BE CIVIL ENGINEERING
PROJECT REPORT

DAMAGE BASED TOLL TAX AND AUTOMATED TOLLING SYSTEM FOR MOTORWAYS OF PAKISTAN

Project submitted in partial fulfillment of the requirements for the degree of

BE Civil Engineering

SUBMITTED BY

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MILITARY COLLEGE OF ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES & TECHNOLOGY

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This to certify that the

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Has been accepted towards the partial fulfilment of the requirements for

BE Civil Engineering Degree

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Dedication

This work is especially dedicated to our parents who prayed for us tirelessly, our supervisor, supportive friends and all faculty members of the transportation department.

For their support, encouragement and belief in us. We are truly indebted.

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It all starts with life and its Creator. First of all, we thank Allah the Almighty for the countless blessings and opportunities he bestowed on us in helping us complete this effort. There are number of people without whom this might not have been possible, and to whom I am greatly obliged. Among these people are the DD Weigh Station Mr. Malik Abdul Rahman, Toll booth operator Arif, Capt Saad Khalid and Capt Mohsin Zamir.

Last but not the least, my deepest gratitude goes to our all beloved parents for having prayed for us days in and out, particularly my father Lt. Col(R) Khalid Ghumman, who has always had faith in me and had been a source of light in times of darkness and uncertainty.

Distinctive regards to all our mothers and sisters for their never-ending love and prayers. To those who in some way contributed in this research, your kindness and assistance meant a lot to us and this project as a whole. Thank you all very much.

All Syndicate members

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LIST OF ABBREVIATIONS

NSHO	**National State Highway Ordinance**
M-1	Motorway 1
M-2	Motorway 2
AASHTO	American Association of State Highway and Transportation Officials
HVUT	Heavy Vehicle Use Tax
SSWIM	Slow Speed Weigh In Motion
NHA	National Highway Authority
NTC	National Trade Corridor
ETC	Electronic Toll Collection System
OBU	On-Board Unit
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ATA	American Trucking Association
HCAS	Highway Cost Allocation Study
RFID	Radio Frequency Identification
RD	Road Distance
CRD	Combined Road Distance
LEF	Load Equivalence Factor
GW	Gross Weight
s	Standard Weight
∑	Summation
AATT	Average Annual Truck Traffic
AVI	Automatic Vehicle Identification
WIM	Weigh In Motion
OMR	Optical Mark Recognition
BOT	Build-Operate-Transfer

EXECUTIVE SUMMARY

Transportation has long been an agent of human evolution. For man, it has proved pivotal in understanding our world and achieving our dreams. From land to air and across the seas, transportation has been the fundamental element in mankind's advancement through the ages in to what he is today.

Highway transportation is the means of transport offered by specialized road networks. It forms the basis of any sort of human interaction internationally. From trade and commerce to military movements and social interactions, most if not all are done by means of roads. Having established their importance, it is equally pertinent that we manage these resources just as well. Since pavements are alive structures, they have a limited design life and tend to devalue over use. Management of these resources includes efficient tolling so that the damage done to them can be assessed and correspondingly repaired with the generation of ample funds. Efficient tolling of highways means that the tolls applied on vehicles should be representative of the damage done to them by the vehicles which use them. In our country, most of the freight industry operates by road and therefore pavement damage is excessive. Whereas, the pavements get more damaged then what the freight industry pays for. Therefore, an efficient system of tolling which is mostly automated and dependent on a more direct relationship between pavement damage and freight weight should be made.

This study focuses on the development of a framework which constitutes components for LEF computation, Route Distance evaluation, Toll Tax evaluation and an entire framework tool for extrapolation-analysis purposes. It also highlights the apparatuses of a functioning ETC that include Weigh-In-Motion sensors necessary for the implementation of such a damage based toll tax.

Chapter 1
INTRODUCTION

1.1 Study Background

In today's world and age, effective and efficient communication is necessary between organizations to keep up with the developing world. As such, one of the most operative means of communication happens to be the roads and highways that connect places, cities and in turn, people with one another. For a country such as ours this importance is ten folded since everyday businesses, markets, industries and even the armed forces rely on such a system of roads for communication and operative purposes. In Pakistan, the roads used in immensity are asphalt concrete pavements of flexible nature. And since pavements are alive structures, they are to live a certain design life before giving way to the distresses and consequently failing. For theses pavements, it is imperative that maintenance and rehabilitation measures be taken on time so that the required level of comfort, safety and economy are preserved. Millions of dollars are spent every year on these measures to ensure that these road assets perform to their expected outputs.

The national highways on Pakistani roads have been greatly damaged due to the menace of overloaded freight trucks. Among such national assets is the M-2. Connecting Lahore to Islamabad and then on to Peshawar (M-1), M-2 serves millions of users on a nationwide scale. This motorway is not only the backbone of the industry in the upper region of our country but also serves as an extension of urbanization in Pakistan.

The carriageways of M-2 have been greatly devastated due to overloaded freight vehicles and henceforth a more robust system of toll should be introduced which would cater to the rehabilitation needs of the resultant damage. To do this, we aim at studying the Motorways existing approach at countering this issue and suggesting improvements that could be made on the system, such as installation of more weighing stations and implementation of charges to be put on vehicles exceeding a certain weight in a specific category. Not only that, we aim at finding the existing loophole routes which a driver could take when moving his vehicle from one point to another without having to have his vehicle weighed. The ultimate aim of our study and the consequent analysis is to evaluate the deplorable state of the motorways due to overweighed traffic and introduce more reasonable fund generation to alleviate this issue by introducing a toll representative of the damage induced.

Our project consists of a framework to evaluate the damage caused on the pavements and the corresponding tolls which are incurred with or without a violation. The ending comprises of analysis of the existing fee structure of the toll and a proposed toll structure based on the damage ratio of trucks. With such a framework at hand, we will be able to quantify the amount of toll tax for a specific overloaded truck.

1.2 Motivation for Study

With the existing figures of commercial development and business infrastructure of Pakistan in mind, it is sufficient to say that the freight industry in our country is among the top contributors to the changing financial conditions of the country. A study maintains that Pakistan's freight transport is dominated by road transportation with trucking loads accounting for 206,404 million tons-km of goods per year, about 93 percent of the country's total. It states that the main problem facing Pakistan's road infrastructure is in the critical situation of the National Trade Corridor (NTC), which faces severe capacity bottlenecks due to poor physical condition, the presence of non-motorized traffic, and the extensive commercial activities located along it. Road services suffer from a lack of trucking industry regulation, which produces numerous downstream problems. According to a report titled "*An Assessment of Opportunities and Constraints in the Logistics Industry in Pakistan*" MENA Logistics (2009), the dependence of the Pakistani logistics chain on road services makes it even more vital for these problems to be corrected to decrease export time and increase product quality, thereby opening up new markets for Pakistani exports.

With these basic truths about our road freight industry in mind, it is natural to assume that the development of Pakistan's Trade Corridor is severely dependent on a functional and sufficient road network that is international standards. Our incentive for this study in formulating a system of toll tax for the heavy freight trucks industry is to ensure that apt funds are collected to cater for the rapid and vehement deterioration of the pavements used by these modes of transport.

1.3 Problem Statement

Pakistan’s highways are the source of most of her productivity with majority of the business and development being done via routes on either the National Highway network or the Motorway network of roads. On such roads, rutting has been one of the most critical sources of failure among flexible pavements due to violation of axle load restrictions, high tire pressure and exceeding the weight limit. The result is the poor state of pavements that we see today on most of our highways. These distresses not only cause discomfort but also contribute to the amount of accidents that happen on these roads annually. Therefore, an understanding can be made that a rusty road condition affects the quality of life of the people.

The motorways were made in 1997 and have since been the premier road service in the country offering the highest quality and the best standards. Pakistan's first motorway, the 367 km 6-lane M-2, connecting the cities of Islamabad and Lahore, was constructed by the South Korean company Daewoo and was inaugurated in November 1997.

Together, the M-1 and M-2 connect Pakistan’s biggest metropolitan belt from Lahore to Islamabad and from Islamabad all the way to Peshawar. With such an expansive network of roads, the primary use is for the development industry. And therefore, trucks, lorries and other freight vehicles use this network vehemently. The use of such vehicles has led to immense damage to these pavements and therefore the use of weigh stations on the interchanges has been done to verify that overloaded vehicles don’t escape without paying the proper fine charges.

The weigh stations on the M-1 and M-2 roads are of either SSWIM nature or STATIC nature. They are placed typically on the interchanges on these motorways and cover most of the road length. Their job is to weigh the vehicles and determine if they are overloaded or not.

However, with the current method of weighing and the fine structure, there is no articulate link between the amount of damage a truck does and the fine it has to pay for it. This has led to many truck drivers utilizing this loophole in having done consequent damage to the pavement without the proper or equivalent damage fine being paid. Therefore, a more coherent fee structure of the toll with the focus at equalizing the damage done and its relevant cost should be in place. Not only that, but we will analyze and suggest measures which would introduce new weighing stations and calculate its break even cost accordingly with our new fee structure in focus. The damage caused to these pavements often goes un-catered for and results in a lesser level of comfort and design life, therefore we wish to alleviate this issue to obtain the most representative toll tax on a vehicle using these motorways.

1.4 Objectives

For our study, we plan on achieving a tax service that would greatly facilitate the National Highway Authority in road maintenance and rehabilitation by providing apt funds and the consequent conditions for a rehabilitation measure to progress. We aim at achieving:

- To develop a highway toll tax representative of the damage induced by the trucks.
- To develop a software framework incorporating all heavy vehicle types and overload categories to compute revenue generation across time periods for analysis purposes.
- To recommend a detailed system of automated toll collection on the motorways of Pakistan.

1.5 Scope & Limitations

The vast corridor served by the motorways of M-1 and M-2 cover an area of roughly the entire width of our country. Our focus will be, however on the M-2. This focus will include the rough traffic figures and other data obtained from NHA HQ G-9 concerning the M-2 only. We will incorporate the factors that affect the toll rates of a vehicle traversing the motorway. These factors include the length of the route, the category of the vehicle, the amount of truck vehicles passing through either per day or per year, the load condition of a specific axle of a truck and the standard acceptable weight limit of a certain axle.

The framework that the culmination of the work would produce would cover all those factors and would be usable in the excel format of the proposed framework. This would be handy in order to keep records as well. This introduced system would include usage of a server based information cloud which would be networked through all the toll stations across the motorway. We will be looking into the M-1 and M-2 corridor with its thirty interchanges between Lahore and Peshawar, forming the skeleton of the area on which the framework is to be applied. Once the toll system is implemented, we will find out the revenue generated on each day or year with the new system of tolls. The revenue generated by this framework will be used to install a new weigh station, if a loophole is found, on the current network of weighing stations on the M-1-M-2 network.

Our study is limited in the sense that it incorporates only the data and information for the motorways 1 & 2. It does not extend beyond that and therefore, the usage and role of the National Highway is not effectively discussed in the research work.

Another limitation to our focus on the study is the ideal revenue collection and usage of these motorways and the proposed toll rate system. Meaning, we did not inculcate any misfortunes into our system for the complete cycle of operation. Naturally, issues could arise deterring any figures from being exact, such as the annual truck traffic, climate control, natural disasters etc.

1.6 Methodology

The processes involved in achieving the said objectives to the problems mentioned earlier sum up to form the methodology of our work. It involves all the steps that led to its culmination with emphases on the founding elements and key procedures that we had to go through in order to accomplish our objectives. A more detailed explanation of the entire phase is done in Chapter 3.

1.7 Organization of the Report

In this chapter, we introduced the concept of our study, its concept, usage and motivation behind the effort. Firstly, we introduced the road freight industry of Pakistan and the national assets which are used by them. The motorways are the prime examples of such assets with our focus lying on the M-2 which runs from Islamabad to Lahore. We highlighted our concern in the problem statement which was the excessive damage caused by the heavy freight vehicles and the inadequate toll rates applied on them. Afterwards, we enumerated our objectives for the study and then we drew the margins of our efforts in the scope of the project. Then, we elaborated on the motivation for our study by citing a few figures from previously completed reports on the role of the heavy road freight industry in our country. Lastly we mentioned the step by step procedure that we would incorporate to achieve our said venture in the methodology. The organization of our thesis is in six chapters:

- Chapter 1: This chapter introduces the reader with our thesis; the reason behind its inception, its conception and an overview of its planned execution.
- Chapter 2: This chapter illustrates the different knowledge based concepts that the thesis will make use of. It also sheds light on efforts done for our said problem across the world.
- Chapter 3: This chapter iterates the methodology or step-by-step working procedure of our proposed solution. From data collection to data analysis.
- Chapter 4: This chapter deals with the conception of the software based solution of our damage based toll. In precision, it deals with the formation of our damage based toll tax and the myriad steps involved in making it a workable function of the dependable variables.
- Chapter 5: This chapter introduces our ETC (Electronic Toll Collection) based approach. It illustrates the components and working of the system along with its benefits and draw backs.
- Chapter 6: This chapter concludes our effort with a deduction that depends on the aforementioned efforts in the report and includes endorsements for the implementation of the proposal and future of the study.

Chapter 2
LITERATURE REVIEW

2.1 General

This chapter will shed light on the importance of the motorways to the economic backdrop of Pakistan and it will highlight its importance financially and socially. Furthermore, it will emphasize on the works that have been done on the analysis of highways across the world to decipher the damage done to them over the course of usage. These studies are pivotal in understanding the factors which affect the road conditions of theses highways and include a varying amount of aspects of road design, vehicle weight distribution and tolling usage.

Overweight traffic is a menace on such highways as they tend to deteriorate the pavements at a faster rate than is considered normal. This traffic, is usually deterred in amount by the imposition of fines on overweight loading. But, the fines sometimes are inadequate and unreflective of the damage done to the pavement. Therefore, in the longer run these highways get more damage done to them than is paid for in terms of fine, and as such people are encouraged to pay the inadequate fee amount and pass on with their immensely overweight freights.

The existing systems of measurement will be discussed too, such as the type of facilities and the managerial aspects of the entire weight recording procedure. Across the world different methods are used for recording these weights for vehicles of different classes.

2.2 AASHTO's Generalized Fourth Power Law

During the AASHTO Road Tests to study the performance of pavement structures of known thickness under moving loads of known magnitude and frequency, different findings were made about the relationship between the loads and their effect on the pavement life. This study was carried out in the late 1590's in Ottawa, Illinois, USA. This road test consisted of six two-lane loops and with each lane subjected to repeated loading by a specific vehicle type and weight. The results so obtained were used to develop a pavement design guide.

According to an article titled “*Equivalent Single Axle Load*” on PavementInteractive.com these tests introduced the *“Generalized Fourth Power Law”* which states that damage caused by vehicles is ‘related to the 4th power of their axle weight’.

2.3 Usage of the Motorways M-1 & M-2

Pakistan's motorways are part of Pakistan's "National Trade Corridor Project". A motorway can be defined as:

“A limited-access (restricted entry) dual carriageway road, not crossed on the same level by other traffic lanes, for the exclusive use of certain classes of motor vehicles (slow moving vehicles not allowed)”.

Figure 2-1: A stretch of M-2

These are owned, maintained and operated federally by the National Highway Authority in Pakistan. They connect the important metropolitan cities with each other and the entire country as well as improve the country’s image as an international trade corridor. These are either four lane or six lane highways. Used mostly for their reach the motorways facilitate the trade realm of the entire country day in and day out.

2.4 Toll Collection Rate & Method in Germany

In Germany, the LKW-Maut (Lastkraftwagen-Maut, literally 'HGV toll') is a toll for goods vehicles. The toll collection is done with a different set of priorities with a heavier focus on the emission rates of vehicles. The toll is based on the route and the pollution class of the vehicle, its weight and the number of axles. Certain vehicles, such as emergency vehicles and buses, are exempt from the toll. Toll Collect is an entity which enforces and oversees toll collection on behalf of the Federal Republic of Germany. The following reports and data have been acquired from the "*Toll Rates*" page on the official TollCollect website: https://www.toll-collect.de.

Figure 2-2: A Toll-Collect Gantry on LKW-Maut

2.4.1 Method of Toll Collection:

Automatic Log-on

Toll Collect has developed an automatic log-on system for truckers, based on a combination of GSM and GPS. To take advantage of the automatic log-on, lorry drivers are required to register the freight company as well as each individual lorry. After registration an on-board unit (OBU) can be installed by an authorized Toll-Collect partner. The OBU automatically determines the distance travelled on the toll route, calculates the toll based on vehicle class and toll rate information entered and transmits the information to the Toll-Collect center for processing via GSM (cellular) communication (Richards, 2006). Once the toll information has been submitted to the

Toll-Collect center a bill is generated and e-mailed to the driver or owner of the lorry. The German government paid for the approximately 450,000 OBUs currently in use and lorry drivers were responsible for covering their installation (UK Commission for Integrated Transport 2007).

Manual Log-on

Alternatively lorry drivers who rarely use German toll roads can log-on manually at one of 3,500 toll station terminals or over the internet. The log-on to a toll station terminal, located near motorway access ramps, is similar to purchasing a ticket. The driver enters the vehicle information, starting point and destination. The toll station calculates the fees based on the shortest route within the toll road network. As of December 2006 90% of the lorries on German roads paid the toll automatically. In 2006 the toll-collection rate for automatic transactions was 99.75% (Toll Collect, 2007).

2.4.2 Toll Rates

The toll rates are set down in the German Federal Trunk Road Toll Act (BFStrMG). The total amount is based on the distance that a vehicle or a vehicle combination travels on a road subject to toll and a toll rate per kilometer that includes the infrastructure costs and costs due to the air pollution caused by the vehicle.

- The partial toll rate for the infrastructure costs is rated differently for trucks with up to three axles and trucks with four or more axles.
- The partial toll rate for air pollution costs is determined according to the emission class, which is used as the basis for assigning each vehicle to one of the six categories: A, B, C, D, E or F.

No costs for modern trucks of emission class Euro 6 (category A) will be charged for causing air pollution. Only the infrastructure costs are calculated for the partial toll rate for this type of truck. The indication of the emission classes is the responsibility of the toll customers; the customers are obliged to declare themselves correctly (principle of self-declaration). Further information can be found in the "Guide for determining emission classes".

Table 2-1: Emission classes per German Federal Trunk Road Toll Act (BFStrMG)

	Category A	Category B	Category C	Category D	Category E	Category F
Emission class	S6	S5, EEV class 1	S3 with particulate reduction class*, S4	S2 with particulate reduction class*, S3	S2	S1, no emission class
Euro emission class	Euro 6	Euro 5, EEV 1	Euro 3 + particulate reduction class*, Euro 4	Euro 2 + particulate reduction class*, Euro 3	Euro 2	Euro 1, Euro 0

*Particulate reduction classes are retrofitting standards to lower particulate emissions.

Table 2-2: Toll rates per kilometer from 1 January 2015, (TollCollect, Germany)

Category	Proportion of toll rate (in cents) Costs for air pollution	Number of axles	Proportion of toll rate (in cents) Costs for infrastructure	Toll rate (in cents)
A	0	up to 3	12.5	**12.5**
		4 or higher	13.1	**13.1**
B	2.1	up to 3	12.5	**14.6**
		4 or higher	13.1	**15.2**
C	3.2	up to 3	12.5	**15.7**
		4 or higher	13.1	**16.3**
D	6.3	up to 3	12.5	**18.8**
		4 or higher	13.1	**19.4**
E	7.3	up to 3	12.5	**19.8**
		4 or higher	13.1	**20.4**
F	8.3	up to 3	12.5	**20.8**
		4 or higher	13.1	**21.4**

2.5 Toll Collection Rate in Illinois

On the Illinois Highway in the state of Illinois, USA, the toll collection is done by the Illinois Tollway. The Illinois Tollway is a user-fee system – no state or federal tax dollars are used to support maintenance and operations. It is a 286-mile system of toll roads and has four highways; we will be looking at the toll collection rate of one of these, namely: Veterans Memorial Tollway (I-355).

Figure 2-3: Gantry Showing I-Pass only lane

The Vehicle categories used in the system are defined as follows:

2.5.1 Vehicle Categories

Table 2-3: Vehicle Categories (Illinois Tollway, USA)

Vehicle Category		Description
Passenger Cars	Auto/Motorcycle	2 axles - four or less tires; auto, SUV, motorcycle, taxi
Commercial Vehicles and Vehicles with Trailers	Small Truck	2 axles - six tires; single unit truck, buses
	Medium Truck	3 and 4 axles vehicle or combination; truck, bus, auto/SUV with 1 or 2 axle trailer
	Large Truck	5+ axles vehicle or combination; trucks, auto/SUV with 3+ axle trailer

The toll rates vary over the following variables:

- Vehicle Class
- Time Category (Daytime/Overnight)
- Route

- Payment Method (I-PASS/Cash)

Some technical details of the system:

According to the "About I-PASS" page at http://www.illinoistollway.com/tolls-and-i-pass/about-i-pass the I-PASS is an automated system of toll collection offered by the Illinois Tollway and is an alternative to procedures dealing with cash.

Daytime Hours: 6:00 a.m.-10:00 p.m. Overnight Hours: 10:00 p.m.-6:00 a.m. The Illinois Tollway is one the many highways across the state of Illinois being used by the expressway tolling system. Automation as well as manned services are used by Illinois Tollway. This gives flexibility over a larger consumer audience since most people who travel casually, still prefer the hassle of manned toll plazas. Among the many highways that the Illinois Tollway facilitates, is the Veterans Memorial Tollway.

2.5.2 Veterans Memorial Tollway (I-355) "2015 Rates by Toll Plaza" from http://www.illinoistollway.com/

Table 2-4: Veterans Memorial Tollway (I-355) - 2015 Rates by Toll Plaza

Trucks							
Toll Plaza Name and Plaza Number		**Daytime (Cash and I-PASS)**			**Overnight (Cash and I-PASS)**		
		Small	**Medium**	**Large**	**Small**	**Medium**	**Large**
Army Trail Road	**73**	**$2.10**	**$3.15**	**$5.60**	**$1.40**	**$2.45**	**$4.20**
North Avenue (Illinois 64)*	75	$1.70	$2.50	$4.50	$1.10	$1.95	$3.35
Roosevelt Road (Illinois 38)*	77	$1.45	$2.25	$3.90	$1.00	$1.75	$2.95
Butterfield Road (Illinois 56)*	79	$1.05	$1.60	$2.80	$0.70	$1.25	$2.10
Maple Avenue*	83	$1.25	$1.90	$3.35	$0.85	$1.45	$2.50
63rd Street*	85	$1.45	$2.25	$3.90	$1.00	$1.75	$2.95
75th Street*	87	$1.70	$2.50	$4.50	$1.10	$1.95	$3.35
Boughton Road	89	$2.10	$3.15	$5.60	$1.40	$2.45	$4.20
Boughton Road*	90	$1.05	$1.60	$2.80	$0.70	$1.25	$2.10
127th Street*	93	$2.10	$3.15	$5.60	$1.40	$2.45	$4.20
Archer Avenue/143rd Street*	95	$2.75	$4.20	$7.30	$1.80	$3.20	$5.45
Illinois 7 (159th Street)*	97	$3.15	$4.85	$8.40	$2.10	$3.80	$6.30
Spring Creek	**99**	**$4.20**	**$6.30**	**$11.20**	**$2.80**	**$4.90**	**$8.40**
U.S. 6*	101	$1.05	$1.60	$2.80	$0.70	$1.25	$2.10

*Unattended ramp plazas

With the table above it can be seen that the toll collected is not directly related to the active damage caused by a specific truck type and in fact related more closely to the vehicle class and the length of the route itself. The system does however offer greater flexibility in the management side with the use of the I-PASS and the E-ZPass electronic toll-collection systems and unmanned toll stations.

