DELAY MODELING USING RADIO FREQUENCY IDENTIFICATION OPERATED TOLL PLAZA – A CASE STUDY AT KORLAPAHAD TOLL PLAZA

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Abstract

Toll plazas in India are being operated electronically based on Radio frequency Identification technology (RFID) (FASTag). In RFID technology, the arriving vehicles should be stopped at the toll booth to confirm payment. In this procedure, a car slows down first, lines up, and then stops to be paid. Later, the car picks up speed gradually as it accelerates. Every such approaching vehicle is delayed by this process. The current study therefore, aims to determine the system latency in this procedure. The sum of waiting time and service time delays in mixed traffic situations is known as system delay. The queue's waiting time is the interval between when the first car enters the line and when it arrives at the booth for the transaction. The system delay model has been proposed with (a) queue waiting time and (b) service time. The field data is collected at selected toll plazas by video recording method. Field delay information has been used to validate the system delays as determined by models. It is found that the observed and estimated delay values do not significantly differ from one another. In order to estimate future vehicle delays, determine the Level of Service and determine the necessary number of toll booths, delay models have been proposed. These service delay models that were put out in the current study can be utilized to assess how well toll plazas work.

Keywords: System delay; Waiting time; Service time; Mixed traffic; Toll Plaza; RFID technology.

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1. INTRODUCTION

On the national highway, toll booths are a significant bottleneck that contributes to delays. Traffic congestion at toll plazas is a current issue that is shown by the rapidly expanding vehicle population and heterogeneity. Any such overall delay model will be used to calculate how long incoming vehicles will be delayed at the toll plaza. This will be used to calculate the LOS and the highway geometry to maintain the specified LOS. (Srinivasa Kumar, 2018).

The length of service at a toll booth is influenced by a number of variables, including vehicle type, service rate, operators, and driver characteristics. As the operator waits for the vehicle to enter the lane, different amounts must be collected due to the heterogeneity in traffic flow, which can cause service times to vary and reduce the tollbooth's capacity.No matter the vehicle class or method of payment, the service time during peak hours must not exceed 10 seconds per car, according to the Indian Roads Congress (IRC-SP-84) (2014). Therefore, in order to enhance the toll plaza's capacity, it is necessary to look into the variation in service times. Many research studies have been conducted to simulate service delays at toll booths around the world. In India, however, service times vary greatly depending on the classes and types of vehicles because of the varied toll costs and the traffic conditions. No explicit attempts to model such service delays for different vehicle categories have been made up until this point. In light of this, the current work makes an effort to create models for service delays for various classes of vehicles by taking traffic volume and composition into account through regression analysis.

The National Highways Authority of India (NHAI), a nodal agency of the Ministry of Road Transport and Highways, introduced "FASTag," often referred to as Radio Frequency Identification (RFID) technology, to enable seamless movement of vehicles with FASTags affixed.

Simple reloadable tags like the FASTag allow automated toll deductions without having to stop at toll booths. started as a pilot project in 2014 on a stretch of the Golden Quadrilateral between Ahmedabad and Mumbai. In 2014, the technology was put into effect used on the Quadrilateral's Delhi-Mumbai portion. More than 240 toll booths currently have the FASTag in use. At these toll plazas, the users' accounts will immediately be debited for the specified toll amount as they pass through the FASTag lanes. Since December 1, 2017, the Indian government has mandated this for all automobiles produced or sold. It is projected that the estimated stoppage delay at toll stations will be greatly decreased, accounting for up to 25% of the overall travel time, after RFID has been fully implemented nationwide. (USCAP, 2015).

1.1 RFID Technology

The digital data recorded in RFID tags can be read by a device employing radio waves thanks to RFID technology. The Automatic Identification and Data Capture (AIDC) technology, which includes RFID, broadly identifies people and objects, gathers data, and records that data straight into a computer system with little to no human interaction.

The three elements that make up an RFID system are as follows:
1. A smart label or RFID tag
2. An RFID reader and
3. An Antenna Figure-

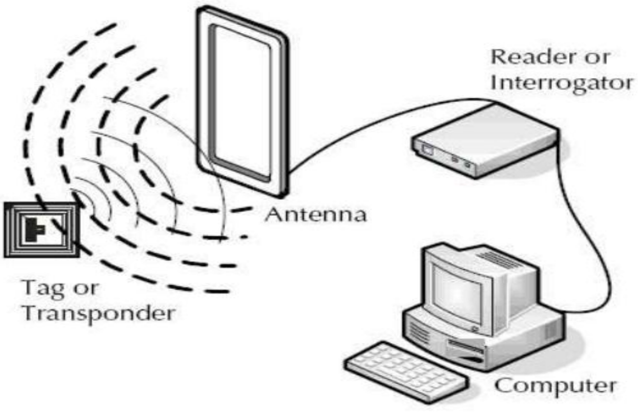
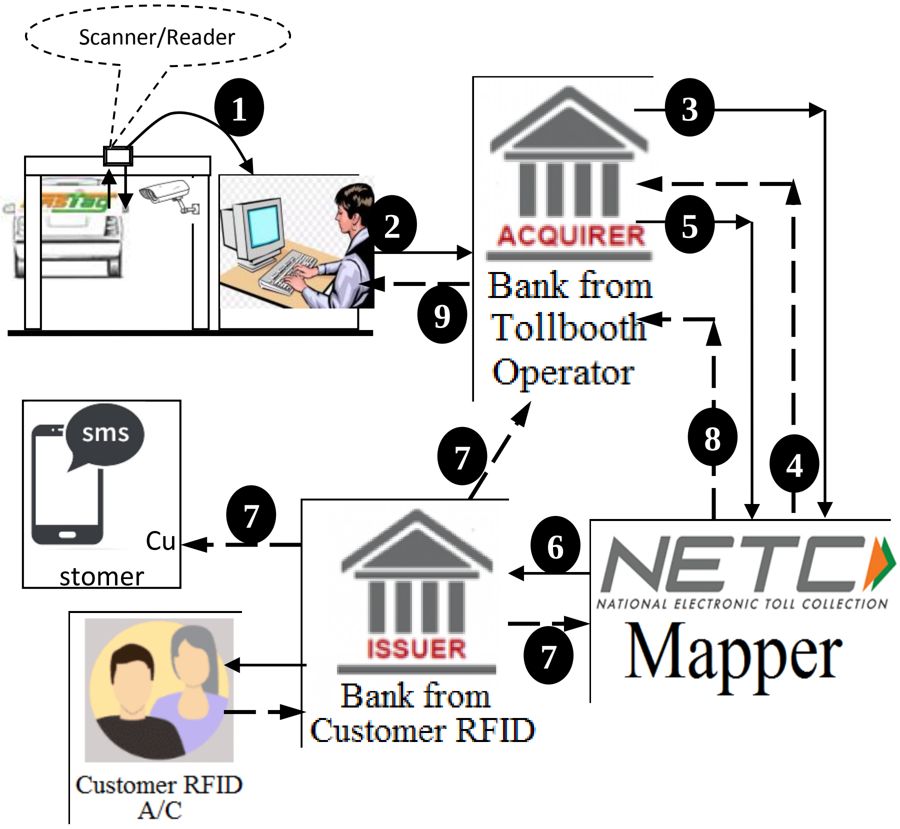


Fig 1 RFID Working Mechanism
(Source: RaghibAbdelkader and BadrAbou El Majd, 2014**)**

An integrated circuit and an antenna make up the RFID tag, which transmits data to the RFID reader (RaghibAbdelkader and BadrAbou El Majd, 2014). These radio waves are afterward into usable form by the RFID reader. For the purpose of data storage and analysis, the information gathered from these tags is then communicated via a communication interface system. As opposed to manual payments, RFID technology allows for the avoidance of traffic jams and lengthy vehicle lines, which immediately reduces service times. Also, this RFID System is able to determine the stamping of each vehicle registered at a toll plaza and alerts enforcers of any violations of toll payments.



