ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

Speed hump effect on pavement condition

(Addis Ababa City Road case study)

A Thesis submitted to the school of graduate studies of Addis Ababa University in partial fulfilment of the requirements for the Degree of

Master of Science in Civil Engineering

(Road and Transport Engineering)

By

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Addis Ababa, Ethiopia

UNDERTAKING

I, the undersigned, certify that this research work titled "speed hump effect on pavement condition: the case of Addis Ababa city road" is my original work performed under the supervision of my research advisor Dr. Ephrem Taddesse and has not been presented elsewhere for assessment and for a degree in any other university. All sources of materials used in this thesis have also been duly acknowledged.

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Place of Undertaking: Addis Ababa, Ethiopia.

Date: January ,2020

Abstract

One of the traffic calming devices used in Addis Ababa, Ethiopia is a speed hump due to low cost and ease of installation. However, these speed humps are randomly placed without proper engineering studies and justification. Due to this, speed fluctuations and the excessive decelerations and accelerations, before and after speed humps, over small distances and infiltration of water to the pavement surface. The pavement condition near to the speed humps show failure and deterioration.

The research study was initiated to investigate the effect of speed humps on pavement condition and also to analyze the relationship between speed hump characteristics and pavement condition. The research methodology involved selecting representative samples of road segments that have at least one section with speed humps. For the selected section pavement condition and IRI data collected from AACRA. Road and speed hump characteristics data collected from site direct measurement. Collected data analyzed and compare the pavement condition of these sections with and without speed hump. Regression analysis models were developed to represent the relationships between pavement conditions and hump characteristics.

Pothole and Raveling were the most widely observed distress at both sections with and without speed hump. But their frequency was higher on sections with speed humps. Pavement condition index (PCI), in road sections with and without speed hump, was calculated from the pavement condition data. The analysis showed that the presence of speed humps significantly affected the pavement condition, reducing the PCI of the pavement sections by 34 PCI points and increase IRI value by 3.4 IRI points. The relation between speed hump characteristics and pavement condition shows that the speed hump height and density have a negative relation to pavement condition index value and the speed hump width has a positive relation with PCI value.

Keywords: Speed humps, Pavement condition index, International roughness index

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List of Acronyms

AACRA: Addis Ababa City Road Authority

AACRTMA: Addis Ababa City Road Traffic Management Agency

AASHTO: American Association of State Highway and Transport Office

ANOVA: Analysis of Variance

ASTM: American Society for Testing and Material

CDV: Corrected deducted value

IRI: International Roughness Index

ITE: Institute of Transportation Engineering

PCI: Pavement Condition Index

TDV: Total deducted value

TPMO: Transport Project Management Office

WRI: World Resources Institute

CHAPTER ONE:-INTRODUCTION

1.1 General

Addis Ababa lies at an elevation of 2,300 meters and is a grassland biome, located at 9°1′48″N 38°44′24″E Coordinates, The city lies at the foot of Mount Entoto and forms part of the watershed for the Awash. From its lowest point, around Bole International Airport, at 2,326 meters above sea level in the southern periphery, the city rises to over 3,000 meters in the Entoto Mountains to the north [1].

The city has a total area of 526.47 km² and divided into ten boroughs, called sub-cities (kifle-ketema which are Yeka, Gullele, Bole, Kirkos, Arada, Lideta, Addis Ketema, KolfeKeranio, Nifas Silk-Lafto, and AkakyKaliti), and 99 wards (kebele)[2].

1.2 Research background

According to ITE the guidelines for design and application of speed humps were approved in 1997 which report that speed humps should be installed at roadway facilities classified as local streets by the AASHTO. The roadway should not be more than two travel lanes or traveled significantly by long wheel-based vehicles. Additionally, it should have a horizontal curve of 300 feet radius or more and a grade of eight percent or less. The posted or prima facie speed limit should be 30 mph or less; ITE warned that installation on roadways with a higher speed limit is warranted careful consideration [9].

The main speed calming device types installed in Ethiopia are speed hump and rumble strip, which are vertical calming measures. Speed humps are raised pavements spanning across a roadway, accordingly; forcing drivers to reduce the speed of their vehicles.

The main cause of fatalities in Addis Ababa City is related to high-speed driving. To counteract this high-speed movement of vehicles, implementing speed hump and rumple strips is one of the road safety works. Speed humps used to reduce vehicle speed to improve road traffic safety. Its speed reduction capability is directly related to its height (height above pavement level) to width (in the longitudinal direction of a road) ratio, which determines the vertical deflection capacity of the sped hump.

Moreover, these speed humps and rumble strips in the Addis Ababa city are constructed in a manner that cut the existing asphalt and casting the asphalt concrete hump on the cut section. Whereas, based on the relevant studies reviewed, there is a consensus that utility cuts have an overall negative impact on the performance of pavements in terms of loss of pavement life and structural pavement strength. Several studies indicated that pavement lives were reduced about 15 to 50 percent, depending on the number and extent of Pavement cuts. The average difference in overlay thickness is 1.58 inches, i.e. the overlay thickness due to the presence of the cuts is 1.58 inches thicker than the control section. These improper speed humps affect the pavement condition and might be a factor in reducing the pavement service life [5].

The presence of such humps has a negative impact on roadway level-of-service, as they increase travel time and delay. They also may cause serious damages to vehicles and passengers and increase fuel consumption and pollution. Moreover, these improper speed humps may deteriorate the pavement condition, before and after the location of a hump, due to excessive acceleration and deceleration movements, and at the time of construction the breaker installed by cutting the existing pavement which may be a factor in reducing the pavement service life [10].

Consequently, there is an urgent need to investigate the impact of speed hump characteristics on pavement condition, in order to assess how much they contribute to the pavement deterioration of city roads dominated by speed humps. Therefore, this paper presents a practical study to collect and analyze visual inspection and International roughness index data for the reason for evaluating the impact of speed hump characteristics on pavement condition. The visual inspection data are carried out or collected by field surveys for pavement distresses that characterized by PCI.

Pavement condition index rates the condition of the surface of a road network. It provides a numerical rating for the condition of road segments within the road network, where 0 is the worst possible condition, and 100 is the best.

1.3 Research problem of statement

The main speed-calming device used in Addis Ababa city is speed hump and rumble strip but due to lack of proper control system different improper design of speed calming device and adaptation of speed hump constructed by asphalt concrete. Due to the rigidity and durability of these materials, they have more permanence and are more effective at slowing traffic. However, they can be difficult to shape and form consistent forms and precise dimensions [10]. This forces vehicles to decelerate and accelerate during this time it results in dynamic load to the pavement.

The pavement condition near to the speed breakers and on speed, breakers show failure and deterioration, which allow water to enter into the pavement structure and result in rough surface conditions difficult to drive and affect the pavement service life.

Thus, quantify the effect of speed breaker characteristics (height, width, and the space between consecutive speed breakers) on pavement condition and develop a proper model for Addis Ababa city case help to improve the next design on characteristics of speed humps.

1.4 Research Questions

- What are the impacts of speed breakers on pavement condition?
- How can we quantify speed breakers' characteristic effects on Pavement?
- What mathematical model is vital for pavement condition and speed breaker characteristic relationship?

1.5 Research Objective

1.5.1 General Objective

The main objective of this research is to investigate the speed hump installation effect on pavement conditions of the Addis Ababa City Road case study.

1.5.2 Specific Objective

- To undertake a pavement condition study.
- To investigate a major asphalt pavement distress and their severity level.
- To develop a mathematical model for pavement condition and speed hump characteristic relationship.
- To recommend the remedial measures for speed hump effect on pavement condition.

1.6 Limitation of the Study

The study, based on Visual inspection and IRI data was used to analyze the effect of speed humps on pavement. Whereas the structural effect that cannot detect visual did not consider since it needs using the falling weight deflection method, but this device is not available here. In addition, the pavement condition study is undertaken in 100-meter sections since available pavement condition data is in this section, but not only pavement condition just near speed humps.

1.7 Structure of thesis

This research is divided into five main chapters. Chapter one intends to introduce the underlying background science to the topic and the intended Purposes in doing the research. The second chapter extends the effort to look at background science in detail by reviewing vast materials in the area. The third one defines the materials and methods that were followed. Fourthly, the data collected from the study area are present and summarized in Tables, and analyzed. Then in Chapter Five, the conclusion and recommendation of the study are presented

CHAPTER TWO: - LITERATURE REVIEW

2.1 Introduction

The concept of traffic calming originated in the Netherlands. In the 1960s, traffic volumes in the Netherlands increased as the automobile became more popular. By the late 1960s, Dutch transportation officials began receiving public complaints about speeding traffic through residential neighborhoods. The Dutch town of Delft in 1970 when city officials built a 0.26-foot (8-centimeter) road hump at the end of an alley. The concept of traffic calming has spread throughout Europe, Canada, the United States, and Australia. In 1975, Berkeley, California, implemented the first major traffic-calming program in the United States. The traffic calming program found throughout the United States. At least 60 local governments in 22 states now have traffic calming programs. Since various interpretations of what traffic calming has emerged, the ITE developed a standard definition of traffic calming in 1997 [6].

Traffic calming measures in Africa were introduced partially during the colonial era when most African countries were under the rule of the white minority. South Africa was the first African country to undertake research on traffic calming devices and this spread to other African countries like Zimbabwe, Tanzania, Uganda, Zambia, and Kenya. This was necessitated by the increase in accident rates in cities due to high traffic volumes causing vehicular and pedestrian conflict at crossing points [6].

Speed humps were introduced in Addis Ababa during 2007E.C with a standard height of 5cm,50 m distance between them, and 50 cm width in traffic direction by using Asphalt concrete type. AACRTMA adopted the speed hump design recommended by WRI in the guidelines cities safer by design [3].

Traffic Calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior, and improve conditions for non-motorized street users [15].

Speed control measures are physical devices designed to reduce vehicle speed. Some of these devices have an impact on traffic volumes. Speed control devices can be divided into three categories: horizontal measures, narrowing, and vertical measures [15].

Horizontal speed control measures are physical devices that require vehicles to shift laterally. Drivers must reduce their vehicle speed to maneuver comfortably through and around the shifter. The most commonly used horizontal measures are the traffic circle. Traffic circles are typically raised circular islands located in the center of an intersection. Typical concerns related to the implementation of traffic circles are the ability of large vehicles to maneuver around an obstacle with a small radius, the safety of pedestrians and bicyclists, and the cost of implementation [15].

Road narrowings are created when the travel lane is physically reduced or perceived to be reduced by the driver and is often used to "pedestrianize" an intersection by creating shorter crossing distances. Several different methods and devices have been used to narrow the travel way. Examples of narrowing are included "neck downs" the addition of a center island and "chokers." Properly designed narrowings also decrease the crossing distance for pedestrians and/or operate as a pedestrian refuge [15].

Vertical speed control measures are physical device design to displace vertically the frame of a vehicle. Drivers must reduce speed to pass comfortably this type of obstacle. Examples of vertical speed control measures include raising intersections, speed humps, and speed tables [6].

2.2 Speed hump types

Traffic calming devices can be made from a variety of materials, including asphalt, concrete, recycled plastic, metal, or vulcanized rubber. Traditionally, most vertical deflection devices have been constructed from asphalt or concrete. Due to the rigidity and durability of these materials, they have more permanence and are more effective at slowing traffic. However, they can be difficult to shape and form consistent forms and precise dimensions [7]. Improper speed hump shape and form results mislead speed hump purpose, it increases travel time, force vehicles to decelerate and accelerate, result in dynamic load to the pavement, increase fuel consumption and result discomfort to driver and passenger. The capacity of a cross-town road varied between 810 and 1300 vehicles per hour and lane with traffic calming devices spacing from 25 to 400 meters [31].

Rubber products pre-shaped to standard sizes to meet industry standards. Preformed rubber products typically bolt down, making them easier to install or remove. Temporarily bolt-down installations can be ideal for planners in testing the use and positioning of speed bumps before implementing them in a larger project. Bolt-down products can also be removed or relocated during winter snow periods. Those types of speed hump can meet required speed hump characteristics and meet speed hump purpose that force the vehicle to drive by giving posted speed when they drive above speed limit [7].

Speed breaker modules are made from 100% recycled rubber and a two-part polyurethane binder making the speed breaker impervious to motor fuels, oils, solvents, road salts, and outdoor environment. The rubber shall be obtained from recycled truck and tractor tire treads only.Which is all rubber as compared to car tires, which contain synthetic rubber [32].

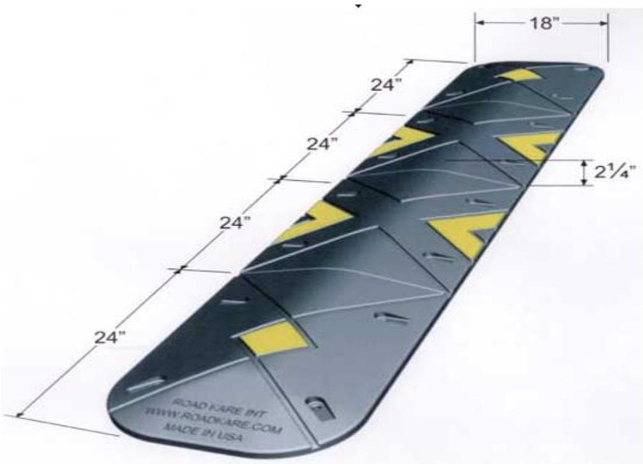


Figure 1: Rubber type Speed Breaker Dimensions and Specifications [32]

Another type of speed hump is automatic height adjustable speed humps, which are designed to get activated only if the vehicles are traveling above a certain speed and vehicles within the speed limit will not experience the discomfort of the speed bump. Since speed bumps are not experienced for vehicles traveling at or under the speed limit, the changing of gear of a vehicle is not necessary and hence fuel consumption of vehicles due to road bumps may reduce [10].

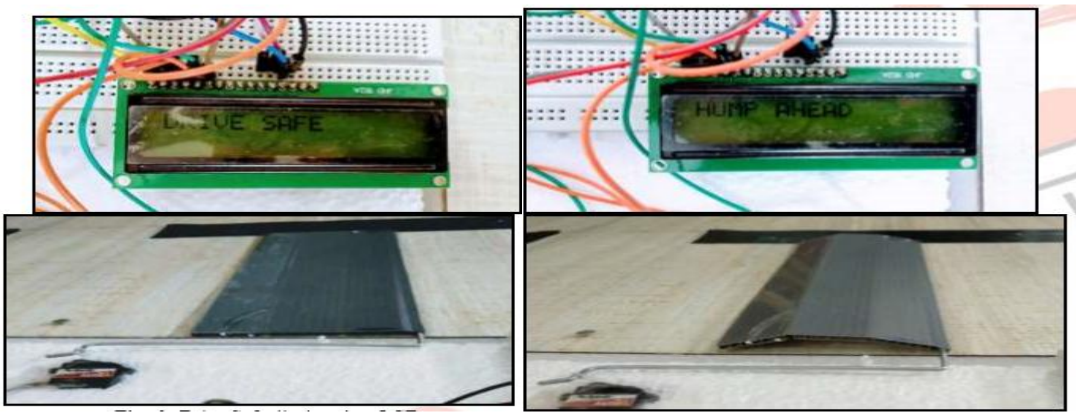


Figure 2: Height Adjustable speed breaker type [10]

2.3 Speed hump characteristics

To achieve the desired speed of driving, the cross-sectional width, and height of speed humps specified.Common speed hump shapes are parabolic,circular,and sinusoidal [3].AACRTMA adopt speed hump characteristics for 30 km/HR, 40 km/HR and 50 km/HR as follows.

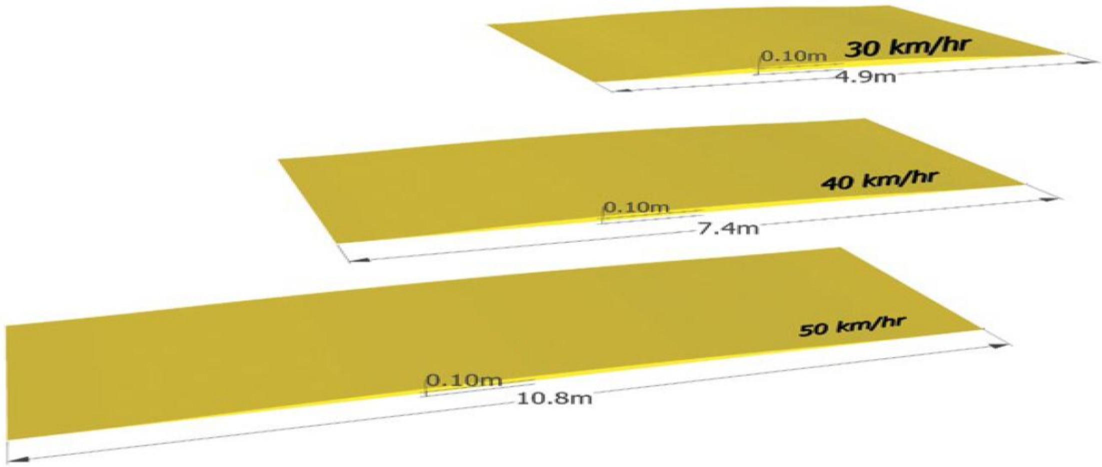


Figure 3: Speed hump characteristic [3]

Based on the field study of humps characteristics and hump-cruising speeds of passenger cars, microbuses, and motorcycles, vehicles, the results have shown that statistically, significant regression relationships could be predicted [28]. Strong correlation found between the hump-crossing speed and speed hump characteristics. The height of speed hump showed a negative correlation with hump-crossing speed. On the other hand, a strong positive correlation found between length and hump-crossing speed. In addition, a strong positive correlation between the distance between the successive humps and vehicle speed [28].