2.6 Pavement Damage due to Freight Traffic

According to an article titled "The Hidden Trucking Industry Subsidy" published in 2009 on truecostblog.com the figures of damage that overloaded freight trucks do to the pavements are manifold greater than that caused by average vehicles. [6] The report sheds light on the fact that it is deceivingly obvious to most people that the heavier the vehicle, the more damage it does to roads over time. However, the relationship is not linear, it one with of the fourth power, as has been elaborated before as the *Generalized Fourth Power Law*. Road damage rises with the fourth power of weight, and this means that a 40,000 pound truck does roughly 10,000 times more damage to roadways than the average car! In other words, one fully loaded 18-wheeler does the same damage to a road as 9600 cars. Furthermore, according to the American Trucking Associations (ATA), the trucking industry represents 11% of all vehicles on the road in the US, while paying 35% of all highway taxes. But if trucks represent 11% of vehicles, their heavy loads cause them to do 99% of all road damage! The trucking industry paid $35 Billion in highway taxes in 2005, according to the ATA. Since most of the $100 Billion in highway taxes paid goes to maintenance (and US infrastructure maintenance is far behind), this implies that the trucking industry receives a $60 Billion annual subsidy from other drivers.

In order to calculate the damage done by trucks versus other vehicles, let's assume that a fully loaded truck does the same damage to the roadway as 9600 cars, as mentioned above. In that case, then 11%, or 0.11 * 9600 = 1056. This is a measure of total damage done by truck traffic. Meanwhile, car traffic does 89% * 1 or 0.89 in damage. So the total damage is 1056 + 0.89 or 1056.89, of which 1056, or 99.9%, is done by trucks.

In the Federal Highway Cost Allocation Study done by the Federal Highway Administration, (1997), it was estimated that light single-unit trucks, operating at less than 25,000 pounds, pay 150 percent of their road costs while the heaviest tractor-trailer combination trucks, weighing over 100,000 pounds, pay only 50 percent of their road costs.

This means that the heavy freight industry gets off without paying for the amount of damage they do to the pavements. To cater for this anomaly, the Heavy Vehicle Use Tax (HVUT) was implemented by the Federal Highway Authority. It's details have been acquired from *http://www.fhwa.dot.gov* under "Heavy Vehicle Use Tax". It is applied annually on heavy vehicles operating on public highways at registered gross weights equal to or exceeding 55,000 pounds. The HVUT is applied as:

Table 2-5: HVUT Application (www.fhwa.dot.gov/)

Gross Taxable Weight	Heavy Vehicle Use Tax Rates
Below 55,000 lbs	No tax
55,000-75,000 lbs	$100 plus $22 per 1,000 pounds over 55,000 lbs
Over 75,000 lbs	$550

2.7 Automated Toll Collection Systems/ETC (Electronic Toll Collection)

Globally, the use of technology has revolutionized all avenues of the transportation industry. One critical aspect of the industry happens to be toll collection. Around the world, different approaches and components are used to perform toll collection automatically. Examples of such technologies include using transponders to tag vehicles. One such successful implementation of the electronic toll collection system is the FasTrak used in the state of California, USA. The system is used statewide on all of the toll roads, toll bridges, and high-occupancy toll lanes along the California Freeway and Expressway System.

FasTrak uses RFID technology near 915 MHz to read data from a transponder placed in a vehicle (usually mounted by Velcro strips to the windshield) moving at speeds that may exceed 70 mph (112 km/h). The RFID transponder in each vehicle is associated with a prepaid debit account; each time the vehicle passes underneath a toll collection site, the account is debited to pay the toll.

As per the “FasTrak talk summary and slides” by Nate Lawson, (2008), if a vehicle does not have a transponder, or if a transponder is not detected at the Toll Plaza, a Violation Enforcement System triggers cameras that take photos of the vehicle and its license plate for processing. If the license plate is registered as belonging to a FasTrak user, the account is debited only the toll charge, and no penalty is charged. This is a backup in case a transponder fails to read. Otherwise, a toll violation notice is sent to the registered owner of the vehicle. In the case of drivers whose vehicles are company owned or leased, as long as the vehicle license plates are not properly listed, the violations will be sent to the registered owner and not the employee driver.

Among the security concerns for this system include the fact that the transponders and can be updated remotely and do no use encryption. With the increased use of wireless devices in in today's world and the provision of Wi-Fi and 3G and 4G services in most countries across the world, these security concerns have heightened and can be very lethal with the application of hacking systems. According to a study published by *root labs*, these could potentially rig the systems by exploiting the tags used in the windshield transponders.

2.8 Report on Overweight Truck Permits in Indiana, USA

According to report titled 'A Synthesis of Overweight Truck Permitting' by M. Irfan et al, (2010), the truck permits for overloading freight vehicles needed to be related to the damage done to the pavements by the trucks themselves. This relied heavily on the axles and overweight conditions of these vehicles. It maintained that there was a significant difference in the truck permit fee across different states bordering the state of Indiana. For its findings it stated that the key criterion included: the extents to which size attributes (length, width, height) are in excess of the legal values, distance traveled by the overweight/oversize truck, type of load carried, and axle spacing. The study documented the revenue streams obtained from the permits issued for extra-legal trucking operations: these were found to be approximately $12 million annually. The report provides nomographs with which INDOT can quantify the increase in pavement damage (and hence repair costs) that can be expected due to additional payload increases for a given axle configuration; and the reduction in pavement damage due to the increase of axles on a truck of a given payload. However, as these relationships between truck load pavement damage costs are based on national level data, there is a need to update these costs using data from Indiana. In the USA, permits have been the bane of the trucking industry as they allow for overloaded trucks to continue operation. Since this is the case with most transportation assets, the need to evaluate a more relevant fee for these permits was necessary. The work introduced new permit fee structure for the state of Indiana based on the pertinent damage done to the highway assets by the overweight trucks that use them. The schemes suggested in the work included certain thresholds as the *Upper Threshold for Legal Weights (UTLW)*, *Upper Threshold for Extra-Legal Weights (UTELW)* and the *Upper Threshold for Extra-Legal Weights for use of Special Routes*. The study also discussed general observations on the permitting processes, thresholds for legal oversize/overweight permits classification, criteria for fee structures and fee levels, state of practice of the weight-distance fee concept for extra-legal weights and sizes, revenue neutrality of annual permit fee structures, and the practice of delineating special routes for extra-legal vehicles. The report conducted case studies in which it had hypothetical values for trucking data, the first case study shed light on annual blanket permits. The study highlighted the gross differences between the permits expenses generated as per the states surrounding Indiana, i.e. the Midwest.

Among the nomographs generated in this study, were ones which were able to predict the pavement cost per distance traveled for different number of axles.

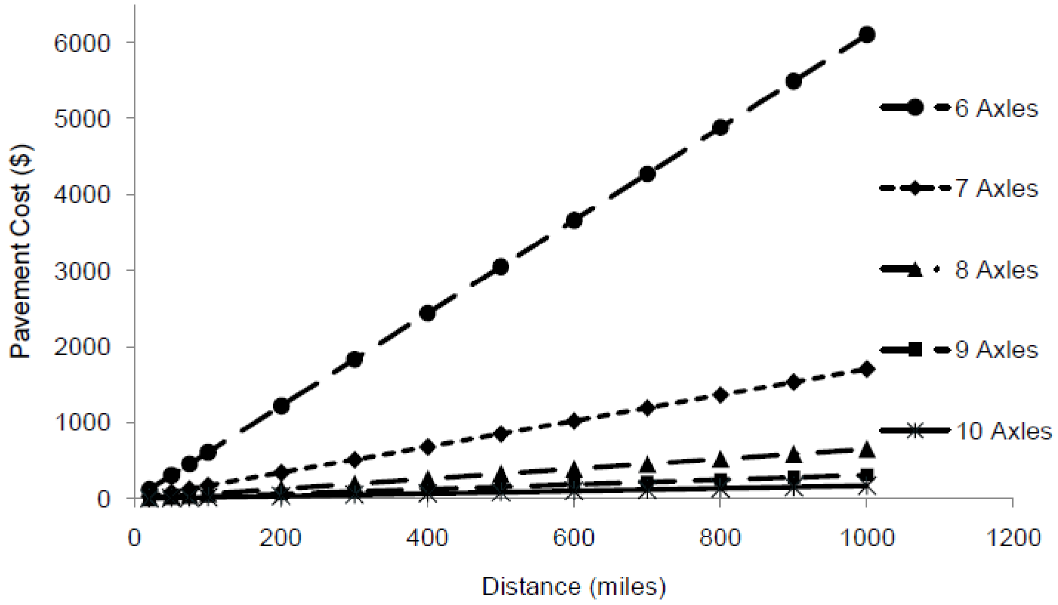


Figure 2-4: Pavement Cost vs. Truck Miles Travelled for Urban Interstate Highways
(0 to 1,000 Miles), 134,000 lb GVW Truck

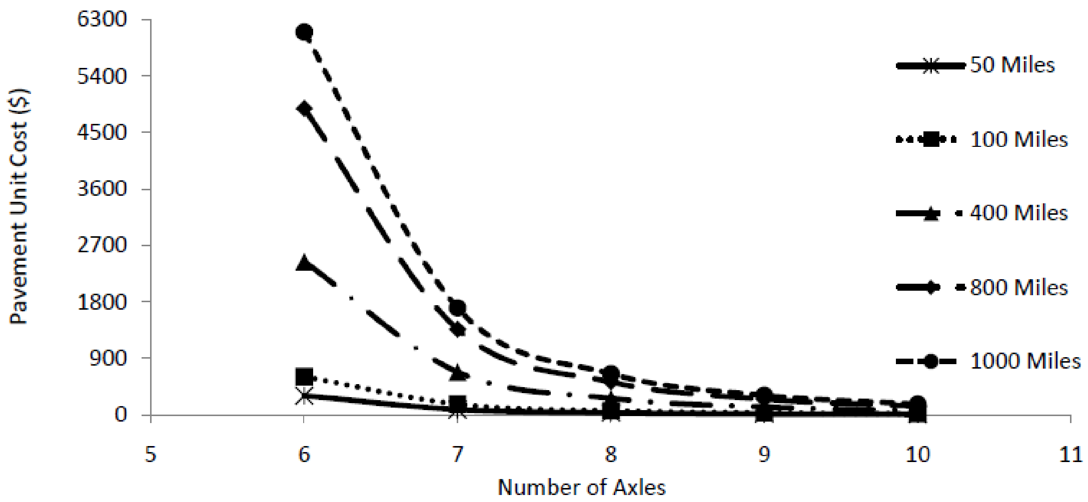


Figure 2-5: Unit Pavement Cost vs. Number of Axles for Urban Interstate Highways ***(0 to 1,000 Miles), 134,000 lb GVW Truck***

It is clearly understandable by the above relations of nomographs, that an increased number of axles for the same distance traveled yields a lower pavement unit cost and similarly, the unit cost increases with distance provided the axle remains the same. Apart from this, it is clearly evident with these nomographs that the 6-axle trucks have the highest pavement unit cost and therefore they damage the pavements the most.

2.9 NHSO 2000

The National Highway Safety Ordinance 2000 is a set of rules and regulations formulated by the President of the time to provide safe driving experiences on the national highways. This ordinance forms the basis of the transportation industry by defining all the key elements and phenomenon included in the industry. It states the vehicle types and the how they are categorized and therefore, it essentially explains the founding terminology used by our highway systems nationwide. It describes some key expressions for our project including the following:

(iii) "**axle weight**" means in relation to an axle of a motor vehicle the total weight transmitted by the several wheels attached to the axle to the surface whereon the vehicle rests

(xvii) "**gross vehicle weight**" means load of all axles of a goods vehicle transmitted by several wheels attached to all axles to the surface whereon the wheels rest

(xviii) “**heavy transport vehicle**” means a transport vehicle, the registered axle weight of which exceeds five thousand kilograms, or the registered laden weight of which exceeds six thousand five hundred kilograms

(xxi) “**laden weight**” means the actual weight of the vehicle as loaded with the crew and passengers and the load carried on it

(xxxv) “**national highway**” means a national highway as defined in the National Highway Authority Act, 1991 (XI 1991); and includes a road declared to be a national highway under the said Act

(xlviii) “**registered laden weight**” means in respect of any vehicle the total weight certified and registered by the registering authority as permissible for that vehicle

(lvii) “**single axle weight**” means load of an axle of a goods vehicle transmitted by several wheels attached to that axle to the surface whereon the wheels rest

(lix) “**tandem axle weight**” means load of a twin-axle (two axles center-to-center spaced between forty to forty-eight inches) of a goods vehicle transmitted by the several wheels attached to that twin axle assembly to the surface whereon the wheels rest

(lxiv) “**tridem axle weight**” means the load of a tri-axle (three axles, the outer two axles center-to-center spaced between eighty to ninety-six inches) of a goods vehicle transmitted by the several wheels attached to tri-axle assembly to the surface whereon the wheels rest

(lxvii) “**weigh station**” means stations incorporating static and weigh-in-motion (WIM) devices installed to measure and enforce legal load limits

(lxviii) “**weight**” means the total weight transmitted for the time being by the wheels of a vehicle to the surface on which the vehicle rests

AS for the limitations to weighing vehicles and how much if an extent can they be overloaded to, it states in the NHSO:

> *75. Offences relating to weights:-*
>
> *Whoever drives a transport vehicle or causes or allows a transport vehicle to be driven on a national highway carrying in excess of fifteen per cent of the permissible load for a goods vehicle as laid down in the Sixth Schedule and in excess of thirty percent of the number of passengers prescribed for a passenger carrier, shall be punished with imprisonment for a term which may*

extend to one month or with fine which shall not be less than one thousand rupees and may extend to five thousand rupees, or with both.

2.10 Summary

In this chapter, we elaborated on the different approaches of road toll collection used globally. We also studied the different systems of toll rates and how they vary depending on variables such as route length and vehicle type. Apart from this, the Generalized Fourth Power Law was explained since it is pivotal to this project in formulating a toll rate for heavy vehicles. The different toll collection systems used in Germany and in USA were explained with their details in length. Furthermore, the link between pavement deterioration and truck axle weight was done with the citation of a study conducted under the US Department of Study. This study also reflected the fact that truck damage and the toll paid by the truckers is not coherent and could use improvement. This has resulted in the use of the HVUT by the Federal Highway Authority in the USA. All these measures used globally point out, firstly to the significance of pavement deterioration on toll rates. Secondly, to the link between highly overloaded truck axle weights to the amount of damage done to them.

Chapter 3
METHODOLOGY

3.1 Overview

In order to achieve a comprehensive study and analyses of the fee cost allocation on freight vehicles we need to first find out the existing structure of facilities which are already in place in the required area of concern, that is the M-2. First and foremost, we need to establish which interchanges are present on the M-2 highway and how many entry-exit points are there exactly.

Once that has been established, we need to mark the existing weigh stations which are already present on the road network and are under operation. These will not include those which are nonoperational due to some reasons such as incomplete structure or equipment installation underway.

After that, we obtained data pertaining to the existing traffic axle streams and the toll fee and fine structure that is currently in place and used by the NHA. Next, we formulated our framework solution and made it on the MS Excel spreadsheet software. This was all done using data and categories which are entirely flexible and tangible so as to accommodate future enhancements of any kind.

Finally, we focused on the automation process for toll collection and studied systems for doing so automatically. With that, we discussed the concerns and their probable solutions in entirety. Finally, we amalgamated all the components which we needed for the scheme to formulate an automated system which worked in tandem with our proposed damage based toll rates.

Our efforts have been explained in the compilation elaborated in the subsequent steps.

3.2 Graphical Representation

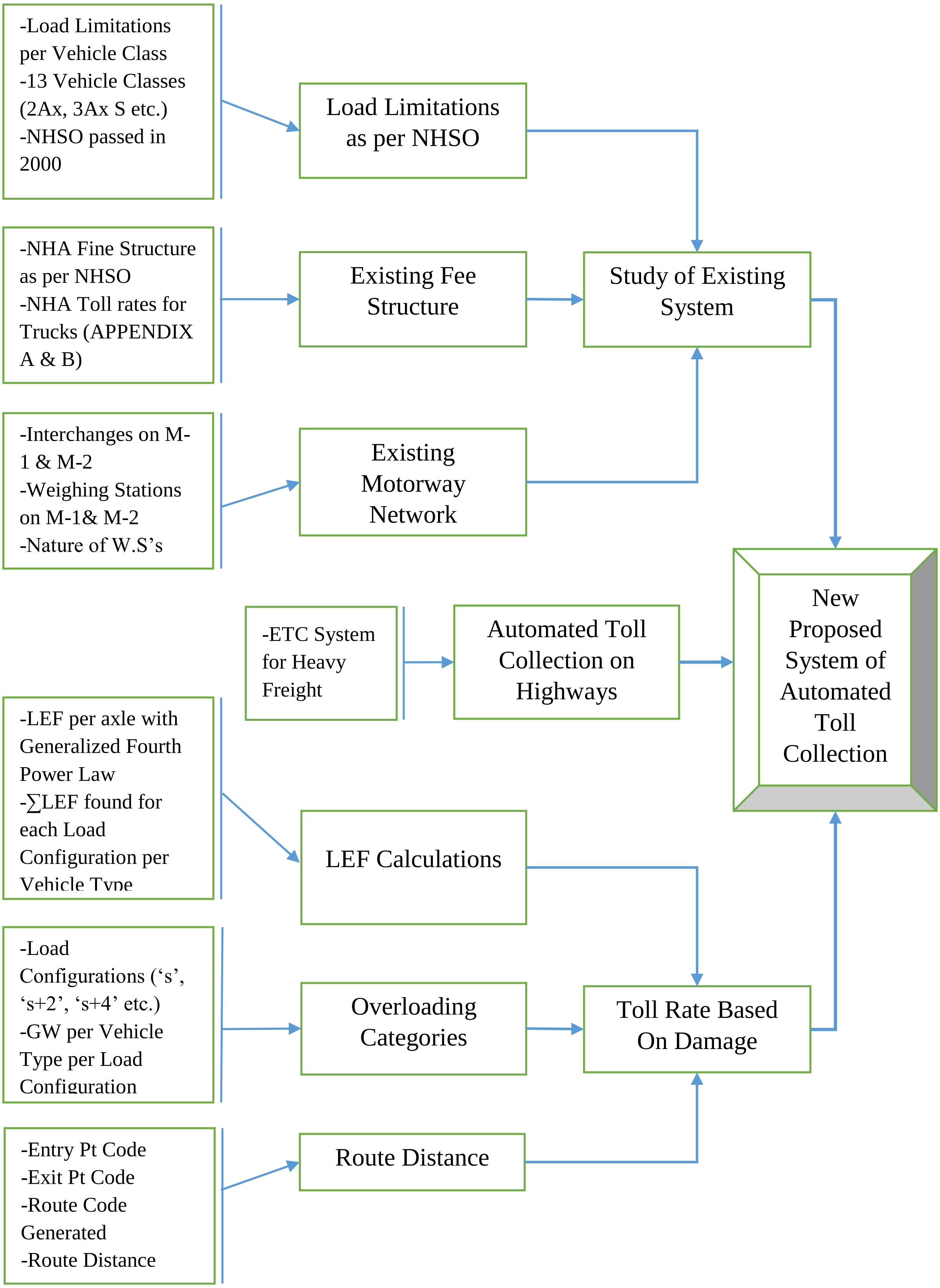


Figure 3-1: Graphical Representation of Methodology

3.2 Studying the Existing Entry/Exit Points

The entire system of road networks comprising the M-1 and M-2 projects stretches over a combined length of around five hundred kilometers. In this stretch, we have different points of importance such as toll stations and interchanges. The facilities and entities on the existing networks were well designed with the future in mind on the conception of these projects. Consequently, there are sufficient resources for the effective performance of these facilities. However, our study will unveil a few details which were previously overlooked.

First, and foremost what we needed to do was find out exactly where can vehicles enter or exit the motorways. For that, we needed a comprehensive set of images and text to go through and finally we went to the head office of the NHA at G-9 Islamabad to get the left over details with a more official approach.

To get a grasp of the way the system works on the Motorway, our syndicate made lots of trips and contacted a lot of key people to obtain the information required. We were lucky enough to get a few technical details regarding the nature of the weighing stations by the NHA officials at the G-9 head office. Apart from that, certain individuals in the toll stations helped us out by intimating us of the procedure and efficacy of the weigh stations.

The details we needed for our framework included the number and placement of the interchanges and the weigh stations along with their respective road distances. Our findings concluded the following details about the motorways.

3.2.1 Motorway Network, M-2

Opened up in 1997 by the then Prime Minister Nawaz Sharif, the M-2 connects the metropolitan hubs of Islamabad and Lahore. This is the most heavily used motorway in the country and therefore its features have been designed with paramount planning endeavors. It is a 6-laned, 369 km stretch of pavement starting from the city of Lahore and passing through important places like Kala Shah Kaku, Sheikhupura, Kallar Kahar, Balksar, and Chakri before ending just outside the twin cities Rawalpindi and Islamabad. Given the quality of the roads, the Pakistan Air Force (PAF) has used the M2 motorway as a runway on two occasions. Following are the interchange details along the M-2 with their respective Road Distances

Interchanges: [RD’s (Road Distances)]

a. M2 Zero Point, Lahore Thokar Niaz Beg, Lahore [RD= 1]

b. Ravi/Babu Sabu Interchange Eastern Exit to Babu Sabu, City center, Chowk Yatim Khana, Lahore Ring Road, Distt. Courts [13]
c. Faiz Pure Interchange Eastern Exit to Shahdra Town and N-5 Western Exit to Sharq Pure, Nankana Sahib and Jardanwala [20]
d. Kot Abdul Malik Interchange [23]
e. Kala Shah Kaku Interchange Eastern Exit to Kala Shah Kaku, Lahore Link Road and N-5 [26]
f. Sheikhupura Interchange Eastern Exit to Gujranwala and N-5 Western Exit to Sheikhupura and Shahkot [45]
g. Khanqah Dogran Interchange Eastern Exit to Hafizabad Western Exit to Khanqah Dogran [82]
h. Sukheki Interchange Eastern Exit to Hafizabad Western Exit to Sukheki [93]
i. Motorway M-3 Pindi Bhattian-Faisalabad Western Exit to Faisalabad [105]
j. Pindi Bhattian Interchange Eastern Exit to Hafizabad, Gujranwala and N-5 Western Exit to Pindi Bhattian, Chiniot and Jhang [107]
k. Makhdoom Interchange Eastern Exit to Gujrat and N-5 Western Exit to Sial More and Sargodha [125]
l. Kot Momin Interchange Eastern Exit to Mela Bhabra [143]
m. Saalam Interchange Eastern Exit to Mandi Bahauddin, Phalia, Gujrat and N-5 Western Exit to Saalam, Bhalwal and Sargodha [175]
n. Bhera Interchange Eastern Exit to Bhera, Malakwal, Sarai Alamgir, Kharian and N-5 Western Exit to Shahpure Saddar and Khaushab [200]
o. Lilla Sharif Interchange Eastern Exit to Pind Dadan Khan, Khewra, Jhelum and N-5 Western Exit to Lilla Sharif, Khaushab [220]
p. Kallar Kahar Interchange Eastern Exit to Chakwal, Choa Saidan Shah, Khewra Salt Mine, Sohawa and N-5 Western Exit to Kallar Kahar, Talagang, Khaushab, Mianwali [248]
q. Balkassar Interchange Eastern Exit to Chakwal, Mandra and N-5 Western Exit to Balkassar, Talagang, Mianwali [282]
r. Chakri Interchange Eastern Exit to Chakri, Rawalpindi and N-5 Western Exit to Pindi Gheb [352]

s. M2-M1 Junction, Islamabad Eastern Exit to Islamabad/Rawalpindi, Islamabad Motorways Link Road, N-5 Western Exit to Gandhara International Airport Road (proposed) [369]

On the next page is a graphical representation of the aforementioned interchanges developed on AutoCAD, along with the weighing stations that have been used there. The types of weigh stations have been mentioned as well.

