EFFECTS OF ROAD IMPROVEMENT ON SAFETY:A CASE STUDY OF NAIROBI THIKA SUPERHIGHWAY, KENYA

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Effects of Road Improvement on Safety:A Case study of Nairobi – Thika Superhighway, Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

This thesis is dedicated to all of the mentors that I have had in my life. My mother, Joyce, for her optimistic view of life and never letting me give up. My father, Micah, for showing me how to always conduct myself honestly and for guiding me to go after my dreams. My wife, Mrs. Faith Jelagat Chepchieng, my children; Austin Cheleywo Chepchieng, Alexandria Jelimo Chepchieng Asher Rotumoi Chepchieng and Andrew Kipkoech Chepchieng for their love, understanding and constant encouragement during my studies.

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LIST OF ABBREVIATIONS/ACRONYMS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AfDB	African Development Bank
ATMs	Automated Traffic Management Systems
CBD	Central Business District
CBS	Central Bureau of Statistics
CMFs	Crash Modification Factors
DoT	Department of Transport
DST	Decision Support Safety Tool
EB	Empirical Bayesian
FOB	Foot Over Bridge
GPD	Gross Domestic Product
GSU	General Service Unit
HICs	High Income Countries
HIV/	Human Immunodeficiency Virus, Acquired Immunodeficiency Syndrome
HSM	Highway Safety Manual
KeNHA	Kenya National Highways Authority

KNBS	Kenya National Bureau of Statistics
LCFs	Local Calibration Factors
LMICs	Low and/or Middle Income Countries
NTSA	National Transport and Safety Authority
OD	Origin-Destination
OECD	Organization for Economic Co-operation and Development Member Countries
PPP	Public Private Partnership
RTA	Road Traffic Accidents
TRL	Transport Research Laboratory
TVC	Traffic Volume Count
USA	United States of America
WHO	World Health Organization

ABSTRACT

Road safety is one of the main transportation problems in developing countries. The major goal of the transportation system is to enhance mobility and road traffic accidents (RTA) are unwanted by-products which have to be minimized while achieving the primary goal. 45km Nairobi – Thika Superhighway Improvement project was inaugurated on December 2009 and completed in November 2012. The project involved redesigns of all intersections and increment in the road lanes to enhance capacity and improve safety. The research aimed to review the crashes occurrences on the improved highway in three phases; before, during and after construction. This research sought to assess the role of incorporation of different safety measures in road projects in Kenya and improve public awareness on the use of road safety provisions with the aim of reducing road traffic accidents and subsequently casualties. The approach used to realize this study involved gathering data from traffic police stations, conducting interviews to get the opinions of road users on safety and making observations on the turning movements of vehicles and pedestrians. The interactions were explored, analysed and modelled using Chi-squared distribution. These were then used to identify accident black spots and assess the effectiveness of road safety measures installed in the new Nairobi Thika superhighway. The total number of accidents recorded over the eight-year period was 993.This study revealed that most accidents occurred before and at the start of reconstruction, reduced by 55% during construction and increased by 79% after completion. 39% of these accidents were fatal, 41% were severe and 20% were slight. Most accidents occurred in the months of July and August. It was observed that the main types of accidents on the highway are Vehicle-Pedestrian; those involving motorcycles were fewer. The highest number of accidents recorded was at Githurai 45, followed by Safari Park and General Service Unit (G.S.U) zones and the least was at Clay works area. Small cars had the highest number of fatal, serious and slight accidents followed by public service vehicles. Most accidents occurred between 1930 and 2030 hours. Drivers and pedestrians were found to be contented with the facilities installed for their safety despite the deficiency in number provided and their locations. The most efficient road safety facilities were found to be footpaths and foot bridges. It is recommended that road safety audits be done on all our roads and retraining offending drivers and all PSV drivers to emphasize change of behaviour and safe driving.

CHAPTER ONE

INTRODUCTION

1.1 Back Ground of Study

Many countries have set ambitious quantified road safety targets (Elvik, 1993). Targets alone cannot guarantee enhanced safety but they can enhance implementation of cost-effective safety measures. To be able to build up a realistic and effective safety programme, the measures must be selected using latest scientific knowledge on their effects. Scientific research has produced lots of good estimates on the effects of safety improving measures (Elvik and Vaa, 2004). The effects are usually presented as a percentage change in the number of injury accidents; so it is vital to be able to evaluate reliably what would have happened if the road safety measure had not been implemented. In addition, experience suggests that the greatest mistakes in evaluating the safety effects of road improvements are done while evaluating the current safety situation. It is a challenge to develop effective measures for improving road safety – especially when resources are scarce and economic means are limited. Nevertheless, a major target for European policy as well for as for national, regional and local decision makers is to improve road safety significantly in our roads (Blaeij et al, 2004).

The transformation of the road from Nairobi City to Thika town into a super highway is one of Kenya's first large-scale transportation infrastructure projects ever undertaken. The road is located at the heart of Kenya's economic engine. The road is part of the classified international trunk road-A2, which originates in downtown Nairobi City and extends to Moyale at the Ethiopian border. Nairobi Metropolitan area is the most dynamic locomotive of growth and employment creation in Kenya accounting for more than 30 per cent of the national GDP. The main features and economic activities along the route are human settlements with urban characteristics, various businesses, light manufacturing, educational institutions, and some farming activities.

The project was jointly funded by Kenya Government, African Development Bank (AfDB) and Chinese Government with a total cost of $360 million. Of the total $360m, the largest share of $180m was financed by AfDB, followed by Exim Bank of China with $100m, while the remaining $80m came from the Kenyan Government. (Graeff & Schumacher-Kocik, 2012).

Beneficiaries of the highway are predominantly people living along the route engaged in various economic activities. More importantly, it serves commuters who travel daily to work in secondary and tertiary sectors within Nairobi city's Central Business District (CBD). Some 100,000 people residing in Kasarani, Kiambu and Thika are salaried workers, while another 125,000 work in the informal sector, a majority of who commute to Nairobi (African Development Bank, AfDB, 2012).

The Nairobi-Thika Highway is one of three major corridors linking downtown Nairobi City to the suburbs and satellite towns. Traffic demand on this road is almost twice the existing capacity. Accident data shows that five years before road improvement up to 2009 ; more than 700 accidents occurred on the Nairobi Thika road of these 227 were fatal. The upgrading of the highway, was expected to provide adequate capacity and considerably improve safety by decreasing the accident rate through minimization of vehicle conflicts by introduction of traffic interchanges and provision of separate service roads for local and non-motorized traffic. The new superhighway has started to yield impressive and visible results. Commuters are enjoying faster, more reliable, comfortable and more affordable journeys. The time taken to traverse the road to Thika town from Nairobi City has dropped from two to three hours to 30-45 minutes. (http://www.kenyaengineer.co.ke/).

The completed 45km Nairobi-Thika superhighway design comprises of six to eight-lanes divided highway with full access control between Nairobi City and Thika Town, service roads along the highway and nine traffic interchanges. The overall objectives of the improvement project were to;

1. Contribute to and improve the accessibility, road safety, affordability, and reliability of the transport infrastructure system.
2. Promote economic growth and socio-economic development in Kenya
3. Contribute to regional integration in the eastern and horn of Africa regions,
4. Improve road transport services along the Nairobi-Thika corridor and enhance urban mobility within the metropolitan area by reducing traffic congestion and improve safety,
5. Contribute to the development of a sustainable urban public transit system for the Nairobi Metropolitan Area
6. Promote private sector participation in the management, operation, and financing of road infrastructure in Kenya. (http://www.kenyaengineer.co.ke/)

The improved facility was primarily expected to spur development, improve safety and reduce losses arising due to traffic congestion and road traffic crashes. With removal of at-grade junctions traffic conflict was expected to be reduced substantially. Road crashes are already a leading cause of deaths in the world and the casualty numbers are expected to increase before they improve. Worldwide over 1.2 million people die per annum due to road traffic accidents, the sixth cause of death according to World Health Organisation (WHO, 2004) after ischaemic heart disease, stroke, lower respiratory infections, chronic obstructive lung disease, diarrhoea and HIV/AIDS. The United Nations has declared this an issue of great concern. Even in low income countries where motorisation is low, road crashes are a leading cause of death amongst males in the prime of life. Road crashes also account for a huge economic loss, as well as human suffering. While road crashes have traditionally been estimated to cost 1 per cent of gross national product (a smaller percentage than in highly motorised countries), this amount has begun to be questioned (Murad, 2011). By 2015 road crashes was predicted by the World Health Organisation

(WHO) to be the leading cause of premature death and disability for children aged 5 and above. In Kenya road accidents account for the loss of more than 3,000 lives annually, a significant proportion of these are young and productive men and women in the 15-45 years age bracket. The economic cost of such road accidents and fatalities has been estimated to be in excess of 4 billion shillings this is a huge loses by any standard that needs an urgent response (Odero et al, 2003). Kenya has one of the highest rates of accident in the world at present with 510 fatal accidents for every 100,000 registered vehicles (http://usalamainitiative.org/). With the high growth of road accidents in Kenya, it is essential that adequate sums of money be spent in dealing with the problem. In the absence of an estimate of accident-related economic issues, it is difficult to identify the sums of money that should be invested each year on road safety countermeasures.

According to Aligula (2010), road transport sector has been increasing from 36.9% in 1997 to 65.3% in 2009 as a share of total transportation sector hence the need to have a reliable road crashes data system which is very important for desirable road safety practice.

Road improvements therefore is geared towards reduction of RTAs by treatment of known accident black spots and other accident prone locations on specific highways, and improvement of journey travel times. Studies on crashes before, during and after improvement of roads gives insight to safety audit taking into considerations the countermeasures provisions.

1.2 Statement of the problem

The Nairobi City -Thika Super highway before 2009 was a dual-carriageway road of about 45 km, constructed to bitumen standard in the early 1970's. The subsequent improvements have been done to address issues of poor level of service, traffic volume capacity and safety. Feasibility report painted the road as a very accident-prone road with high incidences of registered road traffic.

Road crashes kill at least 1.3 million people each year and injure 50 million, a toll greater than deaths from malaria, with up to ninety percent of these road casualties occurring in low and middle income countries. By 2015 road crashes are predicted by the World Health Organisation (WHO, 2013) to be the leading cause of premature death and disability for children aged 5 and above. The economic cost of such road accidents and fatalities has been estimated to be in excess of 4 billion shillings this is a huge loses by any standard that needs an urgent response.

Kenya has one of the highest rates of accident in the world at present with 510 fatal accidents for every 100,000 registered vehicles (Odero et al, 2003). Kenya, being a third world country faces, enormous development challenges and resource needs exceed the supply hence funding of road safety programmes is undermined. Sustainable road safety measures and intervention at national and county levels such as law enforcement, emergency services support, road safety education, hazardous location improvement, public awareness campaigns, rapid mass transport and motor vehicle inspection support are not well coordinated and costed.

Traditionally, rehabilitation design projects have mainly been identified as a result of problems associated with the pavement structure. Although road authorities often require an evaluation of the geometric aspects of a road during a rehabilitation investigation, safety and associated aspects are sometimes neglected (Jordaan G.J, 2006). In addition, Engineering standards and guidelines form the foundation for the design process. They are, however, developed with many objectives not just safety in mind thus strict application of engineering standards may not always result in the safest road environment. Every project, in our case Thika Road has its own specific challenges with regard to safety that need to be addressed. With the high growth of road accidents in Kenya, it is imperative therefore that road safety be considered a priority during and after road constructions and rehabilitation especially of major highways in the country.

This study thus seeks to evaluate the general design standards implemented like horizontal and vertical alignment, intersection and interchange type and layout, sight distances, lane and shoulder widths, super elevation, traffic signals, signing and marking plans, lighting plans, intersection and interchange details, provisions for special users (older pedestrians, the disabled, and bicyclists), drainage, guide rails, and other roadside objects and their effects on safety.

1.3 Research Objectives

1.3.1 Overall objective

The main objective of this study is to assess the effects of road improvement on safety along the 45 km Nairobi -Thika Superhighway.

1.3.2 Specific objectives

1. To assess road traffic accidents black spots along the Nairobi -Thika Superhighway.
2. To establish the trend and characteristics of road traffic crashes before and after rehabilitation.
3. Assess drivers' knowledge and perception of the effectiveness of road safety devices and use of the improved Nairobi -Thika Superhighway.
4. To evaluate the effectiveness of the road safety measures installed on the road and develop counter measures for efficiency.

1.4 Research Questions

1. What countermeasures and safety treatment have been put in place for previously identified black spots?
2. What is the trend of road traffic accidents currently compared to the period before rehabilitation of the Nairobi Thika Superhighway?
3. How receptive are drivers on the use of road safety measures and devices provided in the improved road?
4. How effective are the new safety devices installed in reducing road traffic accidents and how can the devices and safety measures be made more effective and efficient?

1.5 Research hypothesis

This research works on the null hypothesis that:

- o Road rehabilitation improves road safety and reduces road crash rates and frequencies.

And Alternative hypothesis that;

- o Road rehabilitation does not improve road safety and increases road crash rates and frequencies.

1.6 Research Justification

Road traffic safety is a very important concept in the planning, design, construction and operation of road infrastructure. Since independence Kenya government has been gradually being embracing road safety interventions with the aim to reduce the number of crashes on our roads, reduce fatalities and injuries and reduce the severity of injury and optimize the outcome for the injured party. However, the interventions have shown very little evidence of successful implementation due to inconsistency of road safety interventions, multiplicity of uncoordinated institutions, weak and inconsistent regulatory framework, absence of targets to focus road safety interventions and inadequate data for performance tracking and accountability (Aligula, et al, 2010). Road safety engineers are faced with the challenge of addressing safety issues within the three major traffic safety pillars: human, vehicle, and infrastructure. All three aspects must be part of a traffic safety plan and dealt with subject to budget limitations. Consequently, the cost efficiency of systems and countermeasures are decisive factor for policy making.

Currently the government of Kenya has earmarked to rehabilitate and upgrade several roads to bitumen standards with a target of 10,000Km throughout the country within the next five years in order to increase the paved road network from the current 14,000 km to 24,000 km. The improvement is going to be implemented through Roads 10000

Annuity Programme financed through Public Private Partnership (PPP). Currently phase one comprising of 453Km has been approved by the cabinet and implementation stage is on course. (http://www.president.go.ke/2016/03/23/cabinet-meeting-held-on-23rd-march-2016/). With this expected increment in paved road network there is need to audit the safety provisions and its effectiveness on Nairobi City-Thika Superhighway in order to either benchmark on effective measures installed or improve on deficiencies observed for the future road development as planned by the Government. All these factors mentioned boil down to the need to develop infrastructure with a full cycle development attributes which inculcates safety of the users. Therefore, there is need to investigate, analyze available data and improve on incident collection technologies and sensitization of the public.

Road safety devices are being installed on roads throughout the country, and therefore there is the need to address common problems associated with their provision and use. The findings of the safety provisions situation on the Nairobi –Thika Superhighway can be used as a safety benchmark and be replicated in future and existing road projects throughout the country. Therefore, there is the need to establish the performance of road safety devices on roads to justify their installation or planned installation on roads. Traffic characteristics and accident development differ from one country to another. Traffic behavior has also local features in every country hence transfer of modern intelligent transport systems and best practices guaranteeing safety is seldom possible to be replicated from developed countries. It is therefore imperative that local countermeasures befitting the local conditions and culture on our roads need to be formulated. Road safety activities have to be evaluated and monitored to be able to develop countermeasures resulting in the best impact of with scarce resource at our disposal.

The current decade is seeing an unprecedented growth in passenger car use, with numbers almost doubling to reach 1.5 billion by 2020. In 2010, for the first time, sales of light-duty vehicles in (Low and/or Middle Income Countries) LMICs exceeded those in (High Income Countries) HICs. The world is facing major social and environmental issues and safety issues, particularly in LMICs. The challenge will be to promote vehicle safety regulations in LMICs as attentively as the industrialized West has been doing in its own road systems. This shall be made possible through implementation of the good road safety practices in developing countries including Kenya.

The research could have the advantage of pointing out the causes and effects of RTAs. More specifically, this research has the following major significance.

1. Assist concerned bodies in identifying the effects of rehabilitation on road safety.
2. It helps concerned governmental institutions to assess the success of road safety measures.
3. It could also serve as springboard for further studies in the area of road safety audits and put the issue into the ongoing dialogue in the literature review.

1.7 Scope And Limitation Of The Research

1.7.1. Scope of the study

The specific area of research was 45km improved Nairobi –Thika super highway as described in the locational attached in Appendix 5. One element that can aid in transportation safety improvement is an increase in focused transportation safety data collection and analysis. The purpose of this research was to establish and analyse the effectiveness of various safety treatments provided for in the new Nairobi –Thika Superhighway in for improving roadway safety. The measure of the effectiveness of the countermeasures can be replicated in similar or future new road projects in the country.

In addition to the afore mentioned objectives and problems, this study will also establish key elements of the road that still present a threat to safety even after road rehabilitation and a theoretical discussion on safety measures.

1.7.2. Limitation of the study

Limitations of this project include:

- The assumption that all road accidents are reported to the police and recorded. However, some accidents are neither reported to nor recorded by the police.
- The degree of success of a road safety assessment to some extent is dependent on the expertise and experience of the assessor.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews literature on issues pertaining to certain aspects influencing the study and other research contributions in the same line of study. It is otherwise worth to mention that research is a recurring process and this data might not fully cover the comprehensive inclusions of the work done in this thematic area. Given the burden of accidents outcomes which society perceives, it is utterly intuitive to speak about road safety problem(s). Any approach towards the treatment of the problem must basically rise from a complete understanding of the problem, which comprises the definition of the problem and the knowledge of all underlying mechanisms.

Road improvement affects various parameters of the road design that in turn affect road safety. These parameters which affect road safety include;

- Change in road capacity,
- Change in traffic speeds
- Change in number of traffic collisions at some points. (AASHTO, 2010)

In this study other factors that cause road accidents are assumed consistent and further more constant for that matter.

2.2 Defining and Measuring Safety

To be able to determine the level of safety at a road section or site during analysis, it is important to define what safety is and how it is measured. This section discusses the use of crash history as a method to quantify safety. Two methods used for measuring crashes are also presented.

2.2.1 Characteristics of Crashes

Safety has both qualitative and quantitative characteristics. Qualitative characteristics can refer to how safe a driver feels on a transportation facility and are difficult to measure and account for. Quantitative characteristics, such as number of crashes, are easier to measure than qualitative characteristics.

The Highway Safety Manual (HSM) defines safety as "the crash frequency and/or crash severity and collision type for a specific time period, a given location, and a given set of geometric and operational conditions" (AASHTO, 2010). Roadway safety is usually defined and evaluated in terms of the number of recorded crashes. Crash severity also plays an important role in understanding roadway safety. For example, one site may experience considerably more crashes than another; however, the second site may have a much larger proportion of severe, particularly fatal, crashes. Therefore, both crash frequency and crash severity are essential in determining the safety of a facility. In order to understand how to reduce crash frequency and crash severity, it becomes important to first understand the factors behind crashes.

2.2.2 Causes of Crashes

Crashes represent a very small proportion of all of the events that occur on a transportation system. There have been numerous proposed theories that try to explain the causes of crashes. The Handbook of Road Safety Measures (Elvik & Vaa, 2004) provides a more in-depth look at various proposed theories. In this research, it is sufficient to emphasize four conclusions that can be made from these theories:

First, it is probable that all proposed crash theories have an element of truth in them. However, while crash cause theories do include portions of the truth, none of the theories provide a complete understanding or explanation of why crashes occur. One of the key reasons it is difficult to understand why crashes occur is because crashes are usually not the result of one factor, but the combination of multiple events, circumstances, and factors (Grant et al., 2010).

There are three categories of factors that contribute to crashes (AASHTO, 2010):

1. Human – including age, judgment, driver skill, attention, fatigue and experience and sobriety

2. Vehicle – including design flaws, safety features.

3. Roadway/Environment – including geometric alignment, cross-section, traffic control devices, surface friction, grade, signage, weather and visibility.

The combination of multiple events can severely alter the amount of risk a driver may face. For example, imagine a deer runs in front of a driver on a rural highway. Driver A, driving during the daytime, is at considerably less risk than Driver B, driving at night during a snowstorm. Driver A may have to deal with factors such as reaction time, stopping distance, and brake wear. Driver B would be affected by the same factors in addition to reduced surface friction and visibility. Understanding this point helps to understand that crashes are the outcome of a vastly complex random process (Grant et al., 2010).

Secondly, there are certain roadway, vehicle, and driver trends that make the occurrence of a crash more likely. The exact impact these trends have on roadway safety has long been the focus of research. Difficulty arises due to the fact that some are known, while others are not (Grant et al., 2010).

Thirdly, it is also important to understand that even though improvements are continually made to reduce crash frequency, no system is entirely perfect. Drivers are fallible and thus still subject to error in judgment, whether recklessly or not. This provides great difficulty in determining the effectiveness of an improvement (Grant et al., 2010).

Finally, even if it were possible to account for all crash factors, the ability to predict a crash is not absolute. The reason is that crashes are still to some extent a random event (Grant et al., 2010).

The key principle is that understanding the nature of crashes is a vastly complex and random process when considering just the known factors. It is important to remember that there are factors that contribute to crashes that are unknown. The premature assumption might then be made that limited understanding of the contributing factors of crashes make it extremely difficult, if not impossible, to determine the proper remedy for crashes. The Handbook of Road Safety Measures, provides valuable insight in understanding the concept of crash causes. The handbook states "the logic of the argument that you need to know the causes of a problem in order to solve it seems irresistible. Yet, as far as crashes are concerned, there is not necessarily a very close connection between the causes of the problem and its solution" (Elvik & Vaa, 2004). The complexity of known and unknown contributing factors can be overcome through the development and use of proper statistical tools that correctly model crash characteristics and behavior.

2.2.3 Crash Prevention

In general, engineering aspects of safe road infrastructure design revolve around the "5Es" of Safe Road Operations namely: Engineering, Enforcement, Education, Encouragement and Emergency care each one described as follows(Kapila et al., 2013): -

- **Engineering** – Defining the Built Environment including the road design and vehicle design.
- **Education –** Teaching good road behavior through awareness campaigns.
- **Encouragement –** Rewarding people for good road behavior.
- **Enforcement** – Strict application of law.
- **Emergency Care –** Road side medical care and access to para-medics in the "Golden Hour", or the hour immediately following a road accident during which the provision of first aid can greatly enhance the prospects of the accident victim's survival.

In this regard, the role of engineers is paramount to ensuring roads are as safe as possible. From an engineering perspective, road safety can be enhanced by Highway Engineers into various stages of road projects, as follows;

- **Planning Stage -** through land use control policies; providing by-passes for congested
  towns and linking them by spurs; and creating self-contained zones to avoid nonessential traffic in the neighborhood.
- **Design Stage -** designing "Self-Explaining Roads" and "Forgiving Road Side" by selecting the most desirable design standards (and NOT the minimum standards) involving:

  i. Design speed
  ii. Horizontal and vertical geometry
  iii. Cross-sectional elements
  iv. Design of at-grade and grade separated junctions
  v. Provision of service roads for segregation of slow and fast traffic
  vi. Designing effective road furniture, vis-à-vis guard rails, traffic signage, Roadside illumination provisions, etc.

- **Construction Stage -** Proper separation of the construction zone through effective barricading; construction of proper traffic diversions; provision of road signage; environmental controls for reducing noise, dust and other environmental hazards.

- **Maintenance and Operation Stage -** providing an Automated Traffic Management System (ATMS) for safe operation of Traffic and Incident Management. This includes providing Mobile Communication Systems, Variable Message Signs, Weigh-in-Motion System, and Central Control Room.

The key to safe road infrastructure design is consistency of standards so that road users do not encounter unexpected situations. While road crashes are overwhelmingly caused by human failings, the greatest untapped potential to prevent death and injury is through the roads themselves. For example, there has to be a clear distinction between inter-urban roads for high speeds and urban roads for lower vehicle speeds and priority for vulnerable road users. By making the roads more predictable, consistent and forgiving, we can produce a long-term solution that helps save lives and reduce injuries. For example, between 2005 and 2015, in Kenya, infrastructure treatments combined with speed management measures through NTSA saw reduced number of deaths of vulnerable road users by around a third. The road fatalities per 10,000 vehicles has been on decline for the last 5 years and stood at all-time low of 12.34 deaths per 10,000 vehicles in 2015 (NTSA, 2015) as illustrated in Appendix 8. In this regard, it is important for all road engineers to acknowledge the key elements of safe road infrastructure design. (Kapila et al., 2013)

2.2.4 Crash Rate

To model crashes, it first becomes necessary to define what exactly is being measured. Traditional practice has been to use crash rates as a measure of safety. The crash rate is the frequency of crashes adjusted to account for volume or exposure. The general relationship between crash frequency and crash rate is explained in Equation by Roess et al. (2004) as:

$$Crash\,rate = \frac{average\ crash\ frequency\ in\ a\ period}{during\ the\ period\ of\ exposure} \qquad (Equation 2.1)$$

Crash rates for road segments are typically reported in crashes per million vehicle miles traveled (MVMT) or per hundred MVMT. Crash rates for intersections are typically reported in crashes per million entering vehicles (MEV). Equation 2.2 shows the crash rate equation for a section of roadway (Roess et al., 2004).

$$CR_{sec} = \frac{N}{V_{sec} X\ 365\ X\ L} X10^6 \qquad \textit{(Equation 2.2)}$$

Where:

CR_{sec} = crash rate for section (in crashes per MVMT),

N = number of crashes per year,

V_{sec} = average annual daily traffic (AADT) of road section, and

L = length of section (in miles)

Equation 2.3 gives the crash rate equation for intersections (Roess et al., 2004).

$$CR_{int} = \frac{N}{V_{int} X\ 365} X 10^6$$ (***Equation 2.3)***

Where:

CR_{int} = crash rate for intersection (in crashes per MEV), and

V_{int} = sum of average daily approach volumes of intersection.

When using crash rates, an assumption is often made that the relationship between frequency and exposure is linear. Studies have shown that this assumption is not always valid (Hauer et al., 2002). It has been determined that the use of crash frequency is a more accurate indicator of roadway safety than the use of crash rates. Research shows that the relationship between traffic volume and crash count is more complex and relates to quantities such as the distribution of traffic through the day and the types of crashes experienced. Some studies have indicated that there is indeed a relationship between the number of crashes and traffic volume (Miaou, 1994). The exact form, however, is still unknown and likely depends on crash type. Models using aggregate data (not separated by crash type) and exposure as inputs ignore significant variation in highway crashes resulting from hourly volume changes and human behavioral changes throughout the day. A study performed using disaggregate data (crashes broken down by type) revealed how the relationship between crashes and traffic volumes varies from location to location and by crash type (Qin et al., 2004). New approaches are also being developed for incorporating traffic volumes in crash rate analysis and forecasting studies (Grant et al., 2010).

