ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

ASPHALT ROAD PAVEMENT REHABILITATION AND MAINTENANCE
CASE STUDY IN ADDIS ABABA CITY ROADS AUTHORITY

By

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Asphalt Road Pavement Rehabilitation and Maintenance

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ABBREVIATIONS AND ACRONYMS

AACRA	Addis Ababa City Roads Authority
ERA	Ethiopian Roads Authority
NDT	Nondestructive testing
DT	Destructive testing
BPN	British Pendulum Number
PMMS	Pavement Maintenance Management System
MRR	Maintenance Rehabilitation and Reconstruction
CBR	California Bearing Ratio
BB	Benkelman Beam
FWD	Falling Weight Deflectometer
PSI	Present Serviceability Index
PSR	Present Serviceability Rating
AASHTO	American Association of State Highway and Transportation Officials
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
PI	Priority Index
APWA	American Public Works Association
ADT	Average Daily Traffic
FHA	Federal Highway Administration
ID	Identification
PMS	pavement management system
VDS	Vehicle Detector Stations
ESS	Environmental Sensor Stations
NOMAD	national optimization of maintenance allocation by decade
TCC	traffic control centers
TMC	Traffic Management centers
SARENA	South African National Roads Agency

Abstract

Addis Ababa City Roads Authority representing the Addis Ababa City Administration manages the entire city roads. Currently it is engaged in increasing Addis Ababa city road coverage to reach 25% within 2012 E.C. However, literatures indicate that most of the city roads severely suffering from lack of proper maintenance. Hence, identifying critical problems can be input towards improving road maintenance and rehabilitation activities of the City roads.

After detail review of scientific literature and international experience in managing asphalt maintenance, based on pavement evaluation, maintenance and pavement management system questionnaires was developed and interview was conducted. Through interview and questionnaire survey of professionals; the present maintenance and rehabilitation practice of AACRA was assessed. Responses were graded by average index method.

In conclusion, the finding of this study implies that Addis Ababa City Roads Authority doesn't conduct adequate pavement condition evaluation that can be sound input for recommending maintenance options and the maintenance work is limited to overlay and pouching and performing maintenance without adequately defining the route cause of distress, moreover this study identifies the greatest challenge for road rehabilitation and maintenance in AACRA is the absence of well established pavement management system. The study recommended that AACRA shall asses and apply alternative pavement evaluation and maintenance methods. Moreover, AACRA has to establish pavement management system to manage maintenance activities for better and optimum utilization of resource. Further research is also recommended which includes development of pavement management system and pavement treatment selection alternatives for Addis Ababa City Roads Authority.

Key Words: pavement evaluation, pavement maintenance, pavement management

CHAPTER- 1

Introduction

1.1. Introduction

Addis Ababa is located nearly in the central part of Ethiopia. It is the capital city of Ethiopia and the seat of African Union and other international organizations. To give adequate infrastructure service to the occupant's AACRA allocates huge amount of Budget and resource to expand and rehabilitate the existing road network.

As the demands on the national highway network continue to grow, so does the need for construction and maintenance practices that will help extend the life of pavements. No pavement has been constructed that does not need maintenance. Many community associations find out too late that proper maintenance could have prevented costly replacements

Before any maintenance activity is taken for proper maintenance of asphalt pavements; understanding the causes of failures are essential using detail pavement evaluation techniques. To make the most of maintenance budgets, proven methods must be used to correct failures and to prevent their recurrence.

Road deterioration due to lack of maintenance has become a growing issue in a number of developing countries. The problem has been discussed at length and the results of a lack of maintenance have been well defined and quantified. Nevertheless, the extent of the problem is not fully appreciated and the solutions are still not commonly understood. Equally, the measures required to rectify the shortcomings are under-estimated. These include the scale of support and capacity development required, and the time-scale necessary for establishing an effective road management system. Such a system should halt road network deterioration and ensure that financial, material and human investments are made in a manner which maintains the quality and value of the assets and, in addition, improves the network in relation to the demands and priorities of the users [1].

The basic objective of road maintenance is implicit in the word itself. It is done to ensure that the road that has been constructed, or improved, is maintained in its original condition. No matter what technical designs are chosen, all roads, from major highways to local gravel roads, require regular and timely maintenance in order to secure a reasonable lifetime on the construction investment. Attempts to find technical designs which are maintenance-free are disillusions and in the long run only prove that lack of maintenance leads to accelerated rates of deterioration [1].

Timely and regular maintenance requires securing sufficient funding before repairs and maintenance become an urgent issue. The most effective form of maintenance is achieved when an organization is capable and prepared to carry out appropriate interventions at an early stage of deterioration and thus limit the extent of damages. This implies that the responsible authority is furnished with the necessary human and financial resources to effectively manage all facets of the maintenance works.

1.2. Road Construction and maintenance in Addis Ababa

The development of Addis Ababa road has dated back to the Emperor Minillik II era , the Emperor and his wife Empress Taitu both had the vision in constructing roads.The first roads was constructed from Addis Ababa to Addis Alem and from the palace to English Embassy streching to other places. In the following years the Emperor soon understand the road quality need to be improved by any means , so he bought the first stone roller in 1984 Et.cal. to improve the road quality furhter .The modern road construction era has started during the reigm of Emperor Haile silassie. Public works department was established and their major tasks were to construct roads through out addis and to other regions.

It was since 1942 E.C. that road maintenance and rehabilitation duty within Addis Ababa was made to be the responsibility of the Roads and Building Department of the Addis Ababa municipality. However, the municipality was unable to cope up with its maintenance duties due to lack of resource particularly experienced personnel in the field of road construction [2].

The maintenance and rehabilitation operation was at a very bad condition when a new city organization formed in 1981 E.C. This new organization had created three administrative levels namely the Kebele Urban Dwellers Association (UDA), Higher UDA and Central UDA. Each of the three Administrative levels was responsible for the city roads construction, maintenance and rehabilitation without proper coordination and clear division of work. No proper engineering work was done in advance or during construction of a kebele road. The road construction and maintenance division was not even consulted during preparation of the annual program leave alone making of proper pavement evaluation and site investigation. Little attention was given to drainage and pedestrian walk ways [3].

The Addis Ababa city road adminstration responsibility had been influenced by the city inconsistant growth for about a centurey ,solely the city structural foundation adminstration could be held responsible for the unsustainable road construction and maintenace growth . this was a major step for addis ababa city development beraue to be established as an Authority.These were the first major step taken by the city adminstration to resolve all the problemes related to road construction and maintenace.

The newly established road department constructed and maintained the city roads till the establishment of the Addis Ababa City Roads Authority in March 15, 1998 by regulation No. 7/199 to be administrated by board of directors to construct maintain and administer the road works in Addis Ababa, by the city Administration [3].

1.3. Statement of the problem

The general objectives of roadway pavement maintenance are to provide a safe roadway surface, preserve the state's capital investments in the pavement and to maintain a riding quality satisfactory to the traveling public. Maintenance is intended to slow down this deterioration and should begin on the first day after the road improvement works are completed. In practice the effect of regular and timely maintenance is to increase the life of the road by putting off the date at which it needs to be reconstructed.

Now a day's AACRA is engaged in increasing Addis Ababa city road coverage to reach 25% within 2012 E.C [4]. The question is what to do after the ribbon has been cut and start functioning. AACRA carries out road maintenance activities every year after evaluating roads of the city. But the maintenance is not conducted properly; out of the classified 4,900 km of the road net work only 56% of the roads are reported as good [5]. So the increasing the road coverage and preserving the existing pavement condition shall be done simultaneously to increase the life of the road.

1.4. Objective of the Study

The main objective of this research is to assess the present AACRA'S road maintenance strategy and maintenance management in Addis Ababa City Roads, scientific and international experience in managing asphalt maintenance. It investigates how to improve road maintenance and pavement management practice in Addis Ababa City Roads Authority (AACRA). To achieve the aim, the following are major tasks to be performed during undergoing the case study.

1. Review maintenance, rehabilitation and pavement management process in different literatures and international practice exhaustively as possible.
2. Investigate current maintenance, rehabilitation and pavement management procedure of AACRA.
3. Compare the international practice with AACRA'S experience and forward recommendations based on the findings.

1.5. Scope of Study

The scope of this research is focused on AACRA'S asphalt pavement maintenance and maintenance management in Addis Ababa City Roads.

1.6. Research Methodology

a) Literature review: international scientific maintenance, rehabilitation and pavement approaches for the maintenance of major asphalt failures.

b) **Data Collection:** uses primary data this includes record review, interview, questionnaire and secondary such as literature, reference books, news- paper, internet and conference papers**.**

c) **Analysing the findings:** findings of case study is analysed in relation using descriptive statistics method of analysis.

d) **Conclusion and Recommendation:** concluding the research findings, and drawing recommendations.

Chapter- 2

Literature Review

2.1. Introduction

The purpose of literature review was to study the theoretical background on Road Maintenance Management System through the journals, books, references, internet and articles. This chapter investigates the causes of pavement deterioration, pavement evaluation, pavement maintenance, road maintenance process, Road Maintenance Management System and road maintenance experience of other countries. This investigation is important as it provides baseline for evaluation of present AACRA'S road maintenance and management practice by assessing different scientific principles and international experience around the world.

2.2. Functions of a pavement

Pavement is the actual travel surface especially made durable and serviceable to withstand the traffic load commuting upon it. According to South African National Roads Agency, the primary functions of a pavement are to [6]:

a) ***Provide a reasonably smooth riding surface***: A smooth riding surface (Low Roughness) is essential for riding comfort, and over the years it has become the measure of how road users perceive a road.

b) ***Provide adequate surface friction (skid resistance)****:* In addition to a riding comfort, the other road user requirement is that of safety. Safety, especially during wet conditions can be linked to a loss of surface friction between the tyre and the pavement surface.

c) ***Protect the subgrade***: The supporting soil beneath the pavement is commonly referred to as the subgrade, should it be over-stressed by the applied axle loads it will deform and lose its ability to properly support these axle loads. Therefore, the pavement must have sufficient structural capacity (strength and thickness) to adequately reduce the actual stresses so that they do not exceed the strength of the subgrade.

d) ***Provide waterproofing***: The pavement surfacing acts as a waterproofing surface that prevent the under laying support layers including the subgrade from becoming

saturated through moisture ingress. When saturated, soil loses its ability to adequately support the applied axle loads, which will lead to premature failure of the pavement.

Pavement grants friction for the vehicles thus providing comfort to the driver and transfers the traffic load from the upper surface to the natural soil. Pavements usually fall into two broad categories namely flexible and rigid pavements [7].

2.3. Types of pavement

Pavements are typically divided into the following three general categories: flexible, rigid and unpaved (gravel or dirt) [8]. For the purpose of this document only flexible and rigid pavements are discussed.

Flexible Pavement: usually asphalt, is laid with no reinforcement or with a specialized fabric reinforcement that permits limited flow or repositioning of the roadbed underground changes.

Rigid Pavement: are made of cement concrete plain, reinforced or prestressed concrete. Rigid characteristic of the pavement are associated with rigidity or slab action so that the load is distributed over a wide area of subgrade soil.

From the paved roads in Addis Ababa town, rigid pavement construction is limited whereas the majority of pavements are Flexible pavements. Therefore, focus will be concentrated on flexible pavements maintenance. Flexible pavements comprised of several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layers underneath [8, 9].