Table 3-1: Legend/Key for Rendered Depictions

Denotation	**Explanation**
S.B	Southbound
N.B	Northbound
W.S	Weigh Station
■	Weigh Station
●	Interchange

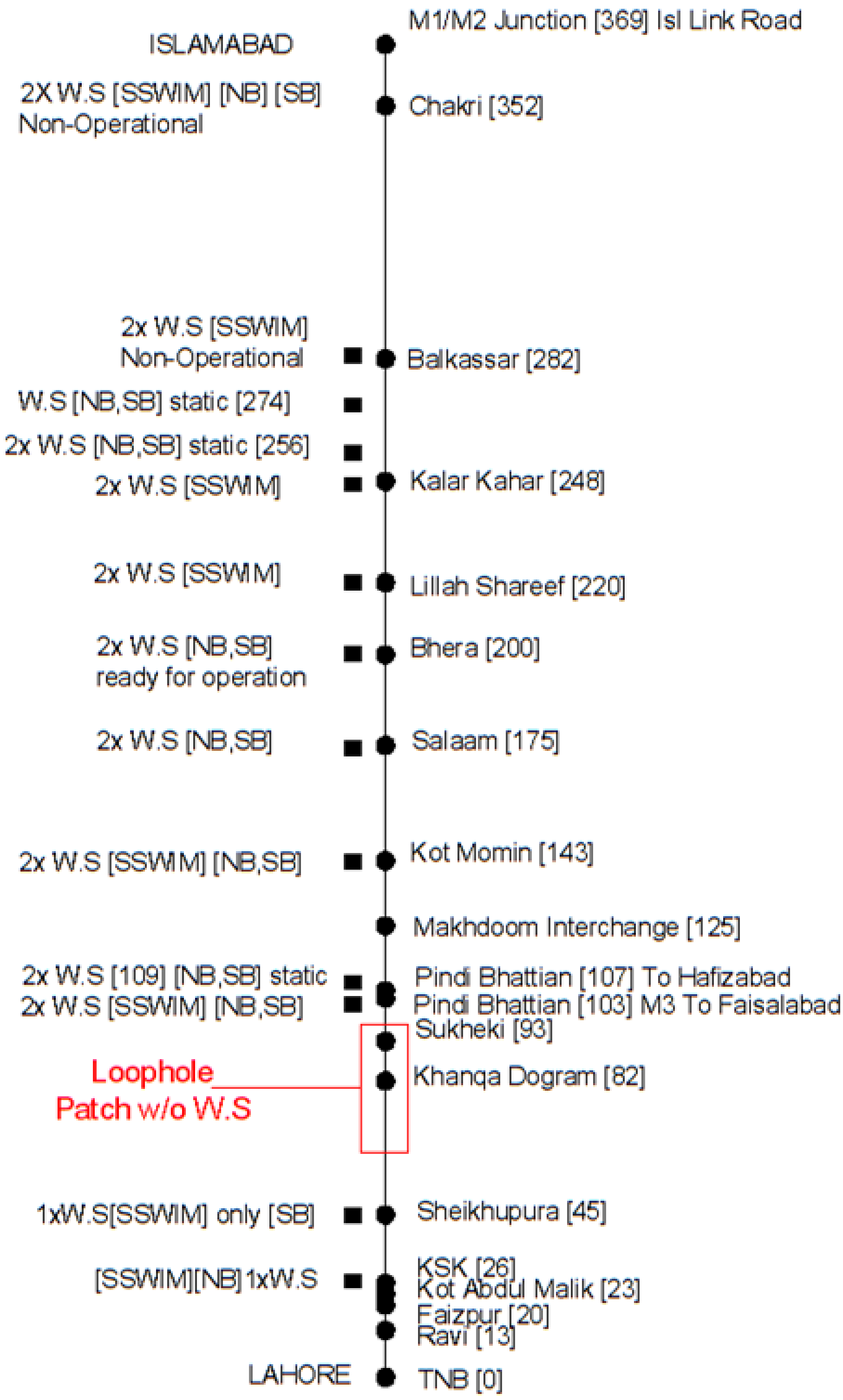


Figure 3-2: Motorway 2 Interchanges & Weighing Stations

3.2.2 Motorway Network, M-1

The M-1 motorway was officially opened up in 2007 by the then President, Pervaiz Musharraf. It is a 155 km long stretch of highway with 67 km in Punjab and 88 km in the province of Khyber Pakhtunkhwa. It has become a vital link to Afghanistan and

Central Asia and is expected to take much traffic off the highly used N5, which happens to be the country's longest highway running from Karachi all the way to the border at Torkham.

M1 begins northeast of Peshawar as it moves in an eastern direction, crossing over the Kabul River. From here it passes through Charsadda, Risalpur, Swabi and Rashakai before crossing the Indus River. It leaves Khyber-Pakhtunkhwa province and enters into Punjab, in which it passes through Attock, Burhan and Hasan Abdal. It ends as the continuation of the M2. The whole stretch of the M1 consists of 6 lanes with a number of rest areas along the route.

Following are the interchange details along the M-2 with their respective Road Distances

Interchanges: [RD's (Road Distances)]

a) Islamabad [0]

b) Fateh Jang [12]

c) Brahma Bahtar [26]

d) Burhan [38]

e) Ghazi [48]

f) Chach [53]

g) Swabi [70]

h) Karnal Sher Khan [90]

i) Rashakai [112]

j) Charsadda [133]

k) Peshawar [155]

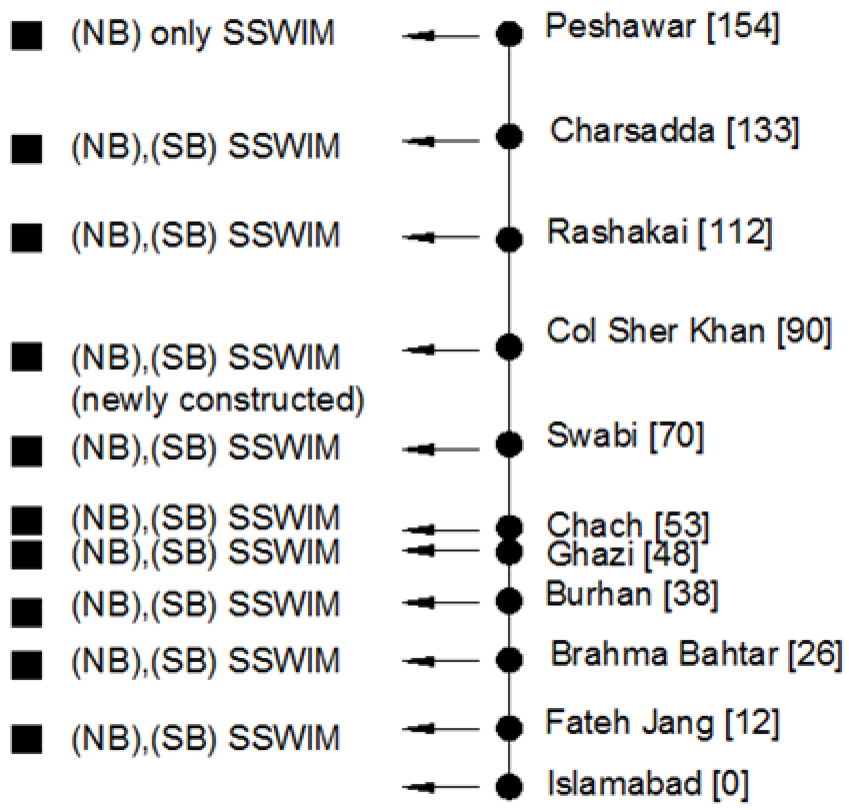


Figure 3-3: Motorway 1 Interchanges & Weighing Stations

3.3 Determining the Existing Framework for Weighing

We had to not only figure out where the weighing devices were set up but also, which type they were of and how they worked. With this information at hand we were able to understand how the whole M-1-M-2 stretch was arranged and prepped to encounter any overloaded vehicles on its pavements.

3.3.1 Types of Weigh Stations

There are currently two types of weighing stations being used on the Motorways with a third type used without credibility. Weigh stations perform the task of weighing the heavy vehicles one axle at a time and are therefore mandatory components in running highways as they take most of their damage due to the overloaded haulage of these vehicles.

1) SSWIM

Figure 3-4: A truck using SSWIM

Slow Speed Weigh-In-Motion: These measure the weight of a vehicle while it is in a relatively slow motion and these are very convenient in their operation. These provide a low cost alternative to traditional static weigh scales. Reduced speed increases the accuracy of the reading, hence the slow speed. All devices on M-1 and most of the weigh devices on M-2 are SSWIM type. A fine example is the LO-TRAC® 300 system by TDC.

2) Static

Figure 3-5: A truck using STATIC weight sensor

Static sensors are those placed on the road at the interchange entry/exit points. These are, as the name implies, stationary and require the vehicle to be immobile at a podium in order for the weight to be measured. They are not used on the M-1 and are lesser in amount on the M-2.

3) Local-Mobile Weigh Stations

These are the itinerant weigh stations operated by third party contractors and consist of a moveable arrangement of apparatus with which a vehicle is weighed. The NHA does not keep a record of these are these are not used in any official capacity. Therefore, these will be overlooked in our area of study.

3.3.2 M-2

The arrangement of the interchanges and weighing stations is as shown below:

Table 3-2: Weigh Stations & their types on M-2

S.NO	WEIGH STATION	TYPE	AMOUNT	REMARKS
1	Islamabad link Road (SB)			Operational
2	Chakri (NB)	SSWIM		Operational
3	KM-274 (NB)	STATIC		Operational
4	KM-274 (SB)	STATIC		Operational
5	KM-256 (NB)	STATIC		Operational
6	KM-256 (SB)	STATIC		Operational
7	Kalar Kahar (SB)	SSWIM		Operational
8	Lillah (NB)	SSWIM		Operational
9	Lillah (SB)	SSWIM		Operational
10	Salim (NB)	SSWIM	19	Operational
11	Salim (SB)	SSWIM		Operational
12	Kot Momin (NB)	SSWIM		Operational
13	Kot Momin (SB)	SSWIM		Operational
14	P Bhattian (NB)	SSWIM		Operational
15	P Bhattian (SB)	SSWIM		Operational
16	KM-109 (NB)	STATIC		Operational
17	KM-109 (SB)	STATIC		Operational
18	Sheikhupura (SB)	SSWIM		Operational
19	Kala Shah Kaku link Road (NB)	SSWIM		Operational
20	Kalar Kahar (NB)	SSWIM		Civil works complete
21	Bherra (NB)	SSWIM	3	Weigh equipment is
22	Bherra (SB)	SSWIM		installed and ready for use
23	Balkasar (NB)	SSWIM		Civil works complete
24	Balkasar (SB)	SSWIM	3	Installation of equipment
25	Chakri (SB)	SSWIM		required

3.3.3 M-1

For the M-1 the details are shown in the table below.

Table 3-3: Weigh Stations & their types on M-1

S.NO	WEIGH STATION	TYPE	AMOUNT	REMARKS
1	**Chech I/C(NB)**	**SSWIM**	21	Operational
2	Chech I/C(SB)	SSWIM		Operational
3	Ghazi I/C(NB)	SSWIM		Operational
4	Ghazi I/C(SB)	SSWIM		Operational
5	Swabi I/C(NB)	SSWIM		Operational
6	Swabi I/C(SB)	SSWIM		Operational
7	Rashakai I/C(NB)	SSWIM		Operational
8	Rashakai I/C(SB)	SSWIM		Operational
9	Charsadda I/C(NB)	SSWIM		Operational
10	Charsadda I/C(SB)	SSWIM		Operational
11	Fateh Jung/Ternol I/C(NB)	SSWIM		Operational
12	Fateh Jung/Ternol I/C(SB)	SSWIM		Operational
13	Brahma Bhatar I/C(NB)	SSWIM		Operational
14	Brahma Bhatar I/C(SB)	SSWIM		Operational
15	Burhan I/C(NB)	SSWIM		Operational
16	Burhan I/C(SB)	SSWIM		Operational
17	Col. Sher Khan(NB)	SSWIM		Newly Constructed
18	Col. Sher Khan(SB)	SSWIM		
19	Wali Khan(SB)	SSWIM		
20	Wali Khan(NB)	SSWIM		
21	Peshawar Entry(SB)	SSWIM		Operational

3.4 Analyzing the Existing Weight Limitations

We had to get the official weight limitations for each category of vehicles to base our study on. The maximum allowable load was ascertained for each Truck Type.

The details so obtained from the NHA included values of the existing limits of overloading on said truck types. Obtained from a report titled "*Effects of Variation in Truck Factor on Pavement Performance in Pakistan*" Chaudry R., Memon A. (2011), the following image includes the load limitations and the permissible gross weight of the vehicles in tons.

TRUCK TYPE	Permissible Gross Vehicles Weight (in Tons)
2 AX SINGLE (Bedford)	17.5
2 AX SINGLE (Hino/Nissan)	17.5
3 AX TENDEM	27.5
3 AX SINGLE	29.5
4 AX SIGNLE-TENDEM	39.5
4 AX TENDEM-SINGLE	39.5
4 AX SINGLE	41.5
5 AX SINGLE-TRIDEM	48.5
5 AX TENDEM-TENDEM	49.5
5 AX SINGLE-SINGLE-TENDEM	51.5
5 AX TENDEM-SINGLE-SINGLE	51.5
6 AX TENDEM-TRRIDEM	58.5
6 AX TENDEM-SINGLE-TENBDEM	61.5

Axle Load Limits			
Single Axle =	12 Tons	Tridem Axle =	31 Tons
Tandem Axle =	22 Tons	Front Axle =	5.5 Tons

Tire Pressure	
Rear Axle =	120 psi
Front Axle =	100 psi

Figure 3-6: Allowable Load Limits & Truck Configuration in Pakistan

3.5 Analyzing the Existing Rates of Toll Tax and Fine Collection

The amount of tax and fines applied on the motorways needed to be considered first, as the basis of our study is on the formation of a more accurate rate of toll based on the damage caused by a specific heavy vehicle to the road. The figures we were able to obtain from the authorities included toll taxes on the aforementioned categories of trucks. It showed a rather stern level of flexibility with little variation of loading conditions and inculcated only three loading scenarios for overweight trucks with a specified ceiling load after the three overloading cases. The table on the next page was obtained from the NHA Head Office at G-9, Islamabad and it details the appropriate fines and ceiling loads of various truck types and weight categories.

Table 3-4: NHA Fine Rates& Load Limits (NHA Head Office, G-9)

Vehicle Category	Allowed Weight Limit = 17500 KG	Fine Rates (Rs.)
2 Ax	17501 KG - 18375 KG	1000/-
	18376 KG - 19250 KG	2500/-
	19251 KG - 20125 KG	5000/-
	Above 20125 KG is NOT ALLOWED	
3 Ax Tandem	**Allowed Weight Limit = 27500 KG**	
	27501 KG - 28875 KG	1000/-
	28876 KG - 30250 KG	2500/-
	30251 KG - 31625 KG	5000/-
	Above 31625 KG is NOT ALLOWED	
3 Ax Single	**Allowed Weight Limit = 29500 KG**	
	29501 KG - 30975 KG	1000/-
	30976 KG - 32450 KG	2500/-
	32451 KG - 33925 KG	5000/-
	Above 33925 KG is NOT ALLOWED	
4 Ax Single-Tandem	**Allowed Weight Limit = 39500 KG**	
	39501 KG - 41475 KG	1000/-
	41476 KG - 43450 KG	2500/-
	43451 KG - 45425 KG	5000/-
	Above 45425 KG is NOT ALLOWED	
4 Ax Single-Single	**Allowed Weight Limit = 41500 KG**	
	41501 KG - 43575 KG	1000/-
	43576 KG - 45650 KG	2500/-
	45651 KG - 47725 KG	5000/-
	Above 47725 KG is NOT ALLOWED	
5 Ax Single-Tridem	**Allowed Weight Limit = 48500 KG**	
	48501 KG - 50925 KG	1000/-
	50926 KG - 54450 KG	2500/-
	54451 KG - 56925 KG	5000/-
	Above 56925 KG is NOT ALLOWED	
5 Ax Tandem-Tandem	**Allowed Weight Limit = 49500 KG**	
	49501 KG - 51975 KG	1000/-
	51976 KG - 54450 KG	2500/-
	54451 KG - 56925 KG	5000/-
	Above 56925 KG is NOT ALLOWED	
5 Ax Single-Single-Tandem	**Allowed Weight Limit = 51500 KG**	
	51501 KG - 54075 KG	1000/-
	54076 KG - 56650 KG	2500/-
	56651 KG - 59225 KG	5000/-
	Above 59225 KG is NOT ALLOWED	
6 Ax Tandem-Tridem	**Allowed Weight Limit = 58500 KG**	
	58501 KG - 61425 KG	1000/-
	61426 KG - 64350 KG	2500/-
	64351 KG - 67275 KG	5000/-
	Above 67275 KG is NOT ALLOWED	
6 Ax Tandem-Single-Tandem	**Allowed Weight Limit = 61500 KG**	
	61501 KG - 64575 KG	1000/-
	64576 KG - 67650 KG	2500/-
	67651 KG - 70725 KG	5000/-
	Above 70725 KG is NOT ALLOWED	

3.6 Determining any Loopholes Inside the Existing Framework

The existing outlay of the weigh in stations had encompassed much of the entry/exit points on the motorways. However, once we had detailed results about the whereabouts and nature of the weighing apparatus placed, we could determine any soft-spots or weaknesses in the outlay. This, helped us mark the weaknesses in the existing system and henceforth gave drive to our recommendations.

After having ascertained the details of the interchanges and the corresponding weigh stations on both the M-1 and the M-2, we ported them to a graphic representation for better understanding and loophole demarcation, if any.

3.7 Formulation of Framework Based on Varying Overloading Amount

Lastly, we are to create a framework which gives us the expected damage to the pavement by an overloading of so-and-so units of weight. We will use the *Generalized Fourth Power Law* to compute this. For simplicity of the study and expanse of the analysis, we will use the Truck Traffic Spectra as per the NHA statistics obtained from "*Axle Load Control - Over Loading*" on the NHA website for the truck traffic percentage, the truck type percentage and the overweight haulage percentage.

Table 3-5: Truck Type Spectra ("Axle Load Control" www.nha.gov.pk/)

Type	Numbers	Percentage
Two Axle	53864	70
Three Axle	16805	21.5
Three Axle Trailer	944	1.2
Four Axle	5076	6.5
Five & Six Axle	1503	1.92
Total	78192	100

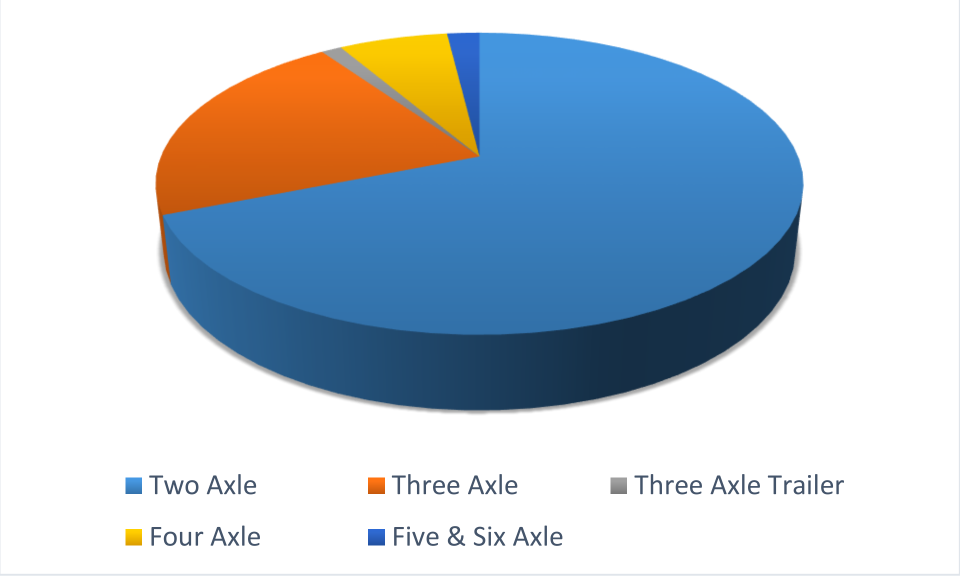


Figure 3-7: Composition of Trucks by Axle Configuration ("Axle Load Control" www.nha.gov.pk/)

3.8 Proposal of New Weigh Station

After having finalized the new toll rates, we will propose new weighing stations in the loopholes that exist in the working network. These would be either SSWIM or STATIC depending on their requirement, their periphery and lastly the budget that the toll would assimilate. The budget so earned is from a specific portion of vehicle loading conditions with the occurrence percentages of the different truck types used from the NHA's vehicle spectra. The specified percentages of the overweight categories were estimated however and can be manually changed within the framework we are to design. Again, we were able to obtain the percentages for overweight vehicles among all classes of trucks through a report titled *"Road Freight Strategy Paper"* by the Engineering Development Board of the Government of Pakistan. Below is the excerpt from the report:

"*4.4 Overloading: The illegal modification of trucks in the back street markets, low freight rates due to unhealthy competition and prevalence of ineffective vehicle examination system in the country encourages overloading which damages the roads and cause accidents. According to an estimate, 70% of the 2, 3 axle trucks are overloaded while 40% of 4, 5, and 6 axle trucks are overloaded.****"***

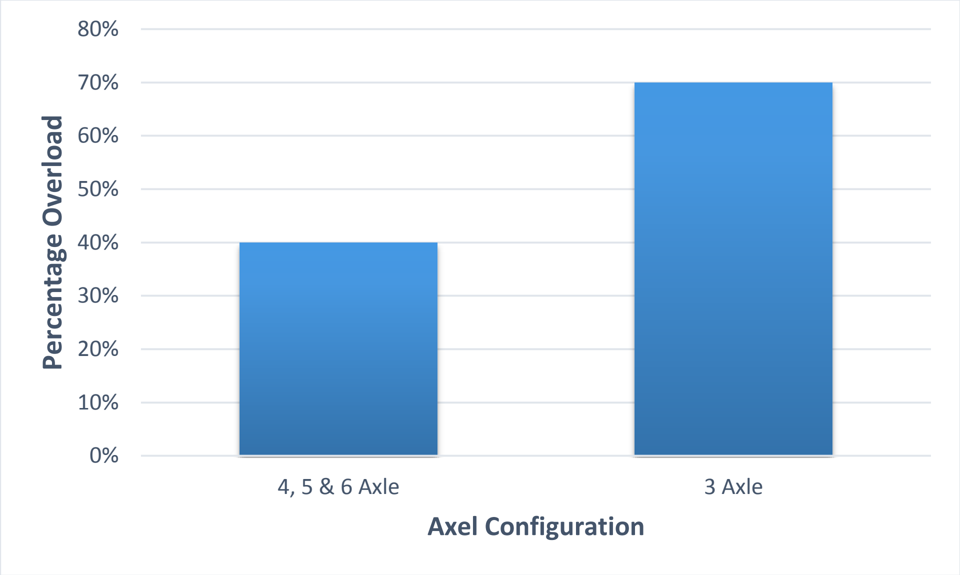


Figure 3-8: Overloading Percentages of Truck Types (Road Freight Strategy Paper, EDB 2006)

3.9 Figuring the Time for Revenue Generation for Weigh Station Installation

Once, the proposed systems are said to have been finalized, we will work out how much time they will require after installation to break-even the initial investment. This time would be beneficial in understanding when can the investment become self-sufficient after initiation. This would be constructive for any future use by the motorway authorities, if need be.