2.4 Speed hump impacts on speed

Speed profile using GPS, over closed speed humps, demonstrates the speed fluctuations and the excessive decelerations and accelerations before and after speed humps. This will cause an increase in travel time and delay, probable damages to vehicles, discomfort to passengers, and an increase in fuel consumption and pollution as well as deterioration in pavement condition [4].

Rash driving is the cause of many road accidents all over the world. Road bumps play a crucial role and significantly contribute to the overall road safety objective through the prevention of accidents that lead to the deaths of pedestrians and damage to vehicles. The speed humps used for discouraging vehicle drivers from driving with excessive speed. These are typically comprised of concrete or solid humps that form a transverse ridge in the road and are generally above the road surface. The vehicles while passing over the hump undergo a jolt; hence, the drivers are discouraged for traveling at high speed. For vehicles that are within the speed limit, unnecessary fuel consumption may occur due to gear changes at the hump. So the speed hump may be required only when the vehicle is above the speed limit [10].

The relationship between traffic safety and road surface conditions where the road surface condition was described in terms of rut depth and unevenness shows that ruts possibly seem to have a tendency to improve traffic safety while unevenness has the opposite effect. Investigated the relation between traffic safety and road surface condition for the Swedish National Road Administration’s further corroborated the findings in the earlier study. The results showed that the accident ratio increases with increasing unevenness higher (International Roughness Index, IRI) [26].

The installation of speed humps contributed greatly to reduce vehicle speed, the flow of traffic and accident rates. On the other hand, the results proved that humps also contribute significantly to environmental pollution, damage to the pavement and vehicles especially when they are poorly designed and located. The majority of respondents attributed the random spread of the speed humps to the weakness of the authorities in law enforcement and the prevention of the installation of new humps without authorization. Finally, with the widespread use of speed humps and with the exception of the positive impact on traffic safety, it also has negative impacts on both the economy and the environment. The use of speed humps can cause many harmful effects to the neighborhood if there no strict control of its installation process [27].

2.5 Impact of speed hump on safety

Analysis of fatal and injury accident data on the road sections with vertical traffic calming measures showed a significant decrease in fatal and injury accidents after the installation of these measures. The number of fatal and injury accidents decreased by 60%, the number of people injured decreased by 63%, the number of people killed decreased by 82% [11].

In foreign countries, the effects of vertical traffic calming measures on the change in the number of road accidents, severity have been evaluated in a number of studies. Based on that studies presented that implementing speed hump on roads reduces the number of injury accidents about 41%.Assessed the effect of various safety countermeasures implemented in New York City. The changes in average accidents per year percolation from the before period to the after period on the sections where speed humps were placed shown that the number of fatal and injury accidents decreased by about 33% [12].

To decrease the number of accidents and the consumption of the fuel due to road bumps, height adjustable speed hump is developed. The primary objective is to detect the speed of a vehicle, whether the vehicle is above or below the speed limit. Then an automatic speed bump is raised according to the speed of the vehicle. Therefore, it can help in avoiding major road accidents and provides comfort for people who are driving within the speed limit. Raising and falling of Hump based on the speed of the vehicle is implemented. This has been developed to avoid road accidents due to over speeding of the vehicles. This kind of system may reduce the fuel consumption of vehicles, which are traveling within the speed limit [10].

2.6 Speed hump effect on pavement condition

Moreover, these speed humps are sometimes constructed in a manner that may cut the water path over the pavement surface. The presence of such humps has a negative impact on roadway level-of-service, as they increase travel time and delay. They also may cause serious damages to vehicles and passengers, and increase fuel consumption and pollution. The possible effects of illegal speed traffic humps of pavement condition in Alexandria city, Egypt. The results proved that the presence of such improper speed humps could reduce the average pavement condition index (PCI) of the examined road sections by up to 19 PCI points [13].

The presence of speed humps contributes greatly to reduce the pavement condition index (PCI) values. The average reduction in PCI values ranged between 15% and 22% due to the presence of speed humps. In addition, the most frequently observed distress on the pavement sections including humps considered for the selected roads was Ravelling and Rutting. Accordingly, to avoid the pavement defects at the locations where the speed humps installed, it is proposed to study the structural section of the road near the speed hump to resist the braking force and the speed reduction effect. [25].

Significant and strong correlations found between PCI and examined speed hump characteristics. The signs of the correlation coefficients are the expected direction. The width of speed hump and distance from preceding hump shows a positive correlation with PCI. On the other hand, the height of speed hump showed a negative correlation with PCI [4].

Serviceability loss is one of the pavement design parameters used in AASHTO pavement design procedures. Initial Serviceability Index (PO): The initial serviceability index (PO) is the PSI immediately after the pavement is open. At the AASHO road test, values of 4.5 for rigid pavement and 4.2 for flexible pavement were assumed. In addition, the Terminal Serviceability Index (PT): The terminal serviceability index (PT) is considered to be the PSI that represents the lowest acceptable level before resurfacing or reconstruction becomes necessary [30].

2.7 Causes of Pavement Deterioration

The sudden increase in traffic loading, especially on new roads where the design is based on lesser traffic is a major cause of cracking. After the construction of new and better roads, traffic from other roads also shifts to that road. This accelerates load-related cracks fatigue failure (Alligator Cracking), rutting and pothole, etc. Temperature variation ranging from 50º C to below zero conditions in the plain areas of North and Central India lead to bleeding and cracking. The provision of narrow shoulders leads to edge failures. Provision of poor clayey subgrade results in corrugation at the surface and increases in the unevenness.

Poor drainage conditions, especially during rainy seasons, force the water to enter the pavement from the sides as well as from the top surface. In the case of an open-graded bituminous layer, this phenomenon becomes more dangerous and the top layer gets detached from the lower layers. If the temperature of bituminou mixes is not maintained properly during mixing and laying, then it also leads to early pavement failure. Overheating of bitumen during mixing in asphalt plants reduces the binding property of bitumen. If the temperature of the bituminous mix has been lowered down, then the compaction will not be properly, leading to longitudinal corrugations [36].

2.8 Pavement Condition Index

A visual inspection of the pavement surface can provide valuable information. Visual inspection data used to evaluate the current pavement condition, predict future pavement performance, determine and prioritize pavement Maintenance and Rehabilitation needs, estimate repair quantities and evaluate the performance of different M-and-R techniques and materials.

The PCI procedure is the standard used by the road industry and the military to assess visually the current pavement condition. During a PCI survey, visible signs of deterioration are recorded and analyzed. The final calculated PCI value is a number from zero to 100, with 100 representing a pavement in excellent condition [14].

The pavement condition rating is determined from a correlation that presents a pavement condition rating as a function of the PCI value.

When interpreting the collected visual condition data, three different aspects of the collected data are of interest: the composite index, the type of distress present and the rate of deterioration. The PCI value it provides a general idea of the pavement condition and the magnitude of work that will be required to rehabilitate the pavement. Pavements at the upper end of the scale are more likely to be candidates for maintenance and minor rehabilitation, while those in the lower ranges are more likely to require structural rehabilitation or reconstruction [14].

To evaluate a pavement, first, the pavement network should be divided into branches (such as streets, parking areas, etc.) and each branch should be divide into sections that have certain consistent characteristics throughout their area or length, such as structural composition, construction history, and traffic and pavement condition. A sample unit is any identifiable area of the pavement section. It is the smallest component of the pavement network. Each pavement section is divided into sample units for the purpose of pavement inspection [26].

2.8.1 Flexible Pavement Distress

As pavements age and experience traffic repetitions, pavement distresses begin to accumulate. For example, the hardening effect increases the stiffness of asphalt with age, making the material more susceptible to thermal cracking [34].

The deterioration of pavement is apparent by various external signs and indicators called distresses. Pavement distress is often a result of a combination of factors, rather than just one root factor discussed in the above paragraphs. Before the appropriate repair strategy to be applied to a distressed asphalt pavement, the type and extent of the deterioration must be Asphalt Road Pavement Rehabilitation and Maintenance Case Study in Addis Ababa City

Roads Authority understood, and the cause of the distress must be identified. Generally, pavement distresses are fall into one of the following categories [33].

The most common distress types of flexible pavements are:

- Potholes: a pothole in a road surface that results from gradual damage caused by traffic or weather. These are bowl-shaped holes similar to depressions. They are progressive failures. First, small fragments of the top layer are dislodged. Over time, the distress will progress down into the lower layers of the pavement. Potholes are often located in areas of poor drainage. Potholes are formed when the pavement disintegrates under traffic loading, due to inadequate strength in one or more layers of the pavement, usually accompanied by the presence of water. Most potholes would not occur if the root cause was repaired before the development of the pothole. Repair by excavating and rebuilding. Area repairs or reconstruction may be required for extensive potholes.
- Raveling Asphalt: Raveling and weathering are progressive deterioration of an asphalt concrete surface as a result of loss of aggregate particles (raveling) and asphalt binder (weathering) from the surface downward. Raveling and weathering occur as a result of loss of bond between aggregates and the asphalt binder. This may occur due to the hardening of the asphalt cement, dust on the aggregate which interferes with asphalt adhesion, localized areas of segregation in the asphalt concrete mix where fine aggregate particles are lacking, or low in-place density of the mix due to inadequate compaction. High air void contents are associated with more rapid aging and increased likelihood of raveling. Increased asphalt film thickness can significantly reduce the rate of aging and offset the effects of high air voids. Surface softening and aggregate dislodging due to oil spillage are also classified as raveling. Raveling and weathering may pose a safety hazard if deteriorated areas of the surface to collect enough water to cause hydroplaning or wheel-spray. Loose debris on the pavement surface which may also be picked up by vehicle tires is also a potential safety hazard
- Alligator cracking: This is commonly called alligator cracking. This is a series of interconnected cracks, creating small, irregular shaped pieces of pavement. It is caused by failure of the surface layer or base due to repeated traffic loading (fatigue). Eventually, the cracks lead to the disintegration of the surface. The final result is potholes. Alligator cracking is usually associated with base or drainage

problems. Small areas may be fixed with a patch or repair area. Larger areas require reclamation or reconstruction. Drainage must be carefully examined in all cases.

- Rutting: Rutting is the formation of longitudinal depression of the wheel paths, most often due to consolidation or movement of material in either the base or subgrade or in the asphalt concrete layer. Another, unrelated, cause of rutting is abrasion due to studded tires and tire chains. Deformation which occurs in the base and underlying layers is related to the thickness of the asphalt concrete surface, the thickness and stability of the base and subbase layers, and the quality and uniformity of subgrade support, as well as the number and magnitude of applied loads. Deformation which occurs only in the asphalt concrete later may be the result of either consolidation or plastic flow. Consolidation is the continued compaction of asphalt concrete by traffic loads applied after construction. Consolidation may produce significant rutting in asphalt layers which are very thick and which are compacted during construction to initial air void contents considerably higher than the long-term air void contents for which the mixes were designed. Plastic flow is the lateral movement of the mix away from the wheel paths, most often as a result of excessive asphalt content, exacerbated by the use of small, rounded aggregates and/or inadequate compaction during construction.
- Block cracking: Interconnected cracks that divide the pavement up into rectangular blocks.
- Longitudinal cracking: Cracks parallel to the pavement's centerline direction.
- Patching: An area of pavement that has been replaced with new material to repair the existing pavement.

The above distress types are the most commonly observed distress type on flexible pavements [22].

The most commonly observed distress trend in Addis Ababa City roads is raveling, rutting, shoving, crocodile crack, failed and pothole respectively, but also often observe distress on the roadside and many vehicles parked on the roadside. In terms of preventive maintenance, distress on the roadside should be repaired, but its importance is lower than distress on the carriageway [24].

2.8.2 Pavement distress severity level

The severity level of distress depends on the type of distress. For pothole, the severity is determined by the area of the pothole, four alligator cracking based on the area and crack width,whereas for routing based on rut depth.

According to ASTM D 6433 severity level for pavement, distresses are the following.

2.8.2.1 Pothole

Potholes are smaller—usually less than 750 mm (30 in.) in diameter—bowl-shaped depressions in the pavement surface. They generally have sharp edges and vertical sides near the top of the hole. When potholes are created by high-severity alligator cracking, they should be identified as potholes, not as weathering.

The levels of severity of potholes, less than 750 mm (30 in.) in diameter based on both the diameter and the depth of the pothole, according to table 1.

Table 1: Levels of severity for pothole failure [14]

Maximum depth of pothole	Average Diameter(mm)(in)		
	100 to 200 mm(4 to 8 in)	200 to 450 mm(8 to 18 in)	450 to 750 mm(18 to 30 in)
13 to ≤ 25 mm(1 ½ to 1 in)	L	L	M
>25 and ≤ 50 mm(1 to 2 in)	L	M	H
>50 mm(2 in)	M	M	H

Where, L; low, M: medium and H: high

If the pothole is more than 750 mm (30 in.) in diameter, the area should be determined in square feet and divided by 0.5 m2 (5.5 ft2) to find the equivalent number of holes. If the depth is 25 mm (1 in.) or less, the holes are considered medium-severe. If the depth is more than 25 mm (1 in.), they considered high-severity.

2.8.2.2 Rutting

Severity level (Mean Rut depth)

Low 6 to 13 mm

Medium->13 to 25 mm

High->25 mm (>1 in)

2.8.2.3 Alligator cracking

Low

Cracks are <= 0.25 in (6mm) in mean width. Cracks in the pattern are no further apart than 1 foot (0.328 m).

Medium

Cracks are >0.25 in. (6 mm) and <= 0.75 in. (19 mm) or any crack with a mean width <= 19 mm and adjacent low severity cracking. Cracks in the pattern are no further apart than 6 in. (150 mm).

High

Cracks are >0.75 in (19mm) or any crack with a mean width <= 0.75 in (19mm) and adjacent medium to high severity random cracking.

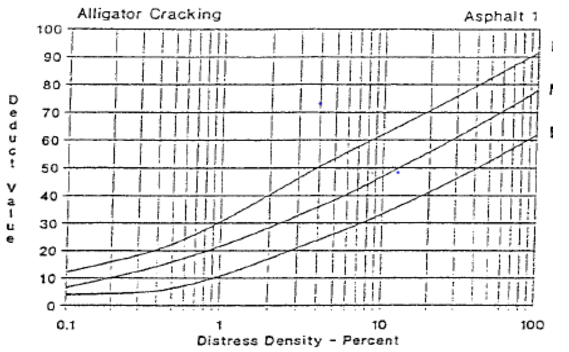
Table 2: Levels of severity for Alligator cracking [14]

SEVERITY LEVELS		**Crack Pattern**		
Crack Width		**LOW**	MED	HIGH
	Low	L	M	H
	MED	M	M	H
	High	H	H	H

Where, L; low, M: medium and H: high

2.8.2 DEDUCT VALUE CURVES FOR ASPHALT

According to ASTM D 6433 deducted value of each asphalt distress type are as the following.