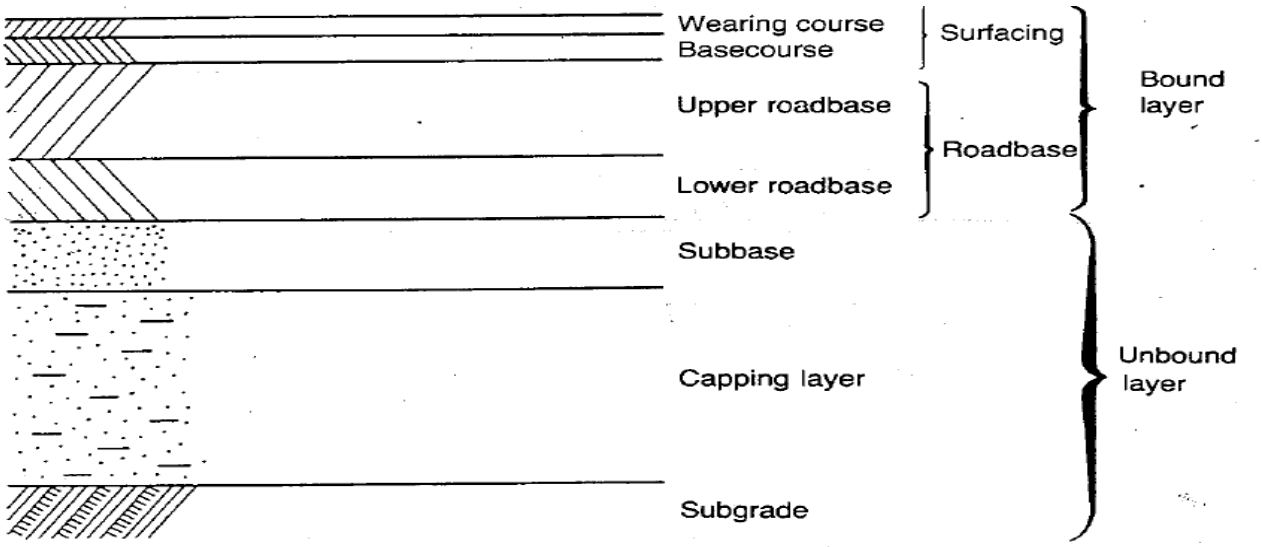


Figure 1.1 Layers within a typical flexible highway pavement [8].

Surfacing - This is the uppermost pavement layer and will normally consist of a bituminous surface dressing or a layer of premixed bituminous material. Where premixed materials are laid in two layers, these are referred to as the wearing course and binder course.

Roadbase -This is the main load-spreading layer of the pavement. It will normally consist of crushed rock or gravel, or of gravel soils, decomposed rock, sands and sand-clays stabilized with cement, lime or bitumen.

Sub-base - This is the secondary load-spreading pavement layer underlying the roadbase. It will normally consist of a material of lower quality, than that used for the roadbase, such as unprocessed natural gravel, gravel-sand or gravel-sand-clay. This layer also serves as a separating layer preventing contamination of the roadbase by the subgrade material and, under wet conditions; it has an important role to play in protecting the subgrade from damage by construction traffic.

Capping Layer - (Selected or improved subgrade) - where very weak soils are encountered, a capping layer is sometimes necessary. This layer may consist of better quality subgrade

material imported from elsewhere or existing subgrade material improved by mechanical or chemical stabilization.

Subgrade - This is the upper layer of the natural soil which acts as the pavement foundation. It may be undisturbed local material or may be soil excavated from elsewhere and placed as fill. In either case it is compacted during construction to give added strength.

2.4. Causes of Road Deterioration

Road deterioration is caused by the effects of the physical environment, traffic, material properties, quality of road construction, design standards and the age of the pavement. The details are discussed in the following paragraphs.

2.4.1. Environmental Factors

Climatic factors such as rain water, solar radiation, temperature, soil type and terrain may cause roads to deteriorate. Rain water can alter the moisture balance in the sub grade of a road with clayey and silty soils. This may cause swelling and shrinkage resulting in reflective cracking and heaving in the road surface. Sunlight may cause a continuous, slow hardening action on bituminous surfaces. This can increase the cracking process of the surface chip seal. Seasonal changes in temperature or night and day temperatures may cause expansion and contraction of the carriage way. This may progressively cause fatigue, failures and reflective cracks in the road surface [10].

2.4.2. Traffic Volume and Loading

Roads are structures basically built to carry and sustain vehicular loads. Therefore traffic is an important factor that influences pavement performance. The impact of traffic on the deterioration of pavements is caused by vehicle loads and volume. Every vehicle, which passes over a road, causes a momentary but significant deformation in the road structure. This is determined by the magnitude of each of its axle loads, the spacing between the axles, the number of wheels, the contact pressures of the tyres and the travelling speed. The passage of many vehicles has a cumulative effect which causes repeated flexing of the pavement leading to fatigue, crazing and structural failure [11].

2.4.3. Material Properties and Composition

The choice of materials used for the construction of pavement layers may also cause road deterioration. This is due to inherent variability in the materials used for road construction in terms of soil properties such as strength or load bearing capacity, gradation, mix properties, elastic and resilience modulus. Poor choice of materials used for pavement layers can have a drastic effect on the strength of the layers and their subsequent performance [10].

2.4.4. Construction Quality

The quality of road construction if not built to the desired specifications can also facilitate road deterioration. For example, failure to obtain proper compaction, improper moisture conditions during construction, poor quality of materials and inaccurate layer thickness (after compaction) all directly affect the performance of a pavement [10].

2.4.5. Road Maintenance Standards

The rate of pavement deterioration is directly affected by the maintenance standards applied to repair road defects. When a maintenance standard is defined it imposes a limit to the level of deterioration that a pavement is allowed to attain. Low maintenance standard therefore causes roads to deteriorate at a faster rate, [10].

2.4.6. Age of Pavement

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 [12].

2.5. Pavement Distresses

The deterioration of a 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

understood, and the cause of the distress must be identified. Generally, pavement distresses are fall into one of the following categories [13].

The four major categories of common asphalt pavement surface distresses are:

A. Cracking

B. Surface deformation

C. Disintegration (potholes, etc.)

D. Surface defects (bleeding, etc.)

A. Cracking

Cracks in flexible pavements are caused by deflection of the surface over an unstable foundation, shrinkage of the surface, thermal expansion and contraction of the surface, poorly constructed lane joints or reflection cracking. The following are examples of cracks that may occur in flexible pavements [13];

1. Fatigue cracking (Alligator cracking)

Fatigue cracking is commonly called alligator cracking. This is a series of interconnected cracks creating small, irregular shaped pieces of pavement. The cracking pattern gives the appearance of alligator skin or chicken wire.

It is caused by failure of the surface layer or base due to repeated traffic loading (fatigue). Eventually the cracks lead to 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 area repair. Larger areas require reclamation or reconstruction. Drainage must be carefully examined in all cases.

2. Longitudinal cracking

Longitudinal cracks are long cracks that run parallel to the center line of the roadway. These may be caused by frost heaving or joint failures or they may be load induced. Understanding the cause is critical to selecting the proper repair. Multiple parallel cracks

may eventually form from the initial crack. This phenomenon, known as deterioration, is usually a sign that crack repairs are not the proper solution.

Filling or sealing longitudinal cracks can work if the cracks are narrow and not deteriorated too much. Multiple cracks may require patching or area repairs to fix the problem.

3. Transverse cracks

Transverse cracks form at approximately right angles to the centerline of the roadway. They are regularly spaced and have some of the same causes as longitudinal cracks. Transverse cracks will initially be widely spaced. They usually begin as hairline or very narrow cracks and widen with age. If not properly sealed and maintained, secondary or multiple cracks develop, parallel to the initial crack.

The reasons for transverse cracking, and the repairs, are similar to those for longitudinal cracking. In addition, thermal issues can lead to low-temperature cracking if the asphalt cement is too hard.

4. Block cracking

Block cracking is an interconnected series of cracks that divides the pavement into irregular pieces. This is sometimes the result of transverse and longitudinal cracks intersecting. They can also be due to lack of compaction during construction.

Low severity block cracking may be repaired by a thin wearing course. As the cracking gets more severe, overlays and recycling may be needed. If base problems are found, reclamation or reconstruction may be needed.

5. Slippage cracking

Slippage cracks are half-moon shaped cracks with both ends pointed towards the oncoming vehicles. They are created by the horizontal forces from traffic. They are usually a result of poor bonding between the asphalt surface layer and the layer below. The lack of a tack coat

is a prime factor in many cases. Repair requires removal of the slipped area and repaving. Be sure to use a tack coat in the new pavement.

6. Reflective cracking

Reflective cracking occurs when a pavement is overlaid with hot mix asphalt concrete and cracks reflect up through the new surface. It is called reflective cracking because it reflects the crack pattern of the pavement structure below.

As expected from the name, reflective cracks are actually covered over cracks reappearing in the surface. They can be repaired in similar techniques to the other cracking noted above. Before placing any overlays or wearing courses, cracks should be properly repaired.

7. Edge cracking

Edge cracks typically start as crescent shapes at the edge of the pavement. They will expand from the edge until they begin to resemble alligator cracking. This type of cracking results from lack of support of the shoulder due to weak material or excess moisture. They may occur in a curbed section when subsurface water causes a weakness in the pavement.

At low severity the cracks may be filled. As the severity increases, patches and replacement of distressed areas may be needed. In all cases, excess moisture should be eliminated, and the shoulders rebuilt with good materials.

B. Surface deformation

Pavement deformation is the result of weakness in one or more layers of the pavement that has experienced movement after construction. The deformation may be accompanied by cracking. Surface distortions can be a traffic hazard [13].

The basic types of surface deformation are: Rutting, Corrugations, Shoving, Depressions and Swell.

1. Rutting

Rutting is the displacement of pavement material that creates channels in the wheel path. Very severe rutting will actually hold water in the rut. Rutting is usually a failure in one or more layers in the pavement. The width of the rut is a sign of which layer has failed. A very narrow rut is usually a surface failure, while a wide one is indicative of a subgrade failure.

Inadequate compaction can lead to rutting. Minor surface rutting can be filled with micropaving or paver-placed surface treatments. Deeper ruts may be shimmed with a truing and leveling course, with an overlay placed over the shim. If the surface asphalt is unstable, recycling of the surface may be the best option. If the problem is in the subgrade layer, reclamation or reconstruction may be needed.

2. Corrugation

Corrugation is referred to as washboarding because the pavement surface has become distorted like a washboard. The instability of the asphalt concrete surface course may be caused by too much asphalt cement, too much fine aggregate, or rounded or smooth textured coarse aggregate. Corrugations usually occur at places where vehicles accelerate or decelerate.

Minor corrugations can be repaired with an overlay or surface milling. Severe corrugations require a deeper milling before resurfacing.

3. Shoving

Shoving is also a form of plastic movement in the asphalt concrete surface layer that creates a localized bulging of the pavement. Locations and causes of shoving are similar to those for corrugations.

Repair minor shoving by removing and replacing. For large areas, milling the surface may be required, followed by an overlay.

4. Depressions

Depressions are small, localized bowl-shaped areas that may include cracking. Depressions cause roughness, are a hazard to motorists, and allow water to collect. Depressions are

typically caused by localized consolidation or movement of the supporting layers beneath the surface course due to instability.

Repair by excavating and rebuilding the localized depressions. Reconstruction is required for extensive depressions.

5. Swell

A swell is a localized upward bulge on the pavement surface. Swells are caused by an expansion of the supporting layers beneath the surface course or the subgrade. The expansion is typically caused by frost heaving or by moisture. Repair swells by excavating the inferior subgrade material and rebuilding the removed area. Reconstruction may be required for extensive swelling.

C. Disintegration

The progressive breaking up of the pavement into small, loose pieces is called disintegration. If the disintegration is not repaired in its early stages, complete reconstruction of the pavement may be needed. The two most common types of disintegration are [15]:

1. Potholes
2. Patches

1. Potholes

Potholes are bowl-shaped holes similar to depressions. They are a progressive failure. First, small fragments of the top layer are dislodged. Over time, the distress will progress downward into the lower layers of the pavement. Potholes are often located in areas of poor drainage, as seen. 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 development of the pothole. Repair by excavating and rebuilding. Area repairs or reconstruction may be required for extensive potholes.

2. Patches

A patch is defined as a portion of the pavement that has been removed and replaced. Patches are usually used to repair defects in a pavement or to cover a utility trench. Patch failure can lead to a more widespread failure of the surrounding pavement. Some people do not consider patches as a pavement defect. While this should be true for high quality patches as is done in a semi- permanent patch, the throw and roll patch is just a cover. The underlying cause is still under the pothole.

To repair a patch, a semi-permanent patch should be placed. Extensive potholes may lead to area repairs or reclamation. Reconstruction is only needed if base problems are the root source of the potholes.