The way we will find this point out is by firstly, evaluating how much excess revenue our system of toll rates produces for a given amount of annual truck traffic passing over the motorways. As mentioned before, the figures used for the truck traffic, truck type percentages and the overweight percentages will be as per reports published of reliable sources. As our framework is made to be flexible, these values are used to show the practicality of the proposed system and most of the details can be adjusted. Then, we will calculate how much toll is generated when the same truck traffic stream passes through the motorways by the existing NHA toll rates and fines. The difference of the two will be either the surplus or the deficit between our proposed toll rate and the existing NHA toll rate. If a surplus results, which should in theory be the case, we will use that surplus amount to install weighing stations if need be. For that, we will simply divide the cost of a weighing station by the surplus amount generated, which will give us the time for resource generation for the proposed weigh station.

Therefore, we will calculate the breakeven point for a specific case of the aforementioned details.

3.10 Summary

In this chapter, we covered the procedure of our approach to alleviate a known issue described in the first chapter. A step by step enumeration of parts of our effort were expounded on. Starting from the data collection phase at the very start, which included collection of the various types of figures and facts which will be used in the formulation of the framework. Following the data collection, analysis of the existing system was done with focus on the infrastructure that is already in place and the resources that are used to expedite the toll tax on the users. After which, the existing rates of toll and the fines on overweight truck vehicles were discussed as per the NHA standards. With the relevant information on toll taxes of different vehicles, we then proceed to find any loopholes in the system of weigh stations and find our probable location for a weigh station, if need be. Then, we discussed how we would obtain the truck traffic stream data from various credible sources for overloading vehicle percentages, truck types, truck type percentages and other crucial variables. Finally, we highlighted how we would obtain the revenue generated by our framework in contrast to the already existing rates of toll by using the same traffic stream data and evaluating the difference. With this difference and a proposed site for a weighing station we would finally be able to find out how much time the new toll system would need to balance out the investment for the new proposed weigh station. This would yield the point in time when the proposed weigh station could be made by surplus funds accumulated from the proposed toll rates.

Chapter 4

DEVELOPMENT OF FRAMEWORK FOR TOLL TAX

4.1 Concept of the Design

The framework solution we wish to make for toll collection of the heavy vehicles based on toll as per their respective damage factors is at its core a software solution. This will be based on MS Excel 2013 and will be used to calculate the exact amount of toll a specific truck type with a specific loading will pay and it would also compute the exact amount of toll which would be collected over a year, provided that the truck type and traffic percentages are known. At its base, the solution will have tables representing values and an input section for distance computation.

All in all, the entire system is made to assist a toll booth operator on the field so that he may be able to correctly compute the toll tax which is inherently based on the Generalized Fourth Power Law. For this endeavor, it was our effort to make it as user friendly and simple to understand as possible. Also, the said framework that we will produce will be easily editable or upgradable, meaning that any future inclusions or exclusions can be effectively incorporated.

4.2 Operational Objectives

The framework that we wish to make will successfully attain the following goals:

- Computation of Road Distances for a trip along the motorway
- Calculation of the LEF or Load Equivalence Factor for a said condition of overloading or a specific truck
- Evaluation of toll for a specified truck type, undergoing a specific overloading category
- Evaluation of toll tax for a complete year or month or day for a given percentage of specific truck types, and their respective overloading categories

4.3 Hierarchical Correlation

The entire software suite consists of four components which work in tandem to accomplish the display of the working and analysis of the data. The four components are as follows:

a. Load Equivalence Factor Calculator

b. Route Distance Calculator

c. Toll Calculator

d. Framework for Extrapolation

a. Load Equivalence Factor Calculator

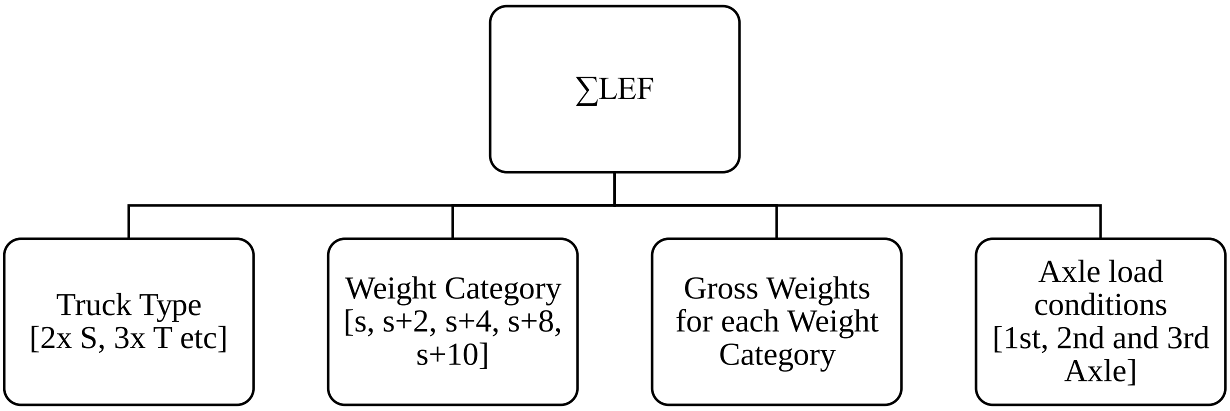


Figure 4-1: Hierarchical Depiction of LEF Calculator

b. Route Distance Calculator

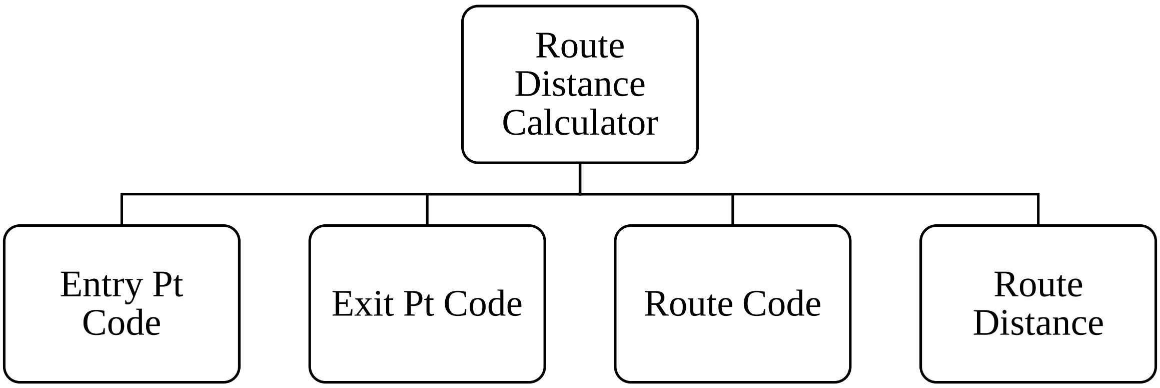


Figure 4-2: Hierarchical Depiction of Route Distance Calculator

c. Toll Calculator

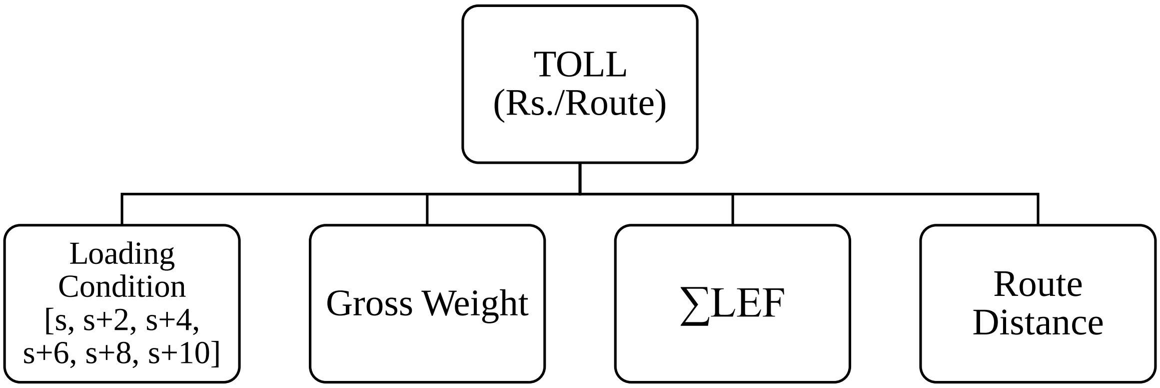


Figure 4-3: Hierarchical Depiction of Toll Calculator

d. Framework for Extrapolation

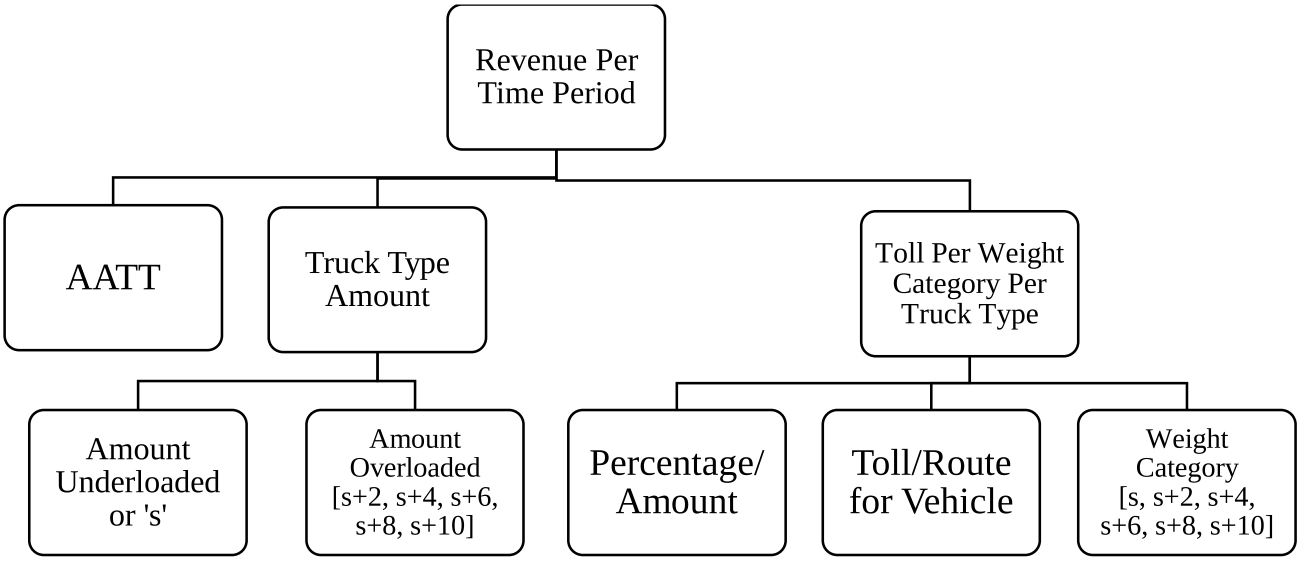


Figure 4-4: Hierarchical Depiction of Framework For Extrapolation

e. Component Process Relationships

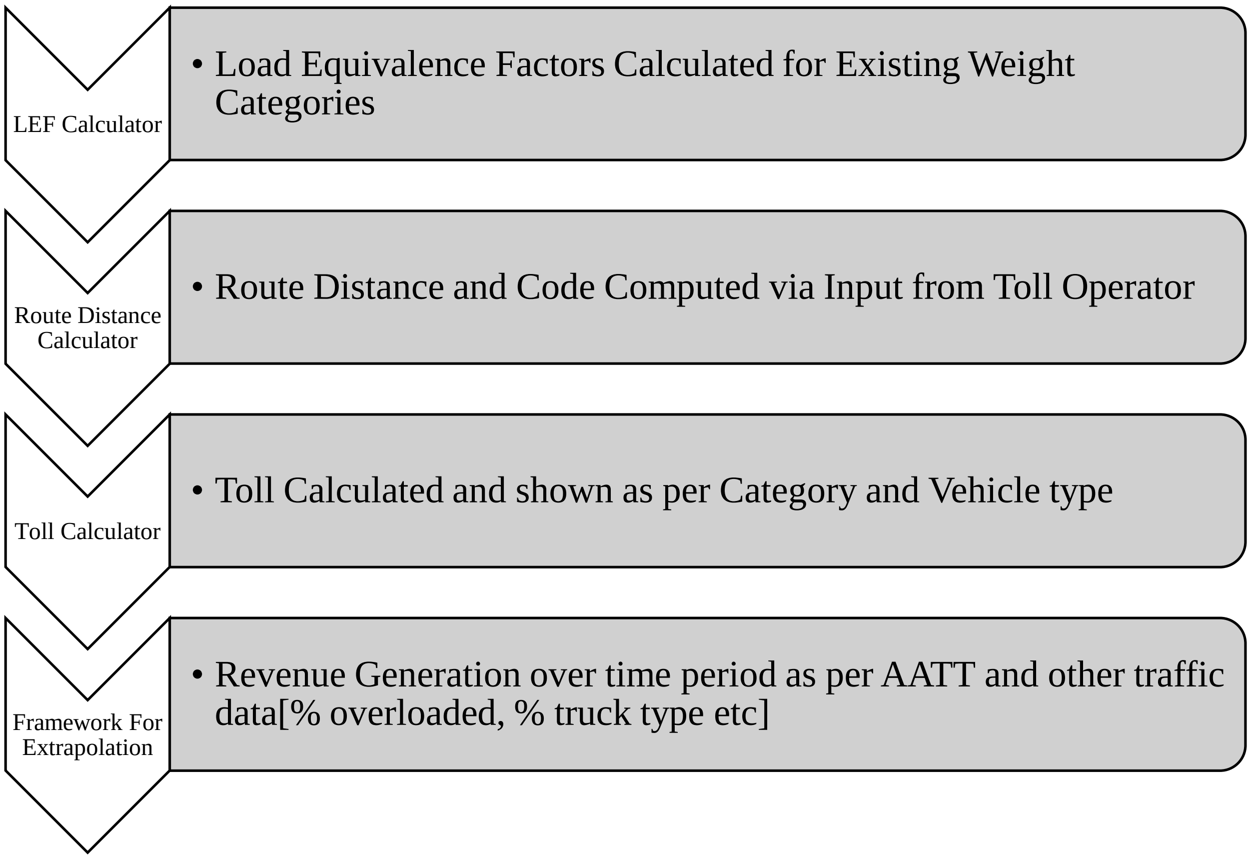


Figure 4-5: Component Stages & Processes

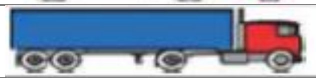
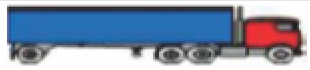
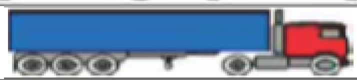
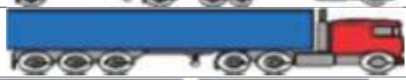
4.4 LEF Calculator

At the base of our framework lies the fourth power law which states that the pavement deterioration is actually the fourth power of the ratio of the loading of the standard axle to the overloaded axle. The usage of this law to assess pavement damage is owing to the fact that the practical results which support this preposition are pretty strong. In fact, in some studies, the relationship has been known to rise to the fifth or sixth power. But, generally the Generalized Fourth Power Law is accepted by all as it is time tested and pragmatically proven under the AASHTO banner.

4.4.1 Weight Categories and Loading Conditions

We will be incorporating the thirteen types of truck as per NHSO. They will be used as:

Table 4-1: Truck Types & Axle Configurations (NHA Head Office, G-9)

Truck Type	Axle Configuration	Depiction
2x S	2 Axle Single (Bedford)	
2x S	2 Axle Single (Hino/Nissan)	
3x T	3 Axle Tandem	
3x S	3 Axle Single	
4x S-T	4 Axle Single-Tandem	
4x T-S	4 Axle Tandem-Single	
4x S	4 Axle Single	
5x S-Tr	5 Axle Single-Tridem	
5x T-T	5 Axle Tandem-Tandem	
5x S-S-T	5 Axle Single-Single-Tandem	
5x T-S-S	5 Axle Tandem-Single-Single	
6x T-Tr	6 Axle Tandem-Tridem	
6x T-S-T	6 Axle Tandem-Single-Tandem	

Five types of overloading scenarios will be taken into account. Starting from the standard axle load denoted by an ‘s’ to increments of 2 ton all the way till ‘s+10’. This means that a total of six overweight categories were formulated. The first three green columns show, the first axle load weight, the second axle load weight and the third axle load weight correspondingly. They are all summed up and a front axle load of 5.5 tons for the front axle is added to it to come up with the gross weight or GW for a specific truck type under the specified loading condition: i.e. ‘s’ or at standard.

The following tables illustrate part of the LEF calculator which deals with the Loading Conditions and GW (Gross Weight) computation.

In the table below, a standard axle weight condition is being shown for the types of trucks with the weights on each axle of the trucks (1^{st}, 2^{nd} or 3^{rd}) displayed and the gross weight (GW) of the truck shown in the last column.

Table 4-2: LEF Calculator Loading Conditions-1

Truck Type	Permissible GW	s			
		1st	2nd	3rd	GW
2x S	17.5	12	0	0	17.5
2x S	17.5	12	0	0	17.5
3x T	27.5	22	0	0	27.5
3x S	29.5	12	12	0	29.5
4x S-T	39.5	12	22	0	39.5
4x T-S	39.5	22	12	0	39.5
4x S	41.5	12	12	12	41.5
5x S-Tr	48.5	12	31	0	48.5
5x T-T	49.5	22	22	0	49.5
5x S-S-T	51.5	12	12	22	51.5
5x T-S-S	51.5	22	12	12	51.5
6x T-Tr	58.5	22	31	0	58.5
6x T-S-T	61.5	22	12	22	61.5

As such, the following construct was made for all loading conditions:

Depictions of the ‘s+2’ and ‘s+4’ configurations with the ‘s’ columns hid.

Table 4-3: LEF Calculator Loading Conditions-2

Truck Type	Permissible GW	s+2				s+4			
		1st	2nd	3rd	GW	1st	2nd	3rd	GW
2x S	17.5	14	0	0	19.5	16	0	0	21.5
2x S	17.5	14	0	0	19.5	16	0	0	21.5
3x T	27.5	24	0	0	29.5	26	0	0	31.5
3x S	29.5	14	14	0	33.5	16	16	0	37.5
4x S-T	39.5	14	24	0	43.5	16	26	0	47.5
4x T-S	39.5	24	14	0	43.5	26	16	0	47.5
4x S	41.5	14	14	14	47.5	16	16	16	53.5
5x S-Tr	48.5	14	33	0	52.5	16	35	0	56.5
5x T-T	49.5	24	24	0	53.5	26	26	0	57.5
5x S-S-T	51.5	14	14	24	57.5	16	16	26	63.5
5x T-S-S	51.5	24	14	14	57.5	26	16	16	63.5
6x T-Tr	58.5	24	33	0	62.5	26	35	0	66.5
6x T-S-T	61.5	24	14	24	67.5	26	16	26	73.5

Depictions of the ‘s+6’ and ‘s+8’ configurations with the ‘s’, ‘s+2’ and ‘s+4’ columns hidden.

Table 4-4: LEF Calculator Loading Conditions-3

Truck Type	Permissible GW	s+6				s+8			
		1st	2nd	3rd	GW	1st	2nd	3rd	GW
2x S	17.5	18	0	0	23.5	20	0	0	25.5
2x S	17.5	18	0	0	23.5	20	0	0	25.5
3x T	27.5	28	0	0	33.5	30	0	0	35.5
3x S	29.5	18	18	0	41.5	20	20	0	45.5
4x S-T	39.5	18	28	0	51.5	20	30	0	55.5
4x T-S	39.5	28	18	0	51.5	30	20	0	55.5
4x S	41.5	18	18	18	59.5	20	20	20	65.5
5x S-Tr	48.5	18	37	0	60.5	20	39	0	64.5
5x T-T	49.5	28	28	0	61.5	30	30	0	65.5
5x S-S-T	51.5	18	18	28	69.5	20	20	30	75.5
5x T-S-S	51.5	28	18	18	69.5	30	20	20	75.5
6x T-Tr	58.5	28	37	0	70.5	30	39	0	74.5
6x T-S-T	61.5	28	18	28	79.5	30	20	30	85.5

Depictions of the ‘s+10’ configuration with the other configurations hidden.

Table 4-5: LEF Calculator Loading Conditions-4

Truck Type	Permissible GW	s+10			
		1st	2nd	3rd	GW
2x S	17.5	22	0	0	27.5
2x S	17.5	22	0	0	27.5
3x T	27.5	32	0	0	37.5
3x S	29.5	22	22	0	49.5
4x S-T	39.5	22	32	0	59.5
4x T-S	39.5	32	22	0	59.5
4x S	41.5	22	22	22	71.5
5x S-Tr	48.5	22	41	0	68.5
5x T-T	49.5	32	32	0	69.5
5x S-S-T	51.5	22	22	32	81.5
5x T-S-S	51.5	32	22	22	81.5
6x T-Tr	58.5	32	41	0	78.5
6x T-S-T	61.5	32	22	32	91.5

4.4.2 Load Equivalence Factor

The load equivalence factor is computed for each truck type with a specific loading condition. Again, we will use the same six loading conditions used previously to compute the Gross Weights or GW. The LEF evaluated for all truck types of the standard or ‘s’ loading condition is shown as follows:

Table 4-6: LEF Calculator-1

Truck Type	Permissible GW	s			
		1st	2nd	3rd	∑LEF
2x S	17.5	1.00	0.00	0.00	1.00
2x S	17.5	1.00	0.00	0.00	1.00
3x T	27.5	1.00	0.00	0.00	1.00
3x S	29.5	1.00	1.00	0.00	2.00
4x S-T	39.5	1.00	1.00	0.00	2.00
4x T-S	39.5	1.00	1.00	0.00	2.00
4x S	41.5	1.00	1.00	1.00	3.00
5x S-Tr	48.5	1.00	1.00	0.00	2.00
5x T-T	49.5	1.00	1.00	0.00	2.00
5x S-S-T	51.5	1.00	1.00	1.00	3.00
5x T-S-S	51.5	1.00	1.00	1.00	3.00
6x T-Tr	58.5	1.00	1.00	0.00	2.00
6x T-S-T	61.5	1.00	1.00	1.00	3.00

Here, the LEF is found out for each axle, the 1^{st}, 2^{nd} and 3^{rd} axles respectively. It is done so by dividing the weight of the concerned axle with the weight of its standard and raising the answer to the fourth power. Naturally this means that a standard loaded axle will have an LEF of 1 as can be seen in all cases for the standard or ‘s’ loading condition. In the last column, the sum of all the axle’s LEFs is added together to show the **∑LEF** of the configuration for each truck type. The LEF is calculated as:

LEF = (standard axle load/axle load for specific condition)^4

Next, we move to the ‘s+2’ and ‘s+4’ categories with the ‘s’ category hidden for convenience.

