Socio-economic Evaluation of Users Delay at Manually Operated Tollbooths– A Case Study of Ghoti Toll Plaza

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Abstract: The inefficient system at tollbooth may result in early delays which persist throughout the day. These traffic delays therefore results in opportunity cost to the passengers using that route. Beside this the uncertain and irregular movements of traffic queues compels the passengers to keep the engines switch on, which results in excess fuel consumption and amounts to some social cost as well by deteriorating the air quality and health of people in vicinity. Thus it is necessary to estimate the combined effects of loss occurred due to delays and excess emission. Present research work estimates monetary cost of traffic induced delay, value of delay, the combined cost of excess fuel consumption and its social cost as total emission cost for toll plaza which is located in India. The value of time is calculated as Rs 8.7 million per annum whereas pollution cost as Rs. 2 million per annum for Ghoti toll plaza. Further, the present study also proposed some mitigation majors to reduce delay and cost of value of time and emission at Ghoti toll plaza.

Keywords: Toll Plaza; Economic Evaluation; Delay; Value of Delay; Fuel Consumption

1. INTRODUCTION

With the advent of urbanization, a tremendous traffic explosion has happened, which has created pressure on the existing road infrastructure, exposing its incompetency, and thus resulting in traffic congestion and delay. Poor road conditions along with incompetent infrastructure has further aggravated the scenario. The government has entered into a Public-Private Partnership (PPP) module due to requirement of heavy investment in the road infrastructure. The private stakeholders and the concessionaries first invested their funds for

development of new road infrastructure and for the maintenance too. Under the PPP module, the private stakeholder has right to levy taxes on the road users in the form of toll to get back the invested amount for a specific period of time as per agreement. Toll plazas are provided for the collection of tolls from the road users, but, causing a hindrance for fast-moving vehicles on the highway due to provision of Manual Toll Collection (MTC) lanes (Bari et al. 2020). Further, in developing country like India, the traffic is non-lane based and highly heterogeneous in nature and same has been observed at toll plaza. The mixed traffic condition (i.e., presence of different vehicle class in a single lane, see Figure 1) is observed at toll plaza in dedicated lanes, causing variation in service time (Bari et al. 2019).

Figure 1: Mixed traffic conditions

A significant delay occurs during the peak hours at the toll plaza, which can be attributed to the passenger's opportunity cost. Travel time reliability and comfort are disrupted due to delay caused at the toll plaza, which also results in a monetary loss to the passenger and the tollbooth operators in the form of inefficient toll collection. The time lost due to delay can be quantified and can be estimated in monetary terms, which is called the value of time (VOT); also monetary analysis gives us a better understanding of economic repercussions.

Delay also has a psychological impact as it leads to uneasiness, irritation, fatigue etc., (Saad et al,2018). Delay gives a reliable measure of the road efficiency but is difficult to estimate as it has various factors, including delay due to deceleration, stopped delay, and delay associated while accelerating from a stop. Severe environmental impacts can be related to delay, as drivers have a habit of keeping engine in ON condition, leading to excess fuel consumption and emission release (Carbon Monoxide (CO), sulphur oxides, particulate matter (PM)) (Bari et al. 2020). Considering a single vehicle, the fuel consumption and emission might be low but the vast pool of vehicles with various delays at a toll plaza leads to heavy fuel loss and high pollutant emissions.

The peak hour worsens the situation leading to high $PM_{2.5}$ in the vicinity of the toll plaza affecting the people working at the tollbooth and the daily commuters causing various respiratory diseases (Sehgal et al, 2014). Most of the impacts due to delay can be easily mitigated with proper planning and infrastructure. Impact analysis at the MTC lanes is the focus of this project, highlighting the alarming situation with possible mitigation measures to be incorporated.

The aim of the present study is to understand the economic repercussions of delay for an individual, and its impact as whole on the economy. Further, the effect owing to delays and the pollution cost is also estimated to understand the economic impacts of emissions.

2. LITERATURE REVIEW

In the past few decades, extensive research has been conducted on the various factors influencing and affecting the service time, delay, and efficiency of the toll plazas in developed and developing countries. In relation to the undertaken case study, some of the relevant studies are briefly discussed henceforth. Ardekani and Torres (1991) studied the passenger travel cost and came up with an analytical method of estimating the value of time and the economic consequences of the delay at the toll plaza. They concluded that the toll charge must be a function of vehicular demand and implied value of time and discovered that the total toll constitutes 90% of break-even toll (cost incurred during toll collection). Kandlikar and Ramchandran (2000) suggested that the vehicular emissions are a major contributor in pollutant emission after industrial and power plant.

Xia and Shao (2004) conducted a study on the Langrangian traffic flow model and estimated the traffic-induced emission through the stimulated traffic flow and atmospheric dispersion model. They used these data and the empirical emission factors for various categories and thus estimated the emission rates of major air pollutants like CO, NOx, and PM10 and predicted the area's air quality. Coelho et al. (2005) quantified the emission at the toll plaza, for Electronic , manual and no toll collection scenario, taking into account of queue length and stop-go cycles as a measure. It was found that maximum emission was due to final acceleration of vehicle after paying toll, leading to almost 99% of CO emission along with roughly 75% of NO_2.

Indian Road Congress (IRC) SP: 30 (2009) has given the value of delay for various vehicle types and passenger travel cost in monetary terms with respect to the year 2009. Aditi and Sarkar (2009) conducted a study to estimate the congestion cost by evaluating the operating cost of vehicles, delay, pollution, stress and physical fatigue. Pal and Sarkar (2012) conducted

a study in capital city of Tripura, Agartala, to estimate the fuel loss and noise pollution during vehicle idling. They found out that there is a direct correlation between traffic volume versus delay and traffic volume versus noise level. At various intersection of Agartala city the average vehicle delay was 60 sec/vehicle during peak hour.

Rakha and Ding (2013) attempted to quantify the impacts of vehicle stops on fuel consumption and emission rates using VT-micro models. The vehicles cruising at higher speeds tends to emit more pollutant when it comes to halt than when crusing at slightly lower speed. Khan et al. (2013) estimated the congestion cost of traffic delays in Dhaka city. In the study, various parameters for delay were considered travel time cost, vehicle cost of operating and external environmental damage. In the study of delay cost, opportunity cost of travelling time was an important factor considered with suitable consideration for uncertainty in travel time. Ministry of economic planning and budget (MEPB) (2013) estimated the socio-economic cost of traffic congestion in Lagos. The total cost consists of various components like cost associated to delay, increased vehicle operating costs, excess accident externality costs, and excess vehicle emissions externality costs. Finally, some mitigation measures like cable car system and imposing congestion charges were proposed.

Aksoy et al. (2014) conducted a study to analyze the queue/delay performance of the toll queues by micro simulation model in Istanbul by incorporating the queuing theory. It was observed that the effects of the former queues were propagated to the queues that were formed latter and thus minimizing the bottleneck capacity. Finally, some suitable traffic management strategies were suggested to improve the condition.

Bhivina and Landge (2014) conducted a study to estimate the socio-economic impact of traffic delays. They conducted a willingness to pay survey and found out the value of time as the slope of the plot of travel time (X) and travel cost(Y) for each vehicular type. They thus empirically correlated the increase in operating time at the tollbooth with its monetary value and also demonstrated how it would lead to an increase in vehicular emission through the amount of extra fuel combusted during traffic delay. Das et al. (2016) conducted a study to evaluate the traffic congestion at Surat corridor through speedo graph approach. They utilized the speed profile diagrams which is obtained by conducting speed and delay survey studies on one of the stretches of major corridor in Surat. Thereafter travel speed indices (TSI) had been developed to describe the traffic congestion scenario on the road stretch.

Ricke and Drouet et al. (2018) conducted a study to estimate the social cost of carbon (SCC), so as to quantify the economic damages expected to occur due to CO_2 emission in

atmosphere. Thus SCC provides an economic valuation of the marginal impacts of climate change. Bari et al. (2020) conducted a study to evaluate the service time for various vehicular type under mixed traffic conditions at manually operated toll plazas. It was found that service time is the main factor for the queue formation thus leading to traffic delay. Vehicle characteristics influences the service time, example, service time is more for long vehicles like trailers and buses. Also, the results showed that the service time for same leader follower is lower than the mixed traffic conditions.