D. Surface defects

Whereas the previous types of distress are mostly related to the supporting layers beneath the surface, surface defects are related to problems in the surface layer. The most common types of surface distress are [13]: Ravelling , Bleeding, Polishing, Delamination

1. Ravelling

Ravelling is the loss of material from the pavement surface. It is a result of insufficient adhesion between the asphalt cement and the aggregate. Initially, fine aggregate breaks loose and leaves small, rough patches in the surface of the pavement. As the disintegration continues, larger aggregate breaks loose, leaving rougher surfaces. Ravelling can be accelerated by traffic and freezing weather. Some ravelling in chip seals is due to improper construction technique. This can also lead to bleeding. Repair the problem with a wearing course or an overlay.

2. Bleeding

Bleeding is defined as the presence of excess asphalt on the road surface which creates patches of asphalt cement. Excessive asphalt cement reduces the skid-resistance of a pavement, and it can become very slippery when wet, creating a safety hazard. This is caused by an excessively high asphalt cement content in the mix, using an asphalt cement with too low a viscosity (too flowable), too heavy a prime or tack coat, or an improperly applied seal coat. Bleeding occurs more often in hot weather when the asphalt cement is

less viscous (more flowable) and the traffic forces the asphalt to the surface. In some cases, a repair can be made by applying hot sand or slag to blot up the excess asphalt. This is a very difficult problem to solve. It sometimes requires removing the bleeding pavement and placing a new surface. A thin wearing course will only solve the problem temporarily. The bleeding asphalt will eventually work its way upward.

3. Polishing

Polishing is the wearing of aggregate on the pavement surface due to traffic. It can result in a dangerous low friction surface. A thin wearing course will repair the surface.

4. Delimitation

Delimitation is a failure of an overlay due to a loss of bond between the overlay and the older pavement. Common causes of delimitation include: wet or dirty surface during paving of the overlay, failure to use a tack coat, or poor compaction of the overlay. Proper paving techniques, including cleaning the surface and use of tack coat, will reduce the chances of delimitation.

2.6. Pavement Failure

A failure of a flexible pavement is a complex phenomenon because it is an outcome of a series of interacting process. It may occur as a result of pavement deterioration due to accumulation of distresses. Distinction will be made between two different types of pavement failure: structural and functional [16].

***Structural failure*:** includes a collapse of the pavement structure or a breakdown of one or more of the pavement components that makes the pavement incapable of sustaining the loads upon its surface.

Functional failure: may or may not be accompanied by the structural failure but the pavement will not carry out its intended function without causing discomfort to passengers and vehicles. The functional failure causes distress in pavement surface resulting in cracks, depressions, rut formation and poor riding quality [17].

2.7. Pavement Evaluation

The purpose of pavement evaluation is primarily to determine why the present pavement prevails so that the appropriate rehabilitation measures can be identified. Pavement evaluation involves detailing appropriate methods for pavement investigations, relating the symptoms of distress to their cusses and design using appropriate design methods [18].

Since pavement rehabilitation costs continue to increase, making it essential to have fast, reliable methods to accurately determine a pavement's condition. When a pavement's condition begins to show deficiencies, the development of certain types of surface distress appears. After the pavement management inventory has been created and all the data has been collected for each segment, pavement condition evaluation can begin.

In Washington, there are three methods for determining pavement condition [19].

a) ***Visual rating***: none destructive testing (NDT), and destructive testing. The visual rating method is most commonly used. Most agencies are gathering information on their pavements based on a visual survey. However, the extent to which they gather the data varies [19]. Ideally, for any given section of highway, two or more evaluators would arrive at the same assessment of the section's current condition. However, there are still many aspects of pavement evaluation that are highly subjective. For example, in visual condition surveys, the percent of surface area affected by alligator cracking is highly dependent upon the visual acuity of the evaluator. Progress continues in automating the mapping of common surface distress to eventually eliminate this subjectivity [20].

b) ***None destructive testing (NDT)***: method is generally used in the for project level information to enhance visual ratings. NDT enables an agency to identify problems, examine their extent, and solve them effectively. It can provide sufficient information to determine a pavement's structural load-carrying capacity, and it can be used to determine the overlay thickness required to support future expected traffic. NDT can also provide measurements of the overall pavement structural

response to an external force or load without disturbing or destroying the pavement components.

Among different nondestructive testing devices which are commonly used to evaluate on-site properties of pavement are Road Rater, Falling weight deflectometer etc. These devices operate by measuring the pavement response to an imposed force. The response is generally in terms of surface deflections at one or more points on the pavement. The following are some advantages that NDT has over destructive testing methods [19]:

- Provides on-site information about physical properties of the pavement
- It does not damage the pavement and minimizes laboratory tests.
- NDT can be accomplished in a timely and efficient manner.

C*) Destructive testing (DT)*: It is primarily used to support design analysis in identifying roadway makeup, reasons the roadway failed, and solutions for improving the roadway. It provides more detailed data about the pavement not possible to obtain through non-destructive testing. Such detailed data include [20]:

- Laboratory mechanical, physical, and chemical properties (obtained through coring, Shelby tubes, and trenching), and
- Visual inspection of pavement layers through coring and trenching.

Four characteristics of pavement condition are usually objectively measured to evaluate pavement performance and need for rehabilitation. These measurable characteristics are [21]:

- ***Functional evaluation*** -pavement roughness (rideability);
- ***Structural evaluation*** - pavement deflection, cores and test pits;
- ***Surface condition evaluation*** - pavement distresses; and
- ***Safety evaluation*** - skid resistance.

2.7.1. Functional evaluation

Functional evaluation of highways is primarily concerned with the ride quality or surface texture of a highway section. Pavement roughness is defined as an expression of irregularities in the longitudinal profile of its surface that adversely affects the ride quality of a vehicle, thus causing discomfort to the user. Smoother roads are required because they provide comfort and safety to road users, reduce vehicle operating cost by reducing fuel and oil consumption, tire wear, maintenance cost and vehicle depreciation, and reduce pavement maintenance cost. Smooth roads result in less dynamic loading from truck traffic, which reduces pavement distresses thus resulting in less maintenance and lower life cycle cost. Therefore, it is expected that smoother roads will last longer.

Evaluation of the surface condition is done by the ruts, potholes, cracks, patches and uneveness of the pavement surface. Various equipments useful in the functional evaluation pavement are Uneveness Indicator, Profilograph, Roughmeter, Bump Indicator and others. Methods of functional evaluation are:

1. Uneveness Index

The numerical Uneveness Index of the surface in cm/km length of road is useful in deciding riding quality of road. Uneveness Index values below 95 indicate excellent riding quality and above 240 indicate very poor riding quality for roads. Table 2.1 gives recommended Uneveness Index [22].

Table 2.1: Recommended Unevenness Index for New and Old Pavements [22].

Uneveness Index (cm/km)	**Riding Quality**
For New Pavement	
Below 120	Good(Acceptable)
120-145	Fair (Acceptable)
Above 145	Poor (Not acceptable)
For Old pavements	
Below 95	Excellent
95-119	Good
120-144	Fair
145-240	Poor (Possible Resurfacing)
Above 240	Very Poor(resurfacing required)

2. Present Serviceability Index (PSI)

The Present Serviceability Index Concept was first presented by Carey and Irick. It is based upon the concept of correlating user opinions with measurements of road roughness (as measured by the roughmeter or profilometer), cracking, patching and rutting. Pavements were rated on a scale runs from 0 to 5, where 0 – 1 indicated a pavement in a very poor condition, 1 – 2 was a poor condition, 2 – 3 was fair, 3 – 4 was good and 4 – 5 was very good. The average of the rating numbers for each section was termed the Present

Serviceability Rating (PSR) of the section (8, 10). The original serviceability equation for flexible pavements as developed on the AASHTO Road Test is shown below:

$$PSI=5.03 –1.9\ Log\ (1+SV) – 0.01\sqrt{C+p –1.3\ RD^2} \qquad \text{[Eq.2-1]}$$

Where PSI = Present Serviceability Index (Pt)

SV = Mean slope variance. (measured by Slope Profilometer Instrument) Assesses
. Surface irregularity.

C = Linear feet of major cracking per 1000 ft^2 area

P = Bituminous patching in ft2 per 1000 ft^2 area

RD = Rut Depth in inches (both wheel tracks) measured with a 4 ft straight edge

2.7.2 Structural evaluation

Pavement structural evaluation is concerned with the structural capacity of the pavement as measured by deflection, layer thickness, and material properties. It is used to obtain information on the load-bearing capacity for both roads and airports to evaluate the need for maintenance and rehabilitation, asset pavement evaluation, and construction quality control. Structural adequacy is the primary response of pavement to transient loads and consists in deflections, stresses, strains and pavement deformation at critical points in pavement layers. Evaluation techniques may include [17]:

California Bearing Ratio (CBR)

It is possible to obtain an estimate of the strength of a subgrade from original California Bearing Ratio tests that were made prior to the original design. However, densification of the road under traffic and environmental factors often make these estimates unreliable. It is possible to perform in-place field CBR tests.

Plate-Bearing Tests

Plate-Bearing tests can be made on individual components of the pavement for the purpose of determining modulus of deformation as well as the modulus of subgrade reaction. They require test pits of substantial size be dug and hence, is time consuming and often expensive.

Laboratory Tests

In the evaluation of any pavement structure, it is necessary to perform standard laboratory tests for quality of the pavement components. These tests include grain-size distribution, density and moisture content. In addition, cores may be obtained of the pavement and properties can be determined by use of split tensile tests, compression tests and other laboratory tests.

The Benkelman Beam (BB)

The beam was developed by A.C. Benkelman. The deflections are recorded by means of a dial placed at one end of the beam; the deflection is measured by means of the deflection dial. The deflections are measured relative to the reference points. The BB is desired that the pointer can be placed between the dual tires of a set of duals. Generally, the measured values are the rebound of the pavement upon removal of the load. BB measurements are taken as follows: first, the pointer of the beam is placed between the dual tires of a loaded truck over the point that is to be measured. After the dials are zeroed, the truck is driven from the location and the amount of pavement rebound is recorded as the deflection. An 18000-pound single axle is used on the test trucks. The BB principle has been mechanized

so that a large number of readings can be obtained by continuous reading of deflection under a loaded axle.

The Falling Weight Deflectometer

Falling Weight Deflectometer (FWD) device has gained acceptance as the most efficient deflection testing due to its ability to perform rapid testing, causes no damage to the pavement, simulates actual traffic wheel loading over a large range, including very heavy loads, and its results are satisfactory [23]. The test basically involves a mass that is lifted to a predetermined height and released. The mass falls free, guided by a vertical rod, and impacts on a spring shock system resting on the pavement. The magnitude of force and duration of impulse on the pavement can be controlled by changing the height of drop and the rate of deceleration.

A circular plate transmits the load caused by the decelerating mass to the pavement and the deflection of the pavement is recorded. The data obtained with the FWD is essentially the same as that obtained by using the Benkelman beam and a loaded wheel, which is the value of deflection under a specified load. This data is then used in determination of bearing strength, residual life and overlay design.

2.7.3. Surface condition evaluation

Pavement condition refers to the condition of the pavement surface in terms of its general appearance. A perfect pavement is leveled and has a continuous and unbroken surface, while a distressed pavement may be fractured, distorted, or disintegrated. In order to obtain a useful condition assessment of the pavements, unbiased and repeatable survey procedures must be used.

The most common survey technique used in the US and World Wide is the Pavement Condition Index (PCI) procedure developed by the US Army Corps of Engineers. The condition of the pavements is determined by a field survey of the surface operational condition of all pavements using this procedure. The PCI - a measure of the pavement's

surface operational condition and ride quality on a scale of zero to 100, with 100 being excellent. Figure 2.1. illustrates Pavement Condition Index ratings[24].

Figure 2.1. Pavement Condition Index ratings [24]

2.7.4. Safety evaluation

Surface friction or skid resistance is considered a safety characteristic of the pavement surface layers. Skid resistance is a measure of the resistance of pavement surface to sliding or skidding of the vehicle. It is a relationship between the vertical force and the horizontal force developed as a tyre slides along the pavement surface. Therefore, the texture of the pavement surface and its ability to resist the polishing effect of traffic is of prime importance in providing skidding resistance.

