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# Cost – Benefit Analysis of GPS based toll Collection System (Case Study: Umred and Borkhedhi Toll Plaza)

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**ABSTRACT:** Developing countries like India needs a significant improvement in infrastructure such as Roads or Highways. Construction of these highways is a costly affair, which can't be invested by the government alone. Normally Public private partnerships are made to construct such a huge projects. The money spent on these projects can be regained by collecting toll from the passengers who use the roads. The toll collection system, especially in India faces some problems such as long queue lines, escaping from toll plazas etc. These systems can service only 300 vehicles per hour, and if more than that number of vehicles arrive at that plaza, server traffic jams may occur. To solve this we are proposing to create geofences using GPS by giving latitude and longitude of the corner of the toll plaza. By comparing the position of the vehicle and toll plaza, the owner of the vehicle can be charged from the account.

**KEYWORDS:** Infrastructure, toll plaza, geofences, Traffic jams.

## I. INTRODUCTION

Road pricing or tolling can be defined as the practice of fee collection from motorists who use roadway facilities (U.S. Department of Transportation Federal Highway Administration, n.d.). The collected toll fees are often used for expansion, operational and maintenance purposes. Traditionally, toll fee was manually collected via cash or card transactions at dedicated toll booths. However, this system was often criticised as motorists were required to stop to pay the fees. The stopping of vehicles results in traffic congestion at the toll booths during peak hours and have been proven to result in fuel inefficiency. To effectively address the complications from manual toll collection, electronic toll collection (ETC) was proposed. The idea was originated from the Nobel Economics Prize winner, William Vickrey, who suggested to equip all cars with an electronic identifier (Library Economics Liberty, n.d.). The electronic identifier refers to a transponder that allows personalized signal to be delivered to a central computer from specific road sections for bill calculation (Kelly, 2006). This idea was first adopted at toll booths in Norway in the year 1986. By 1991, Trondheim in Norway became the world's first city that implemented the unaided full-speed electronic tolling (ONE-ITS, n.d.). This system is advantageous as it significantly reduced time delay due to toll payment. As popularity grew with this concept, gantries gradually replaced the traditional toll booths, allowing sensors to be installed for easier detection. Unfortunately, from here, additional issues were raised in response to gantry usage. First, gantry constructions are expensive. Next, gantry breakdown may disrupt toll collection and regular maintenance is thus necessary. A possible solution to these issues is to implement road pricing based on the Global Positioning System (GPS). The earliest project on GPS-based road pricing was accompanied with a field test in Hong Kong in 1997 (Catling, 2000). In 1998, the European Union published a report that proposed the usage of Global Navigation Satellite System (GNSS) to charge vehicles by distance (Brussels, 1998). These early works gave rise to more concepts and variations of GPS-based road pricing. Lee, Jeng, Tseng, and Wang (2004) and Xu (2005) both provided comprehensive investigations and reviews on the architecture of GPS-based toll collection system as well as addressing possible design issues. Srinivasan, Cheu, and Tan (2003) proposed a GPS-based road pricing system using map matching method. Moreover, Ren and Xu (2010) proposed another system rooted upon node matching. Not least, Dias, Matos, and Oliveira (2014) came up with the concept of a smartphone-based toll collection system which was interoperable between traditional ETC and new GNSS tolling. Interesting as these concepts may seem, their implementations, however, require sophisticated algorithms and complex system setup, resulting in commercialisation challenges.

