

**INTRODUCING ELECTRONIC TOLL COLLECTION SYSTEM: A
CASE STUDY FOR MEGHNA BRIDGE**

BY

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ABSTRACT

Toll plazas usually appear to be a bottleneck for highway traffic flow. They cause traffic congestion in the highways which in turn causes loss of time and money. To overcome this problem, one alternative is to build additional lanes. But this option is expensive. Introduction of electronic toll collection system can be another alternative. Under such circumstances, the present study was undertaken to find out the economic benefit of introducing electronic toll collection system (ETC). Due to the limited scope of the study, one particular location was chosen for the purpose of the study to find out the benefits of ETC.

It was found that due to the introduction of ETC, there will be three types of benefit. The most significant one is the saving in travel time. About 9,52,500 travel hour would be saved yearly due to the introduction of ETC with an estimated cost of about Tk. 7.96 crore every year. Along with this saving in travel time, there would be savings in fuel. About 1,34,566 gallons of petrol would be saved annually with an estimated cost of Tk. 3.88 crore every year. This amount would be 1.89 crore if we consider diesel as fuel and would be around 47 lacs if we consider compressed natural gas (CNG). ETC would also help in reducing emission of harmful gases. About 3323 kg of NO_x, 18569 kg of HC and about 38499 kg of CO would be saved every year. Considering all these aspects, about 12 crore taka could be saved due to the introduction of ETC at Meghna toll plaza every year.

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ABBREVIATIONS

ADDT	: Annual Average Daily Traffic
APT	: Annual Daily Traffic
ALB	:Automatic Lane Barrier
AVC	:Automatic Vehicle Characterization
AVI	:Automatic Vehicle Identification
AT	:Acceleration time to normal speed
DHV	: Design Hourly Volume
CO	:Carbon Oxides
DDHV	: Directional Design Hourly Volume
DT	:Deceleration time
EPA	:Environment Protection Agency
ETC	: Electronic Toll Collection System
JMBA	: Jamuna Multipurpose Bridge Authority
LGED	: Local Government Engineering Department
LTL	:Lane Traffic Light
HC	:Hydrocarbon
HVTF	: Hourly Variation of Traffic
MLB	:Manual Lane Barrier
NO_x	:Nitrogen Oxides
OECD	:Organization for Economic Cooperation and Development
OTL	:Overhead Traffic Light
PHF	: Peak Hour Factor
RHD	: Roads and Highways Department
RUC	: Road user costs
TOD	:Tour of Duty
TT	:Toll Transaction Time
VDU	Visual Display Unit
VES	:Vehicle Enforcement System
VOF	:Vehicle occupancy factor
WB	: The World Bank

CHAPTER 1

INTRODUCTION

1.1 General

Transportation is the backbone of any country's economy. Advancement in transportation systems has led to a lifestyle characterized by freedom of movement, trade in manufactured goods and services, high employment levels and social mobility. In fact, the economic wealth of a nation has been closely tied to efficient methods of transportation.

Due to increasing number of vehicles on the road, problems such as congestion, incident, air pollution and many others have become a major factor of concern. Evidently, nearly all-economic activities at some point use different means of transportation to operate. For that reason, enhancing transportation will have an immediate impact on productivity and the economy.

Rapid development of the country especially in providing good infrastructure facilities to the people has constantly become an important agenda to the Government. To realize the Government's aspirations the Roads and Highways Department of Bangladesh strives to guarantee modern, efficient, quality highway's that are attuned towards growth of the nation.

Tolled highways were built looking at many factors, one of them being the heavy traffic and congestions around Meghna Bridge Toll Plaza. For many cases, tolled highways in major cities are basically roads that have been upgraded to highways. The situation becomes more complex when it involves a spectrum of local infrastructure that consists of housing areas, industries, factories and schools. The network of highways built, however, helps with the development of surrounding communities and defines the highways as the main route for local residents. The strategic location also encourages

locals to use the highway more than once and here is where during peak hours toll plazas become as congested as normal roads.

Delay and queuing problems are most common in daily life situation, especially in traffic. Many roads and highways in Bangladesh have heavy traffic congestions due to driving convenience, such as delays and queuing problems at toll plazas. In effort to have this issue resolves as an innovative supervision committee, Roads and Highways Department encourages the use of modern technology.

1.2 Background of the Study

Dhaka-Chittagong National highway is one of the busiest highways of Bangladesh. A huge volume of traffic moves everyday along this road between the capital city and the commercial capital of the country.

The vehicles moving through this route have to cross the Meghna Bridge and pay tolls at Meghna Toll Plaza. But due to delay in collection system, the users of this road normally have to face long queue. All the parties concerned are being negatively impacted by this delay. The passengers and the transport owners are to sacrifice the time while the toll collection authority is being deprived of getting more tolls within a stipulated time. According to a traffic survey in 2005, about 3584314 vehicles were recorded to cross Meghna Ghat toll plaza.

With passage of time, it is expected that more vehicle would be passing through the bridge and the problem of long queue would be increased. Introduction of an electric toll collection system may be one way to solve this problem. It would benefit all the parties concerned. The benefits of toll plaza can be broadly divided into three categories: benefits of toll agency, user benefits, and social benefits. The toll agency benefits include reduction in operating cost, reduction in man labor, reduction in maintenance cost, and

enhanced cash handling. The user benefits include time saving due to the elimination of the hassle of digging for change and the elimination of acceleration and deceleration as the vehicles do not stop for toll transaction. In addition, there is time saving due to the reduced toll transaction time and average waiting time. Moreover, considerable fuel is saved due to elimination of acceleration.

1.3 Statement of the Problem

It is evident that toll plazas are usually the bottlenecks for highway traffic flows. For this congestion problem, one alternative will be to build additional lanes. However, this option requires a huge investment. According to Al-Deek (Mohamed et al. 1997), with the use of Electronic Toll Collection (ETC), the throughput of the system can be increased three times. For that reason, ETC systems might represent a more feasible alternative than building additional toll lanes.

Under such circumstances, the present study has been undertaken to find out the economic benefit of introducing electronic toll collection system. Due to the limited scope of the study, one particular location has been chosen for the purpose of the study with the following objectives.

1.4 Research Objectives

The objectives of the research are as follows:

1. To study the existing Toll Collection System at Meghna Bridge Toll Plaza
2. To compare various aspects of this existing system with the electronic toll collection system.
3. To find out the economic benefits of introducing Electronic Toll Collection System.

1.5 Methodology

In this study, a suitable computerized Toll Collection System with Manual Transaction would be selected. Secondary data on the traffic flow would be collected from the toll collectors. A primary survey would be conducted to observe the delay time, required acceleration and deceleration for various vehicles and time for transaction. An assessment of the existing system of the toll plaza would be made including the operating system being used, the efficiency of toll collection, problem faced by the toll collectors and the road users etc. An in depth analysis of the Electronic Toll Collection System would then be made. Various aspects of these two systems would then be compared and the benefit of introducing Electronic Toll Collection System would be found out in terms of saving in time, fuel and emission reduction

1.6 Thesis Structure

The research works performed in this study are divided into different topics and presented in six chapters.

A brief introduction to the background and statement of the problem is presented in the first chapter. The chapter also contains the objective and scope of the study along with brief description of the study plan.

Chapter 2 presents a brief description of the toll collection system in Bangladesh and toll collection system at Meghna bridge in particular.

In chapter 3, a brief description of the Electronic Toll Collection System has been given. This includes the components of Electronic Toll Collection System, its benefits and other characteristics.

Chapter 4 contains the estimation of benefits of introducing Electronic Toll Collections System to find out the saving in travel time, fuel and emission of exhaust gases.

Chapter 5 presents the results of estimation of benefits of ETC system that shows the possible saving in time, fuel and emission of harmful gases in monetary value.

The conclusion of the entire study along with summary of study results is presented in Chapter 6. The chapter also contains suggestions and recommendations for future study and limitations of this study.

Five appendices are attached at the end of this report containing showing calculation of travel time saving, fuel saving and emission saving. Figure-1.1 shows the flow of methodology.