2.2.5 Crash Frequency

One solution that overcomes the non-linear relationship between crash frequency and exposure associated with crash rates is to use crash frequency as the fundamental basis for safety analysis and measurement of treatment effectiveness (AASHTO, 2010). The use of crash frequency as a measure of safety eliminates the inclusion of exposure altogether. A crash frequency is obtained by counting the number of crashes at a certain site of interest, usually a roadway segment or intersection, over a certain period of time. Crash frequency and crash severity are important elements of crash history and form the basis of quantifying and measuring safety. Along with understanding these elements of crash data, it is also important to understand trends exhibited within the data so that an appropriate statistical approach can be used in analysis of crashes (Grant et al., 2010).

2.3 Characteristics of Crash Statistics

This section provides an understanding of the crash statistic characteristics used to determine proper statistical analysis tools. Misunderstanding of crash statistic characteristics has long been the source of great difficulty in accurately predicting crash frequency. Proper understanding the random nature of crashes, regression-to-the-mean (RTM) bias, and long and short-term trends, as discussed in this section, is fundamental to more accurate model crash behaviour.

2.3.1 Crashes as Random Events

In Section 2.2.2, various factors that contribute to crashes were examined. One of the key discoveries from that examination is that crashes are still not completely predictable, even though there are trends and factors that increase the likelihood of crashes. One of the reasons crashes are not completely predictable is that crashes, by nature, are still random events. As such, crash frequencies will naturally fluctuate from year to year. The random nature of crashes must be considered during analysis because it presents a problem when performing studies using a short-term period. It would be nearly impossible to determine if short-term values are representative of the long-term behavior of the site (AASHTO, 2010).

Fluctuations in crash frequency make it difficult to determine whether a reduction in the number of crashes is the result of a specific treatment, changes in site conditions over time, or simply the result of the natural fluctuations due to the random nature of crashes. This phenomenon is referred to as RTM bias.

2.3.2 Regression-to-the-mean (RTM) Bias

The RTM phenomenon expects that a value that is determined to be extreme will tend to regress to the long-term average over time. This means that it is statistically probable that a period of high crash frequency at a site will be followed by a period of low crash frequency (Hauer, 1997). RTM bias refers to the selection of a site as a result of the short-term trend it exhibits, thus not taking into account the RTM. One of the primary limitations with many current safety analysis practices is that they do not account for RTM bias. If RTM bias is not accounted for, it could lead to an inaccurate overestimation or underestimation of the effectiveness of a treatment due to natural fluctuation in the long term statistical characteristics of a site (Grant et al., 2010).

2.3.3 Conflict between the use of short-term and long-term periods in analysis

The RTM bias provides evidence of limitations inherent in using short-term data for analysis. This leads to the assumption that using data from a longer period of time provides a better representation of crash behavior at a site. However, there are problems associated with this method as well. The characteristics of a site, such as traffic volume, weather, and pavement condition change over time. Some of these characteristics, such as weather, continually fluctuate with time. Other factors, such as pavement condition and roadway markings deteriorate gradually from use over time. These latter factors create a legitimate limitation of using long-term crash statistics for site analysis. If longer periods of time are studied to account for RTM bias and site variation characteristics, it is probable that site characteristics have changed during that time period (AASHTO, 2010).

Difficulties exist in the use of both short-term and long-term periods to predict the average crash frequency of a site. Long-term crash statistics operate on the false assumption that all factors contributing to crashes remain constant over time; the use of short-term crash statistics fails to account for the RTM bias. If not properly accounted for, these characteristics may produce misleading results related to the effectiveness of a specific treatment. Fortunately, these issues have been addressed by improved statistical methods of analysis (Hauer, 1997).

2.4 Accident Analysis before and after the Road Improvement

Road rehabilitation involves road reconstruction and therefore road changes. To estimate the effect of such changes, and therefore of the rehabilitation at particular site on the frequency of accidents, the usual procedure is to obtain the details of RTAs at the site in convenient periods before and after and to compare the ratio after to before with the corresponding ratio for a large control area. The latter value may be the whole of the Police Division (Area controlled by the police for a particular network) or some other area for which trends due to external factors can be reliably assessed. The significance between the two ratios can be tested by means of the χ^2 (Chi-squared) test with one degree of freedom.

The general equation of the Chi-squared test is:

$$\chi^2 = \sum \frac{(obs - \exp)^2}{\exp}$$

(Equation 2.4)

Where:

Obs -is the observed count and

exp -is the expected count under the corresponding null hypothesis.

The corresponding probabilities may as well be obtained from the chi-square table of critical χ^2 distribution for various levels of significance shown in the table given in Appendix 2.

Frequently, it is necessary to combine the data from a representative sample of changes of a given type since frequencies for any single change are usually too small to enable useful conclusions to be drawn. This gives rise to three problems. Firstly, unless all the before periods and also all the after periods are of the same length (or more generally, if the 'control ratios after to before are the same at all sites), it is not immediately obvious how the average how the average effect of the type of change concerned should be estimated. Secondly, it is desirable to test whether the effect of a given type of change is the same at all sites. Thirdly, if there is a reason to suppose that it varies, then complications arise in testing the significance of the average change (Hauer, 1997).

Using,

N =Number of sites from which data are to be combined

b_i =Number of accidents in the before period at the site i (1, 2, 3…..., N)

a_i =Number of accidents in the after period at the site i (1, 2, 3…...,N)

C_i-Ratio of accident after to before in the control area for site i (generally assumed to be free from errors), then $N_i = a_i + b_i$

$k_1 = a_1 / (b_i C_1)$-This measure is the apparent effect of the change at site i (it is the ratio of accidents after to the number that it would have been expected if the change had no effect)

It is assumed throughout that b_i and a_i are drawn from a binomial distribution:

$$[\frac{1}{1+k1C1} + \frac{k1C1}{1+k1C1}]^n \qquad \textit{(Equation 2.5)}$$

in which n is regarded as fixed while k is the true value corresponding to the expected values of 1 and b.

When data from only one site is available, there is little choice of the method and the obvious procedure is

$$k=\frac{a}{bc} \qquad \textit{(Equation 2.6)}$$

A value of k greater than unity denotes an increase compared with the control area while a value less than unity denotes decrease.

To test the significance of the change, χ^2 is calculated with one degree of freedom as follows:

$$\chi^2 = \frac{[b-n/\,1+C]^2}{n/(1+C)} + \frac{[a-n/\,1+C]^2}{nC/(1+C)} \qquad \textit{(Equation 2.7)}$$

$$\chi^2 = \frac{(a-bc)^2}{nC} \qquad \textit{(Equation 2.8)}$$

The change is then judged to be real (at the 5% level of significance) if χ^2 exceeds 3.84.

2.5 Distribution of Crash Statistics

Traditional methods have used overly simple before and after approaches to analyze crash statistics. Such methods often involve nothing more than comparing the crash frequency at an entity immediately before an improvement was made to the crash frequency directly after the improvement to determine the effectiveness of the treatment meted (Hauer, 1997).

2.5.1 Crashes as Counts

A common mistake when performing a statistical crash analysis is to model crash data as continuous by using traditional methods such as standard least squares regression. This method is incorrect because such models can produce results that are non-integers or negative values that are inconsistent with crash data (Washington et al., 2003). Crash data are statistically classified as count data and by nature are non-negative integers. Therefore, generalized linear models for crash studies are insufficient because of the false assumption that the dependent variable is continuous (Liu et al., 2008). It then becomes essential to use a different type of analysis when analyzing crash data.

2.5.2 Poisson and Negative-Binomial Distribution

Previous studies have suggested that the use of Poisson models or Negative-binomial models is more appropriate for crash statistics. However, one of the basic assumptions to the Poisson distribution is that both the mean and the variance are equal. Recent research has shown that in crash studies the variance often exceeds the mean (Liu et al., 2008). In this case, the data are said to be over dispersed, which is a major complication when using the Poisson assumption. One of the ways to address this complication is to use a variation of the Poisson distribution called the Negative-binomial distribution which accounts for the over dispersion parameter (Bonneson & McCoy, 1993). The larger the over dispersion parameter, the more the crash data varies in comparison to the Poisson distribution. The various methods discussed further in this research are based on the assumption that crash statistics follow the Negative-binomial distribution.

2.5.3 Predicting Crash Frequency

When performing any type of analysis related to the effectiveness of a treatment on the safety of an entity, it is relatively simple to determine the actual change in crashes between the before and after period through observational analysis. However, it is not only important to determine this change, but it is also important to consider what change in crashes would have occurred had the treatment not been implemented

(AASHTO, 2010). It is difficult to predict what effect a treatment would have on a site if it has not yet been implemented since no observation of the result can be made. Therefore, the use of statistical models is required. This section describes the types of statistical tools that are useful in creating the aforementioned estimation including the development of Safety Performance Functions (SPFs), Crash Modification Factors (CMFs), and Local Calibration Factors (LCFs).

2.6 Safety Performance Functions (SPFs)

One method of predicting the average crash frequency of an entity requires the development of SPFs. SPFs are developed through statistical regression modeling using historic crash data collected over a number of years at sites with similar roadway characteristics (AASHTO, 2010). SPFs use characteristics particular to each site, such as Average Annual Daily Traffic (AADT) and segment length, to create an estimate of the average crash frequency for a specified facility type.

The regression coefficients used in SPFs are determined based on the assumption that the data follows a Negative-binomial distribution. As stated earlier, the Negative-binomial distribution is an extension of the Poisson distribution that accounts for differences between the mean and variance. When the variance exceeds the mean, the data are said to be over dispersed. Studies have shown that this is often the case when dealing with crash data (Hauer et al., 2002). The degree of over dispersion is represented by an over dispersion parameter. This is estimated along with the regression coefficients in the Negative-binomial model. The larger the value of the over-dispersion parameter, the more the data varies compared to the Poisson distribution (Grant et al., 2010). Until recently one of the major deficiencies of SPFs is that they need to be derived for each site. Recent research has helped derive several of these for different facility types, some of which are covered in the Highway Safety Manual (HSM).

In the first edition of the HSM SPFs have been developed for three facility types (AASHTO, 2010):

1. Rural Two-Lane Two-Way Roads
2. Rural Multilane Highways
3. Urban and Suburban Arterials.

And for three site types:

1. Signalized Intersections
2. Un-signalized Intersections
3. Divided and Undivided Roadway Segments

Methods for additional facility types will be added to later editions of the HSM as future research is performed. As these become more widely available, the methods outlined in the HSM will become simpler to use. Agencies with sufficient expertise may develop SPFs unique to their jurisdiction but it is not a requirement for the method outlined in the HSM.

2.7 Crash Modification Factors (CMFs)

The CMF is the ratio of the expected crash frequencies associated with two different conditions and may serve as an estimate of the effectiveness of a specific type of design, control feature, or treatment. The expected average base condition crash frequency represents the expected crash frequency under the initial or base conditions of the site. The expected average condition 'x' crash frequency represents the expected crash frequency when a specific characteristic of interest differs from the base condition while all other characteristics remain constant. Therefore, the CMF represents the relative change in crash frequency due to a change in one specific characteristic, while all others are being held constant (AASHTO, 2010).

$$CMF = \frac{Average\ Condition\ X\ crash\ frequency}{Expected\ Average\ Base\ Condition\ Crash\ Frequency} \qquad \textbf{\textit{(Equation 2.9)}}$$

To illustrate how a CMF is calculated, consider the following example: The CMF value is sought for the effect of increasing the lane width. For the purposes of this example, assume that the expected crash frequency before the change (under base conditions) was 100 crashes per year and that the expected crash frequency after the change (under condition 'x') was 90 crashes per year. Using equation 2.9, the value of the CMF = 90/100 or 0.90.

If a particular site has a specific design feature or treatment that results in a CMF greater than 1, by definition the crash frequency of the site is greater than it would have been without that feature or treatment. Conversely, if the CMF is less than 1, then the site experiences a reduction in crash frequency as a result of the treatment. Finally, a CMF value equal to 1 implies that the treatment or feature had no effect. The CMF can also be used to determine the expected percentage reduction (or increase) in crash frequency using Equation 2.10

$$\textit{Percent Reduction in crashes} = 100 \times (1.0 - CMF) \qquad \textbf{\textit{(Equation 2.10)}}$$

Consider the above example of a proposed change in lane width. In the example, the CMF was calculated to be 0.90 using Equation 2.9. Inputting this value into Equation 2.10 yields an expected percent change of 100 x (1.0 – 0.90) = 10, or a 10 percent reduction in the average crash frequency.

SPFs are multiplied by the CMFs to account for the unique characteristics of a specific site. The Highway Safety Manual (HSM) assumes that CMFs can be multiplied together to estimate the effect of multiple treatments or characteristics. This is based upon the assumption that the effects of treatments or features are independent of each other (Grant et al., 2010).

2.8 Local Calibration Factor (LCF)

One of the critical steps in the HSM (Highway Safety Manual) method is to include locally calibrated factors to adjust the base model for each site type to local crash tendencies. Jurisdictions can vary widely in climate, driver demographics, crash reporting methods, etc. As a result, crash frequencies on similar facility types can vary from one jurisdiction to another. Calibration factors function in a similar fashion to CMFs. Multiplying local calibration factors with the crash frequency calculated by the SPF account for differences between the jurisdiction and time period for the site of interest from the facility type the models are based on (Bauer et al., 2004).

While the use of SPFs and the Empirical Bayesian (EB) method corrects for previously mentioned shortcoming of traditional methods such as correcting for the RTM bias, effects related to changes in demographics, weather, and other characteristics unique to each geographic jurisdiction (such as states) still need to be addressed (AASHTO, 2010). This is accomplished by calibrating the model for the jurisdiction of interest using a local calibration factor, calculated according to Equation 2.11, which compares the actual observed crash frequency of facility type with the frequency, predicted using SPFs and CMFs.

$$C_i = \frac{\sum Observed\ crashes}{\sum Predicted\ crashes} \qquad \textit{(Equation 2.11)}$$

Where,

C_i = Local Calibration Factor for site type i.

Crash frequencies, even with relatively similar characteristics, can vary widely between jurisdictions. This result was emphasized in research done on two-way left-turn lanes using the EB method (Lyon et al., 2008). The results of this study displayed a wide range of effects outlining a need to disaggregate analysis to determine if significant effects can be detected for specific conditions.

Roadways that experience higher crash frequencies than those the SPFs are based on will have calibration factor values greater than one; roadways that experience lower crash frequencies will have calibration factor values less than one. Methods for developing calibration factors to adjust SPFs to local conditions are included in the HSM. Equation 2.12 displays how local calibration factors and CMFs are combined with SPFs to more accurately predict crash frequency (AASHTO 2010).

$$N_{predicted} = N_{spf} \text{ x } (CMF_1 \text{ x } CMF_2 \text{ x } \ldots\ldots \text{ x } CMF_n) \text{ X } C_i \qquad \textit{(Equation 2.12)}$$

Where,

C_i = Local calibration factor,

$N_{predicted}$ = Predicted crash frequency for a specific site type,

N_{spf} = Predicted crash frequency under base conditions, and

CMFi = Crash Modification Factor.

Combining SPFs with factors such as CMFs to adjust for differences in site characteristics, and local calibration factors to adjust for differences within jurisdictions, creates a more accurate estimation of the crash frequency of a given site or facility. This approach helps to correct the uncertainty of both known and unknown factors that contribute to crashes and thereby reduce the amount of error (Grant et al., 2010).

2.9 Methods of Analysis

Several methods have been developed that more accurately determine the effectiveness of a safety measure by combining observed crash statistics with predicted values obtained by the use of Safety Performance Functions (SPFs), Crash Modification Factors (CMFs) and Local Calibration Factors. Some of those approaches include the (Empirical Bayesian) EB approach and the (Highway Safety Manual) HSM predictive method. In recent years, interest in the use of various Bayesian approaches in traffic safety studies have increased significantly. This section provides an overview of these different approaches.

2.9.1 Empirical Bayesian (EB) Approach

Several methods are available to model count data such as crash statistics. One of the more common methods being used in safety studies is the use of Empirical Bayesian (EB) method of analysis. The EB approach has been demonstrably better suited to estimate safety than more traditional statistical methods (Hauer, 1997).

The EB method combines an estimation of the study site crash frequency with characteristics of similar sites using SPFs to estimate the predicted number of crashes. This is combined, in Equation 2.13, with crash records at the site to create an estimate of the site-specific expected number of crashes.

$$N_{expected} = w \text{ x } (N_{predicted} + (1 - w) \ x \ N_{observed} \qquad \textbf{\textit{(Equation 2.13)}}$$

Where,

w = Weighting factor,

$N_{expected}$ = Estimate of expected average crash frequency,

$N_{predicted}$ = Predicted value determined by Equation 2.12, and

$N_{observed}$ = Observed crash frequency at the site.

The weighting factor is used to determine how much "weight" is given to the two estimate methods; i.e. The estimate derived using SPFs based on roadways with similar characteristics and the estimate of the expected number of crashes on the site of interest. The over-dispersion parameter that coincides with each SPF is used in the determination of the value of the weighting factor. Therefore, the reliability of the safety estimation depends greatly on the strength of the crash record and on the reliability of the SPF used. The weighting factor is also used to reflect the statistical reliability of the model.

The strength of the EB method is in the use of a weight that is based on sound logic and on real data (Hauer, 1997). Equation 2.14 shows how the weighting factor is calculated.

$$w = \frac{1}{1+k\ X\ (\sum_{all\ years} N_{predicted})} \qquad \textbf{\textit{(Equation 2.14)}}$$

Where,

k = Over-dispersion parameter of the associated SPF used to determine $N_{predicted}$, and

$N_{predicted}$ = Predictive model estimate determined using Equation 2.12

The EB method addresses two problems encountered when performing safety estimation analysis: First, it corrects for the previously mentioned RTM bias by determining the expected crash frequency of an entity. The elimination of the RTM bias is important whenever the safety of a site is estimated partially or completely by crash history at the site. Second, it also can use crash data older than the traditionally used three year period (Hauer, 1997).

The EB method does suffer from several deficiencies. Perhaps the most unfortunate among these is the need to spend time, resources, and effort on the development of SPFs required for implementation of the EB method. Another major disadvantage of the EB approach is that the SPF is estimated using an aggregate of more than one year of crash data. Therefore, to accurately apply this model, the units of crash frequencies per three years need to be maintained, i.e., annual crash data cannot be used in place of three year aggregated data (Powers & Carson, 2004). Furthermore, the EB method is only applicable when both predicted and observed crash frequencies are available for a roadway network.

2.9.2 Highway Safety Manual (HSM) Predictive Method

The Highway Safety Manual (HSM) produces a step-by-step guide for estimating crash frequencies at a site using the EB method. The HSM predictive method uses functions that are based on a Negative-binomial crash distribution. This method combines the SPFs, CMFs, and local calibration factors to predict the expected crash frequency of an entity. These can then be used independently or as part of the EB method. Various additional studies have been done to aid in developing methods for evaluating safety impacts of highway projects using the EB approach (Al Masaeid et al., 1993).

2.9.3 Accident Prediction Model

Accident prediction models are usually used to monitor the effectiveness of various road safety policies that have been introduced to minimize accident occurrences. They also give an idea to transportation planners and/or engineers to determine new policies and strategies about road safety. Over the past 60 years, many models have been developed to estimate traffic accidents all over the world (Akgungor & Dogan, 2009).

The most common methodological approach used in modeling the relationship between highway geometrical elements, traffic characteristics and accident frequency was conventional linear regression. However, recent research has shown that linear regression has undesirable statistical properties when applied to accident analysis which the results such as vehicle kilometers traveled are directly proportional to variance of the accident frequency, is in a direct violation of the homogenous assumption of linear regression. The effect of this violation invalidates hypothesis tests because confidence intervals are erroneous, thus making it difficult to assess the significance of the estimated coefficients (Jovanis & Chang, 2004).

Another problem is that linear regression is not restrained from predicting negative accident frequency. This would be a significant factor where a main highway section has a low or no accident frequency for some period of time. Negative accident prediction will bias the estimated coefficients, invalidating the model unless corrective measures are taken (Ahmed, 2005). This research seeks to bridge this gap by using Chi Squared analysis models which addresses the association between categorical variable from a single population taking into consideration the set specific hypothesis.

2.9.4 Vehicle Speed versus Road Accident

Speed is one of the contributory factors to road accidents. Speed is also the major parameters in geometric design and safety is synonymous with accident studies. Higher speeds reduce the amount of time any driver has to respond to the unexpected and increases the force of any impact. The importance of lower speeds can be reflected in the following text published by the Association of British Drivers; "Virtually the only factor that road accidents have in common is that all would have been avoided if those involved had known with certainty, a few seconds in advance, that an accident was about to occur.". Therefore, lower speeds provide those extra few seconds (Ahmed, 2005).

Speed is used to measure the quality of traffic flow. It is a scalar quantity which has a magnitude component and it was defined as a rate of motion expressed as distance per unit of time, generally as kilometers per hour (km/hr). The equivalent vector quantity to speed is velocity. As velocity, speed is measured by the same physical units of measurement, but speed does not contain the elements of direction that velocity has.

The Transportation Research Laboratory in its Report TRL 421 (2000) mentions that the faster the traffic moves on average, the more crashes there are. The report also concluded that the crash frequency increases approximately with the square of average traffic speed and that higher speed drivers are associated with a significantly greater crash involvement than are slower speed drivers. It is also noted that for every 1 mph reduction in average speed, crashes are reduced by between 2 to 7 %. More specifically, the crash reduction figure for urban road with low average speeds is 6%, for medium speed urban road and lower rural main roads is 4%, and for higher speed urban roads and rural main roads is 3% (TRL, 2000).

There are various speeds on the road and its difference depends in every area. This difference is determined by the difference posted speed limit on that area. The posted speed limit is achieved by the determination of 85^{th} percentile speed (Mohd, 2011). Nairobi Thika Superhighway has speed limits designated for particular sections of the road; speeds vary from 50Km/h to a maximum posted speed of 100Km/h. 85^{th} percentile determines the speeds at which vehicles are required to travel on a specific sections of the road. It is interesting to note that the relationship between the design speed and the speed limit is not referred to in the geometric design standards of many countries

2.9.5 85^{th} percentile speed

Determining the 85^{th} percentile speed is the first step in establishing a reasonable speed limit for a section of road or street. The 85^{th} percentile speed is the speed at or below which 85 percent of the motorists drive on a given road unaffected by slower traffic or poor weather. This speed indicates the speed that most motorists on the road consider safe and reasonable under ideal conditions. It is a good guideline for the appropriate speed limit for that road (Ghani et al., 2008). The 85th percentile speed was obtained from the cumulative frequency distribution curve which is obtained from the conducted of the spot speed study done by KeNHA's consultant (*M/s CES Pvt Ltd, 2015).*

Studies of crashes on the road carried out in year 2000 in United State have shown that crash rates are lowest at around the 85^{th} percentile speed. Drivers traveling significantly faster or slower than this speed are at a greater risk of being in a crash. It is not high speeds alone that relate to crash risk on our roads; it is the variation of speed within the traffic stream based on posted speed limits (Mohd, 2011). Non adherence to posted speed limits by motorist affects accidents rates on specific location taking into consideration road cross-section effects and Alignment effects.

2.9.6 Traffic volume versus road accident rates

According to Mohd (2011), the number of road accidents naturally depends on the traffic the road carries. The conventional wisdom among the general population is that accident rates should increase with the increasing of traffic volumes, as there is more interaction between vehicles.

Traffic volume studies are conducted to collect data on the number of vehicles that pass a point on a highway facility during a specified time period. This time period varies from as little as 15 minutes to as longer as a year, depending on the anticipated use of the data (Mohd, 2011). The volume is commonly measured in unit of vehicles per hour (veh/hr).

A number of researchers have investigated this complex interaction in the past. One of the first such studies was by Gwynn (1967) who analyzed accidents and traffic flow on US Route 22 through the City of Newark, New Jersey. Crash rates were plotted against hourly volume class, and the author found a distinct U-shape relationship, with more accidents observed at higher and lower traffic volumes. From Masaeid et al. (2004), level of travel and population has a strong influence on urban accidents. Reduction of the need for travel and locating major streets on the edge of an urban zone as well as limiting population density could enhance traffic safety.

2.9.7 Number of Access Points Versus Road Accident

Access point or access control is the condition where the right of owners or occupants of abutting land or other persons to access, in connection with a road is fully or partially controlled by the public authority (Mohd, 2011).

Driveways, median opening and intersections are few of access points commonly found along urban roads. Driveways, either for commercial or private purposes, are roadside openings which lead into business centers, shopping complexes, car parks and hotels. Median openings serve to facilitate vehicles doing right-turning and U-turn. Intersections, signalized or unsignalized, may exist in the form of T-junction, crossroads and roundabouts, all of which serve the purpose of connecting to other roads of either the same or different hierarchy (Mohd, 2011).

The presence of access points, especially in large numbers, hinders traffic flow, as vehicles require adequate time and space to perform their maneuvers at these points (Mohd, 2011).

2.10 Effects of Characteristics of Road Geometrical Design Elements

Some of the primary geometric design elements that can effect on highway safety are carriageway, grade, horizontal curvature, shoulder, median, vertical curve. The relationship between some characteristics of these elements and traffic accidents, including studies made in different countries are classified into groups: Cross-section effects and Alignment effects on traffic Accident

2.10.1 Cross-Section Effects

The widths of the various cross section elements affect the capability of driver to perform evasive maneuvers and determine the lateral clearances both between vehicles and between vehicles and other road users. In the existing literature the following parameters are specially mentioned: lane width, number of lanes, shoulder width and type, median width and type and climbing lanes.

2.10.2 Lane Width

Wider lanes are traditionally associated with higher operating speeds and increased safety. The Highway Capacity Manual (HCM) documents that wider lanes for multilane highways result in higher free-flow speeds. On the other hand, very little has been found on the safety implications of wider lanes. It is reasonable to assume that wider lanes may provide additional space to the driver to correct potential mistakes and thus avoid crashes. However, a driver could be expected to adapt to the available space, and the positive safety effects from the wider lanes may be offset by the higher speeds.

According to Hameed, 2013, most studies agree that lower accident rates are attributed to wider lanes. But it seems that there is an optimal lane width around 3.5m. Other studies have also noted that approaches should base on more parameters of the cross section, at least also on traffic volume. However, Hearne's results suggested that there was a marginal increase in accident occurrence with an increase in carriageway width. Hedman noted that some results indicated a rather steep decrease in accidents with increased width of 4m to 7m, but that little additional benefit is gained by widening the carriageway beyond 7m. TRL pointed out lanes wider than 3.70m do not contribute to a higher safety because they may result in unsafe maneuvers such as over taking despite of oncoming traffic. Another reason is the higher speed on wider lanes which leads to more accidents. Wider cross sections are not attributed by positive influence on road safety. All mentioned works have pointed out a decline of accident risk for wider cross sections. This positive trend is proved up to a certain lane width, wider cross sections are characterized by a lower safety benefit or even by increasing accident risk.

2.10.3 Number of Lanes

The number of lanes is another variable which has been discussed in detail by various researchers. Almost all studies do conclude that the higher the number of lanes, the higher the crash rate. In his research Hameed 2013 found that increasing the number of lanes was associated with increasing traffic crashes. In another study, Abdel-Aty and Radwan found that more lanes in urban roadway sections are associated with higher crash rates. Garber, considered flow per lane and found that there was an increase in the crash rate as the flow per lane increased. Thika road improvement project saw increment of the number of lanes from two to four on the superhighway.

