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COMPARATIVE STUDY OF VARIOUS ROAD TOLL COLLECTION SYSTEMS BASED ON IDLING TIME OF VEHICLE AND CO_2 EMISSION – A CASE STUDY

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ABSTRACT

ITS stands for intelligent transportation system. As name suggests it is a smart version of conventional transportation methods. In today's smart world where we use everything smart whether it is a smartphone or a watch, a new idea of smart transportation system came forward which leads to birth of ITS. It is a huge concept and not only limited for roadways but also covers the other forms like airways, railways and waterways. Here we are using this system for road transportation. As we know a country's development depends on the communication means of that country. Hence every country is aware of having good transportation means and builds roads. To build roads countries need large amount of sum, to deal with this problem they come up with solution like toll system. Toll system is also part of ITS. There are different types of toll collection methods and these are covered in this paper. These methods are: manual toll collection method, electronic toll collection method and open road toll collection method. In this paper we have compared these methods to choose which is the efficient method amongst them. For this we did comparative study of methods also we have used cost benefit analysis for better results. As India is a developing very fast especially in transportation sector, we hope this paper will help in the right way, as we in India are also using toll collection methods like manual toll collection as well as electronic toll collection methods.

KEYWORDS:*ITS, ORT, ETC, intelligent transportation*.

I. INTRODUCTION

In the world of more than 7 billion populations, we are facing problems like global warming, less energy resources, hunger, unemployment etc. These problems vary according to time and place in different countries. Problems of developed and developing countries are different from each other. The problem of traffic is mostly faced by the people of developed countries. There are other similar problems like parking problem, accidents also. But even these problems can be tackled by use of intelligent transportation systems. In cities where population is beyond 10 million these kinds of problems are crucial

compared to the cities with less population. Talking about India, we have more than 10 cities which are having population more than 10 million e.g. Mumbai, Delhi etc. The people of these cities facing problem of frustration which is occurred due to traffic. So it is the duty of government to give people a smooth transportation system as it is their fundamental right to ask for smooth traffic because they pay taxes directly or indirectly.

There are three sectors of economy that shapes every country. These sectors are primary, secondary and tertiary. These sectors have a direct impact on GDP of the country therefore they are must to look after by the government of the country. Primary sector deals with the raw materials therefore also called as agricultural sector. Secondary sector deals with manufacturing process hence it is called as industrial sector. Tertiary sector deals with the services. And transportation is the bridge between these sectors. Especially road transportation has the more importance to connect them in India. India is country of cities and villages. Raw material from villages brought to the mills, industries by road transport for production then after production is done it is taken to the markets by the road transport or to the cities. Therefore, we can see here road transport has a crucial role in shaping the economy of the India. In India we are having 40000 km of national highways that connects every states of the country and every city to the town in the country. Across these national highways there are total 377 toll plazas to collect the toll. Collection of toll is necessary as to build and to maintain and repair these roads, huge amount of sum is needed. Indian government once tried to cover this sum in the yearly budget of country but it was disaster and could not meet the target. And hence the government decided to use only toll plazas to cover this sum. Initially India was having only manual toll collection in all of the toll plazas on national highway but in past year government installing electronic toll collection system all over the country. It is still on trial bases as not every toll is getting this system. Every year billions of rupees are invested in road transport but it is because it is a must need for our development. And by using toll collection method this invested money can be regained. Also toll collection helps government to unload the problem of this investment as these roads are built and operated by private sectors and then they are transferred to government.

II. TOLL COLLECTION METHODS:

A. Manual Toll Collection

Manual toll collection is the conventional method of toll collection. In India, all toll plazas are having this method for toll collection. This method requires man-power. It requires toll attendant. Base on the type of vehicle, toll is collected by the attendant. Then attendant gives the ticket to vehicle user. Operation time is high for this method. At the peak hour of traffic, there can be long queues of vehicles may happen.