Legends

① Scanner reads the RFID and displays the vehicle information in Tollbooth

② Tollbooth Operator forwards the RFID details to Acquirer' Bank for necessary action

③ Forwarding of the RFID details to NETC Mapper for verification by comparing with data-library

④ NETC Mapper reply to the Acquirer Bank on status & validity of the RFID. In case of invalid RFID, the Acquirer' Bank warns the Tollbooth Operator - by step 9

⑤ If the RFID is valid, the Acquirer Bank debit-request to NETC for the Toll fare

⑥ NETC Mapper forward the debit-request to the Issuer bank

⑦ Issuer Bank deducts & Transfer to Acquirer Bank and informs to NETC Mapper & sends SMS

⑧ NETC Mapper inform this successful deduction details to Acquirer Bank

⑨ Acquirer Bank inform the successful deduction details to Tollbooth Operator & Release the Gate

Fig.2 The sequential opertions involved with RFID (Source: Srinivasa Kumar 2022)

The RFID has the capability to store vehicle information, details of the owner and account credentials. It permits the toll charges to be deducted automatically and allows those cars to travel past the toll gate without pausing for the cash collection. The process involved with RFID operations in sequence are depicted in Fig. 1.

1.2 Need of the study

Countless passenger-hours are lost when driving in crowded areas, which results in significant environmental and productivity losses. It has been reported that service delays at toll plazas cost around 870 billion annually. The purpose of this research is to model service and queue delays at toll plazas that are operated by RFID and manually. The delay model can be used to describe LOS and associated geometrics as well as to predict the vehicle delay at the toll plaza. (Srinivasa et al, 2019).According to the IRC:SP:84 (2014), any toll collecting system must comply to a maximum service time of 10 seconds per vehicle and a maximum waiting time of 180 seconds for any arrangement of tollbooths and lanes.

1.3 Scope and objectives

The main objective of the present work is to estimate the system delay at a toll plaza with RFID technology using regression analysis and the MINITAB software.

The scope of the project includes:

(i) To compile available information regarding Delay analysis using literature review.
(ii) To select appropriate toll plaza location to cater variations in terms of geometry, location and traffic composition.
(iii) To develop delay models using statistical methods such as multiple linear regressions using MS-Excel and MINITAB software respectively to estimate the system delay at RFID operated toll plazas.
(iv) Optimize the level of service and increase the efficiency of a toll plaza.

2. LITERATURE REVIEW

Akshay and Guna (2021) has examined into the level of client satisfaction at the FASTag-operated toll booths in Coimbatore.The author of this work attempted to examine the general effectiveness of the FASTag RFID-enabled tolling collection mechanism. By presenting them in tabular form and using demographic Characteristics as the Content, the author carried out a survey using a straightforward percentage analysis. Through a questionnaire, the author gathered information from a variety of occupations. The ranking analysis was also employed by the author to gauge how satisfied she was with the FASTag toll collection procedure. The ranking analysis took into account variables such as simplicity of payment, convenience, time and money savings, online portal, and fuel usage.This study has some limitations, including the inability to assess respondent bias given the small sample size. Since the study was restricted to one city in South India, it cannot be applied to other regions of India. **Chintaman et al, (2020)** has conducted delay modelling at manually operated toll plazas in India in the presence of variable traffic circumstances. The delay model, which includes deceleration delay, waiting delay, service delay, and acceleration delay, was developed by the author for the entire delay experienced at the toll plaza. The regression analysis was used to build the delay model. The author employed the P-BOX instrument to gather the data necessary for the acceleration delay and deceleration delay, and the videographic approach was used for waiting and service delay. MINITAB software was used to conduct the regression analysis. According to length, weight, and other factors, the author grouped the vehicles into seven categories for an efficient examination.The deceleration and acceleration delay model was created using the discretization of speed profile technique. The zone of influence, which is composed of 50m zones of deceleration and acceleration, was discretized into 10 pacts of 50m each in this technique. Physical data and paired testing were used to validate the delay model. The results of this study can be used to assess the toll plaza's overall effectiveness and efficiency. Additionally it is useful to designers and performance analysts. This study only considers toll booths that are manually operated, however India has just introduced the FASTag tolling system, which uses RFID technology. **Navandar et al, (2019)** has examined models for predicting vehicle class service times in environments with mixed traffic. The creation of service time estimation models for various vehicle categories was the goal of this study. By using a video recording technique, the field data were gathered at 3 toll booths and 14 separate lanes in various parts of the nation. Seven categories were used to group all cars. In the cases of the small car and trailer, the service time values were found to be 2.64 seconds at the minimum and 58.76 seconds at the maximum. These variations in service times were influenced by the tollbooth operator's personality traits and the cars' sporadic arrival at the tollbooth.