## II. RELATED WORK

The system architecture of GPS-based ETC system is illustrated in Fig. 1, which includes five key parts of unit: interfacing hardware device, manual toll collection team, control unit, Transaction management unit and the money Payment Center. The working process of GPS-based ETC system is described as follows procedure:

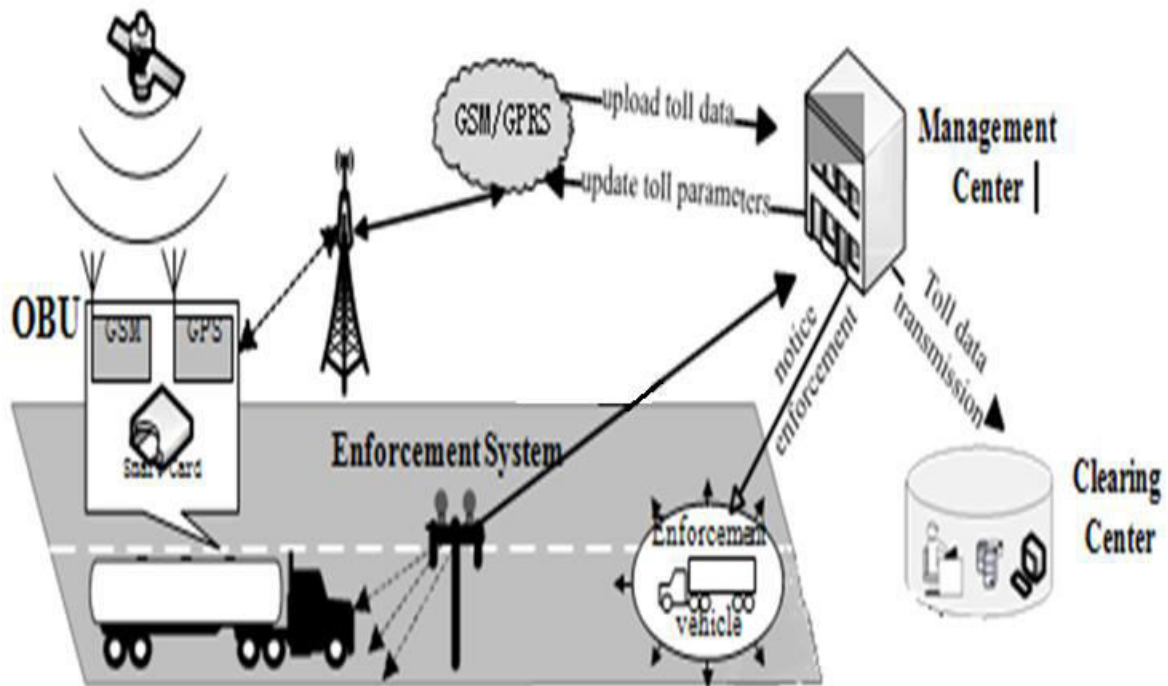


FIG. 1 ARCHITECTURE OF GPS-BASED ETC SYSTEM.

Drivers goes to the money payment center registers and installs interfacing hardware device and applies for pre-paid card or post-paid card. When vehicle moves into the toll area, interfacing hardware device checks current vehicle's position coordinate from GPS with the virtual toll node coordinate, kept in the storage of interfacing hardware device. After logistic determining, the interfacing hardware device sets up wireless communication channel through GSM module. Interfacing hardware device sends transaction message to control system by the GSM module through mobile network. After auditing to control system saves toll data and sends back transaction information to the Interfacing hardware device. The Interfacing hardware device receives and displays the transaction result then it is working properly. If there is an error in transaction the result either there is a problem in the interfacing device or may be installation not properly done. When the vehicle crosses the charging zone, if the Interfacing hardware device has abnormal state or the vehicle doesn't install an Interfacing hardware device the violation will be processed. The transaction control unit clears all information according to toll data from control unit, and divides in road service providers.

The money Payment Center collects toll records and clearing data for account query.

Problem Setup and Notations

Input: Taking latitude and longitude through GPS

Output: Vehicle Location.

Result: Receiving message about deduction of balance.

I is a set of various vehicle types  $I = \{t_1, t_2, \dots, t_n\}$

V is a set of individual vehicles  $V = \{v_1, v_2, \dots, v_n\}$  P is a set of prepaid account for different users.

