International Journal of Applied Engineering & Technology

TRAFFIC FLOW SIMULATION AND DEVELOPMENT OF DELAY MODELS AT TOLL PLAZAS UNDER HETEROGENEOUS TRAFFIC CONDITIONS

GVLN Murthy[1], Dr. D. Ram Prasad Naik[2] and Dr. M Anjan Kumar[3]
[1.]Research Scholar, GIET University, Gunupur, Odisha State, India
[2]Professor, GIET University, Gunupur, Odisha State, India
[3]Principal, D.N.R College of Engineering and Technology, Bhimavaram, West Godavari District, Andhra Pradesh State, India
[1]gvln.murthy@giet.edu, [2]dnaik@giet.edu, [3]principal@dnrcet.org

ABSTRACT
The traffic in metropolitan cities, particularly in India, is extremely complicated. Due to varying traffic conditions, road safety and congestion reduction have become major concerns for vehicle users, resulting in increased delays for moving vehicles. A public or private road that collects taxes for use is referred to as a toll road. It is a form of road pricing that is comparable to a taxing state and often used to assist cover the costs of road development and operation. The current work highlights the significant issues encountered on toll roads. The delays caused by vehicle users at toll plazas are of primary concern because they result in loss of productive time and fuel. On the chosen stretch, there are two typical toll plazas that are manually operated, and toll plazas that use RFID are chosen for the current study. As a general design goal, these toll plazas are designed so that vehicles spend the least amount of time queuing in these areas. In this regard, an analysis was carried out at these selected toll plazas (manually and RFID operated) based on queuing theory, which is dependent on specific parameters such as flow rate, service rate, number of lanes, and delay occurring. Delay models were created using the regression analysis technique. These models are statistically validated, and another hypothesis test, such as auto correlation, is used to validate the developed model.

Index Terms – Regression Analysis, RFID, Traffic Delays, Traffic Simulation.

INTRODUCTION
Transportation engineering is the use of Science and Technology to the planning, operational design, and administration of facilities for any mode of transportation to assure the efficient, cost-effective, quick, comfortable, convenient, and good for the environment flow of people and products. Since Ashurbanipal's rule in the seventh century B.C., when travellers on the Susa-Babylon highway were required to pay tolls, toll roads have been around for at least the past 2,700 years. Aristotle and Pliny both mention tolls in relation to Arabia and other regions of Asia. The Artha-shastra states that tolls were utilized in India before 4th century B.C. In the United States, new toll road building increased considerably throughout the first two decades of the twenty-first century as states sought out ways to construct new highways without depending on federal financing, to create cash for ongoing road maintenance, and to decrease congestion. These are two innovations—the electronic toll collecting system and the Iintroduction of high occupancy and express lane tolls—lead to significant road construction projects in many parts of the United States, particularly in major urban centers. By eliminating toll collectors from the road, electronic toll collection, first used in the 1980s, lowers operating costs. By allowing free-to-use roadways to collect payment and enabling cars to bypass traffic congestion by paying a toll, tolling for express lanes, which designates specific lanes of a motorway as "toll only," increases income. The E-Z pass system, which is utilized for both fast lanes and completely tolled highways, is the largest E.T.C. system in the United States. It works with a variety of state systems. The first toll road without toll booths was built in Carolina. Drivers were billed by mail and taxed using optical license plate recognition or E.T.C. Tolls are collected to recoup the whole capital expenditure, which includes the cost of building, fixing, maintaining, operating the toll facility, and adding interest to the purchase price. The newly constructed facility should offer faster travel times and better service. Public-private partnerships serve as the foundation for the vast majority of roadway construction in India. The facility is financed and constructed by a private entity, and the toll tax recovers the

users' investment. The facility will become publicly owned and transferred if this tax is fairly collected. In an effort to clear the streets and cut pollution, a toll levy on parking for vehicles in cities has recently been put in place. This process is termed as Congestion pricing.

1.1 Definition of Toll Plaza

Toll systems are intended to benefit road users by reducing the average travel time, increasing speed and safety, and increasing the capacity of road sections.

1.2 Types of Tolls Plazas

There are two types of the plaza

1. Open toll plaza

2. Closed toll plaza

Not every customer has to pay a toll under an open toll system. In such a system, the toll booth is frequently located outside of the city. In a closed toll system, customers pay the toll in accordance with the facility and vehicle category. There are plazas at each point of entry and exit in a closed toll system. The collector writes the customer a ticket and determines a fee based on the type of vehicle and the distance travelled.

1.3 Methods of Toll Collection

There are three ways to collect tolls, which are as follows:

1. Manual toll collection
2. Automatic toll collection
3. Electronic toll collection

1.3.1 Manual toll collection

In India, it is the most typical way of collection. It requires a toll collector or attendant to be present. Depending on the classification of the vehicle, the collector receives a cash toll. Scrip, tickets, and coupons may be purchased and sold by the collector, who also gives out change. The collector registers the customer's vehicle in the system and gives them a receipt. The processing time is the longest because there is manual intervention.

1.3.2 Automatic toll collection

It means utilising an automatic coin dispenser (A.C.M.). Coins and tokens of the operating agency are both accepted. Depending on the toll rate, switching from manual to electronic cash or token collection reduces operating costs and transaction and processing times.