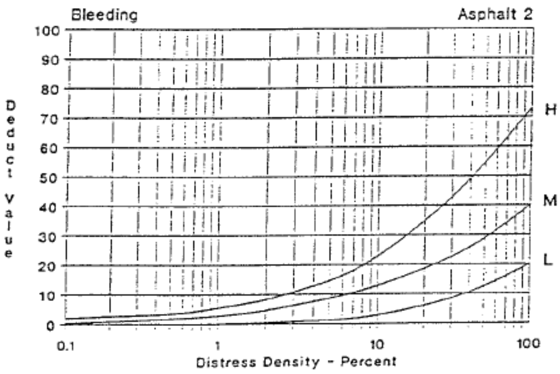
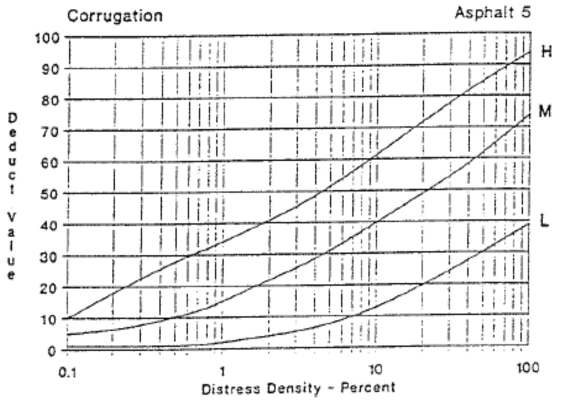


Figure 4: Alligator cracking deduct value curve [14]

Figure 5: bleeding deduct value curve [14]



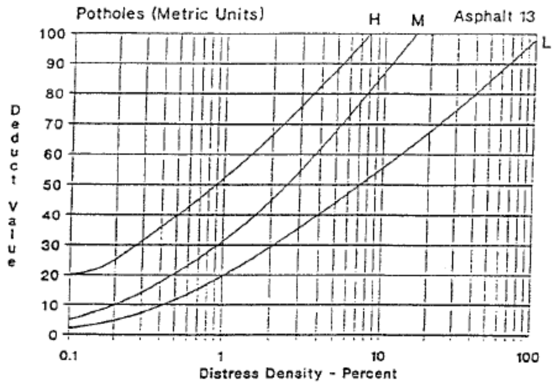
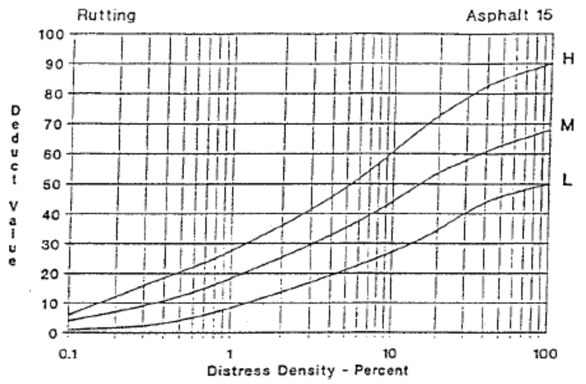


Figure 6: corrugation deduct value curve [14]

Figure 7: Pothole deduct value curve [14]



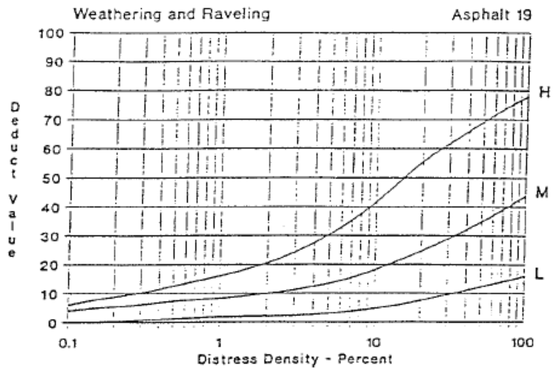


Figure 8: Rutting deduct value curve [14]

Figure 9: Revelling deduct value curve [14]

2.8.3 Corrected deduct the value (CDV) and Pavement Condition Index (PCI), Rating Scale

According to ASTM D4633 corrected deducted value-form total deducted value and the number of deducted will ready from figure 9 and PCI rating scale from Figure 10.

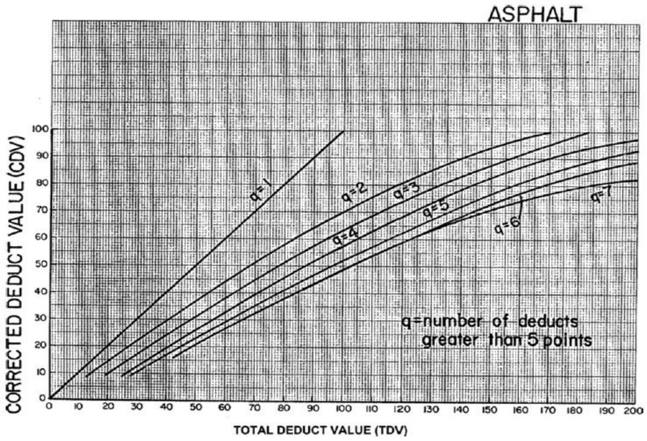


Figure 10: Corrected deduct value [14]

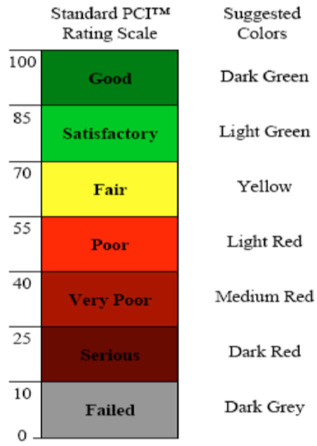


Figure 11: PCI Rating Scale [14]

2.9 International Roughness Index (IRI)

Roughness of the road surfaces are a measure of the amount and type of deviations from a smooth road surface. There exist longitudinal roughness (e.g. Bumps in asphaltic concrete in front of traffic lights), transverse roughness (e.g. Tracks that can cause aquaplaning), road surface irregularities (e.g. Holes in the road surface) and then there is roughness caused by road material (e.g. A brick road). Irregular road surfaces result in a certain amount of noise and vibration, thereby decreasing driver comfort. The effect on driving speed is not the result of the roughness of the road surface per se, but rather an effect of a reduction in driver comfort. A road surface can be described in terms of material and structure, micro-roughness and color. A subtle measure would be to use a road surface that has a micro-rough structure that only causes an increased noise level inside the car [37].

There are a number of different ways to measure ride quality, but the IRI has become the standard international scale. The IRI was developed in the late 1970’s and early 1980’s based on initial research in the United States and subsequent research sponsored by the World Bank. The IRI can be measured by an extensive range of equipment from rod and level through response-type meters with very accurate laser-based profilometers. Unevenness is a prolonged profile picture of the pavement, which is a picture of the comfort of driving on the highway. This quantitative value of unevenness is expressed in the International Roughness Index (IRI), i.e., the cumulative length of rising and fall of the surface per unit length in which IRI units are shown in meters down the length of road miles (m / km). [20]

Table 3: Rating scale for IRI scale [20].

IRI Scale m/Km	Pavement Criteria
0-2	Very Good
2-4	Good
4-6	Fair
6-8	Poor
8-10	Very poor

The PCI functional survey method requires time, cost and is labor-intensive. With such regular road conditions, it is necessary to create a model illustrating the relationship between IRI and PCI values, thereby improving the results of better identification of the functional conditions of the roads to make appropriate decisions for the road conditions. The relationship between PCI value and IRI value are$IRI = 16.07e^{-0.26PCI}$ [21].

The International Roughness Index (IRI) uses to define a characteristic of the longitudinal profile of a travel wheel track and constitutes standardized roughness. The commonly recommended units are meters per kilometer (m/km) or millimeters per meter (mm/m). IRI gathered by the profile van. The index measures pavement roughness in terms of the number of inches per mile that a laser, mounted on the Profiler van, jumps as the van driven along the roadway. Typically, the lower the IRI number, the smoother the ride; but IRI is not known as a direct measure of rider discomfort [23].

Rough roads are about more than just an uncomfortable ride. The roughness of a road is one indicator of how soon a road needs maintenance or reconstruction, which is tied to federal and state budget allocations. Furthermore, rougher roads can decrease the efficiency of a vehicle, increasing fuel use and greenhouse gas emissions [28].

CHAPTER THREE: RESEARCH METHODS AND MATERIAL

3.1 Description of Research Area

Addis Ababa city has a total road network of 6537 km from which 2,763km Asphalt 1,675 Gravel and 2,135 km Coble stone. Generally, this city reach above 20% road network up to June, 2010ec [1].

Addis Ababa city adopts speed calming device since 2008e. c by AACRA road segment Wingat to 18 mazoriya, Bisrategebrael to Kore and worsen to Kara, currently speed hump and rumple strips are constructed by AACRTMA.

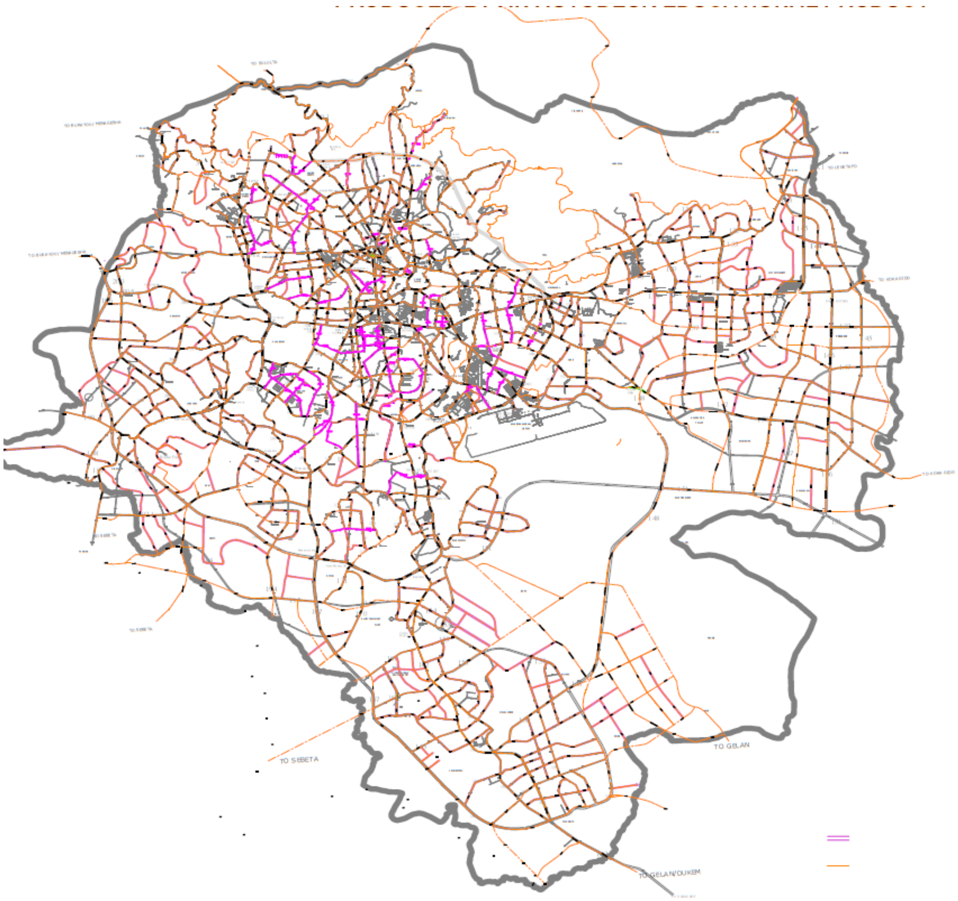


Figure 12: Layout of Addis Ababa City Road network [2]

3.2. Study design and site selection strategy

The sequence of the methodologies used was that the first literature reviewed and assesses relevant documents related to the speed hump effect on pavement condition, due to the result of dynamic load, pounding of water during rainy season and result infiltration to the pavement. Secondly, sites selected for an in-depth analysis of the existing conditions of the pavement. The site selected based on their representation of the condition of Addis Ababa city roads.

According to ASTM D6433, the minimum number of sample units (n) must be Surveyed within a given section to obtain a statistically adequate estimate (95 % confidence) of the PCI of the sections calculated using the following formula and rounding n to the next highest whole number.

$n = NS^2/\left(\left(\frac{e^2}{4}\right)(N-1)+S^2\right)$. .... *(3-1)*

Where:

e = acceptable error in estimating the section PCI; commonly, e=±5 PCI points;

s = standard deviation of the PCI from one sample unit to another within the section. When performing the initial inspection the standard deviation assumed 10 for AC pavements.

N = the total number of sample units in the section.

Then, according to Equation 3-1, the minimum number of n inspected are as follows.

$n = 26*10^2/\left(\left(\frac{5^2}{4}\right)(26-1)+10^2\right) = 10$, Where N=26 from Appendix table A-1 which is the total number of road segments in Addis Ababa have speed hump on them.

Ten-road segments had a speed hump selected for detail analysis and data collection as the following table 4 based on speed hump installation year on them since the pavement condition can be easily detected for those years serve several years.

Table 4: Selected site for detail pavement condition analysis [3]

No.	Speed hump location	No. of speed hump	No. of rumble strip	Speed Limit (km/HR)	Construction date
1	Aware RA - Parlama signalized intersection	3	7	30	April 2010 E.C
2	Minilik II hospital - KokebeTsibah secondary school	4	8	40	April 2010 E.C
3	Semen hotel signalized intersection - Afinchober	2	4	30	April 2010 E.C

4	Mendida intersection - Tor hayloch	10	18	30	May 2010 E.C
5	Jackros intersection - Goro RA	17	-	30	June 2010 E.C
6	Mekanisa Abo-Bridge	8	9	30	May 2010 E.C
7	Torhayiloch -mendida	8		30	May 2010 E.C
8	Wingate RA -18 mazoria RA	5	6	80	December 2008 E.C
9	Bisrategebireal -korae	5		40	December 2008 E.C
10	Abem-Kara	9		30	December 2008 E.C

3.3. Data collection

To assess the effect of a speed hump on pavement condition and to study the characteristic of speed humps on pavement condition different methods and approaches used for data collections. The data collection focuses on acquiring both secondary and primary data. The secondary data could help to have a comprehensive understanding of what are the effects of speed hump installation on pavement condition and overall road conditions for the Addis Ababa city case. It also enables us to gain knowledge on what has done in the past and current situation, the attempted solutions, and possible achieved solutions to the problems existing in the study area. On the other hand, primary data collected based on the knowledge gained through the secondary data to assess the extent of the problem and to select the appropriate site to collect visual inspection, road characteristics, and International roughness index value.

3.3.1 Primary source of data

To attain the objective of the research, different types of data collected through different techniques from field of direct measurement of road and speed hump characteristics. for each ten selected road segments divided by 100-meter sections

The data includes the following information, but not limited to:

- Road length (km)
- Speed limit (km/h)
- Average pavement width (m)
- Number of speed humps
- Average height of humps (cm)

- Average width of speed humps (m)

3.3.2 Secondary source of data

All necessary documents from different public organizations such as AACRA, TPMO, and AACRTMA collated. And different related documents such as; books, international journals, studies, and other speed claim related materials were reviewed to assess the current condition of speed hump installation rate conditions and its effect on pavement life and deterioration of pavements near to speed hump.

3.3.2.1 Pavement condition data

Use this data for pavement condition analysis by using quantitative data gathering methods, visual inspection pavement distress data collected by using ASTM standard data collection method by measure the size of failure for each section is collected from AACRA.

Figure 13:Torhayiloch –Mendida pavement condition measurement [2]

3.3.2.2 International roughness Index

International roughness Index data are collected by AACRA by using a vehicle that measures the unevenness of a prolonged profile picture of the pavement, which is a picture of the comfort of driving on the highway. Each road segments have sections divided by 100 m long; here IRI data were a measure for each section by considering speed hump as pavement distress.

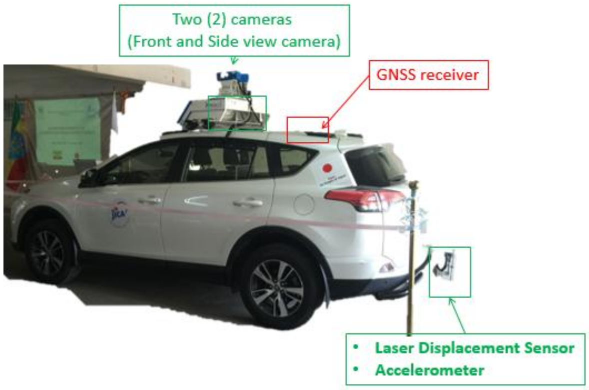


Figure 14: Vehicle measure International roughness index [2]

3.4 Methods of Analysis

In order to characterize the populations of PCI, IRI and speed hump characteristics, some statistical analyses like arithmetic mean, standard deviation, coefficient of variation, F-test, T-test and regression analysis done to determine the uniformity and the relationship of the collected data.

The approach used for examining the effect of speed humps was to select road segments that had sections with speed humps and sections with no speed humps. In total, 10 road segments had at least one section with speed humps and one without speed hump. In this research, speed humps were observed in 40% of the pavement sections considered in the study. As a result, enough data were available to investigate the effect of the presence of these humps on the pavement condition.

Therefore, for the data analysis purposes, three approaches are discussed, namely detail distress distribution, Pavement condition index, and International roughness index, which are discuses as follows.

3.5.1 Detail distress distribution

By this part, the type and frequency of distress distribution examined for overall study road segments and for sections with and without humps. Severity level for each distress identified from ASTM standard severity level rating guidelines for each distress type separately.

3.5.2 Pavement condition index

From the collected data of different road segments and sections, from visual inspection data for each section PCI value calculated according to distress type, distress quantity, and distress severity. The steps for determining the PCI rating are conducted as per the literature ASTM D 4633.

1. Inspect the sample unit, determine distress type and severity level and then measure the density.
2. The deduct values are determined from the deduct value curves for each distress type and severity.
3. A total deducts value (TDV) is computed by summing all individual deduct values.
4. Once the TDV is computed, the corrected deduct the value (CDV) can be determined from the correction curves. When determining the CDV, if any individual deduct value is higher than the CDV, the CDV is set equal to the highest individual deducts value.
5. The PCI is computed using the relation PCI = 100 − CDV.