Meanwhile, equations were developed linking the observed traffic volume and composition to the service times of each type of vehicle. These equations were examined using predetermined assumptions regarding traffic volume and composition. Each vehicle type's impact on the observed service times was discussed. By comparing the estimated value with the field data, the accuracy of the estimated service time values provided by these equations is established. The performance of toll plazas may be assessed using these proposed delay models. **Darshana and Rao (2018)** have conducted research on control delays at signalised intersections, it was discovered that the delay ratio for mixed traffic conditions in India was 1.19. These studies also showed that at some toll plazas and signalised intersections, delays were estimated using various methodologies, including GPS data, video recording data, and queuing theory. Despite attempts to estimate average delay, system delay, and queue delay in a few small studies, the overall delay at manually and RFID operated toll plazas under mixed traffic situations has not been effectively simulated. A few studies took into account overall delay by assuming constant values for all vehicle types' acceleration and deceleration rates. **Valdéset al, (2016)** investigated on risk factors which influence toll plazas safety by a driving simulator experiment. The authors examined how drivers entered and exited toll plazas based on overhead signs. They found that the entry and exit of the toll plazas reduced the acceleration's standard deviation by 8.33% and 16.66%, respectively. In addition, the overhead signs' placement at the entrance and exit of the toll plazas has reduced the standard deviation by 41.66% and 50%, respectively. They got to the conclusion that the overhead sign is helpful for the toll plaza's operation and safety. **Venkatesh and Patalia (2015)** were examined on a few RFID toll collection systems, and predictions for real-world situations, were made. They also underlined the need to use their review as a starting point for future system improvements in order to achieve higher performance and efficiency. **Aycin (2006)** has investigated delays at a toll booth that is manually operated for effective operation and enhanced methods. According to the author, the toll plaza's delays were primarily caused by waiting and service times. Additionally, the author created a method for calculating capacity, queuing patterns, and delay by taking approach roadway conditions and traffic flow characteristics into account. The author calculated the queue delay as the total of the delays caused by each booth and queue area individually. **Rogers et al, (2007)** conducted tests on delay at the Dublin M50 toll booth. Authors looked into what was causing the traffic jam at this toll plaza. They investigated the reliability of this claim and highlighted further capacity restrictions on the link that would offer more logical and technically sound justifications for the delays encountered by drivers near the toll plaza. **Ozmen-Ertekin et al, (2008**) were presented a set of delay equations for the toll booth on the New Jersey Turnpike using simulation and the PARAMICS programme. Discount rates transfer the drivers from manually operated to ETC, according to the sensitivity analysis. The total demand is unaffected for maximal discounts, but it was discovered that only a shift in the drivers may occur. **Lee et al, (2011)** examined the Korean closed toll plaza type's service times and arrival rates distribution. The service time during the non-peak hour was lengthier during the peak hour, the authors found. **Aksoy and Ergun (2014)** created a micro-simulation model and examined the efficiency of tollbooth operations. By taking into account the discrepancy between the actual journey time and the projected travel time, the authors calculated the overall delay. **Amrin (2019)** describes the difficulties that India's traditional toll collection methods face and emphasises the necessity for an automated toll collection system like FASTag, a project launched by the National Highways Authority of India (NHAI) for Electronic Toll Collection on National Highways. **Bains et al, (2017)** Using VISSIM to simulate traffic flow and optimise operations in terms of LOS and operational costs, a model for the Sanand toll plaza in India was created. **Sahaet al, (2017)** For the prediction of delays at the signalised intersection under mixed traffic flow conditions, a delay model based on platoon ratio and Simpson's rule was developed. **Wanisubut (1989)** created a cutting-edge technology for fully automatic, continuous toll collection has been created and is being used. This innovation could result in a major rise of toll booths. Capacity also satisfies space requirements while overcoming queueing and delay issues requirements. **Weng et al, (2015)** has created a workable model based on field data to assess how the ETC system affects vehicle emissions and fuel economy. First, laboratory tests using seven different types of cars in a variety of toll collection scenarios were carried out using the Vehicle Emissions Testing System (VETS). The indicator calculation models were then developed to evaluate the full benefit of the ETC system by comparing the test results of the MTC lane and the ETC lane. Beijing was used as a case study after calibrating the model parameters and calculating the monetization value of the environmental benefit of the ETC system in terms of reduced fuel use and vehicle emissions. According to the findings, implementations of the ETC system are anticipated to cut pollution emissions by 730.89 tonnes and fuel consumption by 4.1 million gallons in Beijing in 2013. **Yang et al, (2018)** estimated a constant acceleration rate is occasionally for the purpose of simplicity after estimating the length of time that vehicles must accelerate from a halt. However, there is currently no conclusive evidence demonstrating whether a constant acceleration rate is desirable in order to provide suitable acceleration lengths. Investigated were the estimating flaws brought on by the assumption of constant acceleration. A piecewise-constant acceleration model was used to calculate the vehicle's speed versus location profile for each sample, which led to the establishment of the constant acceleration rate. This constant acceleration rate was used to predict speeds at the predetermined locations, and the results of the piecewise-constant acceleration model were contrasted. The constant acceleration model was found to be unable to accurately represent the field-observed acceleration profile based on the statistical analysis of 575 distinct vehicle-accelerating trajectories. **Yang et al, (2016)** has examined the actual acceleration characteristics for metered on-ramps with various geometric features and has established speed profiles to assist with designing the acceleration-lane length. The properties of vehicle acceleration were modelled using a piecewise-constant acceleration model, which makes the assumption that moving objects move at a constant rate within each brief interval of time or space.For acceleration-length design, the method of employing distance against speed profiles was also shown. According to the results, acceleration rates at metered on-ramps vary. Instead, whether moving at a lesser speed or vice versa, cars frequently accelerate more quickly. It was shown that drivers' acceleration behavior would also be affected by the length of the existing acceleration and that taper ramps frequently produce higher acceleration rates than ramps with an auxiliary lane.

3 METHODOLOGIES

3.1 General

In several countries, research has been done with the goal of finding various delay factors of road features at toll booths. For determining various delays and levels of service at toll plazas, numerous approaches are utilised around the world. These methodologies are based on various characteristics that are taken into consideration and build various correlations between the parameters studied. Based on these factors approaching traffic volume, volume to capacity ratio, number of dedicated lanes, and toll plaza location toll plaza performance is determined. Regression models based on approaching traffic volumes and the volume to capacity ratio at toll plazas are among those mathematical models. The aforementioned parameters take into account the variation in the data. The framework of the procedure involved in the present study is intended to develop the model and shown in Fig 3.

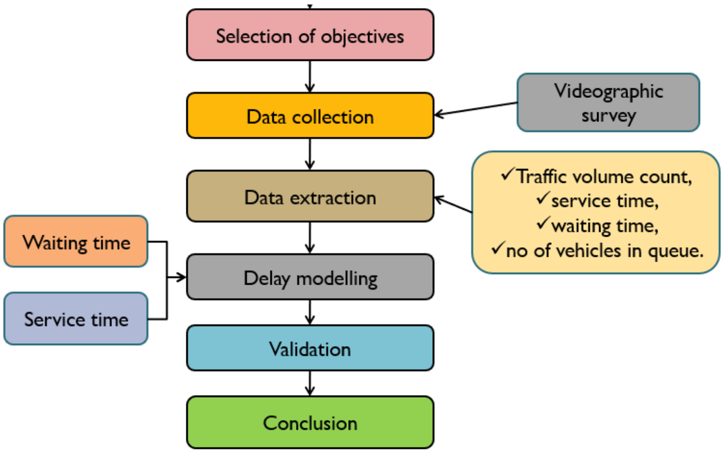


Fig. 3 Framework of procedure adopted to develop the delay model

3.2. Variables involved in delay modelling

It was observed from the literature review and the Indian Roads Congress (IRC) that four elements are crucial for determining the system delay at the toll plaza. At the peak periods of traffic at the toll plaza, the waiting time, service time, number of vehicles in line, and type of approaching vehicle were all measured on the spot.

3.3 Traffic Flow Data

The traffic flow per hour values are also necessary for the delay estimation model in addition to the previously specified factors. The information will be gathered in the form of video footage at the toll plaza during times of heavy traffic. After that, they were connected to calculated delays using the best-fit regression analysis.

3.4 Development of Model

The present model's development has taken into account as many different strategies as feasible in order to produce the greatest results. Data from toll plazas operating under peak flow conditions is required for this purpose. The following information must be gathered from the data so obtained: waiting time, service time, approaching vehicle type, traffic volume, and how many vehicles are in the queue. Using statistical methods such as regression analysis with the help of MINITAB software, the delay models are developed.

4 DATA COLLECTION

4.1 The Study Area

The study's details are listed below, along with a few guiding considerations for choosing the toll plaza location for data collecting and model development:

- *Traffic Composition*

Due to the vast differences in transportation amenities, the type of traffic flow varies depending on the place. For the present study mixed traffic conditions have been considered at the toll plaza with different vehicle classes having to pass through the toll plaza.

- *Type of toll collection*

There are two types of toll collection considered in this study such as RFID and manually operated toll plazas. To satisfy the requirements of site selection the following site is selected: KORLAPAHAD toll plaza on National Highway 65 (i.e. Vijayawada Highway), which is located at 120 km from Hyderabad illustrated in Fig. 4. The lane-layout plan of Korlapahad Toll Plaza is shown in Fig. 5.