Table 4-7: LEF Calculator-2

Truck Type	Permissible GW	s+2				s+4			
		1st	2nd	3rd	∑LEF	1st	2nd	3rd	∑LEF
2x S	17.5	1.85	0.00	0.00	1.85	3.16	0.00	0.00	3.16
2x S	17.5	1.85	0.00	0.00	1.85	3.16	0.00	0.00	3.16
3x T	27.5	1.42	0.00	0.00	1.42	1.95	0.00	0.00	1.95
3x S	29.5	1.85	1.85	0.00	3.71	3.16	3.16	0.00	6.32
4x S-T	39.5	1.85	1.42	0.00	3.27	3.16	1.95	0.00	5.11
4x T-S	39.5	1.42	1.85	0.00	3.27	1.95	3.16	0.00	5.11
4x S	41.5	1.85	1.85	1.85	5.56	3.16	3.16	3.16	9.48
5x S-Tr	48.5	1.85	1.28	0.00	3.14	3.16	1.62	0.00	4.79
5x T-T	49.5	1.42	1.42	0.00	2.83	1.95	1.95	0.00	3.90
5x S-S-T	51.5	1.85	1.85	1.42	5.12	3.16	3.16	1.95	8.27
5x T-S-S	51.5	1.42	1.85	1.85	5.12	1.95	3.16	3.16	8.27
6x T-Tr	58.5	1.42	1.28	0.00	2.70	1.95	1.62	0.00	3.58
6x T-S-T	61.5	1.42	1.85	1.42	4.69	1.95	3.16	1.95	7.06

Next, we move to the 's+6' and 's+8' categories with the 's', 's+2' and 's+4' categories hidden for convenience.

Table 4-8: LEF Calculator-3

Truck Type	Permissible GW	s+6				s+8			
		1st	2nd	3rd	∑LEF	1st	2nd	3rd	∑LEF
2x S	17.5	5.06	0.00	0.00	5.06	7.72	0.00	0.00	7.72
2x S	17.5	5.06	0.00	0.00	5.06	7.72	0.00	0.00	7.72
3x T	27.5	2.62	0.00	0.00	2.62	3.46	0.00	0.00	3.46
3x S	29.5	5.06	5.06	0.00	10.13	7.72	7.72	0.00	15.43
4x S-T	39.5	5.06	2.62	0.00	7.69	7.72	3.46	0.00	11.17
4x T-S	39.5	2.62	5.06	0.00	7.69	3.46	7.72	0.00	11.17
4x S	41.5	5.06	5.06	5.06	15.19	7.72	7.72	7.72	23.15
5x S-Tr	48.5	5.06	2.03	0.00	7.09	7.72	2.51	0.00	10.22
5x T-T	49.5	2.62	2.62	0.00	5.25	3.46	3.46	0.00	6.92
5x S-S-T	51.5	5.06	5.06	2.62	12.75	7.72	7.72	3.46	18.89
5x T-S-S	51.5	2.62	5.06	5.06	12.75	3.46	7.72	7.72	18.89
6x T-Tr	58.5	2.62	2.03	0.00	4.65	3.46	2.51	0.00	5.96
6x T-S-T	61.5	2.62	5.06	2.62	10.31	3.46	7.72	3.46	14.63

Finally, we move to the ‘s+10’category with the other categories hidden for convenience.

Table 4-9: LEF Calculator-4

Truck Type	Permissible GW	s+10			
		1st	2nd	3rd	∑LEF
2x S	17.5	11.30	0.00	0.00	11.30
2x S	17.5	11.30	0.00	0.00	11.30
3x T	27.5	4.48	0.00	0.00	4.48
3x S	29.5	11.30	11.30	0.00	22.59
4x S-T	39.5	11.30	4.48	0.00	15.77
4x T-S	39.5	4.48	11.30	0.00	15.77
4x S	41.5	11.30	11.30	11.30	33.89
5x S-Tr	48.5	11.30	3.06	0.00	14.36
5x T-T	49.5	4.48	4.48	0.00	8.95
5x S-S-T	51.5	11.30	11.30	4.48	27.07
5x T-S-S	51.5	4.48	11.30	11.30	27.07
6x T-Tr	58.5	4.48	3.06	0.00	7.54
6x T-S-T	61.5	4.48	11.30	4.48	20.25

It can be clearly observed that the LEF changes exponentially with the increase in loading conditions and it affects different truck types differently.

These LEF’s contribute to the vital essence of toll rate establishment for our project since they depict the relationship between the overloading category and the truck type. As such, this relationship will be critical and form the backbone of our introduced toll rate as we will see in the following stages.

4.5 Route Distance Calculator

Since our toll tax depends on the route and is evaluated on the basis of toll per distance, it is imperative that the distance be first calculated for a trip. The distance depends on where the truck enters and exits the framework of existing interchanges. This means that the entry and exit points define the distance of the trip or route traversed by the vehicle. So, in order to find the distance we need to quantify the interchanges, and to do that, we must first code them and attach respective RD’s (Road Distances) to them, as can be seen the following tables:

M-2		
RD	**Interchange**	**Code**
0	Thokar Niaz Baig	TNB
13	Ravi	RAV
20	Faizpur	FZP
23	Kot Abdul Malik	KAM
26	Kala Shah Kaku	KSK
45	Sheikhupura	SHK
82	Khanqa Dogran	KHD
93	Sukheki	SKI
105	Pindi Bhattian [To Faisalabad]	PBF
107	Pindi Bhattian [To Hafizabad]	PBH
125	Makhdoom Interchange	MKD
143	Kot Momin	KMN
175	Salaam	SLM
200	Bhera	BHR
220	Lillah Shareef	LIS
248	Kalar Kahar	KKR
282	Balkasar	BLR
352	Chakri	CRI
369	M1/M2 Junction	MMJ

M-1			
RDs	**CRD**	**Interchange**	**Code**
0	369	Islamabad	ISL
12	381	Fateh Jang	FTJ
26	395	Brahma Bahtar	BRB
38	407	Burhan	BUR
48	417	Ghazi	GHZ
53	422	Chach	CCH
70	439	Swabi	SWB
90	459	Karnal Sher Khan	KSK
112	481	Rashakai	RSK
133	502	Charsadda	CHR
155	524	Peshawar	PSW

Figure 4-6: Codes of Interchanges on M-2 & M-1

The RD's or Road Distances of each interchange let the user know where these are placed in terms of distance from a specific point. In our approach, we have specified TNB or Thokar Niaz Baig Interchange as RD 0. Also, for M-1 the interchanges have CRD's or Combined Road Distances which show the exact location of the interchanges with respect to RD 0 at TNB. This has been done to compute the distance accordingly. And is pivotal in providing flow to the computation of distances regardless of which stretch of motorway the vehicle uses.

The user can also adjust the Price Per Km for two broad categories as defined by the NHA. This function is called the Price Per Km Adjustment Function. These prices will be applied to the respective categories. Following this, the user can look up the code for the interchanges to be used and put them in the distance calculator shown:

	Route		
	Entry Point	**Exit Point**	**Distance**
CODE	TNB	MMJ	TNB - MMJ
RD	0	369	369

Figure 4-7: Route Distance Calculator

2 Ax & 3 Ax			Articulated (4, 5 & 6 Ax)	
Rs. Per Km	Rs. [0]-[369]		**Rs. Per Km**	Rs. [0]-[369]
2.47	910		**3.17**	1170

Figure 4-8: Price Per Km Adjustment Function

The user needs to input the codes for the entry and exits points. This will fetch their respective RD's from the previous tables. Also, a route code will be generated under the green column labeled 'Distance'. Then, the distance will be calculated as the absolute value of the difference between the Entry Pt RD and the Exit Pt RD.

Route Distance = ABS(Entry Pt RD – Exit Pt RD)

After the Route Distance Calculator is the *Price Per Km Adjustment Function*. It is table for Rs. Per Km charges for two categories; one for two and three axle trucks and the other for four axle and above articulated trucks and over a specific route. The way this has been found out is that the existing toll prices for both the categories has been found for a route between TNB [RD=0] and MMJ [RD=369] from the official toll rates found on the NHA website. The tables for each category are in APPENDIX A and APPENDIX B respectively.

With this, the toll tax per route will vary, as we will see in the next few steps. Since our toll is one of direct relation between the damage caused to a pavement and money paid for its use, it is imperative to incorporate the essential variables such as route length and the LEF or damage factor.

4.6 Toll Calculator

Now, after the working of the LEF has been done, the linkage between the route and the LEF has to be made in order to produce the figures for the appropriate toll rates. To accomplish this, we had to make a table based on the specific loading condition and truck type. From this, the desired toll would be looked up by the operator. However, this toll would be calculated as per the distance calculated in the route distance calculator in the previous section and such the following construct was made for the 2 axle – single type trucks:

Table 4-10: Toll Calculator-1

	2 Axle Single		
	GW (ton)	**DF / LEF**	**TOLL (Rs/Route)**
s*	17.5	1.00	247
s+2	19.5	1.85	458
s+4	21.5	3.16	781
s+6	23.5	5.06	1252
s+8	25.5	7.72	1908
s+10	27.5	11.30	2793

**S is standard*

In this, the GW or gross weight has been retrieved from the gross weight tables of the specified loading conditions. The DF/LEF represents the accumulated damage factor/load equivalence factor for the specified truck type and its loading condition. Here, the LEF is fetched from the previous LEF Calculator Tables.

Lastly, the Toll(Rs/Route) is calculated by:

Toll (Rs/Route) = LEF * Route Distance * Rs. Per Km

For our example the values are for the case that the entry point is at Thokar Niaz Baig [0] and the exit point is at M1-M2 Junction [369], therefore the length of the journey computes to 369 Km. Following are the Tolls calculated for the other truck types for the same route:

Table 4-11: Toll Calculator-2

	3 Axle Tandem			3 Axle Single			4 Axle Single-Tandem		
	GW (ton)	**DF / LEF**	**TOLL (Rs/Route)**	**GW (ton)**	**DF / LEF**	**TOLL (Rs/Route)**	**GW (ton)**	**DF / LEF**	**TOLL (Rs/Route)**
s	27.5	1.00	247	29.5	2.00	494	39.5	2.00	494
s+2	29.5	1.42	350	33.5	3.71	916	43.5	3.27	808
s+4	31.5	1.95	482	37.5	6.32	1563	47.5	5.11	1264
s+6	33.5	2.62	649	41.5	10.13	2503	51.5	7.69	1900
s+8	35.5	3.46	855	45.5	15.43	3815	55.5	11.17	2762
s+10	37.5	4.48	1107	49.5	22.59	5586	59.5	15.77	3900

Following tables depicts the toll calculated for each loading condition for the 4 Axle Tandem-Single truck, the 4 Axle Single truck and the 5 Axle Single-Tridem category of trucks in toll calculator-3. The toll collected for the 5 Axle Tandem-Tandem, the 5 Axle Single-Single-Tandem and the 5 Axle Tandem-Single-Single truck categories in toll calculator-4. And finally, the 6 Axle Tandem-Tridem and the 6 Axle Tandem-Single-Tandem truck categories in toll calculator-5.

Table 4-12: Toll Calculator-3

	4 Axle Tandem-Single			**4 Axle Single**			**5 Axle Single-Tridem**		
	GW (ton)	**DF / LEF**	**TOLL (Rs/Route)**	**GW (ton)**	**DF / LEF**	**TOLL (Rs/Route)**	**GW (ton)**	**DF / LEF**	**TOLL (Rs/Route)**
s	39.5	2.00	494	41.5	3.00	742	48.5	2.00	494
s+2	43.5	3.27	808	47.5	5.56	1374	52.5	3.14	775
s+4	47.5	5.11	1264	53.5	9.48	2344	56.5	4.79	1183
s+6	51.5	7.69	1900	59.5	15.19	3755	60.5	7.09	1753
s+8	55.5	11.17	2762	65.5	23.15	5723	64.5	10.22	2527
s+10	59.5	15.77	3900	71.5	33.89	8379	68.5	14.36	3549

Table 4-13: Toll Calculator-3

	5 AX Tandem-Tandem			**5 AX Single-Single-Tandem**			**5 AX Tandem-Single-Single**		
	GW (ton)	**DF / LEF**	**TOLL (Rs/Route)**	**GW (ton)**	**DF / LEF**	**TOLL (Rs/Route)**	**GW (ton)**	**DF / LEF**	**TOLL (Rs/Route)**
s	49.5	2.00	494	51.5	3.00	742	51.5	3.00	742
s+2	53.5	2.83	700	57.5	5.12	1266	57.5	5.12	1266
s+4	57.5	3.90	965	63.5	8.27	2045	63.5	8.27	2045
s+6	61.5	5.25	1297	69.5	12.75	3152	69.5	12.75	3152
s+8	65.5	6.92	1710	75.5	18.89	4670	75.5	18.89	4670
s+10	69.5	8.95	2213	81.5	27.07	6693	81.5	27.07	6693

Table 4-14: Toll Calculator-3

	6 AX Tandem-Tridem			6 AX Tandem-Single-Tandem		
	GW (ton)	DF / LEF	TOLL (Rs/Route)	GW (ton)	DF / LEF	TOLL (Rs/Route)
s	58.5	2.00	2340	61.5	3.00	3510
s+2	62.5	2.70	3159	67.5	4.69	5482
s+4	66.5	3.58	4184	73.5	7.06	8263
s+6	70.5	4.65	5444	79.5	10.31	12063
s+8	74.5	5.96	6976	85.5	14.63	17119
s+10	78.5	7.54	8817	91.5	20.25	23692

As can be seen by the tabulated results of the toll taxes for the ascertained journey that the toll doesn't depend on truck type as much as it depends on the extent it is overloaded by and the axle configuration of the truck.

From the table above, it can be seen that the 6 Axle Tandem-Tridem Truck which has been overloaded to the 's+10' category or 10 tones overweight, has the LEF of 7.54; whereas for the same condition, the 6 Axle Tandem-Single-Tandem truck has an LEF of 20.25 for the same 10 overweight tonnage. This clearly shows that the amount of damage inferred on the pavement is not just subject to the amount of overloading, but also to the configuration of the truck type, which is more indicative of relative overloading of the truck.

With the existing system of toll rates, both categories would not have been allowed to traverse the roads because they exceed the certain limit. However, even for acceptable limits such as those in the 's+8' category the fines for the two trucks would be the same, i.e Rs.5000 (Section 3.5), excluding the toll tax that the trucks would have to pay which would be Rs.1170 (APPENDIX B), so they would both equate to a combined toll tax and fine of Rs. 6170. And our measure of toll indicates that, for the s+8 category, a more representative toll rate of Rs. 6976 for the 6 Axle Tandem-Tridem and a toll rate of Rs. 17119 for the 6 Axle Tandem-Single-Tandem would be collected.

4.7 Framework for Extrapolation

Now, after having made the toll calculator, we needed a framework that would give us the results for bigger scenarios rather just individualized truck toll details. These scenarios make for the use of this framework is deciphering the amount of revenue or toll collected by the system itself over a given period of time with a given percentage of truck vehicles and data pertaining to their occurrence of overloading and frequency of individual load categories in each truck type.

The figures so obtained for these percentages were from existing studies and research done on traffic composition of freight vehicles in Pakistan and can be referred to in the previous chapter of methodology.

For the framework that we wanted to make, we had to establish a link between the truck types, the AATT (Average Annual Truck Traffic), the amount of each category and the amount of overloaded trucks for each category. This can be shown in the framework which was developed as follows:

Table 4-15: Framework-1

	Traffic	**Type Amount**		**Overloaded**	
	AATT	**%**	**Amount**	**%**	**Amount**
2x S	10000	70	7000	70	4900
3x T	10000	21.5	2150	70	1505
3x S	10000	1.2	120	70	84
4x S-T	10000	3	300	40	120
4x T-S	10000	2.5	250	40	100
4x S	10000	1	100	40	40
5x S-Tr	10000	0.3	30	40	12
5x T-T	10000	0.5	50	40	20
5x S-S-T	10000	0.3	30	40	12
5x T-S-S	10000	0.3	30	40	12
6x T-Tr	10000	0.4	40	40	16
6x T-S-T	10000	0.12	12	40	4.8

As can be seen that the type amount is subject to the AATT and so is the overloaded amount. Both are subject to the AATT which is by itself changeable since it is a flexible framework with emphasis on the least possible constants. Next, the amount is calculated for each loading condition. First the ‘s’ category which is under the overloading condition and is the ‘under-loaded’ category. Naturally, the amount of vehicles inside the weight limitation would be equal to the overloaded amount of trucks deducted from the total amount of trucks.

Table 4-16: Framework-2

	Traffic	Type Amount		Overloaded		s			
	AATT	**%**	**Amount**	**%**	**Amount**	**%**	**Amount**	**TOLL/ Vehicle**	**TOLL**
2x S	10000	70	7000	70	4900	30	2100	247	519183
3x T	10000	21.5	2150	70	1505	30	645	247	159463
3x S	10000	1.2	120	70	84	30	36	494	17801
4x S-T	10000	3	300	40	120	60	180	494	89003
4x T-S	10000	2.5	250	40	100	60	150	494	74169
4x S	10000	1	100	40	40	60	60	742	44501
5x S-Tr	10000	0.3	30	40	12	60	18	494	8900
5x T-T	10000	0.5	50	40	20	60	30	494	14834
5x S-S-T	10000	0.3	30	40	12	60	18	742	13350
5x T-S-S	10000	0.3	30	40	12	60	18	742	13350
6x T-Tr	10000	0.4	40	40	16	60	24	494	11867
6x T-S-T	10000	0.12	12	40	4.8	60	7.2	742	5340

Here the computations are done as:

s % = 100 – Overloaded %

s Amount = s % * Type Amount

TOLL/Vehicle = Toll(Rs/Route)

Where, Toll(Rs/Route) is extracted from the Toll Calculator for the specified Route

TOLL = Amount * TOLL/Vehicle

Now, for the other loading types:

Table 4-17: Framework-3

	Traffic	Type Amount		Overloaded		s+2			
	AATT	%	Amount	%	Amount	%	Amount	TOLL/ Vehicle	TOLL
2x S	10000	70	7000	70	4900	35	1715	458	785511
3x T	10000	21.5	2150	70	1505	35	526.75	350	184442
3x S	10000	1.2	120	70	84	35	29.4	916	26932
4x S-T	10000	3	300	40	120	35	42	808	33943
4x T-S	10000	2.5	250	40	100	35	35	808	28286
4x S	10000	1	100	40	40	35	14	1374	19237
5x S-Tr	10000	0.3	30	40	12	35	4.2	775	3257
5x T-T	10000	0.5	50	40	20	35	7	700	4902
5x S-S-T	10000	0.3	30	40	12	35	4.2	1266	5318
5x T-S-S	10000	0.3	30	40	12	35	4.2	1266	5318
6x T-Tr	10000	0.4	40	40	16	35	5.6	668	3739
6x T-S-T	10000	0.12	12	40	4.8	35	1.68	1158	1946

For this, the computations are done as:

% ‘s+2’ = Constant Amount [Based on Observation]

The formulas for the Amount, TOLL/Vehicle and TOLL are the same as before. After this, all the other overloaded categories have been computed in the same way with the variation being only in the percentage of each loading category. This has been found under observation and can be changed subject to practical vehicle counting tests. The flexibility of the framework is primal here as it can accommodate all these changes if and when necessary.

Table 4-18: Load Condition Percentages

Load Condition	s+2	s+4	s+6	s+8	s+10
Percentage	35	25	20	12.5	7.5

The other types’ toll collected is shown as:

Table 4-19: Framework-3

	s+4				s+6			
	%	**Amount**	**TOLL/ Vehicle**	**TOLL**	**%**	**Amount**	**TOLL/ Vehicle**	**TOLL**
2x S	25	1225	781	957177	20	980	1252	1226570
3x T	25	376.25	482	181460	20	301	649	195258
3x S	25	21	1563	32817	20	16.8	2503	42054
4x S-T	25	30	1264	37910	20	24	1900	45607
4x T-S	25	25	1264	31591	20	20	1900	38006
4x S	25	10	2344	23441	20	8	3755	30038
5x S-Tr	25	3	1183	3549	20	2.4	1753	4208
5x T-T	25	5	700	3502	20	4	965	3858
5x S-S-T	25	3	2045	6135	20	2.4	3152	7565
5x T-S-S	25	3	2045	6135	20	2.4	3152	7565
6x T-Tr	25	4	884	3536	20	3.2	884	2829
6x T-S-T	25	1.2	1746	2095	20	0.96	2549	2447

Lastly, there is a column totaling all the toll collected for the AATT mentioned. This column at the last totals up the amount of toll collected per category and then it totals the entire categories worth of toll in the Grand Total section, as can be seen in the table below:

Table 4-20: Framework-4

	s+8				s+10				Total
	%	**Amount**	**TOLL/ Vehicle**	**TOLL**	**%**	**Amount**	**TOLL/ Vehicle**	**TOLL**	
2x S	12.5	612.5	1908	1168429	7.5	367.5	2793	1026418	5683288
3x T	12.5	188.125	855	160821	7.5	112.875	1107	124913	1006357
3x S	12.5	10.5	3815	40060	7.5	6.3	5586	35191	194856
4x S-T	12.5	15	2762	41437	7.5	9	3900	35097	282997
4x T-S	12.5	12.5	2762	34531	7.5	7.5	3900	29247	235831
4x S	12.5	5	5723	28615	7.5	3	8379	25137	170969
5x S-Tr	12.5	1.5	2527	3790	7.5	0.9	3549	3194	26900
5x T-T	12.5	2.5	1710	4274	7.5	1.5	2213	3320	34690
5x S-S-T	12.5	1.5	4670	7005	7.5	0.9	6693	6023	45397
5x T-S-S	12.5	1.5	4670	7005	7.5	0.9	6693	6023	45397
6x T-Tr	12.5	2	1474	2948	7.5	1.2	3617	4341	29260
6x T-S-T	12.5	0.6	3617	2170	7.5	0.36	5006	1802	15801
							Grand Total (Per Year)		7771741
							Grand Total (Per Day)		21292

4.8 Application

The solution we have devised for the overhauling of the toll rates on the motorways is two tiered. Firstly is the usage on an individualized level with the toll operator using the toll calculator to obtain toll taxes for each vehicle as it passes-by. The other usage is more of an analytical tool and generates the revenue generated by an entire truck traffic flow consisting of varying overloading, loading, overloading category and truck type percentages.

4.8.1 Toll Booth Level

At this level, the operator is to use the system to obtain an amount of toll which should be collected for a truck vehicle when it has been categorized as per weight and truck type category. This would of course mean that the truck would need to be weighed first and therefore weighed stations are critical for this approach. The operator would use the Route Distance Calculator to first find out the distance for the trip. It would generate a two-word trip code and would automatically adjust the toll values depending on the distance in the Toll Calculator. However, all these values are subject to the Rs. Per Km value which can be adjusted in the Price Per Km Adjustment Function. With the route marked and the weight and consequential weight category and truck type of the vehicle known, the operator can simply look up the toll tax for the specific credentials of the vehicle.

4.8.2 Using the Framework

The framework is more of a complicated device and can be sued to ascertain toll collected revenues over larger periods of time. For this, the inputs that need to be known are the:

- Annual or Daily Truck Traffic
- The Percentage of Each Type of Truck in the Categories
- The Percentage of Overloaded Trucks in Each Category
- The Percentage of Each Overloaded Category

Rest all other variables will be used from the Toll Calculator.

With these details known, the total revenue can be calculated for a specified amount of time. This will help is in calculating the amount of time we will need to break even the investment that will be used in formulating a new proposed weigh station. Also, this is a formidable analysis tool and can be used to extrapolate the revenue generated by the assets over a larger period of time. The flexibility of the framework makes the incorporation of any changes to the AATT and other variables seamlessly easy.