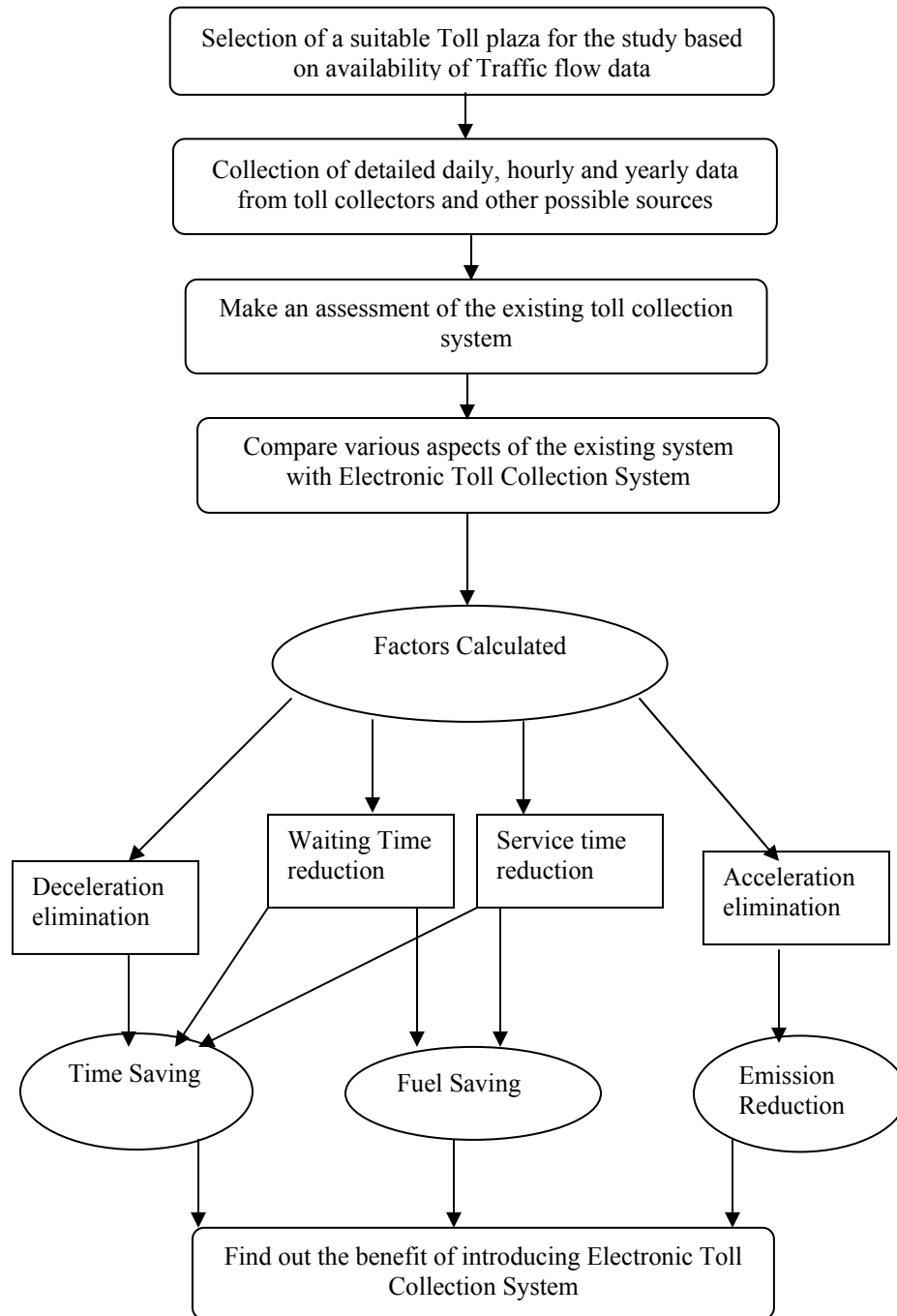


Figure 1.1 Flow Chart of Methodology

CHAPTER: 2

TOLL COLLECTION SYSTEM IN BANGLADESH

2.1 General

The role of an efficient transport and communication system is extremely critical for the socio-economic progress of a country. As physical infrastructure is indispensable, a well-knit transport and communication network ensures a well-balanced distribution system for the means of production, efficient marketing of produced commodities, maintaining stability of price and rapid industrialization. Transport demand in Bangladesh has grown faster than the GDP, doubling between 1974 and 1984 to 35 billion passenger-kilometers. In 1996, it reached 72 billion passenger-kilometers. Whereas in 1971 there were around 40,000 motor vehicles, at present there are almost 600,000, following an average growth rate of around 10% per year. In the future, as the country becomes more prosperous, high growth can be expected in light vehicles. Different vehicles have different rates of utilization. For example, in Bangladesh commercial vehicles, and in particular buses, are used intensively. Large buses operating on intercity routes are utilized up to 80% of the time, while most other vehicles average around 60% utilization. If smooth movement on the road is interrupted, it affects the economy of the country in various ways. Toll collection system is such a barrier which hinders smooth vehicle movement.

2.2 Road Network of Bangladesh

In Bangladesh, responsibility for roads is divided between the Roads and Highways Department (RHD), which is responsible for the planning, construction, and maintenance of national highways, regional highways, and zila roads (formerly feeder road A), and the Local Government Engineering Department (LGED), which is responsible for upazila roads, union roads, and village roads (formerly feeder road B). National highways connect the national capital with district headquarters, port cities, and international

highways. Regional highways connect different regions and district headquarters not connected by national highways. In mid-2003, the total length of road network under RHD was 21,000 kilometers (km), of which 12,500 km was paved and 8,500 km was earthen. Road network of Bangladesh has been shown in *Annex-1*

2.3 Existing Toll Collection System in Bangladesh

Manual toll collection system is probably still the most widely used method in Bangladesh for collecting tolls. In this system an operator collects money manually in the toll plaza. The operator is located in a toll booth servicing one lane of traffic. A fully manually operated barrier is used. It is generally also necessary to employ some simple auditing systems, such as counting the vehicles passing through the lanes and more commonly now providing a paper receipt on request for each transaction.

Manual toll collection usually requires the building of a toll plaza that divides the free flowing multilane road into a number of single lanes. Each lane is serviced by a tollbooth, which houses an operator who manually collects toll payments that the driver has to pay. The general rule for the design of toll plazas is that there should be at least three tollbooths to service each one lane of traffic leading into the toll plaza. In Bangladesh, apart from some of the National highways, most of the highways are double lane and there is only one toll collection booth with a few people for toll collection. Two such booths are placed to collect tolls for up bound and down bound vehicle. A receipt is given to the driver after paying the tolls in cash. The enforcement of manual toll systems relies on the use of a barrier that is not opened until confirmation by the operator or the collecting machine that the correct toll has been paid. In some National highway, these systems are often augmented by vehicle detectors, to count the vehicles passing through the lane, and by some form of vehicle classification, to distinguish different classes of vehicles.

The collector takes money with respect to different types of vehicles from all the drivers passing through the lane. If the transaction requires that change is given or a paper receipt is provided, then this process takes longer.

The government decided to introduce computerized toll systems for the highways and their bridges in all the country's seven road zones in July 2004 with a hope that such toll-collection programme would help increase government revenue earnings and stop irregularities, corruption and terrorism as well. All roads and bridges would be brought under a package programme and Operation and Maintenance (O&M) operator would be appointed through international tender. Necessary equipment would be installed in all computerized toll plazas within three or four months. The new computerized systems, in place of traditional leasing one, would help give a boost to the country's economy. These are mainly semi manual in nature.

Such systems are already installed at a number of places like Meghna Bridge. These are microprocessor based manual toll collection system, where transaction is manual but other systems are automatic. The system is installed in 6-lane toll booths and is responsible for the registering of tolls collected and controlling the vehicles through various signs / indicators in the toll lane and capturing data from vehicle detection equipment, video cameras. These normally consists of island, traffic signals, barriers, a local area network, plaza computer, workstation computer, laser printers, as well as a complete revenue audit management system and other input devices in conjunction with Toll Collector inputs.

2.4 Responsible Agencies for Administering Toll Collection

Roads and Highways Department and Local Government Engineering Department are responsible for administering the toll collection system in their respective jurisdiction. After successful completion of the construction of Jamuna Multipurpose Bridge, Jamuna Multipurpose Bridge Authority (JMBA) was renamed as Bangladesh Bridge Authority

with extended responsibilities and is responsible for collecting toll at bridges those are 1500 metre or more in length.

2.5 Problems of Existing Toll Collection System

There are several problems associated with the existing toll collection system in Bangladesh. As money has to be handed over manually both in case of manual and computerized system, a vehicle has to decelerate, stop, hand over the toll money, take the receipt, accelerate and move out of the toll plaza. These are associated with extra travel time that increase the road user cost, extra air pollution due to deceleration and acceleration and traffic congestion in some busy roads causing further increase in travel time and the road users cost.

Road user costs (RUC) are the costs borne by the people through use of the road network facility. A road infrastructure project involves three types of cost in its useful life; they are construction cost, maintenance cost and road user cost. While construction and maintenance costs are incurred by the concerned road development agency, road user costs are borne by the users of road output. Of these three components of life-cycle cost, road user cost occupies the major proportion depending on the volume of traffic plying on road. According to an empirical study carried out by the Organization for Economic Cooperation and Development (OECD) in 1994 on cost-shares under optimal maintenance situation of road infrastructure, the proportion of RUC is about 38% on a road with 50 vehicles per day, about 75% on a road with 300 vehicles per day and above 90% on a road with 5000 vehicles per day. This huge road user costs can be reduced substantially through proper and timely maintenance of the road network and reducing obstructions pose through various activities like toll collection.

The existing toll collection system in Bangladesh also is prone to corruption. In case of the manual toll collection system, some time tolls are being collected without giving any receipt causing loss of government revenue. Even in computerized toll plaza, such

corruption is taking place. Recently an Anti Corruption Commission probe carried out as part of the measures against institutional corruption found that the concerned personnel skimmed the money after collecting those as tolls for Tongi-Ashulia highway and Meghna and Meghna-Gomati bridge through fake money receipts or without any receipt.

2.6 Toll Collection System at Meghna Bridge

In our study, one toll collection system we observed is Meghna Bridge Toll Plaza. This is a six lane toll plaza having manual transaction with automatic processing system. Systec constructed a toll collection system. The toll plaza stands on the busy Dhaka Chittagong road with an average daily traffic of 15277.

2.6.1 Description of the system

It is a Maxtoll ICS-50 Lane Processor System (LPS). This offers an effective solution to operating, managing, and auditing a toll collection facility. The Maxtoll ICS-50 Lane Processor System (LPS) provides real-time monitoring of lane equipment, support for money room operations, and a full suite of audit reports implemented via a relational database management system accessible by an easy to use graphic interface. Use of local area network technology connects lane controllers to the plaza computer. Depending upon the size of the operation, the audit portion of the system is implemented either on the local plaza computer or via a central host computer connected to the plaza(s) by a wide area network. For the Meghna Toll Plaza system the audit functions are combined with the plaza computer. The different components of the toll collection system at Meghna bridge are presented through figure 2.1 to 2.5.

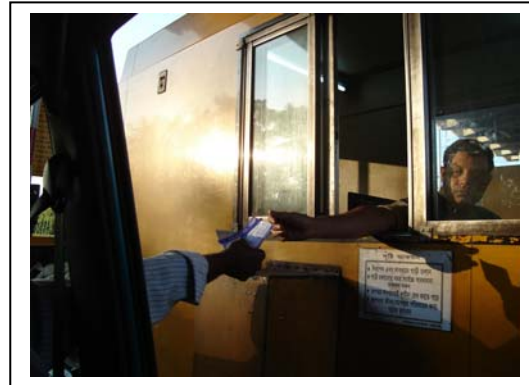


Figure 2.1 : Toll collection system at Meghna Ghat Toll Plaza

The LPS computer is housed in a specially designed Control and Interface Cabinet (CIC) and is linked to the following equipment:

Toll Collector Console

The toll collector console comprises of the following components:

Visual Display Unit (VDU):

The VDU is a standard 15" computer colour VGA monitor



Figure 2.2 : Visual display unit

Toll Collector Keyboard & Magnetic Card Reader:

The toll collector keyboard comes with an integrated magnetic card reader. The magnetic card reader is used for the identification of toll collectors.

LOGIN/OUT	O/I	A/LP	MAINT MENU	VIEW	LOOP	TRANSFER	ALARM RESET
CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS FREE	CASH		CANCEL
CLASS 5	CLASS 6	CLASS 7	CLASS 8	TEST PRINT	VOUCH		OK

Figure 2.3: Layout of the Toll Collector Keyboard. The Magnetic Card Reader (not shown here) is located at the top of the keyboard.

The Toll Collector Keyboard consists of a magnetic card reader and three rows of keys. The top row of the keyboard consists mainly of function and control keys while the bottom two rows consist mainly of transaction keys.

At Meghna Toll Plaza currently Eight (8) classes of vehicles are used. Each has up to Eight (8) types of payments

This feature allows new vehicle classes or payment discounts to be added dynamically and at predetermined dates/times without making programming changes to the lane controller, plaza, or database software

Thermal Receipt Printer

The receipt Printer is used for printing receipts.

Lane Control Board

The Lane Control Board provides the communications link between the LPS computer and the various lane equipment. It is mounted within the CIC.

Loop Detector

Connects to a Loop Coil (See below) to detect the presence of vehicles in the lane. This is also mounted within the CIC.

Overhead Traffic Light (OTL)

The OTL is normally a two-aspect traffic light and is mounted on the toll plaza canopy above a lane to indicate to all approaching motorists whether the lane is open (Green) or closed (Red).

Lane Traffic Light (LTL)

The LTL is a two-aspect traffic light and is used to give the motorist an indication of when to stop and pay toll (Red) and when to go (Green). The LTL is normally mounted alongside the TFI and is positioned such that it is easily visible to a motorist as they stop to pay toll.

Toll Fare Indicator (TFI)

The toll fare indicator is used for displaying the vehicle class, toll amount to be paid and the vehicle weight. The TFI is normally mounted alongside the LTL.