The British Pendulum Tester, available at the RCP, is one of the commonly used equipment in evaluating road surface friction. The device includes a pendulum on which a rubber slider is mounted, then raised into position and released. The slider contacts the surface at the end of the downswing. At the end of the upswing, a pointer indicates a British Pendulum Number (BPN), which is related to the distance that the slider travels. The procedure (ASTM E303) is performed on a cleaned and wetted pavement surface.

2.8. Pavement Maintenance

Pavement maintenance work is performed from time to time to keep a pavement, under normal conditions of traffic and forces of nature, as nearly as possible in its as-constructed condition. [9]. It is the art of keeping pavements in full service, with minimum expenses,

and the least inconvenience to the public and the residence. Improper maintenance is usually worse than none at all. No pavement has been constructed that does not need maintenance. Many community associations find out too late that proper maintenance could have prevented costly replacements [25].

The purpose of maintenance is to ensure that the road remains serviceable throughout its design life. Maintenance is important because it [2]:

- Prolongs the life of the road by reducing the rate of deterioration ,thereby safeguarding previous investments in construction and rehabilitation,
- lowers the cost of operating vehicles on the road by providing a smooth running surface
- keeps the road open for traffic and contributes to more reliable transport services
- Sustains social and economic benefits of improved road access.

2.8.1 Maintenance Types

Three types of pavement maintenance operations generally recognized Figure 2.2 are the following [25].

A. Preventive Maintenance: Performed to improve or extend the functional life of a pavement. It is a strategy of surface treatments and operations intended to retard progressive failures and reduce the need for routine maintenance and service activities.

B. Corrective Maintenance: Performed after a deficiency occurs in the pavement, such as loss of friction, moderate to severe rutting, or extensive cracking. May also be referred to as “reactive” maintenance.

C. Emergency Maintenance: Performed during an emergency situation, such as a blowout or severe pothole that needs repair immediately. This also describes temporary treatments designed to hold the surface together until more permanent repairs can be

performed. Figure 2.2. Illustrates the differences among these three Categories of Pavement Maintenance operations. As indicated on the graph, the main difference is the condition of the pavement when the treatment is applied.

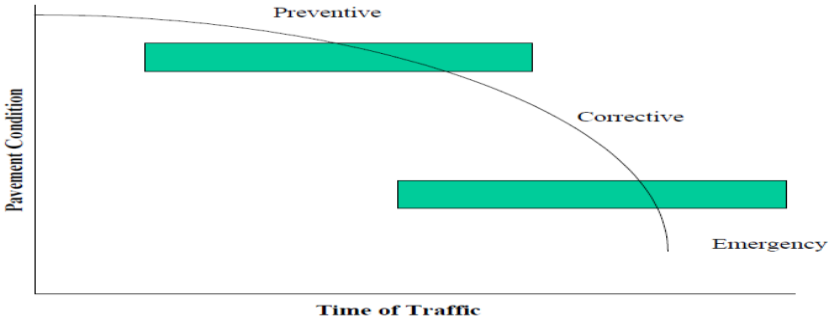


Figure 2.2. Categories of Pavement Maintenance [25].

Based on their required frequency, forms of maintenance can also be categorized to "routine", "recurrent", "periodic" and "urgent", [9].

a) Routine maintenance: required continually, whatever its engineering characteristics or traffic volume. Example - grass cutting; drain clearing; recutting ditches; culvert maintenance; road signs maintenance.

b) Recurrent maintenance: required at intervals during the year with a frequency that depends on the volume of traffic using the road. Example - repairing pot-holes; patching; repairing edges; sealing cracks.

c) Periodic maintenance: are repairs that carried out less frequent are considered periodic maintenance. Periodic maintenance includes all sorts of repairs including resurfacing, overlays, and reconstruction of pavement, base and even subbase course. Periodic maintenance intervals vary according to the needs and may be irregular. The intervals depend to a large extend on the quality of the construction. Example – resealing (surface dressing, slurry sealing, fog spray, etc.); regravelling shoulders and road surface marking. [9, 26].

d) Urgent maintenance: maintenance activities that have to carried out immediately to safe lives or prevent disastrous consequences of damaged infrastructure. Needed to deal with emergencies and problems calling for immediate action when a road is blocked. Example - removal of debris and other obstacles; placement of warning signs and diversion works. [9, 26].

2.8.2. Maintenance Strategies

The deterioration process continues up to a point where maintenance intervention is applied to remove the defects. Then the cycle repeats itself until the road reaches the end of its service life known as terminal serviceability where it is reconstructed. Road maintenance intervention delays the rate of total failure until the pavement reaches the end of its design life. The process is referred to as the road deterioration cycle [11] and it is illustrated in Figure 2.3.

To minimize the deterioration process and maintain the road with in the acceptable standard limit, engineering studies have determined that there are preferred strategies for the different levels of deterioration. As a pavement ages and the amount of deterioration increases, the strategy changes. When the pavement is in a good condition, relatively inexpensive preventive maintenance treatments are cost-effective. When the pavement reaches the end of its design life, expensive reconstruction will be necessary.

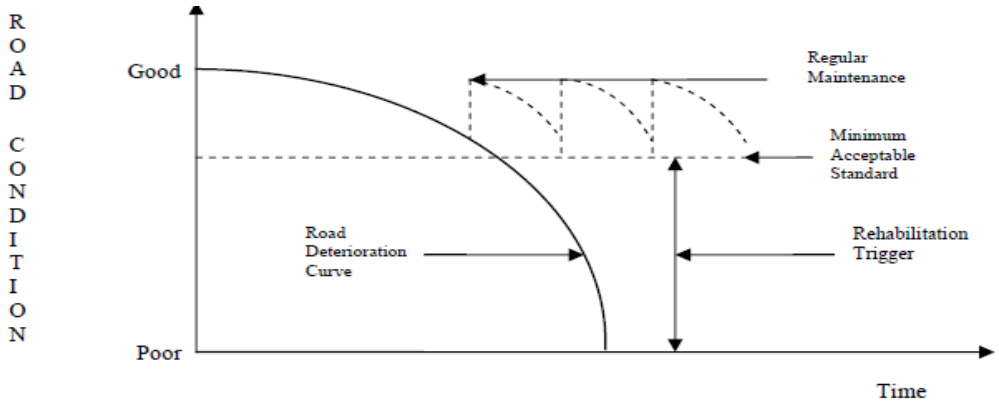


Figure 2.3: Pavement Deterioration Curve [11].

A. Preventive maintenance:

Preventive maintenance is designed to preserve the investment in pavements, extend pavement life, enhance pavement performance, and reduce user delays. It includes corrective and preventive maintenance and minor rehab, and is often used to repair environmental damage. [10]. It is typically applied to pavements in good condition having significant remaining service life. Preventive maintenance is a strategy of extending the service life by applying cost-effective treatments to the surface or near-surface of structurally sound pavements [27]. Examples of preventive treatments that can be considered for road surfaces are [28]:

1. Routine Patching

Isolated responses to minor pavement failure caused by subgrade problems or poor pavement construction. This includes filling potholes, covering trenches dug for utility work and other miscellaneous repair.

2. Crack Sealing

Placement of an asphalt sealing material in major cracks to prevent moisture from entering the pavement and causing potholes or street failure.

3. Slurry Seal

Spreading a very thin layer of asphalt/sand/small aggregate mixture over the pavement to reduce moisture penetration, improve skid resistance and slows the rate of deterioration. It extends the pavement life by 3 – 5 years.

4. Cape Seal

Liquid asphalt sprayed on pavement followed with a layer of small stone chips followed 1 week later with a slurry seal to reduce moisture penetration. This method can also be utilized with a rubberized asphalt mixture which improves its long term performance. It extends the pavement life by 5 – 7 years. Slurry seals are generally applied to roads

surfaces that are basically in a good condition but cape seals are applied to roads that have at least a fair condition rating.

B. Pavement Rehabilitation:

Pavement rehabilitation consists of "structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity ". Rehabilitation techniques include restoration treatments and structural overlays. Rehabilitation projects extend the life of existing pavement structures either by restoring existing structural capacity through the elimination of age-related, environmental cracking pavement surface or by increasing pavement thickness to strengthen existing pavement sections to accommodate existing or projected traffic loading conditions [27].

The preferred rehabilitation strategy should consider cost-effectiveness, repair of the specific problems of the existing pavement, prevention of future problems, meeting all existing constraints of the project [20]. Strategies may include [28, 29]:

1. Pavement Overlay

Adding a new layer of hot-mix asphalt to the existing pavement reduces moisture content, improves skid resistance and restores pavement surface to like new condition. It extends the pavement life by 10 years.

2. In-Place Cold Recycling

It is a process with specialized equipment that grinds and removes several inches of the existing pavement surface, mixes it with a rejuvenating agent and new asphalt binder and places it back on the road. This is followed later with a thin overlay surface, improves skid resistance and restores pavement surface to like new condition.

3. Reconstruction

It occurs by removing the existing pavement and base and installing an entire new road section. This strategy is a last resort because of the high cost and disruption to traffic. Reconstructed pavements are designed to a 20 –year design period.

2.8.3. Maintenance treatment selection techniques

There are many factors that are considered in the process of selecting an appropriate treatment for a pavement. These include pavement age, condition, traffic levels, expected future plans, as well as available funding and agency policy. At the network level, a general relationship exists between pavement condition and pavement age. For a properly constructed new pavement, the only treatments that are required are preventive maintenance (maintenance performed to delay the onset of distress). Then, as the pavement ages, it may become a candidate for routine maintenance (crack sealing or chip sealing), rehabilitation and eventually reconstruction. The first step in selecting the appropriate maintenance treatment is determining, based on the life cycle and pavement condition index of the existing pavement [30].

Once an appropriate maintenance strategy has been chosen, a specific treatment is selected to address the specific distress mechanism for the pavement. The most important factors to consider when choosing a maintenance treatment include [30]:

a) Will the treatment address the distresses present? (i.e., Will it work?)
b) Can the required preparation for the treatment be carried out?
c) Is the treatment cost effective?
d) Will the treatment be performed before the situation being addressed changes?

Remedial measures for different types of distress severity are shown in Table 2.2. As an example, rutting distress requires shallow patching when its severity is medium but deep patching is required when it is high.

Table 2.2: Remedial Measures for Different Types of Distress Severity [31]

ID	Distress Type	Distress Severity (Density)		
		Low	Medium	High
1	Alligator Cracking	X3	X1	X1
2	Block Cracking	X3	X3	X3
3	Edge Cracking	X3	X3	X1
4	Reflection Cracking	X3	X3	X1
5	Slippage Cracking	X1	X1	X1
6	Longitudinal and Transverse Cracking	X3	X3	X1
7	Corrugation and Shoving	-	X1	X1
8	Depression	-	X2	X2
9	Rutting	-	X1	X2
10	welling	-	X2	X2
11	Utility Cut Patching	-	X1	X1
12	Potholes	X1	X1	X2
13	Raveling	-	X4	X4
14	Bleeding	-	X5	X5
X1 = Shallow Patching X2 = Deep Patching X3 = Sealing		X4 = Overlaying X5 = Spreading and rolling fine gravel aggregate		

Table 2.3 shows the suggested pavement maintenance treatment according to the *PCI* condition evaluation of the network segments. When *PCI* of a segment ranges between 70 and 100 (condition is excellent or very good), routine maintenance including small patching and crack sealing is required while reconstruction is needed for segments of failed or very poor condition.

Table 2.3: Suggested Pavement Maintenance Treatment versus PCI Ranges [31].