Thus from the extensive literature review, it was found that to achieve maximum efficiency at the toll plaza, it is necessary to minimize the traffic delay. The margin between the toll collected and cost incurred during collection is significantly less, and over time even if the need to collect more toll is increasing (due to inflation and cost projection), the perception of the cost remains unchanged among passengers. Hence, this study focuses on the economic evaluation of the toll plaza including the loss due to delay, emissions and fuel consumption. Therefore, the yearly loss at Ghoti Toll is estimated by combining the value of delay (VOD) and the emission cost and possible suggestions are provided in order to minimize the loss.

3. Objectives

The study's scope is constrained within the domain of evaluating total loss due to delay at the selected toll plaza. The study was conducted on Ghoti toll plaza at Igatpuri in Nashik district on Mumbai – Agra National Highway (NH-3). The present study is focused on delay, estimation of economic loss in travel due to delay, quantifying the fuel loss, extra fuel consumption, pollution repercussions in terms of economics, and user's perception for the actual delay.

The following are the objectives framed based on existing literature and research gaps:

- To estimate the delay time for vehicles at Ghoti Toll Plaza.
- To estimate different costs associated with delay time.
- To estimate the pollution emission costs.
- To assess the overall socio-economic impact of delay at Ghoti toll plaza and suggestion of mitigation measures.

4. METHODOLOGY

The methodology for the present study is illustrated in Figure 2. The videographic traffic data was collected at the Ghoti Toll Plaza (GTP). GTP is located on Mumbai – Agra National Highway (NH-3), near Igatpuri taluka in Nashik district. This toll plaza consists of total 10 lanes to curb heavy traffic. This toll plaza observes heavy traffic at peak hours leading to excessive delay times faced by the commuters. The data was collected in the normal weather

conditions for week and weekend days. The videographic data was analysed with the help of AVIDEMUX software to get the required accuracy of time, i.e., up to two decimal places. Extraction of the required delay time and other parameters such as the following vehicle, inter-vehicle time was done. The data was tabulated in the excel sheets with the various parameters incorporated. The entry and exit time at the tollbooth was precisely noted. To get the service time, the difference between exit and entry time was obtained. The total delay was the sum of service time and the time spent in the queue waiting to reach the tollbooth. The primary objective was to evaluate the time lost owing to delay to the corresponding economic aspect. Value of time (VOT) is the translating parameter used by the authors in the present paper. VOT model is taken from Indian Road Congress (IRC) – SP-30, 2009 with adjusting the inflation to get prices with respect to 2020 for the various vehicle to understand the economics of delay. The secondary data from the toll plaza authority was also obtained to get the yearly variation of traffic at GTP. The vehicles were classified into multiple categories, namely Cars, Buses, Light Commercial Vehicle (LCV), Heavy Commercial Vehicle (HCV), and Multi-Axel Vehicle (MAV). The total loss is evaluated, and mitigation measures are suggested to curb the long queue and waiting time menace.

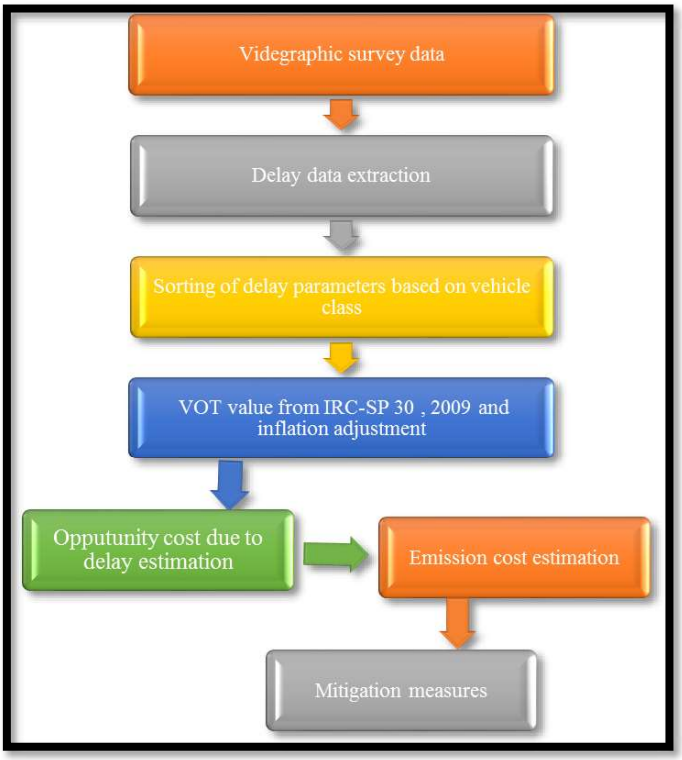

Figure 2: Flow chart for Research Methodology

5. DATA ANALYSIS

5.1 Total average delay calculation

The monthly variation in vehicle count was observed is shown in Figure 3. It is observed that the traffic is lower in the rainy months than the other ones. Wide variation in yearly vehicular composition of all the vehicles classes considered i.e. Car, Bus, LCV, HCV, MAV were observed and can be clearly understood from Figure 4. The average car composition for the yearly traffic is more than 50 percent. The bus composition founds to be 5.30 percent.

