An Interpretation of the Cumulative Impact of FASTag on the Reduction of Environmental Pollution and Traffic Delays at Toll Booths: A Case Study

Anil Kumar Chhotu
Civil Engineering Department, Motihari College of Engineering, Motihari, Bihar, India
akc.jucivil@gmail.com (corresponding author)

Anil Kumar
Civil Engineering Department, Motihari College of Engineering, Motihari, Bihar, India
anil20688@gmail.com

Akash Priyadarshee
Civil Engineering Department, Muzaffarpur Institute of Technology, Bihar, India
i.akashpriyadarshee1@gmail.com

Ghausul Azam Ansari
Civil Engineering Department, Motihari College of Engineering, Motihari, Bihar, India
tausheefakhtar@gmail.com

Niraj Kumar
Civil Engineering Department, Motihari College of Engineering, Motihari, Bihar, India
nirajdsi10@gmail.com

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ABSTRACT

Traffic congestion has been identified as a significant contributor to the environmental degradation and elevated fuel consumption. The causes of traffic delays are multifaceted, with toll booths positioned on highways being a notable factor. This study aims to analyze the impact of toll booths on traffic congestion, with a particular focus on the case study of the highway toll booth in question. The analysis will include a comparison of the delay times before and after the implementation of the FASTag system. The study will also undertake an economic evaluation to assess the cost implications of delay. The findings of this study indicate that congestion is more pronounced in the presence of manual toll booths compared to automated systems. The present study uses the 'Chakiya Toll Plaza on National Highway 27A, located between Motihari and Muzaffarpur, as a case study. This toll booth has been initially operated with a manual toll collection system, but has since transitioned to the FASTag implementation. A comprehensive analysis encompasses both traffic volume and delay studies, with a focus on their environmental and economic ramifications. The analysis reveals that for each Passenger Car Unit (PCU), the environmental cost is 8.3 rupees and the fuel cost is 15.34 rupees. The idle time cost is calculated as 8.34 rupees. The overall cost of the manual toll collection delay, including all the aforementioned factors, is found to be 52.3 rupees. However, the implementation of FASTag significantly reduces this cost to. 8.20 rupees.

Keywords-tollbooth; traffic delay; FASTag; environmental loss; fuel loss

I. INTRODUCTION

The development of any country is greatly influenced by the existence of a robust transportation infrastructure, which facilitates the efficient movement of goods and passengers. The travel time is contingent upon numerous factors, including the velocity of vehicles, geometric characteristics, traffic conditions, environmental factors, and numerous additional elements [1]. A delay is defined as an increase in travel time perceived by the drivers, passengers, or pedestrians due to disruptions in the desired traffic flow. The discrepancy between the actual travel time and the travel time under optimal conditions, i.e., free-flow travel time, is a critical metric for assessing the impact of delays. The impact of traffic congestion on the smooth flow of traffic is a multifaceted issue. The factors contributing to such delays include traffic congestion, vehicle condition, accidents, and delays at intersections, among others. The consequences of these delays extend beyond the individual, affecting the efficient movement of people and materials, and consequently, impeding the development of the nation as a whole. The factors of speed and travel time are of particular importance in the realm of transportation. These factors are interrelated and influence safety, comfort, convenience, and economy. The strategic placement of toll booths along highways contributes to delays in traffic. Furthermore, delays in the traffic flow have been shown to have a negative impact on the environment. Vehicular emissions, comprising carbon monoxide (CO), carbon dioxide (CO2), volatile organic compounds (VOCs), hydrocarbons (HCs), nitrogen oxides (NOx), and Particulate Matter (PM), have emerged as the predominant source of airborne pollutants in numerous regions [2]. The intensifying severity and duration of overcrowding have the potential to significantly elevate the pollutant emissions and degrade the air quality, especially in areas proximate to major highways. As demonstrated by randomized trials, evaluations of proposed vehicle emission standards, and ecological impact assessments for specific road projects, proposed by the World Health Organization (WHO) [3] 2005 and Health Effects Institute (HEI) [4] 2010, these emissions contribute to mortality and disease risks for drivers, commuters, and individuals living near roadways. Toll booths are used for the collection of revenue in the form of taxation. These toll booths can be classified into two categories: manual and automatic. Within India, the majority of toll booths are manually operated. According to the National Highways Authority of India (NHAI) website [5], there are currently approximately 534 toll booths in operation throughout India. The amount payable at these toll booths is predetermined and based on the length of the stretch traversed. The collection of this user fee is governed by the provisions of the applicable fee regulations and the terminology outlined in the concession agreement. In certain instances, the collection of user fees is permitted when the project has reached 75% completion. This provision enables individuals to use the completed segment of the highway. The cost of collecting roadway tolls can be classified into three major categories: operating cost, user cost, and environmental cost. The operating cost category encompasses the remuneration of operators, facility operation and maintenance expenses, and revenue processing. Examples of user costs include the fuel and oil consumption, tire wear, vehicle maintenance and repair, depreciation, accidents, and delays. Additionally, the generation of greenhouse gases and noise pollution at toll facilities is associated with environmental costs [6]. The operating cost for toll facilities is subject to significant variation and is influenced by numerous factors, including the number of employees, the geographical location, the number of booths, and the collection mechanism.