Fig 4 View of Korlapahad Toll Plaza on NH65

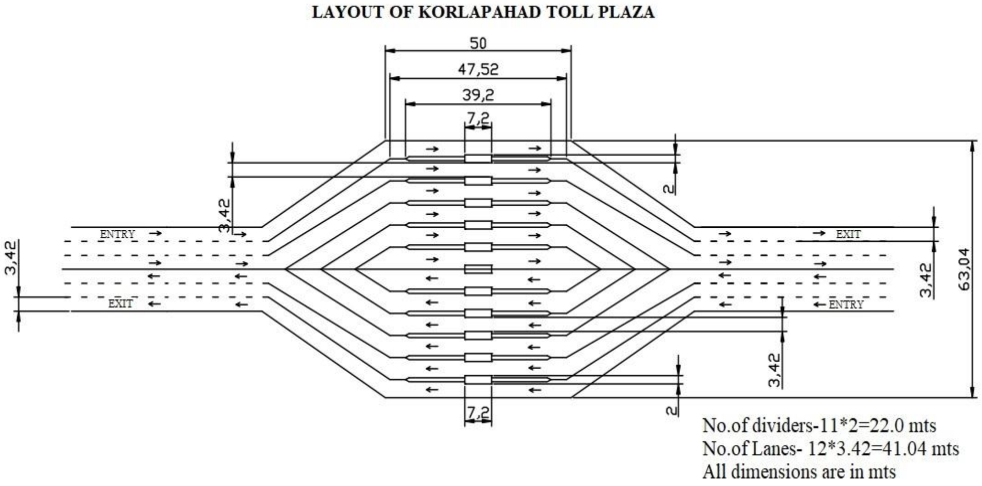


Fig.5 Layout of Korlapahad Toll Plaza

4.2 Data collection

Peak hour traffic volume data has been collected at the selected toll plaza using the video graphic method. The Korlapahad toll plaza is located at nearby Suryapet City and would have peak hours twice a day i.e. morning and evening. Data collection included gathering traffic information from the study region, which is necessary to analyze various delays at the toll plaza. The information was collected from camera footage of the Korlapahad toll plaza's peak-hour approaching traffic flow. The footage that was thusly captured shows the number of vehicles, how long people had to wait in line, and how long it took to service each vehicle. It also provides the type of traffic and indicates the predominant mode of vehicle type which is most operating on the National Highway 65 at the Korlapahad toll plaza and nearby area.

The whole traffic operation are captured with the help of three cameras. To capture traffic characteristics, the three cameras are placed in the zone of approaching, waiting at the zone of transaction and departure. Fig. 6 depicts the on-site arrangement for video graphics data collection.

Fig.6 View of fixing cameras for video graphic survey

4.3 Data Extraction

The necessary data was then extracted from the video footage after analysis. Using a traffic data extractor, the vehicle composition, volume, and flow distribution data were taken from these video recordings. The data that was extracted includes the kind of approaching vehicle, traffic volume, the number of vehicles in the line that belong to various classes, waiting time, and service time.

5 ANALYSIS AND TEST RESULTS

5.1 Analysis of data

A system delay model at an RFID-operated toll plaza has been attempted in this work.

5.2 MINITAB

This is a statistical software product that was developed specifically for professionals for process improvement. It is used as a consistent and dependable data analysis tool since the 1970s. It provides users with convenient ways to input statistical data, categorize data, identify objects with similar patterns and trends and finally analyze the data to solve problems. It is considered a simplified tool for the analysis of data for statistical interpretation at the scientific, engineering and business levels. When Minitab displays charts, patterns or trends, it also provides details of analysis and interpretation to help users draw conclusions.

5.3 System Delay Modelling

When it comes to RFID-operated toll plazas, the delays are primarily brought on by line wait times and transaction processing times at the booth. (Fig. 7). Even if the queue waiting time may be zero with light traffic, the other components will still be non-zero.

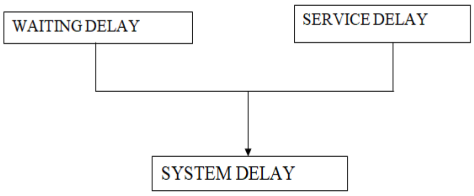


Fig. 7 Types of Delays Considered in the Analysis

The system delay (D_0) is presented beolow:

$\mathbf{D_0 = D_1 + D_2}$. . . . . .Eq(1)

where, D_o=System delay in seconds (s); D_1=Waiting time in seconds (s); D_2=Service time in seconds (s)

5.3.1 Waiting time in queue (D_1)

The capacity of the tollbooth may be reduced as a result of the maneuverability of different-sized cars, which in turn impacts the length of time that people must wait in line. Mixed traffic circumstances are experienced at this particular toll plaza as well as other toll plazas throughout India. When a toll booth is manually operated, a vehicle approaching the toll plaza must stop at the booth and pay the toll, causing a delay. As a result, toll plaza queue length is taken into consideration as a crucial study variable that captures drivers' frustration.

Because cars arrive at the toll plaza at random, the length of time people must wait in line is unrelated to the type of vehicle. As a result, the period of time a vehicle spends in line and the period of time it takes to get to the window of the toll booth for payment is what is referred to as the queue's waiting time.

IRC:SP:84 (2014) states that a toll plaza's line shall move along in no more than 180 seconds. Field research, however, reveals that many users wait longer than what IRC has set as the maximum. As the number of vehicles in the line grows, so does the waiting time and the variance in waiting times, and vice versa. As a result, a multiple linear regression model based on the gathered data was created to describe the fluctuations in the waiting time. Equation (2) represents the traffic flow data divided into seven kinds of vehicles and the vehicle waiting time. Due to the low proportion of trailer vehicles in the field data, the multi-axle vehicle (MAV) and trailer vehicle are mixed in Equation (2). The relationship between waiting delay vs volume is presented in Fig.8 and found as delay increases with an increase in the traffic volume.

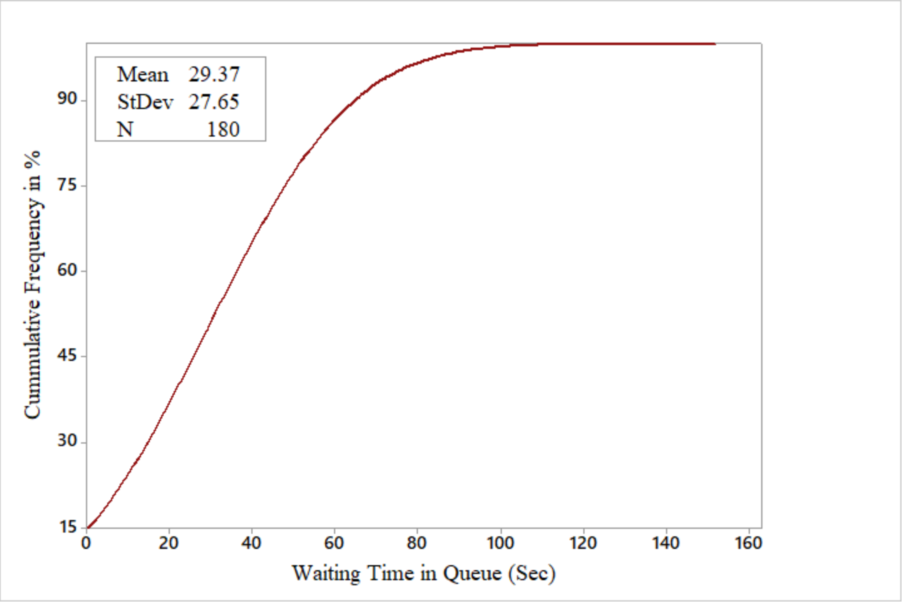


Fig.8Cumulative frequency curve of waiting time in queue (Sec)

A linear equation developed is presented below:

$\mathbf{D_1 = a_1 * N_{SC} + a_2 * N_{BC} + a_3 * N_{LCV} + a_4 * N_{HCV} + a_5 * N_{MAV} + a_6 * N_{BUS} + a_7 * V}$. . . . . .Eq(2)

Where,
N_{SC} = Number of Small Cars in the queue,
N_{BC} = Number of Big Cars in the queue,
N_{LCV} = Number of Light Commercial Vehicles in

the queue,
N_{HCV} = Number of Heavy Commercial Vehicles in the queue,
N_{BUS}= Number of Buses in the queue,
N_{MAV} = Number of Multi Axle Vehicles and trailers in the queue,
V = Approach Volume in vehicle/hr,
a_1 - a_7 = Regression coefficients.