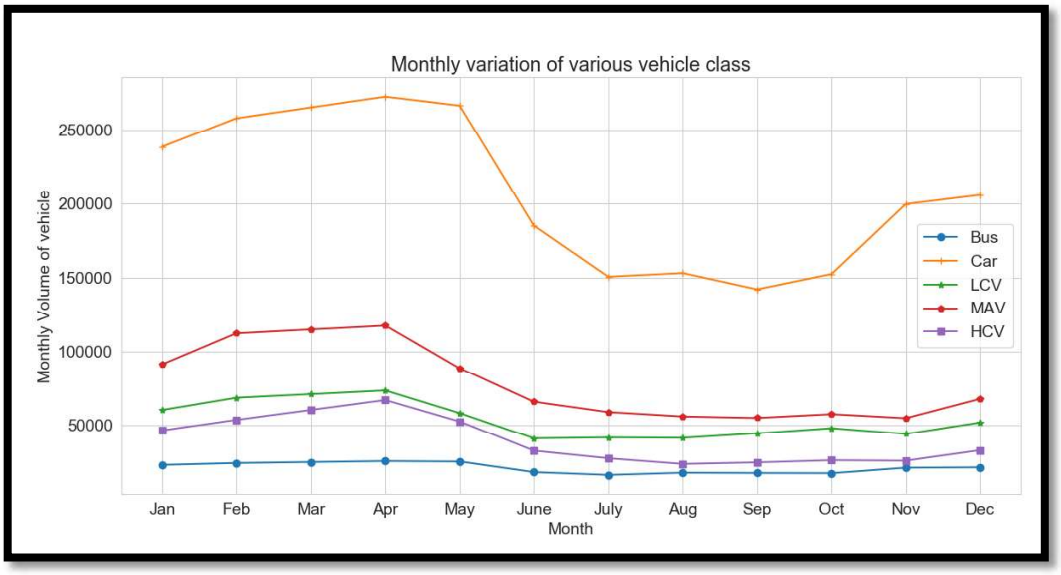

Figure 3: Monthly variation of vehicle class

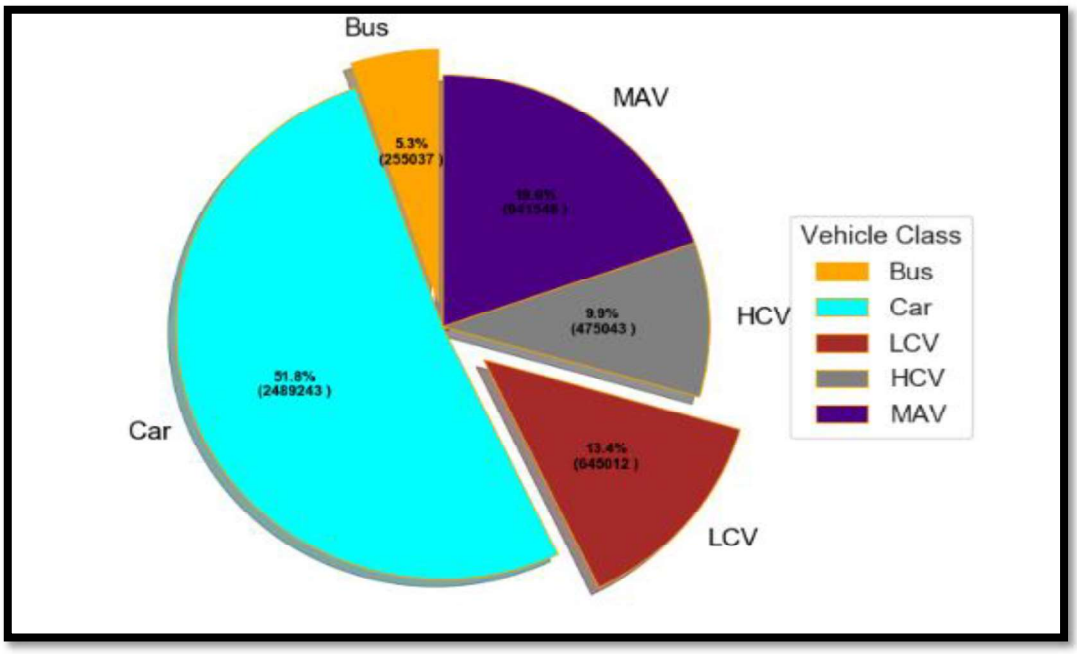

Figure 4: Vehicle compositionn yearly

To have a better understanding of the vehicular delay of various vehicle class at the toll plaza, a box plot (Figure 5) was plotted. In daily run we observe a wide range of delay variation throughout the day, which could be easily inferred from the probability density function (PDF) graph and cumulative distribution function (CDF) as depicted in Figures 6 and 7 respectively.

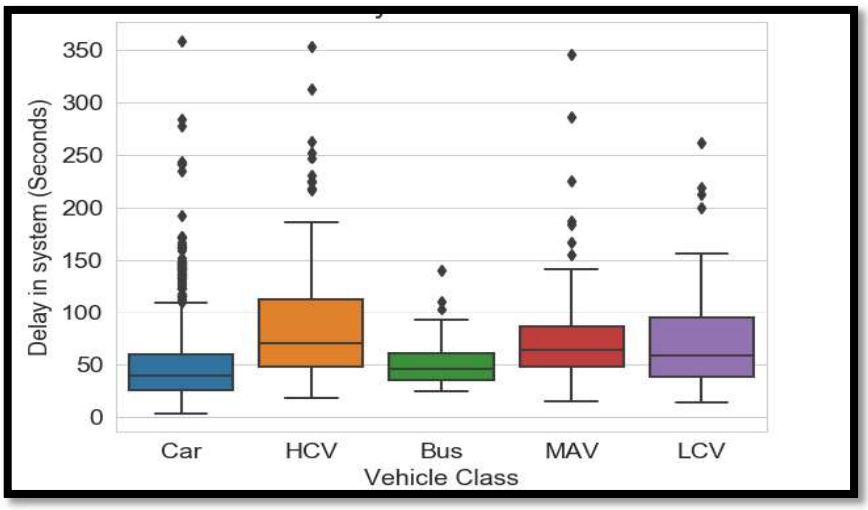

Figure 5: Box plot of delay for various vehicle class

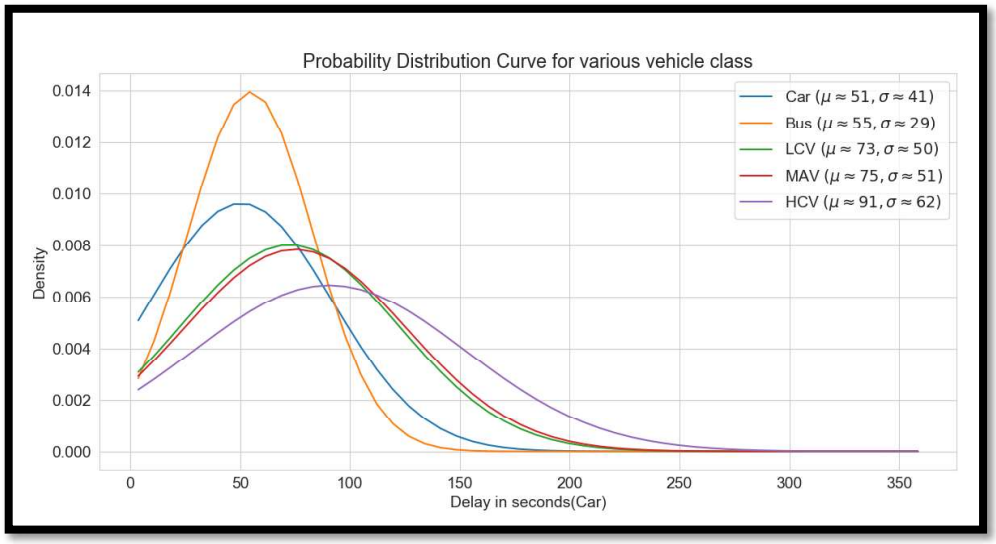

Figure 6: Probability distribution curve for various vehicle class

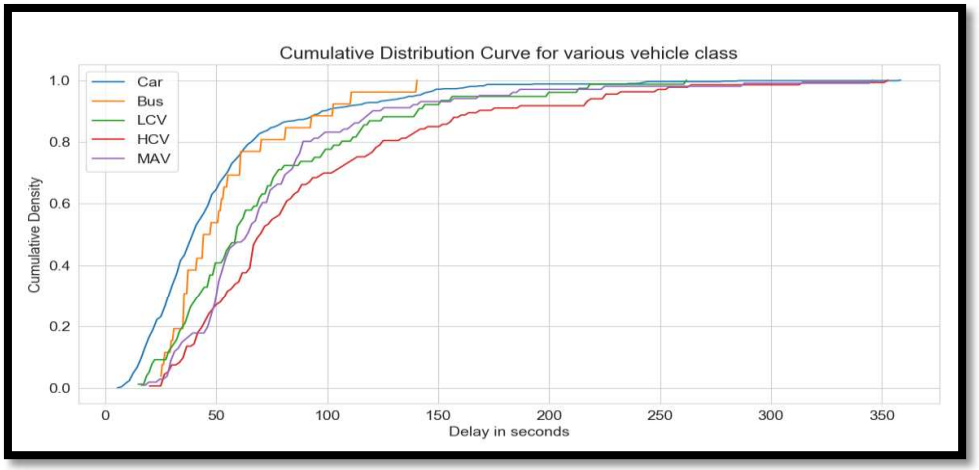

Figure 7: Cumulative distribution curve for various vehicle class

Table 1: The 85th percentile values for delay

Vehicle type	**85th percentile Delay (seconds)**
Cars	82.00
Bus	73.59
LCV	95.76
HCV	115.31
MAV	90.44

Further, the data sorted by vehicle types was used to get the 85th percentile delay for each vehicle type. Here, 85th percentile values taken considering maximum number of vehicle will experience this delay values. It is observed that for Car the value is 82.00 seconds whereas for HCV it is 115.31 seconds.

5.2 Inflation Adjustment

VOT in rupees as given in IRC SP-30, 2009 was adjusted with respect to the current year, i.e., 2020 value, to get the delay loss of passengers in monetary terms. For this purpose, the data regarding the average inflation rate between the 2009-2020 periods was gathered and then, using the equation (1) prices were forecasted to the present value.

$FV = P * (1 + r)^n$ ..... (1)

Where, FV =Future value; P = Present value; r = annual interest rate; n = total no. of years

Average annual inflation rate (2009-2020) = 7.63%, according to yearly statistics.

(Source: www.inflationtool.com)

As per IRC SP: 30, 2009, the VOT value for cars and buses are 62.50 and 39.50 Rs/hr. The VOT values for the commercial vehicles such as LCV, HCV and MAV are given on the basis of commodity holding cost as shown in Table 2.