Automatic Lane Barrier (ALB)

The Automatic Lane Barrier is used to help regulate the flow of traffic through the lane. It is set to open once the motorist pays the appropriate toll and close again once the motorist leaves the lane.

Loop Coil

The Loop Coil is an induction loop cable used to detect the presence and passing of vehicles through the lane. It is installed just below the road surface after the ALB.

Violation Siren and Beacon

These devices give an audible and visible indication of a violation i.e. vehicle passing through the lane without making payment.

Video Camera

The Video Camera is installed at each lane in a protective enclosure and will be facing the motorist's back as they stop to pay toll. The camera will capture an image for each transaction.

Footswitch

When depressed, this switch will cause an alarm to ring in the Control Room.

Manual Lane Barrier (MLB)

A manually operated barrier used to reinforce the signal displayed by the OTL. For safety reasons, it is linked to the LPS so that the Users cannot switch the OTL to its Green aspect if the MLB is not locked in a fully open position.

2.6.2 Typical operation

Normal operation

This section describes a typical operation for a User in Operator Mode.

The User opens the MLB, and puts his "float" in the cash drawer. When there is nobody logged in to the system, it will be in its "Normal" state. That is;

- a. The OTL and LTL will show its Red aspect
- b. The ALB will be in its "Down" position
- c. The TFI display will be blank.

The User performs a *login* to start a new shift, presses the “OTL” key to change the OTL to its green aspect and waits for a vehicle to arrive.

When a vehicle arrives, the User selects the appropriate Vehicle Class.

The system will allow for nine vehicle classes. For example;

- a. Cars (Class 1)
- b. Small Bus (Class 2)
- c. Large Bus (Class 3)
- d. Small Truck (Class 4)
- e. Medium Truck (Class 5)
- f. Large Truck (Class 6)
- g. Trailers (Class 7)
- h. Taxi (Class 8)
- i. Exempt / Free (Class 9)

Classes 1 to 8 are categories of vehicles that are required to pay toll while Class 9 is for vehicles such as VIP vehicles, Emergency vehicles etc. which are exempt from paying toll

When a valid class has been selected, the TFI will display the Vehicle Class and Fare due.



Figure 2.4: Main Menu Screen – Vehicle Class Selected

The User then collects payment from the vehicle driver and presses the appropriate payment key. (i.e. Cash or Vouch)

Once the transaction is completed, the system will turn the LTL to its Green aspect and raise the ALB. If the system has been setup to automatically print a receipt, then a receipt will be printed at this time. If not, the User can print the receipt manually by pressing the *Print Receipt* key.

When the fare (if any) has been collected, the vehicle will proceed past the tollbooth. After the vehicle passes the loop detector, the TFI will return to its blank state, the LTL will display its Red aspect, the ALB will be lowered, and a new transaction can begin.

The User repeats Steps 3 to 8 until his shift ends.

To end a shift, the User presses the Login key. A pop up screen will appear asking the User to confirm the logout. To confirm, the User should press the *OK* key. To abort the logout, the User can press the *Cancel* key.

After a logout, the system will return to its “Normal” state and will automatically print a shift detail report.

The User will then proceed to the Toll Plaza to count the monies collected and enter the data into the Tour of Duty (TOD) terminal. (See PCS description for more information on the TOD terminal)

Violations

A violation will cause the rotating Alarm Beacon to light up and the Alarm Siren to sound. To acknowledge and clear the violation, the User has to press the *Alarm Reset* key. The system can also be setup to automatically reset the alarm after a set period of time. All violations are recorded by the LPS. Some examples of violations are:

- a. If a vehicle passes a tollbooth without paying the required toll, a violation (alarm) is deemed to have occurred. The LPS will send a picture of the offending vehicle to the PCS.

- b. If the Toll Collector presses the Class keys more than five times without pressing the Cash or Voucher keys. The LPS will send a text picture regarding the violation to the PCS.

- c. If a vehicle passes a tollbooth in a wrong direction, a violation (alarm) is deemed to have occurred. The LPS will send a picture of the offending vehicle to the PCS.

- d. If any metal related tools like Iron etc., touches the loop cable installed just below the road surface after the ALB (while cleaning the toll booth area etc and toll system is not in operation), a violation (alarm) is deemed to have occurred. The LPS will send a picture to the PCS.

- e. If heavy thunderstorms occur when rainfall, a violation (alarm) may occur. The LPS will send a picture to the PCS.

- f. If towing of vehicles, a violation (alarm) will occur. The LPS will send a picture of the vehicles to the PCS.

View Screen

The View screen is accessed by pressing the *View* key and is used to review the last 18 images captured by the system. Users are only allowed to use the View screen up to 25 times per Lane Processor Program startup. (i.e. After 25 times if the User wishes to use the View Screen again, the Lane Processor System Program must be restarted). The *View* key can be disabled in the Setup Screen.

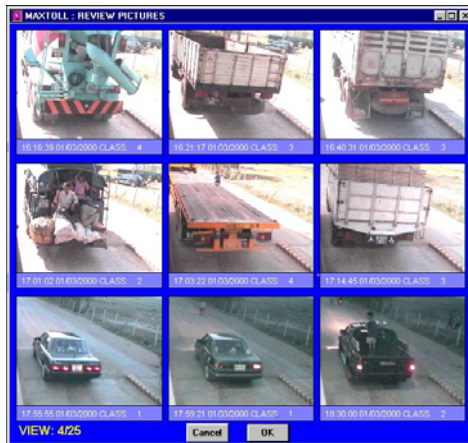


Figure 2.5: Review Picture Screen

When the Review Screen is displayed, the User can press the *OK* key to view the next 9 images or press the *Cancel* key to exit from the screen.

The counter at the bottom left hand corner of the screen indicates the number of times the screen has been accessed.

CHAPTER 3

ELECTRONIC TOLL COLLECTION SYSTEM

3.1 General

Electronic toll collection system is used as a technology for fast and efficient collection of toll at the toll plazas. This is possible as the vehicles passing through the toll plaza do not stop to pay toll and the payment automatically takes place from the account of the driver.

The electronic toll lanes are set up with the special antennas that continuously send out signals. These signals are used to automatically identify the vehicles that travel by them. To use the electronic toll facility, the driver needs to set up an account and get an electronic transponder fixed in the vehicle. These transponders commonly known as the tags are usually fitted on the windshields of the vehicles. The tag has all the information regarding the patron's account. The antenna continuously sends out a radiofrequency (microwave) pulse, which returns only when it hits a transponder. These pulses are returned back from the transponder and are received by the antenna. These microwaves reflected from the tags contain information about the transponder's number, patron's account, balance, etc. Other information such as date, time, and vehicle count could be recorded depending upon the requirement of the data needed by the toll agencies. After encrypting the contents of this microwave, the unit then uses fiber-optic cables, cellular modems or wireless transmitters to send it off to a central location, where computers use the unique identification number to identify the account from which the cost of the toll should be deducted. ETC system uses diverse technologies for its working.

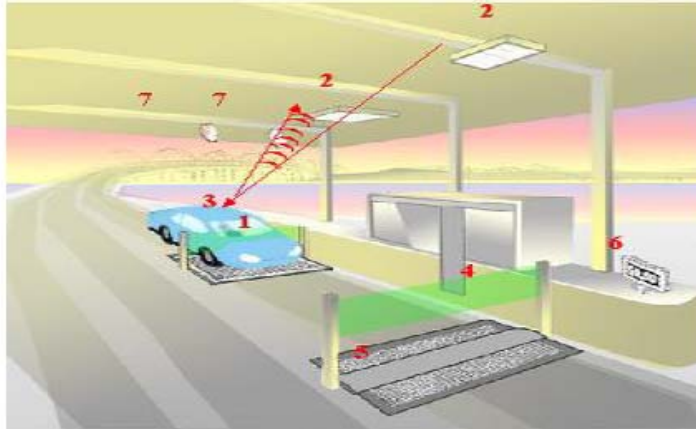


Figure 3.1: Operation of Electronic Toll Collection System

Figure 3.1 shows the working of the electronic toll collection system with its components. These components may vary depending upon the technology used. As the vehicle enters the toll lane, sensors (1) detect the vehicle. The two-antenna configuration (2) reads a transponder (3) mounted on the vehicle's windshield. As the vehicle passes through the exit light curtain (4), it is electronically classified by the treadle (5) based on the number of axles, and the ETC account is charged the proper amount. Feedback is provided to the driver on an electronic sign (6). If the vehicle does not have a transponder, the system classifies it as a violator and cameras (7) take photos of the vehicle and its license plate for processing. The components of ETC are discussed in the next section.

3.2 Components of Electronic Toll Collection System

An ETC system consists of three sections: Automatic Vehicle Identification (AVI), Automatic Vehicle Characterization (AVC) and Vehicle Enforcement System (VES) (Rezaee-Arjroody et al., 2006). ETC systems deploy various communications and electronic technologies to support the automated collection of payment at tollbooths. Collectively, the application of these technologies increase system throughput, improve customer service, enhance safety, and reduce environmental impacts. The components of the ETC technology are as follows:

- a. Automatic Vehicle Identification : The automatic vehicle identification (AVI) component of an ETC system refers to the technologies that determine the identification or ownership of the vehicle so that the toll will be charged to the corresponding customer.

- b. Automatic Vehicle Classification : Vehicle type and class may have differentiated toll amount. The vehicle type may include light vehicles like the passenger car or heavy vehicles like recreational vehicles. A vehicle's class can be determined by the physical attributes of the vehicle, the number of occupants in the vehicle, the number of axles in the vehicles and the purpose for which the vehicle is being used at the time of classification (or some combination of these determinants). Some toll agencies use as many as 15 or more vehicle classes to assess tolls, although for ETC applications, four or five classes are more typical.

- c. Video Enforcement Systems : When used for ETC, the video enforcement system (VES) captures images of the license plates of vehicles that pass through an ETC tollbooth without a valid ETC tag.

Although the deployment of these technologies makes the initial cost of installation very high, but there exits huge benefits accompanied with such high investment. These benefits are discussed in the next section.