Regression analysis in the MINITAB software is used to estimate the regression coefficients a1–a7 based on field data. The mix of traffic composition at various locations can affect how long a car waits in line. Coefficients a1 through a7 are therefore anticipated to differ. The volume of approach traffic and the number of vehicles in the queue should both be viewed as separate variables because the arrival of any vehicle at a tollbooth is independent of the arrival of the subsequent vehicle. The regression coefficients a1–a7 that were derived from field data using MINITAB software's regression analysis are listed below.

The waiting times in queue with a number of vehicles and histogram for waiting time in queue are presented in Fig. 9 and Fig.10 respectively.

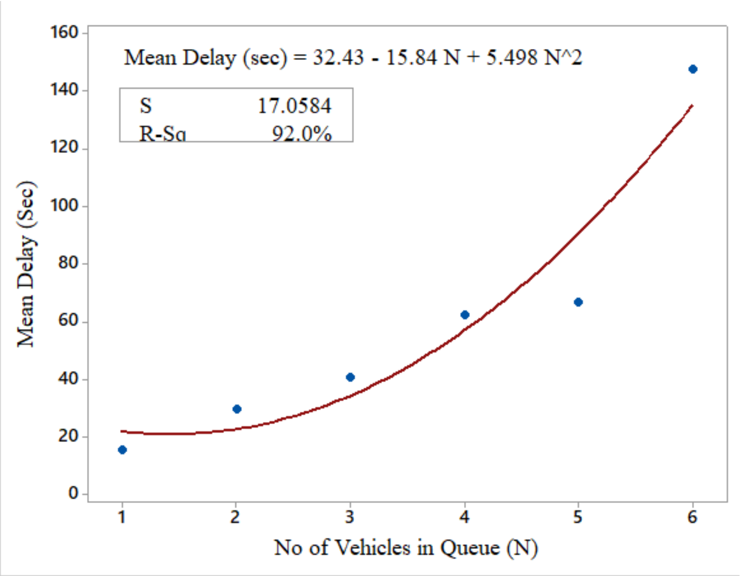


Fig. 9 Plot showing relation ofwaiting time in queue with number of vehicles

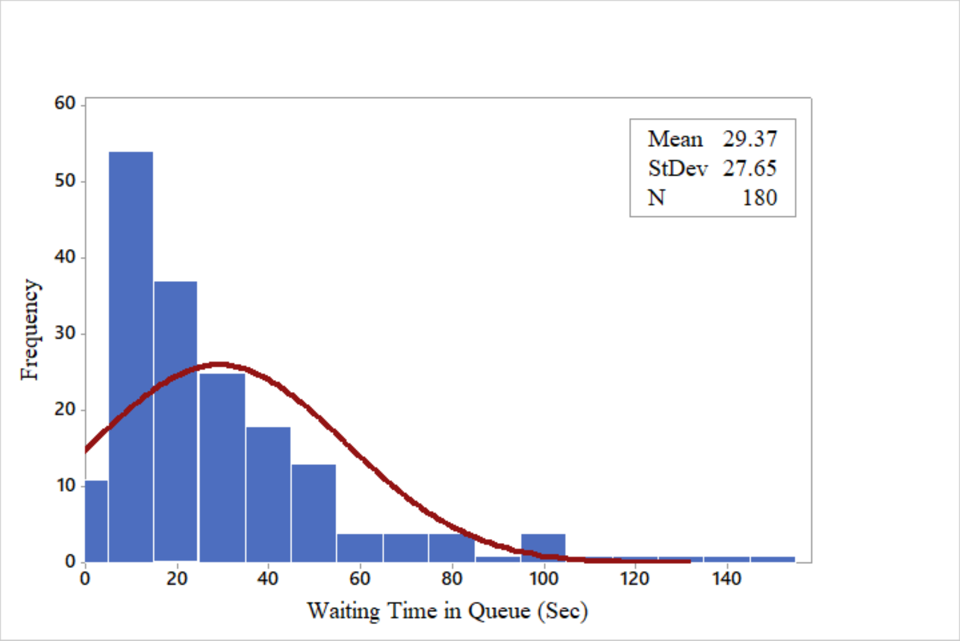


Fig. 10 Histogram for waiting time in queue

Regression analysis has been carriedout and waiting delay model of vehicle is developed. The details of waiting delay model are presented below:

$$\mathbf{D_1= 9.82N_{SC}+11.54N_{BC}+31.06N_{LCV}+22.86N_{HCV}+21.88N_{MAV}+22.37N_{BUS}-0.0303V} \ldots \text{Eq(3)}$$

$(R^2 = 0.78)$

Where,
N_{SC} = Number of Small Cars in the queue, N_{BC} = Number of Big Cars in the queue, N_{LCV} = Number of Light Commercial Vehicles in the queue, N_{HCV} = Number of Heavy Commercial Vehicles in the queue, N_{BUS} = Number of Buses in the queue, N_{MAV} = Number of Multi Axle Vehiclesincluding trailers in the queue, V = Approach Volume in vehicle/hr,

5.3.2Service time (D2)

Using a 30-min classified traffic volume, the interactions between all vehicle classes and their service time variations owing to traffic composition and volume were observed. The service time of each type of vehicle, its traffic volumes, and the makeup of the vehicles was retrieved for each count period. Then, simultaneous equations were created to determine how long each type of vehicle will last in service. Figures 11 and 12 show, respectively, the specifics of the service time of each type of vehicle with log-normal distribution and the derived time of the vehicles observed and the following equation has been utilized to estimate these service durations for each type of vehicle.

$$\mathbf{Log_e[ST_k]=}\ a_1\mathbf{(P_j)} + \mathbf{a_2(P_k)} + \mathbf{a_3(P_l)} + \mathbf{a_4(P_m)} + \mathbf{a_5(P_n)} + \mathbf{a_6(P_o)} + \mathbf{a_7(P_p)+ a_8(N)}. . . . .\text{Eq(4)}$$

Where, ST_k = Service time of vehicle category k (in seconds), P_j = Proportion of vehicle type k in traffic stream (%), N = Number of Vehicles served during an hour. The regression coefficients a_1-a_8 are estimated from field data by regression analysis.

