Statistical Distribution Analysis of Clearance Time at Manually Operated Toll Plazas under Mixed Traffic Conditions

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Abstract: To calibrate simulation models of manually operated toll plazas, accurate data with high degree of precision is required. Clearance time is one of the parameters which cause erroneous results in model, and also affects overall throughput of tollbooths. Hence, an attempt is made to model best fitting distribution for clearance time at manually operated tollbooths, operating under mixed traffic conditions. Data from five different locations of country was collected, to capture the wide variation in driver's and operator's behavior. Vehicular traffic was converted into seven classes for ease of analysis. Abrupt variation of clearance time was observed among the collected dataset. General Extreme Value (GEV) distribution was found best among the selected set of distributions. Hypothesis teste were performed to check suitability of distributions with dataset. Validity of GEV distribution was checked by Probability-Probability (P-P) plots. GEV was found best fit, and can be used for microscopic analysis for simulation.

Keywords: Clearance Time, Distribution, General Extreme Value, Toll Plaza, Mixed Traffic, Shape Factor

1 INTRODUCTION

Transportation industry is of fundamental importance for the development of any nation. India being a developing country, having second largest road network, has extensivedemand for the development of the road networks. Indian Ministry of Road Transport and Highways (MORTH) has announced many highway projects for widening and development of the major expressways and national highways connecting important regions of the nation. But the large infrastructural development also requires a large capital investment. Lack of availability of funds to the government and the extensive need for infrastructure has given rise to the Public-Private Partnership (PPP) and Built Operate and Transfer (BOT) like schemes. The private organisations which are involved in the total development of the project, are allowed to collect the charges from the road users, in the form of toll after completion of the project. These charges are collected for the recovery of the invested capital of the organizations. This includes the design cost, construction cost, maintenance and operational costs of the overall

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project. Once the total revenue including the design, operational and maintenance cost is recovered, the project is to be handed over to the government, as total revenue including the invested capital and profit is recovered. As a purpose for this revenue collection, toll booths are constructed within the road facilities, which turns the uninterrupted traffic of expressways into an interrupted flow (If toll collection facility is manual). But many developing countries, including India still have the manually operated toll plazas (with one Electronic Toll Collecting lane).

In India, approximately 90% of the toll plaza are now having one FASTag (an electronic toll collection system in India) lanes. The FASTag is a passive RFID (Radio Frequency Identification) tag affixed at the center of the windscreen of vehicles. Vehicles can drive through the FASTag lanes at toll plazas with a given speed limit. Electronic Toll Collection (ETC) lanes provide a kind of uninterrupted flow within the toll plaza boundaries, with specified speed limits. But the question still remains for the remaining lanes, where the toll is to be collected manually. Users have to wait into the queues, until the toll is being collected by the toll operators. As the toll rate applicable for each category of vehicle is different, separate lanes (Dedicated lanes) are provided for each class of vehicle to avoid the delay in the toll collection operation, but it has been broadly observed that the drivers tend to occupy the lane having a smaller number of vehicles, regardless of whether it is the dedicated lane for that particular vehicle or not. It was also observed that even they are already engaged in one queue, still change/try to change the lane while the queue is moving forward steadily, for saving the time by entering in the adjacent queue, having a smaller number of vehicles. This heterogeneous driver’s behavior results into a mixed traffic condition at the toll plaza. Almost every lane is occupied by each category of vehicle, which ultimately affects the efficiency of the toll plaza and increases the overall delay. All this adversely affects the overall throughput, i.e. the capacity of the expressway and operational efficiency of the toll plaza. The target to serve desired number of vehicles per unit time is not achieved, and finally results in delays to the users. This scenario gets even worse during the peak hours. Hence a comprehensive study is required to analyse and understand the manually operated toll plaza operations.

The present study focuses on fitting a suitable distribution for clearance time of the vehicles (at manually operated toll plaza) in the queue. Clearance time can be defined as the time required for the following vehicle to acquire the position of leader vehicle, after the toll payment is over, measured from front bumper to front bumper of both vehicles. The follower vehicle here is referred to as the second vehicle in the queue, just after the vehicle which is paying the toll. In short, clearance time is the time taken by the follower vehicle in the queue, to arrive at the booth, after the leader vehicle completes its transaction procedure and exits. Hence, the time difference between the moment when leader vehicle exits, to the follower vehicle arrives and comes to a stop at the booth is measured for all vehicles at the toll plaza. The clearance time is an important characteristic resulting in the overall delays of the toll plaza. Hence attempts are made to fit the distributions for the variation of the clearance time of the different vehicle classes. The traffic is divided into seven vehicle categories according to their dimensions and maneuverability characteristics. The variation of clearance time with different leader-follower pairs of vehicles was observed at five different toll plazas located in India, with varying traffic proportion and composition.

2 LITERATURE REVIEW

Rossi *et al.*(2014) studied the experimental analysis of vehicle time headway for 2-way 2 lane rural roads. Traffic flow rate and varying percentage were found to affect the time headway distribution. Gamma-GQM probability density function was found best suited observed headway distribution in all scenarios considered for the study. Navandar *et al*. (2017) presented the service time distribution at manually operated toll plaza in Indian context. Under mixed traffic conditions at manual toll collecting lanes, various range of service time were given. It was observed that, at a particular range of service time interval, particular distributions were fit best. Hence, various ranges of service time were defined and accordingly the properly fitting distributions were defined. Zhang *et al.*(2007) presented a comprehensive study on headway distribution models for urban freeways. Double displaced negative exponential distribution model was found as best fit for urban freeways. Al-Ghamdi (2001) stated that the distributions which fit best for headways at the freeways, differ with the traffic flow state. As a result, he found that the headways at arterial sections fitted gamma distribution, however for high traffic flows, Erlang distribution found to have a good fit. Lee *et al*. (2011) analysed the trend of increasing tollbooth control and electronic toll collection systems in Korea. He found that negative binomial and Poisson's distribution were responsible for the arrival rate of vehicles. They observed that the service time followed Log-normal distribution.

Dubey *et al.*(2012) modelled five mixture models for time gap data for flow values ranging from 1900vehicles per hour (vph) to 4100 vph. Among the selected set of mixture distributions, the combination of Weibull and Extreme was found to be the best fit. Aycin *et al*. (2009)developed delay model, to find out the emissions causing due to the delays and congestions at toll plaza. The average time headway was calculated by the addition of move up time (clearance time) and service time. Division (1997)carried out a before-after study for the installation of automatic vehicle identification, i.e. the E-PASS lane. The results obtained after installing E-PASS lane showed that the capacity was tripled and average queuing delay was decreased by one minute per vehicle. Considerable decrement in service time and waiting time of vehicles was observed using E-PASS lane. Clearance time followed a shifted negative exponential distribution in this study. Bains *et al*. (2017) developed a microsimulation study to optimize the operational cost and level of service of the tollbooth operations in terms of user's perspective. Successive arrival time gaps of vehicles into the queue were assumed to follow the negative exponential distribution. Robinson and Aerde (1995) utilised the INTEGRATION simulation model for obtaining the expected level of delay for the toll collection process. INTEGRATION permits the departure distribution of individual vehicles to be specified as a shifted (negative) exponential. Also, service time was found to follow the negative exponential distribution for some lanes and lognormal distribution for some another lane. Navandar *et al*. (2018)proposedGEV distribution for the modelling large range of headway from 15 to 40 sec, for the manually operating toll plazas under prevailing mixed traffic. While for a shorter range of headway between 10 to 25 sec, Lognormal distribution was found to be the best fit. Sooksan Panichpapiboon (2012) stated how General Extreme Value (GEV) distribution fits best to model the time headway on expressways. GEV distribution consists of three parameters namely, location factor, shape factor and scale factor. He specified that the overall shape of the GEV distribution can be controlled by adjusting these three parameters accordingly. This proved the flexibility of the GEV distribution over the other distributions.