B. Electronic Toll Collection

Electronic toll collection is advance version of manual method of toll collection. It relies on technologies like RFID (Radio Frequency Identification Technology), Android, Bluetooth, Sensors, GPS etc This system doesn't require any man-power as it automatically collects toll from vehicle user. When vehicle approaches toll plaza, sensors detects the type of vehicle by sensing the tag on the vehicle provided to user by the authority of toll plaza. Then the amount of toll is deducted from user's account and then user receives a SMS of amount deduction from bank. Then gate opens and user is ready to go. Operation time is less as compared to manual method of toll collection.

C. Open Road Toll Collection

Open Road Toll collection method is the method where there is no toll plaza is required. In this method neither man-power nor gates are provided. User doesn't require slowing down his speed when approaching this system. User need not to stop at this system and can retain his speed. Hence there is no queue problem or traffic congestion at this system. This is the most advance method of toll collection and efficient method as it provides maximum vehicles per hour through the facility. Only disadvantage of this method is the possibility of violators who do not pay. This leakage may either be written off as an expense by the toll operator or offset in part or whole by fees and fines collected against violators.

III. CASE STUDY & TRAFFIC VOLUME COUNT

A. Description of Study Area

Location:
Tasawade Toll Plaza,

The toll plaza is having 4 lanes on each side for toll collection. Out of which 1 lane is provided for ETC but it

has not been started yet. ETC is opening soon, here. For ETC they have installed a FASTag reader sensor that works on RFID (Radio Frequency Identification Technology) technology and given the separate lane. Right now they are using conventional method, i.e. Manual Toll collection method, for toll collection.

Volume count at plaza

Total number of vehicles passing through toll plaza in both directions is calculated at toll plaza from Dt. 26th Dec 2016 to 31st Jan 2017 using Volume count method.

Date of count	Car/Jeep	LCV/Mini Bus	Truck/Bus	MAV/HMV	Total traffic
26-12-16	10126	1493	2922	321	14862
27-12-16	10054	1608	3306	343	15311
28-12-16	8857	1856	3401	472	14586
29-12-16	9134	1935	3543	557	15169
30-12-16	10947	1942	3586	488	16936
31-12-16	9754	1857	3286	539	15436
1-1-17	13100	1672	3260	503	18535
2-1-17	9200	1527	3033	501	14261
3-1-17	6323	1522	2996	616	11457
4-1-17	6039	1675	3757	427	11898
5-1-17	6289	1893	3616	497	12295
6-1-17	7082	1826	3573	785	13266
7-1-17	7987	1853	3633	547	14020
8-1-17	9502	1822	3794	671	15789
9-1-17	6990	1598	3178	569	12335
10-1-17	7913	1766	3613	548	13840
11-1-17	6268	1842	4023	604	12737
12-1-17	6261	1872	3696	628	12457
13-1-17	6506	1736	3620	656	12518
14-1-17	6729	1691	3430	667	12517
15-1-17	7601	1584	3505	605	13295
16-1-17	6662	1421	2969	419	11471
17-1-17	6061	1612	3161	547	11381
18-1-17	6082	1776	3644	536	12038
19-1-17	6534	1903	3691	637	12765
20-1-17	6534	1749	3634	704	12621
21-1-17	7426	1853	3776	651	13706
22-1-17	8780	1809	3789	770	15148
23-1-17	6488	1609	3215	520	11832
24-1-17	5899	1709	3613	521	11742
25-1-17	6934	1920	4123	506	13483
26-1-17	11994	1895	4058	463	18410
27-1-17	6603	1624	3141	330	11698
28-1-17	9503	2030	3899	280	15712
29-1-17	13542	1959	4208	429	20138
30-1-17	7431	1774	3532	338	13075
31-1-17	4755	1664	3559	443	10421
Total	294125	64852	130784	19638	509399

Total number of vehicles passing through toll plaza in given period = 509399

Total revenue collected at toll plaza in given period = Rs. 70906370 = Rs. 709.065 lakhs (source: interviewing toll attendant)

IV. IDLING TIME

TRAVEL TIME (waiting time for vehicles to pay the toll)

Travel time of vehicle at toll plaza includes following three stages –

1. Deceleration stage –
   Deceleration stage is the stage where vehicles decelerate because they are approaching the toll plaza
2. Service stage –
   Service stage is the stage where vehicle stops to pay the toll.
3. Acceleration stage –
   Acceleration stage is the stage where vehicles accelerate because they are leaving the toll plaza.