3.3 Benefits of Electronic Toll Collection

Electronic toll collection system has several advantages over manual toll collection system. As the vehicles need not to stop to give toll manually, traveled time is saved which in turn helps in reducing traffic congestion, saving fuel and reducing harmful gases.

a. Congestion reduction

The toll transaction rate is highly increased due to the use of ETC systems. Since the vehicles do not stop at the toll facility, the throughput is highly increased. This has considerable effect on the congestion of the toll plaza. As the proportion of the ETC users increases the congestion in the manual as well as the automatic lanes is also reduced. The average number of vehicles waiting in the queue reduces and so the average waiting time is reduced.

b. Increased Capacity

It is observed that the capacity of the electronic lane increases by three fold. The toll plaza would be able to accommodate the increasing traffic without requiring building additional lanes.

c. Fuel saving

The deceleration, acceleration and idling is completely eliminated. This results in gas saving for the patrons using ETC. Besides the elimination of acceleration and deceleration results in reduction of the operating cost of the vehicles.

d. Operating cost saving

Over a period of time, the toll collecting cost is reduced. There is reduction in the man-hour required as the system does not require any human interaction for the toll transaction.

e. Time saving

ETC users do not stop for paying toll, thus there is considerable saving in the travel time. Besides the travel time reliability is increased as the travel time can be estimated fairly accurately.

f. Emission control

Due to the elimination of the acceleration and idling, vehicular emissions are reduced. Though this benefit only affect the surrounding area it is seen that there is an increase in the highway financing by building toll plazas. In many non-attainment areas as declared by Environment Protection Agency (EPA), ETC seems to be one of the possibilities for air pollutant reduction.

g. Enhanced cash handling

There is no cash transaction for the ETC lane so cash handling is reduced so difficulties with cash handling is eliminated. Thus aid in enhanced audit control by centralizing user accounts.

h. Payment flexibility

The patrons do not have to worry about searching for cash for the toll payment. Since the patrons set up account for ETC usage it gives customers the flexibility of paying their toll bill with cash, check, or even credit cards.

i. Enhanced data collection

Information such as vehicle count over the time of the day, date, time etc can be obtained due to the deployment of this technology. This helps in making decisions regarding the pricing strategies for the toll providers. It also helps planner to estimate the travel time that aid in designing decisions.

j. Incident reduction

It is observed that there is reduction in the number of incidents caused near the toll plazas (Gillen, 1999). With all these benefits, it is evident that there exists a lot of opportunity of research in studying the impacts of these benefits over the ETC lanes. This research will address all the quantifiable components of the benefits on the integrated basis.

CHAPTER 4

BENEFIT ESTIMATION OF ELECTRONIC TOLL COLLECTION SYSTEM

4.1 General

In this study, a suitable computerized Toll Collection System with Manual Transaction was selected. Secondary data on the traffic flow were collected from the toll collectors. A primary survey was conducted to observe the delay time, required acceleration and deceleration for various vehicles and time for transaction. An assessment of the existing system of the toll plaza was made. An in depth analysis of the Electronic Toll Collection System was then made. Various aspects of these two systems were compared and the benefit of introducing Electronic Toll Collection System was found out in terms of saving in time, fuel and emission.

4.2 Benefit Calculation

Benefits would be calculated using the following formula.

$$\text{BENEFIT (B)} = T_v * T + F_c * F_s + E_c * E_s$$

where

T_v = Value of travel time per hour

T = Total time saving (in hour) in a year

F_c = Cost of fuel

F_s = Total annual saving in fuel

E_c = Cost of emission

E_s = Total annual emission reduction

4.3 Calculation of Total Time Saving (T)

Total time saving is calculated as per the following formula :

T = Time saving in Peak hours + Time saving during off peak hours.

$$=T_p + T_{op}$$

$$T_p = (OF * T_{s,p} * DDHV * \text{Number of Peak hours} * 2 * 365/3600) \text{ hour}$$

$$T_{op} = (OF * T_{s,op} * AAHV * \text{Number of off peak hours} * 365/3600) \text{ hour}$$

Where

T = Total time saving per vehicle

DDHV = Directional Design Hourly Volume

AAHV = Average Annual Hourly Volume

OF = Vehicle occupancy factor

T_{s,p} = Time saving for each vehicle in peak hours, in seconds

T_{s,op} = Time saving for each vehicle in off peak hours, in seconds

4.3.1 Vehicle occupancy factor (OF)

The vehicle occupancy factor is used to determine the total time saved on an individual basis depending upon the vehicular distribution. Vehicle occupancy factor estimates the average occupancy for each vehicle. The following formula has been used to find out the vehicle occupancy factor:

Average Occupancy factor, OF = (Sum of Average occupancy of passenger in each vehicle type * proportion of that vehicle type)

Number of passenger in each vehicle varies with many factors. Different value has been found in different reports. The project appraisal document for the World Bank financed Clean Air and Sustainable Development Project of Ministry of Forest and Environment considers 2 passengers in each car, 25 passengers in each mini bus and 46 passengers in each large bus (The World Bank 2009). On the other hand, Karim and others reported a value of 2.2 passengers for each car/taxi, 36 passengers for mini bus and 52 passengers for large bus (Karim et al., 2001). Value for Trucks and large trailers were not available. Depending on these, the following values have been considered in this study to calculate the average vehicle occupancy factor. Table 4.1 shows the assumed vehicle occupancy factor used in this study.

Table 4.1 : Assumed occupancy of each type of vehicle

Class	Vehicles	Assumed average occupancy of each vehicle
Class 1	Cars	2
Class 2	Small Bus	30
Class 3	Large Bus	52
Class 4	Small Truck	2
Class 5	Medium Truck	2
Class 6	Large Truck	2
Class 7	Trailers	2
Class 8	Taxi	2.2

4.3.2 Travel time saving

The travel time saving for each vehicle is calculated as per the following formula :

$$T_s = (T_M - T_E)$$

Where

T_M = Total time for manual transaction

T_E = Total time for Electronic transaction

The Directional Design Hourly Volume (DDHV) accounts for the total traffic during the peak hour period. DDHV is calculated using the formula:

$$DDHV = AADT * K * D$$

DDHV = Directional Design Hourly Volume

AADT = Average Annual Daily traffic

K = the proportion of the daily traffic occurring during the peak hour

D = the proportion of peak hour traffic traveling in the peak direction

The K and D factors usually are computed based upon the local and regional characteristics at existing locations (Roes et al., 1998). In general, the K factor decreases as the density of development surrounding the highway increases. The D factor depends upon the development density and upon the specific relationship of the facility in question to major traffic generators in the area.

Table 4.2 : Peak Hour and Peak Direction Factor

Facility Type	Normal range of factors	
	K Factor	D Factor
Rural	0.15-0.25	0.65-0.80
Suburban	0.12-0.15	0.55-0.65
Urban: Radial route	0.07-0.12	0.55-0.60
Urban: Circumferential route	0.07-0.12	0.50-0.55

Source : (Roes et al., 1998)

As Dhaka Chittagong road mostly pass through the suburban areas, the values for K and D has been considered as 0.12 and 0.60 respectively in this study.

4.3.3 Transaction time at manual (TM) calculation

The total time spent in the system is the sum of the deceleration time, waiting time, toll processing time and the acceleration time to the average speed. The total for each of lane type can be estimated as follows. The acceleration time estimation is shown in the next section.

$T_M = \text{Deceleration time (DT)} + \text{average waiting time (}W_M\text{)} + \text{average service time at manual lane (TT)} + \text{acceleration time to normal speed (AT)}$.

$$T_M = DT + W_M + TT + AT$$

4.3.4 Deceleration time (DT) calculation

The time spent for the deceleration is the sum of the perception-reaction time and the braking time to come to stop at the toll plaza for toll transaction or stop and join the

queue for the toll transaction. The American Association of state highway and transportation officials (AASHTO) recommends the use of 2.5 seconds perception reaction time in computations involving stopping or braking reactions. The total deceleration distance required before actually stopping the vehicle is given as follows:

Stopping distance (d_s) = perception-reaction distance (d_p) + braking distance (d_b)

$$d_s = d_p + d_b$$

$$d_p = 1.468vt = 1.468 * 50 * 2.5 = 183.5 \text{ ft}$$

$$d_b = (v^2 - u^2) / 30(f + g)$$

$$d_b = (50^2 - 0^2) / 30(0.31+0) = 268.82 \text{ ft}$$

Where

t = perception-reaction time (sec) = 2.5 seconds

1.468 = conversion factor from mph to fps

v = initial speed of the vehicles (mph) = 50 mph (assumed)

$u = 0$, final speed of vehicles (mph)

$f = 0.31$, coefficient of forward rolling or skidding friction (for asphalt road)

$g = 0$, assumed to be level terrain

30 = unit conversion factor

$$d_s = 183.5 + 268.8 = 453 \text{ ft} = 0.09 \text{ miles}$$

The deceleration rate is 3.86 mph/sec for the given condition of stopping and the deceleration time or the time required to stop at the tollbooth or to stop to join the queue is calculated as follows:

$$v = u + a * D_T$$

$$D_T = 50/3.86$$

$$D_T = 13 \text{ seconds}$$

Hence average deceleration time is 13 seconds for the stopping at the toll plaza.

4.3.5 Toll transaction time (TT) calculation

It appeared from data analysis that average processing time for manual is nearly 24 seconds per transaction. Processing rate for ET lane has been considered 2.4 seconds

(Radwan et al., 1997). The time for ET lane is the headway and it is defined as the time taken between consecutive vehicles arriving at a particular point for the same point of reference on the vehicle. The capacity of manual and electronic system has been considered as follows:

$$\mu_M = 400 \text{ (vehicles per hour, vph)}$$

$$\mu_E = 1500 \text{ (vehicles per hour, vph)}$$

Where

$$\mu_M = \text{Capacity of Manual System}$$

$$\mu_E = \text{Capacity of Electronic System}$$

4.3.6 Waiting time (WM) calculation

The waiting time for each lane is determined using the delay model presented in Highway Capacity Manual (Highway capacity manual 2000). In general, delay can be categorized into three main types: random delay, toll transaction delay, and delay due to acceleration and deceleration. The random delay is due to the stochastic nature of arrivals. When the vehicle arrival is higher than the service capacity during the peak period, they must wait to pay toll. The delay model in HCM is developed to estimate delay for the signalized or unsignalized intersection. This model offers some perspective for estimating the waiting times at the toll plazas. A modified model to the general model has been used in this study to calculate the waiting time (Chaothary 2003) where waiting time or delay is calculated for each type using the formula:

$$W = 900 T [(X - 1) + ((X - 1)^2 + 8 X / C * T)^{0.5}]$$

Where W = incremental, or random, stopped delay (seconds/vehicle),

X = volume to capacity ratio of lane group,

C = capacity of lane group (vehicles/hour),

T = Time for consideration, peak period, (hours).

The model developed is used separately for estimating the waiting time at the manual and electronic system.

$$W_M = 900 T [(X_M - 1) + ((X_M - 1)^2 + 8 X_M / C_M * T)^{0.5}]$$

Where W_M = Average waiting time in minutes for manual lane

X_M = volume to capacity ratio of manual lane,

C_M = capacity of manual lane (vehicles/hour),

T = Time for consideration, peak period, (hours).

4.3.7 Acceleration time (AT) calculation

For estimating the total time for acceleration to road speed of 50 mph, the average acceleration is assumed to be 5mph/sec (W.S. et al.,1982) and the acceleration time (AT) to reach to road speed from complete stop is 10 seconds.