1.3.3 Electronic Toll Collection (E.T.C.)

A vehicle travelling through a toll lane or checkpoint with a working encoded data tag or transponder is recognised by the system. The customer no longer needs to stop and pay the toll because the E.T.C. system applies a debit or charge to their account. Considering that there is no need for stops to pay the toll, E.T.C. stretches the road all the way around.

1.4 RFID (Radio-Frequency Identification)

Tags connected to items are automatically recognised and tracked by electromagnetic fields. Information is electronically stored on these tags.

Tags come in two varieties:

1. Active tags

2. Passive tags

1.4.1 Since active tags have a local power supply, they can function hundreds of metres distant from the RFID reader (such a battery).

1.4.2 The interrogating radio signal from a nearby RFID scanner provides power to passive tag.

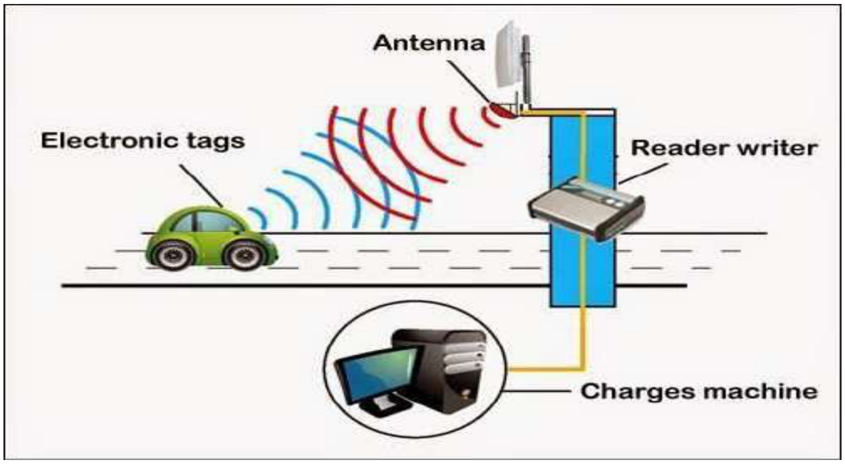


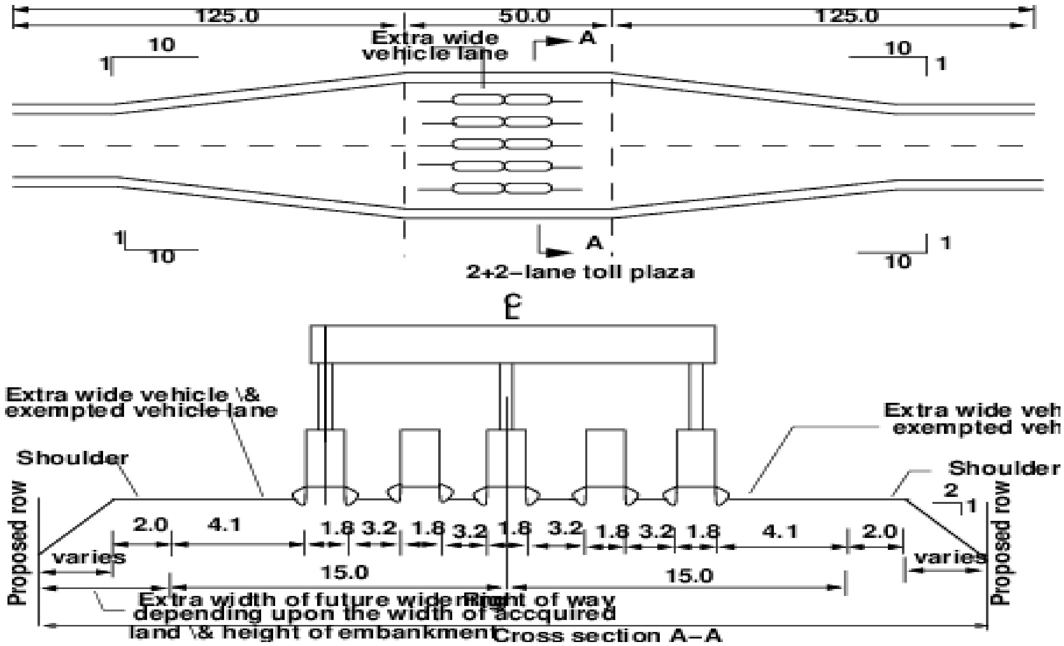
Fig 1 RFID Tag
(**Source:** www.rfid-smart.com/blog/rfid-journal/how-to-track-vehicles-with-rfid.html)

1.5 Toll Plaza Design Specifications
The concessionaire is expected to provide the necessary quantity of Toll Plazas for toll collection under the terms of the concession agreement. The system for collecting fees must be rapid, effective, and easy to use.

1.5.1 General Layout
Initially, the number of lanes corresponds to the number of toll booths in the line-up area. After passing through the toll booth, the number of routes returns to the original width of the roadway, which is two lanes. On the left side of the street, there is a lane designated for extra-wide and exempt cars. Furthermore, some extra room has been reserved in case the plaza has to expand in the future.

The design specification for the flared portions is listed below as per IRC SP084:2014.

1. Lane width should be 3.2 metres in general and 4.5 metres for large vehicles.
2. Median width, (a) = 1.8 m length,(b) = 25m.
3. A transition from one in twenty to one in ten might be made available at a toll booth on either side of the four-lane section.