A considerable body of research has been dedicated to examining the impact of various toll booth types on traffic congestion. Authors in [7] evaluated the performance of open road tolling systems and electronic toll collection systems from the perspective of air quality assessment. Their findings indicated that open road tolling systems can lead to reductions in delays, enhanced user utility, and improved air quality. Authors in [8] proposed a model that incorporates cash payment, toll booth queue, and dynamic traffic flow. This model integrates traffic states and toll booth queues. They concluded that lane expansion reduces the traffic jams (or queues) before toll collectors. Authors in [9] demonstrated the effectiveness of the microsimulation of mixed toll booths with different toll collection technological innovations. They also mentioned that the limited capacity of manual toll collection causes long queues and that the indirect impact reduces the performance of electronically collected toll systems. Authors in [10] employed a finite element model to assess the performance of toll plaza systems based on delays, the number of toll booths, and the type of service (cash or electronic payment). Authors in [11] presented a study that employed the microsimulation and queuing theory to ascertain the number of toll booths equipped with various payment technologies (cash, credit, card, or electronic payment). Additionally, authors in [12] proposed a method for analyzing the toll plaza service levels based on users' perceptions of the service quality. They noted that the queue length exerts a substantial influence on service quality, a factor that road users can readily discern by evaluating the effectiveness and quality of their journey. To assess the efficacy of their model, the researchers employed a simulation model incorporating varying numbers of toll booths and the level of service can be determined by the queue length, as mentioned in [12, 13], or delay times [10]. However, the economic evaluation of the delay due to the manual toll is not a subject that has been effectively addressed by any researcher. To address this gap, a case study approach was employed in this study. This study incorporates the impact of FASTag on the reduction of delay and air pollutants. The former undertakes an economic evaluation of the delay, taking into account various factors, including fuel, environmental impact, and time. It also examines the reduction in delay resulting from the implementation of FASTag in India. This study's findings are expected to provide valuable insights for traffic engineers, enabling them to assess and compare the various alternatives to manual toll booths.

II. METHODOLOGY OF THE STUDY

In the present study, a systematic approach is employed for delay analysis due to toll booths. This approach involves the completion of various activities in a sequential manner. Initially, the study area is selected and the data pertaining to traffic and delays are collected, followed by an economic analysis. The present study focuses on a delay analysis due to toll booths, using the Chakiya toll booth as a case study. This toll booth is situated between the Motihari and Muzaffarpur highways, which are collectively designated as NH-27A, as presented in Figure 1. The strategic importance of this highway is underscored by its role in supporting the agricultural, industrial, and tourism activities in the region, making it one of the most significant transportation routes in India. It is noteworthy that this highway facilitates the connectivity between Patna and Muzaffarpur.