Jang (2012) analysed the sub urban arterials in Korea with an interrupted traffic at an intersection. He examined the characteristics of time headway for a signalized arterial. He proposed Johnson SB distribution for a range of 10 to 14 vehicles per minute flow, and Johnson SU distribution for flows ranging 15 to 19 and 25 to 29 vehicles per minute. Badhrudeen *et al*. (2016) carried out statistical analysis of headways on a suburban arterial road in Chennai, done separately for each class of vehicle combination pairs. It was found that the required headway was more when the heavy vehicles were involved in the leader follower combination. Weibull distribution was found to be the best fit for all vehicle classes. Pueboobpaphan *et al*. (2013) examined the time headway distribution for test vehicles in context with the general vehicles in traffic stream. Test vehicles followed the shifted negative exponential distribution at low volume levels, and it was further provedanalytically for other general vehicles also.

The existing literature primarily focuses on the headway distribution at expressways, rural roads or highways with limited or unlimited accesses available. Even few studies are available on intersections. But very few literaturewas found available for time headway modelling at manually operated the toll plaza. Developing countries, especially from Asia still depend upon manual operations of toll collection procedure. The distribution fitted for the time headway, service time or even the clearance time, which is studied in the present study, plays an important role in developing a well calibrated simulation model of such manual operations. A well calibrated simulation model can be referred as a computer-based model, which accurately calculates and sets the service time, clearance time and headway. At a micro simulation level, the clearance time abruptly varies with a variation in leader-follower vehicle, which needs to be modelled without significant error. This can be done accurately by fitting an accurate distribution for all these time data collected from field. But, just the time data available with each type of operating time during toll operations is not said to be sufficiently effective for preparing a simulation model. However, the time difference data between the operations at toll plaza, along with their distribution gives more accuracy for effectivemicroscopic level analysis of such simulation model. In India, maximum toll booths are still operated manually, with either no ETC lane or a single one. Degree of heterogeneity is often more at such manually operated toll plaza as compared to the studies overcome in the developed countries. These manually operated toll plaza results into a kind of interrupted flow traffic at the expressways and arterials. In this study, an attempt is made to model the best fitting distribution for clearance time headway at the tollbooth, with various combinations of leader follower pairs in queue with different classes of vehicles involved.

3 PRELIMINARY DATA PROCESSING

3.1 Data Collection and Methodology

The field data for the clearance time, during the toll operations, is captured using video graphic method of data collection. High lense widescreen camera was used to capture all working lanes of the toll plaza in a single screen. The toll plaza operators and driver’s behavior at different state regions are obviously unlike. Also, the surrounding atmosphere of traffic like proportion and composition traffic, infrastructure facilities, driving behaviour also affect the response of drivers’ driving capabilities. Hence, data is collected at five different locations from north and west regions, as a need to capture the varied drivers’ behaviour from various regions of India. Out of the total five study locations, three toll plaza locations were selected from various regions of Maharashtra state and remaining two locations were located near Delhi. The locations were classified as, two locations were situated at the national capital region, and one at rural region and remaining two are near Mumbai metropolitan region. Ghoti toll plaza (GTP) located at Mumbai-Agra national highway-3 (NH-3), Mulund toll plaza (MTP) located at the eastern express highway, and Dahisar toll plaza (DTP) located at western express highway, these three are selected from the Maharashtra state region. Whereas

Gurgaon-Faridabad toll plaza (GFTP) and Kerki toll plaza (KTP) located on National Highway-8 (NH-8),are selected from Delhi region for study. Details about the data collection timings and toll plaza locations are specified inthe Table 1.

Table 1. Location and timing details of study

Name of Toll Plaza	Ghoti toll plaza (GTP)	Gurgaon-Faridabad Toll Plaza (GFTP)	Kerki Toll Plaza (KTP)	Mulund Toll Plaza (MTP)	Dahisar Toll Plaza (DTP)
City	Nasik	New Delhi	New Delhi	Mumbai	Mumbai
State	Maharashtra	Delhi	Delhi	Maharashtra	Maharashtra
Date and Day	9/3/2016 to 12/3/2016 (Thursday to Sunday)	24/5/2016 (Tuesday)	26/5/2016 (Thursday)	27/9/2016 (Tuesday)	29/9/2016 (Thursday)
Timing	[9 AM to 12.30PM and 3 PM to 6.30 PM (For all Locations)]				
Number of Lanes	6	7	4	6	2

Total three cameras were placed for the data collection. Two cameras were placed on each either sides of the toll plaza, to record the entry and exit times of vehicles and the third camera was positioned at the front of the operator's cabin, where the challan cutting operations (exchange of toll fare) were done. Camera was placed 20 meters away to record the synergy of the vehicle driver and tollbooth operating staff, clearly.

Various categories of vehicles were observed in almost all dedicated lanes, during the toll plaza operations, which is said to confirm the mixed traffic scenario at the toll plaza. Hence for simplicity in data extraction and analysis, the vehicles were divided into seven classes, deepening on their dimensions and manoeuvrability characteristics. The seven classes of vehicles are categorized as listed in Table 2.

Table 2. Vehicle categories and their length details

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

This study aims to fit the best possible distribution for the clearance time, also known as the move up time for vehicles at toll plaza under the mixed traffic conditions. Easy fit 5.5 software was used to find the best fitting distribution. To properly suite the goodness of fit, Kolmogorov-Smirnoff (KS), Anderson-Darling (AD) and Chi-Squared tests were conducted for the clearance time data of all vehicles. While fitting the distribution, Maximum Likelihood method was used for the estimation of goodness of fit. For collected data set, to check the possibility of resemblance among any of the two distributions, a total five number of theoretical distributions were hypothesized, selected from the past studies. Referring the existing literature, distributions selected for comparison in this study are lognormal, inverse gaussian, generalized extreme value (GEV), Johnson SB and Burr. These distributions were selected and to find the best fitting distribution for clearance time among these, following hypothesis were considered.

Null hypothesis: The clearance time follows certain distribution

Alternate hypothesis: Clearance time does not followparticular distribution considered

From the hypothesis test, it was observed that General Extreme Value (GEV) was best fitted for the collected data set, as compared to other distributions considered for analysis. Thus, General extreme value is chosen for modelling the clearance time for manually operated toll plazas under heterogeneous conditions. Some existing literature modelled on clearance time at toll plaza have proposed inverse gaussian distribution, but to capture all variance in clearance times at the toll plazas, GEV distribution was found best suited. There was large variation observed from the extracted readings of the clearance times among the various categories of vehicles and leader-follower pairs. These variations in clearance time were solely captured by General extreme value distribution parameters, Shape parameter (k), scale parameter (σ) and location parameter (μ) respectively. For each toll plaza location considered, leader-follower pair combinations of vehicles considering small car (SC) as leader and follower with each category and same leader-same follower combinations of each seven categories of vehicles were also studied. For different time values of the day Shape, scale and location parameters of GEV distribution was analyzed. To realise the characteristics of clearance time with time and space, at manually operated toll plaza under mixed conditions, the description of the pattern of shape, scale and location parameters for GEV distribution is important. These parameters give a detailed picture about the variation of clearance time of vehicles at toll plazas.