2.10.4 Shoulder Width and Type

There are several purposes in providing shoulder along the highway; these include to accommodate stopped vehicles so that they do not encroach on the travel lane, to make maintenance work, to facilitate access by emergency vehicles and to protect the structural integrity of the pavement. As an obstacle free zone the shoulder gives drivers the possibility to regain control after losing control over the vehicle. There is also evidence that wider shoulders may encourage higher operating speeds because they may communicate to the driver the presence of wider space for correcting errors. Finally, the number of lanes, lane width, and shoulder width are interrelated, and the choice of geometric value for each of these elements typically affects the other elements. The effect of shoulder width and type has been pointed out by different studies as an important aspect in crash frequency. The effect of shoulder width and shoulder paving material goes hand-in hand with lane width, and road side events. The study of Hameed 2013, has shown that increasing the shoulder width is associated with a decline of accidents. 21% reduction of total accidents was determined on road with shoulders of 0.9m-2.7m compared to road without shoulders. He suggested that for roads without shoulders the optimum shoulder width is about 1.5m. An investigation by Turner et al. has shown that on 2-lane roads with paved shoulders and still higher than on 4-lane roads without shoulder. Similar results were worked out by Hedman who found an accident reduction when shoulder increases up to 2m, above 2m the benefit became less. For 2-lane roads a reduction of accidents by 1% -3% and of injuries of 2% – 4% when the shoulder is widened by one foot. Miaou indicates a reduction of signal-vehicle accidents by 8.8% related to one foot widening. In general the design of shoulders regarding the pavement and width has positive influence on road safety. These effects were shown in numerous research works over the last years. A like the road width the positive effect becomes smaller up to a certain shoulder width. Wider shoulders have no positive impact. Also paved shoulders influence positively safety especially on narrow roads.

2.10.5 Medians and Median Barriers

In Road Design, medians are mainly used for traffic separation. However, medians serve other additional and equally crucial objectives such as provision of recovery areas for errant maneuvers, and the provision for emergency stopping.

One study which evaluated median types found that the safety of the median type decreased in the following order: flush, unpaved, raised curb and crossover resistance

(Hadi et al., 1995). Wider medians also seem superior to narrow medians plus a physical barrier, since these can only be effective if vehicles actually collide with them. Another study found that on high-speed roads with two or more lanes in each direction, medians improve safety in a number of ways, for example by reducing the number of head-on collisions and cross over crashes (Hameed, 2013).

Elvik R and Vaa T noted that the type of the median barrier is also an important aspect, since different types (especially concrete) have the potential to increase crashes and affect accident severity (Elvik & Vaa, 2004)

2.10.6 Horizontal Alignments

The alignment is the route of the road, defined as a series of horizontal tangents and curves. When the curve radius is smaller, the accident rate is higher. The transverse stability (includes slippage and overturn) happens before the longitudinal stability on the curve based on vehicle steering theory, so the radius value is decided by the transverse stability of vehicle (Zhang, 2009).

It has been shown by a number of researchers that in horizontal curves, milder curves are associated with lower crash rates compared to sharper curves (Glennonet al., 1985 and Zeeger et al., 1991). Those researchers also found that horizontal curves seem to have proportionately more head-on and opposite direction sideswipe crashes, fixed object, crashes, rollover crashes, and nighttime crashes compared to other sections. Most investigations show that with increasing radii the accidents frequency declines (DoT USA, 2007). OECD suggested radii smaller 430 m as critical. In fact, Hameed concluded that small radii are characterized by a higher accident frequency as well as accident severity. Pfundt and Barkov investigated the relation between the number of curves and the number of accidents and found that roads with many curves are characterized by less accidents than roads with few curves (DoT USA, 2007).

2.10.7 Gradients

Steep gradients are generally associated with higher crash rates. Grades of 2.5% and 4% increase crashes by 10% and 20%, respectively, compared with near-horizontal roads (Hedman, 1990). Glennon et al, after examining the results of a number of studies in the United States, concluded that grade sections have higher accident rates than level sections, steep gradients have higher accident rates than mild gradients and down gradients have higher accident rates than up gradients.

2.10.8 Super Elevation

In order to counteract some centrifugal force that acts on vehicle when it is running on the curve, usually the pavement traverse slope is designed as higher outside while lower inside to from single slope, this called super elevation. This can counteract all or some centrifugal force and can improve traveling stability and comfort. The equation of traverse super elevation value (Equation 2.15) can be deduced by balance force act on vehicle when traveling on the horizontal curve as expressed:

$$e = \frac{V^2}{127R} - f \qquad \textit{(Equation 2.15)}$$

Where

e –Superelevation expressed in % gradient

V- Design speed of the road section in Km/hr

R - Radius of curve expressed in metres

f - Coefficient of friction as recommended by AASHTO.

Superelevation value can be calculated according design speed, radius value, road alignment, and considers local natural condition. Improper superelevation value or no superelevation all will cause accident. Maximum rates of superelevation are limited by the need to prevent slow-moving vehicles from sliding to the inside of the curve and, in urban areas, by the need to keep parking lanes relatively level and to keep the difference in slope between the roadway and any streets or driveways that intersect it within reasonable bounds. AASHTO recommends that maximum superelevation rates be limited to 12 percent for rural Horizontal alignment roadways; 8 percent for rural roadways for which snow or ice are likely to be present; and 6 percent or 4 percent for urban streets. In addition, there is a tradeoff between the maximum rate of superelevation and the minimum curve radius permitted at any design speed. AASHTO recommends the minimum curve radii shown in Table 2.2. For the higher design speeds, the superelevation rates for these minimum curve radii, as calculated by Equation (2.15), are less than the maximum superelevation rates given above. Consequently, the maximum superelevation rates really apply only to fairly low design speeds. Superelevation of curve have an impact on the traffic safety performance of highway sections. Research that relates traffic safety to roadway horizontal alignment has consistently shown that traffic accidents increase with increasingly sharper curve. Sharper curves in segments that otherwise have good alignment, tend to surprise drivers and create even more hazardous situation. Consistency in design speeds along significant sections of highways has been advocated by some, as a means of controlling the incidence of surprise curves in other gentle alignments. However, design speeds for horizontal curves serve as function of the maximum superelevation policies adopted by a design agency. Therefore, a single curve design may be regarded as having different design speeds by agencies that have different maximum superelevation policies.

Table 2.1: Values of side friction recommended by AASHTO

Design speed, km/h	**Maximum side friction factor,** ***f***
30	0.17
40	0.17
50	0.16
60	0.15
70	0.14
80	0.14
90	0.13
100	0.12
110	0.11
120	0.09

Source: American Association of State Highway and Transportation Officials, AASHTO

Table 2.2: Recommended minimum radius of curvature

Design speed, km/h	**Minimum curve radius, m**
30	**35**
40	60
50	100
60	150
70	215
80	280
90	375
100	490
110	635
120	870

Source: American Association of State Highway and Transportation Officials, AASHTO

2.11 Chapter Summary

In summary, safety is measured by the frequency and severity of crashes on a roadway segment. There are many known and unknown factors that contribute to the difficulty in understanding why crashes occur. This difficulty can be overcome through the use of the proper statistical tools. In order to properly perform analysis on crash statistics, it is essential to analyze the characteristics of crash statistics so as to determine the proper statistical tools to use. The use of such statistical tools can allow the effectiveness of a safety measure to be properly evaluated.

Effectiveness evaluation is an important component of determining the overall impact that a treatment has on a project as well as assessing how well funds have been invested in safety improvements. Evaluating the change in crashes from implemented safety treatments provides an effectiveness assessment of a specific treatment on reducing crash frequency or severity. Traditional before and after analysis of crash data is usually insufficient to determine the actual effect of a treatment. Such studies are based on the incorrect assumption that all factors aside from the treatment remain unchanged over the course of the evaluation; they fail to take into consideration factors such as the RTM bias, changes in climate and land use that occur over time, and other factors that can impact results. Chi-squared analysis methods overcome limitations of traditional analysis methods and greatly improve the capability of safety analyses to accurately determine the effectiveness of the treatment. With this comparative advantage of Chi-Square statistical method of analysis this research shall use Chi-square test to analyses data collected with respect to the various variables. The Chi-Square statistic is most commonly used to evaluate Tests of Independence when using a cross tabulation (also known as a bivariate table). Cross tabulation presents the distributions of two categorical variables simultaneously, with the intersections of the categories of the variables appearing in the cells of the table. The Test of Independence assesses whether an association exists between the two variables by comparing the observed pattern of responses in the cells to the pattern that would be expected if the variables were truly independent of each other. Calculating the Chi-Square statistic and comparing it against a critical value from the Chi-Square distribution allows the researcher to assess and determine whether the observed cell counts are significantly different from the expected cell counts. This result validates the set hypothesis of the research undertaken.

This chapter has also highlighted the different changes that occur during reconstruction such as, lane widths, shoulder width and type, gradients, horizontal alignment and vertical alignment design, vehicle speed, traffic volume and access point and their said effects on safety.

CHAPTER THREE

METHODOLOGY OF THE STUDY

3.1. Introduction

The main aim of this chapter was to describe the methodology used in this study. The direct method uses experimentation and observation to find out if a 'promise looking' safety devise or idea does in fact increase road safety. The indirect method, more characteristic of scientific research, uses fundamental investigations which endeavor in building up an understanding of the phenomena of Road Traffic Accidents (RTAs) and effects of road improvement on safety.

For scientific purpose it is thought better to regard the phenomena of RTAs as a chance process. At any time, the road, the traffic, the user and the vehicle is a set of circumstance that have a certain chance or probability of leading to an accident.

The following sequence was followed during the study:

a) Field observations were conducted to establish road conditions that pose a threat to safety. Road characteristics that were of interest during the survey include:

- Cross-section
- Drainage
- Roadside
- Safety barriers
- Alignment
- Junctions
- Bus and Parking facilities
- Access to properties
- Speed management
- Pedestrian road usage characteristics and provision of pedestrian facilities

b) Conducting interviews.
c) Collection of road accident data and traffic count data for the study section and its interpretation.

3.2. Assessing traffic road blackspots along in Nairobi –Thika Superhighway

3.2.1 Research Design

Qualitative research was adopted to assess the black spot locations along the study road. According to Polit and Hungler (1999), a survey is used to obtain information from groups of people (i.e. pedestrians and drivers). The information that is obtained may be concerned with the prevalence, the distribution, and/or the interrelationships between variables within these groups.

The purpose of qualitative descriptive research is to;

- observe
- describe
- Document aspects of a situation as it naturally occurs (Polit & Hungler 1999)

3.2.2 Data Collection Procedure

Both primary and secondary data were collected to enable the researcher assess the road accident black spot along the study road.

Secondary data were obtained from the Kenya Police Service raw records documented in P41 forms, and then it is further recorded in the police accident books. A sample of P41 form is attached in Appendix 9. The information recorded in the P41 forms include, the precise location of the accident, date and time of occurrence, type of accident that is whether fatal, serious or slight, age of road user involved and class of road user.

Primary data were collected by direct observations (site visits), spot speed measurements and traffic volume count of the study areas on specific locations identified as having highest number of road accident occurrence. The site visits were conducted for two weeks so as to gain an understanding of the existing conditions and surroundings. The visits were done at different times of day including night so as to collect practical data.

This included taking photographs to aid in the analysis and understanding of the problems. The data obtained were analyzed and presented as described in section 4.3.2 and tables 4.6, 4.7 and 4.10.

3.3 Assessing trends and characteristics of traffic road accidents

3.3.1 Research design

To address research question 2, a benchmark needs to be developed to enable comparison, in qualitative way, of measures based on road improvement, vehicle types, time of the day, month of the year, road surface conditions, traffic volume, traffic composition, traffic speed and driving assistance systems respectively. Mainly based on literature review a set of basic principles for road traffic safety identified and further elaborated, and, in addition, for each of these operational requirements. For each measure of both categories it is established and analysed on which requirement(s) it is specifically acting and relationship thereof. This enables to match measures from the two categories that have comparable functionality in view of traffic safety with respect to road infrastructure improvement. Further quantitative comparative analysis only deals with measures that are functionally related. Road traffic safety principles and operational requirements (that are proposed and used as a benchmark), as well as the functional substitutability relationships between measures, are analysed and described in Chapter 4.

3.3.2 Data Collection Procedure

Raw data for various road traffic accidents were collected from the Kenya police and tabulated in Tables 4.1, 4.2, 4.4 and 4.5. Report on previous accidents, traffic and speed studies were obtained from previous research reports and feasibility and design reports of the new Nairobi Thika Super Highway. Recent traffic counts and forecasting done by KeNHA were also adopted for this study as documented in Appendix 3.

The traffic accidents trends and characteristics parameters were analysed using Chi-square test to establish relationship existence with respect to the set research hypothesis. Analysis were done and presented in Figures 4.1 to 4.7.

3.4. Assessing drivers knowledge and perception of the effectiveness of the road safety devices

3.4.1 Research design

To address the research question 3, Qualitative research methods were adopted to assess the driver knowledge and perception along the study road with regards to the safety devices installed.

Questionnaires and observations were used to collect the required data.

3.4.2 Target population

The target population were motorist and vehicles plying the study road (Nairobi -Thika Superhighway).

3.4.3 Sample Frame

The sample frame included drivers of all types of vehicles, vehicle types including HGVs, MGVs and PSVs and accident occurred along the Nairobi -Thika Superhighway.

3.4.4 Sampling Techniques and Sample Size

Simple random sampling technique was used to get a fair size of the target population. Considering the time, cost and type of targeted data to be collected. Cochran's equation was used in the determination of the sample size as described in equation 3.1. The sample size was found to be 385.

3.4.5 Data Collection Instruments

Data collection instruments used included;

- Questionnaires
- Interviews
- Observations

3.4.6 Data Collection Procedure

Using designed questionnaires, the survey was randomly done on specific location of the study by administering the questionnaire. The results of the survey were summarized as tabulated in the Appendix 1B. The analysis and presentation of the interviews and observations are documented in part 4.5 and 4.6 of the research and illustrated in Fig 4.10.

3.5 Evaluating the Effectiveness of Road Safety Measures installed along Nairobi –Thika Superhighway

3.5.1 Research Design

Qualitative research techniques were adopted to evaluate the effectiveness and efficiency of installed safety devices along the study road. The relationship between the number of accidents before, during and after rehabilitation was analyzed with respect to the safety devices design, availability, location, type and number.

3.5.2 Data Collection Procedure

Using observation, review of the new road design and recorded road accident data obtained from the Kenya Police Service the data were collected and correlated deduce the relationship between accidents occurrence and provision of specific safety device or road design provisions.

Data collected by direct observations (site visits) included carriageway markings, drainage system, street lighting, road signs, road carriageway surfacing conditions and vehicle maneuverability. Measurement were carried out for lane widths, road lengths, , spot speeds and traffic volumes count along the study road. The data obtained were analyzed and presented as described in section 4.6 and figures 4.10, 4.011, 4.12 and 4.13

3.6. Primary Data Collection

3.6.1 Direct Observations (Site Visits)

The following are the parameters that were observed during the field study:

a) Carriageway Markings

The carriageway was traversed on foot as well as mobile quick survey in a moving public service vehicle to establish the presence of carriageway markings and to verify their visibility. This study was carried out to establish if there is a need to improve the markings.

b) Drainage System

The drainage system was inspected during the rainy season and the dry season too. The system was also evaluated by observing parts of the roads that are prone to flooding.

c) Street Lighting

Street lights help in visibility during the night. Thus, a survey was done at night to establish the working condition of the street lights along the road. The spacing between successive street lights was also measures and checked for adequacy.

d) Road Signs

The carriageway was traversed to investigate the availability and usage of road signs like stop signs, pedestrians' crossing signs, speed limits and so forth. The road signs were recorded as vandalized or in good condition.

e) Pot Holes and Other Road Defects

The carriage way was traversed to investigate the presence of pot holes and other pavement defects like broken edges, receding edges, cracked pavement etc. This was done for both directions of the carriage way.

f) Vehicles Manoeuvre Observation

Large buses and heavy goods vehicles manoeuvres were observed at all the roundabout/interchanges between the Museum Hill in Nairobi and Blue Posts Hotel in Thika. In addition, pedestrians' use of walking and crossing facilities was also observed and noted.

3.6.2 Speed Measurements

In order to assess typical speed levels at human settlements on the highway, spot speed measurements were conducted at selected points between Km 0+000 (Museum Hill) and 45+000 Thika town. The vehicle speeds were also taken at sections with specified speed limits. The speed measurement results area described in Table 4.10.

3.6.3 Interviews

Spot interviews using questionnaires (Appendix 1A) were conducted with drivers of both public and private vehicles driving along and around Nairobi-Thika Superhighway. Their responses to specific questions on the questionnaire relating to the use, ease and appropriateness of the road traffic safety measures installed on the road was established.

An assumption was made that the population is unknown, thus Cochran's equation (Equation 3.1) was used in the determination of the sample size.

$$n_0 = \frac{Z^2 * P * Q}{e^2} \qquad \textbf{(Equation 3.1)}$$

Where: n_0 = Sample Size

Z = Z score (area under the normal curve)

P = Estimated proportion of an attribute (Standard Deviation)

e = Desired level of precision

$Q = 1 - P$

With a 95% desired confidence level, standard deviation of 5 and a desired margin of error of ± 5%, the sample size for this study was calculated as follows:

$$= \frac{1.96^2 * 0.5 * (1 - 0.5)}{0.05^2}$$

$= 385$

3.7 Secondary Data Collection

Data was obtained from secondary sources namely; Police stations, Kenya National Highways Authority, newspapers and other written publications and reports.

3.7.1 Road Accident Data

Road accident data used in this study was obtained from police records. The Kenya Police routinely collect and store data on motor vehicle accidents mainly for prosecution and insurance compensation purposes. The accident data used in this study was collected from Kasarani, Githurai ,Ruiru, and Muthaiga police stations and the traffic police headquarters, Nairobi, Kenya.

Accident data in police stations is recorded in the P41 forms, and then it is further recorded in the police accident books. A sample of P41 form is attached in Appendix 9. The information recorded in the P41 forms include, the precise location of the accident, date and time of occurrence, type of accident that is whether fatal, serious or slight, age of road user involved and class of road user. Though the mentioned information is useful it is insufficient. Factors like the weather condition during the accident and cause of the accident would have been of great help for this study.

Accident data used in this study include road accident data collected for the year 2005 to 2013, between Muthaiga roundabout and Ruiru. This data covered the pre-construction period, construction period and post-construction period.

The expected frequency and severity of crashes caused by each safety issue have been identified and rated according to the categories shown in Tables 3.1.

Table 3.1: Severity Rating

TYPICAL CRASHES EXPECTED	EXPECTED CRASH SEVERITY	SEVERITY RATING
Crashes involving high speeds or heavy vehicles, pedestrians, or bicycles	Probable fatality or incapacitating injury	Extreme
Crashes involving medium to high speed; Head-on, crossing, or run-off-road crashes	Moderate to severe injury	High
Crashes involving medium to low speeds; Left-turn and right-turn crashes	Minor to moderate injury	Moderate
Crashes involving low to medium speeds; Rear-end or sideswipe crashes	Property damage only or minor injury	Low

3.7.2 Accident, Traffic and Speed Studies Reports

Report on previous accidents, traffic and speed studies was obtained from previous research reports and feasibility and design reports of the new Nairobi Thika Super Highway. Recent traffic counts and forecasting done by KeNHA were adopted for this study as documented in Appendix 3.

3.7.3 Volume Counts

Vehicle counts also referred to as flow is expressed in vehicles per hour or day (Veh/hr or veh/d). Volume counts help in ascertaining whether the transport facility is adequate or if it is handling volumes that are above its expected capacity. The counts also help in establishing the effects of vehicles volumes on crash rates, and accident severity. The vehicle classification used during the volume counts aid in determining whether a relationship exists between road accidents and type of vehicle.

For this study, vehicle volume counts were obtained from Kenya National Highways Authority (KeNHA) which has conducted traffic volume counts along the road after completion of its reconstruction/Improvement. This study also used the seven-day traffic volume counts that were done by APEC consultants before the improvement /reconstruction of Nairobi Thika Superhighway in 2006. Both of the above studies employed Direct Manual Counting method where the counting is done using hand tally and manual counters. The vehicles were classified as motor cycle, private cars, buses, matatus, light goods vehicles, medium goods vehicles and heavy goods vehicles.

The figure below shows the traffic count stations along the highway.

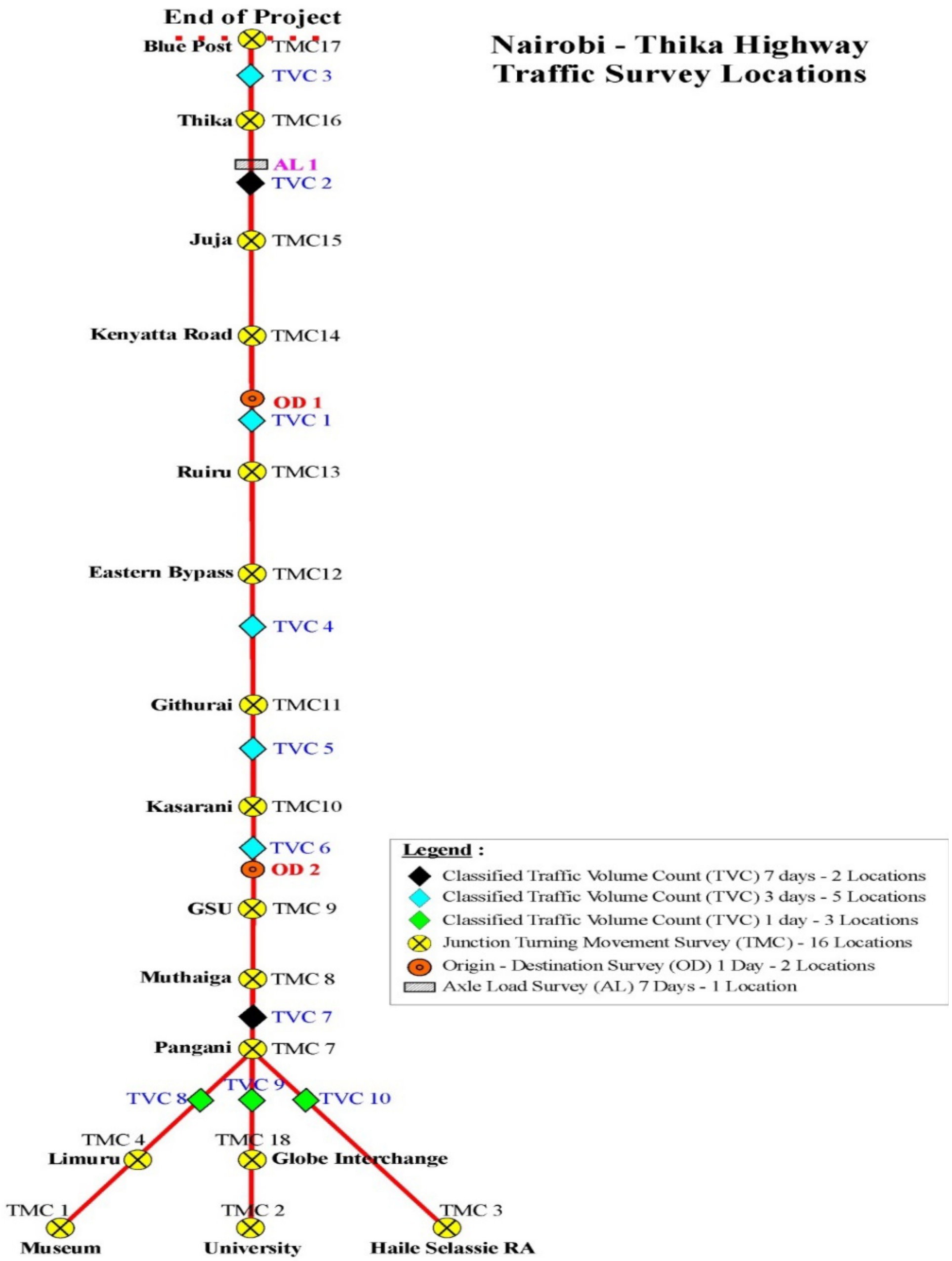

Figure 3.1: Traffic Survey Location (Source: KeNHA, feasibility Report)

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.1 Introduction This chapter presents the requisite data collected as outlined in the previous chapter. The data was analyzed using mathematical tests: -Chi-Square Tests for goodness of fit, linear dispersion and mean. The relationship between safety and road variables has been presented in the form of charts and graphs for interpretation.

4.2 Number of accidents

The total number of accidents recorded in the span of 8 years was 993 (Table 4.1). The most number of accidents occurred in the years before and at the start of construction, that is 2006 to 2009. In the following two years of construction, 2010 and 2011, the number of accidents reduced remarkably. This can be explained by the reduced vehicle speeds during construction. At the end of construction, that is year 2012, when most of the construction was completed, there was a 79% increase in the number of accidents over the previous year. However, the linear graph showing the tendency (Fig. 4.1) indicates that in general the number of accidents reduced over the five-year period. Decrease in accidents during the period before construction phase between 2006 and 2009 can be attributed to law enforcement campaigns including 'Michuki' rules which introduced and emphasized use of safety belts by motorists.