Due to the various proportions of vehicles from various categories influencing an average vehicle type's service time, coefficients a1 to a8 are calculated. All vehicles arrive at the toll booth independently of the next vehicle's arrival time. The volume and character of the traffic should therefore be regarded as an independent variable when determining a vehicle type's service time. These independent variables have been combined to create a correlation matrix. None of these independent variables have been found to have a strong correlation with other independent variables. The regression coefficients a1 to a8 as stated in Equations (5) to Equation (11), which were computed from field data.

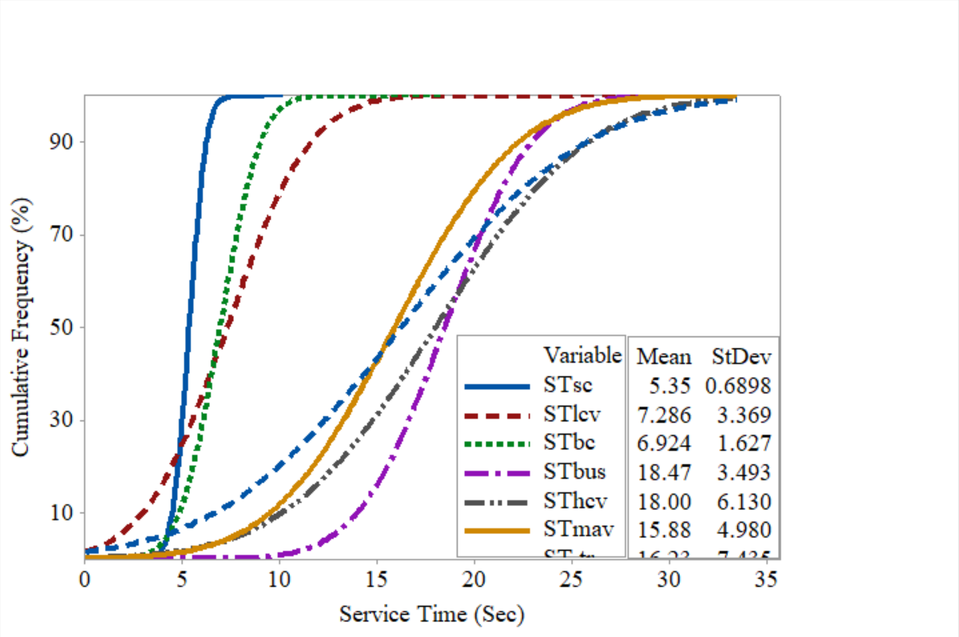


Fig. 11 Cumulative plot showing service time for all vehicle categories

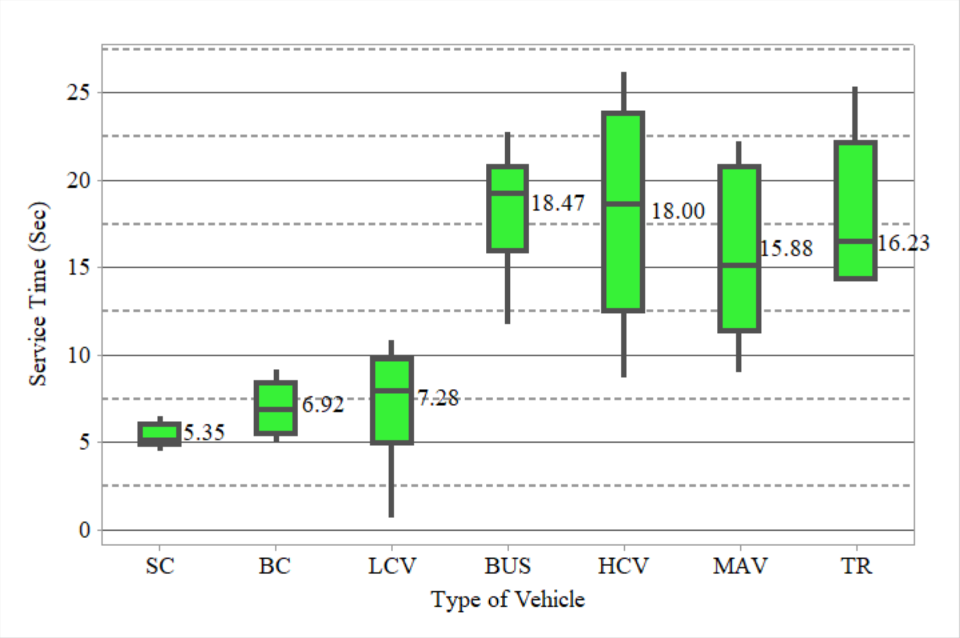


Fig. 12 Service time for all vehicle categories

Service delay model for small car are presented in Fig. 13 and the model developed from this analaysis is presented in Eq. 5

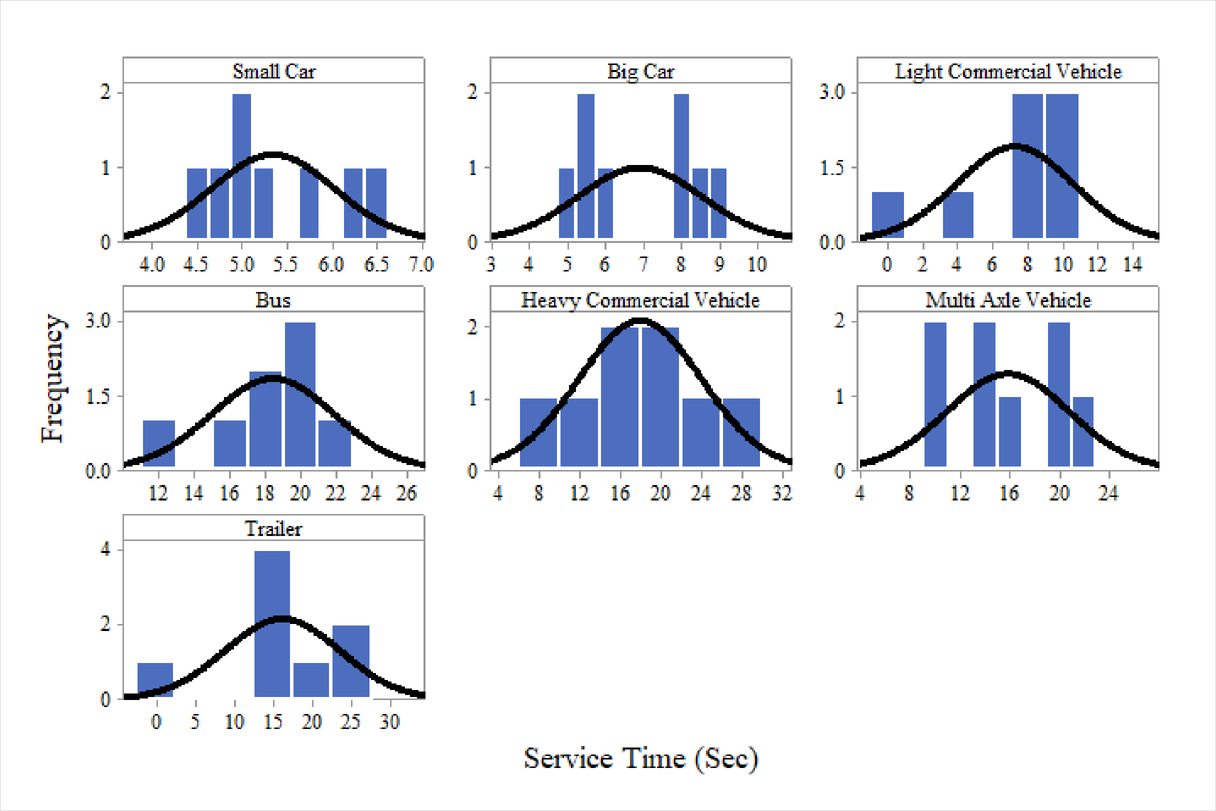


Fig. 13 Lognormal distribution for service time for each vehicle type

Ln $[\mathbf{ST_{SC}}]$**= 0.0140** $\mathbf{P_{(sc)}}$ **+ 0.008** $\mathbf{P_{(bc)}}$ **+ 0.060** $\mathbf{P_{(lcv)}}$ **- 0.006** $\mathbf{P_{(bus)}}$**+ 0.043** $\mathbf{P_{(hcv)}}$ **- 0.0008** $\mathbf{P_{(mav)}}$ **+ 0.082** $\mathbf{P_{(tr)}}$ **- 0.0006 N**.. . . . . .Eq(5)
(R^2=0.90)