3.2 Data Analysis

Avidemux 2.6.1 software was used to extract the video-graphic data from the recorded cameras. The time data was analyzed with ten number of time steps for one second, to seize more accuracy of the time data readings. For the smooth movement of the toll booth with a minimum possible delay, dedicated lanes were provided for each category or group of categories of vehicle classes. But due to illiterate drivers or may be due to the tendency of drivers to avoid the time to be spent in the queue, drivers were quite frequently observed to acquire the lane which is occupied with less number of vehicles in the queue. This ultimately results in a mixed traffic condition. This mixed traffic further affects the clearance time between the vehicles in the queue, as static characteristics like length and projected area and dynamic characteristics like acceleration and maneuverability of each class of vehicle is different. The varied composition of vehicles is observed at all different locations. The car traffic (SC and BC both) was observed to be maximum at all locations. Category wise proportion of the vehicles at various toll plazas is mentioned in the below table.

Table 3. Vehicle categories and their location wise proportion

Vehicle Class	Proportion in Percentage					
	GTP	**GFTP**	**MTP**	**DTP**	**KTP**	**All Combined**
SC	42.60	69.22	65.06	30.46	46.23	53.13
BC	25.52	15.41	15.32	08.95	17.06	15.99
LCV	08.40	06.67	19.63	24.27	11.06	10.51
BUS	03.29	00.36	12.49	13.77	01.49	03.35
HCV	09.52	07.64	19.26	13.77	17.38	11.81
MAV	05.71	00.39	05.58	07.40	04.59	03.50
Trailer	04.94	00.28	02.30	01.38	02.03	01.71

4 DESCRIPTIVE ANALYSIS OF CLEARANCE TIME

Clearance time is one of the imperative parameters in the tollbooth operations to cause the overall delay to the vehicles in queue. To increase hourly throughput and capacity per lane, and to reduce the overall delay, the clearance time should be as minimum as possible. The headway at toll plaza is composed of the service time and clearance time. The service time is the waiting time required to exchange the toll fare for a vehicle, i.e. the time required by the toll operator to serve a single vehicle from collecting the toll(fare), to returning the remaining change (if any) to the serving vehicle. Clearance time is the time required by following vehicle to acquire the same position of the leader vehicle in the queue, after the toll collection of leader vehicle is over, measured from front bumper to front bumper of both vehicles. Service time also affects the efficiency of toll operations, but in the present study, only clearance time is taken into picture. The clearance time varies with the length of leader or follower vehicle, dimensions and engine capacity, maneuverability characteristics of vehicle, etc. Prolonged clearance time of vehicles also affects time required to clear the queue, and leads to form a longer queue, which causes steadiness to the drivers waiting back into the queue. Vehicles suddenly start moving as the serving vehicle gets cleared from the queue. But the vehicles waiting at rear end of queue are observed to take more time to acquire the further position of the leader vehicle. This may be due to waiting for long time or due to temporary lack of attention of drivers, which leads them to take more time to move forward in the queue.

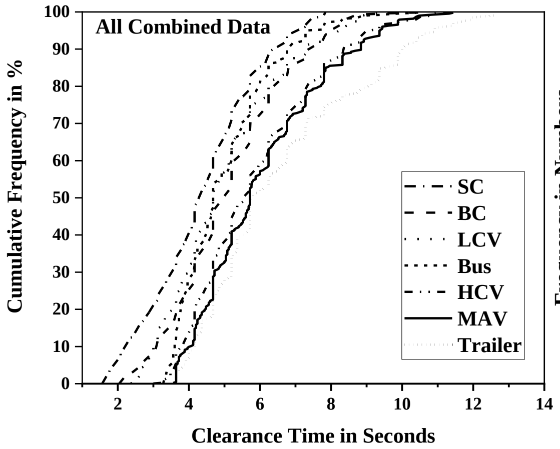
Descriptive analysis for clearance time of 10572 readings recorded and shown in the table 4. Clearance time for each vehicle class and all leader-follower combinations with small car as a leader or follower is analyzed. Also, the pairs of same vehicle category as leader and follower are captured, to quantify the variation of the clearance time with varying combinational pairs of vehicles in the queue. Mean, standard deviation, minimum and maximum values of clearance time for each class is mentioned in the table 4. From the statistics it is observed that the SC samples are found to be highest with

5617 (53.2%) numbers out of 10572. The minimum clearance time for SC was 1.56 seconds (s) and for the trailer it was up to 3.64 s.

Table 4. Descriptive statics of clearance time

Vehicle Class	Sample Size	Minimum (s)	Maximum (s)	Mean (s)	Standard Deviation	Coefficient of Variation
SC	5617	1.56	7.84	4.34	1.51	0.34
BC	1690	2.04	10.72	5.09	1.60	0.31
LCV	1111	2.36	9.40	4.94	1.60	0.32
Bus	354	3.28	10.40	4.99	1.30	0.26
HCV	1249	3.00	11.44	5.85	1.76	0.30
MAV	370	3.56	11.44	6.03	1.75	0.29
Trailer	181	3.64	12.60	6.60	2.24	0.34
SC-SC	3624	1.56	7.84	4.16	1.46	0.35
SC-BC	882	2.04	8.72	4.72	1.39	0.29
SC-LCV	376	2.36	9.36	4.82	1.48	0.30
SC-Bus	99	3.36	9.80	4.89	1.13	0.23
SC-HCV	413	3.32	11.44	5.47	1.56	0.28
SC-MAV	111	3.64	10.92	5.75	1.46	0.25
SC-Trailer	54	3.64	12.6	5.72	1.88	0.33
BC-SC	906	1.56	7.84	4.54	1.38	0.30
LCV-SC	454	1.56	7.80	4.46	1.53	0.34
Bus-SC	116	1.64	7.80	4.14	1.61	0.39
HCV-SC	158	1.56	7.80	4.26	1.69	0.39
MAV-SC	79	1.68	7.80	5.05	1.75	0.34
Trailer-SC	40	2.08	7.28	5.16	1.36	0.26
BC-BC	323	2.08	8.32	4.90	1.30	0.26
HCV-HCV	73	3.76	9.36	5.79	1.64	0.28
LCV-LCV	38	3.32	7.88	4.66	1.27	0.27
Bus-Bus	314	1.40	11.44	7.18	1.98	0.27
MAV-MAV	50	3.56	11.96	6.77	2.14	0.31
Trailer-Trailer	27	3.92	11.96	8.12	2.32	0.28
All Combined	10572	1.56	12.60	4.82	1.69	0.35

The minimum clearance time value is 1.56 s, whereas the maximum value is 12.60 s considering all vehicle classes combined together. There is not a large variation in the clearance times of leader-follower pair samples of SC-SC and BC-BC. This resemblance is observed due to the similar maneuverability characteristics of these two class of vehicles. The mean clearance times for these pairs is 4.16 s and 4.90 s respectively, which implies slightly greater time for BC. This might be due to the larger dimensions of BC vehicles over SC. Great control of SC and BC over the maneuverability, and relatively smaller dimensions as compared to other categories of vehicles resulted in almost similar clearance time for both SC and BC. In case of leader-follower combinations, SC (leader) – SC (follower) has mean clearance time of 4.16 s. But, if considered same leader-same follower combination for heavy vehicles, mean clearance time ranges between 7.18 s to 8.12 s. This large variation between car traffic (SC and BC) and heavy vehicle traffic (HV) was observed due to poor control and acceleration capacity of HV as compared to cars. It is also observed that, for heavy vehicles like HCV, MAV or Trailers, when SC is a leader vehicle, the clearance time required is more. But when SC is follower vehicle, the clearance time required is less. This might be due to more time required for heavy vehicles to acquire the distance ahead after clearing the leader vehicle. The acceleration and maneuverability characteristics of heavy vehicles are poor. SC, however, acquires the frontal cleared space quickly, as it is having good control over acceleration as compared to heavy vehicles. Hence this difference in clearance time was observed. This picture of the difference in the clearance time is made clear in the cumulative distribution of frequency (CDF) plot mentioned in figure 1.