1.5.2 Tunnels
An underground tunnel spanning all toll lanes must be constructed for passage between the toll office for each toll lane and the toll booth. Its measurements would be sufficient to allow for both the requested wring/cable system and easy team movement.

1.5.3 Number of Toll Lanes
In order to guarantee a service time of no longer than 10 seconds per car during peak flow, there must be enough toll booths and lanes overall, regardless of the method used to collect revenue.

1.5.4 Semi-automatic toll lane
240 vehicle /hour (Vehicle identification is automatic, however fees are paid manually)

1.5.5 Electronic toll collection (E.T.C. lanes)
1200 vehicle/hour

(No vehicle stops for toll collection using the on-board unit)

When using the E.T.C. payment system, two toll lanes in each direction of travel must be taken into account.

1.5.6 Canopy
Both toll lanes and toll booths must have a canopy over them. The canopy needs to be big enough to protect the facilities from the elements as well as toll collectors and drivers.

1.5.7 Drainage
A surface and subsurface drainage system must be installed in the toll plaza to guarantee that all storm water is effectively drained and that no areas of the toll plaza experience ponding or stagnant water.

1.5.8 Equipment for Toll Lanes
A microcontroller-based vehicle tracking cum classifier device is required in each entry lane to count the number of cars, their axle numbers, and to determine the kind of automobile. The entrance lane controller, which operates the entry lane equipment and transmits information to the processing facilities at the toll plaza office, is also a required component of the semi-automatic toll collecting system. It gives user charges tickets at the touch of a

button on a touch screen. A synchronized traffic light system and an electronically actuated boom barrier are required for each toll lane.

1.5.9 Pavement

Concrete pavement must be constructed in the toll plaza area and the tapering zone in order to ensure the provision of toll lanes originally intended for anticipated peak hour traffic of ten years, from the standpoint of durability and long-term serviceability.

1.6 Queuing Theory

The study of lines or queues from a mathematical perspective is known as queuing theory. To predict queue sizes and wait durations, a queuing model was created.

1.6.1 Characteristics of queuing system

a. **The procedure for a vehicle to arrive:** The probability density distribution determines when consumers or vehicles enter the system.

b. **The service process that facilitates department:** The service times for system users and vehicles are set by the probability density distribution.

c. **The quantity of servers:** how many servers are available to meet the needs of customers or cars.

To solve a queuing problem, it is important to evaluate a system's performance, which is defined by a set of performance measurements.

The inputs include the following:

1. The input feature (arrival rate)
2. The finite or infinite input source
3. FIFO/LIFO queue discipline
4. The setup of the channels (Number and arrangement)
5. The delay period (service rate)

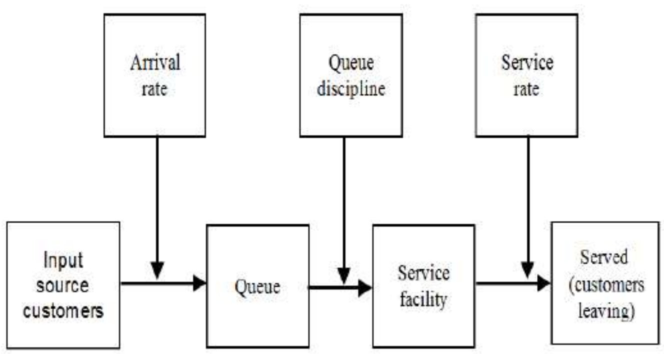


Fig. 2 queuing systems

1.6.2 A service facility's average customer arrival rate is expressed in flow (vehicles/hour) or time headway (Seconds or vehicles).

1.6.3 The factor that explains how consumers arrive at a service location is queue discipline.

The various queuing disciplines include

a) First in, first out [FIFO]
b) First in last out [FILO]

c) Serviced in a random order [SIRO]

d) Priority scheduling

1.6.4 Queuing System Classification

The following convention can be used to categorise queuing systems based on the mentioned features: *A/S/N*

Where, A= Arrival rate nature

S= Service process that defines the departure rate nature and

N= number of servers

Any of the following can define the nature of A and S

M (Markovian, i.e., random): The inter arrivals of vehicles assume Poisson's distribution (use exponential probability density function).

D (Deterministic): Every user who joins the line demands a certain quantity of service that is safe and predictable.

G (General): any broad or random probability distribution (with known mean and variance)

1.6.5 Assumptions made in a simple queuing approach as applied to traffic flow

The queuing theory will be developed based on the following assumption as applicable to the traffic flow:

In a steady state, the system has "settled down. This concept is true only when the patterns of arrival and service are constant over an extended period of time; it does not apply to peak conditions or cyclical behaviour. This implies that the traffic intensity is defined as ρ".

$\rho = (\lambda/\mu) < 1$

The average rate of arrival/average rate of service is less than 1

There is a limited quantity of customers.

There is an endless pool of potential clients.

Since the arrivals are random, the mean rate of arrival is determined by Poisson's distribution.

There won't be any concurrent arrivals.

There will be just one service channel, but numerous tracks can each use a distinct method modification.

1.6.6 Varying Arrival Rate and Constant Service Rate

The service rate does not change with time, however the rate in the left portion of the arrival does. While the right component takes into account all transition periods during changes in arrival rates, the left part is an estimate to make formulations and computations easier. Examples of daily traffic variations on a facility are shown in both sections.

