumer Wait Time Costs. *Transp. Res. Part A*, 1998, **32**, 297–310.
35. McDonald, D. R. and Stammer, R. E., Contribution to the Development of Guidelines for Toll Plaza Design. *J. Transp. Eng. ASCE*, 2001, **127**, 215–222.
36. Astarita, V., Florian, M., and Musolino, G., A microscopic traffic simulation model for the evaluation of toll station systems. *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, 2001, 692–697.
37. Perry, R. F. and Gupta, S. M., Response Surface Methodology Applied to Toll Plaza Design for the Transition to Electronic Toll Collection. *Int. Trans. Oper. Res.*, 2001, **8**, 707–726.
38. Al-Deek, H. M., Analyzing Performance of ETC Plazas using New Computer Software. *J. Comput. Civ. Eng.*, 2001, **15**, 309–319.

39. Lin, F., Delay Model for Planning Analysis of Main-Line Toll Plazas. *Transp. Res. Rec. J. Transp. Res. Board, Washington, D.C.*, 2001, **1776**, 69–74.
40. Klodzinski, J. and Al-Deek, H. M., Transferability of a stochastic Toll Plaza computer model. *Transp. Res. Rec.*, 2002, 40–49.
41. Zarrillo, M. L., Radwan, A. E., and Dowd, J. H., Toll Network Capacity Calculator Operations Management and Assessment Tool for Toll Network Operators. *Transp. Res. Rec.*, 2002, **1781**, 49–55.
42. Al-Deek, H. M., Mohamed, A. A., and Malone, L., A new stochastic discrete-event micro simulation model for evaluating traffic operations at Electronic Toll Collection plazas. *J. Intell. Transp. Syst. Technol. Planning, Oper.*, 2005, **9**, 205–219.
43. Upchurch, J., Service Times and Capacity at National Park Entrance Stations. *Transp. Res. Rec. J. Transp. Res. Board*, 2006, **1981**, 160–170.
44. Zarrillo, M. L. and Radwan, E. A., Methodology SHAKER and the Capacity Analysis of Five Toll Plazas. *J. Transp. Eng.*, 2009, **135**, 83–93.
45. Kim, S., The toll plaza optimization problem : Design, operations, and strategies. *Transp. Res. Part E*, 2009, **45**, 125–137.
46. Shitama, T., Horiguchi, R., Akahane, H., and Xing, J., Traffic simulation for expressway toll plaza based on successive vehicle tracking data. *Comput. Sci.*, 2009, 1–22.
47. Kim, B. J., Conceptualization of Traffic Flow for Designing Toll plaza Configuration: A Case Study using Simulation with Estimated Traffic Volume. *Int. J. Ind. Eng.*, 2011, **18**, 51–57.
48. Gugol, L. M., Izawa, T., and Gueta, G., Evaluation of Philippines' Electronic Toll Collection System for North Luzon Expressway. *J. East. Asia Soc. Transp. Stud.*, 2013, **10**, 1701–1719.
49. Bains, M. S., Arkatkar, S. S., Anbumani, K. S., and Subramaniam, S., Optimizing and Modeling Tollway Operations Using Microsimulation Case Study Sanand Toll Plaza, Ahmedabad, Gujarat, India. *Transp. Res. Rec. J. Transp. Res. Board*, 2017, **2615**, 43–54.
50. Chang, J., Lai, K., and Wang, B., The Design Model of Freeway Toll Collection. *Proc. - 2017 16th Int. Symp. Distrib. Comput. Appl. to Business, Eng. Sci. DCABES 2017*, 2017, **2018-Septe**, 195–198.
51. Zhang, C., He, J., Wu, J., Zhang, H., Liu, Z., and Xing, L., The analysis of ETC lane allocation in a toll collection station based on micro traffic simulation. *APCIM ICTTE 2018 Proc. Asia-Pacific Conf. Intell. Med. 2018 Int. Conf. Transp. Traffic Eng.*, 2018, 161–166.
52. Talavirya, A. and Laskin, M., Using of discrete-event modeling in throughput capacity analysis of a toll plaza at the exit of the interurban toll road. In *32nd European Modeling and Simulation Symposium, EMSS 2020* 2020, pp. 227–234.
53. Liu, X., Yun, M., and Yang, X., Lane Capacity Estimation and Level of Service Evaluation for Freeway Toll Plazas based on Transaction data. In *97th TRB Annual Meeting, Transportation Research Board, Washington, DC* 2018, pp. 1–8.
54. Lin, F.-B. and Su, C.-W., Level of Service Analysis of Toll Plazas on Freeway Main Lines. *J. Transp. Eng.*, 1994, **120**, 246–263.