Table 2: IRC values for commercial vehicles

Vehicle type	Commodity value (Rs/t)	Average load (t/vehicle)	Commodity cost (Rs/day)
LCV	35300	3.20	58.10
HCV	38750	9.00	178.10
MAV	36300	18.30	333.00

(Source: IRC SP:30, 2009)

Table 3: VOT / Commodity cost with inflation adjustment

Vehicle type	VOT/ Commodity cost (Rs/hr) (2009)	VOT/ Commodity cost (Rs/hr) (2020)
Cars	62.50	140.33
Buses	39.50	88.69
LCV	2.42	5.43
HCV	7.42	16.66
MAV	13.88	31.16

Table 4: Calculated VOT Rs/vehicle

Vehicle type	Delay (seconds)	VOT / Commodity cost (Rs/hr)	VOT (Rs/veh)
Cars	82.00	140.33	3.20
Bus	73.59	88.69	1.81
LCV	95.76	5.43	0.14
HCV	115.31	16.66	0.53
MAV	90.44	31.16	0.78

Table 5: Total VOT yearly

Vehicle type	Total vehicles	VOT (Rs/veh)	Total VOT

	(yearly)		(Rs/yearly)
Cars	2489244	3.20	7965579.83
Bus	255307	1.81	461617.36
LCV	645012	0.14	90301.62
HCV	475044	0.53	256523.62
MAV	941548	0.78	734407.81
Total			9508430.24

Total VOT considering all vehicle types comes out to be Rs 9508430.24. i.e., roughly Rs **9.5million/ yearly**

5.3 Evaluation of emission costs

It is important to understand the emission costs at the toll plaza due to increased fuel consumption owing to engine ON during service time. This not only increases fuel consumption but drastically increases the pollutants emission near the toll plaza region. India is among the top 3 nations in pollutions resulting from CO_2, leading to $216 billion social cost of emission yearly (Ricke et al., 2018). Pollutions from toll plaza also contribute to this social cost, hence there is need to evaluate this emission cost and devise mitigation methods for the same.

The vehicle emission factor (g/km) is available to us as secondary data, multiplied by the vehicle population to get the total concentration of the pollutant in g/km. The emission factor used is tabulated in table 7.

Table 6: Emission factor for various vehicle class (g/km)

Pollutant	Car	Bus	LCV	HCV	MAV
CO	26.00	23.00	23.00	11.00	12.00
NO_x	5.00	61.00	61.00	28.00	30.00
PM	5.00	7.00	23.00	22.00	6.00
SO_x	0.08	0.31	0.30	0.15	0.18
VOC	3.00	5.20	5.20	2.90	3.00

(Source: Bari et al. 2020)

Concentration of pollutant (g/km) = total vehicle population * emission factor (2)

Pollution cost = concentration * cost per kg of pollutant * distance (3)

Distance is taken as 0.5 km to account for the toll plaza zone

Cost per kg of pollutant = Rs 7.22 /kg *(Source: Aditi and Sarksr, 2009)* (4)

Accounting for inflation, cost per kg = Rs 16.21/ kg

Table 7: Concentration of Pollution (kg) yearly at the toll plaza

Pollutant	Car	Bus	LCV	HCV	MAV
CO	64720.34	5865.86	14835.26	5225.48	11298.58
NO_x	12446.22	15557.27	39345.70	13301.22	28246.45
PM	12446.22	1785.26	14835.26	10450.96	5649.29
SO_x	199.14	79.06	193.50	71.26	1694.48
VOC	7467.73	1326.20	3354.06	1377.63	2824.64
Total	97279.65	24613.64	72563.88	30426.55	48188.451

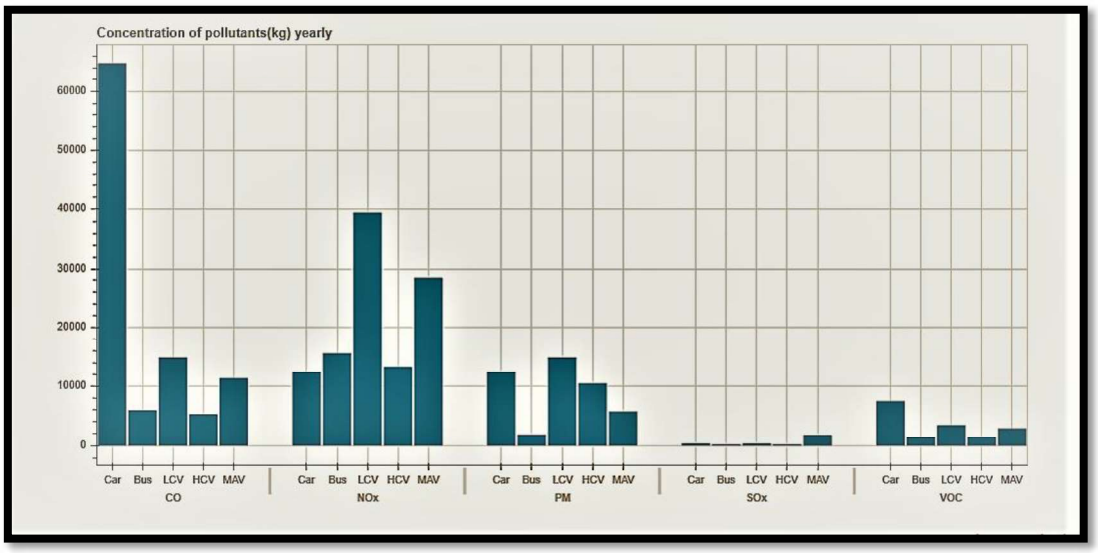

Figure 8: Pollutants concentration of various vehicle class

Table 8: Pollution cost

Vehicle type	Yearly cost (Rs)
Cars	788451.51
Bus	199493.56
LCV	588129.61
HCV	246607.20
MAV	390567.40
Total	2213249.28

Pollution cost is obtained to be Rs. 22,13,249.28, i.e., roughly around Rs. 2.2 million/per annum.

6. RESULTS

The case study was conducted at the Ghoti toll plaza for the vehicles plying towards Mumbai direction. The delay experienced by them at the toll plaza was obtained from the field studies. Value of Time (VOT) was obtained around Rs 8.7 million per annum. The monetary values signify the heavy loss incurred, which goes unchecked as an opportunity cost. This figure will tend to go up more drastically if the traffic of vehicles plying towards Nashik is also considered. Delay caused forgoes not only the opportunity cost but also affects the environment.

The pollution cost comes to about Rs 2 million per annum, which is significant in monetary terms and a health hazard for the workers at the toll plaza. Following mitigation measures can be implemented with scope for future improvement

7. MITIGATION MEASURES:

The entire process of toll collection could be automated with the use of Artificial Intelligence (AI) and image processing. Each tollbooth should be installed with a camera that should continuously note and maintain a database of number plates of vehicles passing through the toll plaza. The toll tax over a vehicle should be collected on a monthly basis. If done correctly, significant traffic delays can be curbed.

The whole traffic can be diverted over various lanes so that better efficiency can be achieved, and this can be achieved through a better traffic flow model. Each vehicle should be notified at a certain distance before the toll booth, which lane they should occupy. This could be done through visual signboards, which would be suggesting the vehicles based on the current occupancy of each lane.

Alternate toll collection, for example traffic delays could be reduced by making the process of toll collection discontinuous. This way, only a certain number of vehicles should be levied the toll tax at a time, depending on the then-present traffic situation and the rest allowed to move unhindered and for them, the toll tax is carried over for their vehicle number, such passengers could thus be notified of the same through messaging services.

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Abstract: The inefficient system at the tollbooth may result in early delays, which persist throughout the day. These traffic delays, therefore, results in opportunity costs to the passengers using that route. Besides this, the uncertain and irregular movements of traffic queues compel the passengers to keep the engines switch on, resulting in excess fuel consumption and amounts to some social cost by deteriorating the air quality and health of people in the vicinity. Thus it is necessary to estimate the combined effects of the loss that occurred due to delays and excess emission. Present research work estimates the monetary cost of traffic-induced delay, the value of delay, the combined cost of excess fuel consumption, and its social cost as total emission cost for toll plaza which is located in India. The value of time is calculated as Rs 9.5 million per annum, whereas pollution costs as ₹2 million per annum for Ghoti toll plaza. Further, the present study also proposed some mitigation majors to reduce delay and cost of the value of time and emission at Ghoti toll plaza.

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1 INTRODUCTION

With the advent of urbanization, a tremendous traffic explosion has happened, which has created pressure on the existing road infrastructure, exposing its incompetency and thus resulting in traffic congestion and delay. Poor road conditions along with incompetent infrastructure have further aggravated the scenario. The government has entered into a Public-Private Partnership (PPP) module due to the requirement of heavy investment in road infrastructure. The private stakeholders and the concessionaries first invested their funds to develop new road infrastructure and maintenance. Under the PPP module, the private stakeholder has the right to levy taxes on the road users in the form of tolls to get back the invested amount for a specific period of time as per agreement. Toll plazas are provided for collecting tolls from the road users, but causing a hindrance for fast-moving vehicles on the highway due to the provision of Manual Toll Collection (MTC) lanes (Bari et al. 2020). Further, in developing countries like India, the traffic is non-lane-based and highly heterogeneous in nature, and the same has been observed at the toll plaza. The mixed traffic condition (i.e., presence of different vehicle classes in a single lane, see Figure 1) is observed at the toll plaza in dedicated lanes, causing variation in service time (Bari et al. 2019).