Where, $\mathbf{ST_{SC}}$ = service time of small cars, $\mathbf{P_{(sc)}}$ = Proportion of small cars, $\mathbf{P_{(bc)}}$ = Proportion of big cars, $\mathbf{P_{(lcv)}}$

= Proportion of light commercial vehicles, $\mathbf{P_{(bus)}}$= Proportion of buses, $\mathbf{P_{(hcv)}}$ = Proportion of heavycommercial vehicles, $\mathbf{P_{(mav)}}$= Proportion of multi axle vehicles, $\mathbf{P_{(tr)}}$= Proportion of trailers, **N** = Volume(veh/hr).

The details of service delay model developed are presented below (Eq. 6):

$$\mathrm{Ln}\ [ST_{BC}] = -0.0207\, P_{(sc)} + 0.021\, P_{(bc)} + 0.116\, P_{(lcv)} - 0.075\, P_{(bus)} + 0.065\, P_{(hcv)} - 0.0447\, P_{(mav)} + 0.042\, P_{(tr)} + 0.01090\, N \ldots\ldots\ldots\ldots \mathrm{Eq}(6)(R^2=0.94)$$

Where, $\mathbf{ST_{BC}}$= service time of big cars, $\mathbf{P_{(sc)}}$ = Proportion of small cars, $\mathbf{P_{(bc)}}$ = Proportion of big cars, $\mathbf{P_{(lcv)}}$ = Proportion of light commercial vehicles, $\mathbf{P_{(bus)}}$= Proportion of buses, $\mathbf{P_{(hcv)}}$ = Proportion of heavy commercial vehicles, $\mathbf{P_{(mav)}}$ = Proportion of multi axle vehicles, $\mathbf{P_{(tr)}}$ = Proportion of trailers, **N** = Volume(veh/hr).

Regression analysis has been carriedout and Service delay model for low commercialvehicle developed is presented below (Eq. 7):

$$\mathrm{Ln}\ [ST_{LCV}] = 0.185\, P_{(sc)} - 0.128\, P_{(bc)} - 0.129\, P_{(lcv)} + 0.084\, P_{(bus)} - 0.202\, P_{(hcv)} + 0.181\, P_{(mav)} + 0.475\, P_{(tr)} - 0.00279\, N \ldots\ldots\ldots\ldots \mathrm{Eq}(7)(R^2=0.95)$$

Where, $\mathbf{ST_{LCV}}$= service time of light commercial vehicle, $\mathbf{P_{(sc)}}$ = Proportion of small cars, $\mathbf{P_{(bc)}}$ = Proportion of big cars, $\mathbf{P_{(lcv)}}$ = Proportion of light commercial vehicles, $\mathbf{P_{(bus)}}$= Proportion of buses, $\mathbf{P_{(hcv)}}$ = Proportion of heavy commercial vehicles, $\mathbf{P_{(mav)}}$ = Proportion of multi axle vehicles, $\mathbf{P_{(tr)}}$ = Proportion of trailers, **N** = Volume(veh/hr).

Regression analysis has been carriedout and Service delay model for high commercial vehicle is presented below (Eq. 8):

$$\mathrm{Ln}\ [ST_{HCV}] = 0.0807\, P_{(sc)} - 0.0688\, P_{(bc)} - 0.149\, P_{(lcv)} + 0.083\, P_{(bus)} - 0.0474\, P(hcv) + 0.0988\, P_{(mav)} + 0.368\, P_{(tr)} + 0.00732\, N \ldots\ldots\ldots\ldots \mathrm{Eq}(8)(R^2=0.98)$$

Where, $\mathbf{ST_{HVC}}$= service time of heavy commercial vehicles, $\mathbf{P_{(sc)}}$ = Proportion of small cars, $\mathbf{P_{(bc)}}$ = Proportion of big cars, $\mathbf{P_{(lcv)}}$ = Proportion of light commercial vehicles, $\mathbf{P_{(bus)}}$= Proportion of buses, $\mathbf{P_{(hcv)}}$ = Proportion of heavy commercial vehicles, $\mathbf{P_{(mav)}}$ = Proportion of multi-axle vehicles, $\mathbf{P_{(tr)}}$ = Proportion of trailers, **N** = Volume(veh/hr).

The details of service delay model developed for MCV are presented below.

$$\mathrm{Ln}\ [ST_{MAV}] = 0.0302\, P_{(sc)} + 0.0251\, P_{(bc)} - 0.210\, P_{(lcv)} + 0.143\, P_{(bus)} - 0.0527\, P(hcv) + 0.0555\, P_{(mav)} + 0.332\, P_{(tr)} + 0.00663\, N \ldots\ldots\ldots\ldots \mathrm{Eq}(9)(R^2=0.98)$$

Where, $\mathbf{ST_{MAV}}$= service time of multi-axle vehicle, $\mathbf{P_{(sc)}}$ = Proportion of small cars, $\mathbf{P_{(bc)}}$ = Proportion of big cars, $\mathbf{P_{(lcv)}}$ = Proportion of light commercial vehicles, $\mathbf{P_{(bus)}}$= Proportion of buses, $\mathbf{P_{(hcv)}}$ = Proportion of heavy commercial vehicles, $\mathbf{P_{(mav)}}$ = Proportion of multi axle vehicles, $\mathbf{P_{(tr)}}$ = Proportion of trailers, **N** = Volume(veh/hr).

The details of service delay model developed for Buses are presented below.

$$\mathrm{Ln}\ [ST_{BUS}] = 0.0263\, P_{(sc)} - 0.0090\, P_{(bc)} + 0.033\, P_{(lcv)} - 0.014\, P_{(bus)} + 0.0462\, P_{(hcv)}) + 0.0102\, P_{(mav)} + 0.216\, P(tr) + 0.00697\, N \ldots\ldots\ldots\ldots \mathrm{Eq}(10)(R^2=0.98)$$

Where, $\mathbf{ST_{SC}}$ = service time of bus, $\mathbf{P_{(sc)}}$ = Proportion of small cars, $\mathbf{P_{(bc)}}$ = Proportion of big cars, $\mathbf{P_{(lcv)}}$ = Proportion of light commercial vehicles, $\mathbf{P_{(bus)}}$= Proportion of buses, $\mathbf{P_{(hcv)}}$ = Proportion of heavy commercial vehicles, $\mathbf{P_{(mav)}}$ = Proportion of multi axle vehicles, $\mathbf{P_{(tr)}}$ = Proportion of trailers, **N** = Volume(veh/hr).