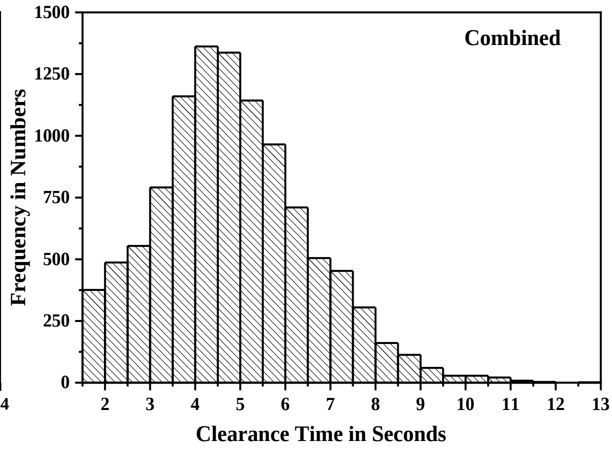


Figure1. CDF for clearance time Figure2. Histogram representing the clearance time

In the CDF plot, purposefully the vehicles are plotted in their increasing order of length and maneuverability characteristics. From the plot, it is clearly visible that the profile of heavy vehicles is skewed towards the right, affirming more time required to acquire frontal position in the queue. However, SC has the leftmost profile which proves that SC required the least clearance time as compared to all other classes of vehicles. As the length and overall dimensions of vehicle increases, the clearance time also observed to increase. From the Histogram shown in figure 2, it is observed that the maximum range of clearance time data for all vehicle classes wholly lies between 3.5 to 6.5 seconds, for all combined data together. This varied clearance time, we can say is the function of umber of variables like, vehicle maneuverability characteristics, dimensions and mainly the leader-follower pairs of the vehicles in the queue. The mixed condition causes more delays to vehicles, and the clearance time required is also affected by different pairs of vehicles in the queue. This is also one of the reasons for amplified clearance time and the overall delay at the toll plaza causing due to the mixed condition.

5 GEV DISTRIBUTION ANALYSIS

To model the clearance time, GEV distribution was used in this research. To find out the goodness of fit for clearance time of all vehicle categories and leader-follower combinations, Anderson Darling (AD), Kolmogorov Smirnov (KS) and Chi-squared test were carried out to find the best fitting distribution. P-test is carried out to decide whether to accept or reject the hypothesis at 5% level of significance. Null hypothesis is accepted if field observations follow the General Extreme Value distribution. It was observed that the field data followed the GEV distribution. It can also be verified from the fitness tests results of Chi-squared, AD and KS tests. From these tests, field data was observed to follow the GEV distribution.

Table 5. GEV Distribution parameters and results

Vehicle Class	**General Extreme Value Distribution parameters**			**Test Results**		
	Shape factor (k)	**Scale Factor (σ)**	**Location Factor (μ)**	**Chi-squared**	**AD Test**	**K-S Test**
SC	-0.2357	1.4866	3.7712	Accepted	Accepted	Accepted
BC	-0.1515	1.4769	4.4417	Accepted	Accepted	Accepted
LCV	-0.0443	1.3513	4.2251	Accepted	Accepted	Not Accepted
BUS	0.0580	0.9669	4.3760	Accepted	Accepted	Accepted
HCV	-0.0085	1.4333	5.0317	Accepted	Accepted	Accepted
MAV	-0.0132	1.4354	5.2269	Accepted	Accepted	Accepted
Trailer	0.0510	1.7166	5.5244	Not Accepted	Accepted	Accepted
All Combined	-0.1405	1.535	4.1288	Accepted	Accepted	Accepted
SC-SC	-0.2241	1.4305	3.6049	Accepted	Accepted	Accepted
SC-BC	-0.1724	1.2946	4.1471	Accepted	Accepted	Accepted
SC-LCV	-0.0792	1.2950	4.1699	Not Accepted	Accepted	Accepted
SC-Bus	0.0065	0.8815	4.3789	Accepted	Accepted	Accepted
SC-HCV	0.0492	1.1825	4.7313	Accepted	Accepted	Not Accepted
SC-MAV	0.0034	1.1591	5.0772	Accepted	Accepted	Accepted
SC-Trailer	0.2205	1.0329	4.8464	Accepted	Accepted	Accepted
BC-SC	-0.3371	1.4234	4.0939	Accepted	Accepted	Accepted
LCV-SC	-0.2399	1.5199	3.8892	Accepted	Accepted	Accepted
Bus-SC	-0.0420	1.3726	3.4098	Accepted	Accepted	Accepted
HCV-SC	-0.0298	1.4098	3.4959	Accepted	Accepted	Accepted
MAV-SC	-0.0420	1.3726	3.4098	Accepted	Accepted	Not Accepted
Trailer-SC	-0.5317	1.5223	4.8464	Accepted	Accepted	Not Accepted
BC-BC	-0.2241	1.4305	3.6049	Accepted	Accepted	Accepted
HCV-HCV	0.0474	1.2724	4.9931	Not Accepted	Accepted	Accepted
LCV-LCV	0.2046	0.7896	4.0064	Not Accepted	Accepted	Accepted
Bus-Bus	-0.2241	1.4305	3.6049	Accepted	Accepted	Accepted
MAV-MAV	-0.2050	2.0757	5.9349	Accepted	Accepted	Accepted
Trailer-Trailer	-0.4756	2.5627	7.5114	Accepted	Accepted	Accepted

GEV distribution parameters for each vehicle category and leader-follower pair are mentioned in Table 5. Shape factor (k), scale factor (σ) and location factor (μ) are evaluated from the distribution test results of clearance time. Location wise and vehicle proportion wise variation of clearance time with respect to shape factor is also plotted. Table 5 shows the GEV parameters and their respective test results.

5.1 Variation of Clearance Time with Location

As the overall dimension, especially the length of vehicle increases, the clearance time required was also observed to increase. This was observed due to the poor acceleration characteristics of large-sized vehicles. The box plots for vehicles are purposefully plotted in the increasing order of their dimensions (length), and the variation of clearance time was observed. A rising trend was observed at overall locations. Variation of clearance time for the selected vehicle class was represented with the box plots at all five selected study locations. The box plot representing the combined data of all locations is also plotted. The first and third quantile value of clearance time of the vehicles can be examined using these plots. Large variation in the clearance time is observed at all locations. SC is having the average clearance time of 4.5 for GTP and GFTP locations, whereas for DTP this value ranges between 2.5 to 2.8 seconds. This variation in the clearance time for same vehicle class at different locations may be due to the proportion of traffic, location characteristics, number of lanes, behavior of user and toll booth operator, etc. Not only the location characteristics but also the length, width, maneuverability characteristics of these vehicles is the responsible factors behind this variation. The box plots representing location wise variation in clearance time are mentioned in figures 3(a) to figure 3(f).