1.7 OBJECTIVES OF THE STUDY

To assess, using a queuing theory, the performance of a few selected manually operated and RFID operated toll plaza stations at Unguturu and NH-16.

1. To analyze the performance of selected toll plaza stations situated at Unguturu and Ehakota on NH-16.
2. To suggest optimum no of toll plaza required during peak hours.
3. Comparison of service rate of RFID with manually operated toll plaza.

LITERATURE REVIEW

AL Deck 1997 studied the benefits of electronic toll collection from an operational standpoint and how plaza traffic operations have improved as a result of electronic collection of tolls. According to this investigation, the measured capacity for dedicated electronic toll collection lanes had tripled, service time for each vehicle had reduced by 5 seconds, the average waiting time had reduced by 2.5–3 minutes per vehicle, and the overall waiting time had reduced by 8.5–9.5 vehicle-hours per morning peak hour for that lane.

Zarrillo 1998 Researchers created the toll booth model (T.P. model), a macroscopic quantitative queuing model, to estimate peak hour traffic delays at toll plazas. It demonstrates how E.T.C. affects traffic management at toll collection facilities and considers the fact that queues are made up of a range of cars that require different services at different times.

According to this model, delays will rise as approach values climb, the proportion of vehicles using manual tolls will increase, and delays will fall as E.T.C. usage and the service rate for different services both had rised. The model was constructed using uniform arrival rates.

McDonald 2001 The design, construction, and operation of toll facilities have increased, as demonstrated in the United States. The adoption of computerized toll collecting has made it even more crucial to follow the minimal criteria that exist for toll plaza design. Previous studies revealed a number of shortcomings in toll plaza design. The vertical and horizontal geometrical specifications for toll plaza design are examined in this study. Current design documents, such as the manual on uniform traffic control devices (MUTCD), the highway capacity manual (H.C.M), and a strategy on the geometric design of roads and streets, do not sufficiently give the rules necessary to build a toll plaza successfully (commonly referred to as the "green book").

Boxma and Takine 2003 calculated the overall queue length distribution using FIFO service rules and customers from different classes in the M/G/I queue. One server queue with K customer classes that are served FIFO and without respect to priority makes up the model under consideration. Each class's customers come via a Poisson process.

Klodzinski and Al-deek 2004 analysed how open-road tolling was implemented. In this study, a mainline toll plaza had two E.T.C. lanes added, which improved operational conditions during rush hour. According to the survey, The average wait per car was cut in half by A.C.M. lanes and by 8 seconds by manual cash lanes. The average lane delay was decreased for A.C.M. lanes by over 4560 seconds and for manual routes by 3360 seconds. A 43.8% increase in capacity was attained as a result of the introduction of open road tolling. Although a lot of work has been put into simulating toll plaza wait times and creating mathematical models, it is not entirely acceptable that these models use deterministic arrival and service rates.

Dirluba Ozmenertekin 2007 It was created an analytical delay model that takes into consideration the additional travel time brought on by acceleration, paying tolls, deceleration, and line waiting. The model was calibrated using a stochastic microsimulation model. The outcomes showed that the delay model could generate estimates that were 10% or less off from the simulated values. The delay model should be used for initial screening of different designs and techniques, the author advised, as well as future research to see whether the model can accurately estimate delay based on field data.

Zarillo 2009 Plaza capacity and performance can be determined at toll collection facilities with the help of traffic modelling. It might assist planners and operators in determining which lane configurations are suitable for specific hourly approach volumes and vehicle types. It is possible to use it to locate bottlenecks on a network of toll roads. To do this, the plaza's capacity is contrasted with an adjacent highway section. The state of the road both before and after the plaza, the characteristics of the oncoming traffic, and other variables are all relevant. Toll plaza throughput can be increased by selecting a lane structure with an appropriate number of dedicated electronic toll collecting lanes that match to the expected traffic demand.

K.I.M. 2010 When toll plazas are simulated, the dependability of toll plaza performances, such as line length and waiting time, depends on the accuracy of traffic flow data. This study examines how toll plaza performance is aware of additional traffic.

In order to investigate the concept of traffic flow, this study evaluated projected traffic levels for a proposed toll bridge in eastern North Carolina. Toll plaza performance indicators such as average queue length, average waiting time, maximum queue length, and maximum waiting time were compared across two different types of anticipated traffic volume representations. Predictable traffic counts for a certain time period can be used as an input parameter to generate the flow of traffic in a simulation model rather than taking into consideration a probabilistic distribution. Users with less simulation modelling experience will benefit from the traffic generating module's simplicity of design.

Spiliopoulou 2010 In circumstances where the overall volume exiting from tolls exceeds the capacity of the downstream highway, bridge, or tunnel, generating congestion and poorer efficiency due to capacity drop, a simple real-time merging traffic control solution is offered for effective toll plaza management. The core concept for a particular toll plaza, which is based on the Oakland-San Francisco Bay bridge plaza in California, is illustrated via microscopical simulation. It is demonstrated that the concept might considerably reduce delays and throughput, with the amount of fine-tuning required for future field applications being limited due to low sensitivity. The proposed concept backs a variety of possibilities and goals. The theory is especially demonstrated to be equally suitable for circumstances in which lanes are only partially regulated, i.e., when some vehicle categories, such as buses, H.O.V.s, and emergencies, are permitted to pass without being metered.