Form the above estimation of the parameters, the total time at the manual (Highway capacity manual 2000) is given as follows:

$$T_M = 13 + 24 + W_M + 10$$

$$T_M = 47 + W_M$$

4.3.8 Transaction Time at ETC (TE) Calculation

The time taken to cover the accelerating distance, waiting distance, toll transaction and acceleration distance is the total time for electronic transaction. For ETC lane, the vehicles do not stop so there is elimination of the deceleration and acceleration. Thus the deceleration and acceleration distance along with the waiting distance are covered at the average road speed. The average car length for the design purpose is taken to be 19ft (W.S. et al., 1982)

Hence :

$$TE = \text{Distance covered (D) /average speed} + \text{toll transaction time (headway)} + WE$$

Distance covered (D) = Distance covered during deceleration + Average length of queue
 * Average length of passenger car + distance covered during
 acceleration

$$D = (0.09 + 19/5280 * QM + 0.05) m$$

Where QM is the average queue length and 19 is the average length of a vehicle in ft.

$$\text{Distance covered (D)} = (0.14 + 0.004 * \text{QM}) \text{ m}$$

Average queue length, QM = vehicle arrival rate * Average waiting time at the manual

$$\text{QM} = \lambda_M / 3600 * \text{WM}$$

Where

λ_M is the vehicle arrival rate per lane per hour.

As there are six lanes in the toll plaza, λ_M would be equal to DDHV/6.

The time for ET transaction is the headway and it is defined as the time taken between two consecutive vehicles arriving at a particular point of reference on the vehicle. The headway is taken to be 2.4 seconds. The processing rate (μ_E) is 1500 vph.

The waiting time (WE) at the ET lane is given as follows:

$$W_E = 900 T [(X_E - 1) + ((X_E - 1)^2 + 8 X_E / C_E * T)^{0.5}]$$

Where X_E = volume to capacity ratio of automatic lane,

C_E = capacity of automatic lane (vehicles/hour),

T = Time for consideration, peak period, (hours).

Transaction time at manual (TE) considering all the parameters is determined as follows:

$$T_E = [0.14 + (0.004 * \text{Qm} * \text{Wm}) / 3600] / 50 + 2.4 + W_E$$

4.3.9 Calculation of value of travel time (Tv)

Travel Time Cost (TTC) also referred to as Values of Time is an important component of road user costs. The concept of travel time costs is based around the premise that time spent in travelling has an “opportunity cost” and could be used in an alternative activity which also produce or may produce some significant utility popularly known as benefit.

Time costs will vary between different vehicle types according to the socio-economic characteristics of the occupants, their trip purpose and the type of freight carried. A report of the World Bank mentions some value for the passengers of car and microbus (The World Bank 2009). Similar values were also obtained from the report of Roads and Highways department of Bangladesh (RHD 2005). In case of truck and trailers, this value of time depends on how much an extra hour would pay back. Depending on these reports and considering the inflation factor, the following values shown in Table 4.3 have been assumed to be used in this study.

Table 4.3 : Assumed travel time value for various mode of transport

Class	Vehicles	Value of time saving (Tk. per hour)
Class 1	Cars	79.96
Class 2	Small Bus	35.4
Class 3	Large Bus	55.28
Class 4	Small Truck	80
Class 5	Medium Truck	80
Class 6	Large Truck	80
Class 7	Trailers	100
Class 8	Taxi	80

Value of travel time is calculated by multiplying the average value of travel time of persons traveling by that mode and the proportion of that particular type of vehicle in the vehicle stream and then summing up this product for all vehicle types. i.e

$$\text{Value of travel time (T}_v\text{)} = \sum (\text{Average value of travel time of persons in a type of vehicle} * \text{proportion of that type in the vehicle stream.})$$

4.3.10 Fuel savings

With the elimination of the deceleration, waiting, and acceleration, there is a considerable amount of fuel savings. The acceleration of the vehicles consumes major of the fuel and the fuel consumed is less during deceleration and waiting for the toll transaction. Thus the fuel used during the deceleration and waiting is neglected. The total fuel saving is estimated as follows:

$F_s = \text{Number of gallons saved}$

$F_s = \text{Total time saving due to elimination of acceleration } (T_{s,a}) * \text{Average road speed for the ET lane} / \text{average miles traveled per gallons.}$

Where,

$T_{s,a} = \text{Total time saving due to elimination of acceleration (second per vehicle)}$

$T_{s,a} = [\text{Acceleration time} - (\text{distance covered during acceleration} / \text{average speed})], \text{ sec}$

$$F_s = F_{sp} + F_{sop}$$

Where

$F_{sp} = \text{Fuel saving during peak hour}$

$F_{sop} = \text{Fuel saving during off peak hour}$

$$F_{sp} = [T_{s,a} * DDHV * \text{Number of Peak Hours} * 2 * 365 * 50\text{mph} / 22.1\text{mpg}/3600]$$

$$F_{sop} = [(T_{s,a} * ADHV * \text{Number of Off peak hours} * 365 * 50\text{mph} / 22.1 \text{ mpg}/3600)]$$

4.4 Emissions Reduction

Motor vehicles contribute significantly to emission inventories in certain regions specially on urban areas.

The pollutant species most often of concern with respect to transportation facilities are carbon monoxide (CO), hydrocarbons (HC), photochemical oxidants e.g., ozone (O₃), nitrogen oxides (NO_x), particulate matter (PM), and lead (Pb). Recent studies indicate

that motor vehicles are also a major or primary source of other toxic air pollutants including 1,3-butadiene, benzene and a number of carcinogens, associated with particulate matter (Karim 1997). Mobile emissions are the result of the deceleration, vehicle idling and acceleration. Since very less gas is used when decelerating, mobile emissions are negligible during deceleration. The major components of the mobile emissions are carbon oxides (CO), nitrogen oxides (NO_x), and hydrocarbon (HC) during vehicle idling and acceleration. There are various methods for estimating the mobile emissions.

The time saving for idling is due to the reduction of waiting time and toll transaction time at the ET lane. The time saving is calculated for each vehicle and the total time saving for the proportion of vehicles using ETC system is estimated.

During idling of the vehicles, the NO_x is negligible as compared to CO and HC (Kirchstetter, et al. 1998). In this research, the mobile emissions has been estimated using the study done by Kirchstetter, *et al.*. The financial values are evaluated using the study done by Kenneth and others (Kenneth, et al. 1995).

Total idling time saving for the manual system, $T_{s,i} = T_{s,i,p} + T_{s,i,op}$

Where,

$T_{s,i,p}$ = Total idle time saving during peak hour

$T_{s,i,op}$ = Total idle time saving during off-peak hour

Total idling time saving during peak hour, $T_{s,i,p} = t_{s,i} * DDHV * 3 * 2 * 365$

Total idling time saving during off peak hour, $T_{s,i,op} = t_{s,i} * AAHV * 21 * 365$

Where,

$t_{s,i}$ = Idling time saving for each vehicle

$t_{si} = (WM + TT) - (WE + 2.4)$, in second

$t_{si} = (WM + 24) - (WE + 2.4)$

$t_{si} = WM - WE + 21.6$

Amount of CO saved due to idling reduction, CO_I (grams) = $1.5 * T_{s,i}$

Amount of HC saved due to idling reduction, HC_I (grams) = $2.5 * T_{s,i}$

Emissions reduction due to acceleration elimination and subsequent fuel saving has been calculated as follows :

$NO_{X(A)}$ (grams) = 24.7 grams/gallons * number of gallons of fuel saved.

$NO_{X(A)} = 24.7 * (Fs)$

$HC_{(A)} = 9.5 * (Fs)$

$CO_{(A)} = 209 * (Fs)$

Where $NO_{X(A)}$ = NO_x reduction due to elimination of acceleration or fuel savings

$HC_{(A)}$ = HC reduction due to elimination of acceleration or fuel savings

$CO_{(A)}$ = CO reduction due to elimination of acceleration or fuel savings

The emission cost is used from the study done by Kenneth and others (Kenneth et al., 1995) and the value suggested is \$0.0063 /Kg for CO, \$1.28 /Kg for HC and \$1.28 /Kg for NO_x .

Total saving (EB) = $0.0063 * CO \text{ saved} + 1.28 * HC \text{ saved} + 1.28 * NO_x \text{ saved}$

$EB = 0.0063 * (CO_I + CO_{(A)})/1000 + 1.28 * (HC_I + HC_{(A)})/1000$

$+ 1.28 * NO_{X(A)}/1000$

All these formula used in benefit estimation has been summarized in Annex-2-5.

CHAPTER 5

DATA ANALYSIS AND RESULTS

5.1 Analysis of Traffic Data

Both primary and secondary data has been used in this research. Data was collected from Roads and Highways Department and also from the toll plaza authority. Toll authority classified vehicle in various categories. Yearly data of the vehicles those crossed the bridge were collected for the year 2006-2007. It as found from thee data that average annual daily traffic at Dhaka Chittagong road is around 15277 number of vehicles.

According the practice of the toll plaza, the vehicles are classified into eight categories as shown in Table 5.1:

Table 5.1 : Classification of vehicle at Meghna Ghat Toll Plaza

Class	Vehicles
Class 1	Cars
Class 2	Small Bus
Class 3	Large Bus
Class 4	Small Truck
Class 5	Medium Truck
Class 6	Large Truck
Class 7	Trailers
Class 8	Taxi

Various types of motorized and non motorized vehicles run over Dhaka Chittagong road every day. Composition of various types of vehicle has been shown in figure 5.1

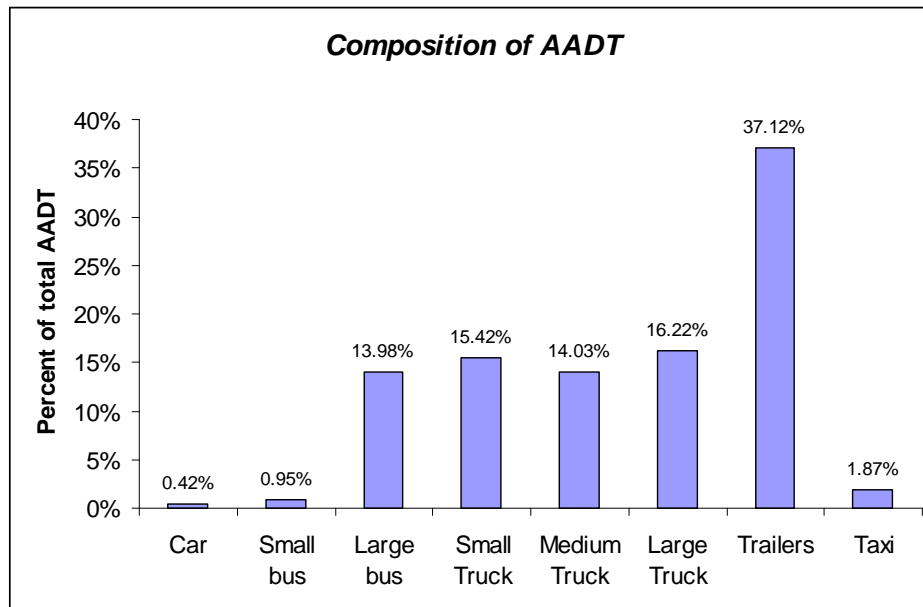


Figure 5.1 : Composition of various types of vehicle in vehicle stream

Source: Secondary data from Toll plaza authority

It can be found from the above figure that trailers are the major shareholder of the road which is around 37% followed by large truck with 16.22% and small truck by 15.42%. This is mainly because Chittagong is the port city of Bangladesh from where many exported items are brought to Dhaka with the help of trailers and various types of trucks. The movement of buses is also high which indicates that along with container services, people also widely travel along this road.