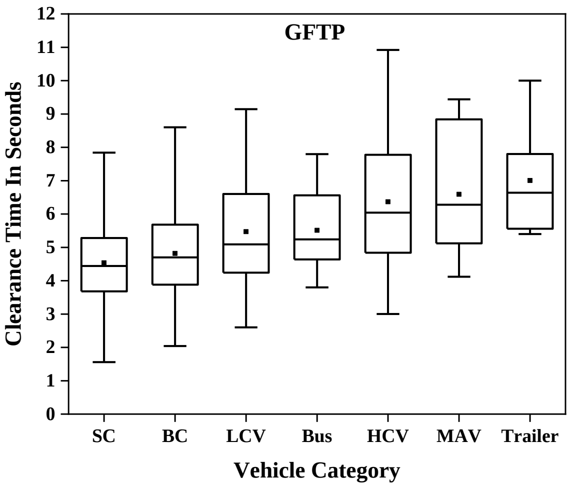


Figure 3(a). Box plot for GFTP

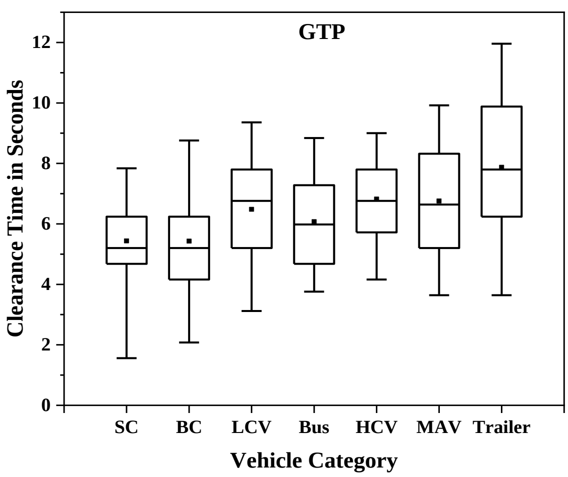


Figure 3(b). Box plot for GTP

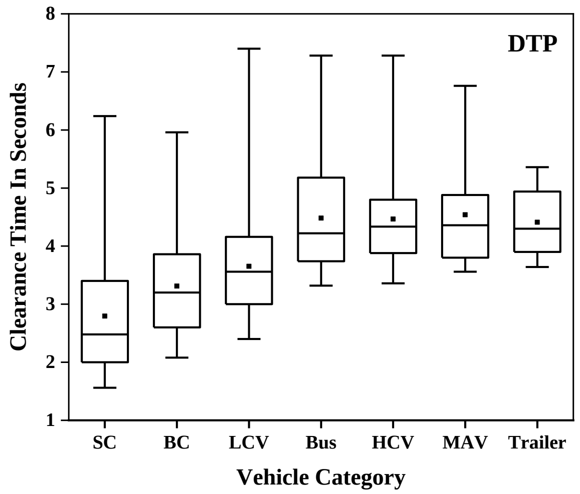


Figure 3(c). Box plot for DTP

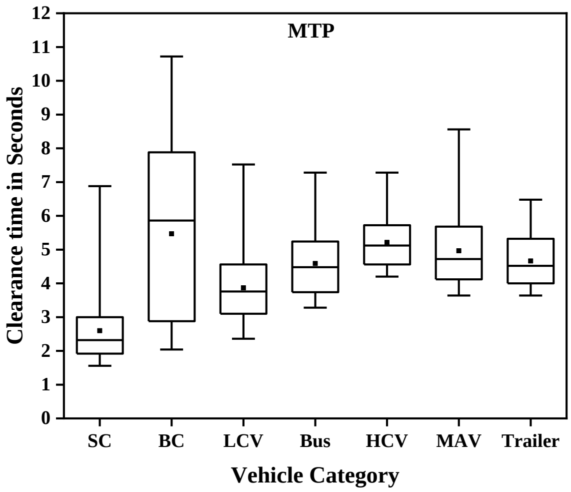


Figure 3(d).Box plot for MTP

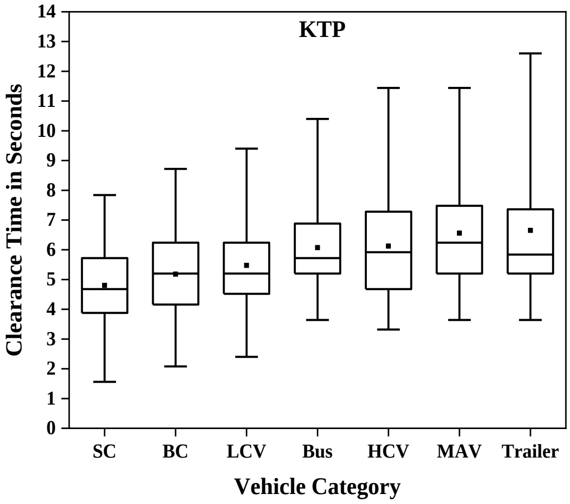


Figure 3(e). Box plot for KTP

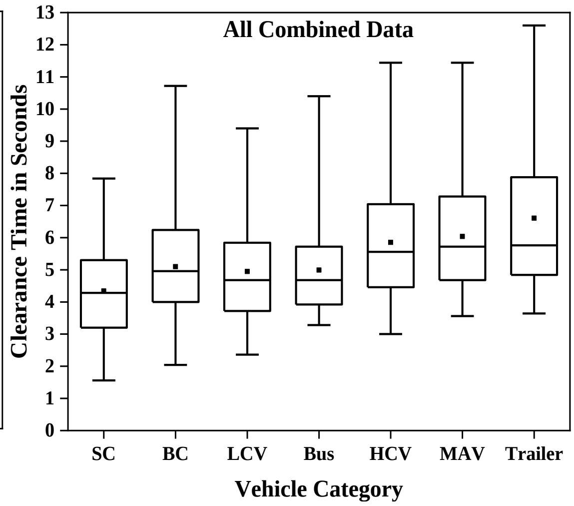


Figure 3(f).Box plot for combined data

Figure 3. Location wise variation in clearance time

5.2 Effect of Shape Factor on Location

Shape factor (k) which is one of the representative parameters of GEV distribution was studied and its variation with the location for different vehicle classes was analyzed. Abrupt variation of shape factor was observed at all locations. For combined data, an increasing trend was observed for the shape factor ranging from -0.25 to 0.1. The range of shape factor was observed similar for all locations except GFTP. As there were total seven lanes at GFTP, which were maximum among all five study locations. Due to such location characteristics this odd range of shape parameter might have been observed. Whereas an overall increasing trend of shape factor, with increasing length of vehicles, was observed at MTP and KTP.