Dheeraj Duhan 2014 If the amount of traffic on the roadway keeps increasing until it is out of control, the arrival time becomes unmanageable. Thus, one of the undeniable disadvantages of creating toll plazas is traffic congestion. The congestion causes the route commentators to endure uncomfortable waiting times in the service lanes. The purpose of this study is to use queuing theory to examine the existing situation of traffic congestion at highway toll plazas and to propose alternative solutions to promote greater efficiency, hence reducing customer waiting times and money lost as a result. The problem identification phase of this study was followed by the outcomes at the chosen toll plaza in north India.

Feng Zhang 2017 The capacity of the highway has always been constrained by the toll station, which functioned as its bond. To evaluate the shortcomings of conventional toll stations, the thesis creates a quantitative model of power and computes two evolution indicators based on probability distributions and queuing theory.

METHODOLOGY

Developing delays at toll plazas using analysis simulation of methodology, which is explained in the flow chart.

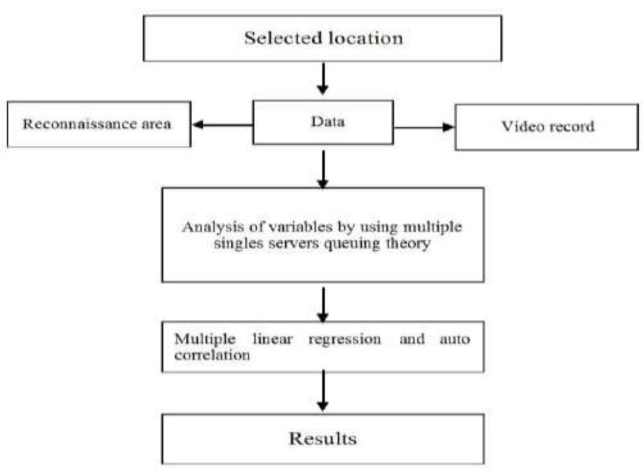


Fig. 3 Flow Chart

3.1 Selected locations

Study area is Unguturu toll plaza located on Vijayawada-Visakhapatnam highways NH-16, which is having highest traffic potential. Along with the toll plaza, there are developing industrial areas and capital formation nowadays. Another toll plaza is Ethkota which is also situated on the same highway.

3.2 Analysis of Variables By Using Queuing Theory Multiple Single Servers Model

The mathematical study of lines or queues is known as queuing theory. In order to forecast line lengths and waiting periods, a queuing model is developed.

A toll plaza with an exponential distribution of arrival and service rates is modelled using the multiple single server model. The vehicles arrive at these identical separate parallel servers in similar queues, yet they come from the same source.

1 Number of vehicles in the system on average = $\rho/(1 - \rho)$

2. Average number of vehicles waiting in line = $(\rho * \rho)/(1 - \rho)$

3. Average amount of time spent waiting = $1/(\mu - \lambda)$

4. Average length of time in line = $\lambda/(\mu(\mu - \lambda))$

5. Wasted time = $1/(\mu - \varphi /T)$

Where

ρ= utilization coefficient or traffic intensity

μ= service rate

λ=arrival rate

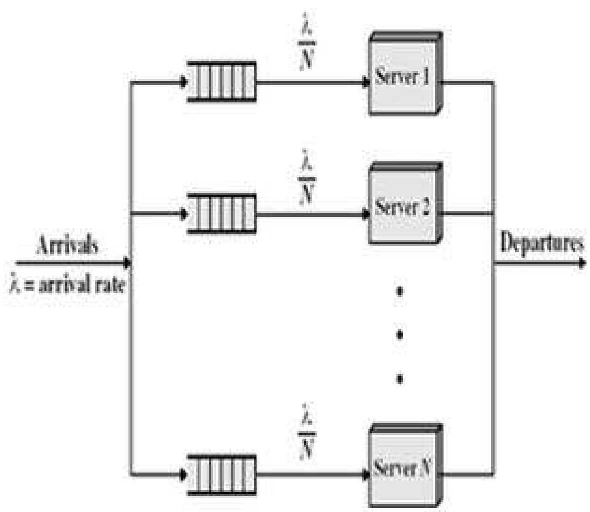


Fig.4 Multiple Single Servers

3.3 Multiple Linear Regression Analysis

The most popular statistical method for forecasting future congestion and figuring out the ideal number of toll booths is multiple linear regression analysis. When two or more independent factors are assumed to influence the amount of travel at the same time, this technique measures the separate influence of each factor acting in conjunction with the other elements.

$Y = K + b_1X_1 + b_2X_2 + b_3X_3 + ... + b_nX_n$

Where Y is the dependent variable (toll plaza), X1 to Xn are independent variables related to arrival rate, service rate, speed, and queue length, b1 to bn are the coefficients of each independent variable, and K is a constant to represent the portion of the dependent variable's value Y that is not explained by the independent variables.

The presented data in a typical regression analysis refers to the current values of the independent variables (X1 - X2) and the dependent variables (Y) for the toll plaza under investigation.