The reduction of the accident rates within the three phases of construction can attributed to the behaviour of drivers, pedestrians and motorist with regard to the provided road safety facilities provided. It was observed that pedestrians tend to risk crossing on undesignated sections of the roads due to the distances between the provided feet over bridges. The risk crossing taken by the pedestrians could explain the high number of fatal and serious accidents recorded between 2009 and 2013. The same scenario points out to the adequacy of the safety measure provided. The road agency maintaining the road have already proposed additional safety measure to reduce these types of accidents as illustrated in Appendix 8. With the improved road drivers tended to exceed posted speed limits on different road section whereas installation of speed and rumble strips helped to calm traffic rear end collision type of accidents were reported on these spots. Head-on collisions type of accidents also reduced substantially since the traffic separation was effected and accesses to the highway were minimised

Table 4.1: Accident data before, during and after construction (Source: Kenya Police, 2013)

ACCIDENT DATA									
Period	**Year**	**Veh to Ped**	**Veh to Road**	**Veh to Cyclist**	**Veh to Veh**	**Slight**	**Fatal**	**Serious**	**Total No of Accidents**
Before	2006	96	35	15	62	32	53	72	**208**
	2007	84	42	21	45	56	62	58	**192**
	2008	53	16	6	34	29	55	26	**109**
	2009	76	18	7	58	28	76	55	**159**
	Total 1	**309**	**111**	**49**	**199**	**145**	**246**	**211**	**668**
During	2010	30	27	7	28	14	36	40	**92**
	2011	32	8	3	14	16	12	27	**57**
	Total 2	**62**	**35**	**10**	**42**	**30**	**48**	**67**	**149**
After	2012	76	9	2	15	7	44	55	**102**
	2013	48	10	3	13	5	31	48	**74**
	Total 3	**124**	**19**	**5**	**28**	**12**	**75**	**103**	**176**
Grand Total		**495**	**165**	**64**	**269**	**187**	**369**	**381**	**993**

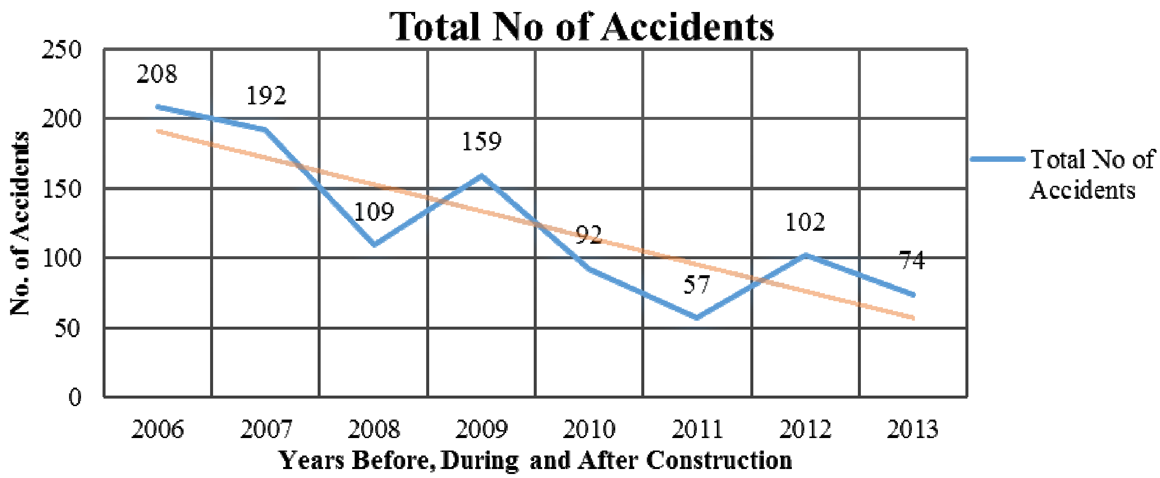

Figure 4.1: Total numbers of accidents and their trend.

4.2.1 Location of Accidents

Githurai 45 recorded the most number of accidents (173) along the highway followed by Kahawa Barracks, Safari park and G.S.U with 107, 104 and 100 accidents respectively (Table 4.2). These areas, especially Githurai were and still are, characterised by high population densities and unruly road users. For Kahawa Barracks the accidents before construction were the highest due vehicular –human traffic conflict; zebra crossing points were minimal and road side development encroached into the road reserves. After construction minimal number of accidents were recorded due to provision of safety measures which ensured separation of traffic by provision of walkways, service roads, guard railed median barrier and pedestrian footbridges.

The accident trends for Githurai 45 shows minimal improvement before, during and after construction of the Nairobi –Thika superhighway. The safety device provided at this section is an overpass with service roads serving the Githurai 45 residents, the service road is characterised by crowding of matatu and pedestrians despite provisions of walkways. The all-time high accidents on this location can be attributed to the lack proper provision of safe crossing points especially before and after the overpass. Also failure by pedestrians to use the provided walkways and matatus failure to use designated bus bay to collect or drop passengers.

It was observed that the accident trend at G.S.U, Roysambu, Kahawa barracks and K.U reduced because of the construction and usage of pedestrian footbridges in those areas. It was noted that at Roasters a footbridge and zebra crossing had been provided, but the number of accidents increased in spite of this. Enforcement by the traffic police and sensitization of all road users is proposed to change the motorist culture of lawlessness. It is also observed that there is inadequacy of the specific safety device on the accident spots to address specific type of accidents.

Table 4.2: Accident Location along the Highway (Source: Kenya Police Database 2015)

LOCATION OF ACCIDENTS									
LOCATION	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
K.U	11	9	6	12	5	3	5	7	**58**
Engen	15	13	5	14	4	4	1	10	**66**
Kahawa Barracks	27	32	9	11	12	6	7	3	**107**
Githurai 45	25	36	28	26	9	8	26	15	**173**
Clayworks	10	8	5	13	7	3	5	3	**54**
Roysambu	22	10	11	15	6	5	15	7	**91**
Safaripark	17	16	10	16	17	12	8	8	**104**
Roasters	9	7	10	7	4	4	13	8	**62**
G.S.U	19	15	14	16	11	4	9	12	**100**
Crescent P.S	5	6	2	3	1	1	0	0	**18**
Total P.S	3	2	1	1	0	0	0	0	**7**
	163	**154**	**101**	**134**	**76**	**50**	**89**	**73**	**840**

4.2.2 Crash Rates by Location

This part of the analysis identified statistically dangerous locations on the road i.e. black spots. In order to obtain crash rates at each location, the Annual Daily Traffic (ADT) was assumed to vary insignificantly at the different locations on the highway. Table 4.3 shows the crash rates for the different locations over the years. Using Equation 2.2, Githurai 45 recorded the highest crash rate of 4.06, 1.96 and 2.56 before, during and after construction respectively. The crash rates are more than 1.0 showing the safety interventions and treatments provided for the section have not shown any improvement.

Table 4.3: Crash Rates for each Location

LOCATION	CRASH RATE FOR LOCATIONS(PMVKT)		
	Before	**During**	**After**
K.U	1.19	0.91	0.86
Engen	1.51	1.00	0.96
Kahawa Barracks	3.12	1.32	1.42
Githurai 45	4.06	1.96	2.56
Clayworks	1.05	1.05	0.50
Roysambu	1.96	1.12	1.32
Safari Park	1.96	2.05	1.10
Roasters	1.19	0.68	1.32
G.S.U	2.19	1.42	1.50
Crescent P.S	0.59	0.23	0
Total P.S	0.27	0.05	0

The same scenarios were observed for Kahawa Barracks, Roysambu, Safari Park, Roasters and GSU area where the crash rates before shows a decrease from before to after but still crash rates exceeding 1.0. The trends can be attributed to the inadequacy of the safety devices, lawlessness and changes of types of accidents with respect to the increment in traffic volumes on the new improved Nairobi –Thika Superhighway.

4.2.3 Traffic Accident Severity

Out of the 993 accidents, 39% were fatal and 41% were serious (Figure 4.2). The trend of slight accidents generally decreased during the 8-year period; however, that of fatal and serious accidents reduced then later increased after the completion of the project as shown in Figure 4.2. and Table 4.4. The fact that fatal accidents are still the most type of accidents shows that additional safety measures (policy and physical) still need to be put in place and effected.

The accident severity reduced significantly after the road improvement by construction by 70%, 51% and 92% for fatal, serious and slight injuries respectively.

Table 4.4: Comparison of Accident Severity before and after construction (Source: Kenya Police Data base, 2013)

Severity	Before	After	Total No of Accidents
Fatal	246	75	321
Serious	211	103	314
Slight	145	12	157
Grand Total	602	190	792

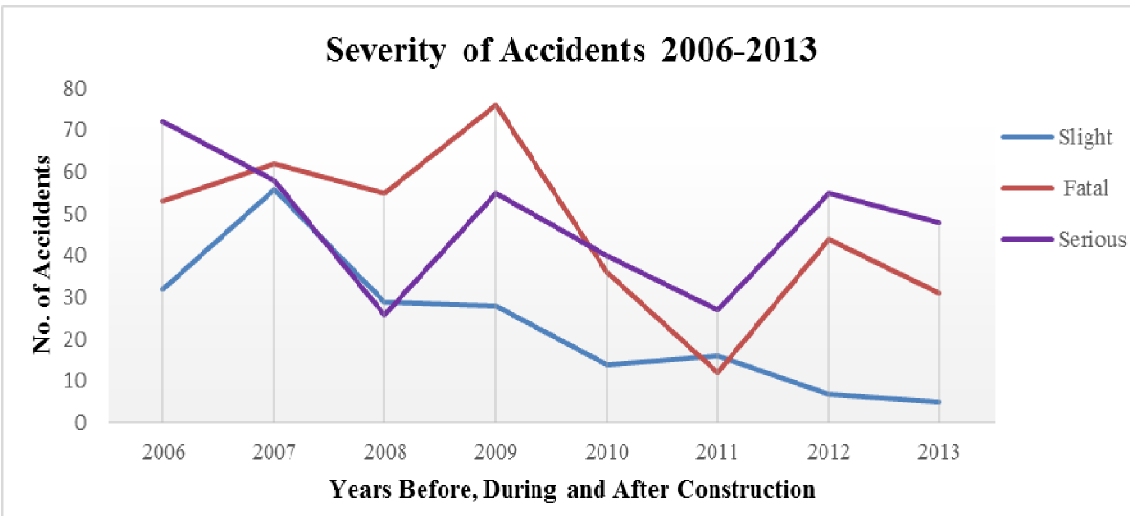

Figure 4.2: Severity of Accidents Before, During and After Construction

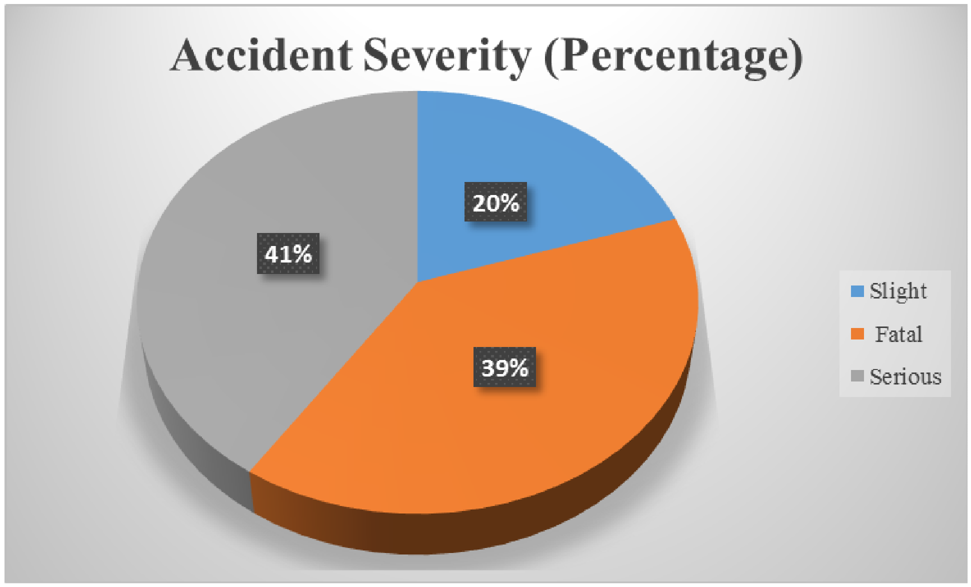

Figure 4.3: Severity of Accidents Before, During and After Construction

Before construction period was taken to be between 2006 and 2009 while construction period was from 2009 to 2011 whereas after construction period began from 2011 to 2013. Fatal accidents increased during and after the construction of Nairobi –Thika Superhighway. The reasons for the increment of the fatalities severity during the construction stage can be attributed to the inadequate provision of safety devices including provision of proper signage to forewarn motorists, lack of workable traffic management plan and poor condition of the road diversions. After construction period the fatal and serious accidents severity increased mainly because the motorist's failure to observe posted speeds limits on specific sections of the road, lack of knowledge/driving skills on the new superhighway and pedestrian's failure to use provided safe crossing footbridges.

4.2.4 Type of Accidents

The primary type of crashes/accidents along the highway was found to be Vehicle to Pedestrian, 50%, followed by Vehicle to Vehicle, 27% (Figure 4.3). Pedestrians continue to be the most vulnerable road users despite installation of foot bridges, zebra crossings bumps and pedestrian foot paths along the highway. The number shot after completion of the project because of the tendency of drivers to exceed the posted speed limit because the additional lanes ease vehicle manoeuvrability. In addition, it was observed that some pedestrians had the tendency of not using the facilities (foot bridges) provided for them. Vehicle to Road accidents have reduced significantly owing to the new features in the highway like additional lanes and grade intersections (Figure 4.4).

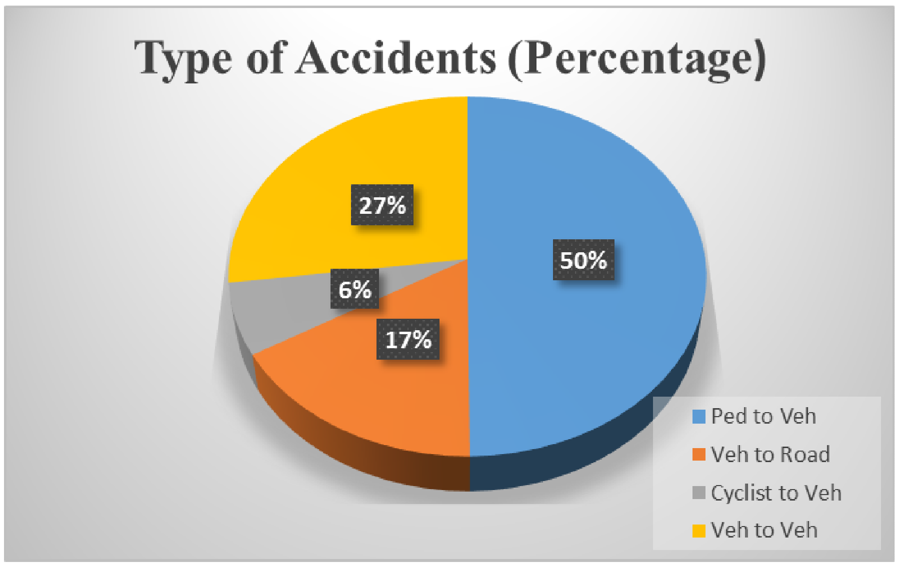

Figure 4.4: Types of Accidents (Percentage)

Figure 4.5 brings out the comparison of the numbers of the different types of accidents. The highest number of accident types was pedestrian to vehicle in all the years under consideration. A drop was recorded during the construction period due to reduced speeds and reduced traffic conflict points. The rise of the pedestrian to vehicles type of accidents after construction can be attributed to failure of the pedestrians to use provided road safety devices including use of footbridges, pedestrian crossing and walkways. Also new blackspots sections may have contributed to the increment whereas the inadequacy of the number of the crossing points provided along the entire road section could greatly reduce human vehicular traffic. KeNHA in its feasibility report to be implemented by 2017 identified sections of the road to construct more footbridges with a view to minimising human-Vehicular traffic conflict points and effects. Vehicle to road type of accidents rose between 2006 and 2007. The numbers dropped during and after construction periods. Increment between 2006 -2007 was attributed to the lack of adequate road design elements including poor vertical alignment, narrow and deep shoulders, lack of provision of guard rails on bends and high fills section, poor road signage wider and poor sight distances. The improvement during and after construction was manifest of the road safety elements provided in the new design including wider shoulders to allow drivers to pull aside safely, improved road riding surface, wider curves and increased carriageway lane widths. Vehicle to vehicle type of accidents were highest in the year 2006 and 2009. The observation can explained in two fold; before the construction began illegal accesses and junction conflict were rampant hence head on collisions were common, secondly as the capacity of the road had greatly been reduced due the volume of vehicle plying the route and the carriageway riding surface condition was poor due defects including potholes, cracks, rutting and depressions hence minimal manoeuvrability of vehicles; rear end collision was common, this element contributed to the increment .

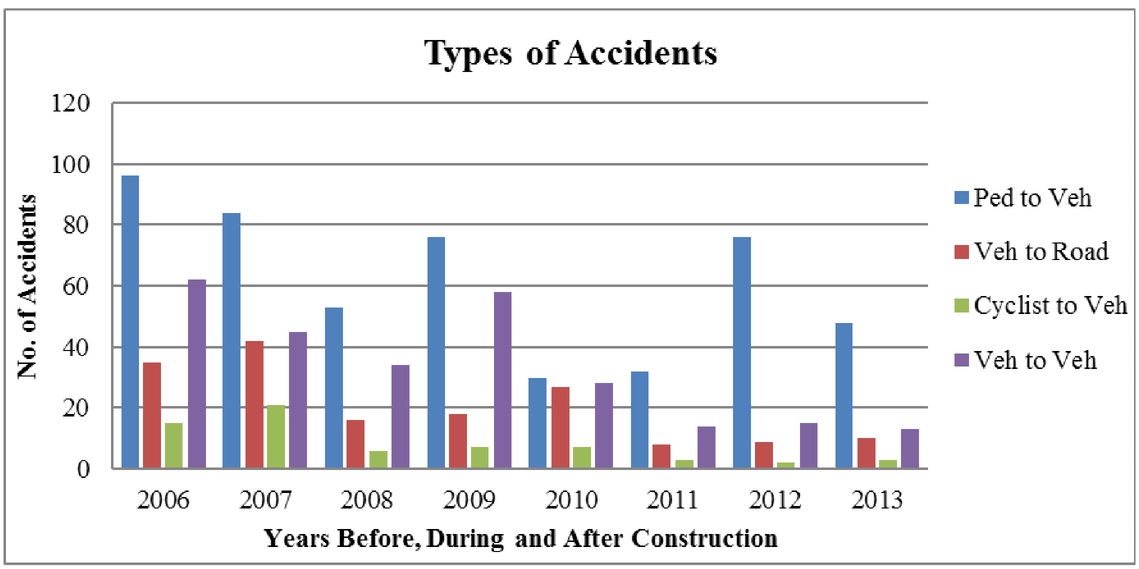

Figure 4.5: Types of Accidents

4.2.5 Traffic Accidents by Vehicle Type

Small cars were the leading vehicle type in fatal, severe and slight accidents, with 40% of the total accidents recorded (Table 4.4). This was partly because small cars and four wheel drives tend to be the dominant vehicle type in the daily traffic volume using the highway. Table 4.9 shows that there were approximately 120,000 cars ply the route daily. 14 seater public service vehicles i.e. Matatus and buses accounted for 16% and 10% respectively.

Table 4.5: Traffic Accidents by Vehicle Type (Source: Kenya Police database, 2015)

Vehicle Type	Fatal	Serious	Slight	Total
Bus	14	17	10	82
Car	70	82	52	355
Lorry	21	21	7	69
M/Cycle	4	9	1	34
Matatu	26	39	31	136
Pick Up	7	17	4	34
Van	5	6	5	26
Minubus	8	7	1	65
Unknown	22	7	8	50
Others	2	1	1	23
TOTAL				874

4.2.6 Traffic Accidents by Month and Time

Accidents were found to occur more in the months of July and August (Figure 4.6) and were distributed randomly over the months; hence, there was no definite and precise way of determining whether certain safety measures were affected by weather. Kenya weather is characterised by onset of short rain between the month of July and September. Road safety parameters likely to be affected during rainy season include visibility, sight distances, slippery roads surfacing and travelling speeds. The listed parameters may have contributed largely to the highest number of accidents between the month of July and August. The greatest number of accidents occurred between 1930hrs and 2030 hrs. (Figure 4.7). This was the time traffic density was at its maximum on the subject road. Those accidents occurring at this time were not speed related rather they were characterised by difficulty in vehicle manoeuvring, turning, poor visibility , drivers' driving habits and most drivers state being tired hence low concentration, others being drunk driving . Hence, most of these accidents were slight with vehicle damage only.

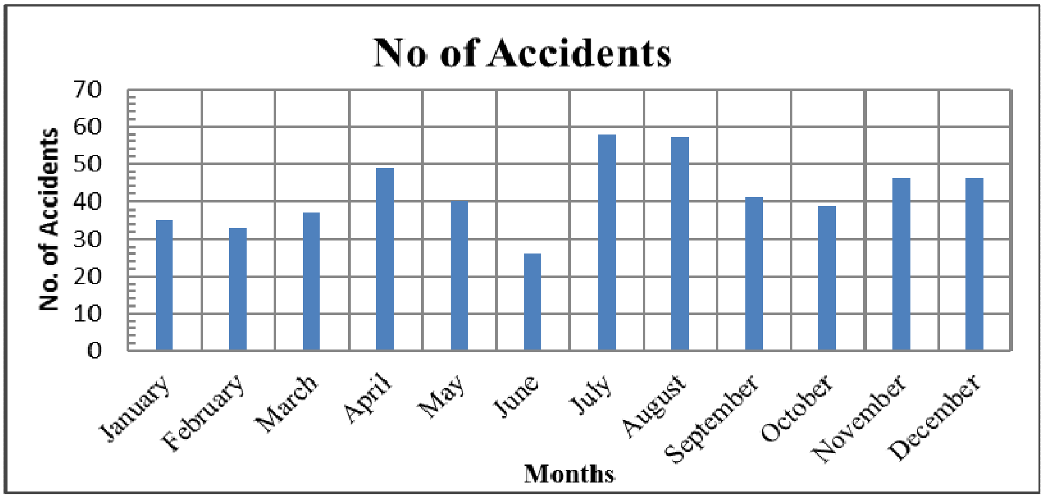

Figure 4.6: Number of Accidents by Month

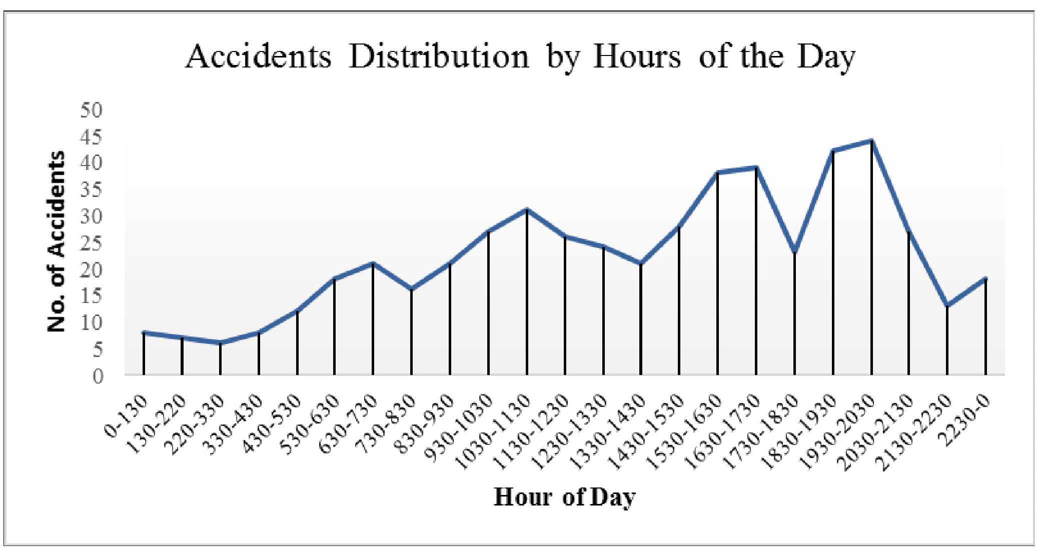

Figure 4.7: Accident Distribution by Hour of Day

4.3 Evaluation of Effectiveness of The Road Safety Measures Provided

This analysis endeavours to assess whether the provision of safety measures on the improved Nairobi -Thika Superhighway has real and significant change on accident rates reduction over the phases under study. Accident reduction rates was evaluated with respect to various parameters including timed of the day, location of accidents spots, month of the year, type of accidents and location of safety countermeasure treatment.

The parameters were analysed using Chi-square statistical test to correlate the relationship between the various road safety parameter provided on the study road with hypothesis statement.

4.3.1 Number of Accidents Vs Time of Day

This analysis determined whether or not the number of accidents was related with the time of day. Table 4.6 shows a calculated χ^2 - value of 125.73 for 3 d.f. and a critical χ^2 - value of 19.675 at 0.05 confidence level. Since the calculated χ^2 - value was found to be greater than the critical χ^2 - value, the null hypothesis i.e. road rehabiliattion does not improve road safety and reduces road crash rates and frequancies is rejected; accidents frequencies are not uniformly distributed over the hours of the day. Thus, it indicated that accidents were not uniformly distributed over the hours of the day before, after and during construction. Accidents occurred randomly across the hours of the day despite improvement of the road.

Table 4.6: Chi Square Analysis for Goodness of fit (a) Time of the day

Hrs	Observed Frequency	Expected Frequency	D.F	Critical Chi-Sqr	Calculated Chi-Sqr	
0000-0230	15	43.17	11	19.675	18.38	125.73
0230-0430	14	43.17			19.71	
0430-0630	30	43.17			4.02	
0630-0830	37	43.17			0.88	
0830-1030	48	43.17			0.54	
1030-1230	57	43.17			4.43	
1230-1430	45	43.17			0.08	
1430-1630	66	43.17			12.07	
1630-1830	62	43.17			8.21	
1830-2030	86	43.17			42.49	
2030-2230	40	43.17			0.23	
2230-0000	18	43.17			14.68	

4.3.2 Number of Accidents versus Location

Table 4.7 shows a calculated χ^2 - value of 22.06, 38.56, 36.6, 23.9 and 73.54 for the years 2008,2009,2010,2011 and 2012 respectively, for 10 degrees of freedom and a critical χ^2- value of 10.307 at 0.05 confidence level. Since the calculated χ^2 - value is greater than the critical χ^2 - value, the null hypothesis i.e. road rehabilitation does not improve road safety and reduces road crash rates and frequencies is rejected; the accidents are uniformly distributed over the whole road section. Thus, it indicates that accidents black spots do exist at specific areas along Nairobi-Thika Highway. Since the calculated value appears greater than the critical value, it confirms that the treatment or the introduction of the countermeasures at specific locations has caused significant reduction in crashes.

Table 4.7: Chi-Square Analysis for Goodness of Fit (c) Location of accidents

<table>
<tr><th rowspan="2">Location</th><th></th><th colspan="8">Calculated χ^2 - value</th></tr>
<tr><th>Critical</th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th></tr>
<tr><td>K.U</td><td rowspan="11">10.307</td><td rowspan="11">39.88</td><td rowspan="11">39.84</td><td rowspan="11">22.06</td><td rowspan="11">38.56</td><td rowspan="11">36.6</td><td rowspan="11">23.9</td><td rowspan="11">73.54</td><td rowspan="11">17.51</td></tr>
<tr><td>Engen</td></tr>
<tr><td>Kahawa Barracks</td></tr>
<tr><td>Githurai 45</td></tr>
<tr><td>Clayworks</td></tr>
<tr><td>Roysambu</td></tr>
<tr><td>Safaripark</td></tr>
<tr><td>Roasters</td></tr>
<tr><td>G.S.U</td></tr>
<tr><td>Crescent P.S</td></tr>
<tr><td>Total P.S</td></tr>
</table>

Using formulae definitions from in chapter two (Equation 2.1 to 2.6) the significance of change was tested as to whether it was real for each site. The ratio C of accidents before and after construction in the entire road was found to be 0.57. Table 4.7 shows that the Chi-Square figure for each individual site was less than 3.84 (from χ^2 table) hence the decrease of road accidents at each site can be said to be real at a 5% significance level.