PCI Range	Pavement Condition	Condition Class	Suggested Maintenance
70 – 100	Excellent / Very good	I	Routine Maintenance (RM)
55 – 70	Good / without effect of loads	II	Routine Maintenance (RM) Very
55 – 70	Good / with effect of loads	III	thin Asphalt Overlay layer(AO1)
25 – 55	Fair / Poor	IV	Doubled Asphalt Overlay layer(AO2)
0 – 25	Very Poor / Failed	V	Reconstruction (RC)

2.8.4. Road Maintenance Process

The approach involves defining activities, planning, allocating resources, overseeing implementation, monitoring and evaluation of works [32]. It normally contains the following components:

a) ***Inventory:*** This is used as the basic reference for planning and carrying out maintenance and inspections. Inspection of road condition is the process of taking physical measurements of defects on the road network in the field.

b) ***Maintenance needs:*** These are determined by comparing the measurements of road condition with predetermined maintenance intervention levels that are based upon economic criteria.

c) ***Costing:*** Unit costs are applied to the identified maintenance tasks to determine the budget required.

d) ***Priority setting:*** If the budget is insufficient for all of the identified work to be carried out, it is then necessary to determine priorities to decide which work should be undertaken and which should be deferred.

e) ***Execution of works:*** The work identified is carried out through with the assistance of several systems of scheduling and cost-accounting.

f) ***Monitoring:*** Monitoring serves two purposes. That is it ensures that work identified has, in fact, been carried out and it also provides data to enable unit cost and intervention levels to be checked and adjusted if necessary.

2.8.5 Maintenance Equipment

There are many different types and models of equipment that can be used for pavement maintenance. The equipment types that are commonly used by maintenance crews include: pavement removal, maintenance, compaction, crack and joint sealing and removal of pavement marking equipment [33]

A. Pavement Removal

1. ***Power Saws***: These saws are capable of cutting straight line through asphalt and leaving vertical sides.

2. ***Cutting Disks***: The cutting disk is much faster than sawing and is recommended where larger areas must be removed. However, it is limited to approximately 3 inches (75 mm) in cutting depth.

3. ***Jack Hammers***: They are commonly used for cutting pavement surfaces.

4. ***Pavement Grinders***: The grinder may outline an area to be patched by cutting a vertical faced trench into the existing pavement that will anchor the feathered edge of a patch.

5. ***Cold Milling Machines***: Cold Milling Machine uses a rotating mandrel with cutting bits to remove various depths of pavement material.

6. ***Hand Tools***: They can be used to make vertical cuts through pavements as well as to break up deteriorated pavement.

B. Maintenance Equipment

1. ***Asphalt Kettle***: They are usually small tractor mounted units that have a capacity of heating and storing 0.15 m^3 to 2.0 m^3 of bituminous material. These units are used for priming and tacking on small jobs and for crack or surface sealing of bituminous surfaces.

2. ***Aggregate Spreaders***: They can be either truck mounted or separate units. They are used to evenly place a controlled amount of sand or aggregate on an area.

3. ***Hand Tools***: They are used to move and level material after it has been placed in a patch area.

C. Compaction Equipment

1. ***Vibratory Plate Compactors***: They are hand operated units used to compact granular base or bituminous plant-mix materials.

2. ***Vibratory Steel***-Wheel Rollers: They are used to compact material including bituminous concrete in patch work areas. Smaller rollers can be hand operated while larger ones are self-powered.

3. ***Rubber-Tired Rollers***: They are self-powered and used to compact bituminous concrete.

D. Crack and Joint Sealing Equipment

1. ***Joint Router***: it is used to clear existing cracks or joints to be resealed.

2. ***Power Brush***: A power-driven wire brush may be used to clean joints after all of the old joint sealer has been removed.

3. ***Air Compressors***: Cracks should be blown out with compressed air immediately prior to application of new sealer.

4. ***Pavement Sweeper***: It can be used for cleaning the pavement surface and removing excess aggregate. Cleaning operations are necessary in preparation for seal coating and crack filling.

5. ***Heating Kettle***: It is a mobile indirect-fired double boiler used to melt hot applied sealing material.

6. ***Pouring Pot***: It is hand carried and used to pour hot sealing materials into previously prepared cracks.

7. ***High-Pressure Water Sprayers***: They can be used to clean out cracks prior to resealing and vertical faces of pavement to be patched.

E. Removal of Pavement Markings

1. ***Water Jetting***: By making use of high-pressure water with proper selection of spray nozzle and pressure.

2. ***Abrasive Blasting***: Pavement markings can be removed by the impact of edged particles accelerated by pressurized air.

3. ***Solvent Cleaning***: Chemical agents can be employed to remove markings from pavement with proper attention to environmental concerns.

2.9. Pavement Management System

Pavement management, in its broadest sense, encompasses all the activities involved in the planning, design, construction, maintenance, evaluation and rehabilitation of the pavement portion of a public works program. A pavement management system (PMS) is a set of tools or methods that assist decision makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a given period of time. The basic is to develop and use sustainable PMS; means that there is strong will, commitment and resources within the organization to maintain operate and subsequently improve the PMS by using local resources and staff.

The function of a PMS is to improve the efficiency of decision-making, expand its scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the agency [9].

Systematic management of pavements has become increasingly important as pavements continue to age and deteriorate and funding levels have decreased due to reduced funding or increased competition for funds. The use of a pavement management system (PMS) is intended to provide roadway managers with a systematic process for generating answers to questions such as [34]:

What roads am I responsible for? When were they built and last rehabilitated?

a) What is the existing condition of the road network?
b) What is an acceptable condition goal (level of service) to provide?

c) What amount of funding is needed to obtain the desired condition of the roads now and into the future?

d) How will the road network condition change if funding levels are changed?

e) What maintenance, preservation, and rehabilitation strategies have been most cost-effective on our road network?

f) Are there alternate treatment strategies that would be more cost-effective and result in better conditions?

g) What is the most economical way to maintain the road network over time?

2.9.1 Pavement management levels

Pavement management can support decisions at various levels (strategic, network, and project) within the organization. The decisions made at each level include [34]:

Strategic – At the strategic level, policy makers make decisions that influence long-term strategic efforts within the organization. These decisions may include setting performance targets, funding allocations, and preservation strategies.

Network – At the network level, information such as the current and future network conditions are used to make tactical decisions about the effects of various short- and long-range budgets, the consequences of various investment strategies, and the work options for the pavement network over a typical 5-year time frame.

Project – At the project level, the decisions are focused over a short time frame (e.g., 2 years) and can include the selection of maintenance activities, materials, and pavement design thicknesses.

2.9.2 Benefit and Costs of PMMS

It is important to understand the benefits and associated costs of any investment in pavement management before starting the process. Therefore, the types of benefits that can be realized by an agency that implements a pavement management process include [34]:

- Providing a centralized location for pavement inventory condition information, construction, maintenance, and rehabilitation records
- Providing a method to analyze the consequences of various funding levels on pavement conditions.
- Improving scheduling of pavement works; assisting as a decision making tool in optimizing rehabilitation, maintenance, and trade-off options.
- Providing the information needed to analyze the cost-effectiveness of treatment repairs.
- Allowing an agency to answer "what-if" type questions regarding pavement repair programs and funding levels.
- Monitor the efficiency and effectiveness of the works carried out
- Allocate funds in a rational and optimized manner to the various maintenance
- tasks and administrations, particularly under budgetary constrains;
- Justifying budget needs to elected officials and other stakeholders.

The costs associated with pavement management can include software acquisition and installation, personnel training, data collection, database building, and system maintenance and updates.

2.9.3 Pavement management process

Pavement management process is a key component in the effective planning and management of a pavement network, the presses shall be systematic and repeatable. Pavement management process basically comprises the following [34].

1. **Define the Roadway Network and Collect Inventory Data**

The first step in designing a pavement management process is to define the roadway network. A roadway network is comprised of an inventory of the physical characteristics of the roadways being managed by the agency. After segments are defined in a manner that best fits the needs of the given agency, the inventory information for each segment is collected by either estimating the data or collecting all needed information. The exact type

of inventory information required by an agency depends on what data will be used by the agency to support its decisions.

2. Collecting Condition Data

Pavement condition data are a major factor in any data-driven, decision-making pavement management process. Within the pavement management process, the condition data can be used to help identify current maintenance and rehabilitation needs, to predict future needs, and to assess the overall impact on the network. Therefore, the type of condition data required and the level of detail depends on the agency and the pavement management process used. Condition data will be collected using either manual or automated data collection methods. With either method, distress data will be estimated or measured.

3. Predict Condition

With current pavement condition assessed, agencies are equipped with the information needed to predict the future condition of a segment. In pavement management, conditions are predicted in terms of performance models that estimate the average rate of pavement deterioration each year. Pavement conditions can be predicted for the pavement network using either average deterioration rates or performance prediction models.

4. Select Treatments

The fourth step in designing the pavement management process is to select appropriate treatments for the roadway network. Treatments are selected using cyclical schedules or treatment trigger rules. The recommended treatments are then prioritized using ranking or benefit/cost analysis.

5. Report Results

Project results can be reported using different methods to highlight important factors which will assist decision makers with their final decisions. Data reporting is an effective method of communicating not only the recommendations from the pavement management process but also transferring related information to decision makers. The data can be used to generate reports and charts to extract relevant information pertaining to any segments under

consideration. The results can be presented either by using standard charts and reports or customized summaries.

6. Select Pavement Management Tool

The selection of a pavement management tool is influenced by the requirements of the agency and users needs. The tool provides a platform to store the pavement management information and to perform different types of analysis depending on whether a spread sheet, GIS tool, and/or a pavement management system is selected. Depending on the needs of the agency, a local agency can also adopt to use a combination of pavement management software and customized spreadsheets and/or GIS software to suit their requirements.

7.Keep the Process Current

Pavement management is a dynamic process that requires regular updates. Pavement management is not a one-time activity, so agencies must make an effort to update the information incorporated in the pavement management process. Data management is a key component to maintaining the database and keeping the information current.

2.9.4. Implementation of sustainable Pavement Management system

The components of a PMS are well defined and their methods of operation, its merits and demerits is well elaborated in the above paragraph. Pavement management systems that have been introduced in many developing countries are often too complicated and too demanding to be sustainable [33]. Most importantly, organizations must be capable of utilizing the PMS in the decision making process about pavements. The basic is how to develop and use PMS sustainably; sustainability in the pavement management context therefore means that there is strong will, commitment and resources within the organization to maintain operate and subsequently improve the PMS by using local resources and staff. Consequently according to Haas,R.(98) the implementation of a sustainable PMS should consider [35]:

a) Existing institutional arrangements and any required changes;
b) The relevance and need for management information produced;
c) The capability of the agency to collect the required data and keep them current;

d) Technical knowledge required to operate and subsequently improve the system if and when the need arises;

e) Knowledge and computer skills available within the agency (if a computerized system is adopted);

f) Staff training programmes in the area of pavement management.

2.9.5. Maintenance Priorities

All road works agencies need to factor in budgetary limitations when planning their maintenance programme. Engineers responsible for road maintenance faces additional challenge that available funds are never sufficient. It is therefore necessary to assess the importance of the various work interventions to ensure that available resources are utilized in the most effective manner [2].

In most cases, funding needs will exceed available funding. When this happens, one of the methods for prioritizing and optimizing will be needed in order to prepare maintenance and rehabilitation program. Prioritization of maintenance activity may be depends on several factors such as present condition of road i.e. quantity and quality of deterioration, increasing rate of deterioration, importance of the selected road, traffic load on the selected road etc. [36]. The following is a list of methods for establishing priorities; however, alternate methods can be used based on an agency's policies and administrative decisions to select its own prioritization routine over time [19].

A. ***Matrix method*** can be based on such factors as condition and traffic; i.e., the highest priority is given to pavements in the worst condition and with the heaviest traffic.

B. ***Condition index method*** can be based on relative scores usually ranked from 0 (for worst) to 100 (for best). Priorities can combine condition score with such factors as functional class or traffic in order to develop a final list of projects.

C. ***Benefit-cost*** ratio process, the segments with the highest benefit-to cost ratio would have the highest priority. Whereas the previous methods are likely to favor a "worst-first" policy, the benefit-cost rationale can provide high priorities for pavements in fair-to-poor condition rather than always starting with the pavements in the worst condition.