A. Collection of Traffic Data at the Toll Booth

In order to estimate the traffic volume and characteristics, the number of vehicles and types of vehicles passing through the Chakiya toll plaza is manually counted. Over the course of 21 days, traffic data for both directions—from Motihari to Muzaffarpur and Muzaffarpur to Motihari—were collected by different surveyors. In order to estimate the influence of each vehicle properly, all types of vehicles were converted into a PCU. The data collection spanned 21 days, with observations having been made during different time periods throughout the day. The dataset was then filtered to include only peak-hour periods for the purpose of delay analysis.

Fig. 1. Chakiya toll plaza.

During periods of peak traffic congestion, the queue length reached its maximum. It was observed that with an increase in queue length, there was a corresponding rise in delay. The dataset, which includes information on the various types of vehicles and their average flow rate between Motihari and Muzaffarpur and vice versa, is displayed in Table I. The data refer to the peak-hour, which was subsequently used for further analysis. A parallel set of data was collected post-FASTag implementation to assess its impact. The findings reveal a substantial decline in the FASTag mandate delay during the peak hours, resulting in a significant reduction in traffic congestion. This decline may contribute to a reduced travel time and a decrease in air pollution.

TABLE I. TRAFFIC DATA COLLECTED FOR BOTH MOVING DIRECTIONS

Moving in the direction of Motihari to Muzaffarpur					
	Peak Hour	Cars	Buses	Trucks	Lorries
Average	5.00 6.00PM	990	68	85	24
Moving in the direction of Muzaffarpur to Motihari					
Average	5.00 6.00PM	906	82	86	22

B. Analysis of Traffic Data without FASTag

In the PCU (IRC: 106 -1990 [13]), the averages for cars, buses, trucks, and vans were modified:

$$\text{PCU} = \text{cars} + (\text{buses} + \text{trucks}) \times 3 + \text{lorries} = 990 + (68 + 85) \times 3 + 24 = 1473\ PCU \quad (1)$$

Similarly, from the data of the vehicles moving from Muzaffarpur in the direction of Motihari we have:

$$\text{Convertin PCU} = \text{cars} + (\text{buses} + \text{trucks}) * 3 + \text{lorries} = 906 + (82 + 86) \times 3 + 22 = 1432\ PCU$$

The total traffic volume in peak hours, including both directions, was determined to be 2,905 PCU based on the data collected.

C. Traffic Delay at Tool Booth before FASTag Implementation

Traffic delays can be attributed to two distinct components: one that occurs under unrestricted traffic conditions and another that occurs under high-traffic conditions. The present study focuses on the components of traffic delay under congested traffic conditions. The occurrence of traffic congestion is defined as the circumstance in which the volume of traffic on a given road exceeds the capacity of the toll booths along that route. This results in vehicle queues and traffic delays. Conversely, when the traffic volume is below the capacity of the tool booth, vehicles may pass through with minimal delay. The traffic delay experienced at the tool booth is calculated in the following three cases [14]. Delay due to vehicles decelerating before entering the toll booth zone is the first case. The delay due to vehicles accelerating after exiting the toll booth zone is the second case, and delay due to vehicles in queues is the third case.

1) Delay due to Vehicle Deceleration before Entering at Tool Booth Zone

The delay due to vehicle deceleration before entering a toll booth is essentially the difference between the time required to cover the Stopping Sight Distance (SSD) with deceleration and without deceleration. The SSD is defined as the minimum sight distance available on a highway at any given point, with sufficient length to enable a driver to stop a vehicle traveling at its designed speed safely without colliding with any other obstruction. The SSD is the sum of the lag distance and the braking distance:

$$SSD = v \times t + v \times v/2gf \quad (2)$$

where t=2.5, g=9.81m/s^2, f= 0.35, and v = designed velocity for NH (100 km/h). Using these values, the result is SSD=185. Following the calculation of the SSD, the time required to cover this distance with and without deceleration is calculated:

$$v^2 = u^2 + 2 \times a \times s \quad (3)$$

$$a = 2.08\ m/s^2$$

$$v = u + at \quad (4)$$

$$0 = 27.782 - 2.08 \times t$$

$$t = 14.35\ \text{sec}$$

where v is the final velocity, *u* is the initial velocity, *a* is the deceleration, and *t* is a/the time of travel. The following equation can be used to calculate the time required for the vehicle to cover the SSD while traveling at a constant speed of 100 km/h:

$$t' = \frac{\text{SSD}}{\text{v}} = \frac{185}{27.78} = 6.35 \text{ sec}$$

The occurrence of delay due to the deceleration of vehicles or the additional time taken by the vehicles is defined as (*t-t'*), and can be calculated: $\text{Delay} = 14.35 - 6.35 = 8 \text{ sec}$.

2) Delay in Acceleration Zone after Exiting from Tool Booth

Subsequent to the completion of the procedures at a toll booth, the vehicle accelerates. It has been determined that vehicles require additional time to reach their designed velocity after the toll submission. This delay is attributed to the vehicle's cessation of movement during the toll transaction. The delay experienced due to the vehicle's acceleration can be defined as the difference in the time spent during acceleration and the time required to travel the same distance at design speed without acceleration. It was observed that the pavement condition before entry and after exiting the toll booth was consistent. Assuming equal acceleration and deceleration rates, the delay in this scenario is estimated to be 8 sec. It is further assumed that the vehicle would maintain its design speed in the absence of a toll booth.

3) Delay due to Vehicle Queues

The delay due to queueing at the toll booth was manually recorded during peak hours (5:00 pm to 6:00 pm). The mean delay due to vehicles in queues over a 21-day period during peak hours was determined to be 9 min and 30 sec. Based on the delays calculated above, the total delay at the toll booth is estimated as: $8 \text{ sec} + 9 \text{ min } 30 \text{ sec} + 8 \text{ sec} = 9 \text{ min } 48 \, sec$

D. Analysis of Delay after FASTag Implantation

1) Delay due to Deceleration and Acceleration of the Vehicle at the Tool Booth Zone

The delay resulting from the deceleration and acceleration of the vehicle is equivalent to the values calculated before. This phenomenon occurs because the driver's speed and reaction time remain constant despite the adoption of FASTag at toll booths. Subsequent to the completion of toll payment at a toll booth, the vehicle accelerates and continues its journey. This acceleration delay is a consequence of the aforementioned phenomena. The delay due to acceleration can be understood as the temporal difference between the acceleration phase and the time required to travel the same distance at design speed without interruption. It was observed that the pavement condition before entry and after exiting the toll booth remained unchanged. Assuming that the acceleration rate is equivalent to the deceleration rate, the delay in this scenario is estimated to be 8 sec.

2) Delay due to Vehicle Queues

The queue formation is reduced in comparison to manual fee collection, and the system delay and queue delay are drastically decreased. Preliminary data collected from the toll booths following the implementation of FASTag indicate that the average delay during peak hours is 90 sec, while during non-peak hours, it is approximately 30 sec.

III. RESULTS AND DISCUSSION

This section uses the delay experienced at the toll booth as a metric to calculate the loss of capital. The study found that such delays can lead to various forms of losses, including time loss, fuel loss, environmental loss, health deterioration, vehicular loss, and numerous others. These losses are classified as either direct or indirect. Direct losses, such as time and fuel expenditures, are directly experienced by drivers or owners and are therefore easily quantifiable. Conversely, indirect losses, such as environmental and health deterioration, are not directly observable or quantifiable by drivers. This study aims to estimate various forms of loss, including time loss, fuel loss, and environmental loss, with the objective of comprehensively assessing the total loss incurred due to delays. These losses are calculated for the purpose of manual fee collection and FASTag fee collection.