Calculations of the time required for completion of each stage are carried out as follows –

A. DECELERATION STAGE

Deceleration stage is the stage where vehicles decelerate because they are approaching the toll plaza. For calculation purpose the area for this stage is fixed as 100 feet. At the end of this stage there is toll booth. And at the end of the stage speed of vehicle is minimum. To calculate the time in this stage, readings of 10 vehicles are taken with the help of stopwatch:

Following are the readings taken at toll plaza

For Manual toll collection
At peak hours:

Table 1. Deceleration Time at peak hour

Vehicle Number	Time (sec)
1	50
2	65
3	80
4	65
5	80
Avg.	68

At normal hours:

Table 2 Deceleration Time at normal hour

Vehicle Number	Time (sec)
1	15
2	35
3	35
4	20
5	20
Avg.	25

For ETC
Average Time = 7-10 sec
Assume, deceleration time for ETC = 8 sec

For ORT
There is no deceleration stage for ORT. Hence no deceleration time for ORT.

B. SERVICE STAGE

This is the stage where vehicle stops to pay the toll. Toll is fixed according to type of vehicle. Service stage requires time for payment of toll and receiving the receipt from toll booth. To calculate this service time, readings of 10 vehicles are taken with the help of stopwatch.
Following are the readings taken at toll plaza.

For Manual toll collection

Table 3 Service Time for manual

Vehicle Number	Time (sec)
1	14
2	15
3	15
4	13
5	15
Avg.	14.4

For ETC
Average Time = 5-7 sec
Assume, service time for ETC = 6 sec

For ORT
There is no toll booth installed for ORT. Hence no service time for ORT.

C. ACCELERATION STAGE

Acceleration stage is the stage where vehicles accelerate because they are leaving the toll plaza. For calculation purpose the area for this stage is fixed: 100 feet. At the starting point of this stage there is toll booth. And at the end of the stage speed of vehicle is maximum. To calculate the time in this stage, readings of 10 vehicles are taken with the help of stopwatch:
Following are the readings taken at toll plaza
For Manual toll collection

Table 4 Acceleration Time for manual

Vehicle Number	Time (sec)
1	7
2	8
3	7
4	9
5	9
Avg.	9.6

For ETC
Average Time = 7-9 sec
Assume, acceleration time for ETC = 8 sec

For ORT
There is no acceleration stage for ORT. Hence no acceleration time for ORT.
For ORT there no deceleration stage, acceleration stage or service stage, hence a consumption factor is assumed, say 6 sec.

Total travel time for each toll collection system is given as,

$$T = t_{deceleration} + t_{service} + t_{acceleration}$$

1. Total travel time of manual toll plaza
   = (68+14.4+9.6) = 92 sec _ at peak hour
   = (25+14.4+9.6) = 49 sec _ at normal hour
2. Total travel time of ETC = (8+6+8) = 22 sec
3. Total travel time of ORT = there is no deceleration and thus acceleration of vehicle at ORT. But, for emission calculation purpose consumption factor is assumed, say 6 sec

V. Method for Calculation of Road Transport Emission

The methodology for the estimation of CO2 emissions applied to the case of the Indian toll road network is based on COPERT IV, which is a European tool for the calculation of emissions from the road transport sector. The framework of methodology is shown in Fig.