$P = \{b_1, b_2, \dots, b_n\}$

R is a set of fixed amount for different vehicles



$R = \{c_1, c_2, \dots, c_n\}$

Then,

- $\forall I \mid V$  pay R cash from prepaid account P

### III. METHODOLOGY

The functional concept of a manual toll system is simple: the motorist takes a ticket at the entrance to the motorway and presents it at the tollbooth at the exit. Ticketing and toll barriers can also be placed on each section of motorway. With technological progress, these systems have evolved towards electronic toll collection, allowing traffic to flow more smoothly and improving service to both users and operators. System consists of Automatic Toll Collection Centre, control gates and on-board

The system is based on an innovative combination of mobile telecommunications technology (GSM) and GPS, the satellite-based Global Positioning System. The main element of the automatic log-on system is the On-Board Unit (OBU). With the aid of GPS satellite signals and other positioning sensors, the OBU automatically determines how many kilo meters have already been driven on the toll route, calculates the toll based on the vehicle and toll rate information that has been entered, and transmits this information to the ATCS computer centre for further processing. Software will be support with electronic road maps and data of users registered in as well as data charges of highways and expressways. Charge counting will be started after highway entrance gate and finished after highway exit gate. Data on vehicle position will be additionally approved by GPS system and delivered to ATCC by GSM net. The toll amount is based on the truck's emission category and number of axles, as well as on the length of the toll route. GPS placed in the toll system gives the location information to the user. As the vehicle enters the toll gate, RFID tag in the vehicle is read by RFID scanner placed in the toll gate. RFID tag is linked with the users account. When RFID scanner reads the tag the amount is deducted from the users account and the notification is sent to the user through android application. Account information updated in the database and in RFID card linked with the user.

### IV. EXPERIMENTAL RESULTS

1. Average fuel consumption per hour is calculated for a vehicle.
2. Total reduced travel time when replacing the ETC method with the GPS system is calculated.
3. Saving in fuel consumption is obtained by multiplying the above two values.

To do so, the following steps should be taken:

1. The number of vehicles using ETC system in one day (24 hours) is calculated using the following equation:

$$GPS_n = TV_n \times i_{GPS} \tag{1}$$

where:

$TV_n$  : Total number of vehicles that pass a tollbooth in a day (24 hours)

$i_{GPS}$  : Percent vehicles using the GPS system

2. Reduced travel time for a vehicle due to utilization of GPS system instead of the current method, is calculated as follows:

$$T_{GPS} = t_{etc} - t_{gps} \tag{2}$$

where:

$t_{etc}$  : Stop time for a vehicle to pay the toll by ETC system

$t_{gps}$  : Payment time for a vehicle in the GPS system with no stops





Reduced time for a vehicle due to elimination of deceleration/acceleration in tollbooth area would be calculated using the following equation:

$$T_{al} = t_a + t_l - t \quad (3)$$

$$t_a = d_a / v_d \quad (4)$$

$$t_l = d_l / v_a \quad (5)$$

$$t = d / v \quad (6)$$

where:

$t_a$  : Tollbooth approach time. It is calculated as the time it takes for the vehicle to stop in front of the booth, from the moment it starts to decelerate.

$t_l$  : Tollbooth leave time. It is calculated as the time it takes for the vehicle to reach its normal speed, from the moment it leaves the booth.

$t$  : Travel time between two ramps with normal speed

$d_a, d_l$ : Distance required for a vehicle to decelerate from normal speed until it stops or to increase speed to reach normal speed which is called ramp.

$v_d, v_a$  : Average speed of the vehicle during deceleration or acceleration period

$d$  : Distance between the ramp before and after tollbooth

$v$  : Average normal speed of the vehicle

If  $T_q$  is the reduced time for a vehicle due to elimination of waiting in a queue, the total reduced time that is a function of payment time, deceleration, acceleration, and waiting in a queue, would be:

$$TS = T_{etc} + T_{al} + T_q \quad (7)$$

3. Fuel consumption should be considered in two ways:

Average fuel consumption per hour for a vehicle while moving:

$$FC_v = v/d_f \quad (8)$$

Where  $d_f$  is the average distance a vehicle has passed using one litre fuel.