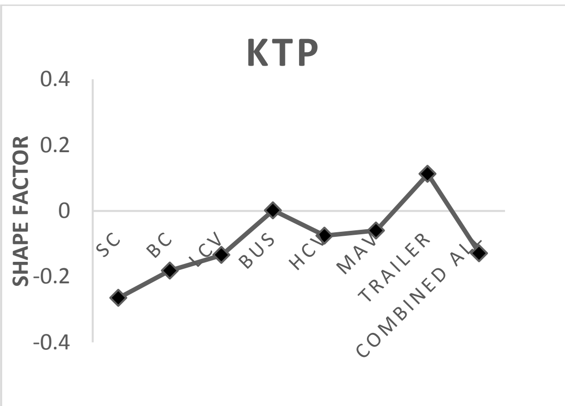


Figure 4(a).Shape factor at KTP

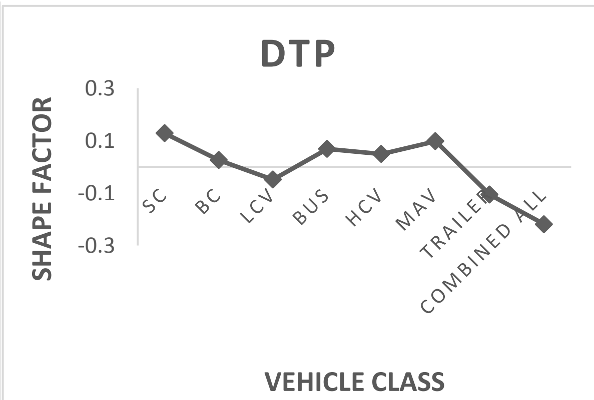


Figure 4(b).Shape factor at DTP

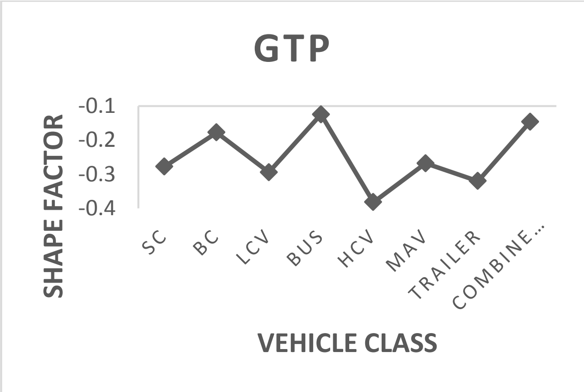


Figure 4(c). Shape factor at GTP

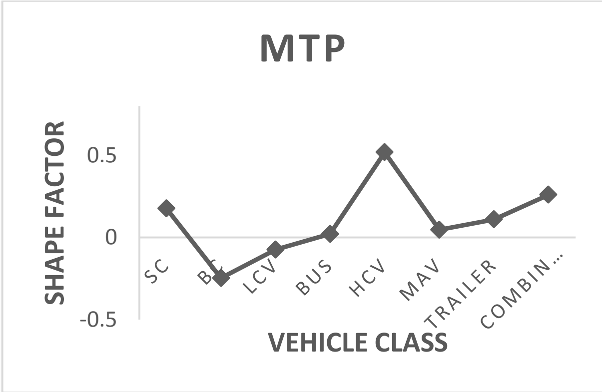


Figure 4(d).Shape factor for MTP

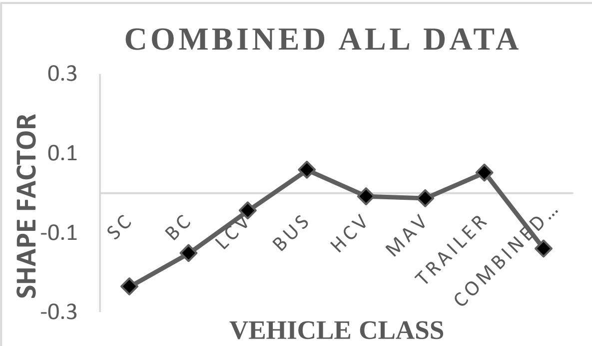


Figure 4(e). Shape factor for Combined Data

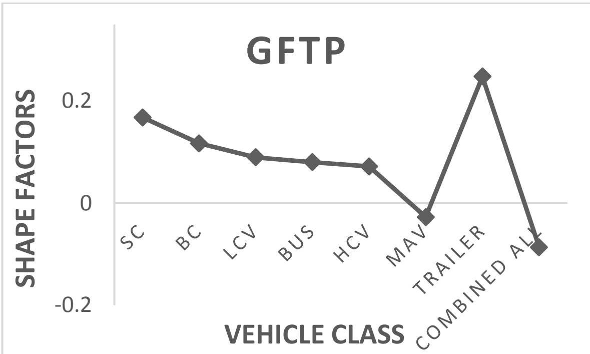


Figure 4(f). Shape factor for GFTP

Figure 4. Location wise variation in shape factor of GEV distribution.

Another probable reason for this kind of variation of shape factor can be made understood by one common observation from the field. Let say, a truck (HV) driver is waiting in queue for a couple of minutes, notices adjacent lane (dedicated lane for cars only traffic) getting cleared at a faster rate as compared to the current queue he is waiting in. The movement truck enters the adjacent lane, although his waiting time reduces and he could clear the toll plaza in a comparatively shorter time. But, until he was approaching towards the operator (while steadily moving forward in the queue), the cars which joined the queue after the truck had a truck as a leader vehicle. Obviously, the clearance time required for cars behind the truck was moreas compared to a SC or a BC in front of them. This way, all types of vehicles were observed to share and utilize all available lanes for paying toll in the least possible time. This resulted in unexpected combinations of leader-follower pairs within the toll plaza lanes, and extremely uneven variation of clearance time. Considering the case of an individual vehicle, these extended clearance time values may or not be significant. But, wholly, for operations throughout the day this clearance time aspect is likely to affect the overall throughput of the roadway and longer queue lengths. This heterogeneous behavior within the lanes was the most important reason for the astonishing variation of shape factor.

5.3 Effect of Shape Factor on Leader-Follower Pair

From the field data, it can be easily observed that the vehicles tend to change the lanes for quick payment, to leave the toll plaza soon. This heterogeneous behavior of vehicles resulted into mixed traffic condition at toll plaza. Various leader-follower pairs of vehicles were observed in the queue, and their combination was marked from the video graphic data. It can be stated that when SC was a leader vehicle, there was an increasing trend of shape factor, as the length of vehicle goes on increasing. Same was observed from the field data, as the length of vehicle increases, the time required for it to acquire the position of SC was also more. But, when SC is a follower vehicle, an overall decreasing trend was observed. SC quickly acquires the position of leader vehicle, as it clears from the queue. This can be realized from figure 5.

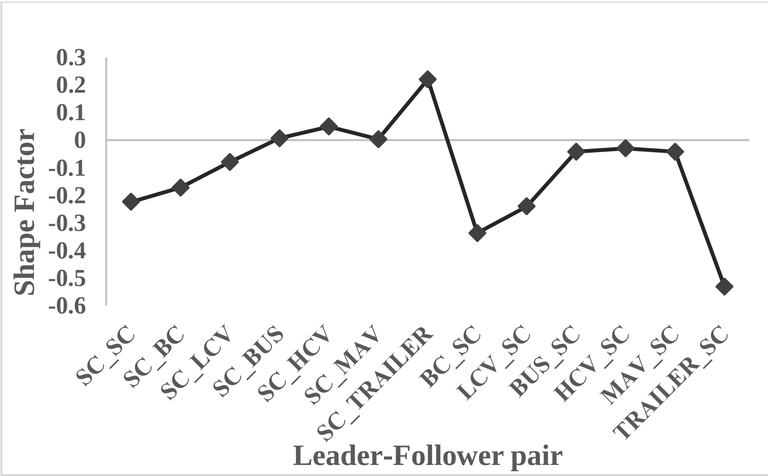


Figure 5. Effect of leader-follower pair on Shape Parameter

6 MODEL VALIDATION

The model is validated using the part of data kept unused for further validation purpose. P-P (Percent-Percent or Probability-Probability) plots were used to check the validity of the GEV distribution used in the present study.

A P-P diagram plots two cumulative frequency distributions (CDF) against each other, through which we can judge about the outliers within the data, or skewness and kurtosis within the two datasets. In short, a P-P diagram shows whether the selected (plotted) distribution matches with the theoretical standard distribution frequency of desired distribution. This important application of P-P plot has achieved great popularity in hypothesis testing and distribution fitting processes. Das and Imon (2016) used P-P plots to check the closeness between the two datasets. Yue and Jin-yang (2016) also stated that can be used to check the consistency of the distributions using P-P diagram. They concluded that P-P diagrams are more convenient and better as compared to the traditional analysis methods. This resembles that statistical tests may or may not be necessary to be performed along with the P-P or Q-Q graphs plotted to check the distribution fit. These plots alone can be used as a sole purpose of validation. In a P-P diagram comparison among the empirical CDF of the dataset is done with the specified theoretical cumulative frequency of the assumed distribution. The least scattering of the P-P plot showing no curve (i.e. followed by matching a straight line) or nearly matching with the empirical CDF line is thought to follow the assumed distribution with slight or negligible outliers. However, more spread of plotted data against empirical CDF fails to fit the assumed distribution with the dataset.