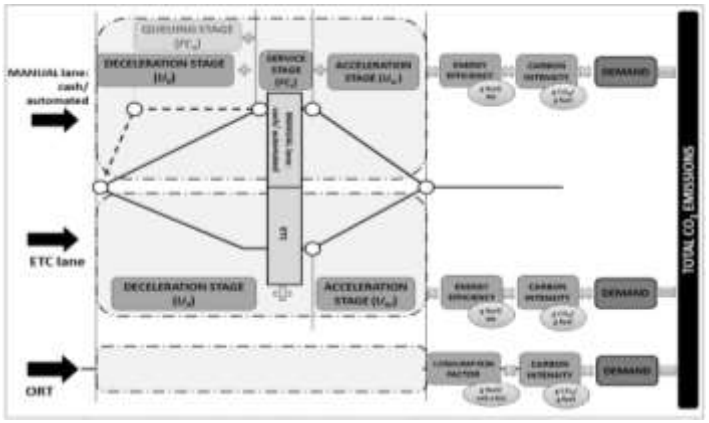

Figure 4: The framework of methodology for estimating emission of CO_2

The physical layout and operation of a toll plaza offers an approaching vehicle different lanes to choose from, depending on the payment system selected. An integrated methodology is proposed here for use in evaluating the energy consumption and CO_2 emissions of three toll collection systems – MANUAL, ETC and ORT – according to traffic demand.
be forced to wait at the entrance of the toll plaza, creating a possible additional step: the queuing stage. In an ETC system, the energy consumption formula has only two phases, deceleration and acceleration stage.

CO_2 INTENSITY

Data of CO2 emission from vehicles in idling position is taken from the source: "Indicative Impacts of Vehicular Idling On Air Emissions" by Dr. Sarath Guttikunda. Here CO2 emission is calculated for diesel, petrol and CNG vehicles. CO2 emission of vehicles is given in the form of gm/day/vehicle:

Table 5 CO2 intensity for vehicles (gm/day/vehicle type)

	Gasoline			Diesel				CNG			
	2Ws	3Ws	Cars	Cars	LDV	HDT	Bus	3Ws	Cars	LDV	Bus
PM_{10}	1.0	3.3	0.4	4.7	5.0	12.0	9.0	1.7	0.2	0.1	0.1
PM_{25}	0.5	1.3	0.1	2.8	2.0	6.0	4.8	0.8	0.1	0.0	0.1
SO_2	0.2	0.3	0.3	1.9	1.2	6.0	6.0	0.0	0.0	0.0	0.0
NO_x	1.5	1.7	0.8	5.8	8.0	60.0	60.0	5.8	0.8	10.5	15.0
CO	25.0	133.3	20.0	9.3	10.0	21.0	21.0	58.3	4.0	10.5	21.0
CO_2	400	1333	800	1167	2000	5100	5100	1167	400	1350	2700
HC	15.0	83.3	4.0	1.9	0.8	6.0	6.0	2.5	0.1	0.3	0.6

Here,
LDV = Light Duty Commercial Vehicle
HDT = Heavy Duty Truck
Above table is having readings given in form gm/day/vehicle type. As it is given in day, it is converted in seconds for calculation purpose. Following table is showing CO2 emission for gm/sec/vehicle type:

Table 6 Conversion of CO2 from gm/day to gm/sec

Vehicle Type	CO2 emission in gm/day	CO2 emission in gm/sec
Car (Petrol)	800	0.0092
Car (Diesel)	1167	0.0135
Car (CNG)	400	0.0046
Bus	5100	0.0590
Truck	2000	0.0231

TOTAL CO_2 EMISSION

Total CO2 emission is the product of time required for deceleration plus time required for service time plus time required for acceleration multiplied by carbon intensity and vehicle number. Total CO2 emission is calculated in gm.
Following is the detailed calculation of CO_2 emission for Manual, ETC and ORT.

Formula for CO_2 emission for Manual toll collection:

Total CO_2 emission = {(Deceleration time + Service time + Acceleration time) x Carbon intensity x Number of vehicles }

At peak hour:

Table 7 Total CO_2 emission for Manual toll collection at peak hour

Vehicle Type	Deceleration Time (in sec)	Service Time (in sec)	Acceleration Time (in sec)	Carbon Intensity (in gm/sec)	Total Vehicle Count	**TOTAL CO2 EMISSION (in gm)**
Car (Petrol)	68	14.4	9.6	0.0092	58825	49789.48
Car (Diesel)	68	14.4	9.6	0.0135	102650	127491.3
Car (CNG)	68	14.4	9.6	0.0046	102650	43441.48
Bus, LCV	68	14.4	9.6	0.0590	195636	1061912.21
MAV/HMV	68	14.4	9.6	0.0231	19638	41734.68
					Total	**1324369.15 gm**