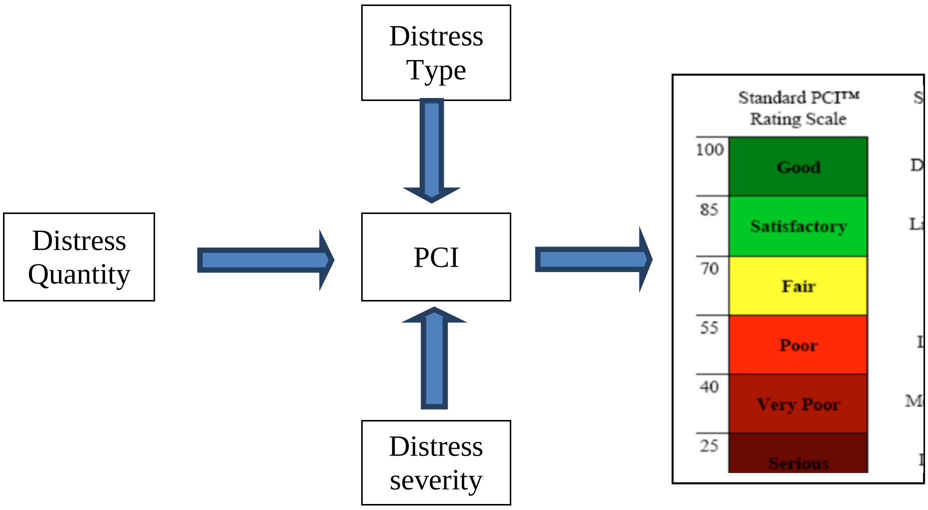


Figure 15: PCI vs distress type, distress quantity and distress severity

The PCI value is calculated using the above steps, where deducted value indicates how much the pavement condition is deducted from the normal pavement condition level of existence of one failure type and total deducted value indicate the total deduction of pavement condition by the total edition of all deducted value for each distress type and severity level. Whereas not all distress type and severity level can have an equal contribution to pavement condition deduction, the total deducted value corrected by using the corrected deduct value curve. The pavement condition index calculated by deducting CDV from 100. Where 100 PCI value point is the excellent condition of the pavement.

3.5.3 International roughness index

The measured IRI value of each section of the road, analyzed and compared for sections with and without humps for a similar road segment. Using statistical analysis of the T value for comparing the two mean values of roughness index at section have and have not to hump for each road segment.

3.5.4 Statistical Analysis and Model development

PCI and IRI values for each road segment compared to those sections with and with no humps by using analysis of variance assume null hypotheses of two-pavement condition mean is equal at sections with and without humps and alternative hypothesis unequal mean. In addition, the other approach was the average condition of the sections with humps as compared to those no humps within the same road segment. This comparison allowed for investigating the effect of speed humps on pavement condition, in isolation of other factors such as traffic, structural capacity, age, construction quality, etc.., since all these factors are constant within each road segment.

For ten different road segments after an average PCI value difference for each road segment calculated. The relation between speed hump characteristics and pavement condition developed using the Minitab regression method by choice model parameters and sensitive parameters selected.

CHAPTER FOUR: -DATA ANALYSIS AND DISCUSSION

In this chapter, the collected data needs to be calculated and analyzed in order to know how the application of speed hump affects the pavement condition the research findings are analyzed and discussed analytically, statistically, graphically, in tabular form, and qualitatively.

4.1 Detailed distress analysis

4.1.1 Distress Distribution on total road segments

At this level of analysis, the individual pavement sections are analyzed to investigate the more frequently observed distresses. Figure 16 shows the frequency of occurrence of individual distresses in the pavement sections considered in this research, regardless of the severity level. From the analysis, the figure shows that the most widely observed distress is raveling and Pothole, which observed in 42 % of the sections considered in the analysis. While potholes are load-related crack caused by the freeze-thaw cycle. When moisture seeps into the pavement, it expands when it freezes and contracts when it thaws, this flexing of the pavement, combined with the melted water and the stress of vehicular traffic results pothole. Pothole distress type have a highest deducted value as compared to other distress types since the distress distribution here show one of the most frequently observed distress type is pothole which result lowest PCI value means that it affects the pavement condition highly. Raveling functional distress caused by the disintegration of hot mix asphalt lay from the surface downward because of the dislodgement of aggregate particles. This results in loose debris on pavement, roughness, and water collecting in the raveled location. Whereas, some distress, such as bleeding, block cracking, bumps and sags, corrugation, depression, reflective cracking, and slippage cracking were not observed in any section. On the other hand, the figure also shows that the other load-related distress was not frequently observed, where Alligator cracking, rutting, edge crack, and longitudinal cracks were observed in 3%, 4%, 2% of the sections.

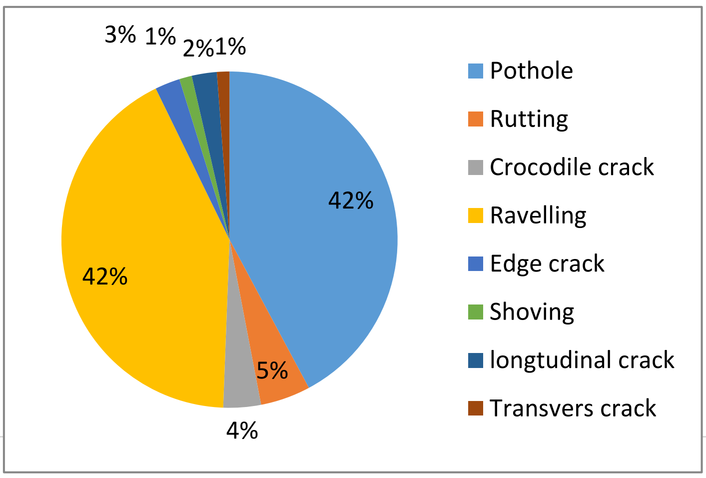


Figure 16:Total Distress Distribution on total road segments.

4.1.2 Distress Distribution on sections with vs without speed hump

At this level of analysis distress distribution at a section with and without speed analyzed. The overall number of distress on all road segments is 83 from this 76% of distress found in sections with speed hump and 24% of distress at sections without speed hump. here the analysis show due to the presence of speed hump distressing increase by 52% from a control point that has not speed humps.

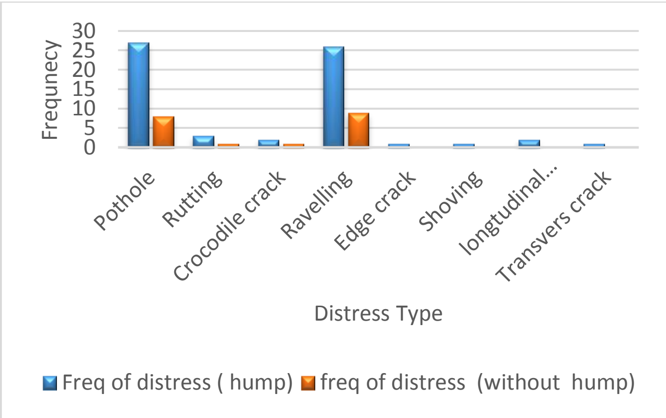


Figure 17: Frequency of distress on section with and without speed hump

From Figure 17 distress, frequency for each distress type is high for sections with hump and lower for sections without a hump.

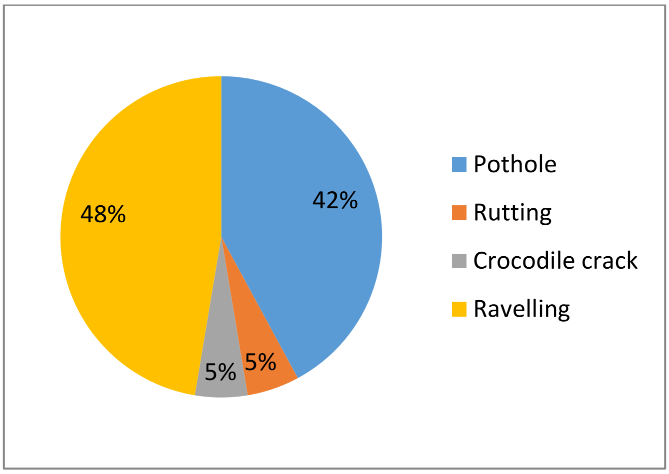


Figure 18: Total Distress Distribution on sections without speed hump.

Figure 18 shows the frequency of occurrence of individual distresses in the pavement sections considered in this research, regardless of the severity level. From the analysis, the figure shows that the most widely observed distress is raveling and Pothole, which was observed in 42 and 48 % of the sections respectively. Whereas, some distress, such as edge crack, longitudinal cracks, bleeding, block cracking, bumps and sags, corrugation, depression, reflective cracking, and slippage cracking were not observed in any section. On the other hand, the figure also shows that, where Alligator cracking, rutting, was observed in 5% of the sections

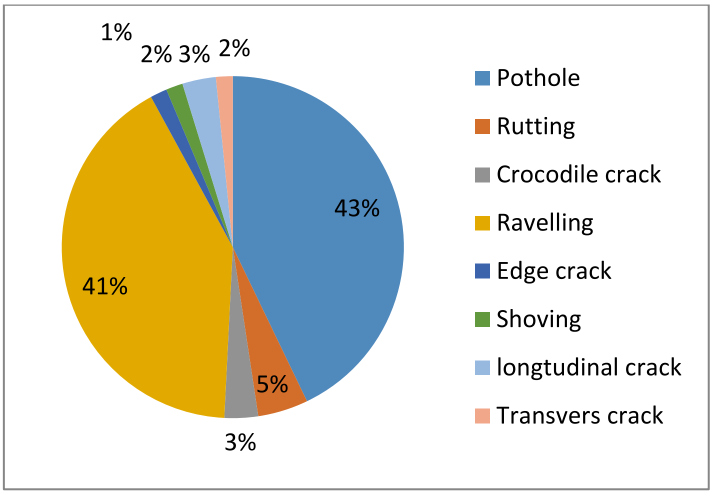


Figure 19:Total Distress Distribution on section with speed hump.

Figure 19 shows the frequency of occurrence of individual distresses in the pavement sections considered in this research, regardless of the severity level. From the analysis, the figure shows that the most widely observed distress is raveling and Pothole, which was observed in 41 and 43 % of the sections respectively. Whereas, some distress, such as, bleeding, block cracking, bumps and sags, corrugation, depression, reflective cracking, and slippage cracking were not observed in any section. On the other hand, the figure also shows that, where Alligator cracking, rutting, edge crack, longitudinal cracks and shoving was observed in 3%, 5%, 1%, 3%, 2% of the sections.

Here from the analysis, the distress distribution is similar at sections with and without speed hump, but the frequency of distress, occupancy is high for each distress type at sections have speed hump. For raveling and pothole type of distress, it accelerated by traffic and water for that section with a speed hump increase by raveling distribution due to the manner of construction that expose the pavement to water and due to dynamic load application. The application of dynamic load on the pavement exposed to water results pothole.

4.2 Distress severity level

The pavement condition survey would be measured in terms of the severity of distress and the extent of the distress in addition to distress type. The Severity and Extent are recorded as from highest to lowest. The extent of the defect is the extent or area of the distress or defect for the pothole type of defect, extent of depth for the rutting type of distress, area, and depth of the crack for alligator type of crack and for all types of distress the severity level is determined as per ASTM standard severity level rating. The severity level is determined for each distress type and for each road segment as presented in the appendix part of the paper. The extent combined with the severity will determine the quality of the relevant activity to be undertaken on the road section. Many of the distresses or defect severity level distribution is as below.

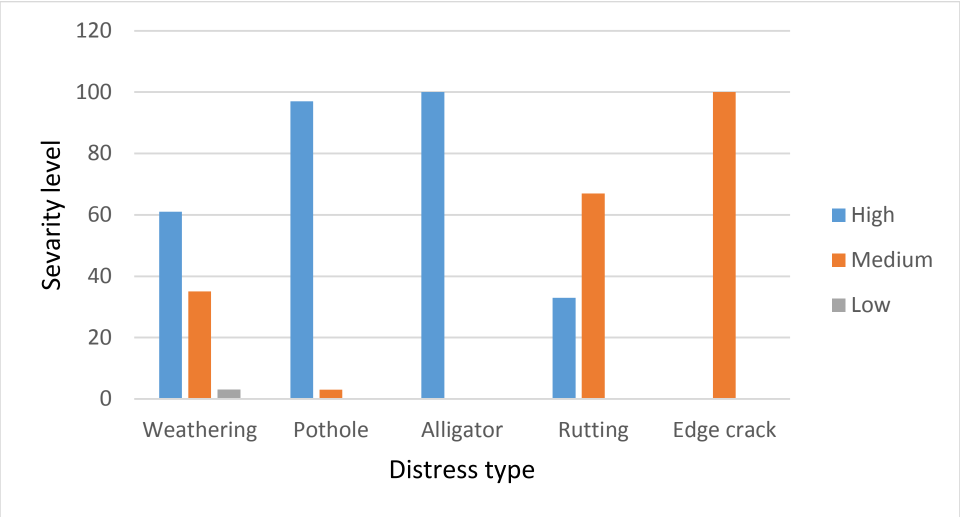


Figure :-Distress severity level

From Figure 20 for weathering type distress 61% of the distress are at a high level of severity level, 35 % medium severity and 3 % are low severity level. so the higher level of high severity means the higher the deductible value. For this particular type of distress, 61 % of distresses are at a high level of severity, which results in the lower the PCI value. For Pothole, type of distress 91 % at the highest level of severity and 3 % medium level of severity. Pothole type of distress has higher deducted value as compared to other types of distress since pothole and other types of distress cannot affect the pavement smoothness equally. In addition, the percentage of this distress severity shows that 91% of the distress are at a high level of severity so this affects the pavement condition highly. Alligator crack is about 100 % is a high level of severity level. Rutting 33% higher and 67% medium severity level, whereas edge crack is 100 % medium severity level. From severity level distribution the highest the level of the severity level result from the highest deducted value and the lowest PCI value. From the figure for all distress types, the most observed severe level is highest severity level.

4.3 Pavement Condition Index and International Roughness Index value for selected site

4.3.1 Pavement Condition Index value

PCI value calculated for each section using ASTM standard PCI determination steps mentioned in the methodology part. For each distress type severity level is determined and density is calculated for the given area. From table 5 section number and the result of PCI value for each road segment with and without speed hump is presented. From the table, for most cases, the PCI value is near to 100 PCI value for those sections without hump and lower than this value for sections with speed humps.

For Torhaloch to mendida road segment section one have the PCI value of 40. But this section is without hump and near to Torhaloch intersection. Which indicate in addition to speed hump other traffic calming device also have an effect on pavement condition. And for Wingate to 18 measure sections, one has a PCI value of 5 which indicates that proved speed hump near or on the intersection affects the road condition more as compared to the installation of a speed hump on normal road segments.

Table 5: Pavement condition index value results

Torhayiloch to Mendida									
Sections No with speed hump	4	5	6	9	12	17	18	19	25
PCI Value	75	25	62	52	100	10	100	100	100
Sections No with not speed hum	1	2	3	7	8	10	11	13	14
PCI Value	40	100	100	100	100	100	100	100	100
Wingate to 18 Mazoria									
Sections(hump)	1	2	4	5	6	7	8		
PCI Value	5	100	15	75	0	55	100		
Sections (not hump)	3	10	13	14	15	16	9		
PCI Value	100	100	18	100	100	100	100		
B/gebrael to korae									
Sections have speed hump	5	6	9	10					
PCI Value	80	50	62	65					
Sections have not speed hump	1	2	3	4					
PCI Value	100	72	100	100					
Awarae parlama									
Sections have speed hump	4	5	6						
PCI Value	62	55	80						
Sections have not speed hump	1	2	3						
PCI Value	100	100	100						
Wossen Kara									
Sections have speed hump	6	7	8	9	10				
PCI Value	100	58	48	71	40				
Sections have not speed hump	1	2	3	4	5				
PCI Value	100	100	100	100	100				
Mendida to torhayiloch									
Sections have speed hump	9	10	12	13	14	15	17	18	19
PCI Value	62	100	100	73	42	100	52	54	100
Sections have not speed hump	1	2	3	4	5	6	7	8	11
PCI Value	100	100	100	100	100	100	100	75	100
Abo mazoria to mekanisa bridge									
Sections have speed hump	4	6	9						
PCI Value	37	62	68						
Sections have not speed hump	1	2	3						
PCI Value	100	100	100						
Minilik to kokebe tsibah									
Sections have speed hump	1	2							
PCI Value	75	42							
Sections have not speed hump	3	4							
PCI Value	100	100							
Goro to Emperial									
Sections have speed hump	5	7	8	9	10	11			
PCI Value	55	60	100	100	19	60			
Sections have not speed hump	1	2	3	4	6	13			
PCI Value	100	100	100	52	52	100			
Semen hotel to afincho ber									
Sections have speed hump	3	6	7						
PCI Value	61	58	40						
Sections have not speed hump	1	2	4						
PCI Value	100	100	100						

From table 5 for sections have 100 PCI value indicate that there is not a failure at that location and the condition of the pavement is in good condition and for those have PCI value different from 100 is have failure in that section and the lower PCI mean the damaged pavement section.