D. ***Cost-effectiveness*** procedure is similar to benefit-cost except that the function is to maximize the performance of the segment while considering cost. Performance, in this case, is a measure of the effectiveness of a particular strategy on a segment over time. Each segment or road ranked against each other to arrive at a list of maintenance and rehabilitation options. This method does not require a "worst first" approach.

E. ***Maximum benefits procedure*** is inherent in most optimization methods. However, methods for maximizing benefits can also be developed with prioritization and life cycle costs. For example, that group of projects from all candidate projects, which maximizes the combined benefit-cost ratio or cost effectiveness for a specific budget, would be selected for maintenance and rehabilitation treatments.

2.9.6. Maintenance delivery systems

As per Sega1 2003,There are two main types of pavement maintenance contract delivery systems that government officials can choose when contracting road maintenance, these are method based (traditional) and performance based road maintenance contract [37]:

1. ***Method-Based Specified Maintenance Contracts***: A method-based maintenance contract is a traditional procurement model wherein the road controlling authority, referred to as the client, is responsible for managing the network and the maintenance of physical works are outsourced. This requires the client to have sound asset management skills. In this model, the client demands the contractor what work is to be done, when to do it, and the extent of the work. The contractor is paid on the basis of a defined output or quantity accomplished, and the schedule of rates. Risk transfer is very low in this model as the client retains most of the risk involved in the contract. This type of procurement model does not encourage the contractor to innovate, as the client's engineer is required full-time supervision and is responsible for work identification and programming [38].

2. ***Performance-Based Specified Maintenance Contracts:*** Performance specified maintenance contracts (PSMC) are called performance-based specified maintenance

contracts (PBSMC) in some road authorities. Performance-based contracts define what goods and services are required, not how to produce them. The expected outcomes are explicitly defined in the contract and paid on a fixed lump sum price.

In this procurement model, the contractor is responsible for all aspects of road asset management, professional services and physical works. As the contractor is in full control of the network, he must know and understand the current condition and future needs of the asset, thus, the contractor will be able to introduce innovations and be proactive in his maintenance management programme. The goal is to prescribe performance specifications that allow contractors to demonstrate their individual expertise, creativity, and resources without controlling them with predetermined methods or processes. Since there is a substantial risk transfer from the client to the contractor, the latter must have strong asset management skills to be able to mitigate the risks involved. The model involves a low level of supervision, requiring only verification of outcomes on the part of the client. The contractor is expected to have more initiative in preparing forward works and programmes, requiring high- level skills and expertise.

New Zealand is in the forefront of this new development, followed by most developed countries. Over time, road authorities have expanded contracts from maintenance activities to all attributes of road network management [39].

2.10. Road maintenance and management practice in other countries

Different countries have their own way of dealing with road maintenance activities. The following brief review of countries experiences including ERA has been selected based on their institutional arrangements, pavement evaluation, maintenance method, and road maintenance management system that can provide valuable insights by highlighting countries relative strength and weakness from which useful lessons can be learned in the effort to provide efficient and sustainable road maintenance.

2.10.1 New Zealand experience

New Zealand is one of the countries in the world with the best-managed road network. The road network in New Zealand is made up of the state highways, motorways and local roads. The latter is operated and managed by local councils acting as road controlling authorities, while the rest of the network is controlled by Transit New Zealand. RCAs are the owners of the local road network; therefore, they are responsible for its operation and maintenance [6, 40].

Authorities identify community outcomes at least once every 6 years with the intention to evaluate desired community outcomes, priorities identified outcomes, quantify accomplishments, and assess community resources. Generally road surface damage is uncommon typically one or less incidents per kilometer travelled; they are constantly improving their asset management techniques and systems with greater focus on customer service, local government reforms, technical and financial policies, and national legislation. Customer surveys conducted and analyzed monthly, quarterly, yearly or at random are measures of the performance of key players in the maintenance of roads and performance of the network. New Zealand's 'State Highway Asset Management Plan 2012-2015' highlights their customers first approach, which links customer input from focus groups and consultation with the Automobile Association and the Road Transport Forum

Road asset managers in New Zealand currently use the Road Asset Maintenance Management (RAMM) system as a technical management tool having high quality inventory data covering road network conditions and history of maintenance activities. Likewise, the Road Information Management and Support System (RIMSS). They use RAMM software mainly inventory database storage for road structures, drainage and surfacing plus condition data including skid resistance, rutting, and cracking. It contains the treatment selection algorithm (TSA), plus national optimization of maintenance allocation by decade (NOMAD), which stores the 10 year forward works program. The TSA was made to indicate which works should be performed in the coming year. Maintenance management tools like RAMM have written and modified their own maintenance specifications [41].

The proposed PMS included techniques on prioritizing road maintenance projects using the pavement condition index, taking into consideration the severity and type of distress more over New Zealand Transport Agency has prioritized seven key state highway routes that have been designated roads of national significance.. RBIA has information related to inventory consisting of the visual condition assessment, roughness, video imaging, pavement strength, pavement thickness, centerline survey, and skid resistance.

New Zealand's annual road condition surveys are made across the entire network using a mix of high speed data for rutting, texture, skid resistance etc., and site specific investigation for surface cracking or pavement strength. The results are used to filter and inform detailed field inspections leading to nationally prioritized annual programmes of surface or pavement repairs, surface dressing, pavement recycling/rehabilitation, pavement reconstruction. The mix and timing of repairs to pavement reconstruction is selected to minimize the long term costs of providing reliable access along the State highway network, and to reduce safety and comfort service level risk appropriate for each classification of road arising from the occurrence of surface defects. where it was noted that roads are inspected routinely at one to six week cycles, commonly with a video record being kept and analyzed in a regional office to identify defects for treatment by routine road maintenance crews [41].

Physical works and professional services are all supplied under contract using Alliance, Performance Specified Maintenance Contract, Hybrid or Measure and Value contract forms. About one-third of state highway maintenance in New Zealand is outsourced through PBSMC wherein both network management and physical works are contracted for a lump sum price. These long-term contracts, usually 10 years in duration, define outcomes in terms of the levels of service and performance measures [40, 41].

2.10.2. Singapore experience

Singapore is as a city state with a small road network (compared with other countries). However, the road network as a percentage of the total land area is 12% and this is difficult

to increase further. Road surface damage is Uncommon - typically one or less incidents per kilometer travelled. Major causes of road damage are due to severe climate events/natural hazards to the road condition and poor quality reinstatements [42].

Singapore carries out regular inspections with higher frequency for roads subject to higher traffic loading. The road inspections are done by road inspectors as well as annual network condition surveys by machine to obtain riding quality in term of IRI and skid resistance by SCRIM. Singapore manage and control road diggings for utilities layings with power given under the Street. They also manage and control road usages such as obstruction on footway and carriageways

They also carry out preventive maintenance to reduce the need to carry out structural maintenance. Due to the adoption of preventive maintenance practice, generally the road surface damage such as ravelling or surface cracking can be repaired by milling and patching. For older surfaces, generally resurfacing is used to renew the surface or to improve the skid resistance [42].

Singapore manage the maintenance of their road network and the maintenance works are carried out by contractors through maintenance term contracts. They use different asphalt mixes that are considered more appropriate and durable under different traffic conditions based on the field working experience. In general dense-graded asphalt mixes are used for major arterial, collector and local roads. At traffic junctions with high traffic loading and stresses, rigid or semi- rigid pavements are used. For motorways, they use opened graded mix or drainage mix due to its ability to reduce splash/spray and aquaplaning and traffic noise.

Singapore takes a practical approach to highways work saying that highway maintenance activities will inevitably affect the public either as road users or nearby residents. It is a good practice to inform the affected parties in advance of the carrying out of maintenance activities. The timing of the maintenance activities have to take into consideration the community e.g. night works, works near schools during examinations etc [42].

2.10.3. Australia experience

Australia had strong use of long-term financial plans at the local level have mandated that local governments use 10-year financial plans. The financial plans consider the wholeof-life costs associated with the maintenance and renewal of a road (e.g., initial cost, operating costs, maintenance and renewal costs, disposal costs), which has enabled local governments to move from annual budgeting to long-term financial planning that links service levels with funding requirements [43].

Asset management programs are well thought out and include prioritization modeling as well as cost-benefit analysis. Asset management programs have been used effectively in identifying needs and in convincing management that more funding is needed for road maintenance. Pavement management strategies for allocating maintenance resources vary by state, according to state perception of user needs. In more urbanized areas, roughness and functional considerations, such as ride and noise abatement, drive project selection in the pavement management systems employed. In more rural areas, structural considerations are emphasized. Asset condition measures such as roughness, rutting, texture, and skid resistance are measured network-wide each year and form part of the performance monitoring framework, together with commentary on whether the investment produced the expected outcome. Queensland has developed in-house software to serve as a decision support tool for the road asset maintenance policy and strategy at the state and district levels. Other states use commercially available software for this purpose [44].

Both operational services and maintenance work are contracted out using a variety of contract delivery models that include conventional models, performance- specified maintenance contracts, and a hybrid of the two. Alliance contracts that share risk and rewards are also used to some degree .Western Australia has contracted out more than 90 percent of its activities.

2.10.4. South African experience

SANRAL manages the national roads of the tenth longest road network in the world road network consists of 19,704km of roads from this 16 percent of the total national road

network is toll roads, This network seamlessly connects major cities, towns and rural areas .South Africa meets maturity level of asset management PAS 55 requirements; and international leader in terms of asset management in the roads sector. Subsequently, the PAS 55 tool has been replaced by the ISO55000 Standard. Preventative maintenance is a key element of SANRAL's management. [6].

Road condition survey is performed by SANRAL's automated road survey vehicles road Survey Vehicle (Truck) which able to measure road surface deflections, 3D surface cracks (>0.75mm) and 3D right of way laser point clouds at 80 km/h, which are equipped with laser, video and computer-based technologies. SANRAL to complete a deflection survey of our current 19704km of roads at 1 metre interval in less than 6 months. The pavement management system has been used effectively to justify increased funding for road maintenance and preservation. Simple but clear presentations of network analyses and maintenance needs have been made to local and national politicians [44].

They have Vehicle Detector Stations (VDSs) continuously record traffic conditions such as speed, flow, vehicle density and vehicle composition in real time. The data is relayed to the TMC and specifically to the Advanced Traffic Management System software. The VDS data is currently in the commissioning phase. They have Environmental Sensor Stations (ESS) Which measures all the relevant weather information Operators will have access to the weather information and will use the information (visibility, humidity, rainfall and wind speed.) to decide on the posting of traffic information and safety messages to road users. The weather stations are mostly mounted on 8-metre poles, while others are mounted on the existing 13-metre camera poles. SANRAL owns and operates 13 traffic control centers (TCCs) which are operated on a 24-hour basis, attached to these are16 satellite weigh stations that are operated as the detected/ recorded overloading incidents increase [6].

Routine road maintenance is undertaken by contractors along the entire national network. This covers crack-sealing (Well-established and standardized guidelines based on research and practical experience are used. Chip seals are routinely used [45] and patching, repair and cleaning of drainage systems, repair and renewal of fences, road signs, road studs and

guardrails, burning of firebreaks, protection of the environment through maintenance of trees and shrubs, weed and litter control and emergency assistance. A minimum of 60% of this work is allocated to SMMEs in line with SANRAL's socio-economic development goals, of which 90% is awarded to black-owned firms. Due to the improved maintenance activity national road roughness less than 4.2 m/km is 96 %in 2013/14. Percentage of travel undertaken each year on national roads with macro texture higher than 0.4 mm and Percentage of travel undertaken each year on national roads with rut depth less than 20mm is 98 % achieved in 2013/14 [6].

From the above international experience it is clearly seen that, the countries stress on road asset management as mandatory tool in road infrastructure and have Road Asset Maintenance Management system as a technical management tool having high quality inventory data covering road network conditions and history of maintenance activities with reasonable prioritization. They perform frequent inspection with automated inspection machinery so as to determine specific coast effective and durable treatment measures. Most countries lead with long-term financial plans and develop their own national standard and specification by giving emphasis on research and trainings for sustainable asset management and maintenance. They use different road preservation, maintenance and rehabilitation delivery systems as an alternative sustainable regular and timely maintenance in order to secure a reasonable lifetime on the construction investment.