A. Valuation of Time Loss

1) Manual Fee Collection

The delay experienced by each traveler was found to be approximately 9 min and 46 sec, which is nearly equivalent to 10 min. The labor manual of India [14] indicates a cost of 50 rupees for the value of time per hour: $\text{volume of traffic in Peak hour} = 2905 \text{ PCU}$, $\text{total idle time} = 2905 \times (9 \text{ min } 46 \text{ sec}) = 28993 \text{ min} = 483 \text{ hours } 13 \text{ min}$, $\text{cost of idletime} = 483.216 \times 50 = 24160 \, rupees$.

2) Using FASTag

The duration of the delay per traveler has been established at 1 min and 30 sec. The labor manual of India [14] indicates a value of 50 rupees for the cost of time, calculated on an hourly basis: $\text{volume of traffic in Peak hour} = 2909 \text{ PCU}$, $\text{total idle time} = 2905 \times (90 \text{ sec}) = 4357.5 \text{ min} = 73 \text{ hours}$, $\text{cost of idletime} = 73 \times 50 = 3636 \, rupees$.

B. Valuation of Fuel Cost

An experiment was conducted to measure the fuel consumption of a different vehicle in idle condition. To this end, a total of ten vehicles were selected for the study, and their engines were kept operational for a duration of 30 min. During this period, the vehicles were maintained in a stationary position and the fuel meter was observed. The results indicated that, on average, 0.22 L of fuel were consumed every 30 sec for a duration of 9 min and 30 sec. This finding aligns with the results reported in [15, 16], where fuel consumption values that are close to this figure were also documented. Given that the vehicle was in the queue for a mere 9 min and 30 sec, the fuel consumption for that specific period is: $\text{fuel consumed by 1 PCU} = 0.220 \text{ lit}/(9 \text{ min } 30 \text{ sec})$, $\text{total vehicles in peak hours} = 2905 \text{ PCU}$, $\text{fuel consumed} = 0.220 \times 2905 = 639.1 \text{ lit}$. The cost of the diesel fuel is 105 rupees per L according to the most recent data (April 2023). The total cost of fuel loss in an idle vehicle during peak hours is calculated as: 639.98 × 105 = 67,197.9

rupees. Similarly, after the FASTag implementation, the total cost of fuel loss in an idle vehicle during peak hours is calculated as: 10,610.19 rupees.

C. Valuation of Environmental Cost

1) With Manual Toll Collection

In recent years, emissions from vehicles have surpassed those from other sources, including CO, CO_2, VOCs, HCs, NO_x, and PM. The congestion on major thoroughfares has the potential to drastically increase the pollutant emissions and decrease the air quality. Recent investigations, assessments of proposed vehicle emission standards, and environmental impact assessments for individual road projects have all shown that these emissions contribute to the risks of morbidity and mortality for drivers, commuters, and individuals living near roadways [3, 4, 17]. These emissions are a consequence of the combustion of fuels during the operation of vehicles. The average CO_2 emission resulting from the combustion of 1 L of fuel (diesel) is 585.7 g. The composition of pollutants released following the combustion of An L of fuel is presented in Table II. The total delay is approximately 10 min, and the fuel consumption during this period is 0.220 L. Consequently, the total CO_2 emission resulting from the combustion of 0.220 L of fuel is 183.7 g. A similar calculation is applied to other gases, as tabulated below. Authors in [18] have proposed a cost of 7.22 rupees per kg for pollutants.

TABLE II. LIST OF POLLUTANTS RELEASED INTO THE ATMOSPHERE AS A RESULT OF THE COMBUSTION PROCESS OF THE FUEL

Green House Gases	**% Contribution**	**Weight of pollutant (g)**	
		With manual toll collection	With FASTag implementation
CO	51	585.5	92.45
CO_2	16	183.7	29.00
N_2O	2.5	28.7	4.53
NH_3	2.1	24.11	3.80
NO_X	24	275.55	43.50
SO_2	0.4	4.6	0.72
CH_4	0.3	3.5	0.54
PM_{10}	1.8	20.7	3.26
VOC	1.6	18.4	2.90
	Total pollutants	1,144.76	180.7

As indicated in Table II, the total weight of the pollutant emitted after burning the fuel is 1.145 kg. The total number of vehicles was determined to be 2,905, and the pollution cost was calculated to be 1.145 × 2,905 × 7.22, which equates to 24,015.3 rupees. According to the inflation index, the cost was approximately 60,120.0 rupees in 2024.