5.2 Determination of Peak Hours

Determination of number of peak hours was necessary to find out the time saving during the peak hours. This was determined using the secondary data. It was found that on an average, 3 peak hours can be considered for the purpose time saving during peak hours in this study.

Directional hourly volume of traffic was calculated from the annual average daily traffic using the formula :

Directional Design Hourly Traffic Volume (DDHV) = AADT * K* D

Considering a value of 0.12 and 0.60 for K and D, the DDHV was found to be 1100 vehicle per hour.

It was also found from the observed data that on an average, in case of both Chittagong bound and Dhaka bound traffic, three distinct peak time is visible. And hence, in the delay model, the number of peak hours has been considered as 3 (three).

5.3 Average Vehicle Occupancy Factor

Vehicle occupancy factor was calculated to see the average number of people traveling by a specific type of vehicle. This was necessary to find out the total travel time that would be saved considering all the people traveling by road.

Table 5.4: Calculation of average vehicle occupancy factor

Vehicle Class	Vehicle Type	Average Occupancy	Proportion of vehicle class	Average Vehicle Occupancy Factor (OF)	Value of time of passengers in each vehicle type (Tk per hour)	Tv (Tk per hour for each passenger)
Class 1	Cars	2	0.0042	9.26	79.96	83.55
Class 2	Small Bus	30	0.0095		35.4	
Class 3	Large Bus	52	0.1398		55.28	
Class 4	Small Truck	2	0.1542		80	
Class 5	Medium Truck	2	0.1403		80	
Class 6	Large Truck	2	0.1622		80	
Class 7	Trailers	2	0.3712		100	
Class 8	Taxi	2.2	0.0187		80	

Average Occupancy factor, OF = (Sum of Average occupancy of passenger in each vehicle type * proportion of that vehicle type)

Calculation of average vehicle occupancy factor has been shown in Table 5.4. It can be mentioned here that the value of passenger traveling by each type of vehicle has been

assumed by the author for this study due to the limited scope. However, a comprehensive survey on this would provide more authentic information and would provide better result. Average vehicle occupancy was thus found as 9.26 as shown in Table 5.4.

5.4 Service Time for Manual System

Average service time for the toll plaza was found out through a sample survey spread over 10 days. Transaction time of each vehicle was recorded with the help of a stop watch. To find out the average service time at the toll plaza, a survey was conducted in ten different days. Result of this survey has been shown in Table 5.5. From the table, the longest service time involving heavy vehicle like large bus, small truck, medium truck, large truck and trailers is 32.1 sec/veh, while for the minimum is recorded at 25.2 sec/veh. As shown in Table 5.5, the longest service time involving small vehicle from cars, small bus and taxi with service time 21.7sec/veh, while for the minimum is recorded at 14.5 sec/veh.

Table 5.5: Typical service time for each class of vehicles on Manual Collection System for out going from Dhaka (Time in Seconds).

Sample	Cars (Time in sec)	Small Bus(Time in Sec)	Large Bus (Time in sec)	Small Truck (Time in sec)	Medium Truck (Time in sec)	Large Truck (Time in sec)	Trailer s (Time in sec)	Taxi (Time in sec)
1	15	18	20	20	25	35	20	16
2	14	20	18	17	23	33	26	14
3	16	22	22	30	26	32	28	18
4	13	20	25	34	30	37	27	15
5	12	26	26	32	32	34	25	18
6	14	30	30	25	35	33	30	20
7	17	20	27	33	31	28	28	22
8	18	23	26	26	29	26	32	16
9	15	20	32	29	34	30	26	14
10	11	18	26	35	33	33	25	15
Average	14.5	21.7	25.2	28.1	29.8	32.1	26.7	16.8

figure 5.2 shows the average service time in the toll plaza.

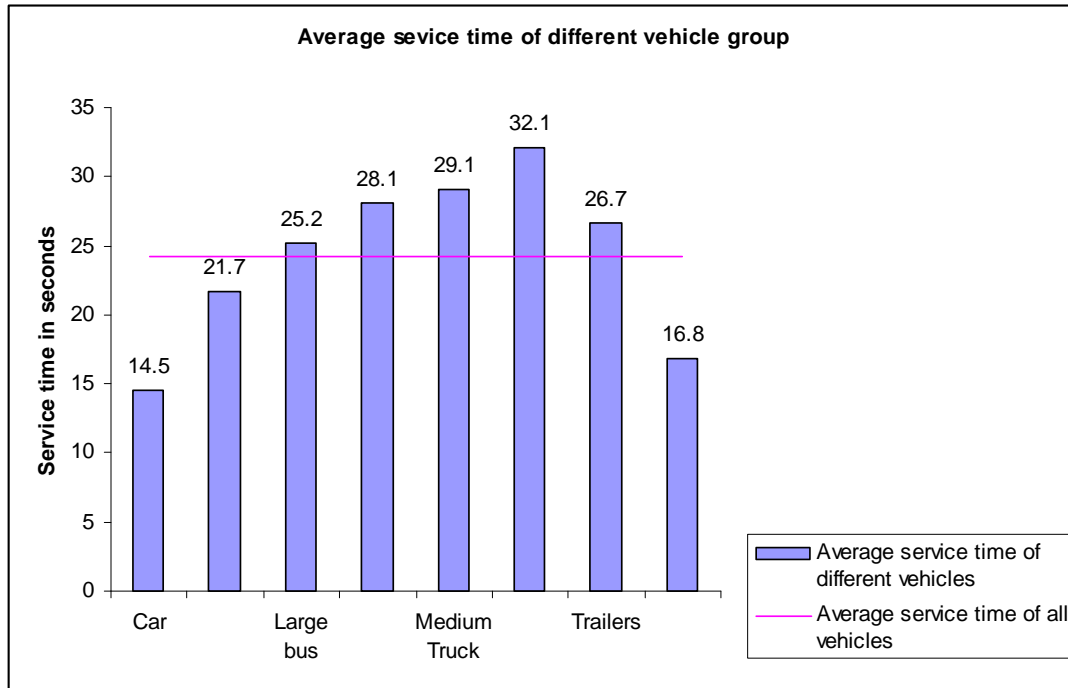


Figure 5.2 : Average service time for Manual System

Average service time was found around 24 seconds per vehicle at each lane.

Time saving was calculated by the formula mentioned in Chapter-4. It is to be noted that in calculating the benefit in terms of financial figure, the value of time was needed to be found out. Due to lack of information in case of Bangladesh, a value for time of different people traveling through various types of vehicles were assumed in this regard as shown in Table 4.3. Average value of time was then calculated considering the proportion of a particular type of vehicle in the total vehicle stream and was found as Tk. 83.55 per hour.

Detail of calculation of time saving has been shown in Annex-2 and 3. It was found that time lost by each vehicle at the toll plaza in case of manual system during the peak hours would around 114 seconds per vehicle and which is 47 seconds during off-peak hours for each vehicle. On the other hand, in case of electronic toll collection system, this time required during peak hours is 5.41 seconds per vehicle while the value is 2.4 seconds per

vehicle during the off-peak hours. This gives a total saving of around 9,52,500 travel hour each year when the total number of vehicle and total number of passengers traveling in each type of vehicle is considered. The financial value of this saving based on the average value of travel time was then calculated which came out as around Tk. 7.96 crore every year. This has been shown in figure 5.3.

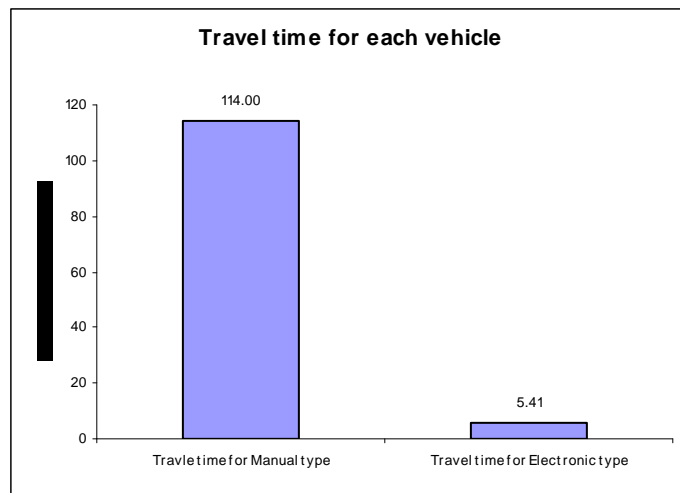


Figure 5.3 Comparison of travel time for Manual and ETC for an individual vehicle

5.5 Saving of Fuel

Due to the fact that ETC system allows for toll collection while the vehicles pass with normal speeds, the decrease/increase speed and stop incidents which lead to extra fuel consumption, will be eliminated. Fuel consumption reduction is calculated as the difference between fuel consumption in the current toll collection method and that of ETC system.

In calculating the fuel saving, average miles traveled per gallon of fuel has been assumed as 22.1 gallon. However, this figure would be different for different types of vehicle and consideration of this fact might produce a better result.

As fuel consumption during the waiting time and during deceleration time is negligible, only fuel saving due to elimination of acceleration time has been taken into account. It was found that a total of 6.4 second could be saved for each vehicle due to elimination of acceleration. Due to this, an yearly saving of around 1,34,566 gallon of fuel would be possible with an estimated saving of Tk.3.88 crore taka per year. Detail calculation has been shown Annex-4.

The above cost has been calculated considering petrol as fuel. However, in reality, not all the vehicles would be running on petrol. Now a days, a good number of vehicles use compressed natural gas (CNG) as fuel while the number of diesel run vehicle is also high. While it was extremely difficult to identify the number of vehicles using a particular type of fuel, a calculation was done just to see the relative cost implication if all the vehicles would use a particular type of fuel. In case of CNG, the concept of miles per gallon equivalent has been taken into consideration where one equivalent gallon is taken equal to 121.5 cubic feet of CNG (EPA, 2010) The comparative cost saving has been shown in figure 5.4.