55. Gulewicz, V. and Danko, J., Simulation-Based Approach to Evaluating Optimal Lane Staffing Requirements for Toll Plazas. *Transp. Res. Rec. J. Transp. Res. Board*, 1995, **1484**, 33–39.
56. Obelheiro, M. R., Cybis, H. B. B., and Ribeiro, J. L. D., Level of Service Method for Brazilian Toll Plazas. *Procedia - Soc. Behav. Sci.*, 2011, **16**, 120–130.
57. Klodzinski, J. and Al-Deek, H. M., New Methodology for Defining Level of Service at Toll Plazas. *J. Transp. Eng.*, 2002, **128**, 173–181.
58. Chakroborty, P., Gill, R., and Chakraborty, P., Analysing Queueing at Toll Plazas using a Coupled, Multiple-Queue, Queueing System Model: Application to Toll Plaza Design. *Transp. Plan. Technol. Taylors Fr.*, 2016, **1060**, 0–18.
59. Osborne, R. P., Implementing Toll Plaza Analysis into Freeplan. University of Florida, 2012.
60. Jun-long, C., Research on Method for Determining ETC Channel Capacity and Service Level. *J. Highw. Transp. Res. Dev. ASCE*, 2015, **9**, 90–95.
61. Navandar, Y. V., Singh, M., Dhamaniya, A., and Patel, D. A., Empirical analysis of level of

service at toll plaza by using ordered probit model. *Transp. Lett.*, 2019, **00**, 1–9.
62. Inacio, P. P. A., Leal, F., and Lima, J. P., Evaluation of the Service Level of a Highway Toll plaza in Brazil using Computational Simulation. In *97th Annual Meeting of the Transportation Research Board, Washington D.C., 1st Jan to 8th Jan, 2018* 2018.
63. Navandar, Y. V., Dhamaniya, A., and Patel, D. A., Empirical Analysis of Level of Service based on Users Perception at Manual Tollbooth Operation in India. *Transp. Res. Procedia*, 2019, **37**, 314–321.
64. HCM, Highway Capacity Manual: A Guide for Multimodal Mobility Analysis. *Transp. Res. Board, Natl. Res. Counc. Washington, D. C.*, 2016.
65. *Highway Capacity Manual for Taiwan Area Inst. Transp. Minist. Transp. Commun. Taipei, Taiwan*, 1988.
66. Zhong, L., Zhou, Y., and Wu, K., Analysis of Level of Service of Toll Lane Allocation of Hong Kong-Zhuhai-Macao Bridge. *CICTP Safe, Smart, Sustain. Multimodal Transp. Syst.*, 2014, 1863–1870.
67. Benekohal, R. F. and Zhao, W., Delay-based passenger car equivalents for trucks at signalized intersections. *Transp. Res. Part A*, 2000, **34**, 437–457.
68. Abou-Senna, H., Congestion pricing strategies to investigate the potential of route diversion on toll facilities using en-route guidance. *J. Traffic Transp. Eng. (English Ed.*, 2016, **3**, 59–70.
69. Gruyer, D., Orfila, O., Glaser, S., Hedhli, A., and Alonso, F., Are Connected and Automated Vehicles the Silver Bullet for Future Transportation Challenges? Benefits and Weaknesses on Safety, Consumption, and Traffic Congestion. *Front. Sustain. cities*, 2021, **2**, 1–24.
70. Shelton, J., Wagner, J., Samant, S., Goodin, G., Lomax, T., and Seymour, E., Impacts of connected vehicles in a complex, congested urban freeway setting using multi-resolution modeling methods. *Int. J. Transp. Sci. Technol.*, 2019, **8**, 25–34.
71. Morita, T. and Managi, S., Autonomous vehicles : Willingness to pay and the social dilemma. *Transp. Res. Part C*, 2020, **119**, 102748.
72. Wang, J., Lu, L., Peeta, S., and He, Z., Optimal toll design problems under mixed traffic flow of human-driven vehicles and connected and autonomous vehicles. *Transp. Res. Part C*, 2021, **125**, 102952.
73. Wu, W., Zhang, F., Liu, W., and Lodewijks, G., Modelling the traffic in a mixed network with autonomous-driving expressways and non-autonomous local streets. *Transp. Res. Part E Logist. Transp. Rev.*, 2020, **134**, 101855.
74. Yu, B. and Mwaba, D., Toll Plaza Lane Choice and Lane Configuration Strategy for Autonomous Vehicles in Mixed Traffic. *J. Transp. Eng. Part A Syst. ASCE*, 2020, **146**, 1–11.