2) Using FASTag

As presented in Table II, the total weight of the pollutant emitted after burning the fuel is 0.1807 kg. The total environmental cost is calculated: the total number of vehicles is 2,905 and the pollution cost is 0.1807×2,905×7.22 = which is equivalent to 3,790.02 rupees. According to the inflation index, the cost in 2024 is approximately 9,488.0 rupees, as shown in Table III. It is evident from the data that the expenditure associated with fuel exceeds that of other categories. The total cost calculated due to the delay is approximately 93,006 rupees during peak hours, and the per PCU loss is determined: During the period with the highest traffic volume, a total loss of 152,077.9 rupees was incurred due to the presence of toll booths. This results in a loss per PCU of 52.3 rupees. It can be observed that the per PCU expenditure is approximately 40 rupees. Similarly, the total losses incurred at toll booths during peak hours due to the implementation of FASTag reached 23734.2 rupees, resulting in an average loss of 8.15 rupees per PCU.

TABLE III. SUMMARY OF EXPENDITURE DUE TO DELAY AT THE TOLL BOOTH

Sl. NO.	**Type of cost**	**Cost (in rupees)**	
		With manual toll collection	With FASTag implementation
1	Environment Cost	60,120.0	9,488.0
2	Time money	24,160.0	3,636.0
3	Fuel cost	67,197.9	10,610.2
Total		152,077.9	23,734.2

In order to minimize expenditures resulting from the delays at toll booths, a variety of techniques can be adopted.

- One such technique is the adoption of an automatic toll booth system in lieu of the manual toll booth. This can minimize delays due to queues, which are a consequence of the manual toll booth system.
- In some cases, toll booth cameras may malfunction, leading to additional delays for the passing vehicles. • During data collection, it was observed that many vehicles routinely passed the toll booth. For such vehicles, the installation of an automatic boom system could facilitate an unobstructed passage after payment of a monthly tax.
- Satellite imaging can be employed to monitor the daily traffic patterns.
- The analysis in Table III indicates that the fuel cost is at its peak during the delay period, which is not acceptable given that most vehicles are powered by petrol or diesel, both of which are limited natural resources.
- It is also important to note that the majority of highway projects nowadays are constructed using the Public-Private Partnership (PPP) model, with toll collection serving as a recovery process for project costs and maintenance. However, it has been observed that this practice exerts a significant environmental impact, ranking second only to fuel cost in terms of its indirect economic implications.

IV. CONCLUSIONS

A comprehensive dataset was collected and subjected to rigorous analysis, which yielded several salient conclusions. The total financial loss incurred during peak hours due to the operation of a manual toll booth per Passenger Car Unit (PCU) was determined to be 52.3 rupees, which corresponds to 9.5 min of idle time. In the region between Motihari and Muzaffarpur, a single toll booth is in operation, and it has been transitioned to FASTag, resulting in a reduction of 8 min in delays during peak hours. It is important to note that these losses are indirect, and their existence is often unbeknownst to the public. The study observed that FASTag, despite its potential, has not been able to completely eliminate the delays at toll plazas. This underscores the necessity for the development of a system that can effectively address all delays and facilitate an uninterrupted passage for vehicles. One potential solution is the implementation of a closed-road tolling system, similar to the highway between Colombo and Matara in Sri Lanka. The adoption of automated and electronic toll collection methods holds a significant potential for the mitigation of these losses. This method has been employed in the German Federal Trunk Road system. The findings of this study indicate that the adoption of an automatic fee collection technique in lieu of a manual one results in a substantial reduction in delay. Additionally, this approach contributes to environmental conservation.

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