Table 4.8: Chi Square Analysis for specific location along Nairobi –Thika Superhighway

LOCATION	Before (b) (2006-2009)	After (a) (2013-2014)	$n = a + b$	$c = \frac{Total\ a}{Total\ b}$	$\chi^2 = \frac{(a-bc)^2}{nc}$
K.U	10	7	17	0.57	0.09
Engen	12	10	22	0.57	0.29
Kahawa Barracks	20	3	23	0.57	1.71
Githurai 45	25	15	40	0.57	0.02
Clayworks	9	3	12	0.57	0.22
Roysambu	15	7	22	0.57	0.04
Safaripark	15	8	23	0.57	0.00
Roasters	8	8	16	0.57	0.38
G.S.U	16	12	28	0.57	0.17
Total	128	73			

4.3.3 Number of Accidents versus Month of Year

In this analysis, whether or not the number of accidents was related to the month of year was analyzed. Table 4.8 shows a calculated χ^2 - value of 23.34 for 11 degrees of freedom and a critical χ^2- value of 19.675 at 0.05 confidence levels. Since the calculated χ^2 - value was greater than the critical χ^2 - value, the null hypothesis i.e. accidents are uniformly distributed over the year was rejected. Thus, it indicated that accidents were not uniformly distributed over the year before, after and during construction.

Table 4.9: Chi-Square Analysis for Goodness of Fit (c) Month of the year

Month	Observed Frequency	Expected Frequency	D.F	Critical Chi-Sqr	Calculated Chi-Sqr	
January	35	42.25	11	19.675	1.24	23.34
February	33	42.25			2.03	
March	37	42.25			0.65	
April	49	42.25			1.08	
May	40	42.25			0.12	
June	26	42.25			6.25	
July	58	42.25			5.87	
August	57	42.25			5.15	
September	41	42.25			0.04	
October	39	42.25			0.25	
November	46	42.25			0.33	
December	46	42.25			0.33	

4.4 Speed and Traffic Count Data

An important traffic characteristic that affects safety is speed variance. A major influence on speed variance is the difference between the design speed and the posted speed limit. It has been shown that speed variance will be minimized if the posted speed limit is correlated with the design speed. This emphasizes the link between posted speed limit and design speed, and supports the recommendation that speed limits should be set by a traffic engineer, based on spot speed studies (Fitzpatrick, 1997). The posted speed limit along Thika road varies from 50km/hr to 100Km/hr. Table 4.10 shows the speed distribution over the different vehicle classes and the number of vehicles recorded over a 24hr period

Table 4.10: Speed and Traffic Data Matrix

Speed (Km/hr)	M-Cycles	Cars	Pickups/ Jeeps/ 4WDS	Matatus/Buses	Buses	Light Trucks	Medium Trucks	Heavy Trucks	TOTAL
10-20	299	1712	31	226	68	27	17	31	2411
20-30	415	8498	233	950	194	96	56	132	10574
30-40	618	27636	440	2199	272	228	63	112	31568
40-50	730	32423	256	1576	104	167	63	32	35351
50-60	590	34090	97	1017	73	63	29	9	35968
60-70	951	11011	30	455	18	15	9	1	12490
70-80	363	3887	3	139	4	10	4	1	4411
80-90	325	1044	2	48	3	8	0	0	1430
90-100	62	295	15	14	0	2	0	0	388
100-110	1	37	12	3	0	0	0	0	53
110-120	1	9	5	3	0	0	0	0	18
120-130	0	2	0	4	0	0	0	0	6
130-140	0	2	1	2	0	0	0	0	5
140-150	0	4	1	1	0	0	0	0	6
150-160	0	9	0	3	0	0	0	0	12
TOTAL	**4355**	**120659**	**1126**	**6640**	**736**	**616**	**241**	**318**	**134,691**

From Table 4.10, 43% of vehicles were traveling at an average speed of 55Km/hr whilst 23% of the vehicles were traveling at an average speed of 35Km/hr. The former speed was mainly achieved during the middle hours of the day and the latter during the morning and evening hours when vehicle flow is at a maximum. Pedestrians have a 90% chance of surviving a car crash at 30km/hr or below but less than 50% chance of surviving impacts of 45km/hr or above (Transport Research Centre, 2006)

Using equations 2.9 to 2.12 the current crash rate for the whole road, using data in Table 4.1 and 4.10 is:

$$C_r = \frac{74}{134691 * 365 * 50} * 10^6 \quad = 0.03$$

The crash rate for Nairobi Thika Superhighway Road before construction was:

$$c_r = \frac{208}{60000 * 365 * 46} * 10^6$$

$$= 0.2$$

The crash rates for the individual sections of road before (2006-2009) and after (2013) are shown in table 4.11 and 4.12 respectively.

Table 4.11: Crash Rates before Construction for individual sites

LOCATION	Chainages	Length (L) (Km)	Before (n) (2006-2009)	$c_r = \frac{n}{AADT * 365 * L} * 10^6$ (PMVKT)
Muthaiga Junction	2+900-5+100	2.2	8	0.17
G.S.U	6+300-7+500	1.2	16	0.61
Roasters	8+000-9+200	1.2	8	0.31
Safaripark	9+200-10+400	1.2	15	0.56
Roysambu	10+400-12+300	1.9	15	0.35
Clayworks	12+300-13+400	1.1	9	0.37
Githurai 45	13+400-14+800	1.4	25	0.80
Kahawa Barracks	14+800-16+000	1.2	20	0.75
Engen	16+000-17+000	1	12	0.54
K.U	17+000-18+000	1	10	0.43
PMVK= Per Million Vehicle Kilometres Travelled				
AADT = 60000 Vehicles				

Table 4.12: Crash Rates after Construction for individual sites after Construction

LOCATION	Chainages	Length (L) (Km)	After (n) (2013)	$c_r = \frac{n}{AADT * 365 * L} * 10^6$ (PMVKT)
Muthaiga Junction	2+900-5+100	2.2	7	0.06
G.S.U	6+300-7+500	1.2	10	0.17
Roasters	8+000-9+200	1.2	3	0.05
Safaripark	9+200-10+400	1.2	15	0.25
Roysambu	10+400-12+300	1.9	3	0.03
Clayworks	12+300-13+400	1.1	7	0.13
Githurai 45	13+400-14+800	1.4	8	0.12
Kahawa Barracks	14+800-16+000	1.2	8	0.14
Engen	16+000-17+000	1	12	0.24
K.U	17+000-18+000	1	0	0.00
PMVK= Per Million Vehicle Kilometres Travelled				
ADT = 135000 Vehicles				

The above crash rate figures in table 4.11 and 4.12 indicate that Githurai 45, Kahawa Barracks and G.S.U were black spots with crash rates of 0.8 PMV, 0.75PMV and 0.61PMV respectively. Accident blackspots are section of the road where the highest number of accidents have been recorded as illustrated in Figures 4.8 and 4.9 below. Accident black spots are also defined as road locations with (relatively) high accident potentials.

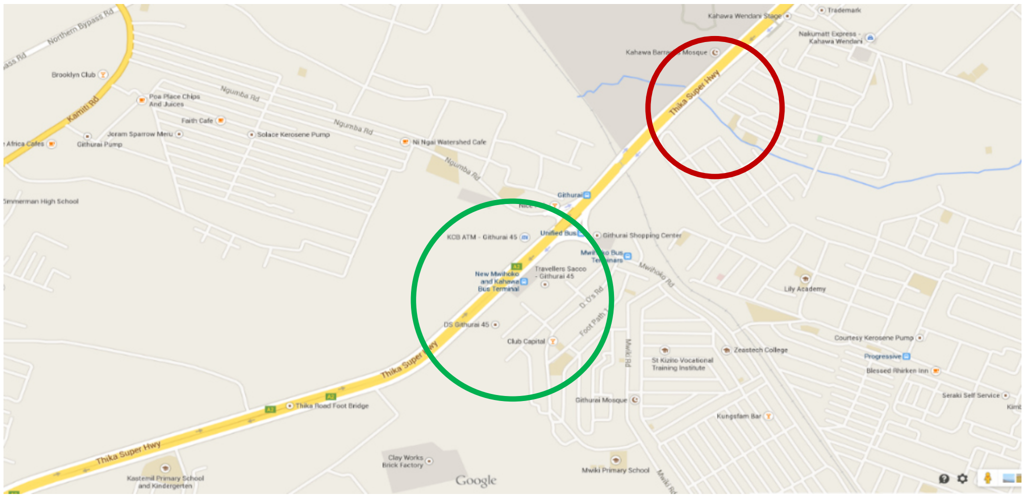

Figure 4.8: Black Spots before Construction

After rehabilitation, Safari Park, Engen and G.S.U emerged as black spots with crash rates of 0.25 PMV, 0.24 PMV and 0.17 PMV respectively. Blackspot treatment interventions provided in road sections of Githurai 45, Kahawa Barracks and G.S.U included provision of overpasses, underpasses, improvement of road vertical curves, clear signage, road marking, service roads, footbridges, median barrier, widened horizontal alignment and separation of various types of traffic. The reduction of the crash rates on the observed blackspots indicates the effectiveness of the safety devices provided in the upgraded Nairobi City Thika Superhighway. The existence of the blackspots even after improvement is attributed to the distances between footbridges for pedestrians crossing which were far apart hence the temptation of pedestrian to jump over the median barrier through the 8-lane carriageway.

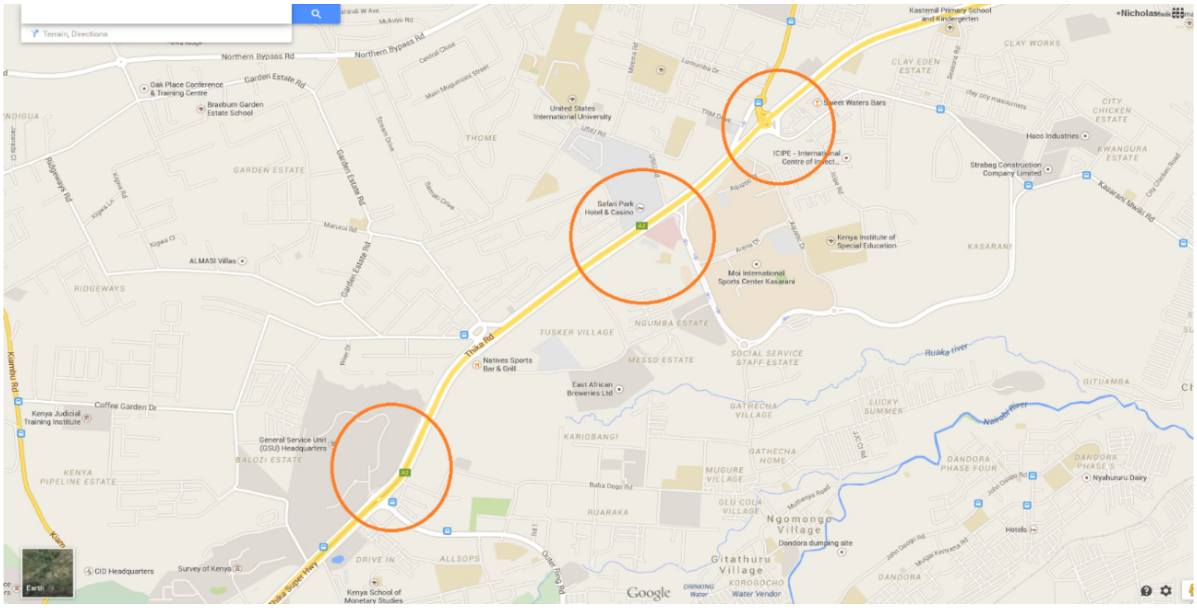

Figure 4.9: Black Spots During and After Construction

It should be noted that for all sites the crash rates reduced implying that the safety measures employed at this sites were functional to some degree. Figures 4.8 and 4.9 illustrates the locational maps for the blackspots before, during and after road improvement. There is clearly slight change in the location of the blackspots indicating that the interventions provided still needed to be audited to addresses them in terms of specific accident attributes.

4.5 Interviews and Vehicle Manoeuvre Observations

A sample of the questionnaire that was used and a summary of the findings is attached in Appendix 1B. 44% of the interviewees were drivers of Public Service Vehicles such as buses, minibuses and matatus who made more than 5 trips in a day through a section of the road. Their origin of travel was from Thika Road environs like Githurai 45 and 44, Thika, Juja, Mwiki, Kasarani, and Baba Dogo and the destination of travel for 80% of them was Central Business District. Personal car drivers amounted to 23% of the interviewees.

From the survey conducted, 64% interviewees had used Nairobi -Thika Road before its rehabilitation and 41% during rehabilitation. 47% on interviewees reported to have been able to go for more than 5 trips per day after reconstruction whilst during and before construction 38% and 24% of the interviewees did respectively. 32% of the drivers interviewed admitted to have been involved in an accident before the Improvement of the Nairobi –Thika superhighway. This number increased to 48% during the construction period. After construction only 18% reported to have been involved in an accident. The improvement of the Nairobi Thika Superhighway has substantially reduced travel travel time hence the increment from 24% before to 47 % after rehabilitation. The chances of getting involved in an accident reduced after construction from 48% recorded during construction to 18%. The high accidents during construction can be attributed to poor signage by contractor, poor state of road diversions provided and lack of information by motorist on contractor's construction schedule.

Pedestrians crossing the road accounted for 35% of accidents before construction, 38% during construction and 24% after construction. The driver losing control of the vehicle accounted for 24% of the accidents before rehabilitation. However, during construction 20% of the drivers lost control of vehicles. This number increased substantially to (40%) after construction. Githurai roundabout had the most number of accidents (38%) before construction, Roasters had the most (41%) during construction and after construction KCA University (Survey of Kenya area) has been recording the most number of accidents.

Over half the drivers who were interviewed reported that it was either hard or very hard to make turning movements in some sections of the road before rehabilitation. Currently, more than 75% feel that it is very easy or easy to make turning movements of heavy goods vehicles. Figure 4.10 shows heavy good vehicles making turning movements at the Kasarani roundabout with ease. This was reaffirmed by observations that were made on Ruiru junction, Kahawa Sukari tunnel, Githurai and Kasarani roundabouts. Figure 4.10 shows photographs taken as the interviews were being administered to illustrate the ease with which vehicles are now able to manoeuvre around curves and roundabouts because of the increased curve radii.

	
Lorry turning at Githurai Roundabout	Medium Goods Vehicle turning at Kahawa Sukari
	
Turning Movement of Heavy Goods Vehicle at TRM (a)	Turning Movement of Heavy Goods Vehicle at TRM (b)

Figure 4.10: Turning Movements of Vehicles along Thika Road

(Source: Author, 2015)

4.6 Thika Road Design Features and Reduction of Accidents.

There are a number of principles and design measures that have been incorporated in the construction of the new Nairobi Thika Superhighway with a view to preventing occurrence of road traffic accidents.

The objective of this study was to assess the effects of road improvement on safety. The following are the design features of Nairobi Thika Superhighway and their effects the safety of road users:

- Footpaths – separating pedestrians from the carriageway
- Wide road shoulders – to allow drivers to stop safely at the road side
- Increased carriageway width to allow vehicle manourves and increase the highway traffic capacity
- Suitable road gradient and curvature – to lessen the risk of rear end collision.
- Appropriate pedestrian crossings –comprising refuge islands, zebra crossings and foot bridges.
- Surfacing conditions ; smooth riding surface hence comfort of motorists.
- Appropriate street lighting which improves visibility at nigth

4.6.1 Footpaths

Segregating pedestrians from flowing traffic by use of footpaths has been very effective in the reduction of accidents along Thika Road. Footpaths, 2m wide cover nearly 85% of the whole length. Figure 4.11 shows numerous pedestrians using the provided footpath. In 2006 and 2013; 96 and 48 numbers of pedestrian to vehicles types of accidents were recorded (Table 4.1) this translates to a 50% reduction of the accident type.

Figure 4.11: Pedestrians Using Foot Path

(Source: mwakilishi.com, 2015)

4.6.2 Carriageway Width

Increasing the number of lanes from two to four contributed to the overall decrease in the number of accidents after construction by 51.7 % considering the average yearly accidents before and after the construction (Table 4.1).

Safety studies have confirmed that a reduction in the severity of accidents involving errant vehicles is achievable by ensuring a maximum side slope of 1:4.5 and/or increasing the recovery area adjacent to the carriageway (Overseas Road Note). This feature is salient also in the improved Nairobi Thika Superhighway

4.6.3 Correct gradient and Curvature

Variables such as gradient and curvature are important, since the risk of collision increases as these features increase in severity. Road alignment in the shape of sharp curves, blind rises and steep gradients can be hazardous at high speed, and maximum speed limits should be reduced if such elements generally occur. Thika Road has no steep gradients, sharp curves or bends, as illustrated in Figure 4.12 thus allowing traffic to manoeuvre freely without collisions associated with the road curvature. The location which had sharp bends and steep gradients included Pangani, NYS, Utalii, Ruaraka-Jambo grill and Kenyatta University-Clay Works area. In these sections the new design took into consideration horizontal and alignment parameter with respect to design speed guidelines as illustrated in Table 2.2.

Figure 4.12: Horizontal Alignment at Allsops

(Source: Skyscrapercity.com, 2015)

4.6.4 Pedestrian Facilities

Before reconstruction of Nairobi-Thika Superhighway most of the accidents resulting in the most severe injuries involved pedestrians and other vulnerable road users including cyclists and motorists. Collisions between vehicles and pedestrians occurred chiefly when the pedestrians were crossing the road. As such, the new design ensured that pedestrians were channeled to cross at designated crossing points. Physical means like barriers were employed to ensure pedestrians use facilities like foot bridges (more than 15 number FOB provided), zebra crossings and refuge islands were incorporated in the design. The foot bridges were built to attract pedestrians to cross at this point by adding ramps rather to the steps and providing an overhead cover for protection against the weather (Figure 4.13).

For 85th percentile speeds of 50km/h the desirable minimum visibility distance recommended by the HSM is 65m. The crossing signs observed were put in place with this in mind hence drivers see pedestrians clearly and visibility is not obscured by street furniture, for example, the zebra crossing at KCA University is placed safely as per above guidelines.

Motor cyclists who are also categorized as vulnerable road users were not considered in the design neither were cycle tracks provided for bicycle riders.

Figure 4.13: Pedestrians Using Foot Bridge at Kasarani

(Source: Skyscrapercity.com, 2015)

4.6.5 Appropriate Street Lighting

Relatively high number of fatal collisions occurred during the hours of darkness when drivers' vision is impaired. The situation for vulnerable road users was thus more hazardous during this time as they were much harder to see.

Street lighting, although expensive, were included in the design and located in positions that minimize the risk of damage by vehicles so as to ensure both safety and security. Safety for pedestrians and motorist and security of the road furniture was improved with the provision of the street lighting in the reconstructed Nairobi Thika Superhighway.

4.6.6 Carriageway Surface Conditions

When asked about the surface condition, more tThan three quaters of the inteviewees were of the opinion that it is currently satisfactory . From the interview results no accidents were recorded to have been caused by bad surface conditions including rutting, potholes, shrinkage, cracking and ravelling . However, the results indicate that during construction 23% of the accidents were caused by bad road conditions.

However, from the interviews conducted most accidents were found to have occurred at KCA University arising from poor road riding surface with heavy potholes, corrugation and base failure before the road improvement.

Thika road rehabilitation was associated with a change in its capacity, traffic volume and traffic speeds. Initially it accommodated traffic volumes of 60,000 vehicles per day. Currently it has a daily traffic of around 135,000 vehicles. This study established that with this change, the trends and characteristics of road accidents have also changed. Before construction, 50% of the accidents were due to pedestrians crossing the road; however, it has been found that, the highest percentage of accidents (42%) were caused by human factors like failure to yield right of way, improper lane use, improper overtaking and over speeding as illustrated in Table 4.10 (5% of the vehicles from the survey were travelling with a speed of over 100km/hr.)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1 Introduction

This study was carried out to explore the effects of road improvement on safety. Thus, the analysis compared the trends of road accidents, characteristics of accidents and road features that affect safety before, during and after Nairobi -Thika superhighway rehabilitation.

5.2 Conclusions

5.2.1 Black Spots Treatment

The study established that some engineering measures were adapted in the road design to eliminate black spots. The following measures were especially found to be very effective: grade separated pedestrian crossings, marked pedestrian crossings, sidewalks, and increased horizontal radius, and improved route guidance, variable message signs and guard rails equipped with reflectors. When the afore mentioned were installed during construction at specific black spots it was found that RTAs reduced remarkably at these locations.

Accident Blackspots identified along the study road included specific stretches on Githurai 45, Kahawa Barracks, Safari Park and G.S.U area

5.2.2 Road Accident Trends

It was observed that road accident trends before, during and after construction varied with the time of day, month of the year, road surface conditions, traffic volume, traffic composition and traffic speed. As such, at a certain point in the time of day, the more the traffic the more number of RTAs, the broader the spread of traffic speeds the more the number of accidents, the higher the proportion of HGVs, MGVs and PSVs the more the accidents; the higher the 'excess speed' the more the number of RTAs; and the more the activity of road crossing by pedestrians the more the number of accidents.

5.2.3 Road Accident Characteristics

Pedestrian to vehicle accidents account for the majority of accidents on the road followed by vehicle to vehicle. The locations of these accidents both before and after construction are concentrated on bazaar locations like Githurai 45 and high pedestrian activity locations like Kahawa Barracks and KCA University before the rehabilitation of Nairobi Thika Superhighway.

During construction, fatal accidents prevailed; however after road rehabilitation most accidents recorded were of serious severity.

Most accidents were recorded in the month of July –August whereas from 7.30 to 8.30 pm the high numbers were attributed to rains characterized with mist hence poor visibility and poor driver's judgement as a result of tiredness and poor vision in the mentioned months and times of the day respectively.

From the analysis and observation small cars were the leading vehicle type in fatal, severe and slight accidents recorded on Nairobi -Thika Super Highway. The trend is attributed the high volume composition of the total daily traffic of small cars and Suvs vehicle types plying the route.

5.2.4 Road Users and Road Safety Devices/Measures

From the observations made and interviews conducted it was found that pedestrians and drivers were contented with the facilities installed for their safety. Pedestrians were especially found to make most use the provided sidewalks and foot bridges and considered them to be very effective in enhancing their safety. However at some locations like Ngara, pedestrians felt that the foot bridges were out of their way and thus encouraging some chose to jay walk across the road. The inadequate provision of the pedestrian footbridges in specific locations has been identified by KeNHA for construction (*M/s CES Pvt Ltd, 2015).*

Majority of drivers appreciated the increased road width and horizontal radius curves which eased their movement and vehicle maneuverability.

5.2.5 Efficiency of Road Safety Devices

The safety devices installed on Nairobi Thika Superhighway included the traffic signs, guardrails, zebra crossings, cat eyes and informatory signs. The devices were found to be inadequate in terms of the locations and the numbers installed.

5.3 Recommendations

5.3.1 Recommendations

a. It was observed that the driving habits of most motorists was not up to standard hence this study recommends the enhancement of skills drivers and to upgrade the requirements, and competence of PSV drivers on the road.
b. The research has also showed that the under-reporting was more likely for motorcyclists, cyclists, males, young people, and injuries occurring in remote and inner Regional areas based on Nairobi-Thika superhighway road which is urban in nature. These results have important implications for road safety research and policy in terms of: prioritizing funding and resources; targeting road safety interventions into areas of higher risk; and estimating the burden of road crash injuries. It is recommended that the National Transport and Safety Authority (Lead government agency handling road traffic safety) in conjunction with established road authorities introduce intelligent transport system to give real time reporting of crashes and improve on safety.
c. The accident, road and the road environment data should be collected regularly in order to have accurate data bank for the road safety analysis. This will help the researchers to know about the changes and the fluctuations so that they have

better understanding and evaluate road users' behavior before and after the implementation of the countermeasures.

d. The accident data collected by the different authorities in Kenya such as Kenya Police Service, Insurance companies and Hospitals should be accumulated together to have more accurate and dependable information for purposes of calculating the cost losses associated with road traffic accidents and precisely measure the efficiency of road safety countermeasures provided. A dependable long term local data bank formation has to be started immediately through collecting necessary information about road section improvements from before and after studies

e. It is also recommended that KeNHA in the current and future performance based routine maintenance programmes for the Nairobi –Thika Superhighway and other new roads include maintenance and improvement of road safety devices as one of the cardinal service scopes under road safety. Levels of service to be considered should include road riding surface conditions, the drainage functionality, Street lighting, the functionality of installed safety measures and road signage and road marking maintenance. Analysis shows that most accidents occurred between 1930-2030hrs and 50% of accident types involved pedestrian to vehicles. Maintenance programme could ensure the street are properly functional and road well lid. The remaining pedestrian –vehicular traffic conflict sections can also be addressed by improving the existing safety facilities including footbridges, zebra crossings, speed bumps, rumbled strips, road signage and signalized junctions.

f. Revise Codes and Manuals for improved vehicle technology and prevailing road user behavior.

g. Initiate Peer–to-Peer Program at National Level and establish Center of Excellence and Road Safety Auditor's Accreditation system.

5.3.2 Areas of further Research and Improvement

a. The procedure outlined in this research is a valuable tool that can be used in transportation safety studies. It is recommended that this procedure be applied to future projects to estimate the effectiveness of other safety measures. It is also recommended that future research be performed to expand the model to identify areas of interest where unusually high proportions of particular crash types may occur. The results of such a study would be beneficial to identify and prioritize sites where safety improvements need to be made.
b. Further study is recommended to conduct road safety audit to evaluate all roadway and roadside features, design elements and local conditions that would increase the likelihood and severity of a crash. The recommended study would;

- Review firsthand the interaction of various design elements with each other and surrounding road network.
- Observe how road users are interacting with the road facility.
- Determine if the needs of all road users have been adequately and safely met.
- Explore emerging operational trends or safety issues at specific locations.
- where no formal procedure for safety audit exists, introduce a mandatory requirement that all major new road schemes be subjected to an independent safety audit
- in time, extend formal procedures to smaller schemes and the safety checking of all existing roads in the country

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APPENDICES

Appendix 1 A: Sample Questionnaire

This Questionnaire is part of a data collection procedure to help in the analysis of accident trends along Thika Road before, during and after construction. Your voluntary assistance in answering this questions will be highly appreciated.

Age:…………………………………………………………………………………………..

Sex:…………………………………………………………………………………………...

i.) **Which type of car do you drive?**

☐ Small Car/4WD

☐ Public Service Vehicle Specify---------------

☐ Medium Goods Vehicle

☐ Heavy Goods vehicle

ii.) **Origin of travel**...

iii.) **Destination of travel**

SECTION 2

2.1) **Did you use Thika Road before it was rehabilitated?**

☐ YES

☐ NO

If NO jump to section 3

2.2) **How frequent did you use Thika Road?**

☐ More than 5 trips in a day

☐ Two or more trips in a day

☐ Twice in a week

☐ Monthly

If option 3 or 4 jump to Section 3

2.3) During that period were you involved in any accident?

☐ YES

☐ NO

2.4) If yes, what was the cause of the accident?

☐ Driver lost control

☐ Pedestrian was crossing road

☐ Car Mechanical Failure

☐ Visibility

☐ Road design made vehicle had to manoeuvre

☐ Harsh weather e.g. Rainfall

☐ Other (Specify)

2.5) What was the location of the accident?...

2.6) Did anyone die or sustain severe injuries as a result of the accident?

☐ YES

☐ NO

☐ I DON'T KNOW

2.7) If yes, how many people died or sustained severe injuries?.............................

SECTION 3

3.1) Did you use Thika Road during the construction period?

☐ YES

☐ NO

If NO jump to Section 4

3.2) How frequent did you use Thika Road?