2.10.5. Ethiopian Roads Authority experience

Ethiopian Roads Authority (ERA) carries out road condition survey two times a year through Ten districts road network directorate using visual condition survey method.ERA has Survey Equipment (Vehicle) that can cover 80km per hour but they usually used the output for planning purpose.

During the interview it is found that districts road network directorate quantifies the defects based on the condition survey output and send to the ERA head office so that the head office allocates maintenance budget. In ERA most of maintenance activities are done by its own construction firm called Ethiopian Road construction Corporation (ERCC) and few labor based works are contracted to private firms. They undergo periodic and routine maintenance

but they did not practice innovative pavement maintenance delivery systems as an alternative road maintenance system.

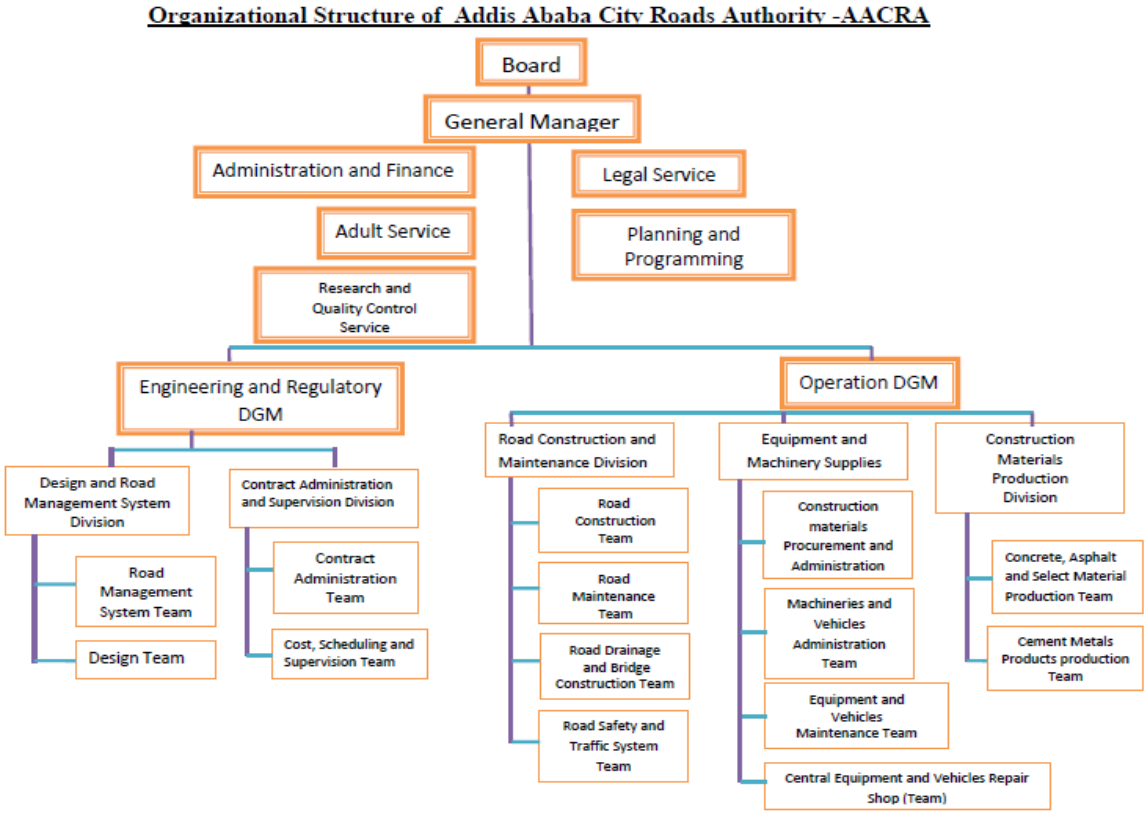
Each district has defined road asset data inventory in spread sheet. They collect visual condition survey data per 5km. Even though the road defects categorized and clearly defined as routine and periodic maintenance activities with clear descriptions and unit rates, the maintenance works volume is depend on the available limited budget.

Chapter-3

Road Maintenance in Addis Ababa City Roads Authority (AACRA)

3.1. Introduction

This chapter investigates the Road Maintenance, rehabilitation and road Management process in AACRA. It explicate the detail procedure how AACRA conducts the above listed tasks currently. The information has been gathered from AACRA official website, from archive, interview with Engineers working in asset management, road construction and maintenance of AACRA and consultants who engaged in consulting AACRS maintenance, construction and design activities. The following chart shows the general organizational structure of AACRA [4].



3.2. Addis Ababa City Road Asset

ACCRA engaged in increasing the road coverage to 20% in 2012 EC of the total coverage of the built up area. The Road asset is growing noticeably; the city road in 1998 was 1360km which is around 5.1%. In 2005 the coverage increase to 15.64%, from this 960 km is asphalt pavement road. Table 3.1 below shows the road asset of Addis Ababa city

administered by AACRA. Total area of Addis Ababa is 54,000 hectar , total road length of road network with 7 meter width is 4671 km total built up area 16,902 hectar or 169,02km^2 and road density is about 22,07km/ km^2 of the built up area, therefore the road coverage of Addis Ababa city is 17.50% of the total coverage of the built up area [4].

Table 3.1. AACRA Road asset in 2007 [4]

Types or Road	Road length/ KM
Arterial	1130
Sub Arterial	425
Collector	342
Local	267
Cobble stone	1330
Gravel Road	1176
Road Average	17.50%

3.3 Pavement evaluation in AACRA

In order to carry pavement rehabilitation and maintenance, the existing pavement condition must be evaluated. Such an evaluation usually involves the assessment of the existing pavement structural, functional, surface condition and safety evaluation using visual evaluation, none destructive testing, destructive testing. Pavement evaluation techniques differ between different countries and highway agencies, they are more focused on establishing the root causes of existing distress in order to determine the best rehabilitation strategies.

In this study period, ACCRA Road Management System Team is responsible for pavement evaluation. It is done on yearly bases using visual condition survey method in spread sheet which comprises. Street number, street name, total length, road type, defect type, defected area detail (specific area, length Width, area and condition). Appendix IV shows the data collection sheet used for condition survey of existing asphalt roads by AACRA.

They perform condition survey for all types of road, walkway, drainage, and bridge with a team composed of three data collectors (technicians) and two engineers. This condition

survey crew covers 2-2.5km per day. After visual condition survey the pavement condition become summarized and reported as very good, good, fair, poor, very poor and also by types of distress. The maintenance type, unit rate and maintenance priority will be defined and reported to the maintenance department. Table3.2 shows the overall technical personnel involved on Road Asset management team.

There is no destructive and none destructive test procedures for structural, functional and safety evaluation other than visual surface condition evaluation method which plays significant role in identifying major causes of distress for recommending the best option for maintenance and rehabilitation decisions.

Table 3.2 Manpower of Road Asset Management Team

Personnel	Quantity
Engineer	3
Data collector	6
Data encoder	2

3.4 Pavement Maintenance in AACRA

The Department of Road Maintenance at AACRA is responsible for performing routine and periodic maintenance works for the city streets. The department develop schedule for the maintenance activities to be done either pouching or overlay which is already specified by road asset management department. The maintenance activates are usually done on night time. The available resources at the department in terms of technical skills, human resources, and the quantity and condition of equipment are the backbone for its capability to carry out the road maintenance and rehabilitation programs. As it was informed by case team head during the field survey, the available equipment and man power at the Maintenance Team and their condition are illustrated in Appendices III. Table 3.3 illustrates the available manpower in Asphalt maintenance case team which is involved in the overall asphalt pavement maintenance work.

Table 3.3 Manpower of Asphalt maintenance case team

Personnel	Quantity
Engineer	1
Technician	1
Forman	3
Operator	35

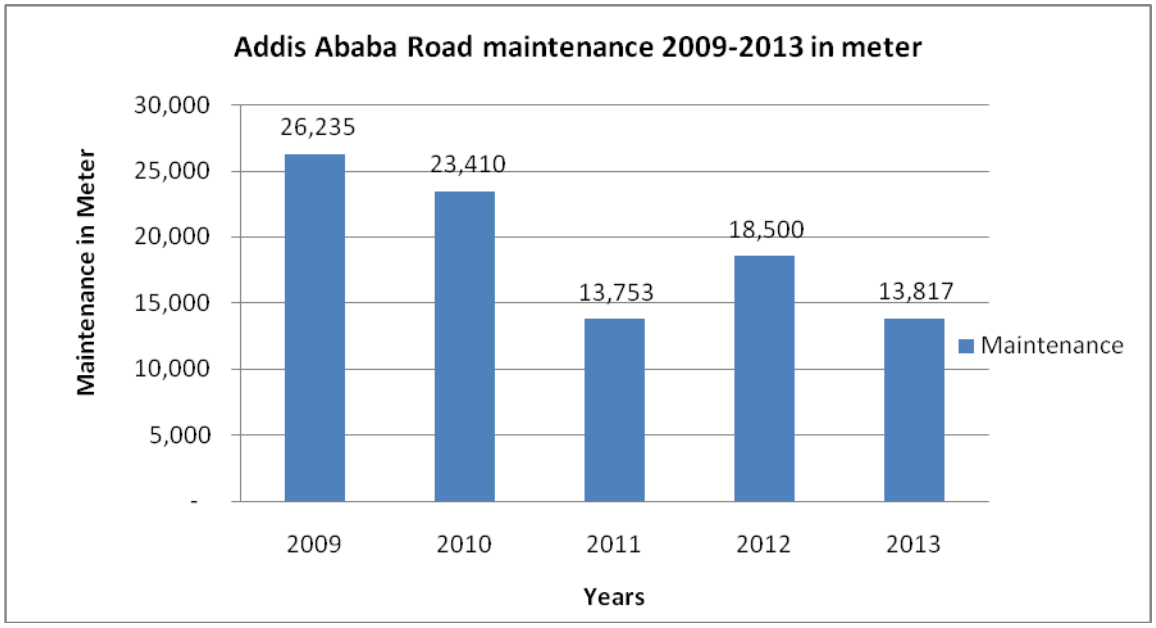


Fig.3.1 Asphalt maintenance per year in meter [4]

3.5. Road Maintenance and Rehabilitation Procedure

The AACRA Road Asset Management Department is responsible for registering all road asset and defining the necessary maintenance activity with the respective maintenance cost to be done for city roads based on the condition survey data. The condition survey data is summarized in this office based on PCI. Sense the budget allocated by the Authority for the maintenance and rehabilitation is limited for maintenance and rehabilitation works they prioritize based on severity grade to the road which is affected worst and currently they

start using Matrix method for maintenance and rehabilitation prioritization. More over they will focus on emergency works and other woks ordered by political pressure.

After defining the specific area, types of maintenance and rehabilitation to be done, volume of work and the unit cost. They will provide to the construction and maintenance department to be rectified.

After receiving the works to be done the road construction and maintenance department will make schedule, inform their schedule to the private consultant who signed contract for supervision and rectify the defects. The whole maintenance and rehabilitation works are done by four crew; from the four crew one crew is newly established specially for maintenance of utility cuts, and equipments listed in the Appendices III are used interchangeably among the crews. They usually do their duets during night time. Every evaluation and maintenance activates not outsourced rather they work by own force.

3.6. Rehabilitation and Maintenance Strategies

Different rehabilitation and maintenance alternatives can be employed after determining the current pavement condition, the minimum acceptable level, and the prediction model for pavement performance deterioration. As we discussed in the literature review maintenance treatment strategies are categorized as preventive maintenance and corrective maintenance. There are two maintenance strategies that are usually done in AACRA these are pavement overlay and patching as preventive maintenance and rehabilitation.

3.7. Maintenance Technique

Different road authorities have different maintenance technique for maintenance of asphalt pavement which helps in enhancing the life of asphalt pavement. For example in Washington they use distress severity (density) to decide shallow or deep patching, sealing, overlaying and also they use PCI values for suggesting either maintenance or rehabilitation works to be done. In AACRA based on the distress types they categorize either overlay or patching. The thickness of overlay and the depth of patching are decided by the

maintenance crew on site. There is no other specific maintenance treatment selection techniques practiced by the authority.