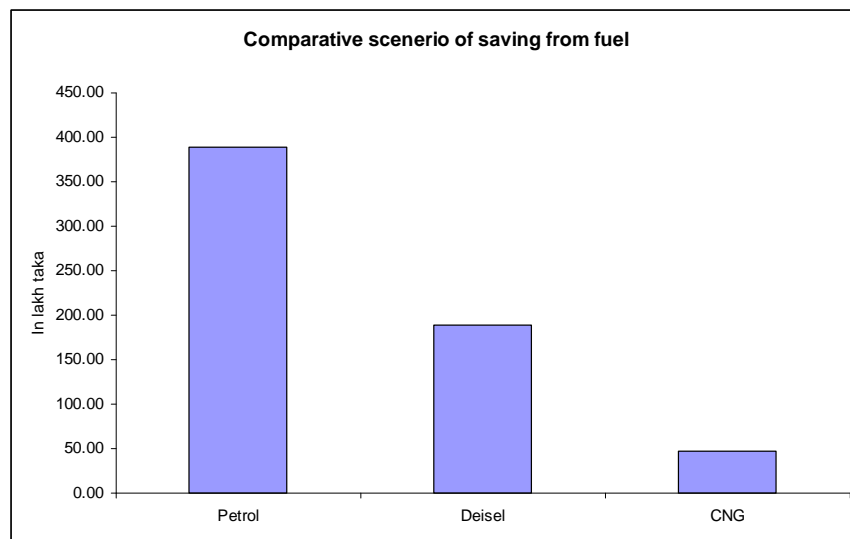


Figure 5.4 Comparison of cost saving in case of different types of fuel

5.6 Emission Saving Due to Introduction of ETC

Another benefit of introducing ETC was found as the reduction of emission of various gases. Air pollution is one of the major concerns in Bangladesh. Quality of air at most of the urban areas is at a peril condition and government is trying hard to have a control over the situation. In the recent past, ban of two stroke auto rikshaw from the capital city was one such attempts to make the air of the capital clean. However, this was only an effort which shifted the problem from one place to another. These two stroke vehicles are widely playing over the roads of secondary towns, on the highways and other sub urban areas. Emission from vehicle depends on the type of vehicle, age of the vehicle and also on the fuel used. Due to limited scope of this study, an average value has been considered for emission reduction. It was found from the study that with the introduction of Electronic Toll Collection System, about 3323 kg of NO_x, 18569 kg of HC and about 38499 kg of CO can be reduced annually. This has been shown in figure 5.5

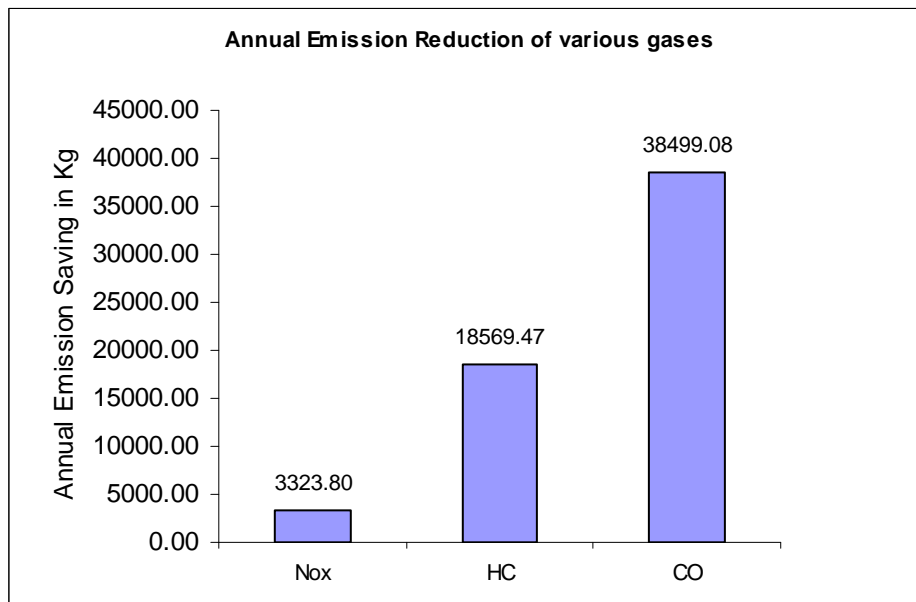


Figure 5.5 Annual Emission Reduction of various gases

Detail calculation of emission reduction has been shown in Annex-5.

Exhaust from all combustion engines combine to produce local adverse effects on the health of car users and all innocent bystanders. Cities have become islands of toxic chemicals from the unrestrained use of vehicles burning fossil fuels.

Common air pollutants also have an affect on blood and thus on organs of the body. For example, carbon monoxide binds to hemoglobin two hundred times more avidly than oxygen and distorts the release to the tissues of any remaining oxygen. Thus, CO poisoning is a form of suffocation. Carbon monoxide can exacerbate cardiovascular disease in humans. Some airborne chemicals stimulate the immune system to activate leukocytes and macrophages that can produce tissue damage, especially to the cells that line human blood vessels. The combined effect of these events is to accelerate the changes that eventually lead to hypertension and ischemic heart disease.

Nitrogen dioxide (NO₂) is one of a group of highly reactive gasses known as "oxides of nitrogen," or "nitrogen oxides (NO_x)." Other nitrogen oxides include nitrous acid and nitric acid. While EPA's National Ambient Air Quality Standard covers this entire group of NO_x, NO₂ is the component of greatest interest and the indicator for the larger group of nitrogen oxides. NO₂ forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO₂ is linked with a number of adverse effects on the respiratory system.

Moreover these emissions also have impact on climate change. Climate change is widely viewed as the most significant long-term threat to the global environment, and man-made emissions of greenhouse gases are very likely the cause of most of the observed global warming over the last 50 years. Burning fossil fuels such as gasoline and diesel releases carbon dioxide (CO₂) and other greenhouse gases (GHGs) into the atmosphere, contributing to global climate change. CO₂ is the most important human made GHG, and highway vehicles account for 26% (1.7 billion tons) of U.S. CO₂ emissions each

year. Every gallon of gasoline a vehicle burns puts about 20 pounds of CO₂ into the atmosphere.

The average vehicle emits around 6 to 9 tons of CO₂ each year. Unlike other forms of vehicle pollution, CO₂ emissions cannot be reduced by pollution control technologies. They can only be reduced by burning less fuel or by burning fuel that contains less carbon.

5.6 Summary of Findings

From the above results, it was found that due to introduction of ETC, there will be three types of benefit. One of the most significant one is the saving in travel time. About 9,52,500 travel hour would saved due to introduction of ETC with an estimated cost of about Tk. 7.96 crore every year. Along with this saving in travel time, there would be saving in gasoline. About 1,34,566 gallons of gasoline would be saved annually with an estimated cost of Tk. 3.88 crore every year. ETC would also help in reducing emission of harmful gases. About 3323 kg of NO_x, 18569 kg of HC and about 38499 kg of CO would be saved. Considering all these aspects, about 12 crore taka could be saved every year due to introduction of ETC at Meghna toll road. This has been shown in figure 5.6

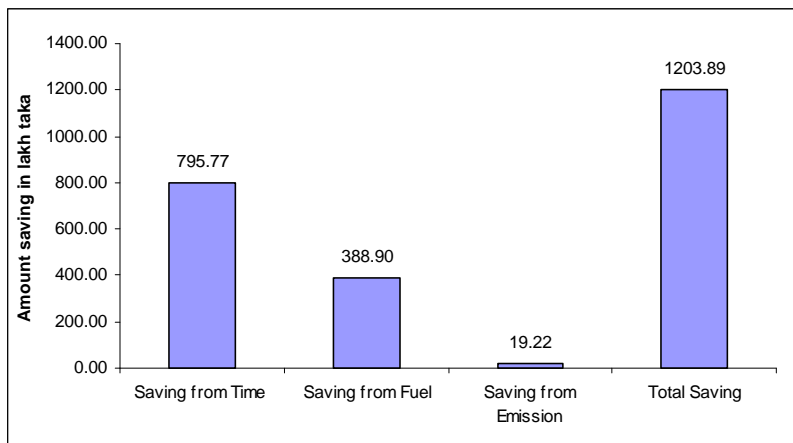


Figure 5.6: Total Saving due to ETC

CHAPTER 6

CONCLUSION

6.1 Findings of The Study

It was found in the study that introduction of ETC can be beneficial. In one hand, it would help in saving travel time. Around 9,52,500 travel hour can be saved by eliminating time lost in manual toll plaza. This is equivalent to saving about 7.96 crore taka yearly. There are some indirect financial benefits which have not been considered in this study. Considerations of those factors might have further increase the value. There would be reduction of harmful gases like NO_x , SO_x, and CO. About 3323 kg of NO_x, 18569 kg of HC and about 38499 kg of CO would be saved. Fuel saving is also an important aspect. It was found that due to introduction of ETC, about 1,34,566 gallon of fuel would be saved yearly. All these would help in saving around 12 crore taka every year.

6.2 Concluding Remarks

It has been observed that major benefits of introducing ETC are the time and gasoline savings. Although the financial value of saving emission seems low, the amount of harmful gases which could be saved demands attention. The Chittagong port is the most important gateway for the external trade of Bangladesh. This is because it handles nearly 90 per cent of the country's export and import cargoes. The growth of the volume of business at Chittagong port is 14 per cent per annum and this growth is expected to shoot up rapidly in the near future. Thus, any reduction in travel time would have positive impact on our national economy. However, the estimation of the travel time saving largely depends on the delay model used to estimate the waiting time. Models developed specifically for toll plaza would certainly help the benefit model to give more accurate results. Besides the above mentioned benefits, ETC increases travel convenience.

On the other hand, ETC might help in reduction of corruption in case toll collection. In the recent days, even the most sophisticated toll collection system of Jamuna Multipurpose Bridge suffered corruption in toll collection. It is expected that introduction of ETC would help in reducing such ill practices. This has not been considered in this study. There are other benefits of ETC like savings from ticket elimination and reduction of staff dedicated to stations which also have not been considered.

6.3 Recommendation for future study

Some extensions that can be made to this research are as follows:

1. A more comprehensive study can be undertaken by incorporating benefits due to reduction in corruption, elimination of tickets and reduced human resources
2. A study by incorporating the value of the increased reliability due to the ETC system can also be undertaken. The reliability of the travel time is increased due to the ETC deployment and it has an impact on the value of travel time. The estimation of this factor would give better estimate of the travel time savings.
3. Study the effects of other delay models on the travel time and delay estimation can also be undertaken. Delay model used for this research was from the Highway Capacity Manual 2000. A model more specific to toll plaza would give better estimate for the waiting times at the manual and automatic lanes.

REFERENCE

Al-Deek, H. M., A. A. Mohamed, et al. (1997). " Operational benefits of electronic toll collection: case study." *Journal Of Transportation Engineering* **123**(N6).

Chaothary, R. H. (2003). A Model for the Benefits of Electronic Toll Collection System. Department of Industrial & Management Systems Engineering, University of South Florida.

Highway capacity manual (2000). Washington, DC 20001, Transportation Research Board.

Homburger and W.S. (1982). *Transportation and Traffic Engineering Handbook*.

Kirchstetter, B. C. S. T. W., et al. (1998). "Impact of California Reformulated Gasoline on Motor Vehicle Emissions: 1. Mass Emission Rates." *Environmental Science & Technology*.

Masud Karim, M. (1997). Traffic Pollution in Bangladesh & Metropolitan Dhaka a Preliminary Investigation. 90th Annual Meeting of Air and Waste Management Association, Toronto, Canada.

McShane and W. Roes (1998). *Traffic Engineering*, Prentice Hall, ISBN-10: 0139261486

RHD (2005). RHD ROAD USER COST ANNUAL REPORT For 2004 - 2005, Economics Circle, Sarak Bhaban Ramna Dhaka.

Saffarzadeh, M. and A. Rezaee-Arjroody (2006). Cost-Benefit Analysis Of Electronic Toll Collection (Etc) System In Iranian Freeways (Case Study: Tehran-Qom Freeway). PIARC International Seminar on Intelligent Transport System (ITS) In Road Network Operations August 14, 2006 to August 16, 2006, The Legend Hotel, Kuala Lumpur, Malaysia.