4.9 Analyses & Results

Now, with our framework readily in place and fully constructed. We devised a few results for analysis purposes to determine which truck category and which loading category was the most toll yielding or in other words the most pavement damaging.

4.9.1 Truck Type & Loading Condition with the Highest Toll/Km

For this, an arbitrary distance on one kilometer was assumed to be traversed by all the truck categories under all the loading conditions. This changed the toll rates and yielded the toll to be collected per kilometer of each truck type and under each loading condition. The results have been tabulated in the following graphs.

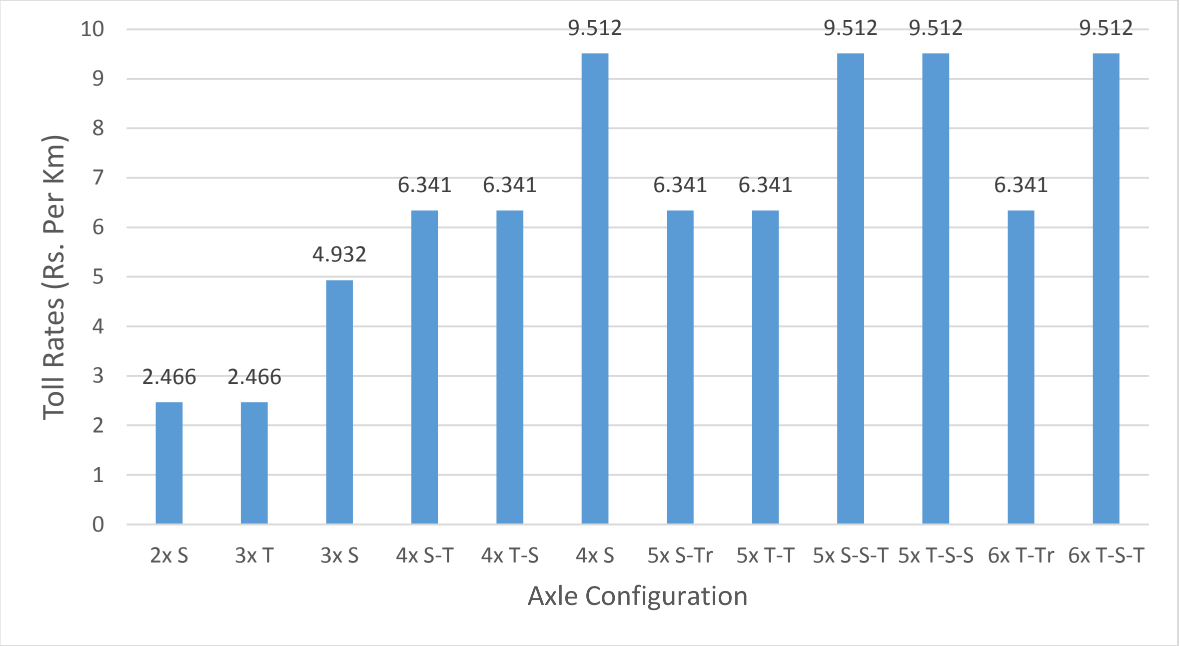


Figure 4-9: Rs/Km for Loading Condition: S

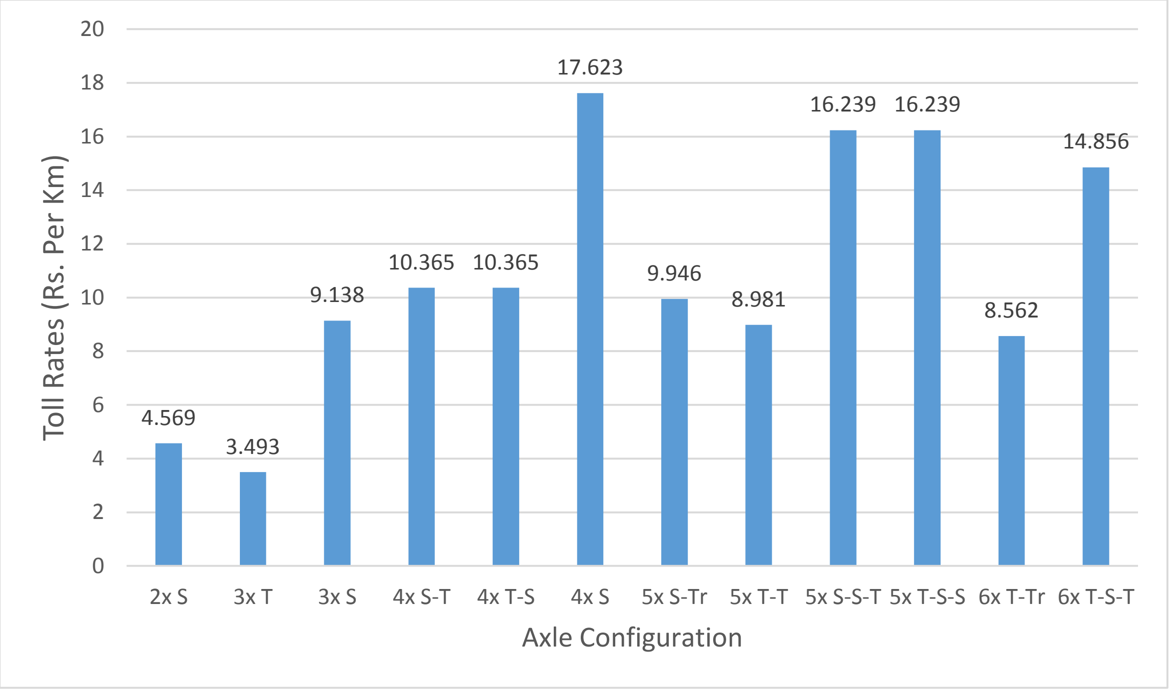


Figure 4-10: Rs/Km for Loading Condition: S+2

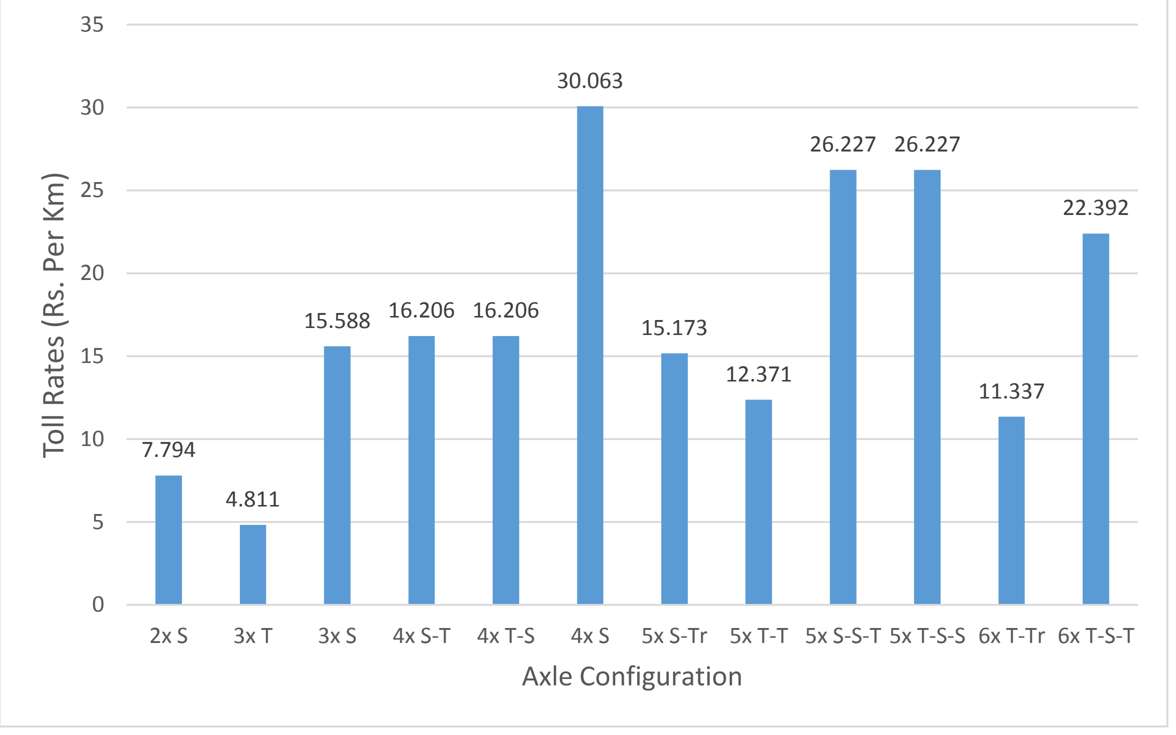


Figure 4-11: Rs/Km for Loading Condition: S+4

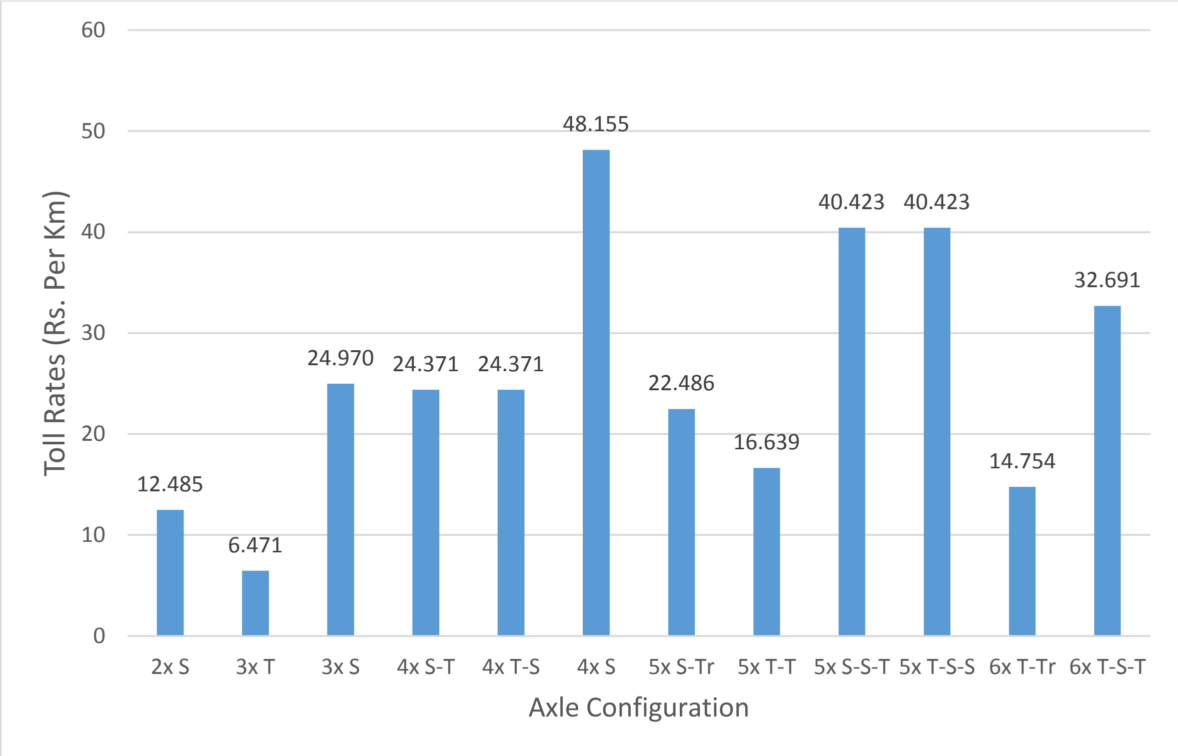


Figure 4-12: Rs/Km for Loading Condition: S+6

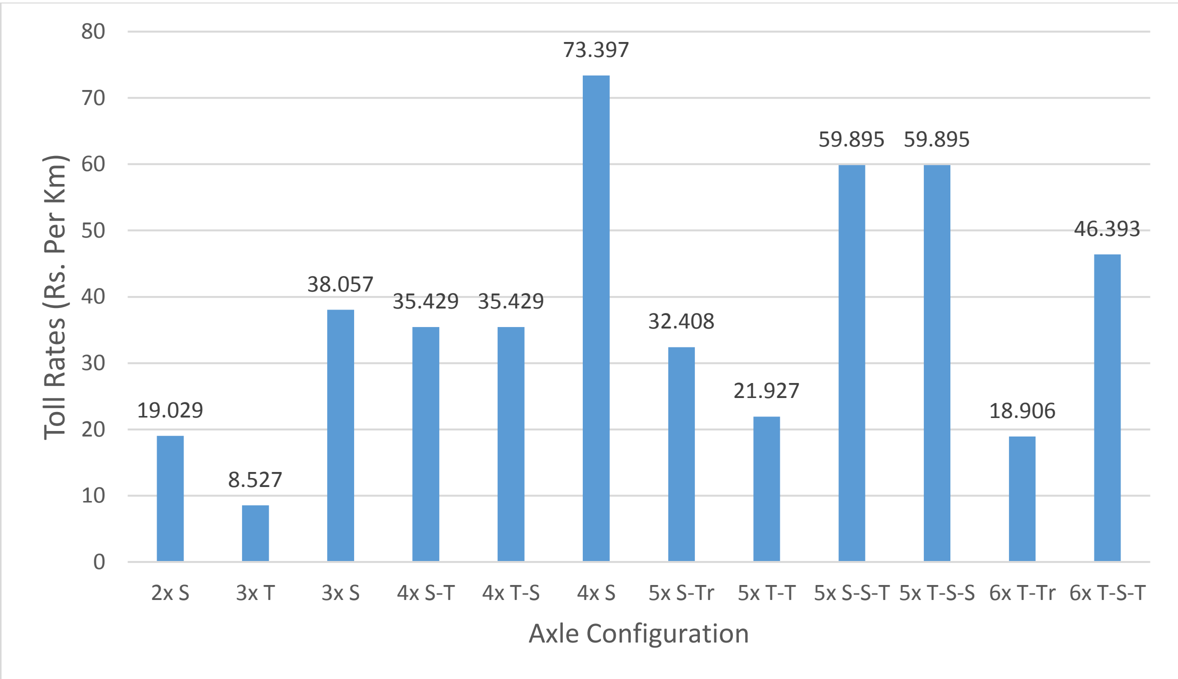


Figure 4-13: Rs/Km for Loading Condition: S+8

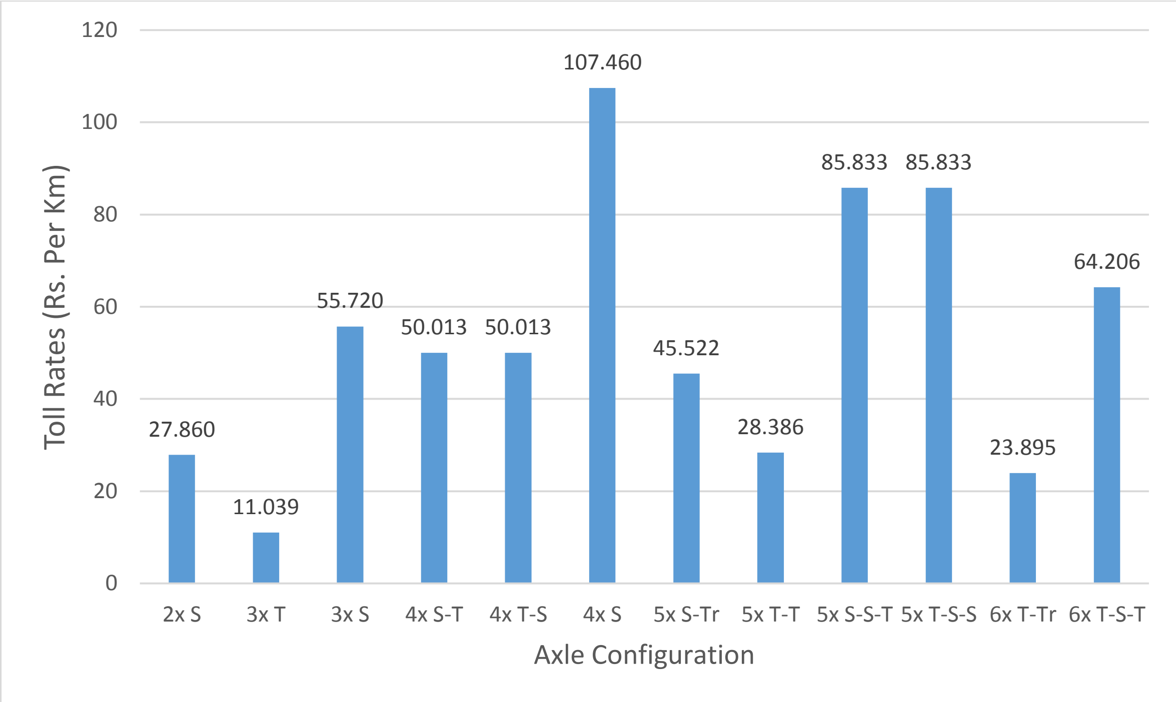


Figure 4-14: Rs/Km for Loading Condition: S+10

It is clearly visible in all of the graphs developed above that the 4 Axle Single truck category yields the most toll among all the truck types and, naturally, the 's+10' loading condition does the most damage with an estimated toll of Rs.107.

4.9.2 Truck Type & Loading with Highest Toll Per Axle-Km

Again, for this analysis, the distance was set to one kilometer to get data and values corresponding to per kilometer values. Furthermore, to evaluate the cost per axle-km, the cost per km had to be divided by the number of axles of the specific truck type configuration. The following results were yielded:

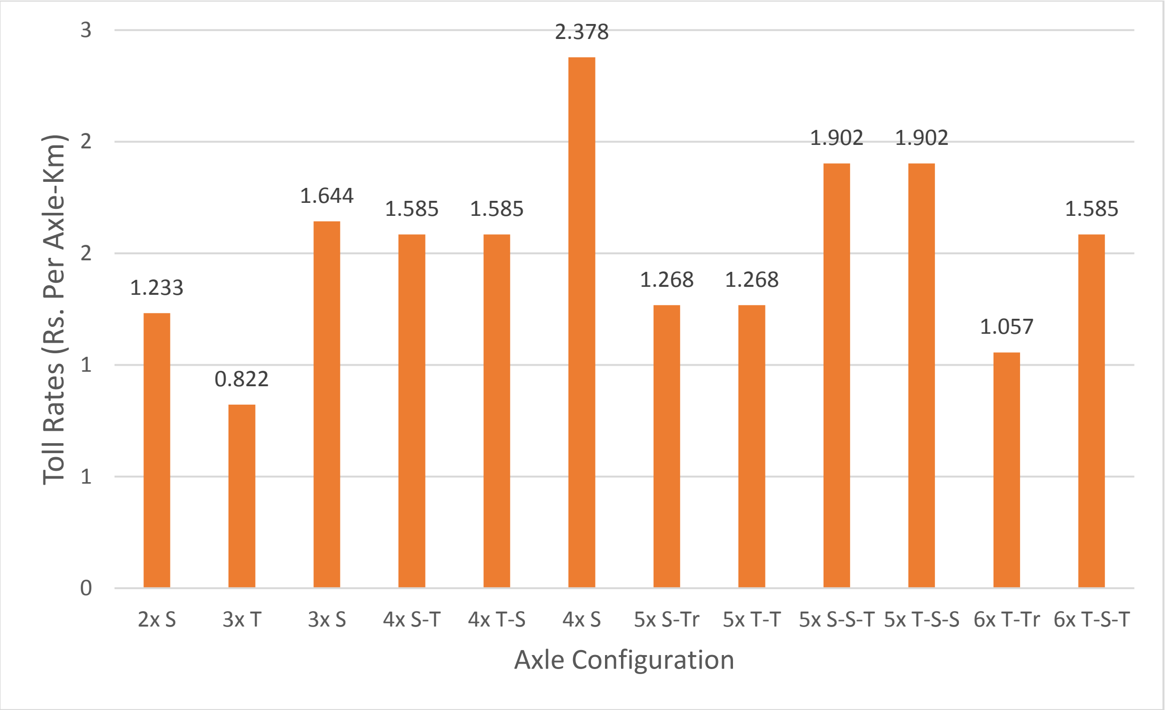


Figure 4-15: Rs/Axle-Km for Loading Condition: S

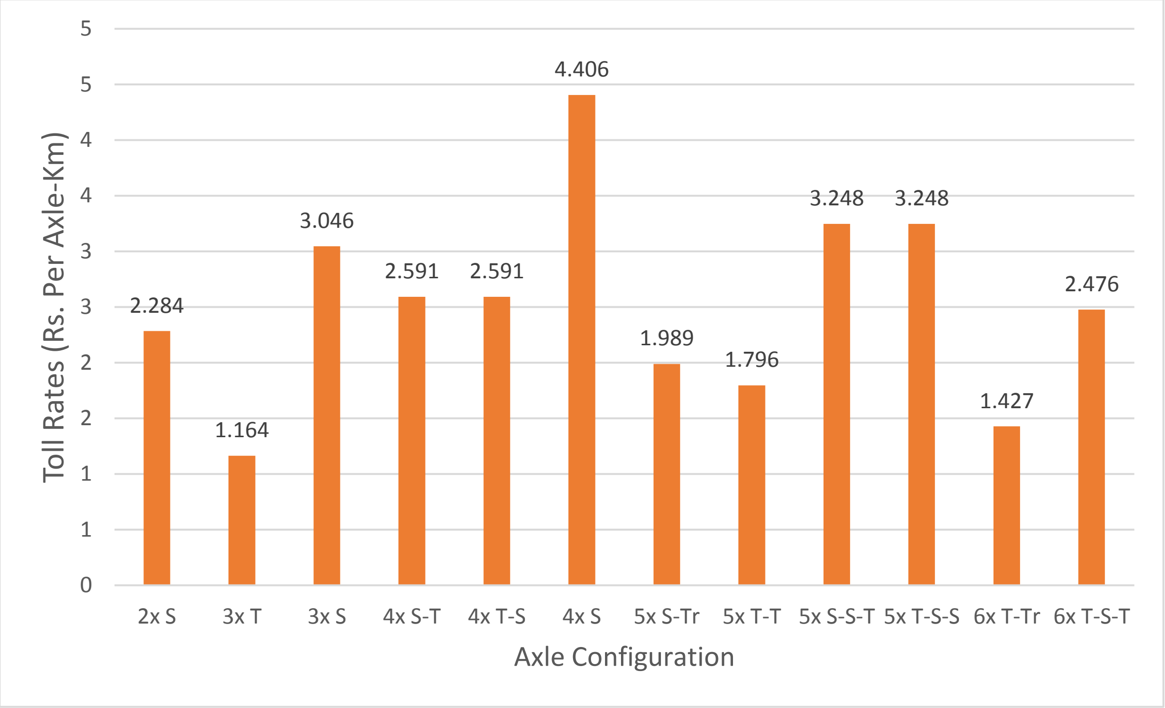


Figure 4-16: Rs/Axle-Km for Loading Condition: S+2

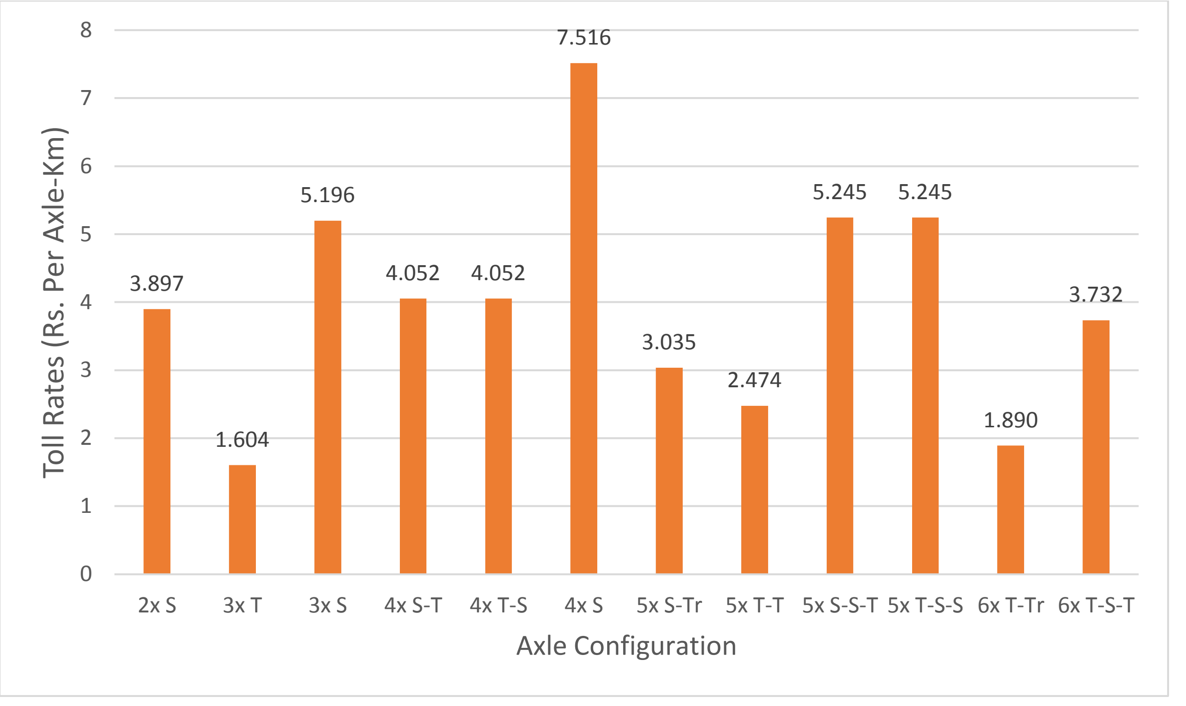


Figure 4-17: Rs/Axle-Km for Loading Condition: S+4

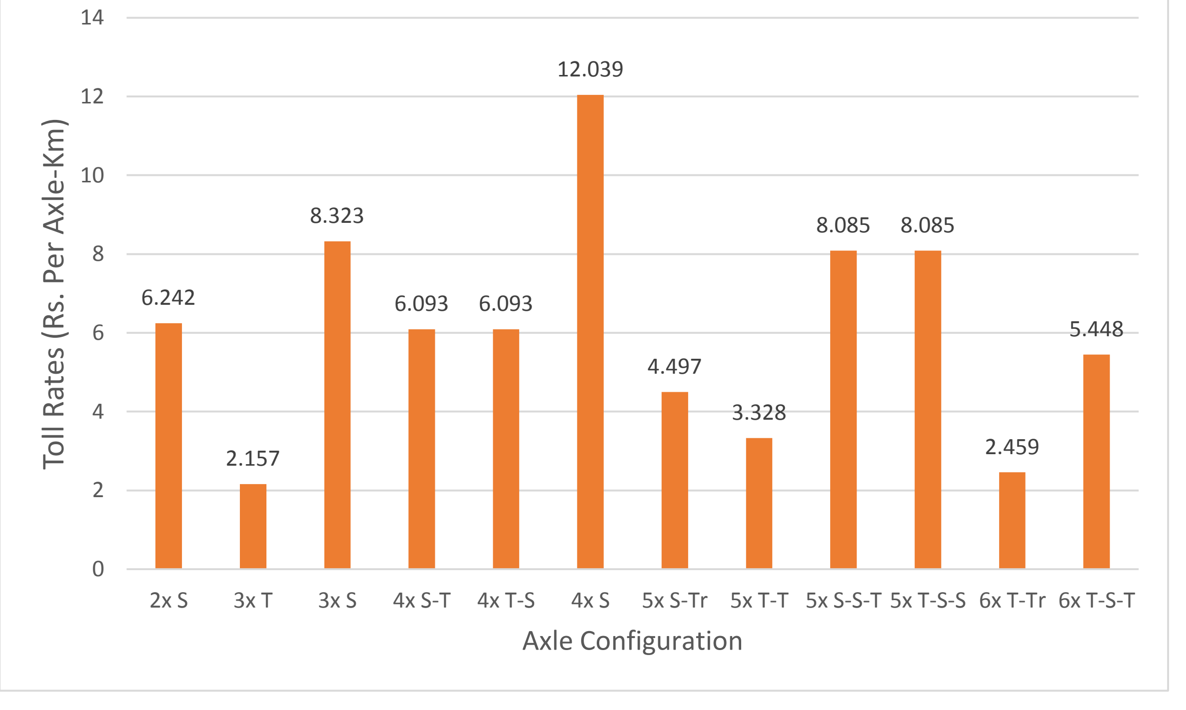


Figure 4-18: Rs/Axle-Km for Loading Condition: S+6

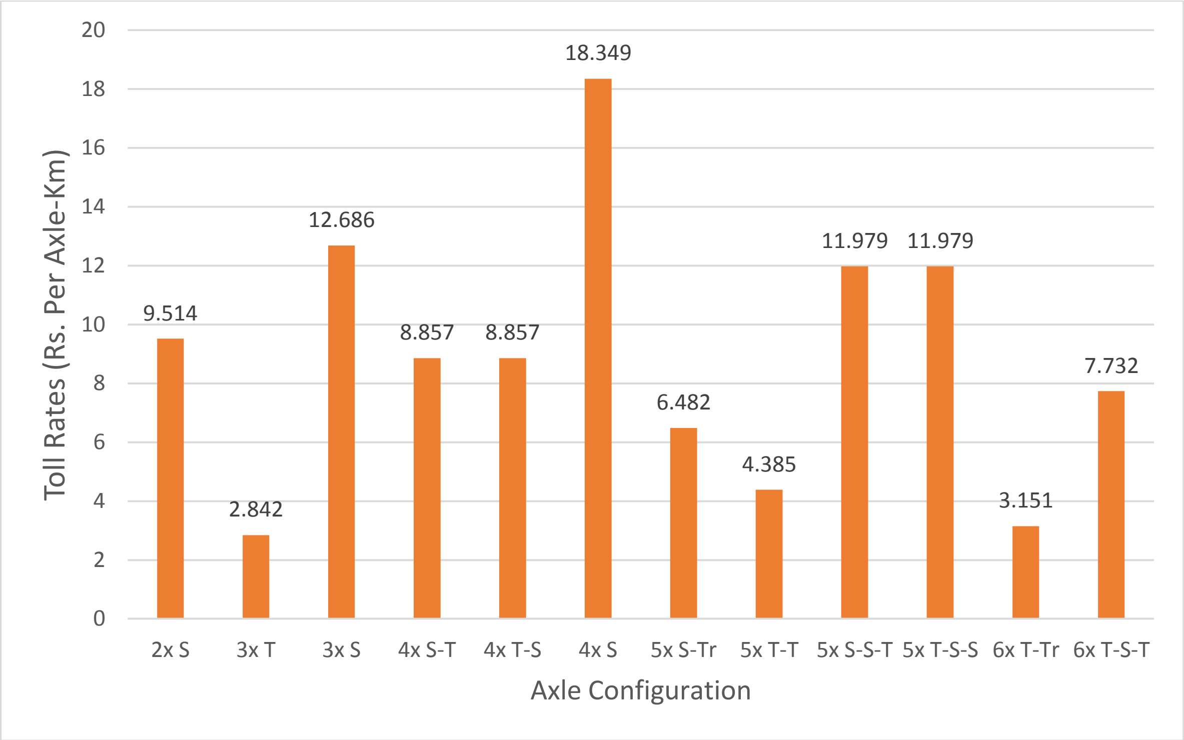


Figure 4-19: Rs/Axle-Km for Loading Condition: S+8

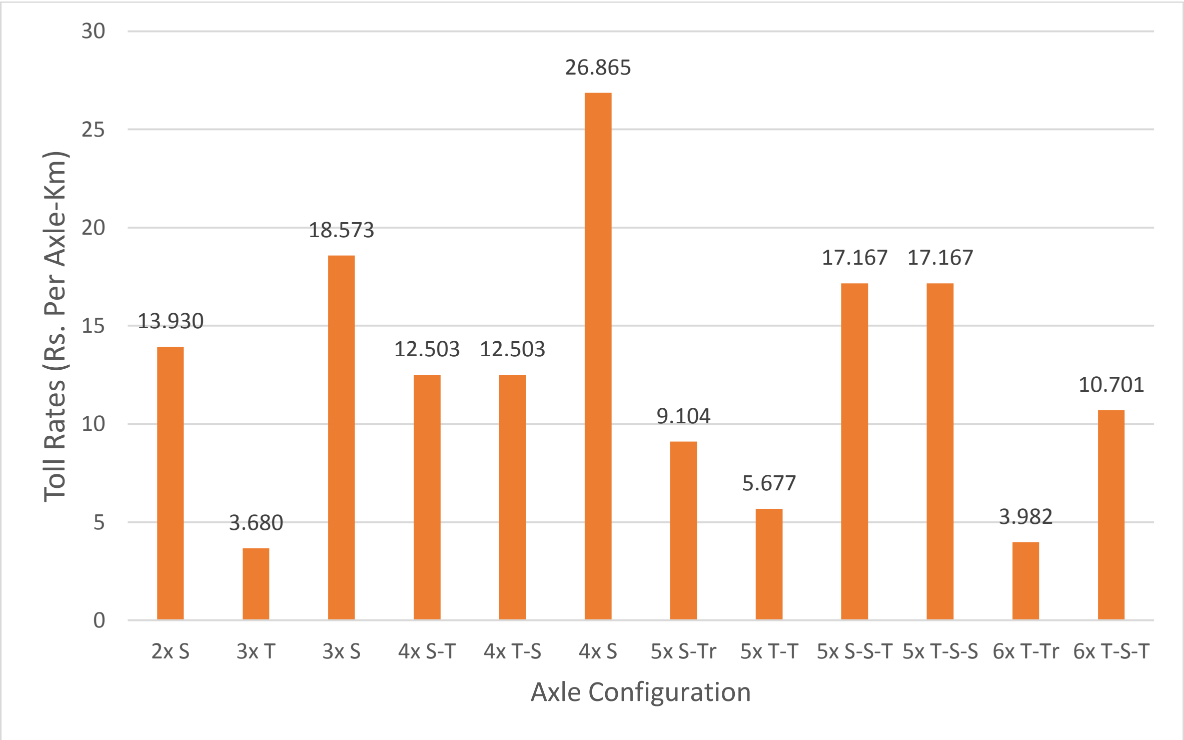


Figure 4-20: Rs/Axle-Km for Loading Condition: S+10

Again, the cost per Axle-Km was highest for the 4 Axle Single type trucks. The analysis also tells us that truck categories and their gross weights do not necessarily control the cost per axle. As is evident by Figure 4-20 above, the cost per axle of 2

Axle truck is far greater than that of a 3 Axle Tandem truck type. And in fact, the 3 Axle Tandem truck is the least damaging and therefore least tolled truck in our pool of categories.

4.9.3 Revenue Forecast Analysis

For this analysis, the truck axle spectra obtained from NHA as discussed earlier was used. And other conditions included: the route was between TNB [0] and MMJ [369], the overloading percentages were same as shown in Table 4-19 and an interest rate of eight percent was used, compounded yearly.

The following data and trends were observed.

Table 4-21: Revenue Generation Forecast (5 Years)

Revenue Generation (8%i)					
Method	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
D.B.T	29539163.14	31902296.19	37210838.28	46874939.51	63772837.71
NHA	24570424.00	26536057.92	30951657.96	38990174.95	53045702.57

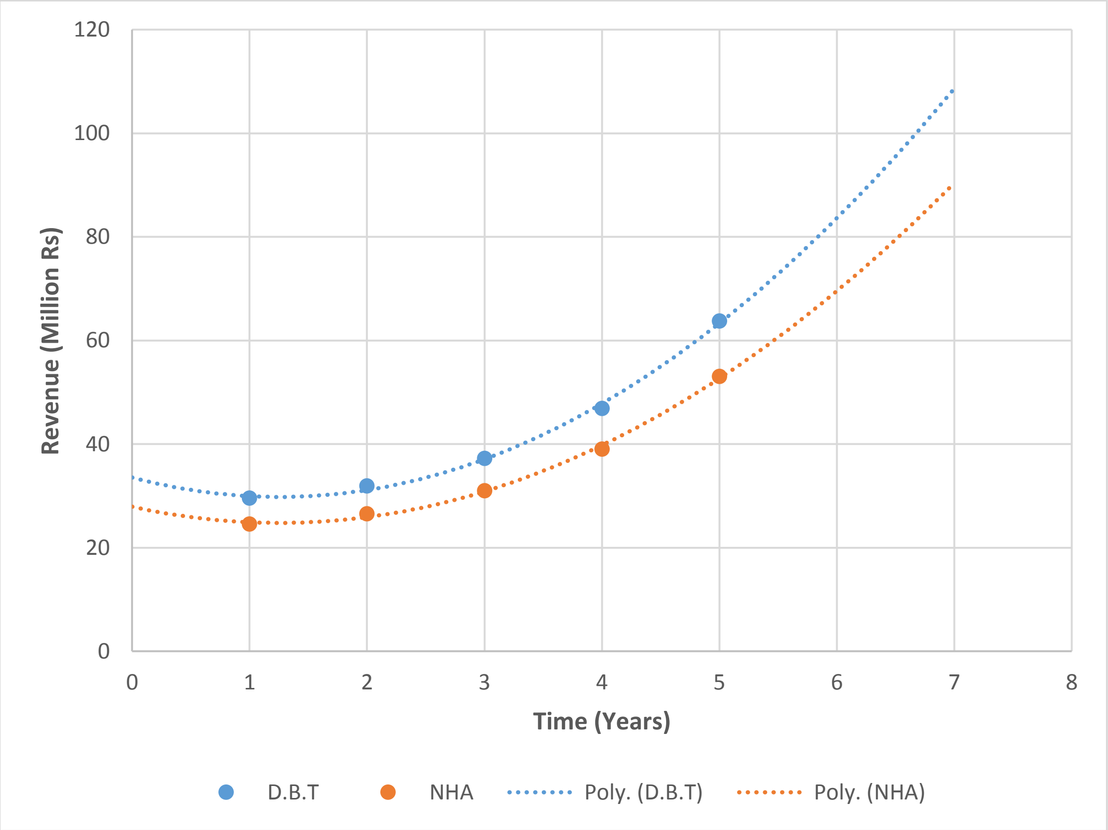


Figure 4-21: Revenue Generation Forecast (8%i, 5 Years)

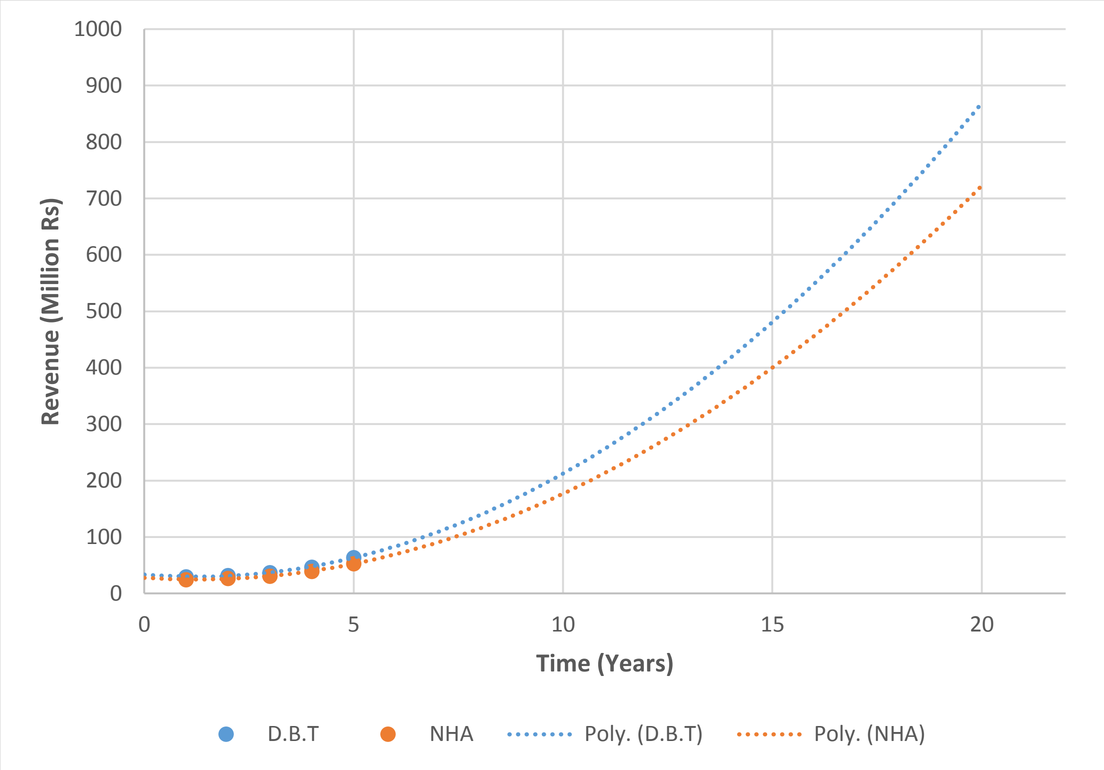


Figure 4-22: Revenue Generation Forecast (8%i, 15 Years)

4.10 Summary

In this chapter, we explained in detail, the solution to the problem that we had pointed out in the first chapter. Our resolution is based on the software package: MS Excel 2013. It makes use of fields, columns, rows and their inter relations to convey information and process it in a uniquely user-friendly manner so that complicated processes need not be worked out over and over again. First, we defined the objectives that we wished to attain with our proposed solution. Then, we went on to explain the components of our system and how they are formed. This includes, the LEF calculator, the Route Distance Calculator, the Toll Calculator and the Framework for Extrapolation & Analysis at the end. The detailed workings of the formation of these tables and their respective functions were explained in details along with the nature of the items, some of which are constants while the others are variables. Finally, the application of the system was elaborated upon with focus on two types of use that the solution would introduce. One, is the individualized use at a toll booth for the application of the new toll rate and second, is the use of the framework for computing detailed results for analysis purposes on a larger scale.

Chapter 5

PROPOSAL FOR AUTOMATED TOLL COLLECTION

5.1 Overview

With the framework of our proposed system of toll rates in place, we need a complementary system to incorporate such a toll tax. For that, we needed to study how the entire system of collection was done across the world. Details of the systems used in place in Germany and Illinois, USA have been shed light on in the second chapter. For such a system as ours to work, it would need a more efficient way of process to be done which would mean that the use of manual labor for toll collection would be minimal and more focus would be on automated systems of toll collection.

5.2 Automation in Toll Collection

Across the world, different technologies are used to automate the process of toll collection. From using electrical components in transponders to using online payment methods for tolls, the advent of technology has created a wide web of alternatives and approaches for tax collection to be done with ease.

However, each method has its own set of advantages as well as disadvantages. Therefore, the most efficient system needs to be worked upon and proposed accordingly. There are four components of an Electronic Toll Collection (ETC); these are described as follows:

5.2.1 Automated Vehicle Identification

As the name suggests, AVI (Automated Vehicle Classification) is the first component of an ETC and is concerned with the process of vehicle identification. They can use a number of technologies to identify the vehicles, with measures such as:

- Barcodes: Are to be read by optical reading systems such as OMR (Optical Mark Recognition). These tend to be unreliable because the barcodes cannot be read with credibility in case of inclement weather or dirt on the barcode itself.
- Radio Frequency Identification: An antenna at the toll gate/site communicates with a transponder on the vehicle via DSRC (Dedicated Short Range

Communications). With this system, RFID tags have been known to be most accurate with a more accommodating range of higher speeds of operation. The disadvantage with such a system is the initial investment that is the cost of installing a transponder.

- Automatic Number Pate Recognition: A system of cameras captures images of vehicles passing through tolled areas, and the image of the number plate is extracted and used to identify the vehicle. The disadvantage is that fully automatic recognition has a significant error rate, leading to billing errors and the cost of transaction processing (locating and corresponding with the customer) can be significant. Systems that incorporate a manual review stage have much lower error rates, but require a continuing staffing expense.

5.2.2 Automated Vehicle Classification

This is closely associated with AVI. It is used in places where toll rates vary for different types of vehicles. Such is the case with most of the motorways across the world.

The simplest method is to store the vehicle class in the customer record, and use the AVI data to look up the vehicle class. For our said effort, we would recommend using this process phase too since the motorways are used by a variety of differing truck types and heavy vehicles. Also, the proposed toll rate that we have devised relies heavily on the truck type and its configuration therefore this phase is essential for our proposed system of ETC.

5.2.3 Transaction Processing

This is the component of an ETC that deals with the payment, transaction logs, deferred or online payments and customer helplines/queries. Depending on the system used, customer accounts may be postpaid, where toll transactions are periodically billed to the customer, or prepaid, where the customer funds a balance in the account which is then depleted as toll transactions occur. In Pakistan, the E-Tag system is prepaid and has been the bane of the everyday user of the motorways since the E-Tag has a prepaid sum in it and is not linked with a credit card or bank account. What happens in this case is that, sometimes when a person has a lower amount than the toll for the required journey in his E-Tag account he has to pay the rest of the sum by hand. Ironically this removes the benefit of using the E-Tag in the first place and clutters the E-Tag lane too. It was found that unfortunately, this is the case too often.

5.2.4 Violation Enforcement

As the name implied, this component of an ETC is critical in establishing the efficiency of the entire system. For this purpose, different approaches are being used.

- Police patrolling: It is done in many places around the world, but the expense of police patrols makes their use on a continuous basis impractical.
- Gate/Barrier: This approach is under use in many places too. It is used on Pakistani Motorways. However, their use completes terminates the benefits of e-tagging in the first place because of stoppage at the toll station.
- Automatic Number Plate Recognition: As mentioned before, this system is not as reliable because it fails to work well under inclement weather, damaged number plate or simply because of dirt.

5.3 Implementation of ETC

For our proposed system of toll rates the most efficient method of toll collection, after having gone through the components and myriad other ETC schemes, would be one identical to the FasTrak system used in the American state of California. It is recommended that we use such a system on our Motorways in Pakistan for the use of freight vehicles only, at first.

5.3.1 Components

The parts used for the system to be recommended for use are as follows:

- **Transponder**

Figure 5-1: Transponder device on windshield

A transponder is a type of device that emits an identifying signal in response to an interrogating received signal. In a communications satellite, a transponder gathers signals over a range of uplink frequencies and re-transmits them on a different set of downlink frequencies to receivers on Earth.

- **Overhead Antennae**

Figure 5-2: An overhead Antenna

Labelled 1 in Figure 5.5. These send and receive signals to and from the Transponder.

- **Treadle**

Figure 5-3: A vehicle passing over a treadle

Treadles are speed independent axle sensing systems that consist of sensors mounted in a metal insert installed directly into a treadle frame in the road surface and are ideal for use in toll and traffic monitoring applications. These basically classify the vehicles into types and are critical to our execution of the proposed damage based toll rate.

- **Light Curtain**

Figure 5-4: Light Curtains installed at a toll station

These sensors determine the start and end of the vehicle and thus signal the start and end of the classification process. It consists of a pair of infrared transmitters and receivers with multiple beams arranged in a light curtain. With this type of sensor arrangement, it is possible to detect all types of vehicles accurately including vehicles puling trailers or vans.