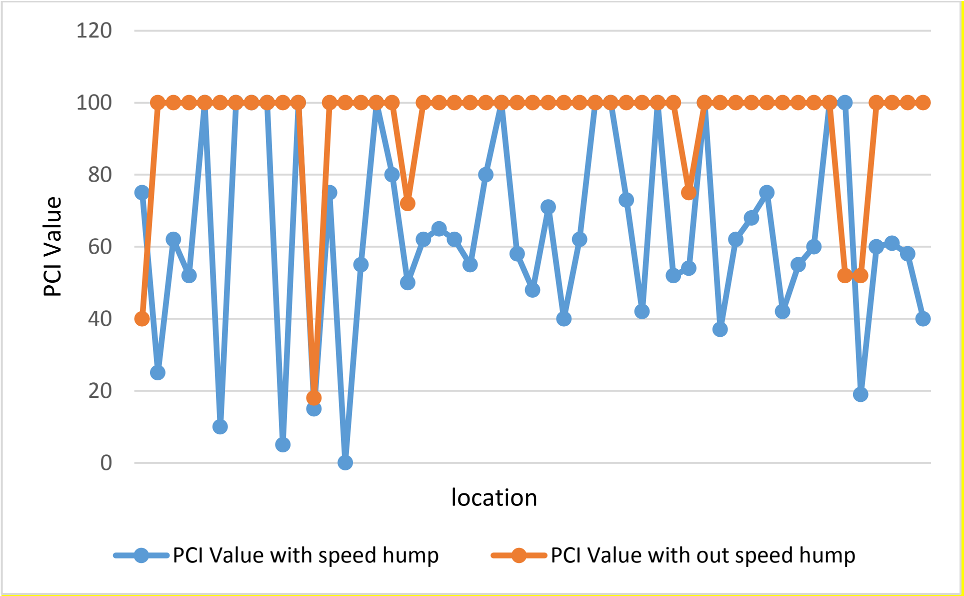


Figure 20: PCI value for sections with and without hump

PCI values at sections with hump are less than PCI values at section without speed humps which indicate that the lower PCI value is the damaged pavement condition. Four sections without speed hump, the PCI value is higher as compared to sections with a hump which implies the pavement condition is in good condition. From figure 21, the PCI value is almost 100PCI value for sections without a hump. For those sections without speed hump and have lower PCI value the section is found near to the intersection and roundabout.

Here the average effect of humps on pavement condition is quantified as the following by using single-factor ANOVA.

Table 6: ANOVA analysis result for PCI value

SUMMARY

Groups	Count	Sum	Average	Variance
PCI Value with speed hump	51	3265	64.01961	767.4996
PCI Value without speed hump	51	4809	94.29412	293.6118

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	23371.92	1	23371.92	44.05178	1.67E-09	3.936
Within Groups	53055.57	100	530.5557			
Total	76427.49	101				

Table 6 shows that the Analysis Of Variance (ANOVA) results for this comparison. As can be noted from the results, F value is greater than the F-Critical, indicating that the presence of the speed humps significantly decreases the PCI value of the section and that the average reduction in PCI values on the section level due to the presence of speed humps was approximately 30.3. This analysis ignores traffic, construction methodology, drainage, age of construction, etc. Since these parameters are different for all road segments. Due to the presence of speed humps so that the pavement condition is changed from good to fair according to ASTM D6433 Pavement Condition Index (PCI) rating Scale.

4.3.2 International roughness Index value

The summary of measured IRI value for each section with 100-meter lengths taken from the AACRA road asset department for each road segment presented in table 7.

From table 7 the IRI result shows us the higher IRI value indicates that the more the rough surface condition of the pavement and the lower the IRI value indicate the better the condition of the pavement. The IRI value reaches up 12.3 for sections with speed hump here the IRI value also considers the Speed hump as a failure since speed hump by itself reduces vehicle speed by increasing the roughness of the pavement. The more the roughness of the surface results the increase travel time, pollution, fuel consumption, and result accident and discomfort for driver and passenger.

Table 7: Roughness Index Value result

Torhayiloch to Mendida									
Sections No with speed hump	4	5	6	9	12	17	18	19	
IRI Value	8.7	9.66	7.7	5.19	7.16	5.26	7.16	7.28	
Sections No with not speed hump	1	2	3	7	8	10	11	13	
IRI Value	7.7	4.73	4.7	4.14	3.49	4.34	3.8	4.5	
Wingate to 18 Mazoria									
Sections(hump)	1	2	4	5	6	7	8		
IRI Value	10.697	10.616	4.56	5.72	6.15	4.08	6.11		
Sections (not hump)	3	10	13	14	15	16	9		
IRI Value	3.23	2.71	3	2.34	2.26	4.85	5.68		
B/gebrael to korae									
Sections have speed hump	5	6	9	10					
IRI Value	5.96	10.27	7.01	5.59					
Sections have not speed hump	1	2	3	4					
IRI Value	3.33	3.36	3.25	4.22					
Awarae parlama									
Sections have speed hump	4	5	6						
IRI Value	5.98	6.09	5.87						
Sections have not speed hump	1	2	3						
IRI Value	3.43	4.06	4.28						
Wossen Kara									
Sections have speed hump	6	7	8	9	10				
IRI Value	4.78	5.29	6.34	5.63	7.09				
Sections have not speed hump	1	2	3	4	5				
IRI Value	3	3.04	2.65	3.04	2.13				
Mendida to torhayiloch									
Sections have speed hump	9	10	12	13	14	15	17	18	19
IRI Value	5.62	6.59	5.36	5.54	8.89	12.3	5.8	14.15	6.3
Sections have not speed hump	1	2	3	4	5	6	7	8	11
IRI Value	11.98	5.24	3.93	3.6	4.05	4.97	4.63	4.89	3.98
Abo mazoria to mekanisa bridge									
Sections have speed hump	4	6	9						
IRI Value	7.6	7.3	7.6						
Sections have not speed hump	1	2	3						
IRI Value	3.1	2.7	2.9						
Minilik to kokebe tsibah									
Sections have speed hump	1	2							
IRI Value	4.5	4.86							
Sections have not speed hump	3	4							
IRI Value	2.27	2.3							
Goro to Emperial									
Sections have speed hump	5	7	8	9	10	11			
IRI Value	6.5	5.9	6.5	6.6	10.6	4.6			
Sections have not speed hump	1	2	3	4	6	13			
IRI Value	4	3	2.5	3.7	4	3.8			
Semen hotel to afincho ber									
Sections have speed hump	3	6	7						
IRI Value	6.6	12.3	7.7						
Sections have not speed hump	1	2	4						
IRI Value	3.2	2.2	3.1						

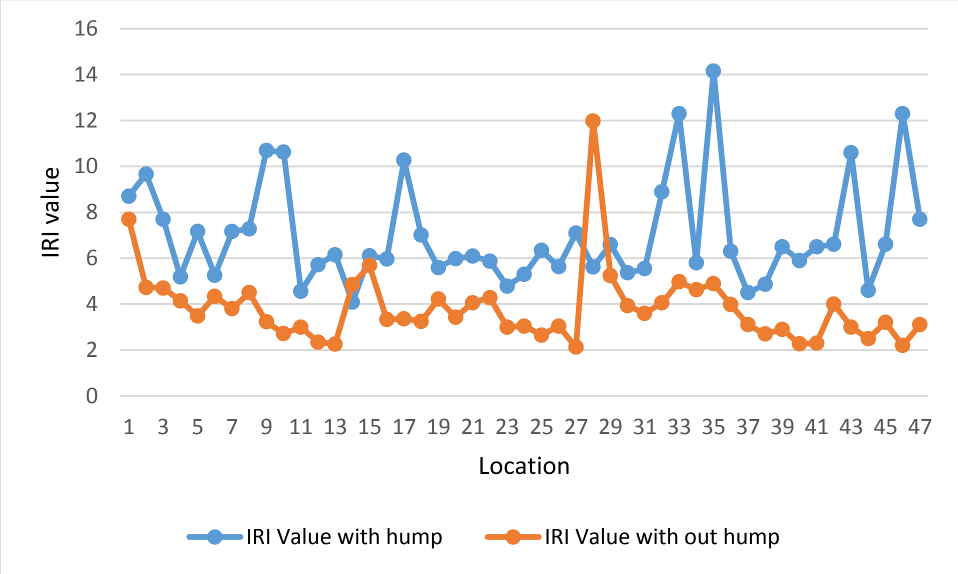


Figure 21: IRI value on sections with and without hump

From figure 22 IRI value is high at the sections that have a speed hump than have not speed hump, which indicates that due to the presence of speed hump pavement roughness is increased. But at some locations, the IRI value is higher as similar to sections with hump, but those points are at roundabouts or intersection. From figure 22 Mendida to torhayilcoch shows the higher IRI value this section is section number one on the road segment found on the roundabout. From the result similar to hump other traffic calm devices also affect the pavement condition. Here the average effect of humps on pavement roughness is quantified as the following by using single-factor ANOVA.

Table 8: ANOVA analysis result for IRI value

SUMMARY

Groups	Count	Sum	Average	Variance
IRI Value with hump	47	329.153	7.003255	5.219864
IRI Value without hump	47	179.8	3.825532	2.644351

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	237.3013	1	237.3013	60.34963	1.09E-11	3.944539
Within Groups	361.7539	92	3.932108			
Total	599.0552	93				

Table 8 shows that the Analysis Of Variance (ANOVA) results for this comparison. As can be noted from the results, F value is greater than the F-Critical, indicating that the presence of the speed humps significantly increases the IRI value of the section, and that the average increase in IRI values on the section level due to the presence of speed humps was approximately 3.2. Due to the presence of speed humps so that the pavement condition is changed from Good to poor, according to the ASTM E1926 IRI Rating Scale.

4.3 Statistical Analysis

4.3.1 Statistical analysis for each road segment

The approach for examining the effect of speed humps was to analyze the PCI and IRI difference value from control points of similar road segments in isolation of other factors traffic, drainage construction method, etc., since these factors is similar for one road segment. By null hypothesis, $\mu 0=\mu 1$ and alternative hypothesis $\mu 0\neq\mu 1$ of isolating other factors traffic, drainage, construction methods, etc.

Table 9: PCI value ANOsegmentt for each road segments

No	Location		Count	Sum	Average	Variance	P-value
1	Torhyiloch-Mendida	Hump	8	524	65.5	1225.1	0.003
		No Hump	8	740	92.5	450	
2	Wingate-18	Hump	7	350	50	1900	0.001
		No Hump	7	618	88.28	960.57	
3	B/gebrael-korae	Hump	4	257	64.25	152.25	0.002
		No Hump	4	372	93	196	
4	Aware-Parlama	Hump	3	197	65.7	166.3	0.01
		No Hump	3	300	100	0	
5	Wossen-Kara	Hump	5	317	63.4	552.9	0.01
		No Hump	5	500	100	0	
6	Mendida-Torhayiloch	Hump	9	683	75.9	590.6	0.02
		No Hump	9	875	97.2	69.44	
7	Mekanisa Abo-Bridge	Hump	3	167	55.7	270.3	0.002
		No Hump	3	300	100	0	
8	Minilik -Kokebetsibah	Hump	2	117	58.5	544.5	0.01
		No Hump	2	200	100	0	
9	Goro-Emeprial	Hump	6	394	65.7	942.7	0.015
		No Hump	6	504	84	614.4	
10	Semen hotel-Afinchober	Hump	3	159	53	129	0.002
		No Hump	3	300	100	0	

From table 9 ANOVA result shows us the p-value for each road segment is less than 0.05 which means that the presence of speed hump affects PCI values of each road segment.

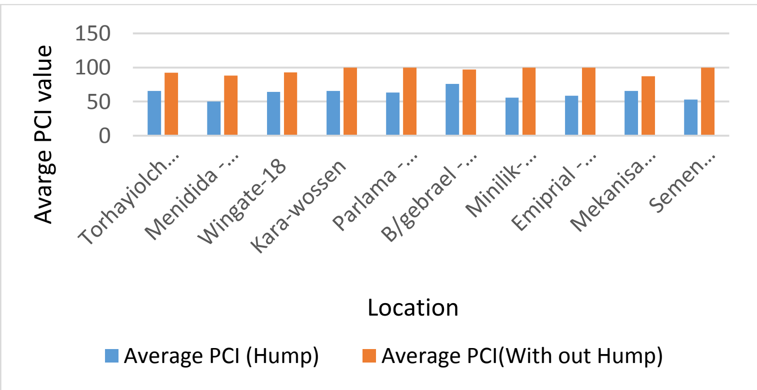


Figure 22: Average PCI values at sections with and without hump

From figure 23 The average PCI value for each road segment sections with hump show lower values as compared to the average PCI value of sections without the hump overall effect of hump in isolation to traffic, drainage, age, construction methods, etc. is the average of the change PCI values for each road segment. The change PCI value for each road segment is as the following.

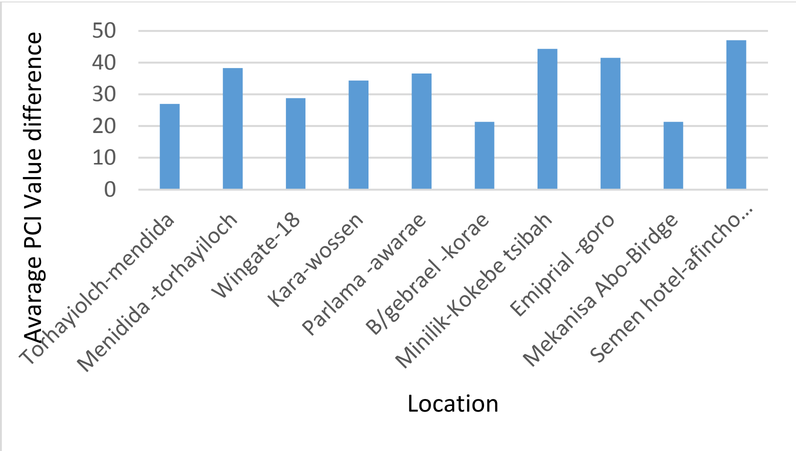


Figure 23: The average PCI diffesegmentlue at each road segments

From figure 24 the change PCI value ranges from 21.3 to 47 PCI value points. For B/gebrael to korae road segments, the change PCI value is lower as compared to others, the lower the change the PCI value means the less the pavement is affected by the speed humps and the higher the change the PCI value means the more the pavement is affected by the presence of the speed hump. For those roads, segments have the lower the change the PCI value the pavement condition near to speed hump is less affected by speed humps and for that road, segments have the higher change PCI values the pavement condition near to speed hump affected more. In general, due to the presence of speed humps, the average change PCI value of Addis Ababa city road case is by 34 PCI value points.

Table 10:IRI value ANOsegmentt for each road segments

No	Location		Count	Sum	Average	Variance	P-value
1	Torhyiloch-Mendida	Hump	8	58.11	7.3	2.3	0.002
		NoHump	8	37.4	4.7	1.67	
2	Wingate-18	Hump	7	47.9	6.84	7.37	0.01
		NoHump	7	24.07	3.4	1.7	
3	B/gebrael-korae	Hump	4	28.83	7.2	4.5	0.01
		NoHump	4	14.16	3.54	0.21	
4	Aware-Parlama	Hump	3	17.9	5.98	0.01	0.001
		NoHump	3	11.77	3.92	0.19	
5	Wossen-Kara	Hump	5	29.13	5.83	0.82	0.002
		NoHump	5	13.86	2.7	0.156	
6	Mendida-Torhayiloch	Hump	9	70.55	7.84	10.66	0.01
		NoHump	9	47.27	5.25	6.67	
7	Mekanisa Abo-Bridge	Hump	3	22.5	7.5	0.03	0.00006
		NoHump	3	8.7	2.9	0.04	
8	Minilik -Kokebetsibah	Hump	2	9.36	4.68	0.06	0.005
		NoHump	2	4.57	2.28	0.00045	
9	Goro-Emeprial	Hump	6	40.7	6.78	4.06	0.0033
		NoHump	6	21	3.5	0.38	
10	Semen hotel-Afinchober	Hump	3	26.6	8.87	9.14	0.02
		NoHump	3	8.5	2.8	0.30	

From table 10 ANOVA result shows us the p-value for each road segment is less than 0.05 which means that the presence of speed hump affects IRI values of each road segment.

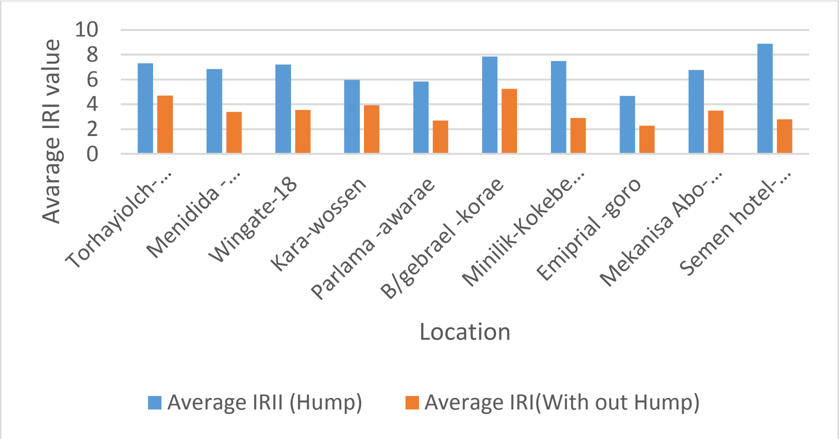


Figure 24: Average IRI values at with and without hump

From figure 25 the average IRI value of each road segment sections with hump show higher value as compared to the average IRI value of sections without the hump overall effect of hump in isolation to traffic, drainage, age, construction methods, etc. is the average of the change IRI values for each road segment. The change in the IRI value for each road segment is as the following.