If  $FC_v$  is taken as vehicle fuel consumption per second during stop time, the total fuel saving for a vehicle in a day can be calculated as:

$$FS_v = FC_v \times (T_{gps} + T_{al}) + FC_i \times T_q \quad (9)$$

$FS$  is the total fuel saving in a day that if multiplied by the number of days in a year, would give the total fuel saving per year.

Therefore, the total fuel saving per year can be calculated as:

$$FS = 365 \times GPS_n \times FS_v \quad (10)$$

Having the statistics of Umred and Borkhedi routes, it is possible to calculate fuel savings as a result of GPS system installation.



Table 1 – Estimated fuel savings when using GPS method instead of ETC system

Item	Umred Toll booth	Borkhedi Toll booth
Total number of vehicles per day	36400	32460
Percent vehicles estimated to use ETC system	85%	85%
Payment time in manual system (second)	5	5
Payment time in nonstop ETC system (second)	2.5	2.5
Total reduced time when using ETC system (hour)	0.00125	0.00125
Vehicle average normal speed (km/h)	80	80
Distance between before and after tollbooth ramp (km)	0.37	0.37
Vehicle average speed during deceleration/acceleration (km/h)	40	40
Tollbooth approach or leave time (hour)	0.00925	0.00925
Travel time between two ramps with normal speed (hour)	0.00925	0.00925
Reduced time due to elimination of deceleration/acceleration (hour)	0.00925	0.00925
Average waiting time in a queue for a vehicle in manual system (second)	240	240
Fuel consumption in one-second stop (litre)	0.000333	0.000333
Total waiting time in a queue per day in manual system (hour)	0.06667	0.06667
Total reduced time per day (hour)	0.077167	0.077167
Fuel consumption per 100 km (litre)	8	8
Average distance traveled using one litre fuel (km)	12.5	12.5
Average fuel consumption per hour for a vehicle (litre)	6.4	6.4
Total fuel consumption per day (liter)	0.15	0.15
Total fuel consumption per year for a vehicle (litre)	53.7	53.7
Total fuel consumption per year (litre)	5,155,200	2,014,824
Total savings per year due to reduced fuel consumption (Rupees)	546451200	213535304

1.1. Savings due to ticket elimination and manpower costs reduction

In the following table, the number of staff dedicated to traditional tollbooths and ETC stations are presented and personnel costs are compared based on monthly income. It is noteworthy that personnel costs in Umred and BorkhediToll are similar; however, ticket prices are proportionate to vehicle passage.

Table 2 - Estimated savings in constant costs when using ETC method instead of traditional system

Item	Umred Toll Plaza	Borkedi Toll Plaza
Number of staff in traditional system	36	28
Annual income of an employee in traditional system (Rupees)	3 lakh	3 lakh
Personnel costs in traditional system (Rupees)	1.8 cr	84 lakh
Number of staff in ETC system	5	3
Annual income of an employee in ETC system (Rupees)	4.8 lakh	4.8 lakh
Personnel costs in ETC system (Rupees)	24 lakh	14.4 lakh

Annual savings in ETC system due to personnel costs (Rupees)	1.56 cr	69.6 cr
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## V. CONCLUSION

A method has been proposed to collect toll fee from the owners of the vehicle. Wastage of time and fuel because of the large traffic jams has been solved by implementing toll collection using GPS. Each vehicle is identified uniquely by SIM of the GPRS, and the amount is debited from the respective account of the vehicle's owner, which is acknowledged by the SMS/ Email to owner of the vehicle. Since everything is computerized, the under charge or over charge collection of toll by private agencies is solved. A uniform fare can be collected throughout the country .

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