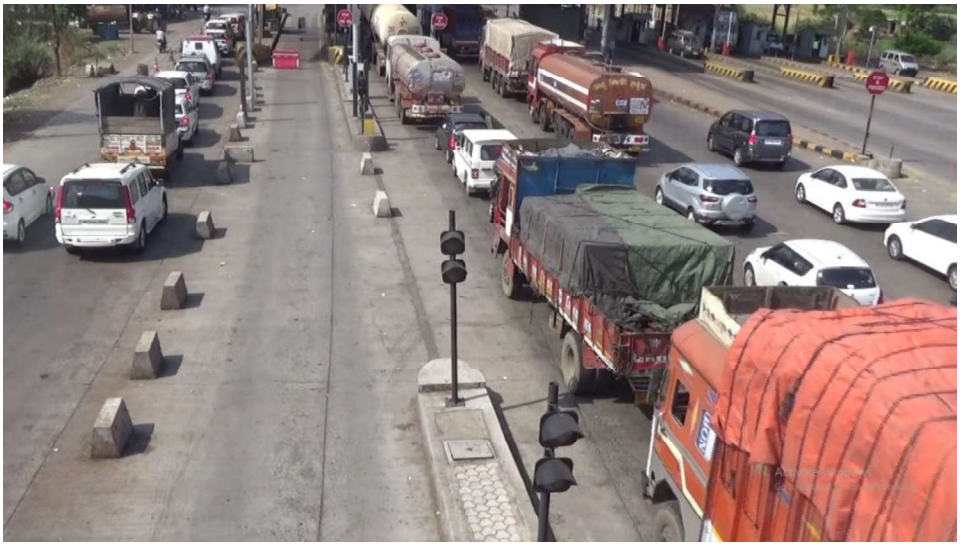

Figure 1: Mixed traffic conditions

A significant delay occurs during the peak hours at the toll plaza, which can be attributed to the passenger's opportunity cost. Travel time reliability and comfort are disrupted due to delays caused at the toll plaza, resulting in a monetary loss to the passenger and the tollbooth operators in the form of inefficient toll collection. The time lost due to delay can be quantified and can be estimated in monetary terms, called the value of time (VOT); also, the monetary analysis gives us a better understanding of economic repercussions.

Delay also has a psychological impact as it leads to uneasiness, irritation, fatigue etc., (Saad et al., 2018). Delay gives a reliable measure of the road efficiency but is difficult to estimate as it has various factors, including delay due to deceleration, stopped delay, and delay associated while accelerating from a stop. Severe environmental impacts can be related to delay, as drivers have a habit of keeping the engine in ON condition, leading to excess fuel consumption and emission release (Carbon Monoxide (CO), sulphur oxides, particulate matter (PM)) (Bari et al. 2020). Considering a single vehicle, the fuel consumption and emission might be low, but the vast pool of vehicles with various delays at a toll plaza leads to heavy fuel loss and high pollutant emissions.

The peak hour worsens the situation leading to high $PM_{2.5}$ in the vicinity of the toll plaza affecting the people working at the tollbooth and the daily commuters causing various respiratory diseases (Sehgal et al., 2014). Most of the impacts due to delay can be easily mitigated with proper planning and infrastructure. Impact analysis at the MTC lanes is the focus of this project, highlighting the alarming situation with possible mitigation measures to be incorporated.

The present study aims to understand the economic repercussions of delay for an individual and its impact as a whole on the economy. Further, the effect owing to delays and the pollution cost is also estimated to understand the economic impacts of emissions.

2 LITERATURE REVIEW

In the past few decades, extensive research has been conducted on various factors influencing and affecting the toll plazas' such as service time, delay, and efficiency in developed and developing countries. In relation to the undertaken case study, some of the relevant studies are briefly discussed henceforth. Ardekani and Torres (1991) studied the passenger travel cost and came up with an analytical method of estimating the value of time and the economic

consequences of the delay at the toll plaza. They concluded that the toll charge must be a function of vehicular demand and implied value of time and discovered that the total toll constitutes 90% of break-even toll (cost incurred during toll collection). Kandlikar and Ramchandran (2000) suggested that vehicular emissions are a major contributor to pollutant emissions after industrial and power plants.

Xia and Shao (2004) conducted a study on the Langrangian traffic flow model and estimated the traffic-induced emission through the stimulated traffic flow and atmospheric dispersion model. They used these data and the empirical emission factors for various categories and thus estimated the emission rates of major air pollutants like CO, NOx, and PM10 and predicted the area's air quality. Coelho et al. (2005) quantified the emission at the toll plaza for Electronic, manual, and no toll collection scenarios, taking into account queue length and stop-go cycles as a measure. It was found that maximum emission was due to the final acceleration of the vehicle after paying toll, leading to almost 99% of CO emission and roughly 75% of NO_2.

Indian Road Congress (IRC) SP: 30 (2009) has given the value of delay for various vehicle types and passenger travel cost in monetary terms with respect to the year 2009. Aditi and Sarkar (2009) conducted a study to estimate the congestion cost by evaluating the operating cost of vehicles, delay, pollution, stress, and physical fatigue. Pal and Sarkar (2012) conducted a study in the capital city of Tripura, Agartala, to estimate the fuel loss and noise pollution during vehicle idling. They found out that there is a direct correlation between traffic volume versus delay and traffic volume versus noise level. At the various intersection of Agartala city, the average vehicle delay was 60 sec/vehicle during peak hours. Al-deek et al. (1997) conducted a study to assess the efficiency of electronic toll lanes in Orlando. For the E-PASS lane, service was reduced 5 seconds/vehicle, with queue delaying reduced to 1min/ vehicle. The efficiency was evident from that cost of toll collection reduced by 10 cents per dollar.

Rakha and Ding (2013) attempted to quantify the impacts of vehicle stops on fuel consumption and emission rates using VT-micro models. The vehicles cruising at higher speeds tend to emit more pollutants when it comes to a halt than when cruising at a slightly lower speed. Khan et al. (2013) estimated the congestion cost of traffic delays in Dhaka city. In the study, various parameters for delay were considered travel time cost, vehicle cost of operating, and external environmental damage. In the study of delay cost, the opportunity cost of travel time was an important factor considered with suitable consideration for uncertainty in travel time. Ministry of economic planning and budget (MEPB) (2013) estimated the socio-economic cost of traffic congestion in Lagos. It was observed that the ETC lane could handle volume three times compared to that of non-ETC toll lanes (Philips Industries 1988a). The total cost consists of various components like the cost associated with delaying, increased vehicle operating costs, excess accident externality costs, and excess vehicle emissions externality costs. Finally, some mitigation measures like cable car system and imposing congestion charges were proposed.

Aksoy et al. (2014) conducted a study to analyze the delay performance of the toll queues by microsimulation model in Istanbul by incorporating the queuing theory. It was observed that the effects of the former queues were propagated to the queues that were formed later and thus minimizing the bottleneck capacity. Finally, some suitable traffic management strategies were suggested to improve the condition. Al-deek et al. (2000) implemented an advanced ETC algorithm with car-following and lane changing in toll selection. It was found that for all plaza configurations simulated with manual payment lanes operating overcapacity, the total plaza can be reduced by half, with 10% of users switching from manual to ETC lanes. Bhivina and Landge (2014) conducted a study to estimate the socio-economic impact of traffic delays. They conducted a willingness to pay survey and found out the value of time as the slope of the plot of travel time (X) and travel cost (Y) for each vehicular type. They thus empirically

correlated an increase in operating time at the tollbooth with its monetary value and demonstrated how it would increase vehicular emission through the amount of extra fuel combusted during traffic delay. Das et al. (2016) conducted a study to evaluate the traffic congestion at the Surat corridor through the speedo graph approach. They utilized the speed profile diagrams obtained by conducting speed and delay survey studies on one of the stretches of the major corridor in Surat. After that, travel speed indices (TSI) had been developed to describe the traffic congestion scenario on the road stretch.