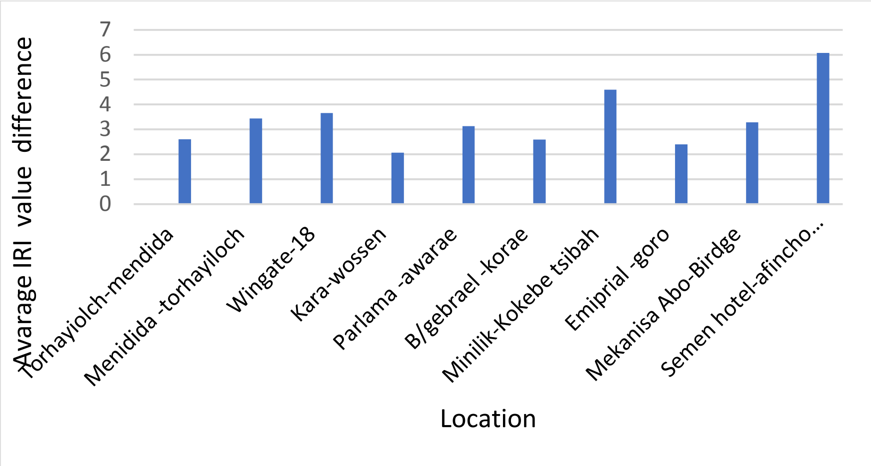


Figure **Error! Unknown switch argument.**: IRI diffesegmentlue at each road segments

From figure 26 change IRI values are different at each location since the speed hump characters are different at each location the effect of it is different at each location. The average change in effect on the IRI value is 3.4 IRI value points for Addis Ababa city case study.

In General, the pavement condition of Addis Ababa City is affected by the presence of the hump and the average effect is decrease by 34 PCI value point and increase by 3.4 IRI value points.

4.4 Regression Analysis

4.4.1 Model parameter selections

These sections discuss the correlation and regression statistical analyses describing the relationships between average PCI value difference and three variables: speed hump width, height, and density. From table 11 the average value of speed hump characteristics and change in average PCI value are presented. The speed hump characteristic value shows variation from speed hump to speed hump and from road segment to road segments even if the standard is similar to speed hump installation due to construction methodology and material type the actual collected data show variation between speed humps. This variation has an effect on pavement condition and the relation between this speed hump characteristic and PCI value is presented in the regression analysis part.

Table 11: Speed hump characteristics data vs PCI difference value data

No	Location	Average Speed hump width(m)	Average Speed hump height(cm)	Speed hump density(No/Km)	Average PCI value difference
1	Torhayiolch-mendida	1	3.5	4	27
2	Menidida -torhayiloch	5	6	4	38.28
3	Wingate-18	6	5	7	28.75
4	Kara-wossen	1	6	7	34.3
5	Parlama -awarae	5	7	6	36.6
6	B/gebrael -korae	0.9	5	4	21.3
7	Minilik-Kokebe tsibah	6	7	8	44.3
8	Emiprial -goro	6	8	4	41.5
9	Mekanisa Abo-Birdge	5	6	8	21.3
10	Semen hotel-afincho ber	5	9	4	47

Table 11 shows us the model parameters average value that used for regression analysis the dependent variable is the average PCI value difference and the independent variables are speed hump width, height, and density.

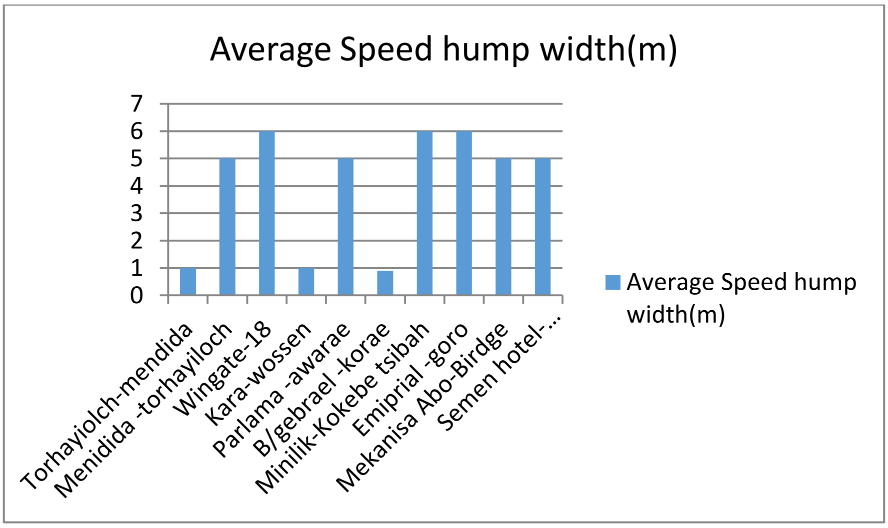


Figure 26: Average Speed hump width

From figure 27 the average speed hump width is the width of a speed hump on the traffic direction and the average speed hump width varies from 0.9 up to 6 meters. It is almost different at each road segment and for minded to torhayiloch, parlama too aware, Mekanisa to Abo bridge and Semen hotel to Afincho per road segment collected data from actual site is equal to design value, but for other road segments the values are above and below the standard design value of speed humps width.

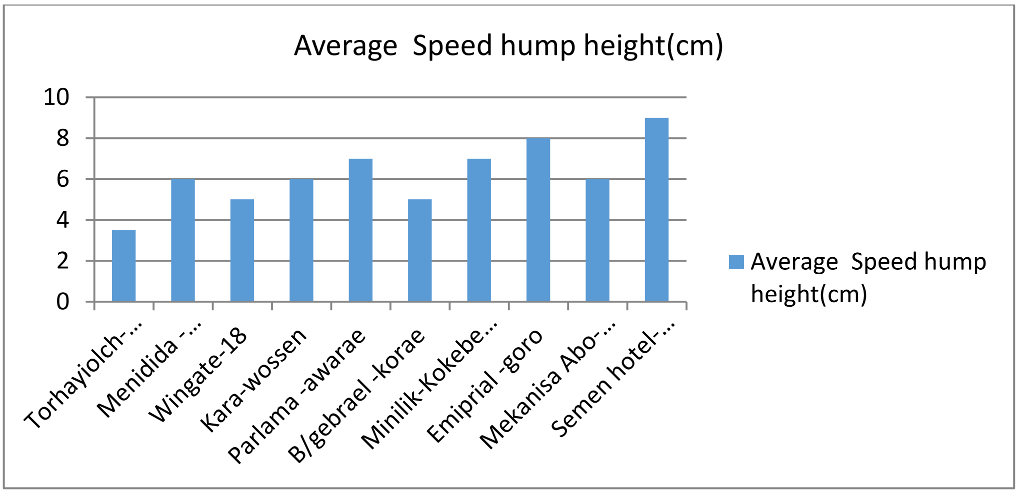


Figure 27: Average Speed hump height

The average speed hump heights vary from 3.5 to 9 cm and the height of the speed hump is equal at each width of a speed hump. Whereas, the design standard allows the height of the hump to be constructed by 0.1 slope difference in the traffic direction along the width of the hump.

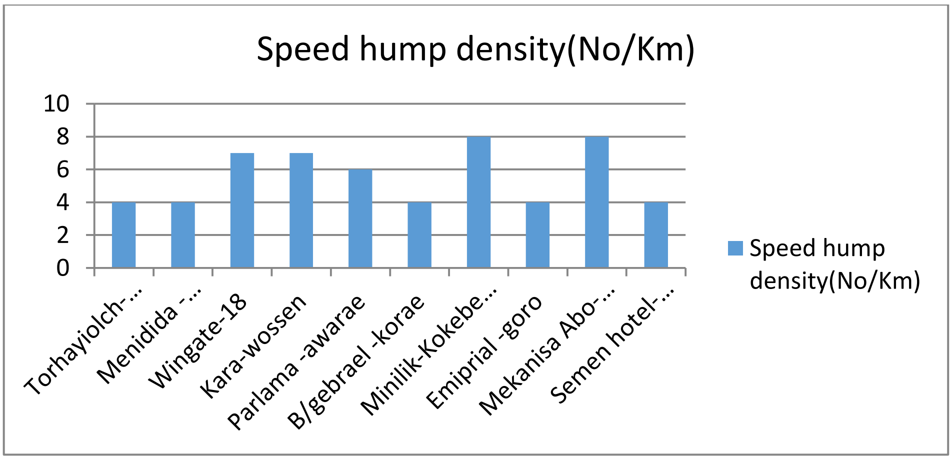


Figure 28: Average Speed hump density

From figure 29 the density or number of a speed hump on one-kilometer length of the road segment varies from 4 up to 8. Minilk to kokebtsibah and Mekanisa Abo to bridge road segments have a high number of hump on one-kilometer length.

4.4.2 Regression Analysis and Sensitivity Analysis

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	291.496	97.165	14.43	0.013
Speed hump density(No/Km)	1	290.036	290.036	43.06	0.003
Speed hump height(cm)	1	0.016	0.016	0.00	0.963
Speed hump width(m)	1	2.979	2.979	0.44	0.0142
Error	4	26.943	6.736		
Total	7	318.439			

From Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.59534	91.54%	85.19%	48.44%

Coefficients

Constant	13.60	5.38	2.53	0.065	
Speed hump density(No/Km)	3697	563	6.56	0.003	1.04
Speed hump height(cm)	4.4	89.2	2.05	0.963	1.56
Speed hump width(m)	-0.386	0.581	-0.67	0.542	1.60

Regression Equation

Average PCI value difference = 13.60 + 3697 SHD+ 4.4 SHH - 0.386 SHW

Where SHW,speed hump width(meter),SHH ,speed hump height(meter) and SHD speed hump density in(No/ meter).

The resulting coefficient of determination of the best model (R2) is 0.91, and it is found to be significant at a 95% confidence level. The coefficients of the independent variables are speed hump width, height, and distance from preceding hump. The hypothesis that each of the coefficients is equal to zero is rejected at the 95% confidence level, as the t values are greater than ±1. 96. The t value shows the relative importance of the variable in the model, as the greater t value indicates the more important the variable is. The sensitive variable form all independent variables is speed hump density since it has the highest T-value it indicates that the speed hump density is a more sensitive variable for pavement condition effect.

From the analysis, the model has a logical explanation for the effect of the independent variables in predicting pavement condition difference. The positive signs of the independent variables speed hump height and density mean that the increase of speed hump height and density increase the PCI value difference. The PCI value difference is higher means the lower PCI value at sections with speed humps, so the higher the height and density of speed hump means the lower PCI values at speed hump location. Pavement conditions are more affected and have a direct relationship with speed hump height and number of speed hump. When speed hump is installed within a small distance it has affected the pavement condition more since the effect is increased when the number of speed hump is increased. When the height of speed hump increases the dynamic effect also increases on the pavement so the height of speed hump becomes higher the effect on pavement condition also increases directly. However, the negative sign of the independent variable speed hump width means the increase of speed hump width will decrease the PCI difference value. The PCI difference value decreases when the PCI value of the speed hump section is high. The higher the PCI value near to speed hump means the pavement condition is less affected by speed hump when the width of the hump is increased.

4.5 Recommended Remedial Measures for effects of speed humps on pavement condition

Based on the analysis of this study and reviewed literature, the following remedial measures are recommended to be taken to reduce the effect of speed humps on pavement condition.

1. For a change of PCI value of 34 caused by the presence of speed humps on the pavement, special pavement design needs to be considered since the terminal serviceability value of the pavement is one of the design parameters of flexible pavement design methods. Serviceability is quantified by the serviceability index this value theoretically ranges between 5 PSI (100 PCI) and zero, the actual range of real pavements is between about 4.5 to 1.5 PSI. The initial serviceability index PO corresponds to road conditions immediately after construction. A typical value of the PO for flexible pavement is 4.2. The terminal serviceability that will be tolerated before rehabilitation or reconstruction becomes necessary. A terminal serviceability index of 2.5 or higher is recommended for the design of major highways [30]. Thus, atypical allowable serviceability loss due to traffic for flexible pavements can be expressed as $\Delta \text{PSI} = \text{Pt} - \text{Po} = 4.2 - 2.5 = 1.7$………. (4.1).

   Where 1.7 PSI value is equivalent to 34 PCI value points. Due to the presence of speed hump the normal PCI value affected by speed hump and the pavement condition near to speed hump reach to the terminal serviceability level before normal pavement condition by 34 PCI points.

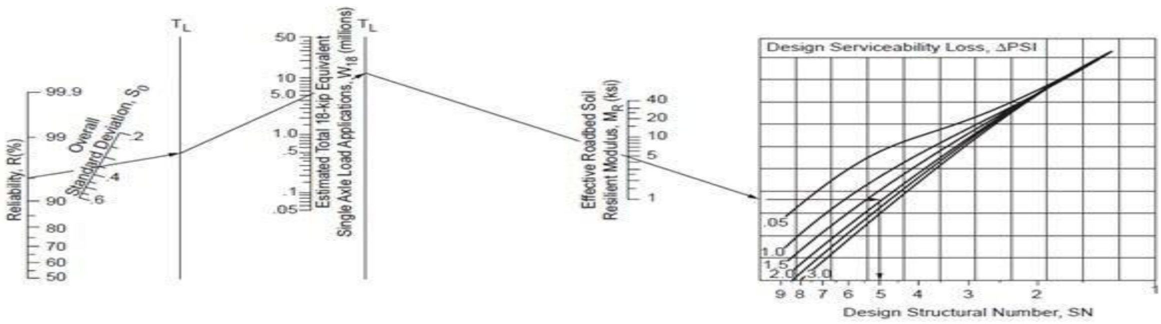


Figure 29 : AASHTO Nomograph for [flexible pavement design[30]

From figure 30 pavement design AASHTO Nomograph the lower the value of ΔPSI has the higher the SN (structural number) of pavement for similar other design parameters. Since SN determines the pavement thickness, the higher the SN of the pavement results in the thicker and stronger pavement layer. Those sections with speed hump the terminal serviceability reach earlier than normal pavement sections, hence the terminal serviceability value for sections with hump should be more than 2.5. In pavement design for road segments with speed humps, the change serviceability index should be below 1.7 to consider the structural effect on the pavement.

2. From the reviewed literature, speed humps made from rubber materials are pre-shaped to standard sizes. They are easy to install or remove by temporary bolting them on the pavement without cutting the existing pavement [32]. So installing this type of speed hump can reduce the effect of vehicles on the pavement due to improper shape of speed hump and the entering of water through the cut pavement.
3. In addition, height-adjustable speed humps are the latest type of speed humps designed to get activated only if the vehicles are traveling above a certain speed by using electronic sensors [10]. Adopting those types of speed humps can reduce the rapid decrease in the pavement condition due to the acceleration and declaration of vehicles near speed humps, as they force vehicles to drive at the specified speed limit (due to the improper shape of speed humps) and hence reduce the dynamic load since the speed humps are pre-shaped to the required design. These speed hump types are installed without cutting the existing pavement so it can reduce the pavement failure due to the cutting of the existing asphalt. In general, adopting rubber and height-adjustable speed humps reduce the rapid deterioration of pavements near speed humps.

CHAPTER FIVE: - CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The primary objective of this paper was to assess the impact of a speed hump on pavement condition using data from the ten-road segment located in Addis Ababa, the capital city of Ethiopia and to develop a model to show the relation between speed hump characteristics and pavement condition. The research study involved 102 sections; out of which 51 sections have at least one-speed hump overall 123 speed calming 71 are speed hump and 52 rumble strips. The data considered in the analysis included visual pavement distress and IRI values one year after the construction of the speed hump. The analysis of the pavement condition of this city was carried out both at the segment level and at the overall road level.

The most important findings of the paper are as follows

- ✓ The most frequently observed distress on the pavement sections considered in the analysis was pothole and raveling, while other load-related distress observed less than 5% of the studied sections. The distress distribution is similar at sections with and without speed hump, but the frequency of distress; occupancy is high for each distress type at sections with speed humps. The presence of hump increases distress severity rather than cause a new distress type for given pavement.
- ✓ The effect of speed humps was investigated both by comparing section with and without speed humps. When comparing sections with and without hump within the same segment, the analysis showed that the presence of speed humps reduces the average PCI value of section by 34 PCI points and increases the roughness of pavement by 3.4 IRI point.
- ✓ Strong correlations found between PCI and examined speed hump characteristics (Speed hump width, height, and density). Speed hump density vs PCI differences are more correlated than other parameters.
- ✓ Regression analysis used to produce the best relationship between PCI difference value and speed hump characteristics. Generally, the multi regression model that includes the three independent variables (hump height, hump with, and speed hump density) found in the best one. This model is very useful and can be used for pavement condition evaluations based on speed hump characteristics that can be used by highway and traffic engineers.

- ✓ The signs of the correlation coefficients in the regression model are as expected. The height of speed hump and the density of hump shows a positive correlation with a PCI value difference. On the other hand, the width of speed hump showed a negative correlation with PCI value.