Statistical tests can be used to determine the statistical validity of the optimal number of toll plazas derived from multiple linear regressions. The multiple correlation coefficients R demonstrate how closely the independent variables and dependent variable Y are related. This coefficient has a range of 0 to 1. The R^2 value derived for developing the regression equation between the independent and dependent variables is actually the ratio of the sum of the squares explained by the regression to the variables. The ratio of the sum of squares is known as the coefficient of determination. It is generally expressed by the following equation.

$$\sum Y_o^2 = \sum e^2 + \sum Y_c^2$$

$$R^2 = \frac{\sum Y_c^2}{\sum Y_o^2}$$

Where $\sum Y_e^2$ is the sum of the square of the deviations explained from the regression line, $\sum Y_t^2$ is the total sum of squares representing the observed value's variance from the mean, and $\sum Y_0^2$ is the square root of the projected Y value magnitude's squared deviations from the values.

The correlation coefficient, or significance of R, is the root of the coefficient of determination. A substantial correlation between the dependent and independent variables is thus demonstrated by many coefficients of determination of 0.999.

The standard error of estimates indicates the degree of variation of data about the regression line constructed and is used to find the value of the regression equation for prediction purposes. Root mean square compares the quality of a matter of Y predicted for the present day situation using the regression equation with the observed value of Y, which is used to derive the regression equation and is calculated as under.

$$SEE = \frac{\sqrt{\sum (Y - Y_{est}^2)}}{N}$$

The test statistic shows the importance of each independent variable's regression coefficient in regression equations. The value of 't' is calculated by dividing the regression coefficient by the regression coefficient's standard error.

It must have a value of at least 2.0 to establish significance.

3.4 Auto Correlation

The lack of first-order autocorrelation in the disturbance is tested using the Durbin-Watson (D-W) test. The null hypothesis is H_o: $\rho = 0$

The D-W test statistic is

$$\frac{\sum_{t=2}^{n} (e_t - e_{t-1})^2}{\sum_{t}^{n} = e_t^2}$$

Positive auto correlation of $e_t's$ = d < 2

Negative auto correlation of $e_t's$ = d > 2

Zero auto correlation of $e_t's$ = d approx. 2 that lies between 0 and 4.

Since e depend on X, different values of (d) are produced for various data sets.

Durbin and Watson thus obtained two statistics, d1 and du, which are critical values of tabular data and have 5% significance levels in Durbin-Watson statistics.

They Prepared the table of critical values for 6 <n<200 and k<10 more than

Where

k = intercept

n = sample size

3.5 Data Collection and Analysis

Fig. 5 Unguturu Toll plaza

Fig. 6 Ethakotha Toll plaza

Table 1 Study Areas at Unguturu Toll Plaza.

S. NO	Parameter	Data Collected
1	No. of toll booths	6
2	Pavement Type	Flexible

3	pavement width	3.35m
4	Toll booth length	1.84m
5	Toll booth width	1.25
6	Type of merging	Merging at one point
7	Type of transaction	Manual

3.6 Modeling toll plaza Unguturu by using multiple single servers during peak hours observed data (manual)

N=6 lanes

λ per lane =135 PCU/hr

μ= 200 PCU/hr

ρ = (λ/μ) = 135/200 = 0.67

The system's average number of vehicles= ρ/(1-ρ) = 2 PCU

The average number of vehicles waiting in line = (ρ * ρ)/(1-ρ) = 1PCU

The average wait time for a system= (1/(μ-λ) = 48 sec

The average length of time spent in line = λ / (μ-(μ-λ) = 33 sec

Table 2 Observed at Unguturu Toll Plaza Input File For Graphs

Time (min)	Arrival rate (vehicle/hr)	Service rate (sec)
15	45	9
30	43	9
45	52	9
60	53	9
75	53	9
90	55	9
105	48	9
120	39	9

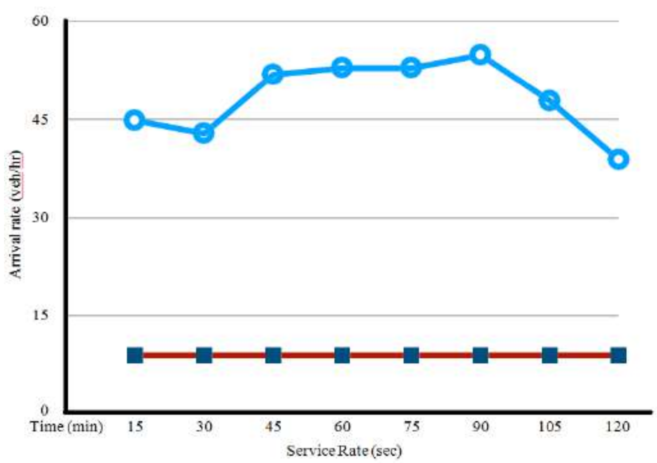


Fig. 7 Varying Arrival Rate and Constant Arrival Rate

Table 3 Study Area at Unguturu Toll Plaza RFID

S.NO	Parameters	Collected Data
1	Total NO of toll booths	6
2	Pavement Type	Flexible
3	pavement width	3.35m
4	Toll booth length	1.84m
5	Toll booth width	1.25
6	Type of merging	Merging at one point
7	Type of transaction	RFID