Ricke et al. (2018) conducted a study to estimate the social cost of carbon (SCC) so as to quantify the economic damages expected to occur due to CO_2 emission in the atmosphere. Thus SCC provides an economic valuation of the marginal impacts of climate change. Tanvir et al. (2020) conducted a study to quantify the black carbon (BC) emission on the manually and electronically operated toll lanes in Shanghai. Despite ETC lanes having higher traffic than MTC lanes, BC concentration was 1.6-2.3 times in manual lanes than electronic lanes. It was concluded that ETC lanes can reduce BC concentration by 50% than manual tolls. Bari et al. (2020) conducted a study to evaluate the service time for various vehicular types under mixed traffic conditions at manually operated toll plazas. It was found that service time is the main factor for queue formation, thus leading to traffic delay. Vehicle characteristics influence the service time; for example, the service time is more for long vehicles like trailers and buses. Also, the results showed that the service time for the same leader-follower is lower than the mixed traffic conditions.

Thus, from the extensive literature review, it was found that it is necessary to minimize the traffic delay to achieve maximum efficiency at the toll plaza. The margin between the toll collected and the cost incurred during collection is significantly less, and over time even if they need to collect more toll is increasing (due to inflation and cost projection), the perception of the cost remains unchanged among passengers. Hence, this study focuses on the economic evaluation of the toll plaza, including the loss due to delay, emissions and fuel consumption. Therefore, the yearly loss at Ghoti Toll is estimated by combining the value of delay (VOD) and the emission cost, and possible suggestions are provided in order to minimize the loss.

3 OBJECTIVES

The scope of study is constrained within the domain of evaluating total loss due to delay at the selected toll plaza. The study was conducted on Ghoti toll plaza at Igatpuri in Nashik district on Mumbai – Agra National Highway (NH-3). The present study is focused on delay, estimation of economic loss in travel due to delay, quantifying the fuel loss, extra fuel consumption, pollution repercussions in terms of economics, and user's perception of the actual delay.
The following are the objectives framed based on existing literature and research gaps:

- To estimate the delay time for vehicles at Ghoti Toll Plaza.
- To estimate different costs associated with delay time.
- To estimate the pollution emission costs.
- To assess the overall socio-economic impact of delay at Ghoti toll plaza and suggestion of mitigation measures.

4 METHODOLOGY

The methodology for the present study is illustrated in Figure 2. The videographic traffic data was collected at the Ghoti Toll Plaza (GTP). GTP is located on Mumbai – Agra National Highway (NH-3), near Igatpuri taluka in Nashik district. This toll plaza consists of a total of 10

lanes to curb heavy traffic. This toll plaza observes heavy traffic at peak hours, leading to excessive delay times faced by the commuters. The data was collected in the normal weather conditions for week and weekend days. The videographic data were analyzed with the help of AVIDEMUX software to get the required accuracy of time, i.e., up to two decimal places. Extraction of the required delay time and other parameters such as the following vehicle, inter-vehicle time was done. The data was tabulated in the excel sheets with the various parameters incorporated. The entry and exit time at the tollbooth was precisely noted. To get the service time, the difference between exit and entry time was obtained. The total delay was the sum of service time and the time spent in the queue waiting to reach the tollbooth. The primary objective was to evaluate the time lost owing to delay to the corresponding economic aspect. Value of time (VOT) is the translating parameter used by the authors in the present paper. VOT model is taken from Indian Road Congress (IRC) – SP-30, 2009 with adjusting the inflation to get prices with respect to 2020 for the various vehicle to understand the economics of delay. The secondary data from the toll plaza authority was also obtained to get the yearly variation of traffic at GTP. The vehicles were classified into multiple categories, namely Cars, Buses, Light Commercial Vehicle (LCV), Heavy Commercial Vehicle (HCV), and Multi-Axel Vehicle (MAV). The total loss is evaluated, and mitigation measures are suggested to curb the long queue and waiting time menace.

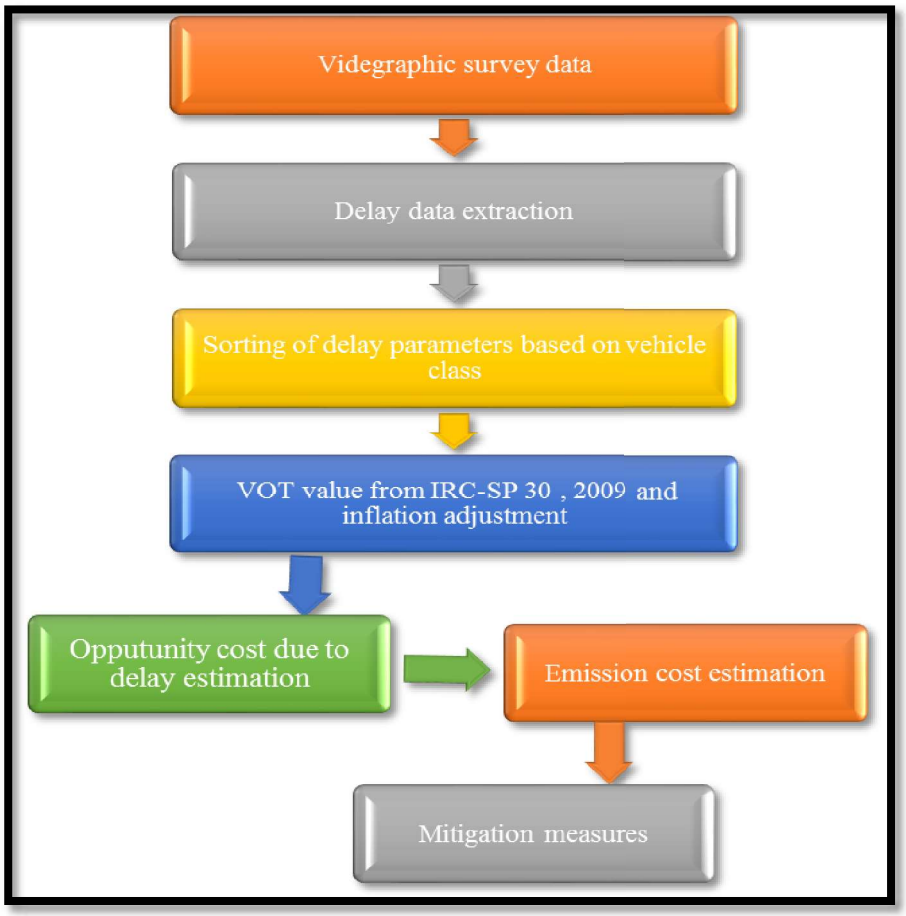

Figure 2: Flow chart for Research Methodology

5 DATA ANALYSIS

5.1 Total average delay calculation

The monthly variation in vehicle count observed is shown in Figure 3. It is observed that the traffic is lower in the rainy seasons than the other ones. Wide variation was observed in the yearly vehicular composition of all the vehicles classes considered, i.e., Car, Bus, LCV, HCV, MAV, and clearly understood from Figure 4. The average car composition for the yearly traffic is more than 50 percent. The bus composition founds to be 5.30 percent.