☐ More than 5 trips in a day

☐ Two or more trips in a day

☐ Twice in a week

☐ Monthly

If option 3 or 4 jump to Section 4

3.3) During that time were you involved in any accident?

☐ YES

☐ NO

3.4) If yes, what was the cause of the accident?

☐ Driver lost control

☐ Pedestrian was crossing road

☐ Car Mechanical Failure

☐ Visibility

☐ Road design made vehicle had to manoeuvre

☐ Harsh weather e.g. Rainfall

☐ Other (Specify)

3.5) What was the location of the accident?..

3.6) Did anyone die or sustain severe injuries as a result of the accident?

☐ YES

☐ NO

☐ I DON'T KNOW

3.7) If yes, how many people died or sustained severe injuries?.............................

SECTION 4

4.1) How frequent do you use Thika Road?

☐ More than 5 trips in a day

☐ Two or more trips in a day

☐ Twice in a week

☐ Monthly

If option 3 or 4, terminate the interview.

4.2) Have you been involved in an accident since the completion of rehabilitation?

☐ YES

☐ NO

4.3) If yes, what was the cause of the accident?

☐ Driver lost control

☐ Pedestrian was crossing road

☐ Car Mechanical Failure

☐ Visibility

☐ Road design made vehicle had to manoeuvre

☐ Harsh weather e.g. Rainfall

☐ Other (Specify)

4.4) What was the location of the accident?...

4.5) Did anyone die or sustain severe injuries as a result of the accident?

☐ YES

☐ NO

☐ I DON'T KNOW

4.6) If yes, how many people died or sustained severe injuries?............................

SECTION 5

Note: To be filled by drivers of Medium Goods Vehicles and Heavy Goods Vehicles only.

5.1) How would you rate the ease with which you would make turning movements e.g. at roundabouts before the rehabilitation of the road?

☐ Very Easy

☐ Easy

☐ Hard

☐ Very Hard

5.2) How would you rate the ease with which you would make turning movements e.g. at roundabouts during the rehabilitation of the road?

☐ Very Easy

☐ Easy

☐ Hard

☐ Very Hard

5.2) How would you rate the ease with which you now make turning movements e.g. at roundabouts after completion of the rehabilitation?

☐ Very Easy

☐ Easy

☐ Hard

☐ Very Hard

5.3) When you drive on the new road which turns do you feel are hard to make?

☐ Ruiru Bypass Junction

☐ K.U Turn

☐ Kahawa Sukari

☐ Githurai Roundabout

☐ Clayworks Turn

☐ Kasarani Roundabout

☐ Allsops Turn

☐ Muthaiga Turn

(Thank You for Your Participation)

Appendix 1 B: Questionnaire Summary

Section 1		
Type of Car Driven	**No.**	**%**
Small Car	88	23%
PSV	154	40%
MGV	77	20%
HGV	65	17%
	384	

Section 2			
Used Thika Road Before Rehabilitation	**YES**	**NO**	
	246	139	
	64%	36%	
More than 5 trips in a day	93	38%	
Two or More trips in a day	125	51%	
Twice in a week	20	8%	
Monthly	7	3%	
Involved in accident during the period	**YES**	**NO**	
	79	167	
	32%	68%	
Cause of Accident			
Driver lost control	59	24%	
Pedestrian Crossing road	86	35%	
Car mechanical failure	22	9%	
Visibility	0	0	
Road Design-Hard manoeuvrability	39	16%	
Harsh weather	7	3%	
Other	32	13%	
Fatal and/or Severe Injuries	**YES**	**NO**	**IDK**
	91	118	37
	37%	48%	15%
No. that died/sustained injuries	Average = 4		

Section 3			
Used Thika Road During Rehabilitation	**YES**	**NO**	
	101	145	
	41%	59%	
More than 5 trips in a day	24	24%	
Two or More trips in a day	62	61%	
Twice in a week	10	10%	
Monthly	5	5%	
Involved in accident during rehabilitation	**YES**	**NO**	
	41	45	
	48%	52%	
Cause of Accident			
Driver lost control	17	20%	
Pedestrian Crossing road	33	38%	
Car mechanical failure	10	12%	
Visibility	2	2%	
Road Design-Hard manoeuvrability	20	23%	
Harsh weather	1	1%	
Other	3	4%	
Fatal and/or Severe Injuries	**YES**	**NO**	**IDK**
	39	30	17
	45%	35%	20%
No. that died/sustained injuries	Average = 7		

Section 4			
Used Thika Road After Rehabilitation			
More than 5 trips in a day	181	47%	
Two or More trips in a day	185	48%	
Twice in a week	27	7%	
Monthly	4	1%	
Involved in accident during rehabilitation	**YES**	**NO**	
	69	316	
	18%	82%	
Cause of Accident			
Driver lost control	29	42%	
Pedestrian Crossing road	17	24%	
Car mechanical failure	10	14%	
Visibility	0	0%	
Road Design-Hard manoeuvrability	2	3%	
Harsh weather	0	0%	
Other	14	20%	
Fatal and/or Severe Injuries	**YES**	**NO**	**IDK**
	38	20	11
	55%	29%	16%
No. that died/sustained injuries	Average = 8		

Section 5				
Ease of movement before rehabilitation	**Very Easy**	**Easy**	**Hard**	**Very Hard**
	11	31	61	38
	8%	22%	43%	27%
Ease of movement during rehabilitation	**Very Easy**	**Easy**	**Hard**	**Very Hard**
	3	24	67	48
	2%	17%	47%	34%

Ease of movement after rehabilitation	**Very Easy**	**Easy**	**Hard**	**Very Hard**
	97	36	7	3
	68%	25%	5%	2%
Hard turns to make				
Ruiru Bypass Junction	3	2%		
K.U Turn	14	10%		
Kahawa Sukari underpass	31	22%		
Githurai Roundabout	61	43%		
Claywroks Turn	6	4%		
Kasarani Roundabout	7	5%		
Allsops Turn	9	6%		
Muthaiga Turn	11	8%		

Appendix ii: Chi-Square Distribution

Critical Values of the χ^2 Distribution

df \ p	0.995	0.975	0.9	0.5	0.1	0.05	0.025	0.01	0.005	df
1	.000	.000	0.016	0.455	2.706	3.841	5.024	6.635	7.879	1
2	0.010	0.051	0.211	1.386	4.605	5.991	7.378	9.210	10.597	2
3	0.072	0.216	0.584	2.366	6.251	7.815	9.348	11.345	12.838	3
4	0.207	0.484	1.064	3.357	7.779	9.488	11.143	13.277	14.860	4
5	0.412	0.831	1.610	4.351	9.236	11.070	12.832	15.086	16.750	5
6	0.676	1.237	2.204	5.348	10.645	12.592	14.449	16.812	18.548	6
7	0.989	1.690	2.833	6.346	12.017	14.067	16.013	18.475	20.278	7
8	1.344	2.180	3.490	7.344	13.362	15.507	17.535	20.090	21.955	8
9	1.735	2.700	4.168	8.343	14.684	16.919	19.023	21.666	23.589	9
10	2.156	3.247	4.865	9.342	15.987	18.307	20.483	23.209	25.188	10
11	2.603	3.816	5.578	10.341	17.275	19.675	21.920	24.725	26.757	11
12	3.074	4.404	6.304	11.340	18.549	21.026	23.337	26.217	28.300	12
13	3.565	5.009	7.042	12.340	19.812	22.362	24.736	27.688	29.819	13
14	4.075	5.629	7.790	13.339	21.064	23.685	26.119	29.141	31.319	14
15	4.601	6.262	8.547	14.339	22.307	24.996	27.488	30.578	32.801	15

Chi-Square Distribution Table

Appendix iii: Classified Traffic Volume Count Results (AADT) for Nairobi Thika Superhighway

S. No.	Location	ADT	Motorized Traffic												Non-Motorized Traffic				Others	Total
			Passenger Vehicle								Goods Vehicles				Passenger Vehicle		Goods Vehicles			
			Car	Taxi	Auto (Tuk Tuk)	Two wheeler (Private)	Boda Boda (For Hire)	Matatu	Mini Bus	Medium and Large Bus	LGV	MGV (2 Axle)	HGV (3 Axle)	MAV (4-7 Axle)	Cycle	Bicycle Boda Boda	Hand Cart	Animal Drawn		
TVC -1	Near Existing Weigh Bridge, north of Ruiru Interchange	Vehicles	27622	52	19	366	849	7183	700	739	1911	4816	1190	771	66	10	2	2	1	46300
		PCUs	27622	52	19	366	849	7183	1401	2218	1911	12041	4166	2697	33	5	5	3	2	60573
TVC-2	Near Mangu High School	Vehicles	24974	0	18	461	692	9368	725	726	7139	1456	972	727	56	0	0	0	0	47314
		PCUs	24974	0	18	461	692	9368	1450	2178	7139	3640	3402	2545	28	0	0	0	0	55895
TVC -3	North of Garissa Road A3 interchange	Vehicles	18190	64	101	427	423	4066	276	238	867	2724	398	338	149	12	3	0	0	28275
		PCUs	18190	64	101	427	423	4066	551	713	867	6809	1392	1182	74	6	7	0	0	34873
TVC -4	North of Kenyatta University	Vehicles	35399	79	16	539	640	8721	1611	814	1679	3523	769	358	95	5	1	0	0	54249
		PCUs	35399	79	16	539	640	8721	3221	2443	1679	8808	2690	1252	48	3	2	0	0	65540
TVC -5	South of Githurai interchange	Vehicles	43131	146	49	1129	2753	7800	1743	3867	1838	2825	594	325	121	30	16	0	0	66368
		PCUs	43131	146	49	1129	2753	7800	3486	11602	1838	7063	2078	1138	61	15	32	0	0	82321
TVC -6	Near Safari Park Hotel	Vehicles	60602	362	89	1176	2022	11517	4673	4317	1773	3027	746	482	154	5	2	0	0	90947
		PCUs	60602	362	89	1176	2022	11517	9347	12951	1773	7568	2610	1687	77	2	5	0	0	111787
TVC -7	Near Muthaiga, Star	Vehicles	89959	0	87	2257	3385	15923	6045	6046	9640	227	648	272	169	1	0	0	0	134659

	Fuel	PCUs	89959	0	87	2257	3385	15923	12090	18138	9640	568	2268	952	85	1	0	0	0	155352
TVC -8	Parkland Road, South of Kariokor Round About	Vehicles	60671	735	37	1024	1208	2297	671	553	1249	1822	620	170	252	15	30	0	1	71355
		PCUs	60671	735	37	1024	1208	2297	1342	1659	1249	4555	2170	595	126	8	60	0	2	77738
TVC -9	Muranga Road, South of Kariokor Round About	Vehicles	39660	593	44	1818	1092	11831	8829	2147	1314	669	102	20	197	27	22	0	0	68365
		PCUs	39660	593	44	1818	1092	11831	17658	6441	1314	1673	357	70	99	14	44	0	0	82707
TVC - 10	Ngara Ring Road, South of Kariokor Round About	Vehicles	29936	320	66	927	3195	2975	6527	1190	1532	2742	450	217	394	7	261	0	11	50750
		PCUs	29936	320	66	927	3195	2975	13054	3570	1532	6855	1575	760	197	4	522	0	22	65509

Source: Kenya National Highways Authority Feasibility Study Report on the Operation and Maintenance of Nairobi-Thika (A2) Highway PPP Project, By Intercontinental Consultants and Technocrats Pvt. Ltd.A-8, Green Park, New Delhi - 110 016, India, Kenya (June 2015)

Appendix iv: Locations of Foot Over Bridge on Nairobi Thika Superhighway

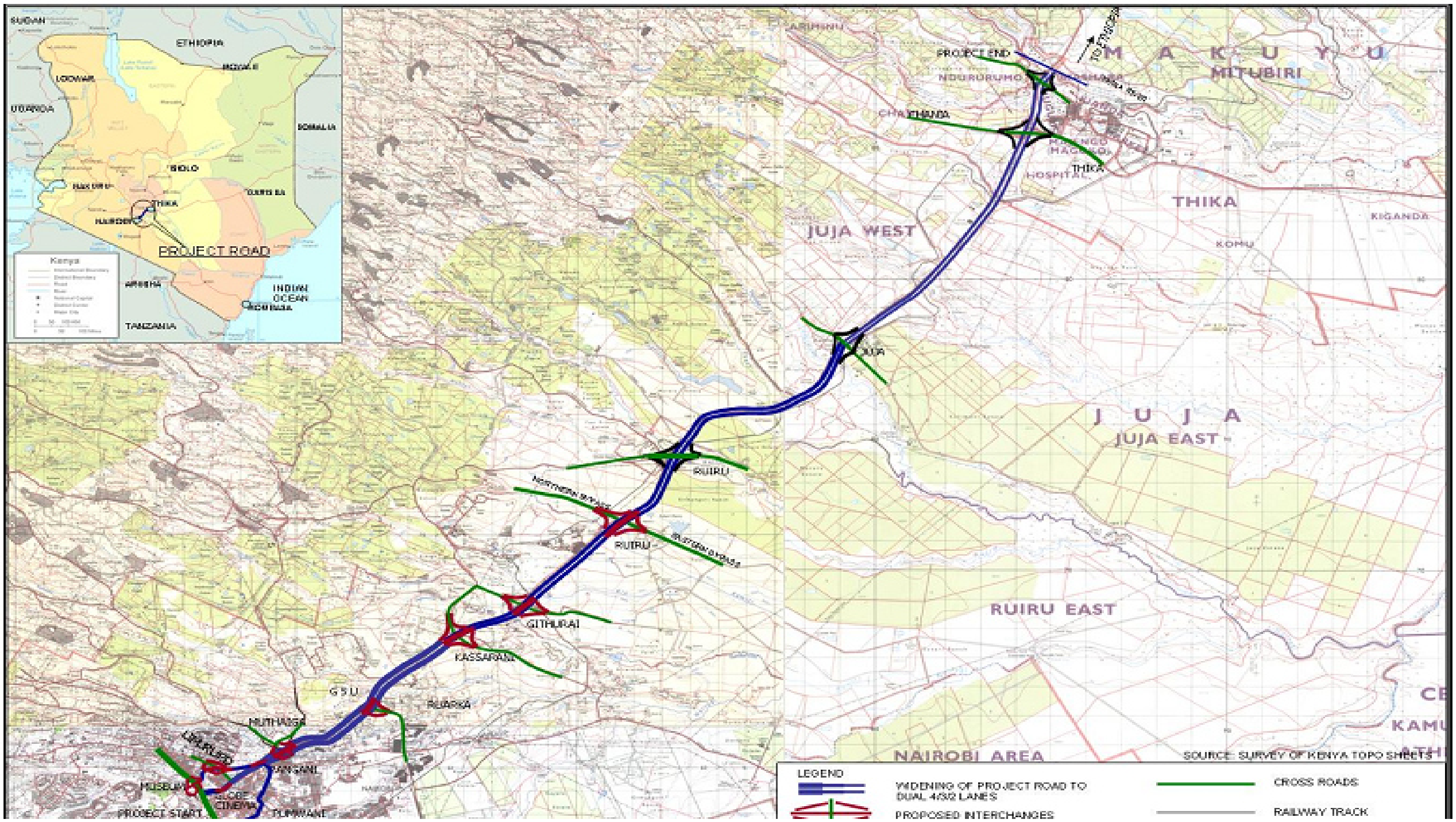
Foot over Bridge

S. No.	Chainage	Location	Total Length (m)	Type of Structure	Remarks	Remarks after site surveys
City Arterials						
1	0+380	(University)	48.6	RCC (3.3 m Wide)	Provided with Ramp at either end.	Found at site
2	0+847.5	(Ngara)	44.6	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
3	1+110	(Kariakor Road)	39.2	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
4	1+290	(Desai Road)	51.8	Structural Steel (2.9 m Wide)	Provided with Stair case only at Either End.	Found at site
5	2+289.406	(Pangani)	98.1	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
6	2+785	(Matahare)	61.2	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
7	3+700	(Muthaiga)	71.1	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
From Muthaiga Onwards						
8	5+065	KSI	73.0	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
9	9+798.5	Safari Park	75.6	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
10	11+223	Kasarani	75.6	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
11	12+840	Kenya Tents	75.6	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
12	15+300	Kahawa	75.6	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
13	17+575	Kenyatta University	75.6	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
14	22+175	Ruiru	39.3	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site

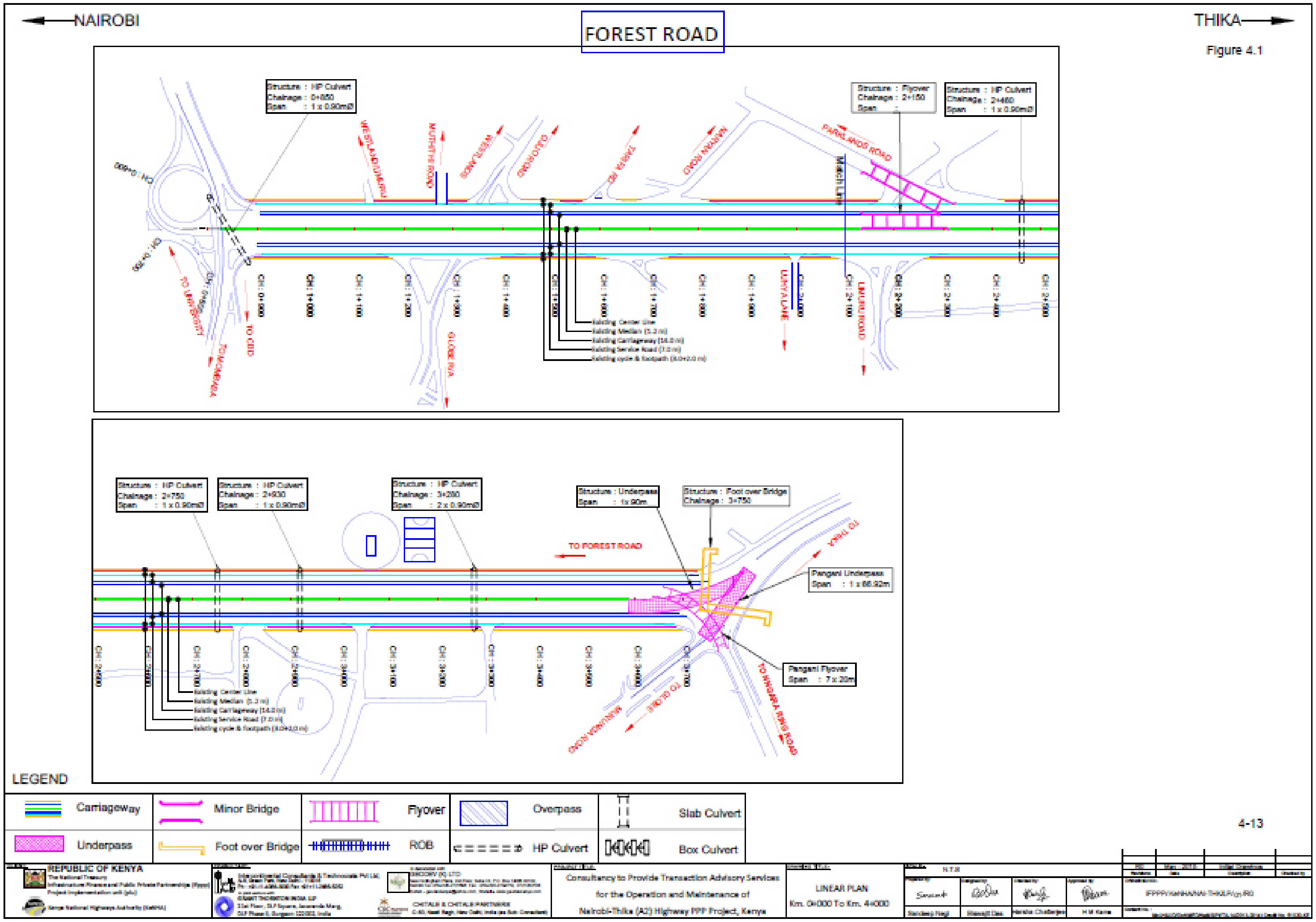
S. No.	Chainage	Location	Total Length (m)	Type of Structure	Remarks	Remarks after site surveys
15	28+525	Juja	75.6	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
16	31+670	JKUAT	75.6	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
17	35+310	Mangu School	75.6	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site
18	38+090	Vincentian Church	39.3	Structural Steel (2.9 m Wide)	Provided with Stair case and Ramp at Either End.	Found at site

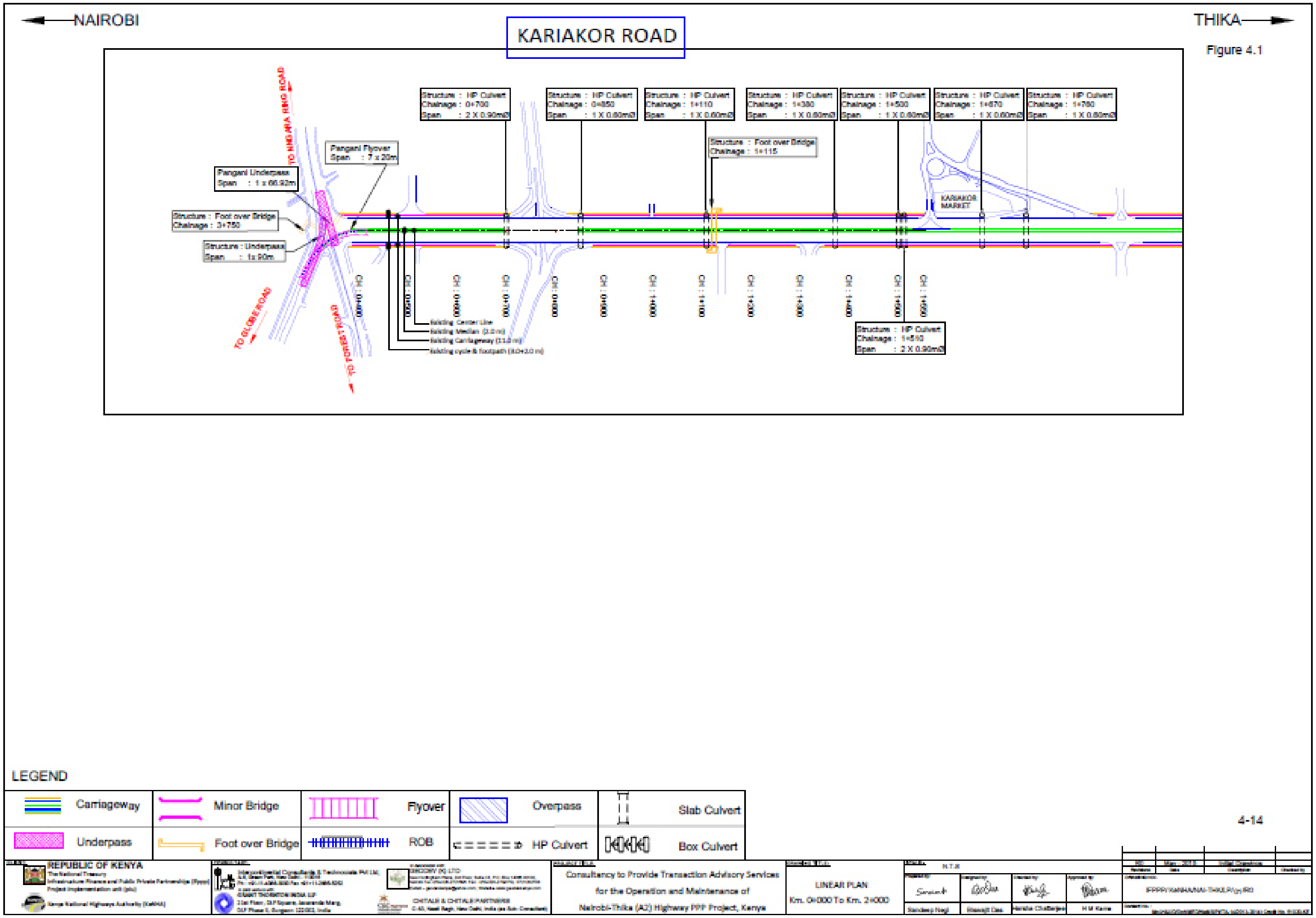
Source: Kenya National Highways Authority Feasibility Study Report on the Operation and Maintenance of Nairobi-Thika (A2) Highway PPP Project, By Intercontinental Consultants and Technocrats Pvt. Ltd.A-8, Green Park, New Delhi - 110 016, India, Kenya (June 2015)