5.2 Recommendations

Based on the findings of this paper recommends the following measures

- Change serviceability Index (ΔPSI) should be below 1.7 for the pavement design of road segments with speed humps.
- The developed model should be used for future installation of speed hump characteristic determination.
- The country should share experiences and adopt modern height adjustable and rubber type speed hump to force vehicles to drive by posting speed.
- Future research or studies should be conducted by using Falling Weight Deflection methods for structural data collection and analysis when the device is available. And AACRTMA adopts WRI speed hump characteristics; however, it is very difficult to construct the shape of hump by asphalt concrete. Most of the speed humps constructed in Addis Ababa force vehicle to decelerate up to zero speed than decrease the speed when the vehicle pass speed limit. AACRTMA should calibrate WRI speed hump characteristics value for Ethiopian current construction methodology, safety, comfort, and pollution like for pavement condition effect

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APPENDIX A

Table A-1: Location, speed limit, & construction date of speed hump and rumble strip in [3].

No.	Speed hump location	No. of speed hump	No. of rumble strip	Speed Limit (Km/hr)	Construction date
1.	Wingate RA -18mazoria	5	6	80	December 2008 E.C
2	Bisrategebireal -korae	5		40	December 2008 E.C
3	Abem-Kara	9		30	December 2008 E.C
4.	Aware RA - Balderas condominium	3	3	30	April 2010 E.C
5.	Aware RA - Parlama signalized intersection	3	7	30	April 2010 E.C
6.	Minilik II hospital - KokebeTsibah secondary	4	8	40	April 2010 E.C
7.	Sidistkillo RA - Afinchober	2	5	40	April 2010 E.C
8.	Semen hotel signalized intersection - Afinchober	2	4	30	April 2010 E.C
9.	Mendida intersection - Tor hayloch	10	18	40	May 2010 E.C
10.	Keranyo RA - Bethel RA	9	13	40	May 2010 E.C
11.	Keranyo RA - Anfo RA	7	10	40	May 2010 E.C
12.	Mekanisa Abo RA - BisrateGebriel	7	11	40	May 2010 E.C
13.	Mekanisa Abo RA - Mekanissa bridge	8	9	40	May 2010 E.C
14.	Lideta interchange - AU Junction (LidetaTsebel)	6	7	40	May 2010 E.C
15.	Lideta interchange - Lideta Condominium	3	3	40	June 2010 E.C
16.	Jackros intersection - Goro RA	17	-	40	June 2010 E.C

17.	Wossen - Kara	5	1	40	October 2011 E.C
18.	French Embassy - Kagnew RA	3	2	40	October 2011 E.C
19.	Goro RA - Gebriel- Figa intersection	17	2	40	October 2011 E.C
20.	Figa - Safari School	9	2	40	November 2011 E.C
21.	Goro RA - Summit Medhanialem	14	3	40	November 2011 E.C
22.	Kolfe - 18 mazoria	5	1	50	December 2011 E.C
23.	Bono Wuhasefer (back of British Embassy)	10	5	40	January 2011 E.C
24.	Kotebe 02 kebele	3	3	40	December 2011 E.C
25.	Kolfe - 18 MazoriaRA	9	2	50	December 2011 E.C
26.	Ayer Tena RA - Jomo Mikael	3	-	50	February 2011 E.C
27.	58 Mazoria - Hana Mariam	9	3	40	February 2011 E.C

Appendix B

Road characteristic data, International roughness index data and pavement condition data

Table B-1: Torhayiloch to mendida road characteristic data

Road characteristic	Value
Road length (km)	2.6 km
Average pavement width (m)	10 m
Average shoulder width (m)	3
Speed limit (km/h)	30
No. of speed humps	8
Speed humps density (hump/km)	4 hump/km
Average height of humps (cm)	3.5
Average width of speed humps (m)	1

Table B-2: Torhayiloch to mendida International Roughness Index data (IRI)

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	7.7	No
2	100	4.73	No
3	100	4.7	No
4	100	8.7	Yes
5	100	9.66	Yes
6	100	4.14	No
7	100	3.49	No
8	100	4.34	No
9	100	7.7	Yes
10	100	3.8	No
11	100	4.5	No
12	100	5.19	Yes
13	100	3.05	No
14	100	2.65	No
15	100	3.7	No
16	100	4.1	No
17	100	7.16	Yes
18	100	5.26	Yes
19	100	7.16	Yes
20	100	3.66	No
21	100	3.44	No
22	100	3.23	No
23	100	7.28	Yes
24	100	3.38	No
25	60	11.96	No

Table B-3: Torhayiloch to mendida pavement condition index

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION | SKETCH

SURVEY DATA SHEET | 11 m

BRANCH: Torhayiloh Mendida | SECTION | SAMPLE UNIT 1 | 100 m | Direction of survey

SURVEYED BY | DATE | SAMPLE AREA(m² 1100

1. Alligator cracking	6.depressior	11.patching and util cut pacthing	16.shoving
2.bleeding	7.Edge cracl	12.polished aggregate	17.Slippage cracking
3.block cracking	8. jt.Refelect	13.potholes	18.swell
4.bumps and sags	9.Lane/shou	14.rail road crossing	19.weathering /ravelling
5.corrugation	10.Lond &Tr	15.rutting	

Section no	DISTRESS SEVERITY	QUANTITY					TOTAL	DENSITY %	DEDUCT VALUE	CDV	PCI VALUE
1	19H	30*9					270	24.55	60	60	40
2											100
3											100
4	13H	(1*1)/0.5=2					2	0.18	25	25	75
5	19H	10*7	50*9	20*9			700	63.64	75	75	25
6	19H	5*7	5*7				70	6.36	38	38	62
7											100
8											100
9	13H	(3*2)/0.5=12					12	1.09	52		
9	19H	10*9					90	8.18	38	48	52
10											100
11											100
12											100
13											100
14											100
15											100
16											100
17											100
18											100
19											100
20											100
21											100
22											100
23											100
24											100
25											100

Table B-4: Torhayiloch to mendida pavement condition Data

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET

BRANCH Torhayiloch mendi SECTION 1 to 25 SAMPLE UNIT

SURVEYED BY DATE SAMPLE AREA(m2) 1100

SKETCH: 11 m; 100 m; Direction of survey

Section No	Pothole Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Rutting Area (m2)	Crocodile Cracking Crack Width (mm)	Crocodile Cracking Area (m2)	Corrugation Area (m2)	Transverse Length (m)	Faild Area (m2)	Longitudinal Length (m)	Bleeding Area (m2)	Ravelling Depth(mm)	Ravelling Area (m2)	Shoving Area (m2)	Low shoulder Area (m2)	Lacy Edge Area (m2)
1													3*9			
2																
3	1*1															
4														5*7		
5													1*7			
5													5*9			
5													2*9			
6													0.5*7			
6													0.5*7			
7																
8																
9													0.99*9			
10																
11																
12																
13																
14	3*2															
15																
16																
17																
18																
19																
20																
21																
22																
23																
24																
25																

Table B-5: Mendida toTorhayiloch road characteristic date

Road characteristic	Value
Road length (km)	2.6
Average pavement width (m)	11
Average shoulder width (m)	3
Speed limit (km/h)	40
No. of speed humps	9
Speed humps density (hump/km)	4
Average height of humps (cm)	6
Average width of speed humps (m)	5

Table B-6: Mendida toTorhayiloch International Roughness Index data (IRI)

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	11.98	No
2	100	5.62	No
3	100	5.24	No
4	100	6.59	No
5	100	5.36	No
6	100	3.93	No
7	100	5.54	No
8	100	3.6	No
9	100	8.89	yes
10	100	12.3	yes
11	100	5.8	No
12	100	14.15	yes
13	100	6.3	yes
14	100	16.9	yes
15	100	16.98	yes
16	100	4.05	No
17	100	9.71	yes
18	100	7.6	Yes
19	100	10.3	yes
20	100	5.12	No
21	100	4.97	No
22	100	4.63	No
23	100	4.89	No
24	100	3.98	No
25	60	4.38	No

Table B-7: Mendida toTorhayiloch Pavement condition index value

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION

SURVEY DATA SHEET

SKETCH: 11 m; 100 m; Direction of survey

BRANCH Mendida tori SECTION | SAMPLE UNIT

SURVEYED BY | DATE | SAMPLE AREA(m: 1100

1. Alligator cracking	6.depression	11.patching and util cut pacthing	16.shoving
2.bleeding	7.Edge cracking	12.polished aggregate	17.Slippage cracking
3.block cracking	8. jt.Refelection cracking	13.potholes	18.swell
4.bumps and sags	9.Lane/shoulder drop off	14.rail road crossing	19.weathering /ravelling
5.corrugation	10.Lond &Trans cracking	15.rutting	

Section nc	DISTRESS SEVERITY	QUANTITY	TOTAL	DENSITY %	DEDUCT VALUE	CDV	PCI VALUE
1							100
2							100
3							100
4							100
5							100
6							100
7							100
8	19H	3*9	27	2.454545	25	25	75
9	19M	10*7	70	6.363636	38	38	62
10							100
11							100
12							100
13	10M	15	15	1.363636	27	27	73
14	13H	(2*2)/0.5=8	8	0.727273	48	56	44
14	19M	(15*9)=135	135	12.27273	60		
15							100
16							100
17	13H	(2*2)/0.5=8	8	0.727273	48	48	52
18	13H	(2*2)/0.5=8	8	0.727273	48		
18	19M	8*9	72	6.545455	38	46	54
19							100
20							100
21							100
22	19H	(1*2)	2	0.181818	10	10	90
23							100
24	13H	(1*1)/0.5	2	0.181818	25		
24	13H	(2*2)/0.5	8	0.727273	48	38	62
25							100

Table B-8: Mendida toTorhayiloch Pavement condition Date

	ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET				SKETCH
BRANCH	mendida to torhayiloch	SECTION	SAMPLE UNIT		11m
SURVEYED BY		DATE	SAMPLE AREA(m2)	1100	100 m Direction of survey

Section No	Pothole		Rutting		Crocodile Cracking		Corrugation	Transverse	Faild	Longitudinal	Bleeding	Ravelling		Shoving	Low shoulder	Lacy Edge
	Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Area (m2)	Crack Width (mm)	Area (m2)	Area (m2)	Length (m)	Area (m2)	Length (m)	Area (m2)	Ravelling Depth(mm)	Area (m2)	Area (m2)	Area (m2)	Area (m2)
1																
2																
3																
4																
5																
6																
7																
8													3*9			
9																
10													1*9			
11																
12																
13										15						
14	2*2								15*9							
15																
16																
17	2*2															
18	2*2												8*9			
19																
20																
21																
22													1*9			
23																
24	1*1															
24	2*2															
25																

Table B-9 Wingate to 18 mazoria Road characteristic data

Road characteristic	Value
Road length (km)	1.57km
Average pavement width (m)	7m
Average shoulder width (m)	3m
Speed limit (km/h)	80
No. of speed humps	11
Speed humps density (hump/km)	7hump/km
Average height of humps (cm)	5
Average width of speed humps (m)	6

Table B-10 Wingate to 18 mazoria International Roughness Index data (IRI)

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	10.697	yes
2	100	10.616	Yes
3	100	3.23	No
4	100	4.56	Yes
5	100	5.72	Yes
6	100	6.15	Yes
7	100	4.08	yes
8	100	6.11	Yes
9	100	2.71	No
10	100	3.00	No
11	100	4.4	Yes
12	100	4.04	Yes
13	100	2.34	No
14	100	2.26	No
15	100	4.85	No
16	70	5.68	No

Table B-11:pavement condition index result for winget to 18 mazoria road segment

	ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION						SKETCH				
	SURVEY DATA SHEET								7 m		
	BRANCH	Vingate-18	SECTION		SAMPLE UNIT			100 m			
								Direction of survey			
	SURVEYED BY		DATE		SAMPLE AREA(m2)	700					
	1. Alligator cracking		6.depression	11.patching and util cut pacthing				16.shoving			
	2.bleeding		7.Edge cracking	12.polished aggregate				17.Slippage cracking			
	3.block cracking		8. jt.Refelection c	13.potholes				18.swell			
	4.bumps and sags		9.Lane/shoulder c	14.rail road crossing				19.weathering /travelling			
	5.corrugation		10.Lond &Trans c	15.rutting							
	DISTRESS						TOTAL	DENSITY	DEDUCT	CDV	PCI
Section no	SEVERITY	QUANTITY						%	VALUE		VALUE
1	13H	(2*2)/0.5=8	(4*3)/0.5=24				32	4.571429	87		
1	1H	10*3					30	4.285714	53	95	5
1	19H	(08*3)=24					24	3.428571	28		
2											100
3											100
4	13H	(3*3)/0.5=18	(2*3)*0.5=12				30	4.285714	85	85	15
5	15M	10*1					10	1.428571	25	25	75
6	13H	(2*2)/0.5=8	(5*4)/0.5=40				48	6.857143	95		
6	15H	80*1					80	11.42857	75		
6	19H	40*10					40	5.714286	66	100	0
7	13H	(2*1)/0.5=4					4	0.571429	45	45	55
8											100
9											100
10											100
11	13H	(2*2)/0.5=8	(4*3)/0.5=24				32	4.571429	87	87	13
12	13H	(4*4)/0.5=32					32	4.571429	87		
12	19M	10*10					100	14.28571	50	86	14
13	13H	(4*3)/0.5=24					24	3.428571	82		
13	1H	15*4					60	8.571429	60	82	18
14											100
15											100
16											100

Table B-12: Wingate to 18 mazoria Pavement condition Data

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET

BRANCH wingate-18 | SECTION 1 to 16 | SAMPLE UNIT

SURVEYED BY | DATE | SAMPLE AREA(m2) 700

SKETCH

7m

100 m

Direction of survey

Section No	Pothole Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Rutting Area (m2)	Crocodile Cracking Crack Width (mm)	Crocodile Cracking Area (m2)	Corrugation Area (m2)	Transverse Length (m)	Faild Area (m2)	Longitudinal Length (m)	Bleeding Area (m2)	Ravelling Depth(mm)	Ravelling Area (m2)	Shoving Area (m2)	Low shoulder Area (m2)	Lacy Edge Area (m2)
1	2*2				15	10*3						2	0.8*3			
1	4*3															
2																
3																
4	3*3															
4	2*3															
5			25	10*1												
6	2*2		30	80*1									4*10			
6	5*4															
7	2*1															
8																
9																
10																
11	2*2															
11	3*4															
12	4*4												0.99*10			
13	4*3				100	15*4										
14																
15																
16																

Table B-13: Wossen–Kara Road characteristic data

Road characteristic	Value
Road length (km)	1.415km
Average pavement width (m)	11m
Average shoulder width (m)	3m
Speed limit (km/h)	30
No. of speed humps	9
Speed humps density (hump/km)	7 hump/km
Average height of humps (cm)	6
Average width of speed humps (m)	1

Table B-14: Wossen–Kara International Roughness Index data (IRI)

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	3.00	No
2	100	3.04	No
3	100	2.65	No
4	100	3.04	No
5	100	2.13	No
6	100	4.78	yes
7	100	5.29	yes
8	100	6.34	yes
9	100	5.63	yes
10	100	7.09	yes
11	100	5.75	yes
12	100	6.25	yes
13	100	3.46	yes
14	115	5.93	yes

Table B-15: Wossen–Kara Pavement condition Data

	ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION						SKETCH					
	SURVEY DATA SHEET								11 m			
	BRANCH	kara to Wossen	SECTION	SAMPLE UNIT				100 m Direction of survey				
	SURVEYED BY		DATE	SAMPLE AREA(m2		1100						
	1. Alligator cracking		6.depression	11.patching and util cut pacthing				16.shoving				
	2.bleeding		7.Edge crackin	12.polished aggregate				17.Slippage cracking				
	3.block cracking		8. jt.Refelectio	13.potholes				18.swell				
	4.bumps and sags		9.Lane/should	14.rail road crossing				19.weathering /ravelling				
	5.corrugation		10.Lond &Tran	15.rutting								
Section no	DISTRESS SEVERITY	QUANTITY					TOTAL	DENSITY %	DEDUCT VALUE	CDV	PCI VALUE	
1												
2												
3												
4												
5												
6												
7	19L	15*6					90	8.1818182	42	42	58	
8	13H	(4*7)/0.5=32					32	2.9090909	78			
8	7M	10					10	0.9090909	18	52	48	
9	19M	5*7					35	3.1818182	29	29	71	
10	13H	(2*1)/0.5=4	(4*4)/0.5=32				36	3.2727273	80			
10	19M	20*5					100	9.0909091	20	60	40	
11												
12	19M	25*10					250	22.727273	30	30	70	
13	19M	2*10					20	1.8181818	10	10	90	
14												

Table B-16: Wossen–Kara Pavement condition Data

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET

SKETCH

11m

100 m

Direction of survey

BRANCH Abem to Kara **SECTION** **SAMPLE UNIT**

SURVEYED BY **DATE** **SAMPLE AREA(m2)** 1100

Section No	Pothole		Rutting		Crocodile Cracking		Corrugation	Transverse Crack	Faild	Longitudinal Crack	Bleeding	Ravelling		Shoving	Low shoulder	Lacy Edge
	Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Area (m2)	Crack Width (mm)	Area (m2)	Area (m2)	Length (m)	Area (m2)	Length (m)	Area (m2)	Ravelling Depth(mm)	Area (m2)	Area (m2)	Area (m2)	Area (m2)
1																
2																
3																
4																
5																
6																
7													1.5*6			
8	4*7															10m
9													0.5*7			
10	2*1												0.2*5			
10	4*4															
11																
12	2*1												0.25*4			
13													1*10			
14																