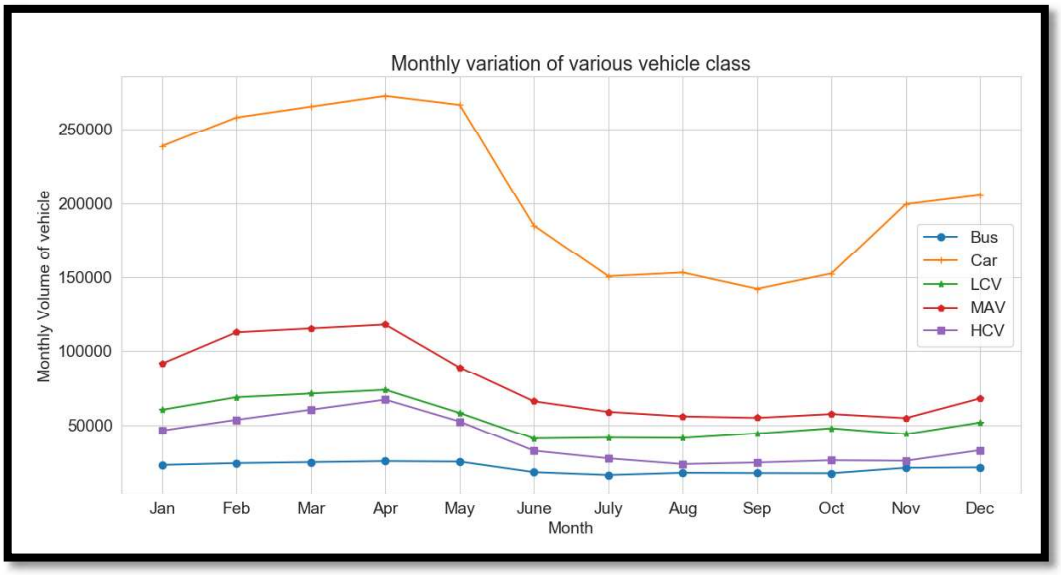

Figure 3: Monthly variation of vehicle class

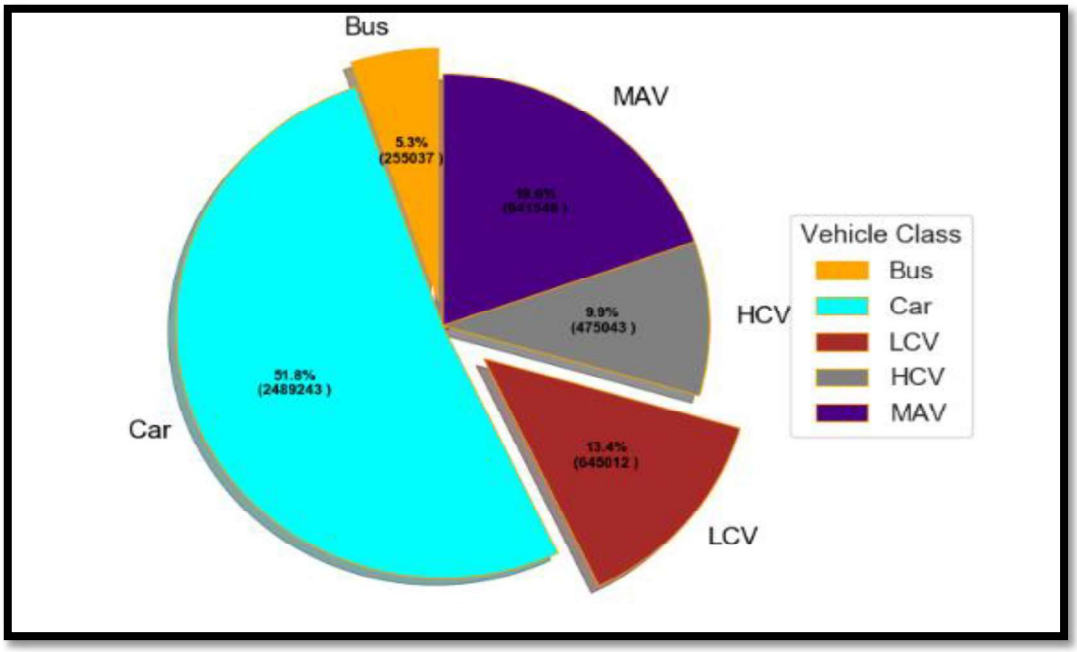

Figure 4: Vehicle composition yearly

To better understand the vehicular delay of various vehicle classes at the toll plaza, a box plot (Figure 5) was plotted. In the daily run, we observe a wide range of delay variations throughout the day, which could be easily inferred from the probability density function (PDF) graph and cumulative distribution function (CDF) as depicted in Figures 6 and 7, respectively.

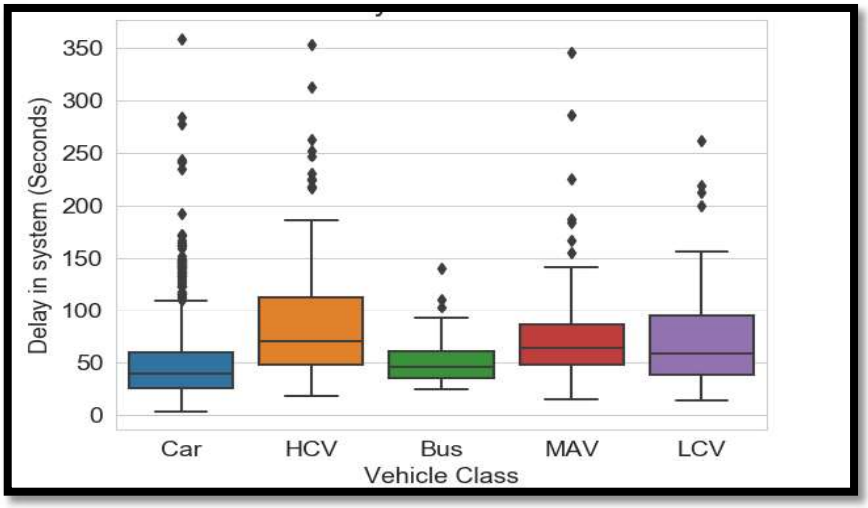

Figure 5: Box plot of delay for various vehicle class

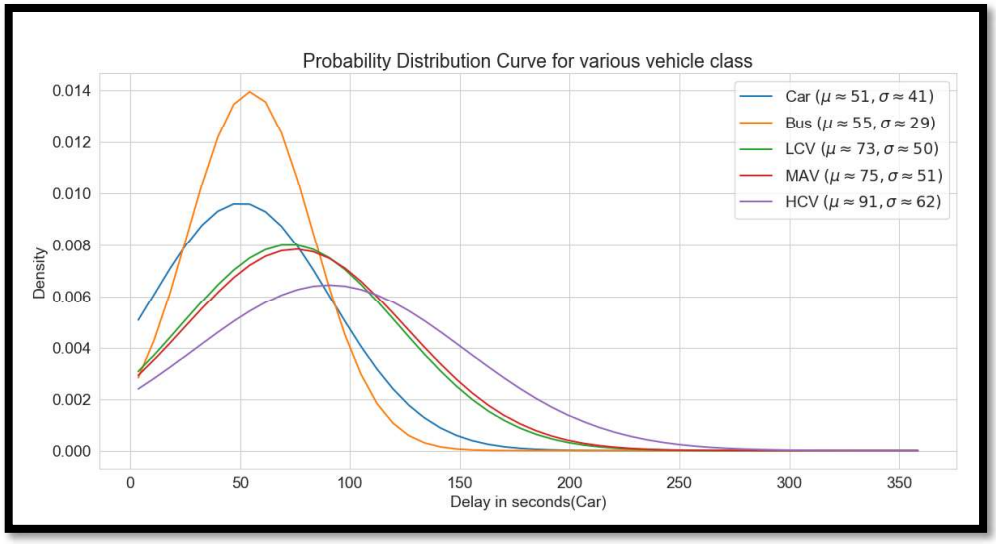

Figure 6: Probability distribution curve for various vehicle class

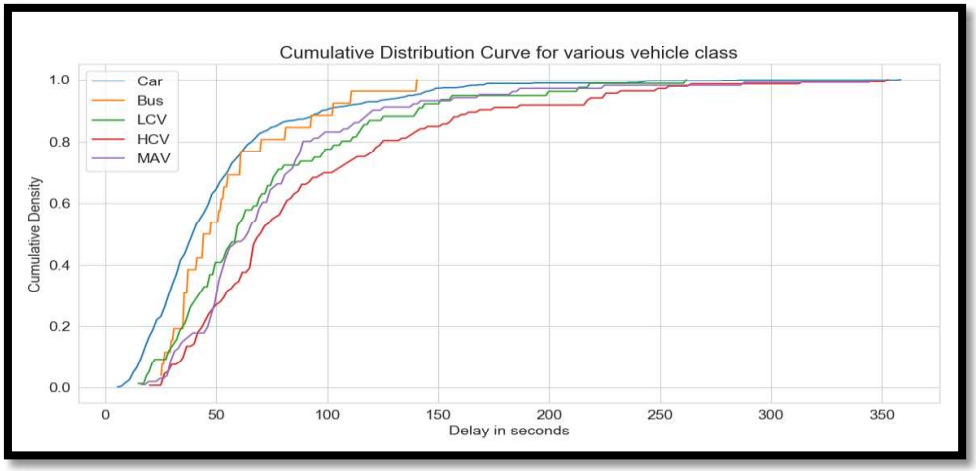

Figure 7: Cumulative distribution curve for various vehicle class

Table 1: The 85th percentile values for delay

Vehicle type	**85th percentile Delay (seconds)**
Cars	82.00
Bus	73.59

Vehicle type	85th percentile Delay (seconds)
LCV	95.76
HCV	115.31
MAV	90.44

Further, the data sorted by vehicle type was used to get the 85th percentile delay for each vehicle type. Here, 85th percentile values are taken considering the 85percent of vehicle will experience this delay values. It is observed that for Car, the value is 82.00 seconds, whereas, for HCV, it is 115.31 seconds.