Appendix v: Nairobi –Thika Highway Locational Map

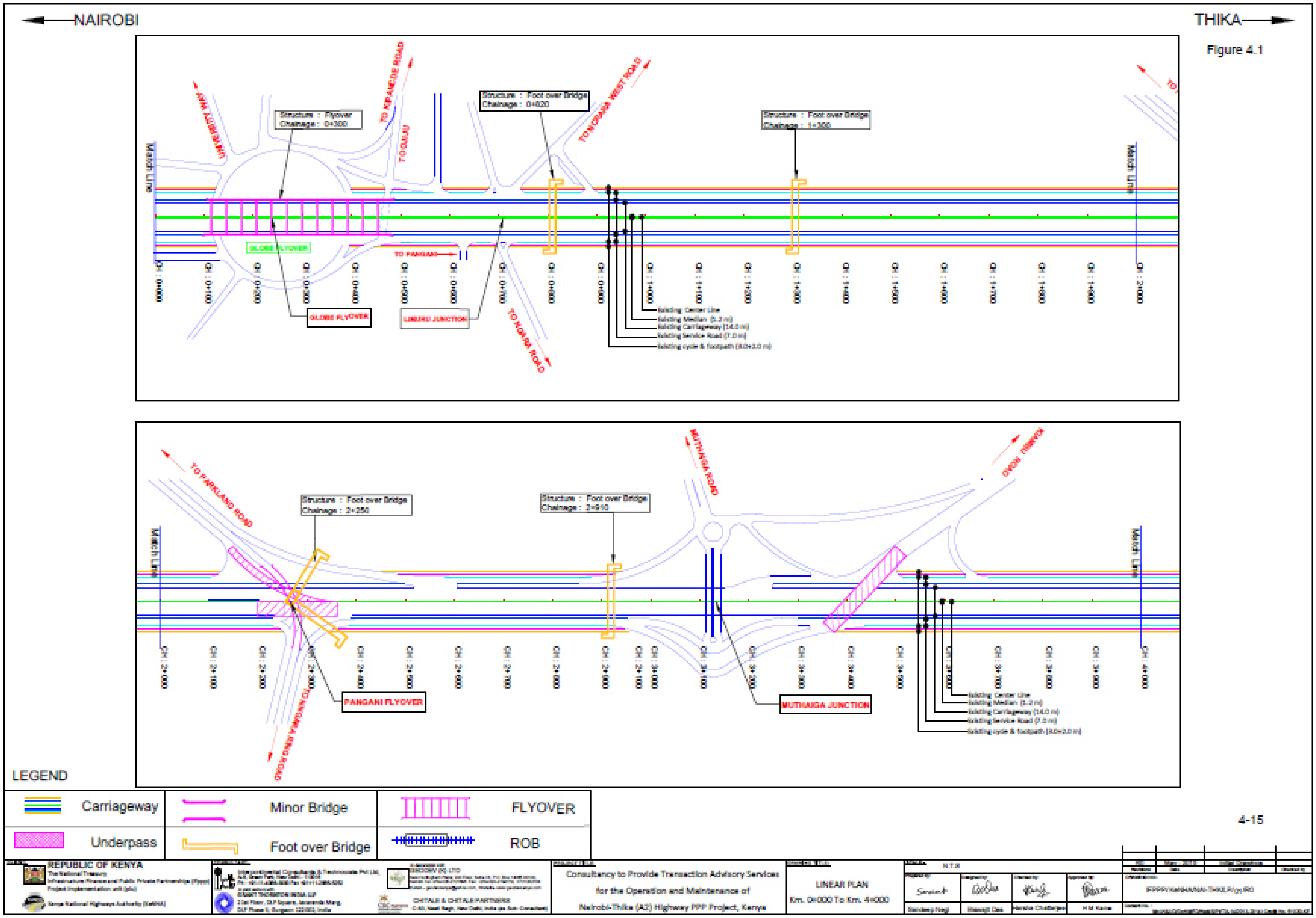


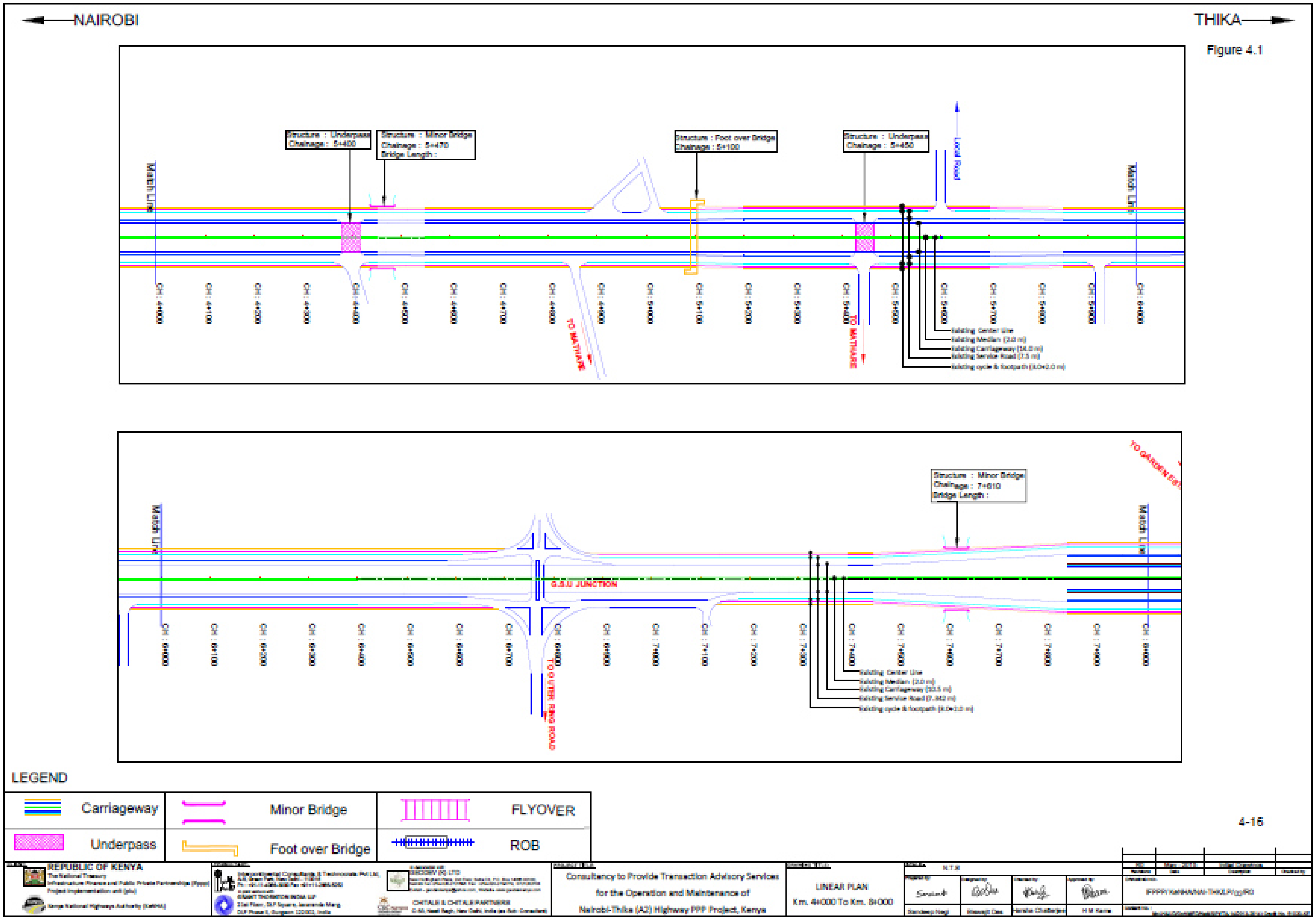
Appendix vi: Nairobi –Thika Highway Locational plan of major safety structure

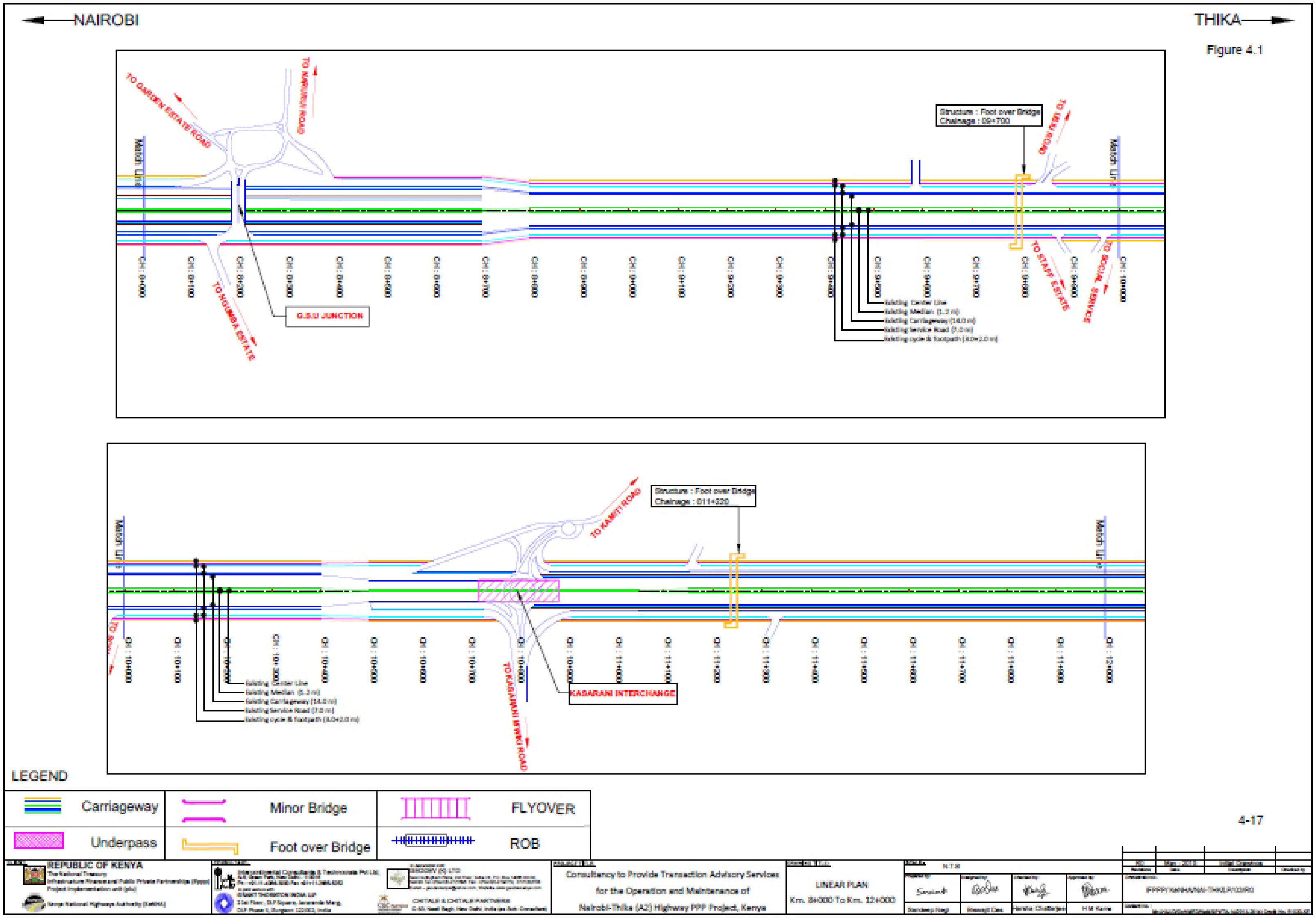


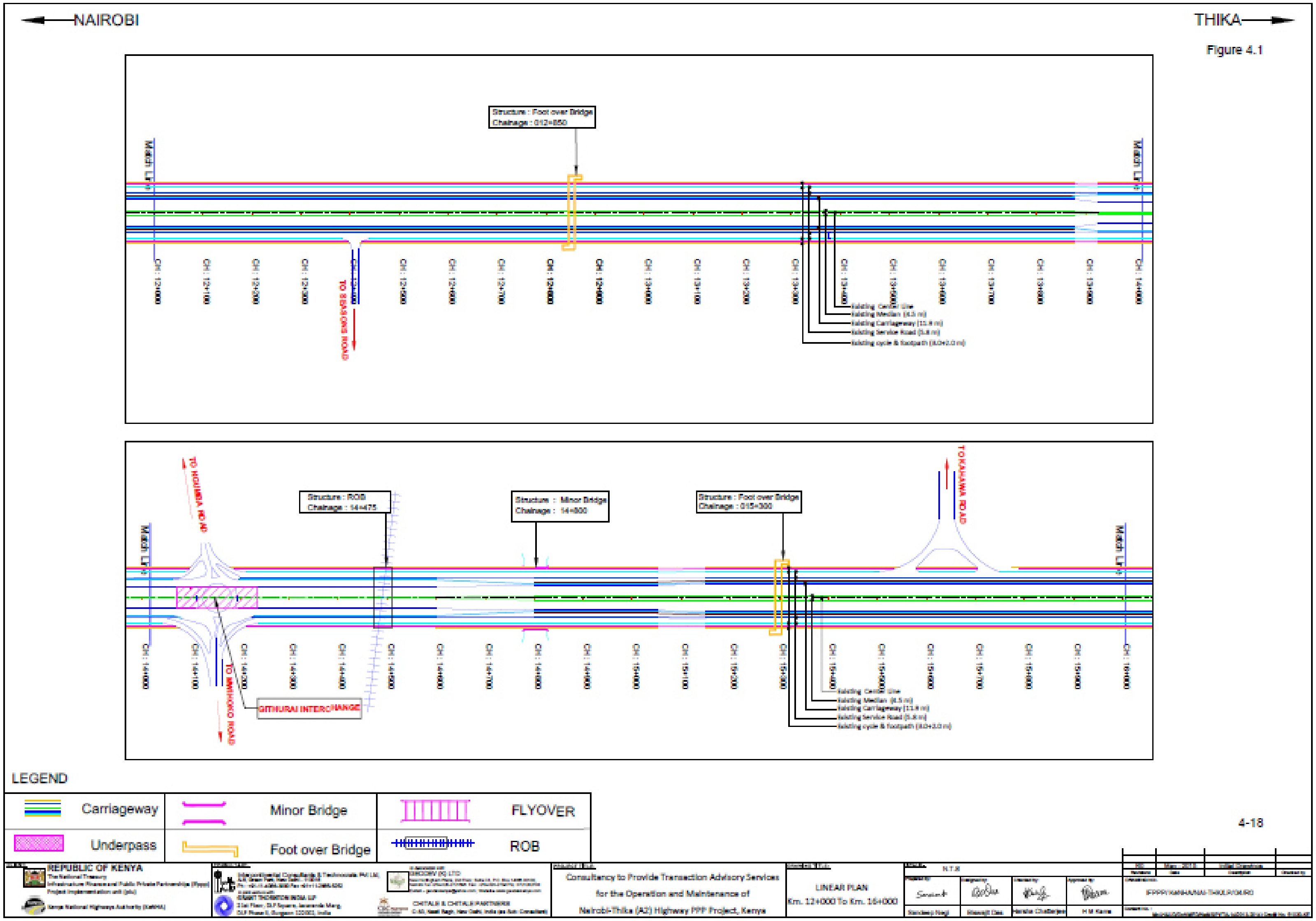


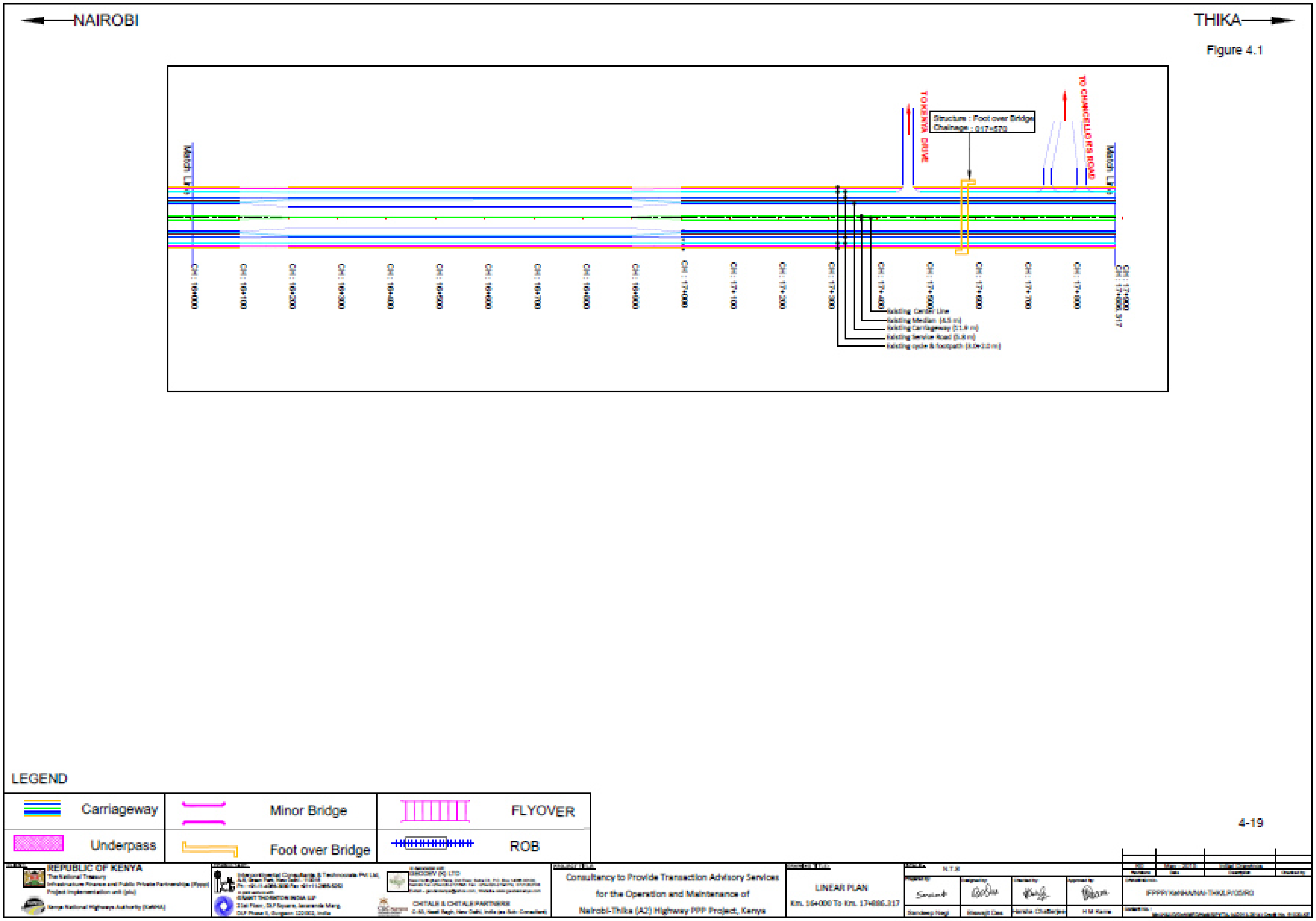
NAIROBI
KARIAKOR ROAD
THIKA
Figure 4.1
TO NGARA RING ROAD
Pangani Flyover
Span : 7 x 20m
Pangani Underpass
Span : 1 x 66.92m
Structure : Foot over Bridge
Chainage : 3+750
Structure : Underpass
Span : 1x 90m
TO GLOBE ROAD
TO FOREST ROAD
Structure : HP Culvert
Chainage : 0+700
Span : 2 X 0.90mØ
Structure : HP Culvert
Chainage : 0+850
Span : 1 X 0.60mØ
Structure : HP Culvert
Chainage : 1+110
Span : 1 X 0.60mØ
Structure : Foot over Bridge
Chainage : 1+115
Structure : HP Culvert
Chainage : 1+380
Span : 1 X 0.60mØ
Structure : HP Culvert
Chainage : 1+500
Span : 1 X 0.60mØ
Structure : HP Culvert
Chainage : 1+670
Span : 1 X 0.60mØ
Structure : HP Culvert
Chainage : 1+760
Span : 1 X 0.60mØ
Structure : HP Culvert
Chainage : 1+510
Span : 2 X 0.90mØ
KARIAKOR MARKET
CH : 0+400
CH : 0+500
CH : 0+600
CH : 0+700
CH : 0+800
CH : 0+900
CH : 1+000
CH : 1+100
CH : 1+200
CH : 1+300
CH : 1+400
CH : 1+500
CH : 1+600
Existing Center Line
Existing Median (2.0 m)
Existing Carriageway (11.0 m)
Existing cycle & footpath (3.0+3.0 m)
LEGEND
Carriageway
Minor Bridge
Flyover
Overpass
Slab Culvert
Underpass
Foot over Bridge
ROB
HP Culvert
Box Culvert
4-14
REPUBLIC OF KENYA
The National Treasury
Kenya National Highways Authority (KeNHA)
CHITALE & CHITALE PARTNERS
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN
Km. 0+000 To Km. 2+000
N.T.S
Sandeep Negi
Biswajit Das
H M Kame

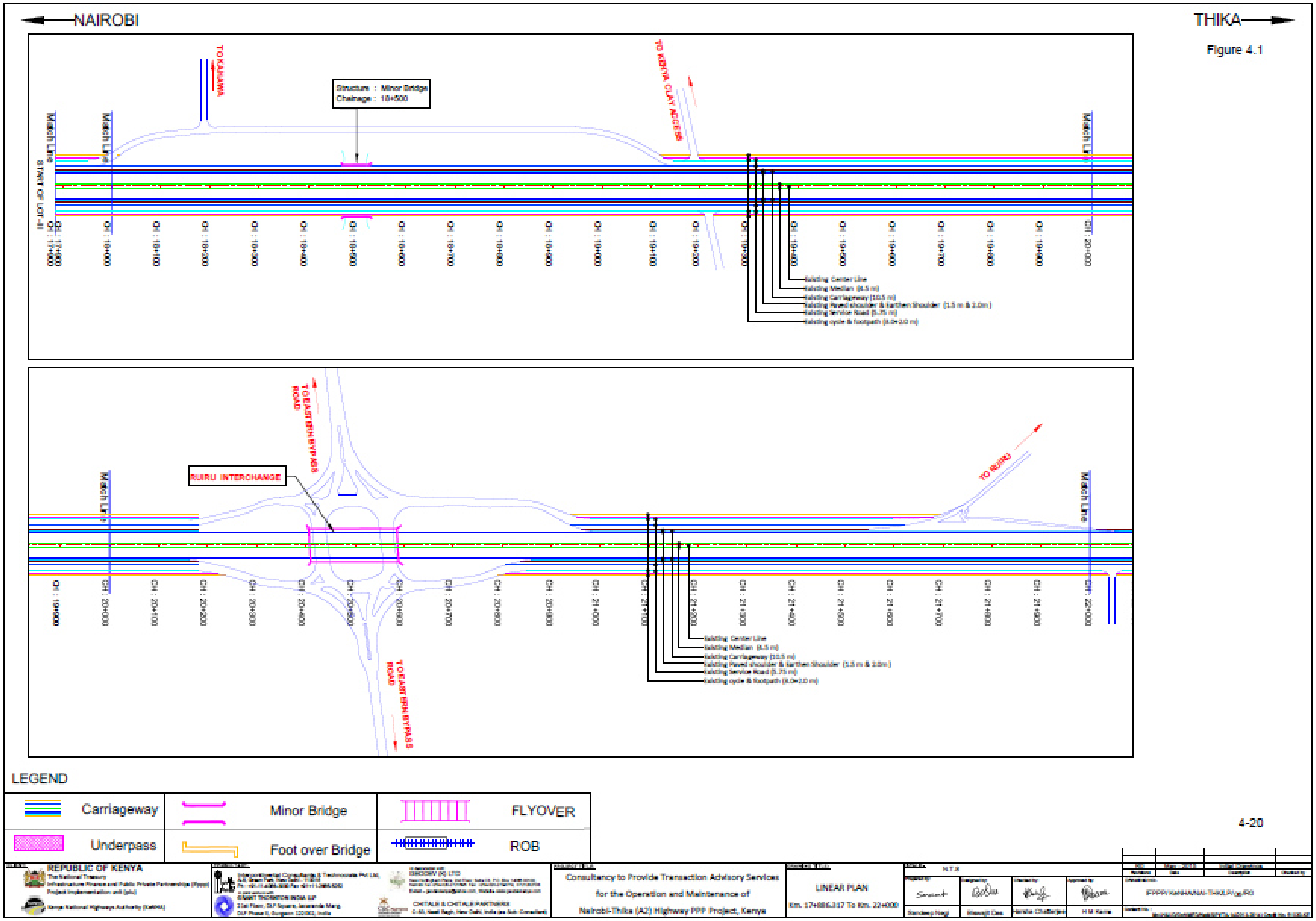

NAIROBI
THIKA
Figure 4.1
Structure : Flyover
Chainage : 0+300
Structure : Foot over Bridge
Chainage : 0+820
Structure : Foot over Bridge
Chainage : 1+300
GLOBE FLYOVER
LIMURU JUNCTION
TO PANGANI
TO KIPANDE ROAD
TO NGARA WEST ROAD
TO NGARA ROAD
Match Line
Existing Center Line
Existing Median (1.2 m)
Existing Carriageway (14.0 m)
Existing Service Road (7.0 m)
Existing cycle & footpath (4.0+2.0 m)
Structure : Foot over Bridge
Chainage : 2+250
Structure : Foot over Bridge
Chainage : 2+910
TO PARKLAND ROAD
MUTHAIGA ROAD
PANGANI FLYOVER
MUTHAIGA JUNCTION
LEGEND
Carriageway
Minor Bridge
FLYOVER
Underpass
Foot over Bridge
ROB
REPUBLIC OF KENYA
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN
Km. 0+000 To Km. 4+000
4-15

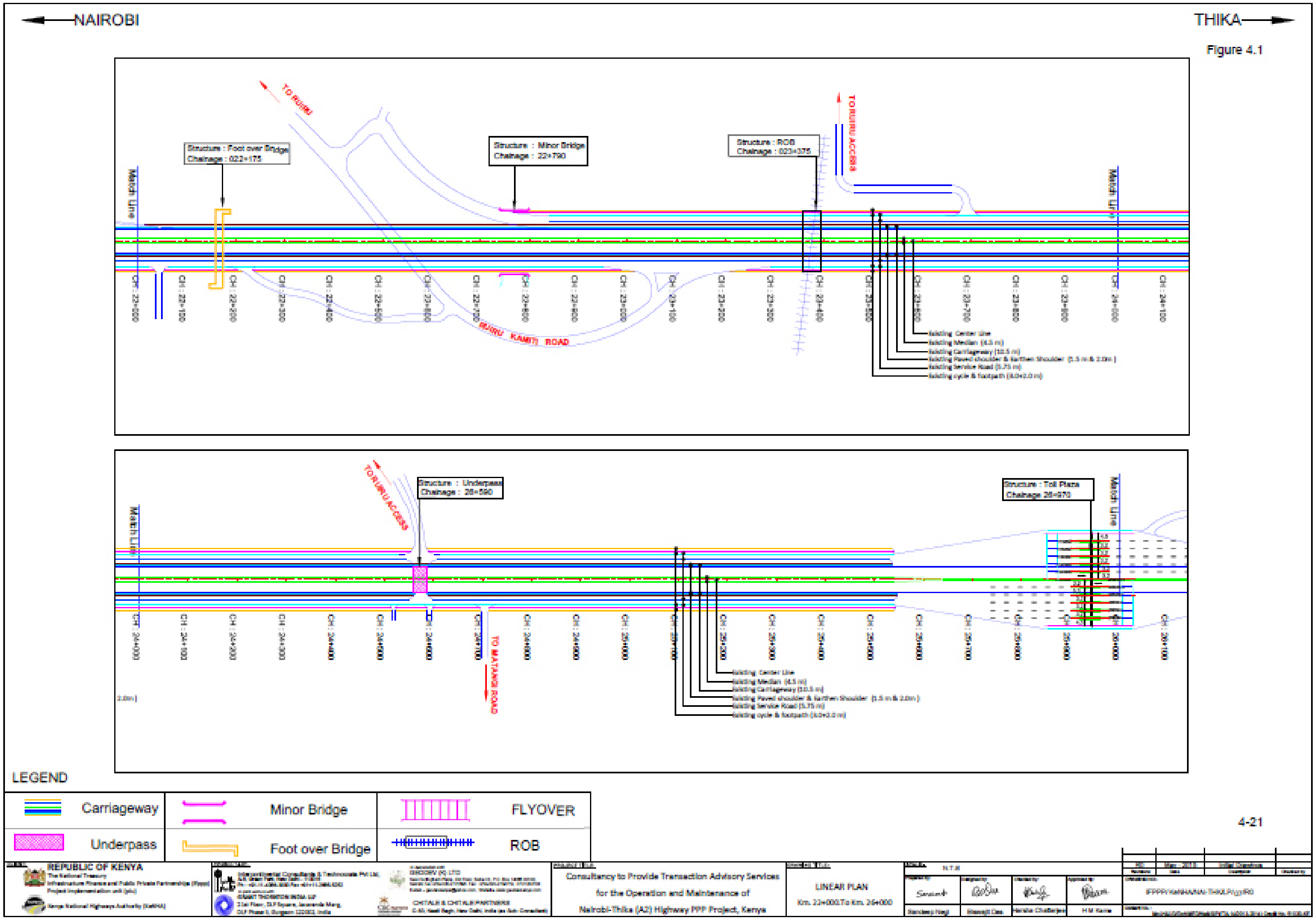

NAIROBI
THIKA
Figure 4.1
Structure : Underpass
Chainage : 5+400
Structure : Minor Bridge
Chainage : 5+470
Bridge Length :
Structure : Foot over Bridge
Chainage : 5+100
Structure : Underpass
Chainage : 5+450
Local Road
Match Line
TO MATHARE
G.S.U JUNCTION
TO OUTER RING ROAD
TO GARDEN EST.
Structure : Minor Bridge
Chainage : 7+610
Bridge Length :
Existing Center Line
Existing Median (2.0 m)
LEGEND
Carriageway
Underpass
Minor Bridge
Foot over Bridge
FLYOVER
ROB
4-16
REPUBLIC OF KENYA
The National Treasury
Kenya National Highways Authority (KeNHA)
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN
Km. 4+000 To Km. 8+000
N.T.S