The P-P plots for clearance time at KTP and MTP locations, respectively for MAV and SC vehicles is plotted. To ascertain the accuracy of the total data set, the P-P plot for overall combined data is also plotted. The figures 6(a) and 6(b) show the P-P plot for SC data at MTP. The scattering observed in figure 6(b) for lognormal distribution is quite more than that in figure 6(a) for GEV distribution. Which implies the GEV distribution being a good fit for the dataset. Also, in figure 6(c), for combined data the scatterings of GEV distribution is nearly negligible, in contrast to this in figure 6(d) for Inverse Gaussian and figure 6(e)for Lognormal distribution, the skewness is considerably more, stating outliers within the distributions are lying in an unacceptable extent. This again gives concreteness for GEV distribution being found to be the best fit for modeling the clearance time. The better fit of GEV for all combined data is a good sign, which validates that GEV distribution is finely suited for modeling distribution of clearance time at manually operated toll plaza under mixed traffic.

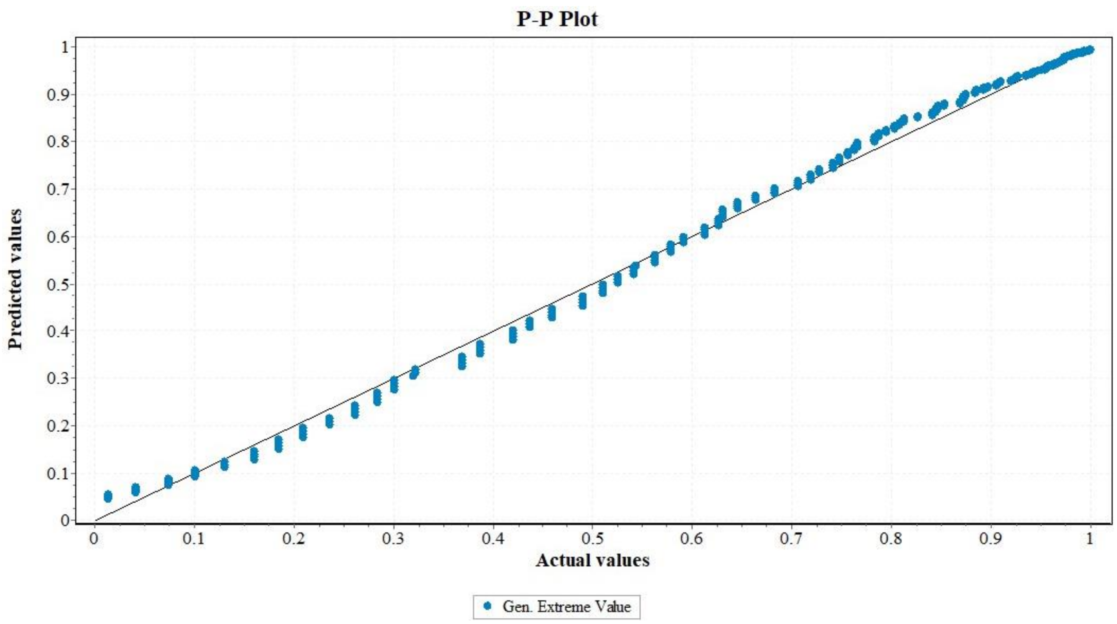


Figure 6(a). P-P plot for SC at MTP location (GEV)

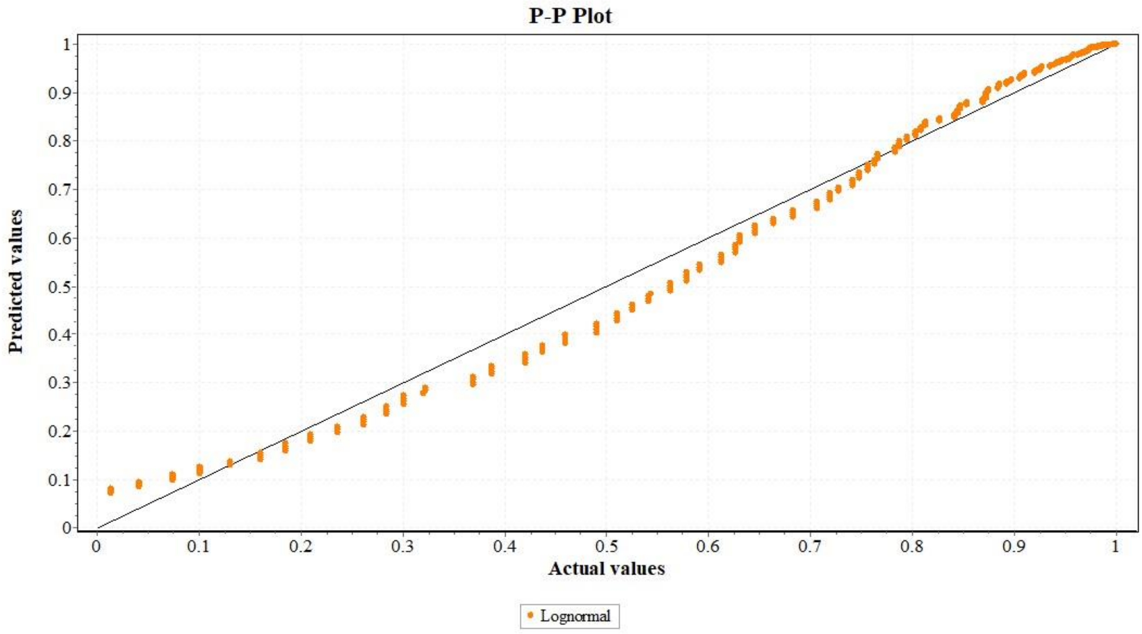


Figure 6(b). P-P plot for SC at MTP location (Lognormal)

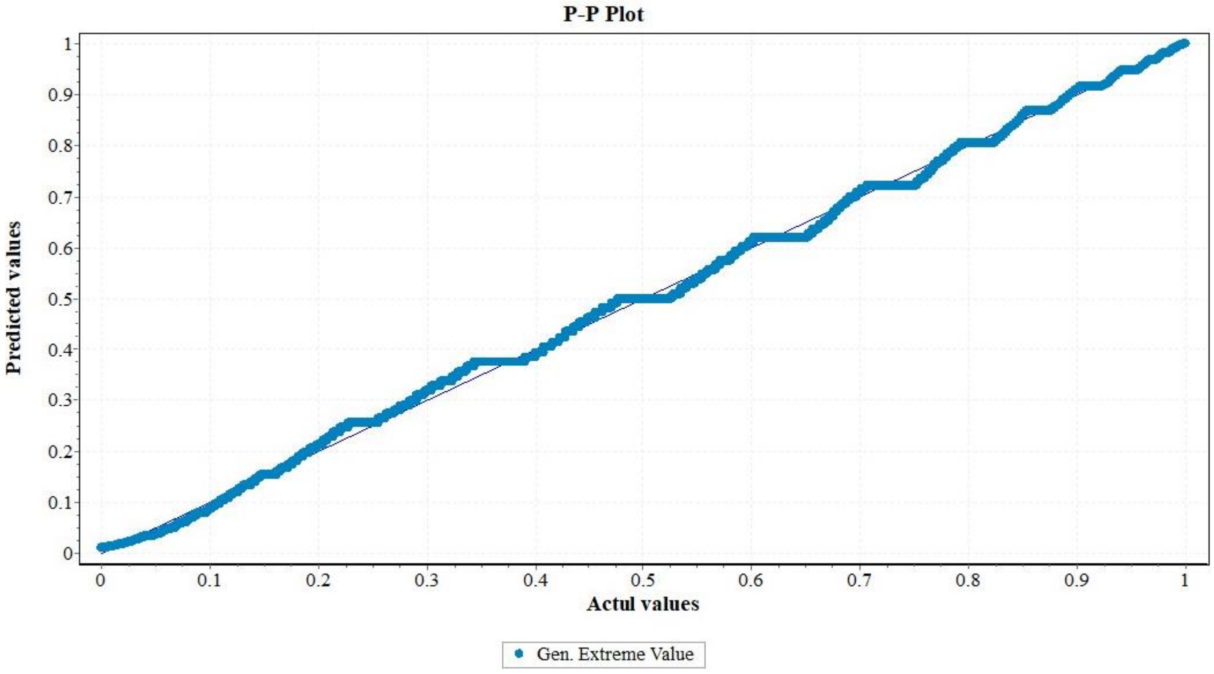


Figure 6(c). P-P plot for combined data of all locations (GEV)