The details of service delay model developed for trailers are presented below.

$$\mathrm{Ln}\ [ST_{TRAILER}] = 0.260\, P_{(sc)} - 0.308\, P_{(bc)} - 0.141\, P_{(lcv)} + 0.068\, P_{(bus)} - 0.320\, P(hcv) + 0.304\, P_{(mav)} + 1.503\, P_{(tr)} + 0.00274\, N \ldots\ldots\ldots\ldots \mathrm{Eq}(11)(R^2=0.98)$$

Where, $\mathbf{ST_{SC}}$ = service time of trailer, $\mathbf{P_{(sc)}}$ = Proportion of small cars, $\mathbf{P_{(bc)}}$ = Proportion of big cars, $\mathbf{P_{(lcv)}}$ =

Proportion of light commercial vehicles, **P$_{(bus)}$**= Proportion of buses, **P$_{(hcv)}$** = Proportion of heavy commercial vehicles, **P$_{(mav)}$** = Proportion of multi axle vehicles, **P$_{(tr)}$** = Proportion of trailers, **N** = Volume(veh/hr).

5.3.3 Validation of the estimated delays

Using information retrieved from the video, such as the number of cars in the line, the types of cars, and the volume of traffic, it is possible to anticipate the waiting time and system delay for various kinds of vehicles. In order to validate the delay prediction model developed in this study, the projected values of delays experienced by cars passing through the toll plaza are compared with the field observed values of such delays. The estimated delay and the actual delay for all vehicles are depicted in Fig. 14. A good fit between the two sets of delay values can be seen in how closely various categories of vehicle delay values match the observed values.

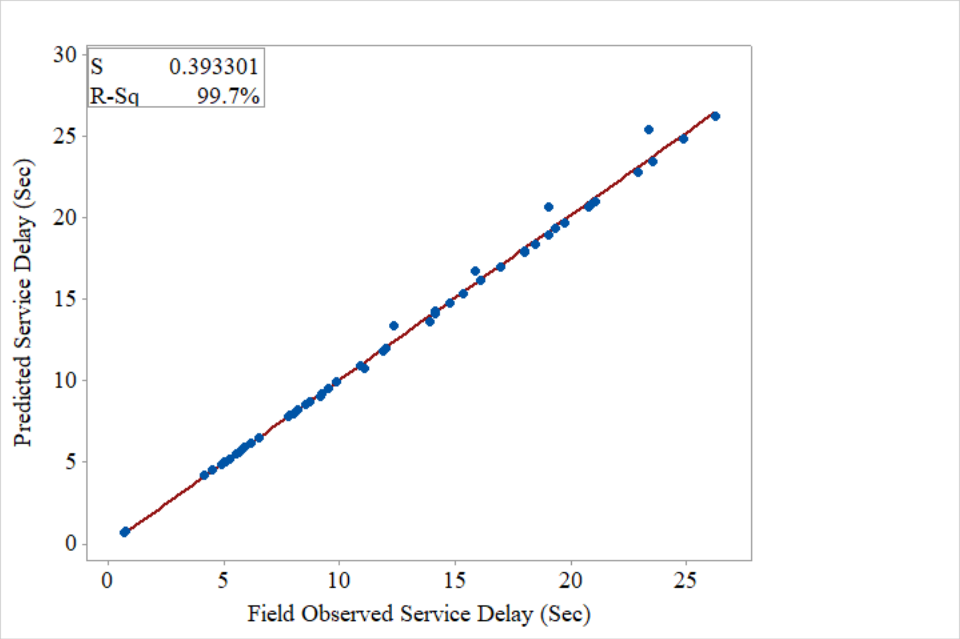


Fig. 14 Scatterplot showing predicted service delay vs field observed service delay

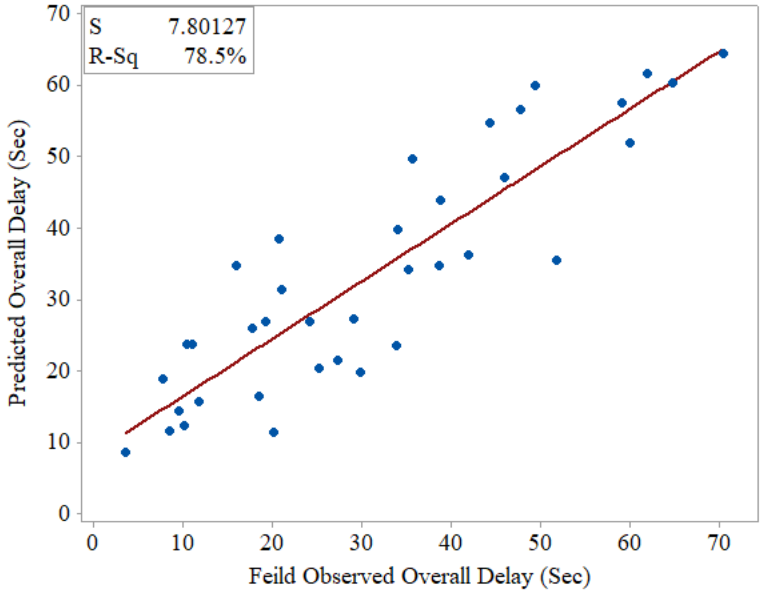


Fig. 15 Scatterplot showing predicted total delay vs field observed total delay

6. CONCLUSIONS

6.1 General conclusions

One of the most crucial factors used to assess the effectiveness of toll plazas is the delay. A higher delay indicates less effective toll plaza operation. System delay is the most frequently used parameter in studies, according to the delay modelling studies that have been discovered in the literature. As a result, the current study has suggested using the system delay model at RFID-operated toll plazas under mixed traffic scenarios. Video-graphic technology is being used at toll plazas in India to collect traffic data in order to research the variation in driver traits and tollbooth operations. The waiting time in a line and the service time are both included in the system delay taken into account in this study.

Additionally, logarithmic regression analysis has been used to build the service delay model equations for various vehicle classifications. Policymakers and tollbooth operators can predict system delays for approaching vehicles at RFID-operated toll plazas in mixed traffic flow situations using the findings of this study. The proposed delay model may be useful for identifying delay-nullifying actions, such as the adoption of ITS tools or devices with a dynamic tolling system based on peak hour demand. The delay modelling will also be used to assess the effectiveness of any toll plaza installed using ITS tools in terms of LOS.

6.2 Specific conclusions

A multiple linear regression model has been developed for the estimation of waiting and service delays at toll plazas operating with RFID technology. The findings of the present study are presented below:

a) The waiting and service delays as obtained from the delay model are slightly less than that of actual values.
b) The maximum waiting time of a vehicle in queue is 152 sec which within the limits as per IRC:SP:84(2014).
c) The minimum waiting time for a vehicle in the queue is 2 sec.
d) The average waiting time of a vehicle in the queue is 29.36 sec
e) The R^2-value of the waiting delay model is 0.76 which indicates satisfaction with the observed values of field delays.
f) The average service times for the observed small car was 5.35 sec, the big car was 6.92 sec, a light commercial vehicle was 8.58sec, a heavy commercial vehicle was 18 sec, the bus was 18.47sec, the multi-axle vehicle was 15.88 sec and that of trailer was16.23 sec.
g) The R^2 value of the service delay model is varying from 0.92 to 0.98 for different vehicles. So, the calculated values are strongly in correlation with the field observed values.

Declaration

The authors declare no competing financial interest.

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