5.3.2 Working of the ETC

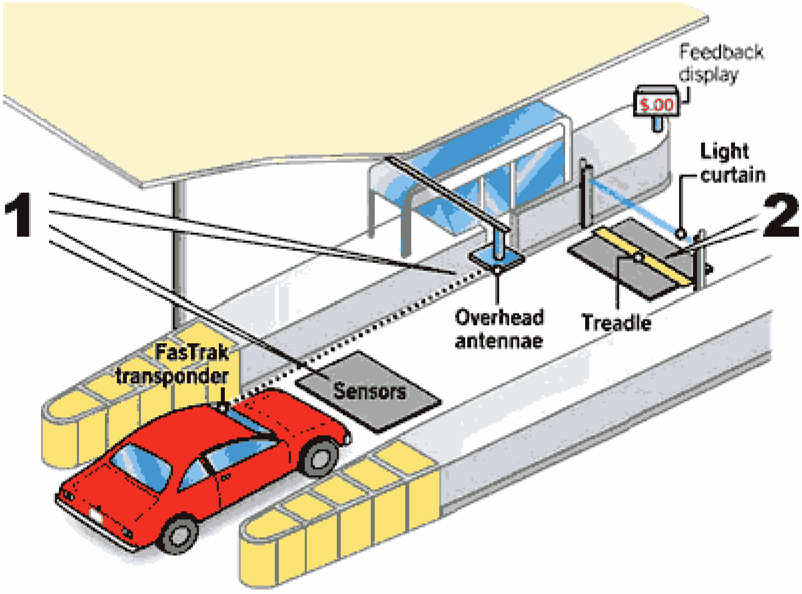


Figure 5-5: Working of an ETC

Here's how the system works in a step by step procedure:

1) As a car approaches a toll plaza, the radio-frequency (RF) field emitted from the antenna activates the transponder.
2) The transponder broadcasts a signal back to the lane antenna with some basic information.
3) That information is transferred from the lane antenna to the central database.
4) If the account is in good standing, a toll is deducted from the driver's prepaid account.
5) If the toll lane has a gate, the gate opens.
6) A green light indicates that the driver can proceed. Some lanes have text messages that inform drivers of the toll just paid and their account balance.
7) The lane is monitored using video cameras. If you try to go through the booth without a transponder, the camera records you and takes a snapshot of your license plate. The vehicle owner then receives a violation notice in the mail.

The entire process takes a matter of seconds to complete. The electronic system records each toll transaction, including the time, date, vehicle type, intersection and toll charge of each vehicle. For our system, we will introduce post-paid accounts only, since a pre-paid account could prove depleted on a point and hence cause time wastage.

The rules regarding how fast you can pass through the toll plaza vary from system to system. To save time and effort, out system will accommodate passing speeds up to 15 km/h so that the heavy vehicles do not have to completely stop.

5.3.3 Benefits of ETC

Among the benefits of ETC are:

- ETC lanes improve the speed and efficiency of traffic flow and save drivers time. Manual toll collection lanes handle only about 350 vehicles per hour (vph), and automated coin lanes handle about 500 vph. An ETC lane can process 1200 vph (Tri-State Transportation Campaign, 2004).
- As a result of better flow, congestion is reduced, fuel economy is improved, and pollution is reduced.
- Increased revenue: time savings, faster throughput, and better service attract more customers, thus increasing revenue.
- Reduced accident rates/ improved safety because of less slow-and-go driving.
- Increased efficiency of roads because of better distribution between tolled and non-tolled routes

5.4 Concerns for the Proposed ETC

Like all systems of automation, certain drawbacks and probable weak spots are bound to be present and as such there do exist some minor setbacks of using automation in toll collection. For our proposed ETC, there are a few concerns in terms of security and economy. Therefore we will provide our solutions for the respective considerations in the following text:

5.4.1 Security Concerns

ETC systems rely heavily on technology with minimum human involvement. As good as such a system might be, it also has its drawbacks. One prime example of such a security issue with a system relying on RFID tags/Transponders and antennae is the fact that all these can be remotely tampered with. Therefore, it could be the case that some hacker could violate the signals and change them to receive inappropriate or false information. Information such as the amount to be deducted or the existing account number affiliated with a specific transponder.

Another grim use of this technology could be for tracking purposes if the servers of the highway service containing vehicle logs ever gets hacked. If such a case ensues, then the privacy of all the users of such a system are at stake.

Solution:

Our proposal to counter this issue is the introduction of encryption services. Using Enhanced encrypted DWDM (Dense Wavelength Division Multiplexing) transponder on the PL-100TE. PL-1000TE is an advanced, all-in-one CWDM/DWDM optical transport product supporting up to 8 transponders with flexible mix of industry standard based protocols by PacketLight Networks.

5.4.2 Economic Concerns

The introduction of an ETC with extensive components such as those mentioned in detail in section 5.2.1, is bound to be an expensive solution initially. The cost of a transponder, its installation, an antennae assembly, a light curtain, a video camera capable of License Plate Recognition and a Treadle is a hefty amount for the initial usage of such a system especially in a country with adverse economic conditions as ours.

Solution:

We propose a two tiered solution. Firstly, that this system be used only on heavy freight vehicles since they form the backbone of the business industry by transporting goods. Therefore, the use of such a system on only one lane would make room for a lesser individual budget.

Secondly, a post-paid system of transponders could be used with registration and installation done by an incentivized amount and with the equipment leased to the truck owner for a specific fee. This would attract only the bigger freight vehicles and hence it would increase the time they would save as the vehicles using these lanes would be only those which have registered with the system. This restrictive usage would also make for a more efficient system from the start with minimal issues because of a marginal user base at the start. Of course, with increasing use of this system and our damage based toll rates, the increased revenue would be ample to expand the system to more lanes and provide even more appealing post-paid account subscriptions.

Another more detailed observation regarding the operation would be the implementation of a BOT scheme. A Build-Operate-Transfer scheme is a form of project financing, wherein a private entity receives a concession from the private or public sector to finance, design, construct, and operate a facility stated in the concession contract. This enables the project proponent to recover its investment, operating and maintenance expenses in the project. Similarly, when applied to our scheme it would mean that a third party would preferably build and manage the new system for an ETC and would initially run the system itself and correspondingly hand over the system once it has achieved a certain amount covering its initial investment.

5.5 Setting up a Proposed Weigh Station

With the revenue generated with our damage based toll tax, we would first invest in setting up a weigh station to cater for any loopholes in the existing system. Since the installation of this weigh station is imperative for the working of our proposed toll rate, it is a priority to first close any potential loopholes on scenarios where the software solution we have made may fail to work.

5.5.1 Location

After having analyzed the current network of weigh stations, we have found a loophole in the stretch between Khanqa Dogran [82] and Sukheki [93]. This portion of the M-2 is devoid of any weigh stations and therefore, heavy freight vehicles entering the through one of these interchanges and exiting from the next would cause damage to the pavement which would not have been quantified for in our toll based tax since the vehicles would not have been weighed in the first place.

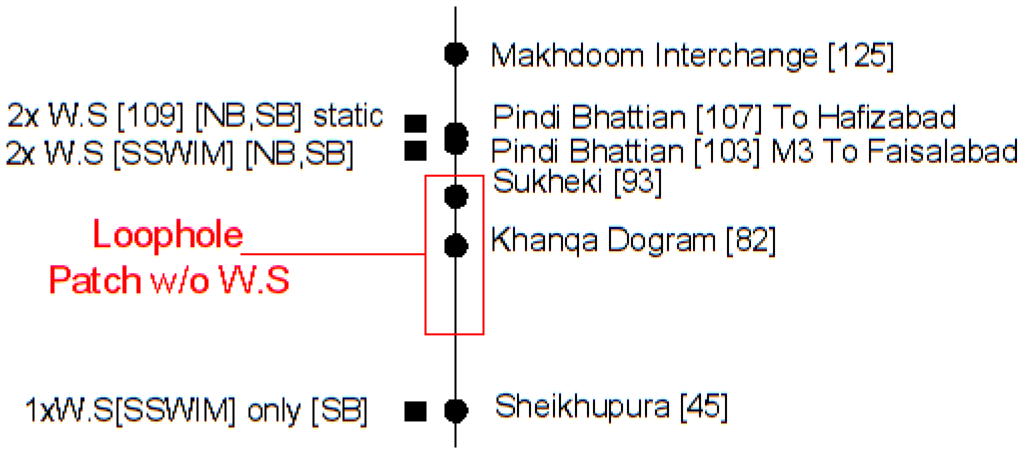


Figure 5-6: Location of Loophole

The proposed weighing station is to be of a SSWIM nature since they are more efficient in performance.

5.5.2 Time for Fund Accumulation for Proposed Weigh Station

We now have the revenue generated by our proposed toll rates and the NHA's existing system of toll tax for a given standard stream of truck traffic. The stream has been defined in section 3.7 and section 3.8 and an AATT of 10,000 has been selected. The revenues generated by both the approaches in the following computations done on the next page. Revenue through the NHA's rates was done manually by crunching the numbers after having deduced the amount of vehicles and the tolls and fines as per APPENDIX A & B and Table 9. For our proposed toll rate, the Framework for Extrapolation gave us the answers after having entered the required inputs.

Table 5-1: Revenue Generation through Proposed Framework

Category	Total Revenue
2x S	Rs20,918,950
3x T	Rs3,704,182
3x S	Rs717,221
4x S-T	Rs1,339,265
4x T-S	Rs1,116,055
4x S	Rs809,101
5x S-Tr	Rs127,300
5x T-T	Rs164,168
5x S-S-T	Rs214,837
5x T-S-S	Rs214,837
6x T-Tr	Rs138,470
6x T-S-T	Rs74,777
Revenue/Year	**Rs29,539,163**
Revenue/Day	Rs80,929

Table 5-2: Revenue Generation through existing NHA Rates & Fines

Category	Results from NHA						
	s	**s+2**	**s+4**	**s+6**	**s+8**	**s+10**	**Total**
2x S	1911000	3001250	6125000	-	-	-	Rs11,037,250
3x T	586950	526750	9406250	1505000	-	-	Rs12,024,950
3x S	32760	51450	105000	-	-	-	Rs189,210
4x S-T	386100	134750	275000	-	-	-	Rs795,850
4x T-S*							
4x S	70200	61250	125000	-	-	-	Rs256,450
5x S-Tr	21060	4200	7500	12000	-	-	Rs44,760
5x T-T	35100	7000	6250	12500	-	-	Rs60,850
5x S-S-T	42120	14700	30000	-	-	-	Rs86,820
5x T-S-S**							
6x T-Tr	28080	5600	10000	16000	-	-	Rs59,680
6x T-S-T	8424	1680	4500	-			Rs14,604
						Revenue/Year=	**Rs24,570,424**

** Revenue for 4x T-S is included in the 4x S-T amount since both are in the same category as per NHA*

*** Revenue for 5x T-S-S is included in the 5x S-S-T amount since both are in the same category as per NHA*

As we can see that the surplus amount equals:

Rs. 29,539,163 – Rs. 24,570,424 = Rs. **4,968,739**

This can be said to equal around 5 million rupees a year. As for the cost of an average WIM (Weigh In Motion) system, according to a report requested by AASHTO Standing Committee on Highways in 2008 which was part of the NCHRP Project 20-07, Task 254, Vehicle Size and Weight Management Technology Transfer and Best Practices, the cost of an in road WIM system is between $9000-$32,500 per lane varying on the basis of weight sensor type, on-site communication requirements etc. We will assume the price for it to be $25,000 using decent weight sensors and on-site communication services. This translates to roughly Rs.2,500,000 or Rs. 2.5 million. Therefore, we can easily get one WIM installed for Rs. 2.5 million of the surplus Rs. 5 million in half a year or six months.

5 million per year / 2.5 million for WIM = 2 devices per year = 1 W.S in half a year or six months

All this is done with the following important points in consideration:

a. The effects of inflation were not accounted for in this rather short break-even period. And due to this short amount of time, it can do little to change the figures.

b. An average annual truck traffic of 10,000 was used arbitrarily. Truck traffic is subject to change and may not remain constant for each year.

c. For the first year, pavement rehabilitation and maintenance is to be done using the Rs. 24.5 million generated as per existing NHA rates since only the surplus will be utilized in purchasing the weigh in motion system.

d. The WIM is to be equipped on a single lane. Successive improvements and expansion can be made in the successive years to cover several lanes.

5.6 Summary

In this chapter, we wrote about the workings of an automated toll collection system. This system was chosen so to save time, money and to better incorporate our damage based toll rate. We started off by defining the ETC, followed by its components and the way it works. After that, we enumerated certain issues that we would face when introducing this system in our country. We also, explained what measures we would be using to alleviate these issues to the greatest extent possible. Finally, we recommended the setting up of a proposed weigh station in a loophole in the M-2 that we found. The place and investment of the proposed weigh station was debated afterwards and finally the break even time period was found by using the revenue generated by our damage based toll rates for a specific stream of truck traffic passing through the motorways. Lastly, we enumerated a few considerations that were not part of the study in evaluating the revenue generation.

Chapter 6
CONCLUSIONS & RECOMMENDATIONS

6.1 Introduction

The findings of this report proved there is enough room for improvement in our existing toll rate structure and toll rate collection method. These can be further impressed upon by the fact that the same damage based toll methods are being used by countries around the world to more aptly justify and cater for the damage done to pavements by the heavy freight industry.

It was also found that with the proposed system of toll rates, revenue generation would increase and therefore the entire ETC system could be progressively expanded to be incorporated on all lanes, across all motorways of our country.

6.2 Pragmatic Use of the Damage Based Toll

As we have seen with figures before, our introduced damage based toll charges truckers and freight movers for the 'hidden subsidy' that their kind takes from the entire industry. What results is a completely relational and apt charging system of toll tax which is representative of the damage done to the pavements themselves. The implementation of such a tolling criteria would not only account for more revenue generation but it would also mean better roads and even better services in the future.

The way it would work is that, a toll operator would need to key in the entry and exit points, and the table would adjust the toll taxes accordingly. After that, the operator just has to see which vehicle type (2 Ax, 3 Ax S etc.) is in front of him and which weight category(s, s+2 etc.) does it belong to. Knowing these two things, he can easily find out the toll the driver should pay in a matter of seconds.

The finalized damage based toll is for use for heavy freight vehicles only since we have proven with earlier studies that most of the damage done to pavements is by the heavily overweight trucks and their like. And not by regular domestic cars. Naturally, since cars are domestic vehicles they tend to not be overloaded in terms of tons and are often times lesser in comparison to overweight conditions of trucks bearing goods. This means that a similar toll rate mechanism would be somewhat not as effective in the case of regular cars which do not do that much damage to the pavements as their counter parts.

With the formulation of this damage based toll and it's framework we have successfully developed a toll tax mechanism to quantify the damage done to pavements by a certain truck category under a certain loading condition.

6.3 Implementation of the ETC

One of the main points to be highlighted in this part of the study is the fact that across the globe, most countries operate these facilities not through government bodies but through private firms. Since the incentive to perform for better figures is more with a more private approach, such a system (ETC) should be given to private bodies which might be interested in running these services. The damage based toll is bound to add to their incentive of increased earnings as well.

With private firms working in our transportation resources, we will likely see an increase in the ingenuity and creativity in this field. Not only that, but more private competition will call for more stakes based risks and henceforth a sector cultivating excellence in performance. With such an environment where toll collection is done through giants such as FasTrak or E-ZPass, we could see native transportation firms coming up to the task and an increased growth in the transportation resource industry of Pakistan.

The ETC formulates a comprehensive automated system of toll collection in our country. Although an initial investment, it can prove to be highly efficient and cost effective in the longer run, provided it is run optimally.

6.4 Existing Renovation of M-2

The Motorway 2 is currently under the process of rehabilitation by the Pakistan Armed Forces Engineers Corps and part of that renovation is bringing about technological changes to the system in places. Among the changes introduced on the motorway are the following highlights:

- Installation of cameras at every one kilometer interval for better detection, security and surveillance purposes
- Installation of weighing stations that would deduce the category of the vehicle when it is at the toll station

Both of these measures would expedite our recommended automated toll collection system of ETC. The cameras could be used for vehicle identification and logging. The weigh stations on the other hand would be even more crucial as they would classify the vehicles as they approach the toll station. Once this is done, the toll operator could easily punch in the details and acquire the toll to be received. Also, if an ETC is to be implemented in the future, the same weighing sensors would be instrumental for automatic classification of the vehicles.

6.5 Future Improvements

For the implementation of damage based toll tax and system of electronic toll collection that we have proposed, there still exists a large area for improvement as our study has been done as a pioneering effort of its kind in our country. Having stated its significance, we do believe there is room for considerable enhancement. Being limited by several factors such as time and resources we were not able to do the following things and we sincerely hope that any future endeavor done regarding this enigma would benefit highly from our study.

- Using advanced software, like Visual Basic, to tailor-make an exclusive software to be used on the manned toll booths.
- Increasing the diversion of the overweight categories by dividing the categories into more segments. I.e. ‘s’, ‘s+0.5’, ‘s+1’ etc.
- Increasing the overloading spectra from ten ton overweight to accommodate more overweight vehicles.
- Using resources to contact the various companies involved in establishing an ETC and perform a feasibility analysis.
- With increase in pollution awareness and green-technology in cars, a similar approach could be made on vehicles classified per emission type (like LKW-Maut, Germany) and factors pertaining to their damage on the environment could be used to compute their results.

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APPENDICES

APPENDIX A TOLL RATES FOR 2 & 3 AXLE TRUCKS ON M-1/M-2

RIGID TRUCKS including 2 axle and 3 axle trucks

Interchanges	Lahore T. P.	Faizpur	kalashahkaku	Sheikhupura	Khanqah Dogran	Kot Sarwar	Pindi Bhattian	Sial More	Kot Momin	Salam Chowk	Bhera	Lilla	Kallar Kahar	Balkasar	Chakri	Islamabad T.P.	Sahiwanwala	Millat	Faisalabad	Fateh Jang	Brahama Bahatar	Burhan	Chach	Swabi	Rashakai	Charsada	Peshawar
Lahore T. P.	0																										
Faizpur	50	0																									
Kalashahkaku	50	50	0																								
Sheikhupura	115	115	65	0																							
Khanqah Dogran	210	195	155	90	0																						
Kot Sarwar	260	260	195	130	50	0																					
Pindi Bhattian	310	310	260	195	105	65	0																				
Sial More	350	350	300	235	145	105	40	0																			
Kot Momin	415	415	375	310	220	180	115	80	0																		
Salam Chowk	455	455	405	340	245	220	155	115	40	0																	
Bhera	520	520	455	405	300	275	210	170	90	50	0																
Lilla	560	560	505	440	350	310	260	220	130	105	40	0															
Kallar Kahar	625	625	585	520	415	390	325	300	220	170	115	80	0														
Balkasar	690	690	650	585	480	455	390	350	275	235	180	145	65	0													
Chakri	830	830	780	715	625	585	520	480	405	375	310	275	195	130	0												
Islamabad T.P	910	910	870	805	700	675	610	585	505	455	405	365	285	235	90	0											
Sahiwanwala	415	415	365	300	210	170	105	145	220	260	310	365	430	495	625	715	0										
Millat	480	480	430	365	275	235	170	210	285	325	375	430	495	560	690	780	80	0									
Faisalabad	480	480	430	365	275	235	170	210	285	325	375	430	495	560	690	780	80	50	0								
Fateh Jang	955	955	915	850	745	720	655	630	550	500	450	410	330	280	135	45	760	825	825	0							
Brahama Bahatar	960	960	920	855	755	725	660	635	560	505	455	415	340	285	145	50	765	830	830	40	0						
Burhan	995	995	955	890	785	760	695	670	590	540	485	450	370	320	175	85	800	865	865	80	40	0					
Chach	1030	1030	995	930	825	800	735	710	630	580	525	485	410	355	215	125	835	900	900	95	50	40	0				
Swabi	1070	1070	1030	965	865	835	775	745	670	615	565	525	450	395	255	160	875	940	940	125	95	70	40	0			
Rashakai	1170	1170	1130	1065	960	935	870	845	765	715	660	625	545	495	350	260	975	1040	1040	245	220	175	150	95	0		
Charsada	1210	1210	1170	1105	1000	975	910	885	805	755	700	660	585	530	390	300	1015	1080	1080	285	260	220	175	150	50	0	
Peshawar	1255	1255	1215	1150	1045	1020	955	930	850	800	745	710	630	580	435	345	1060	1125	1125	320	300	260	220	175	95	50	0

APPENDIX B

TOLL RATES FOR 4 AXLE & ABOVE ARTICULATED TRUCKS ON M-1/M-2

ARTICULATED TRUCKS including Articulated Vehicles

Interchanges	Lahore T. P.	Faizpur	kalashahkaku	Sheikhupura	Khanqah Dogran	Kot Sarwar	Pindi Bhattian	Sial More	Kot Momin	Salam Chowk	Bhera	Lilla	Kallar Kahar	Balkasar	Chakri	Islamabad T.P.	Sahiwanwala	Millat	Faisalabad	Fateh Jang	Brahama Bahatar	Burhan	Chach	Swabi	Rashakai	Charsada	Peshawar
Lahore T. P.	0																										
Faizpur	80	0																									
Kalashahkaku	210	210	0																								
Sheikhupura	155	155	155	0																							
Khanqah Dogran	275	260	260	115	0																						
Kot Sarwar	325	325	340	170	50	0																					
Pindi Bhattian	390	390	405	245	130	90	0																				
Sial More	440	440	455	300	180	130	50	0																			
Kot Momin	530	530	545	390	275	235	155	90	0																		
Salam Chowk	585	585	595	440	310	275	195	145	50	0																	
Bhera	650	650	660	505	390	350	260	220	115	80	0																
Lilla	700	700	725	560	440	405	310	275	170	130	50	0															
Kallar Kahar	805	805	805	650	530	505	415	365	275	220	145	90	0														
Balkasar	885	885	885	725	610	585	495	440	350	300	220	170	90	0													
Chakri	1050	1050	1065	910	790	740	660	610	520	465	405	350	260	170	0												
Islamabad T.P	1170	1170	1170	1015	895	870	780	725	625	585	505	455	365	285	115	0											
Sahiwanwala	520	520	530	375	260	220	130	180	285	325	390	440	545	625	790	910	0										
Millat	595	595	610	455	340	300	210	260	365	405	465	520	625	700	870	985	105	0									
Faisalabad	595	595	610	455	340	300	210	260	365	405	465	520	625	700	870	985	105	50	0								
Fateh Jang	1235	1235	1235	1080	960	935	845	790	690	650	570	520	430	350	180	65	975	1050	1050	0							
Brahama Bahatar	1240	1240	1240	1085	965	940	850	800	695	655	580	525	435	355	190	70	980	1060	1060	50	0						
Burhan	1335	1335	1335	1180	1065	1040	950	895	790	755	675	625	530	455	285	170	1080	1155	1155	85	50	0					
Chach	1440	1440	1440	1285	1170	1145	1050	1000	895	855	780	725	635	560	390	275	1180	1260	1260	125	95	70	0				
Swabi	1500	1500	1500	1345	1225	1200	1110	1060	955	915	835	785	695	615	450	330	1240	1320	1320	195	160	135	110	0			
Rashakai	1625	1625	1625	1465	1350	1325	1235	1180	1080	1040	960	910	820	740	570	455	1365	1440	1440	320	285	260	235	195	0		
Charsada	1690	1690	1690	1530	1415	1390	1300	1245	1145	1105	1025	975	885	805	635	520	1430	1505	1505	355	330	330	300	260	70	0	
Peshawar	1745	1745	1745	1590	1475	1450	1355	1305	1200	1160	1085	1030	940	865	695	580	1485	1565	1565	410	395	370	355	320	175	65	0