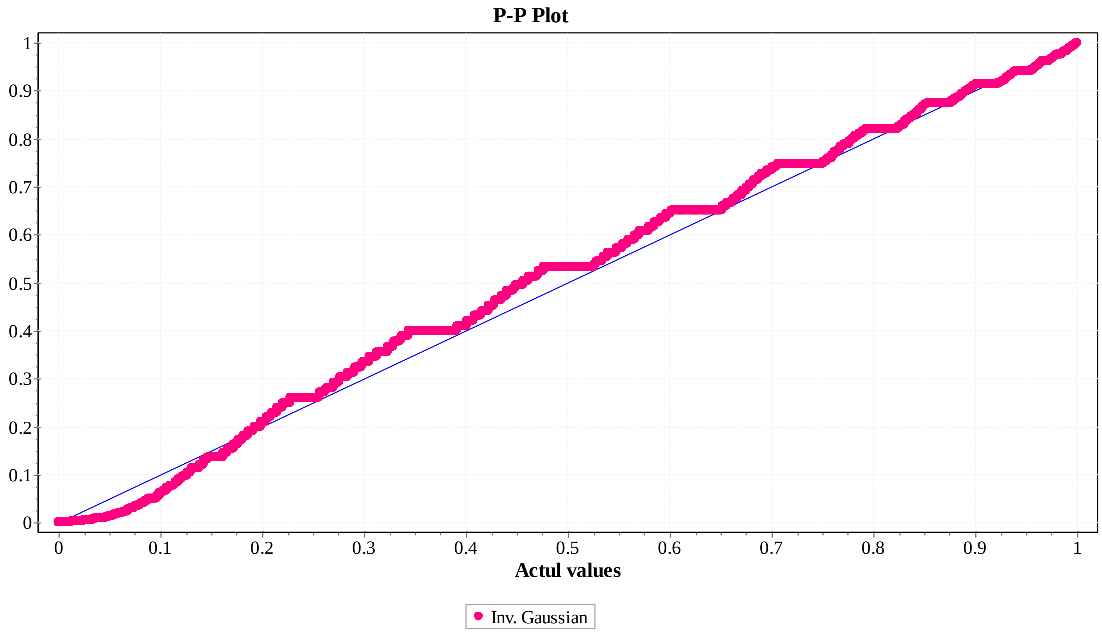


Figure 6(d).P-P plot for combined data of all locations (Inverse Gaussian)

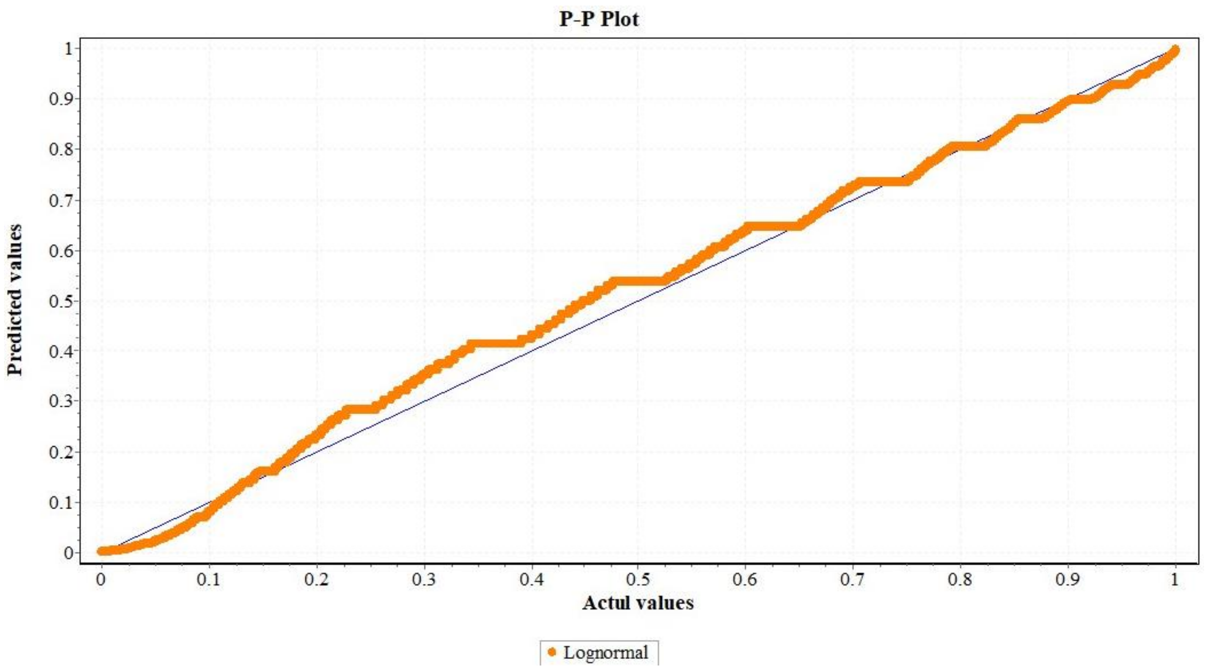


Figure 6(e).P-P plot for combined data of all locations (Lognormal)

Figure 6. P-P plots for model validation

7 CONCLUSIONS

The clearance time at the toll plaza is one of the important parameters causing the overall delay. There is limited research available for the manually operated toll plaza, for clearance time distribution, but there are few studies over the time headway distribution at expressways, rural roads and highways suggesting GEV as best fit distribution. Clearance time considered in the present study is also a kind of time gap difference between successive vehicles at (manually operated) toll plaza.

The Chi-squared, AD and KS tests are performed in this study to find the best fit distribution between the hypothesized ones. Among the selected distributions, The General Extreme Value distribution is found to fit the best for the clearance time at manually operated toll plaza under mixed conditions. This distribution of clearance time can be further utilized for the simulation purposes, to model the graphs for the dwell time into the simulation models and to inter-vehicle time for the tollbooth. Considerable variation in the clearance times among the various classes of vehicles was observed. This variation is shown in the cumulative frequency plots and box plots. The range of clearance time for all vehicles at all locations ranges between 1.56 to 12.60 seconds. This variation is observed due to varying acceleration-deceleration characteristics, dimensions, power to weight ratio of vehicles. Mainly in case of heavy vehicles, Maneuverability characteristics differ from the passenger cars, SC and BC. This results in the discrete ranges of the clearance time of vehicle classes. Also, in case of leader-follower pairs, the clearance time required for heavy vehicles is more, when the leader vehicle is HCV, than the leader vehicle is a SC or BC. This is observed due to the acceleration ability of cars.

The contribution of the present study can be used to model effective implementation of the simulation models of the toll plaza. The overall capacity or efficiency of the toll plaza, accessed from simulation largely affects with minor errors in the clearance time values that studied in the present research. A properly fitting distribution for these clearance time (referred as dwell time in simulation) values should be used while simulation model development. Hence, the GEV distribution suits best to model the clearance time distribution at manually operated toll plaza under mixed traffic.

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