At Normal Hours

Table 8 Total CO2 emission for Manual toll collection at normal hour

Vehicle Type	Deceleration Time (in sec)	Service Time (in sec)	Acceleration Time (in sec)	Carbon Intensity (in gm/sec)	Total Vehicle Count	**TOTAL CO2 EMISSION (in gm)**
Car (Petrol)	25	14.4	9.6	0.0092	58825	265183.1
Car (Diesel)	25	14.4	9.6	0.0135	102650	67902.98
Car (CNG)	25	14.4	9.6	0.0046	102650	23137.31
Bus , LCV	25	14.4	9.6	0.0590	195636	565583.68
MAV/HMV	25	14.4	9.6	0.0231	19638	22228.25
					Total	**944035.32 gm**

Formula for CO2 emission for ETC

Total CO2 emission = {(Deceleration time + Service time + Acceleration time) x Carbon intensity x Number of vehicles}

Table 9 Total CO2 emission for ETC

Vehicle Type	Deceleration Time (in sec)	Service Time (in sec)	Acceleration Time (in sec)	Carbon Intensity (in gm/sec)	Total Vehicle Count	**TOTAL CO2 EMISSION (in gm)**
Car (Petrol)	8	6	8	0.0092	58825	11906.61
Car (Diesel)	8	6	8	0.0135	102650	30487.05
Car (CNG)	8	6	8	0.0046	102650	10388.18
Bus , LCV	8	6	8	0.0590	195636	253935.53
MAV/HMV	8	6	8	0.0231	19638	9980.03
					Total	**316697.4 gm**

Formula for CO2 emission for ORT

Total CO2 emission = {Consumption factor x Carbon intensity x Number of vehicles}

Table 10 Total CO2 emission for ORT

Vehicle Type	Consumption Factor (in sec)	Carbon Intensity (in gm/sec)	Total Vehicle Count	**TOTAL CO2 EMISSION (in gm)**
Car (Petrol)	6	0.0092	58825	3247.62
Car (Diesel)	6	0.0135	102650	8314.65
Car (CNG)	6	0.0046	102650	2833.14
Bus	6	0.0590	195636	69255.144
Truck	6	0.0231	19638	2721.83
			Total	**86372.38 gm**

From above calculations,

i. Total amount of CO_2 emission at Manual toll plaza = 1324.37 Kg _for peak hour
944.035 Kg _for normal hour

ii. Total amount of CO_2 emission at ETC toll plaza = 316.69 Kg

iii. Total amount of CO_2 emission at ORT toll plaza = 86.372 Kg

VI. RESULT & DISCUSSION

a. Total idling time for each toll collection system is given as,

$$T = t_{deceleration} + t_{service} + t_{acceleration}$$

1. Total travel time of manual toll plaza
= (68+14.4+9.6) = 92 sec _ at peak hour
= (25+14.4+9.6) = 49 sec _ at normal hour

2. Total travel time of ETC = (8+6+8) = 22 sec
3. Total travel time of ORT = there is no deceleration and thus acceleration of vehicle at ORT. But, for emission calculation purpose consumption factor is assumed, say 6 sec

b. Total CO_2 emission for each toll collection system is given as,

1. Total amount of CO_2 emission at Manual toll plaza = 1324.37 Kg _for peak hour
944.035 Kg _for normal hour
2. Total amount of CO_2 emission at ETC toll plaza = 316.69 Kg
3. Total amount of CO_2 emission at ORT toll plaza = 86.372 Kg

VII. CONCLUSION

The Most Efficient Method For Toll Collection

- Emission of CO_2at ETC is very less than manual method but there is no CO_2 emission at ORT. The above calculations reveal that ORT system leads to reduction of up to 70% of CO_2 emissions at toll plazas, while ETC system reduces 20% comparing to the manual ones.
- Also ORT leads to saving of time up to 63 seconds more than Manual method and 22.6 seconds more than ETC.
- No doubt ORT is the most efficient method of toll collection as it saves time, there is no wastage of fuel, and very less CO_2 is emitted.

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