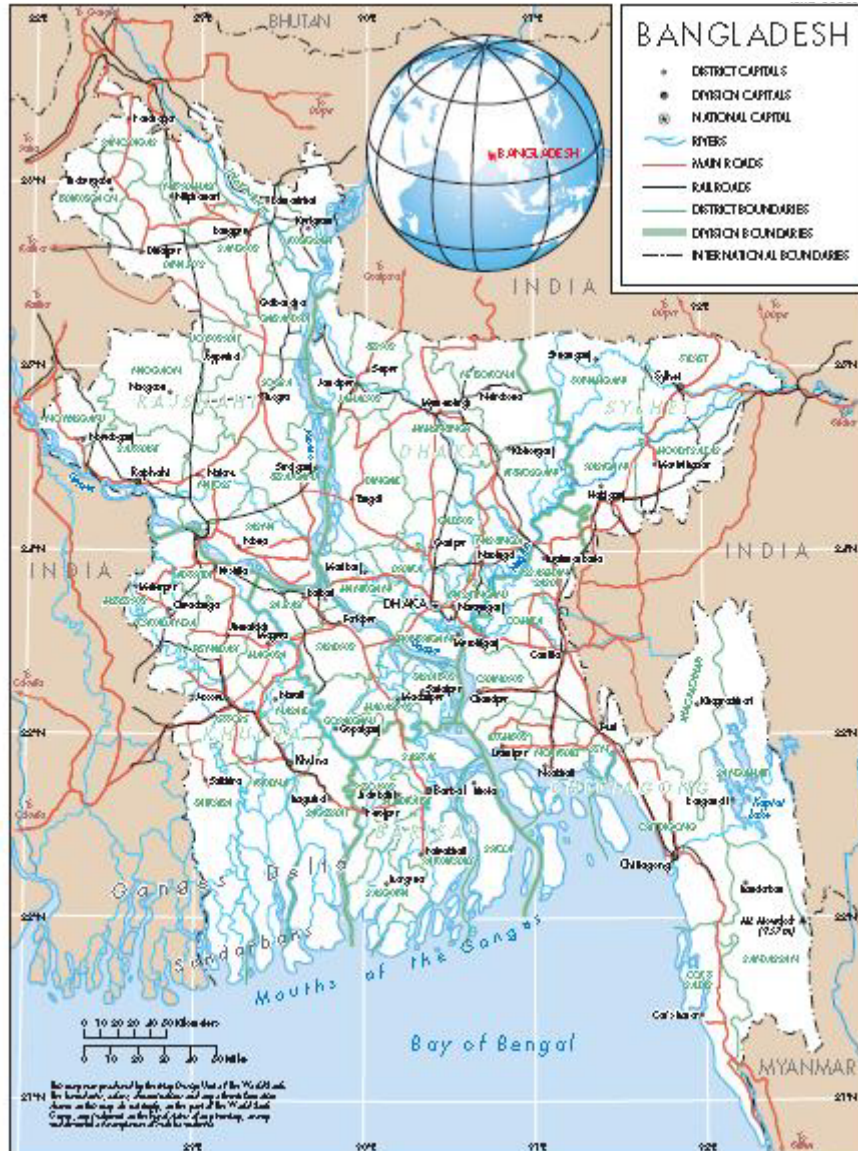
Shafiqul Mannan, M. and M. Masud Karim (2001). Current State of the Mobility of the Urban Dwellers in Greater Dhaka. 94th Annual Conference and Exhibition of Air and Waste Management Association, Orlando, Florida, USA.

Small, A. Kenneth, et al. (1995). "On the Costs of Air Pollution from Motor Vehicles," *Journal of Transport Economics and Policy*: 7-32.

The World Bank (2009). Project Appraisal Document, Clean Air And Sustainable Environment Project, People's Republic Of Bangladesh.

Zarrillo, M. L., A. E. Radwan, et al. (1997). "Modeling traffic operations at electronic toll collection and traffic management systems." *Computers & Industrial Engineering* **33**(3-4): 857-860.

Annex-1 :Road Network of Bangladesh



Annex-2 : Calculation of time required in case of manual system

$$W_m = 900 T [(X - 1) + ((X - 1)^2 + 8 X / C * T)^{0.5}]$$

Where

W_m = incremental, or random, stopped delay (seconds/vehicle),

X = volume to capacity ratio of lane group,
= 0.45831

C = capacity of lane group (vehicles/hour), = 400

T = Time for consideration, peak period, (hours) = 3

Volume of vehicle in each of the six manual lanes (Vehicles/hour) = 83.32

W_m = 67.00 seconds per vehicle

= 1.12 minute per vehicle

T_{mp} = 114.00 seconds per vehicle during peak hour

= 1.90 min per vehicle during peak hour

T_{mop} = 47 seconds per vehicle during off peak hours

Annex-3 : Calculation of time required in case of Electronic system

From methodology chapter, we know that waiting time for electronic system W_E is

$$W_E = 900 T [(X E - 1) + ((X E - 1)^2 + 8 X E / CE * T)^{0.5}]$$

Where

$X E$ = volume to capacity ratio of automatic lane = 0.122216

CE = capacity of automatic lane (vehicles/hour), = 1500

T = Time for consideration, peak period, (hours) = 3

Volume of traffic (vehicle per hour) = 183.32

Vehicle arrival rate = 1100 vehicle per hour

$AADT$ = 15277

K = the proportion of the daily traffic occurring during the peak hour = 0.12

D = the proportion of peak hour traffic traveling in the peak direction = 0.60

$DDHV$ = 1100

Hourly Volume of Traffic = 318.27

Occupancy Factor OF = 9.26

Average value of travel time T_v = 83.55 Tk per hour

W_E = 3.01 seconds per vehicle

= 0.05 Minute per vehicle

Transaction time at manual (T_E) considering all the parameters is determined as follows:

$$T_E = 3600 \{0.14 m + (0.004 * QM)\} / 50 + 2.4 + W_E$$

Vehicle arrival rate per hour = 183.32

Average que length Q_m = 550.98 no of vehicle per hour

T_{ep} = 5.41 seconds per vehicle during peak hour

= 0.09 min/vehicle

T_{eop} = 2.40 seconds during off peak hour

Time Saving for each vehicle during peak hour, $T_{s,p}$ = 108.59 Sec during peak hours

= 1.81 minute

= 0.03 hour

Time Saving for each vehicle during off peak hour, $T_{s,op}$ = 44.60 seconds during off peak

Hour

$$\begin{aligned}\text{Total time saving (T)} &= (\text{OF} * \text{Ts,p} * \text{DDHV} * 3*2*365) + (\text{OF} * \text{Ts,op} * \text{AAHV} * \\ &\quad 21*365) \\ &= 3429001969 \text{ man seconds} \\ &= 952500.55 \text{ man hour} \\ &= 39687.523 \text{ man day} \\ \text{Total annual value of time saving} &= 7,95,76,859.87 \text{ Tk.}\end{aligned}$$

Annex-4 : Calculation of fuel saving

Number of gallons saved (Fs)

Fs = Total time saving due to elimination of acceleration (Ts, a)* road speed for the ET lane / average miles traveled per gallons.

$$F_s = (T_{s, a} * DDHV * \text{Number of peak hours} * 2 * 365 * 50\text{mph} / 22.1 \text{ mpg}) + (T_{s, a} * ADHV * \text{Number of off peak hours} * 365 * 50\text{mph} / 22.1 \text{ mpg})$$

$T_{s, a}$ = Acceleration time –(distance covered during acceleration / average speed)

As discussed in the previous section, the accelerating time (AT) is 10 seconds and the distance traveled (S_D) to the average road speed is calculated as follows:

$$v^2 = 2 * a * S_D$$

$$S_D = 50^2 / (2 * 5)$$

$$S_D = 250 \text{ ft}$$

$$S_D = 0.05 \text{ miles}$$

The distance traveled (S_D) to the average road speed is 0.05 miles.

$$T_{s, a} = AT - (S_D / \text{average road speed})$$

$$T_{s, a} = 10 - ((0.05/50) * 3600) = 10 - 3.6$$

$$T_{s, a} = 6.4 \text{ seconds per vehicle}$$

$$F_s = 134566.6365 \text{ gallons}$$

Cost of Fuel (Fc) is assumed to be 289 Tk per gallon

Total financial value of the Fuel saved = Cost of Fuel per gallons (Tk. 289.00)* total number of Fuel saved

$$\text{Total financial value of the fuel saved (GB)} = 289.00 * T_{s, a, M} * AADT * 365 * 50/22.1/3600$$

Tk 38889757.95

Annex-5 : Calculation of emission saving

Number of gallons saved, $F_s = 134566.6365$ gallons

Total number of vehicle = DDHV = 1100 vph

Emission saving due to reduction in idle time

Total idling time saving for the manual, $T_{s,i} = T_{s,i,p} + T_{s,i,op}$

Idling time saving for each vehicle = $t_{s,i}$

$t_{s,i} = (WM + TT) - (WE + 2.4)$, in second

$t_{s,i} = (WM + 24) - (WE + 2.4)$

$t_{s,i} = WM - WE + 21.6$

Total idling time saving during peak hour, $T_{s,i,p} = t_{s,i} * DDHV * 3 * 2 * 365$

Total idling time saving during off peak hour, $T_{s,i,op} = t_{s,i} * AAHV * 21 * 365$

$t_{s,i} = WM - WE + 21.6 = 85.59$ seconds per vehicle

$T_{s,i} = 414986174.84$ seconds

$= 115273.94$ hour

During idling of vehicle, NO_x emission is negligible and only CO and HC would be taken into account

Amount of CO saved due to idling reduction, CO_I (grams) = $1.5 * T_{s,i}$
 $= 10374654.37$ grams
 $= 10374.65$ kg

Amount of HC saved due to idling reduction, HC_I (grams) = $2.5 * T_{s,i}$
 $= 17291090.62$ grams
 $= 17291.09$ kg

During Acceleration of vehicle

NOX (A) (grams) = 24.7 grams/gallons * number of gallons of fuel saved.

NOX (A) = $24.7 * (F_s) = 3323795.922$ grams
 $= 3323.80$ kg

HC (A) = $9.5 * (F_s) = 1278383.047$ grams
 $= 1278.38$ kg

CO (A) = $209 * (F_s) = 28124427.03$ grams
 $= 28124.43$ kg

Where

NOX (A) = NOX reduction due to elimination of acceleration or fuel savings

HC (A) = HC reduction due to elimination of acceleration or fuel savings

CO (A) = CO reduction due to elimination of acceleration or fuel savings

Assumed value of emission saving

\$0.0063 /Kg for CO

\$1.28 /Kg for HC

\$1.28 /Kg for NOX

	Total emission saving (kg)	Value of per kg reduction	Total Saving (Tk) in Lac Taka
Nox	3323.80	87.04	2.893
HC	18569.47	87.04	16.163
CO	38499.08	0.4284	0.165
Total			19.221