5.2 Inflation Adjustment

VOT in rupees as given in IRC SP-30, 2009 was adjusted with respect to the current year, i.e., 2020 value, to get the delayed loss of passengers in monetary terms. For this purpose, the data regarding the average inflation rate between the 2009-2020 periods were gathered, and then, using equation (1), prices were forecasted to the present value.

$FV = P * (1 + r)^n$ …… (1)

Where, FV =Future value; P = Present value; r = annual interest rate; n = total no. of years

Average annual inflation rate (2009-2020) = 7.63%, according to yearly statistics.

(Source: www.inflationtool.com)

As per IRC SP: 30, 2009, the VOT value for cars and buses are 62.50 and 39.50 Rs/hr. The VOT values for commercial vehicles such as LCV, HCV, and MAV are given on the basis of commodity holding cost, as shown in Table 2.

Table 2: IRC values for commercial vehicles

Vehicle type	Commodity value (Rs/t)	Average load (t/vehicle)	Commodity cost (Rs/day)
LCV	35300	3.20	58.10
HCV	38750	9.00	178.10
MAV	36300	18.30	333.00

(Source: IRC SP:30, 2009)

Table 3: VOT / Commodity cost with inflation adjustment

Vehicle type	VOT/ Commodity cost (Rs/hr) (2009)	VOT/ Commodity cost (Rs/hr) (2020)
Cars	62.50	140.33
Buses	39.50	88.69
LCV	2.42	5.43
HCV	7.42	16.66
MAV	13.88	31.16

Table 4: Calculated VOT Rs/vehicle

Vehicle type	Delay (seconds)	VOT / Commodity cost (Rs/hr)	VOT (Rs/veh)
Cars	82.00	140.33	3.20
Bus	73.59	88.69	1.81
LCV	95.76	5.43	0.14

Vehicle type	Delay (seconds)	VOT / Commodity cost (Rs/hr)	VOT (Rs/veh)
HCV	115.31	16.66	0.53
MAV	90.44	31.16	0.78

Table 5: Total VOT yearly

Vehicle type	Total vehicles (yearly)	VOT (Rs/veh)	Total VOT (Rs/yearly)
Cars	2489244	3.20	7965579.83
Bus	255307	1.81	461617.36
LCV	645012	0.14	90301.62
HCV	475044	0.53	256523.62
MAV	941548	0.78	734407.81
Total			9508430.24

Total VOT considering all vehicle types comes out to be Rs 9508430.24. i.e., roughly Rs 9.5 million/ yearly

5.3 Evaluation of emission costs

It is important to understand the emission costs at the toll plaza due to increased fuel consumption owing to engine ON condition during service time. This not only increases fuel consumption but drastically increases the pollutants emission near the toll plaza region. India is among the top 3 nations in pollutions resulting from CO_2, leading to $216 billion social costs of emission yearly (Ricke et al., 2018). Pollutions from toll plazas also contribute to this social cost; hence there is a need to evaluate this emission cost and devise mitigation methods for the same.

The vehicle emission factor (g/km) is available to us as secondary data, multiplied by the vehicle population to get the total concentration of the pollutant in g/km. The emission factor used is tabulated in table 7.

Table 6: Emission factor for various vehicle class (g/km)

Pollutant	Car	Bus	LCV	HCV	MAV
CO	26.00	23.00	23.00	11.00	12.00
NO_x	5.00	61.00	61.00	28.00	30.00
PM	5.00	7.00	23.00	22.00	6.00
SO_x	0.08	0.31	0.30	0.15	0.18
VOC	3.00	5.20	5.20	2.90	3.00

(Source: Bari et al. 2020)

Concentration of pollutant (g/km) = total vehicle population * emission factor (2)

Pollution cost = concentration * cost per kg of pollutant * distance (3)

Distance is taken as 0.5 km to account for the toll plaza zone

Cost per kg of pollutant = Rs 7.22 /kg *(Source: Aditi and Sarksr, 2009)* (4)

Accounting for inflation, cost per kg = Rs 16.21/ kg

Table 7: Concentration of Pollution (kg) yearly at the toll plaza

Pollutant	Car	Bus	LCV	HCV	MAV
CO	64720.34	5865.86	14835.26	5225.48	11298.58
NO_x	12446.22	15557.27	39345.70	13301.22	28246.45

Pollutant	Car	Bus	LCV	HCV	MAV
PM	12446.22	1785.26	14835.26	10450.96	5649.29
SO_x	199.14	79.06	193.50	71.26	1694.48
VOC	7467.73	1326.20	3354.06	1377.63	2824.64
Total	97279.65	24613.64	72563.88	30426.55	48188.451

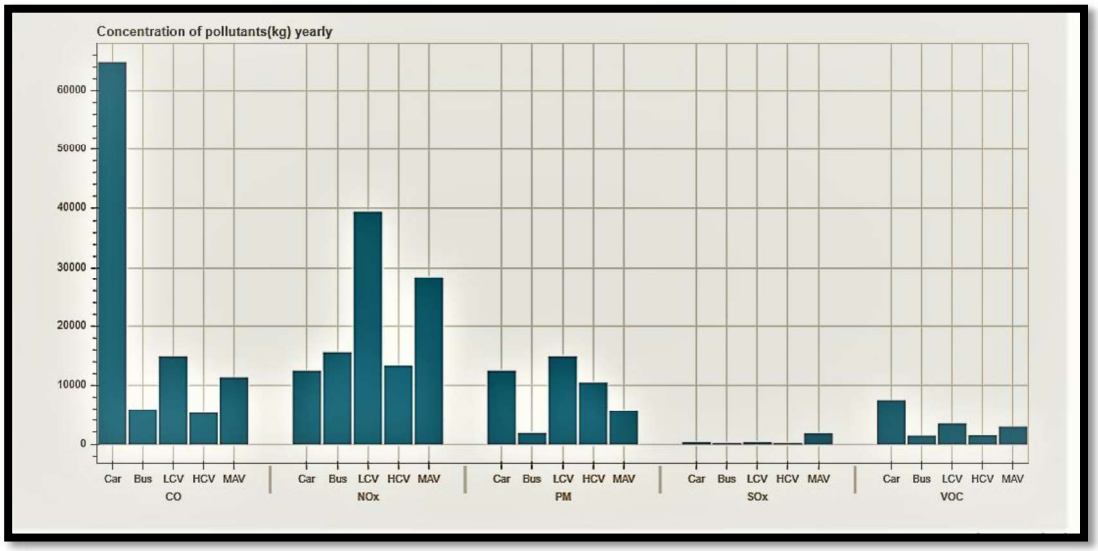

Figure 8: Pollutants concentration of various vehicle class

Table 8: Pollution cost

Vehicle type	Yearly cost (Rs)
Cars	788451.51
Bus	199493.56
LCV	588129.61
HCV	246607.20
MAV	390567.40
Total	2213249.28

Pollution cost is obtained to be Rs. 22,13,249.28, i.e., roughly around Rs. 2.2 million/per annum.

6 RESULTS

The case study was conducted at the Ghoti toll plaza for the vehicles plying towards Mumbai direction. The delay experienced by them at the toll plaza was obtained from the field studies. Value of Time (VOT) was obtained around Rs 9.5 million per annum. The monetary values signify the heavy loss incurred, which goes unchecked as an opportunity cost. This figure will tend to go up more drastically if the traffic of vehicles plying towards Nashik is also considered. Delay caused forgoes not only the opportunity cost but also affects the environment.
The pollution cost comes to about Rs 2 million per annum, which is significant in monetary terms and a health hazard for the workers at the toll plaza. Following mitigation measures can be implemented with scope for future improvement

7 MITIGATION MEASURES

The entire process of toll collection could be automated using Artificial Intelligence (AI) and image processing. Each tollbooth should be installed with a camera that should continuously note and maintain a database of number plates of vehicles passing through the toll plaza. The toll tax on a vehicle should be collected on a monthly basis. If done correctly, significant traffic delays can be curbed.

The whole traffic can be diverted over various lanes to achieve better efficiency, which can be achieved through a better traffic flow model. Each vehicle should be notified at a certain distance before the toll booth, which lane they should occupy. This could be done through visual signboards, which would be suggesting the vehicles based on the current occupancy of each lane.

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