Table B-17: Paralama signalized intersection to aware round about Road characteristic data

Road characteristic	Value
Road length (km)	0.9 km
Average pavement width (m)	11m
Average shoulder width (m)	3m
Speed limit (km/h)	30
No. of speed humps	5
Speed humps density (hump/km)	6 hump/km
Average height of humps (cm)	7
Average width of speed humps (m)	5

Table B-18: Paralama signalized intersection to aware round about International Roughness Index data (IRI)

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	3.43	No
2	100	4.06	No
3	100	4.28	No
4	100	5.98	Yes
5	100	6.09	Yes
6	100	4.5	No
7	100	3.85	No
8	100	3.79	No
9	85	5.87	No

Table B-19: Paralama signalized intersection to aware round about Pavement condition Data

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION
SURVEY DATA SHEET

BRANCH Gebrael to Awa SECTION SAMPLE UNIT

SURVEYED BY DATE SAMPLE AREA(m2) 1100

SKETCH: 11m, 100 m, Direction of survey

Section No	Pothole Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Rutting Area (m2)	Crocodile Cracking Crack Width (mm)	Crocodile Cracking Area (m2)	Corrugation Area (m2)	Transverse Length (m)	Faild Area (m2)	Longitudinal Length (m)	Bleeding Area (m2)	Ravelling Depth(mm)	Ravelling Area (m2)	Shoving Area (m2)	Low shoulder Area (m2)	Lacy Edge Area (m2)
1																
2																
3																
4	20*4															
5	4*3												2.5*14			
6													2*7			
6																
7																
8																
9																

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION
SURVEY DATA SHEET

SKETCH: 11m, 100 m, Direction of survey

BRANCH paralama to awarae SECTION SAMPLE UNIT
SURVEYED BY DATE SAMPLE AREA(m2) 1100

1. Alligator cracking	6.depression	11.patching and util cut pacthing	16.shoving
2.bleeding	7.Edge cracking	12.polished aggregate	17.Slippage cracking
3.block cracking	8. jt.Refelection cr	13.potholes	18.swell
4.bumps and sags	9.Lane/shoulder dr	14.rail road crossing	19.weathering /ravelling
5.corrugation	10.Lond &Trans cr	15.rutting	

Section no	DISTRESS SEVERITY	QUANTITY					TOTAL	DENSITY %	DEDUCT VALUE	CDV	PCI VALUE
1											100
2											100
3											100
4	13M	(2*4)/0.5					16	1.45	60	60	62
5	13H	(4*3)/0.5					24	2.18	68	68	
5	19M	(2.5*14)					35	3.18	27	27	55
6	19H	(2*7)					14	1.27	20	20	80
7											100
8											100
9											100

Table B-20: BisrateGebrael to Korae Road characteristic data

Road characteristic	Value
Road length (km)	1485m
Average pavement width (m)	11 m
Average shoulder width (m)	3
Speed limit (km/h)	40
No. of speed humps	5
Speed humps density (hump/km)	4 hump/km
Average height of humps (cm)	5
Average width of speed humps (m)	0.9

Table B-21: BisrateGebrael to Korae International Roughness Index data (IRI)

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	12.48	No
2	100	3.33	No
3	100	3.36	No
4	100	3.25	No
5	100	5.96	yes
6	100	10.27	Yes
7	100	7.01	Yes
8	100	4.22	No
9	100	5.59	Yes
10	100	5.22	Yes
11	100	3.86	No
12	100	2.63	No
13	100	2.14	No
14	100	3.26	No
15	85	4.7	No

Table B-22: Bisrate Gebrael to Korae Pavement condition Data

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET

BRANCI B/gebrael-kora SECTION 1 to 15 SAMPLE UNIT

SURVEYED BY DATE SAMPLE AREA(m2 1100

SKETCH: 11m, 100m, Direction of survey

Section No	Pothole Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Rutting Area (m2)	Crocodile Cracking Crack Width (mm)	Crocodile Cracking Area (m2)	Corrugation Area (m2)	Transver Length (m)	Faild Area (m2)	Longitudinal Length (m)	Bleedin Area (m2)	Ravelling Depth(mm)	Ravelling Area (m2)	Shoving Area (m2)	Low Area (m2)	Lacy Area (m2)
1																
2	1*1															
3																
4																
5													11*2			
6	2*2															
7													15*5			
8																
9	1*1.5															
10													10*5			
11																
12																
13																
14																
15																

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET

SKETCH: 11m, 100 m, Direction of survey

BRANCH B/gebrael to korae SECTION SAMPLE UNIT

SURVEYED BY DATE SAMPLE AREA(m2) 1100

1. Alligator cracking; 2.bleeding; 3.block cracking; 4.bumps and sags; 5.corrugation; 6.depression; 7.Edge cracking; 8. jt.Refelection c; 9.Lane/shoulder c; 10.Lond &Trans c; 11.patching and util cut pacthing; 12.polished aggregate; 13.potholes; 14.rail road crossing; 15.rutting; 16.shoving; 17.Slippage cracking; 18.swell; 19.weathering /ravelling

Section no	DISTRESS SEVERITY	QUANTITY	TOTAL	DENSITY %	DEDUCT VALUE	CDV	PCI VALUE
1							100
2	13H	(1*1)/0.5	2	0.181818	28	28	72
3							100
4							100
5	19M	11*2	22	2	20	20	80
6	13H	(2*2)/0.5	8	0.727273	50	50	50
7	19H	15*5	75	6.818182	38	38	62
8							100
9	13H	(1*1.5)/0.5	3	0.272727	38	38	62
10	19H	10*5	50	4.545455	35	35	65
11							100
12							100
13							100
14							100
15							100

Table B-23: Minilik II hospital - KokebeTsibah secondary school Road characteristic data

Road characteristic	Value
Road length (km)	0.635 km
Average pavement width (m)	15m
Average shoulder width (m)	3
Speed limit (km/h)	40
No. of speed humps	5
Speed humps density (hump/km)	8 hump/km
Average height of humps (cm)	7
Average width of speed humps (m)	6

Table B-24: Minilik II hospital - KokebeTsibah secondary school International Roughness Index data (IR

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	4.5	yes
2	100	4.86	yes
3	100	2.27	No
4	100	2.3	No
5	100	2.6	No
6	100	2.45	No
7	35	8.41	No

Table B-25 Pavement condition Data

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION

SURVEY DATA SHEET

BRANCH minilk to kokebe tsibah | SECTION | SAMPLE UNIT

SURVEYED BY | DATE | SAMPLE AREA(m2) 1100

SKETCH: 15m × 100 m, Direction of survey

Section No	Pothole Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Rutting Area (m2)	Crocodile Cracking Crack Width (mm)	Crocodile Cracking Area (m2)	Corrugation Area (m2)	Transverse Crack Length (m)	Faild Area (m2)	Longitudinal Crack Length (m)	Bleeding Area (m2)	Ravelling Ravel ling Dept	Ravelling Area (m2)	Shoving Area (m2)	Low shoul Area (m2)	Lacy Edge Area (m2)
1			100	5*3									20*6			
2	3*5				5	15*5										
3																
4																
4																
5																
6																
7																
8																
9																
10																
11																
12																

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION

SURVEY DATA SHEET

BRANCH Minilik to kokebe tsibah | SECTION | SAMPLE UNIT

SURVEYED BY | DATE | SAMPLE AREA(m2) 1500

SKETCH: 15 m × 100 m, Direction of survey

1. Alligator cracking
2. bleeding
3. block cracking
4. bumps and sags
5. corrugation
6. depression
7. Edge cracking
8. jt.Refelection cracking
9. Lane/shoulder drop off
10. Lond &Trans cracking
11. patching and util cut pacthing
12. polished aggregate
13. potholes
14. rail road crossing
15. rutting
16. shoving
17. Slippage cracking
18. swell
19. weathering /ravelling

Section no	DISTRESS SEVERITY	QUANTITY	TOTAL	DENSITY %	DEDUCT VALUE	CDV	PCI VALUE
1	15M	(5*3)=15	15	1	20		
1	19H	(20*6)=120	120	8	38	25	75
2	13H	(3*5)/0.5=30	30	2	68		
2	1H	15*5=75	75	5	53	58	42
3							100
4							100
5							100
6							100
7							100
8							100
9							100
10							100
11							100
12							100

Table B-26: Emperial to Goro Road characteristic data

Road characteristic	Value
Road length (km)	1.65
Average pavement width (m)	11
Average shoulder width (m)	3
Speed limit (km/h)	40
No. of speed humps	6
Speed humps density (hump/km)	4
Average height of humps (cm)	8
Average width of speed humps (m)	6

TableB-27: Emperial to Goro International Roughness Index data (IRI)

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	4.0	No
2	100	3.0	No
3	100	2.5	No
4	100	3.7	No
5	100	6.5	yes
6	100	4	No
7	100	5.9	Yes
8	100	6.5	Yes
9	100	6.6	Yes
10	100	10.6	Yes
11	100	4.6	Yes
12	100	3.8	No
13	100	3.26	No
14	100	1.9	No
15	100	3.3	No
16	50	2.2	No

Table B-28 Emperial to Goro Pavement condition Data

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION
SURVEY DATA SHEET

BRANCH Goro to Emperial SECTION SAMPLE UNIT
SURVEYED BY DATE SAMPLE AREA(m2) 1100

SKETCH: 11m; 100 m; Direction of survey

Section No	Pothole Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Rutting Area (m2)	Crocodile Cracking Crack Width (mm)	Crocodile Cracking Area (m2)	Corrugation Area (m2)	Transverse Crack Length (m)	Faild Area (m2)	Longitudinal Crack Length (m)	Bleeding Area (m2)	Ravelling Depth(mm)	Ravelling Area (m2)	Shoving Area (m2)	Low shoulder Area (m2)	Lacy Edge Area (m2)
1																
2																
3																
4												1	15*10			
5												1	10*4			
5												1	10*10			
6												1	15*10			
7												1	10*10			
8																
9																
10	5*4															
11	2*1															
12												2	50*5			
13																
14																
15																
16																
17																

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION
SURVEY DATA SHEET

BRANCH Emperial to goro SECTION SAMPLE UNIT
SURVEYED BY DATE SAMPLE AREA(m: 1100

SKETCH: 11 m; 100 m; Direction of survey

1. Alligator cracking
2.bleeding
3.block cracking
4.bumps and sags
5.corrugation
6.depression
7.Edge cracking
8. jt.Refelection cracking
9.Lane/shoulder drop off
10.Lond &Trans cracking
11.patching and util cut pacthing
12.polished aggregate
13.potholes
14.rail road crossing
15.rutting
16.shoving
17.Slippage cracking
18.swell
19.weathering /travelling

Section no	DISTRESS SEVERITY	QUANTITY					TOTAL	DENSITY %	DEDUCT VALUE	CDV	PCI VALUE
1											100
2											100
3											100
4	19H	(15*10)=150					150	13.63636	48	48	52
5	19H	(10*4)=40	(10*10)=100				140	12.72727	45	45	55
6	19H	(15*10)=150					150	13.63636	48	48	52
7	19H	(10*10)=100					100	9.090909	40	40	60
8											100
9											100
10	13H	(5*4)/0.5=40					40	3.636364	81	81	19
11	13H	(2*1)/0.5=4					4	0.363636	40	40	60
12	19M	(50*5)=250					250	22.72727	89	89	11
13											100

Table B-29: Mekanisa Abo RA –Mekanissa Bridge Road characteristic data

Road characteristic	Value
Road length (km)	1.12
Average pavement width (m)	11
Average shoulder width (m)	3
Speed limit (km/h)	30
No. of speed humps	9
Speed humps density (hump/km)	8
Average height of humps (cm)	6
Average width of speed humps (m)	5

Table B-30: Mekanisa Abo RA –Mekanissa Bridge International Roughness Index data (IRI)

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	3.1	No
2	100	2.7	No
3	100	2.9	No
4	100	7.6	yes
5	100	7.3	yes
6	100	7.6	yes
7	100	2.3	No
8	100	6.8	yes
9	100	7.6	yes
10	100	3.5	No
11	100	3.5	No
12	20	4.9	No

Table B-31: Mekanisa Abo RA –Mekanissa Bridge Pavement condition Data

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION

SURVEY DATA SHEET

BRANCH mekanisa abo-bridge | SECTION | SAMPLE UNIT

SURVEYED BY | DATE | SAMPLE AREA(m2) 1100

SKETCH: 11m, 100 m, Direction of survey

Section No	Pothole Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Rutting Area (m2)	Crocodile Cracking Crack Width (mm)	Crocodile Cracking Area (m2)	Corrugation Area (m2)	Transverse Length (m)	Faild Area (m2)	Longitudin Length (m)	Bleedin Area (m2)	Ravelling Depth(	Ravelling Area (m2)	Shovin Area (m2)	Low Area (m2)	Lacy Area (m2)
1																
2																
3																
4	1*1												5*3			
4	11*1.5															
5													10*3			
6	1*2															
7																
8																
9	1.5*1.5												11*5			
10																
11	1*1															
12																

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION

SURVEY DATA SHEET

BRANCH mekanisa abo mekanisa bridge | SECTION | SAMPLE UNIT

SURVEYED BY | DATE | SAMPLE AREA(m: 1100

SKETCH: 11 m, 100 m, Direction of survey

1. Alligator cracking	6.depression	11.patching and util cut pacthing	16.shoving
2.bleeding	7.Edge cracking	12.polished aggregate	17.Slippage cracking
3.block cracking	8. jt.Refelection cracking	13.potholes	18.swell
4.bumps and sags	9.Lane/shoulder drop off	14.rail road crossing	19.weathering /ravelling
5.corrugation	10.Lond &Trans cracking	15.rutting	

Section no	DISTRESS SEVERITY	QUANTITY					TOTAL	DENSITY %	DEDUCT VALUE	CDV	PCI VALUE
1											100
2											100
3											100
4	13H	(1*1)=2	(11*2)=44				46	4.181818	82		
4	19H	(5*3)=15					15	1.363636	20	63	37
5	19H	(10*3)=30					30	2.727273	25	25	75
6	13H	(1*2)=4					4	0.363636	38	38	62
7											100
8											100
9	13H	(1.5*1.5)=4.5					4.5	0.409091	38		
9	19M	(11*5)=55					55	5	30	32	68
10											100
11	13H	(1*1)=2					2	0.181818	28	28	72
											100

Table B-32: Semen hotel signalized intersection – Afinchober Road characteristic data

Road characteristic	Value
Road length (km)	0.7
Average pavement width (m)	7
Average shoulder width (m)	3
Speed limit (km/h)	30
No. of speed humps	2
Speed humps density (hump/km)	4
Average height of humps (cm)	9
Average width of speed humps (m)	5

Table B-33: Semen hotel signalized intersection – Afinchober International Roughness Index data (IRI)

Section No	Section length (meter)	IRI Value	Speed hump exist
1	100	3.2	No
2	100	2.2	No
3	100	6.6	yes
4	100	3.1	No
5	100	2.3	No
6	100	12.3	yes
7	100	7.7	yes

Table B-34: Semen hotel signalized intersection – Afinchober Pavement condition Data

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION
SURVEY DATA SHEET

BRANCH semen hotel Afincho ber SECTION SAMPLE UNIT
SURVEYED BY DATE SAMPLE AREA 700

SKETCH: 7m, 100 m, Direction of survey

Section No	Pothole		Rutting		Crocodile Cracking		Corrugation	Transverse Crack	Faild	Longitudinal Crack	Bleeding	Ravelling		Shoving	Low shoulder	Lacy Edge
	Area (m2)	Pothole Depth (mm)	Rutting Depth (mm)	Area (m2)	Crack Width (mm)	Area (m2)	Area (m2)	Length (m)	Area (m2)	Length (m)	Area (m2)	Ravelling	Area (m2)	Area (m2)	Area (m2)	Area (m2)
1																
2																
3	1*2															
4																
5																
5																
6												2	7*2			
7			200	7*1												

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION
SURVEY DATA SHEET

BRANCH Semen hotel Afincho ber SECTION SAMPLE UNIT
SURVEYED BY DATE SAMPLE AREA(m2) 1100

SKETCH: 11 m, 100 m, Direction of survey

1. Alligator cracking
2. bleeding
3. block cracking
4. bumps and sags
5. corrugation
6. depression
7. Edge cracking
8. jt.Refelection cracking
9. Lane/shoulder drop off
10. Lond &Trans cracking
11. patching and util cut pacthing
12. polished aggregate
13. potholes
14. rail road crossing
15. rutting
16. shoving
17. Slippage cracking
18. swell
19. weathering /ravelling

Section no	DISTRESS SEVERITY	QUANTITY					TOTAL	DENSITY %	DEDUCT VALUE	CDV	PCI VALUE
1											100
2											100
3	13H	(1*2)/0.5=4					4	0.3636364	42	42	58
4											100
5											100
6	19M	(7*2)=14					14	1.2727273	45	45	55
7	15H	(7*1)=7					7	0.6363636	60	60	40

APPENDIX C
Photos of Test Sites

Mekanisa Abo to bridge road segment site condition

Torhayiloch to mendida site condition

B/gebrael to korae road site condition

Kara to wossen road site condition