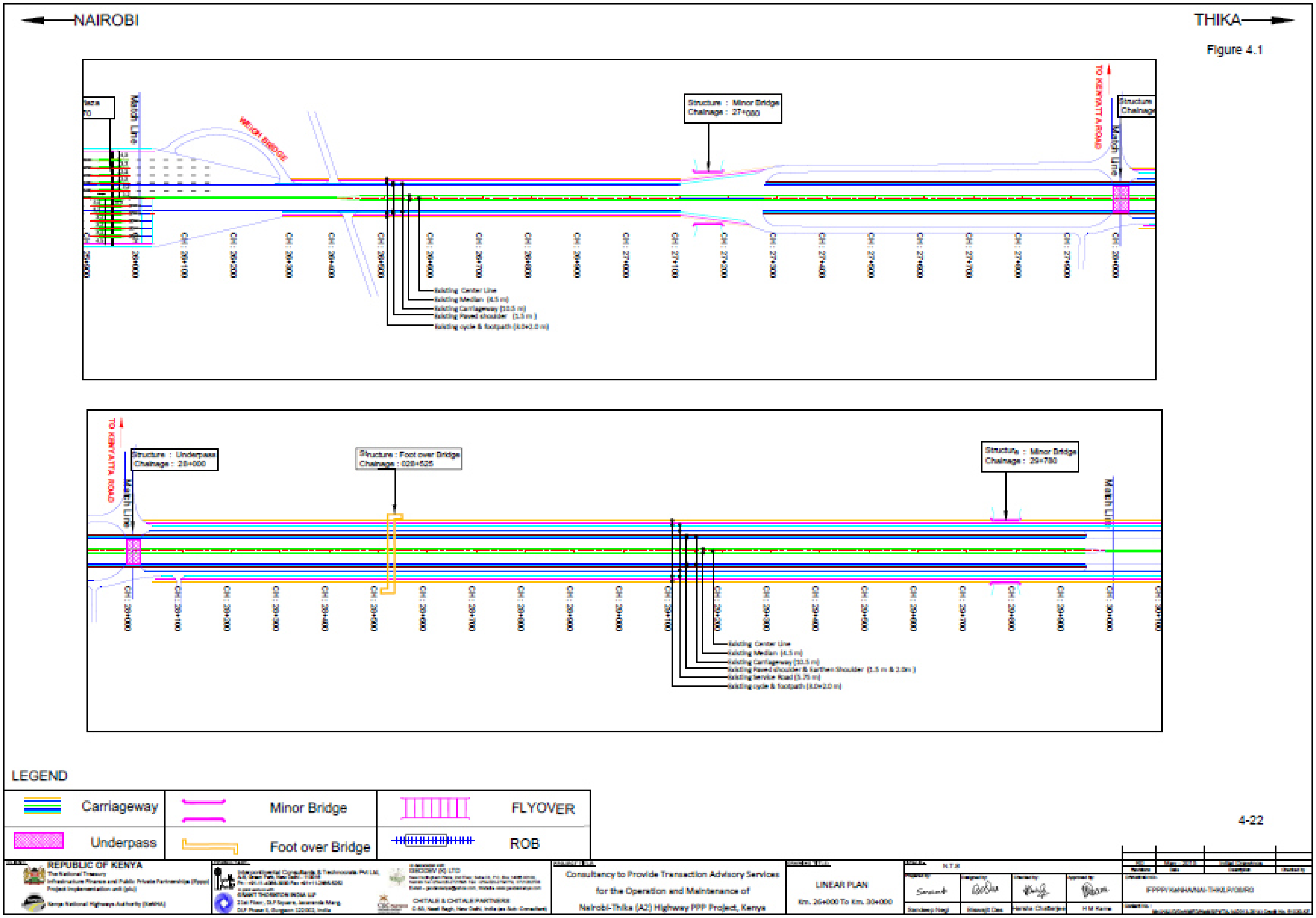

NAIROBI
THIKA
Figure 4.1
TO GARDEN ESTATE ROAD
TO NAIRUHUI ROAD
G.S.U JUNCTION
TO NGUMBA ESTATE
Structure : Foot over Bridge
Chainage : 09+700
TO STAFF ESTATE
Structure : Foot over Bridge
Chainage : 011+220
TO KAMITI ROAD
KASARANI INTERCHANGE
TO KASARANI MWIKI ROAD
LEGEND
Carriageway
Minor Bridge
FLYOVER
Underpass
Foot over Bridge
ROB
4-17
REPUBLIC OF KENYA
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN
Km. 8+000 To Km. 12+000
N.T.S

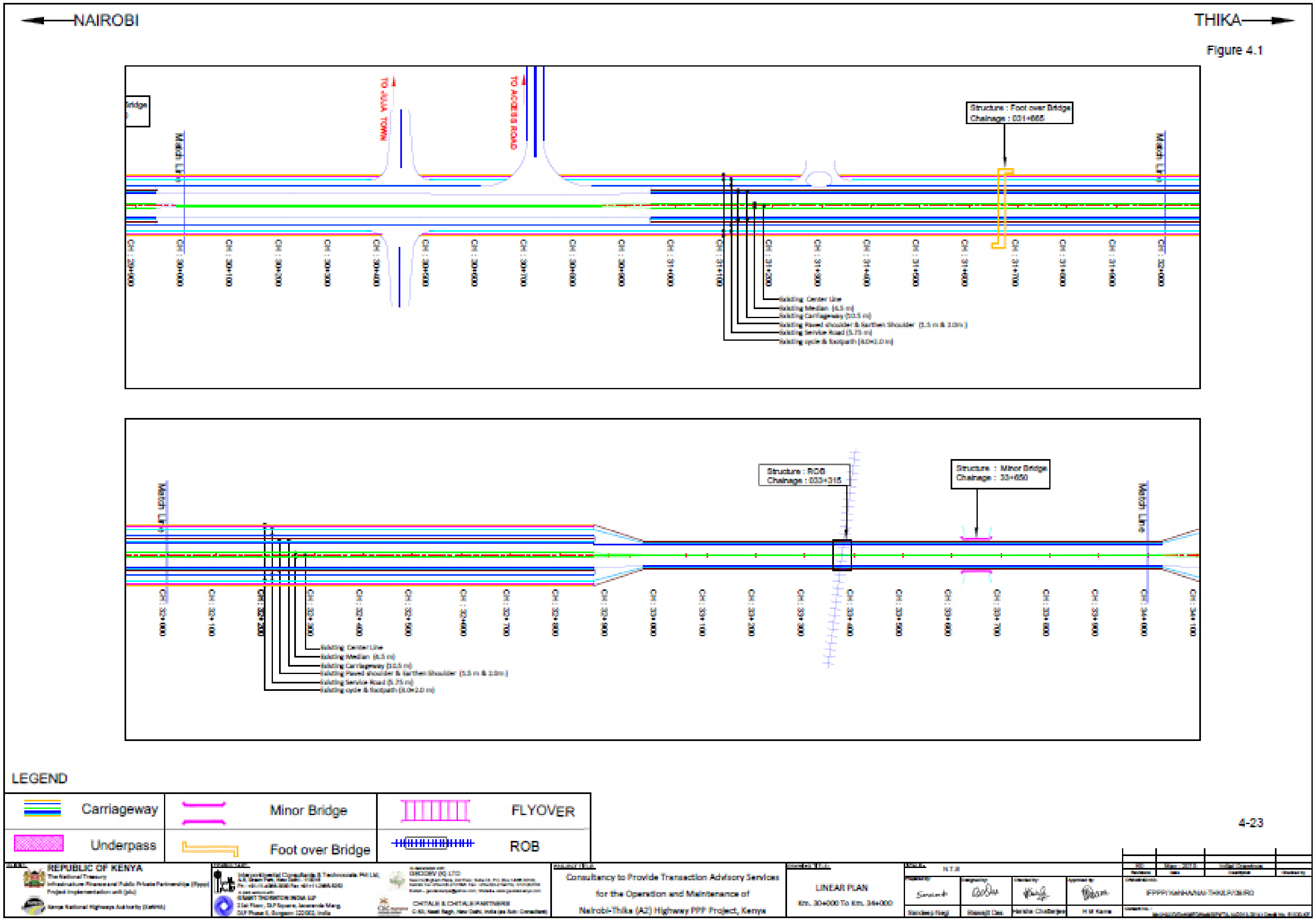

NAIROBI
THIKA
Figure 4.1
Structure : Foot over Bridge
Chainage : 012+850
TO SEASONS ROAD
Structure : ROB
Chainage : 14+475
Structure : Minor Bridge
Chainage : 14+800
Structure : Foot over Bridge
Chainage : 015+300
TO KAHAWA ROAD
TO MWIHOKO ROAD
GITHURAI INTERCHANGE
Match Line
LEGEND
Carriageway
Minor Bridge
FLYOVER
Underpass
Foot over Bridge
ROB
4-18
REPUBLIC OF KENYA
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN
Km. 12+000 To Km. 16+000

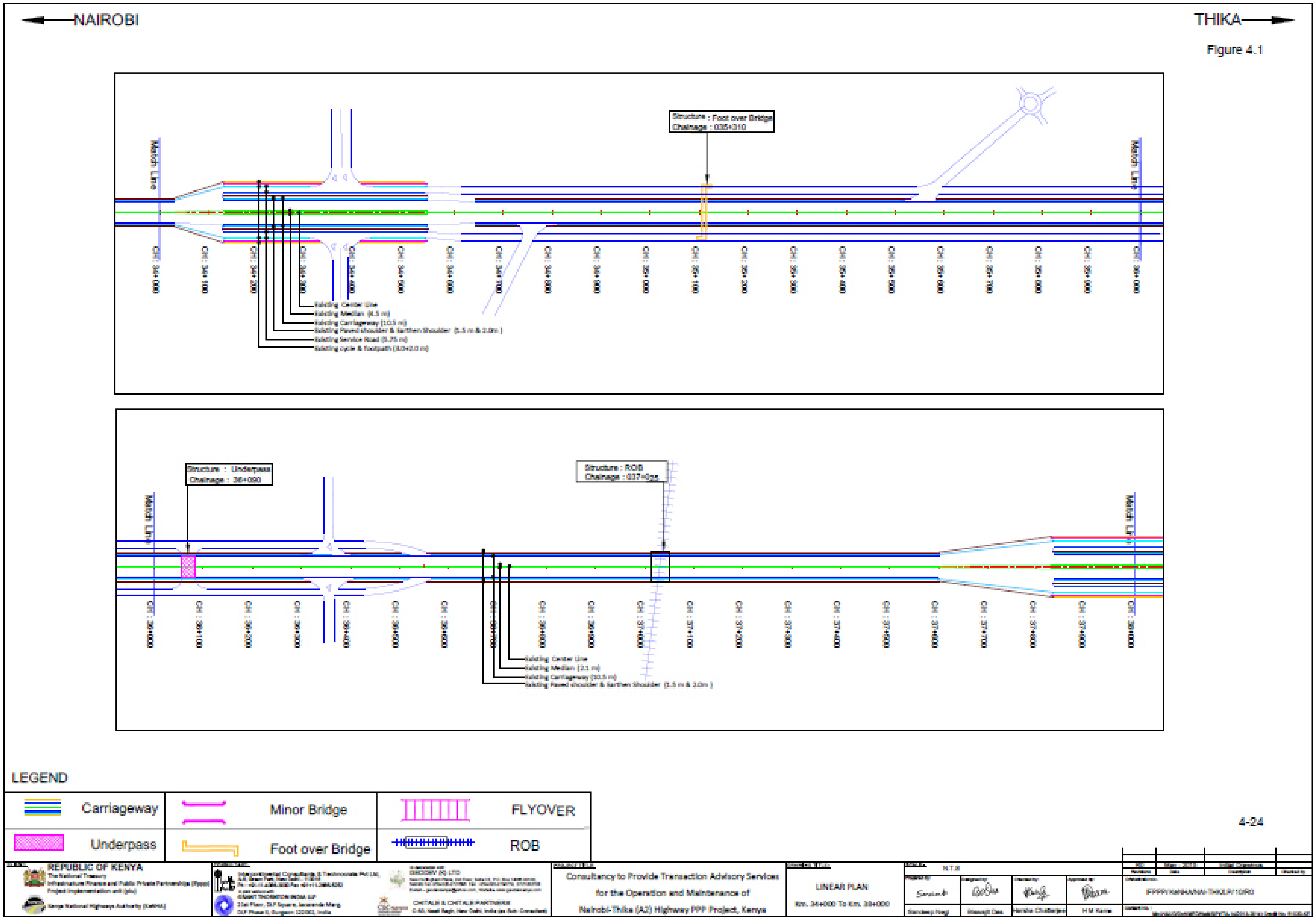

NAIROBI
THIKA
Figure 4.1
TO KENYA DRIVE
Structure : Foot over Bridge
Chainage : 017+570
TO CHANCELLOR'S ROAD
Match Line
CH : 16+000
CH : 16+100
CH : 16+200
CH : 16+300
CH : 16+400
CH : 16+500
CH : 16+600
CH : 16+700
CH : 16+800
CH : 16+900
CH : 17+000
CH : 17+100
CH : 17+200
CH : 17+300
CH : 17+400
CH : 17+500
CH : 17+600
CH : 17+700
CH : 17+800
CH : 17+900
CH : 17+886.317
Existing Center Line
Existing Median (4.5 m)
Existing Carriageway (11.8 m)
Existing Service Road (5.8 m)
Existing cycle & footpath (4.0+3.0 m)
LEGEND
Carriageway
Minor Bridge
FLYOVER
Underpass
Foot over Bridge
ROB
4-19
REPUBLIC OF KENYA
Kenya National Highways Authority (KeNHA)
GRANT THORNTON INDIA LLP
CHITALE & CHITALE PARTNERS
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN
Km. 16+000 To Km. 17+886.317
N.T.S
Sandeep Negi
Biswajit Das
Harsha Chatterjee
H M Rama

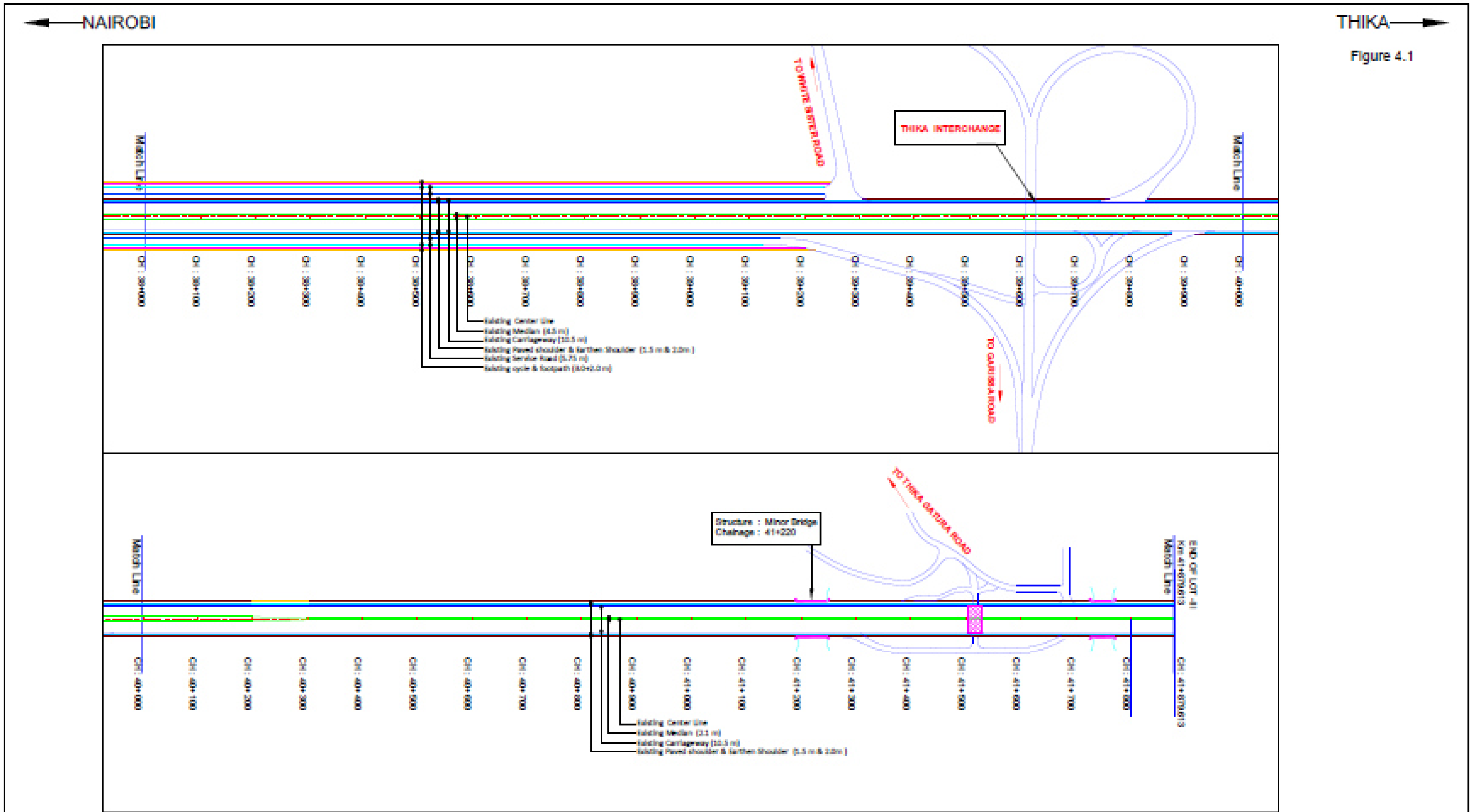

NAIROBI
THIKA
Figure 4.1
TO KANGUNDO ROAD
TO KENYA CLAY ACCESS
Structure : Minor Bridge
Chainage : 18+500
RUIRU INTERCHANGE
TO EASTERN BYPASS ROAD
TO EASTERN BYPASS
TO RUIRU
Match Line
START OF LOT-II
Existing Center Line
Existing Median (4.5 m)
Existing Carriageway (10.5 m)
Existing Paved shoulder & Earthen Shoulder (1.5 m & 2.0 m)
Existing Service Road (5.75 m)
Existing cycle & footpath (4.0+2.0 m)
LEGEND
Carriageway
Minor Bridge
FLYOVER
Underpass
Foot over Bridge
ROB
4-20
REPUBLIC OF KENYA
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN
Km. 17+886.317 To Km. 22+000
N.T.S


NAIROBI
THIKA
Figure 4.1
Structure : Foot over Bridge
Chainage : 022+175
Structure : Minor Bridge
Chainage : 22+790
Structure : ROB
Chainage : 023+375
TO RUIRU ACCESS
MAIRU KAMITI ROAD
Match Line
Structure : Underpass
Chainage : 24+590
Structure : Toll Plaza
Chainage 25+970
TO MATANGI ROAD
LEGEND
Carriageway
Minor Bridge
FLYOVER
Underpass
Foot over Bridge
ROB
4-21
REPUBLIC OF KENYA
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN


NAIROBI
THIKA
Figure 4.1
Structure : Minor Bridge
Chainage : 27+000
WEIGH BRIDGE
TO KENYATTA ROAD
Match Line
Structure : Underpass
Chainage : 28+000
Structure : Foot over Bridge
Chainage : 028+525
Structure : Minor Bridge
Chainage : 29+780
LEGEND
Carriageway
Minor Bridge
FLYOVER
Underpass
Foot over Bridge
ROB
4-22
REPUBLIC OF KENYA
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN
Km. 26+000 To Km. 30+000


NAIROBI
THIKA
Figure 4.1
TO JUJA TOWN
TO ACCESS ROAD
Structure : Foot over Bridge
Structure : ROB
Structure : Minor Bridge
Chainage : 33+650
LEGEND
Carriageway
Minor Bridge
FLYOVER
Underpass
Foot over Bridge
ROB
4-23
REPUBLIC OF KENYA
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN


NAIROBI
THIKA
Figure 4.1
LEGEND
Carriageway
Minor Bridge
FLYOVER
Underpass
Foot over Bridge
ROB
4-24
REPUBLIC OF KENYA
Consultancy to Provide Transaction Advisory Services
for the Operation and Maintenance of
Nairobi-Thika (A2) Highway PPP Project, Kenya
LINEAR PLAN
Km. 34+000 To Km. 38+000



LEGEND

	Carriageway		Minor Bridge		FLYOVER
	Underpass		Foot over Bridge		ROB

4-25

REPUBLIC OF KENYA The National Treasury Kenya National Highways Authority (KeNHA)	CHITALE & CHITALE PARTNERS	Consultancy to Provide Transaction Advisory Services for the Operation and Maintenance of Nairobi-Thika (A2) Highway PPP Project, Kenya	LINEAR PLAN Km. 38+000 To Km. 38+000

N.T.S

Sandeep Negi	Biswajit Das	Harsha Chatterjee	H M Kama

Appendix vii: Distribution of Road Fatalities by Population

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Population(Millions)[,a]	35.1	36.1	37.2	38.3	39.3	40.3*	41.4*	42.5*	43.7*	44.9*	47.8*
Road Fatalities [b]	2,533	2,715	2,921	3,149	4,032	3,045	3,302	3,141	3,218	2,907	3,057
Fatalities per 100,000 popn	7.42	8.21	7.93	8.31	9.54	8.25	7.97	6.82	7.22	6.34	6.4

Source:

- **** a Kenya National Bureau of Statistics Projections/World Bank Report***

[b] ***NTSA/Kenya Police 2015***

Appendix viii: Distribution of Road Fatalities by Motorization level

Distribution of Road Fatalities by Motorization level

NTSA

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cumulative Number of Vehicles [a]	749,680	819,443	896,573	1,009,438	1,165,395	1,417,539	1,616,745	1,789,789	2,011,972	2,210,907	2,458,731
Fatalities[b]	2,533	2,715	2,921	3,149	4,032	3,045	3,302	3,141	3,218	2,907	3,057
Fatalities per 10,000 vehicles	33.79	32.92	33.2	30.85	35.21	21.32	19.65	18.42	16.42	13.15	12.43

a Source: Kenya Revenue Authority (KRA)/National Transport and Safety Authority (NTSA)
[b]*NTSA/Kenya Police*

Keep our roads safe

Appendix ix: Kenya Police Service Accident Abstract Form (P41)

REPUBLIC OF KENYA
THE KENYA POLICE
ABSTRACT FROM POLICE ON A ROAD ACCIDENT

To: The officer i/c ………………………Division. Date…………………………………………..
P.O. Box…………………………………… Our ref………………………………………..
…………………………………………… Police ref……………………….................

I/we understand that your Police Station received a report of an accident involving……………………
…………………………………………………………………………………………………
of(address)……………………………………………………………………………………..
Which occurred on (date)…………………….at (Time and place)……………………………………...
…………………………………………………………………………………………………...
involving vehicle(s) Reg .No. ……………………….make…………....……….……………………..
and………………………………………make…………………………………......................
Name of police station where accident reported……………………………….................................
From the record could you please furnish us with the following information:
1. (a) Name and address of the owner of the vehicle Reg.No……………………………………………
…………………………………………………………………………………………………
(b). Name of the Insurance Company……………………………………………………………….
2. Has the investigation been completed? Yes/No. (Delete as appropriate.)
If so, has anyone been charged? Yes /No.
If this case is still under investigation is there any likelihood of either party being prosecuted? Yes/No.
3. If it is intended to prefer charges, state:
(a) Name of driver/cyclist/pedestrian……………………………………………........................
(b) Vehicle registration No…………………………………………………..................................
4. Name of charge……………………………………………………………………………………...
5. Court Case File No………………………../Traffic Charge Reg. No……………………………..
6. Name of Investigation Officer……………………………………………………………………
7. Result of investigations or prosecutions (if known)………………………………………………...
8. Accident Register/OB Number………………….and date……………………………………………

9. Persons Injured Name	Class of Person	Address	Nature of Injury
………………………	………...........	………….	……. …………….
………………………	…………………	………….	…………………...
………………………	…………………	………….	…………………...

10. Name of Witnesses	Addresses
……………………………………… ……	………………………………………….
….……………………………………………	………………………………………….
……………………………………… ……	………………………………………….

Date …………………………….. (Signed)……………………………………………………..
Officer-in-Charge
…………………………………..
Police Station

11. When completed, this form is to be returned to:
Name and address of Insurance Company……………………………………....................................
…………………………………………………………………………………………………
OR
Legal Representative or other interested party stating interest and/or connection with the accident
…………………………………………………………………………………………………
……………………………………
Signature of Person/Company
Applying for the abstract

Note: - when applying forward in triplicate to officer i/c Division.

MEMORANDUM

1.Police reports, books and records are confidential and privileged and the Commissioner is unable to accede to any request for copies of such documents.

2. In case of a vehicle accident to which police are called, the Commissioner is generally prepared to furnish to the parties interested, or to their properly authorized legal representatives, an abstract (as overleaf) giving the salient facts of the occurrence as ascertained by the police from their own observation, including the names and addresses of witnesses, on the understanding that the abstract is not and does not purport to be, an actual copy of a police report. The police cannot accept responsibility for the accuracy of the names and addresses tendered by the parties and witnesses.

Except with the consent of the Attorney-General, no abstract will be supplied until police proceedings have been completed.

3. The abstract form is issued free of charge.

4. The following particulars will not be supplied:

(a) Details of vehicle tax and driver's licenses.

(b) Reference to conversation held at the time of accident by or between the parties involved, other than statements made to the police.

(c) Expressions of opinion, e.g. as to whether an accident could or could not have been avoided or as a to conditions of any of the drivers or persons involved, or as to estimates or rates of speed of vehicles.

5. Copies of Statements. -No copy of the statement made by a party involved or by a witness, shall be given except on application by the person who made the statement or to his properly accredited representative. If an advocate acting for a party applies for a copy of a statement made to the police by a witness, the Commissioner will write to the witness, and if the witness consents, will supply a copy of the statement to the advocate free of charge.

6. Plans, sketches and Photographs-Plans, sketches and photographs will not normally be supplied.

7. Where vehicle examination report forms part of the evidence and will be adduced in court as such, the parties concerned may have access to that report through the Court Prosecutor. However, a Vehicle Inspection Report normally prepared after inspection of a motor vehicle, which will not jeopardize the police investigations, will be supplied free of charge to the owner/driver of the motor vehicle as and when requested.

8. No police officer will be permitted to give evidence in civil proceedings unless served with a subpoena

9. Interviews with any police officer concerned can generally be arranged at an officer's duty station provided that adequate notice is given. If the exigencies of the services require, the interview may be held at such other places as may be convenient to the Commissioner of Police. The interview will take place in the presence of a superior officer at no cost. The proof of evidence may cover statements made