3.7 Modeling toll plaza Unguturu RFID by using multiple single servers during peak hours observed data

N=6 lanes

λ per lane =290 PCU/hr

μ= 600 PCU/hr

ρ = (λ/μ) = 290/600 = 0.48

The system's average number of vehicles = ρ/(1-ρ) = 1 PCU

The average number of vehicles waiting in line = (ρ * ρ)/(1-ρ) = 0PCU

The average wait time for a system = (1/(μ-λ) = 11 sec

The average length of time spent in line = λ / (μ-(μ-λ) = 5 sec

Table 4 Observed at Unguturu RFID Toll Plaza Input File For Graph

Time (min)	Arrival rate (vehicle/hr)	Service rate (sec)
1 hour	239	10
2 hour	254	10
3 hour	246	10
4 hour	242	10

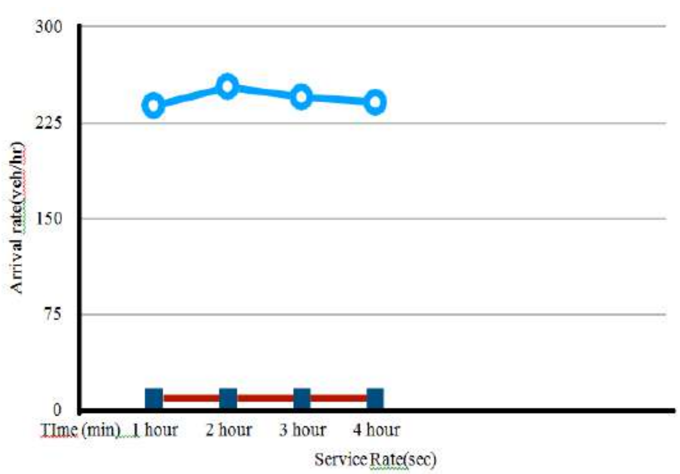


Fig. 8 Varying Arrival Rate and Constant Service Rate Graph

3.8 Development of models by using multiple linear regression analysis Input

Table 5 Observed Variables Data at Unguturu Toll Plaza

Toll plaza	Arrival rate (vehicle/hr)	Service rate (sec)	Speed (KMPH)	Queue length (m)
1	178	8.94	8.22	73.5 m
2	144	7.63	6.97	53.2 m
3	115	8.26	11.71	96.73 m
4	68	5.9	6.88	40.6 m

3.9 Summary Output

Table 6 Output for Regression Statistics

Regression statistics	
Multiple R	0.9027
R square	0.8148
Adjusted R square	0.8016
Standard error	148.1904
Observations	16

$R2$ = 0.8148 it's represented by strong relation between the dependent and independent variables.

Table 7 Study Areas at Ethakota Toll Plaza

S. No	Parameter	Data Collected
1	No. of toll booths	6
2	Pavement Type	Flexible
3	pavement width	3.4
4	Toll booth length	1.84
5	Toll booth width	1.23
6	Type of merging	Merging at one point
7	Type of transaction	Manual

3.9 Modeling toll plaza Ethakota by using multiple single servers during peak hours observed data (manual)

N=6 lanes

λ per lane =135 PCU/hr

μ= 200 PCU/hr

ρ = (λ/μ) = 135/200 = 0.67

The system's average number of vehicles = ρ/(1-ρ) = 2 PCU

The average number of vehicles waiting in line = (ρ * ρ)/(1-ρ) = 1 PCU

The average wait time for a system = (1/(μ-λ) = 55 sec

The average length of time spent in line = λ / (μ-(μ-λ) = 37 sec

Table 8 Observed at Ethakota Toll Plaza Input File for Graphs

Time (min)	Arrival rate (vehicle/hr)	Service rate (sec)
15	58	11
30	61	11
45	50	11
60	66	11
75	67	11
90	57	11
105	53	11
120	41	11

Table 9 Study Area at Ethakota Toll Plaza RFID

S.No	Parameters	Collected Data
1	Total No. of toll booths	6
2	Pavement Type	Flexible
3	pavement width	3.4
4	Toll booth length	1.84
5	Toll booth width	1.23
6	Type of merging	Merging at one point
7	Type of transaction	RFID

3.10 Modeling toll plaza Ethakota RFID by using multiple single servers during peak hours observed data

N=6 lanes

λ per lane =130 PCU/hr

μ= 250 PCU/hr

$\rho = (\lambda/\mu) = 135/200 = 0.52$

The system's average number of vehicles = $\rho/(1-\rho)$ = 1 PCU

The average number of vehicles waiting in line = $(\rho * \rho)/(1-\rho)$ = 0.5 PCU

The average wait time for a system = $(1/(\mu-\lambda)$ = 30 sec

The average length of time spent in line = $\lambda / (\mu-(\mu-\lambda)$ = 15 sec

Table 10 Observed at Ethakota RFID Toll Plaza Input File For Graph

Time (hr)	Arrival rate (vehicle/hr)	Service rate (sec)
1 hour	228	4
2 hour	433	4
3 hour	336	4
4 hour	356	4
5 hour	295	4

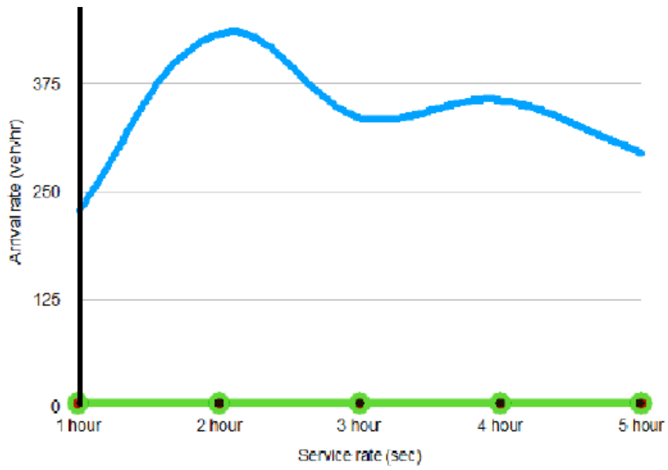


Fig. 9 Varying Arrival Rate and Constant Service Rate Graph

3.11 Development of models by using multiple linear regression analysis Input

Table 11 Observed Variables Data at Ethakota Toll Plaza

Toll plaza	Arrival rate (vehicle/hr)	Service rate (sec)	Speed (KMPH)	Queue length (m)
1	240	5.43	46	250
2	225	6.95	28.7	200
3	179	7.4	24.32	180
4	260	8.7	26.4	230

3.12 Summary Output

Table 12 Output for Regression Statistics

Regression statistics	
Multiple R	0.9027
R square	0.8148
Adjusted R square	0.8016
Standard error	148.1904
Observations	16

R^2 = 0.8148 indicates that the dependent and independent variables have a strong relationship.

CONCLUSIONS

As per the analysis carried out in this study, cars consumed much less time than other vehicles. A separate toll lane can provide additional subdivided toll lanes for cars only. As a result, delays and queue lengths can be reduced. By providing an RFID (E.T.C.) operated toll plaza, you can reduce delays and queues.

A thorough investigation was conducted to evaluate the effectiveness of a selected toll plazas, which were manually operated at Unguturu toll plaza for observing exit four lanes toll plazas and RFID (E.T.C.) operated at Unguturu toll plaza for observing exit two lanes toll plazas.

The following observations were made:

- The traffic volume on six lanes varied from 375 to 220 PCU/hour during peak hours at Unguturu and Ethakota toll plazas.

- The inter-arrival time between two vehicles was 12 sec based on data collected at Unguturu and Ethakota toll plazas.
- During peak hours at Unguturu toll plazas, the traffic volume ranged from 153 to 93 P.C.U./hour on only one lane of RFID.
- The inter-arrival time between two vehicles was 6 sec from Unguturu and Ethakota toll plazas.

REFERENCES

[1] Bari C S 2020, *Delay modeling at manually operated toll plazas under mixed traffic conditions*, International journal of Transportation science and technology.

[2] Boxma, O.J. and Takine .T.2003, " *The M/G/I FIFO Queue with several customer classes*."*Conceptualization of traffic flow for designing estimated traffic volume*, International journal of industrial engineering.18(1),51-57, 2011.

[3] Dheeraj Duhan, 2014," *Application of queuing theory to address traffic problems at a highway toll plaza*," Applied mechanics and material Vol.592-594-2014.

[4] Deek A I et.al 1997," *Operational benefits of electronic toll collection "Case study-*, Journal of Transportation engineering.

[5] Feng Zhang 2017, *Quantization and Analysis of Toll Plaza Based on Probability Distributions and Queuing Theory*, Proceedings of the 2017 2nd International Conference on Automation, Mechanical Control and Computational Engineering (AMCCE 2017), Advances in Engineering Research.

[6] H. M. Al-Deek et.al 1997, *Operational Benefits of Electronic Toll Collection: Case Study*, Journal of Transportation Engineering, Volume 123, https://doi.org/10.1061/(ASCE)0733-947X(1997)123:6(467).

[7] Manraj Singh Bains et.al 2017, *Optimizing and Modeling Tollway Operations Using Micro Simulation*., Journal of Transport research Board.

[8] Monika N et.al 2017, *Analysis of traffic behavior at the toll plazas around Bangalore*, International Research Journal of Engineering and Technology (IRJET).

[9] McDonald David Jr. and Robert E. Stammer Jr. 2001, *Contribution to the Development of Guidelines for Toll Plaza Design*, Journal of Transportation Engineering, Vol. 127, Issue 3, https://doi.org/10.1061/(ASCE)0733-947X(2001)127:3(215).

[10] Klodzinski and Al-deek 2004, *Evaluation of Toll Plaza Performance After Addition of Express Toll Lanes at Mainline Toll Plaza*, Journal of transportation research board, Volume 1867, issue1, https://doi.org/10.3141/1867-13.

[11] Punitha S 2018, *Design and evaluation of traffic delays in toll plaza using a combination of queuing and simulation*, Journal of Physics Conference Series.

[12] Partha Chakroborty et.al 2016 *Analysing queuing at toll plazas using a coupled, multiple-queue, queuing system model: Application to toll plaza design*, Transportation Planning and Technology.

[13] Sangavi G V et.al 2017, *Application of Queuing Theory of a Toll Plaza-A-Case Study*, IJERT.

[14] Spiliopoulou 2010, *Toll Plaza Merging Traffic Control for Throughput Maximization*, Journal Of Transportation Engineering-Asce, Volume 136, 10.1061/(ASCE)0733-947X(2010)136:1(67)

[15] Zarillo 2009, *Methodology SHAKER and the Capacity Analysis of Five Toll Plazas*, Transportation Engineering, Volume 135, issue 3, https://doi.org/10.1061/(ASCE)0733-947X(2009)135:3(83).