3.8 Pavement Management System

AACRA has Road Asset Management Department which is responsible for the management of pavement. They were started using Pavement Management System software before six years. The system collapsed before it becomes well practiced by the Authority. During the interview it was not functional and no one did not know what it was By now it is no more functional and during the interview we have only find the history no one knows what it was.

From the basic pavement management processes components discussed in Chapter 2, they have road network inventory data for rods being managed by the Authority and condition survey data in spreadsheet in hard and soft copy. There was no method to predict the future condition of the road segment to estimate the average rate of deterioration. These has significant role for scheduling short term and long term plan. Moreover there was no system for prioritizing and selection the appropriate treatments for the roadway network; the only treatment they were used are patching and overlay irrespective of cost benefit analysis, pavement age and traffic condition etc. Currently they were started to use matrix method of prioritizing maintenance.

The asset management department defines the segment of the roadway to be maintained either by patching or overlay with the respective unit cost which will be given to the maintenance department to be maintained. There was no detail like working methodology, material specification and maintenance design etc. Maintenance activities are not yet been outsourced to other companies, they perform the activities by their own force. From the above facts during the study period AACRA did not benefit from the merits of well established pavement management system.

3.9. Conclusion

By using the information gathered from AACRA and literature review a questionnaire was developed to collect data from the targeted respondent.

The condition survey data shows us, from the surveyed roads most of them are classified in fail, poor and fair road condition. Unlike the experience of other countries discussed in chapter 2,AACRA did not cover the full roadway stretch condition survey rather they undergo few kilometers per year .Road condition survey methods currently practiced by AACRA was only visual condition survey method. There was no other evaluation mechanisms for structural, functional and safety evaluation which has significant role in justifying the causes of asphalt distress; so that to suggest the effective remedial action to be done.

Among different pavement treatment types categorized under preventive maintenance and rehabilitation strategies discussed in Chapter 2; AACRA was used only overlay and patching as preventive and rehabilitation strategy. Those strategies are inadequate for preserving pavement in good condition and reducing expensive maintenance and rehabilitation work.

From different alternative maintenance techniques, AACRA use ordinary maintenance technique, they categorize either overlay or patching based on the distress types. They were no material specification, design and work methodology etc. Every maintenance detail like depth of path and overlay thickness was decided on site. By doing so it is very difficult to recommend specific remedial measures to be taken.

AACRA use traditional pavement management system, everything was recorded manually in spreadsheet. Even though they currently start matrix method of maintenance prioritization, the system is in early stage rather they are engaged in emergency maintenance works. They were not outsource maintenance works to other organizations. According to this assessment, there was shortage of man power machineries and budget

constraints in road asset management and maintenance department, as the department and the work demands.

Generally, from the above detail assessment pavement maintenance and rehabilitation activates in AACRA were activities limited, not well scheduled and were performed after the worst conditions has come, due to the above listed limited resources and neglected and poorly organized pavement management system. By taking this in to consideration, The study finding provided basic information how to strengthen those activates for better performance for Addis Ababa city roads.

Chapter-4

Methodology

4.1. Introduction

This chapter describes the methodology of this thesis; the main topics included in this chapter are research strategy, research design and data collection. Propose of this section is to screen basic components of pavement maintenance and rehabilitation process discussed in Chapter Two and pavement rehabilitation and maintenance practice in Addis Ababa road Authority discussed in Chapter Three. This Chapter also provides explanation to questionnaire design, distribution and data analysis. The research strategy and design to be followed towards this end are discussed as follows.

4.2. Research type and strategy

This research can be categorized as applied and descriptive type. It is applied and exploratory because the research findings can be applicable. It is also descriptive because it tried to describe the existing road maintenance and management system of Addis Ababa Roads Authority.

The qualitative approaches seek to gain insight and to understand people's perception whether as individuals or groups .The research strategy adapted for this research is quantitative research

4.3. Research design

This research consists of six phases; the first one is the proposal for identifying and defining the problems and establishment of the objectives of the study. The second phase of the research includes literature review. The third phase explains the road maintenance and management process of AACRA.

The fourth phase of the research included a methodology and data analysis of the thesis. The fifth phase of the research includes discussion on critical identified points. The last phase of the research includes the conclusions and recommendations.

4.4. Scope and limitation

The scope of this research for achieving the goals is focused on AACRA'S asphalt pavement maintenance and maintenance management in Addis Ababa City Roads. The road maintenance and road asset management departments are the main target for this thesis.

In this thesis there were limitations which were encountered throughout the preparation of this research. Unavailability of adequate documented information and unwillingness in the construction firms (Client, Consultants and contractors) are one of the limitations.

4.5. Data Collection

The study has used the data sources to produce the following basic documents: respondents' documents and archival documents. The respondents' documents were collected using questionnaire from client, contractors and consultants. Archival documents were mostly Condition survey document, project reports, correspondence letters and bill of quantities were investigated thoroughly which were very important in identifying the current pavement maintenance and management practice of Addis Ababa City Road Authority.

4.6. Sample Size Distributions

The samples were selected based on purposive sampling method from professionals who are working with client (Addis Ababa City Road Authority), contracting companies and consultant offices working with AACRA during the study period.

This will ensure to collect reliable data from professionals not only from their theoretical and practical background but also their organizational relationship will help them to know AACRA maintenance and rehabilitation activities.

There were 13 contractors and 12 consultants, in each organization two individuals are selected purpose full to participate in the study. The participants from each party were selected, based upon their work attachment with AACRA. The participants were identified

by the representative of the respective organizations after explaining the objective and the purpose of the study.

The total number distributed questionnaires were 25 to contractors, 25 to consultants and 20 to client. But the total numbers returned were 15, 18, and 17 from contractor, consultant and client respectively.

4.7. Data analysis approach

The response given by each respondent calculated and summarized using the following average index formula:

$$\text{Average index} = \frac{\sum a_i x_i}{\sum x_i} \qquad \text{[Eqn. 4- 1]}$$

Where.

a_i- constant that represent the weight of i

x_i- Variables that represent the respondent frequency for i

i-1,2,3,4,5

In order to be able to select the appropriate method of analysis, the level of measurement must be understood. For each type of measurement, there is/are an appropriate method/s that can be applied and not others. In this research, ordinal scales were used. Ordinal scale is a ranking or a rating data that normally uses integers in ascending or descending order. The numbers assigned to the agreement or degree of influence (1, 2, 3, 4, 5) do not indicate that the interval between scales are equal, nor do they indicate absolute quantities. They are merely numerical labels. Based on Likert scale researcher has the following:

Table 4.1: occurrence Scale

Chances of occurrence	Very Important	Important	Average	Least Important	Not Important
Scale	5	4	3	2	1

4.8. Questionnaire approach and design

The questionnaire was developed to assess the existing challenges on pavement evaluation, pavement maintenance and rehabilitation, and pavement management practice in AACRA and how to minimize and avoid those challenges for effective and efficient pavement maintenance work. Were first examined and identified through a relevant literature review.

The draft questionnaire was discussed with the supervisor of the thesis. The final questionnaire contains 3 questions related to pavement evaluation, 5 and 3 questions related pavement maintenance and Pavement management system. The respondents were asked to fill the questionnaire and they have assured that the information will be confidential and only for research purpose.

4.9. Questionnaire content

The questionnaire are divided into four sections, which include the respondent background, Pavement evaluation, pavement maintenance, and pavement maintenance management system that are identified as an important factors that are to be considered in road maintenance process.

4.9.1. General Background

Four items were prepared for asking general information about organization such as the name of organization, company type (client, consultant or contractor), respondents designation and his/her experience. (The questionnaire is included in appendix I)

4.9.2. Pavement evaluation

This section incorporates three questions related to pavement evaluation. The respondents will be asked to answer each question by selecting one of five levels of agreement and disagreement choices, and important and non important choices. (The questionnaire is included in appendix I)

4.9.3. Pavement Rehabilitation and Maintenance

This section incorporates five questions related to pavement maintenance. The respondents will be asked to answer each question by selecting one of five levels of agreement and

disagreement choices, and important and non important choices. (The questionnaire is included in appendix I)

4.9.4. Pavement Maintenance Management

This section incorporates three questions related to Road maintenance management. The respondents will be asked to answer each question by selecting one of five levels of agreement and disagreement choices, and important and non important choices. (The questionnaire is included in appendix I)

Chapter-5

Data Analysis and Results

5.1. Introduction

The previous chapters provide general picture of pavement maintenance, rehabilitation and pavement management process. Theoretical background on basic components of pavement maintenance rehabilitation and management processes and its respective international experience has been assessed. Moreover the research detail methodology has been defined.

This chapter discuss on data analysis and results obtained from professionals who are working with AACRA other professionals who have experience on road construction and maintenance moreover working with ACCRA in construction and consulting activities.

The analysis of the data has been made using Likert scale. The analysis illustrates the finding results of survey frequency and importance indices. Besides, the results of each hypothesized questions raised in each section have been dealt with

.

5.2. Analysis of Hypothesized Questions

The respondents were asked to express their opinion by agreement /disagreement on ten hypothesized questions and also they have asked to specify reasons. Moreover they have been asked three questions in each section to rank based on the degree of importance for the listed problems or constraints so that to understand and mitigate the encountered problems.

Though the respondents are asked to respond their agreement /disagreement in five scales, to simplify the analysis the comparison was made on three scales; that is Agree, Neutral and Disagree. The summaries of response have been included in appendix II.

The response for each of the questions are compared and presented herein below.

5.2.1. Section 1: General background

This part mainly designed to provide general information about the respondents in terms of the, company type and experience contact person.

5.2.1.1. Type of respondent's organization

It was aimed to distribute the questioners to 72 professionals; i.e. 20 professionals each working for the client (AACRA), 26 consultant and 26 contractors. It was possible to distribute 70 questioners to the desired professionals as much as possible and attempts have been made. The following table 5.1 illustrates the sample and their distribution as well as the response rate.

Table 5.1: Questionnaire distribution with their respective response rate

Description	Questionnaire Distributed	Questionnaire Returned	% of questionnaire Distributed	% of questionnaire Returned
Client	20	17	100%	85%
Consultant	25	18	100%	72%
Contractor	25	15	100%	60%
Total	70	50	100%	71%

From 70 questionnaires distributed a total of 50 response were received, consisting of 17 (85%) from the client AACRA, 18 (72%) from consultants and 15 (60%) from contractors. The overall response rate was 71% as shown in the Table 4.2 comparing the above response rate the client has more response rate (85%) than contractors (60%) as well as consultants (72%).

5.2.1.2. Experience of respondents

Assessment of experience of individual respondents shows that 14%, 60% and 26% of individuals have less than five years, between five to ten years and greater than ten years of experience respectively as shown below in table 5.2

Table 5.2: Experience of respondents (years)

Respondents Experience	Client	Consultant	Contractor	Total	% of experience
< 5 Years	2	4	1	7	14%
5-10 Years	10	11	9	30	60%
> 10 Years	5	3	5	13	26%
Total	17	18	15	50	100%

5.2.2. Section 2 -Pavement Evaluations;

2.1. In your opinion is Addis Ababa's city road condition status is good?

This general question was aimed to ask the respondents about road maintenance, and pavement surface condition of the city road. Among the respondents, 84% of them disagree that the general current road condition status of Addis Ababa city road is in good condition; showing that the current Addis Ababa city road is not in good condition.

2.2. Did AACRA currently carry out destructive and none destructive tests other than visual pavement condition evaluation method?

Among the respondents, 92% of them disagree that AACRA currently carries out destructive and none destructive tests other than visual pavement condition evaluation method showing that AACRA currently carryout only visual pavement condition evaluation for evaluating Addis Ababa's city roads .

2.3. Does the present pavement evaluation method used by AACRA is adequate for evaluating the pavement for structural, functional and safety of road condition?

Among the respondents, 86% of them disagree to the above hypothesis showing that the current pavement evaluation method practiced by AACRA is not adequate for evaluating structural, functional and safety of road condition.

2.4.What are the main problems for practicing different pavement evaluation methods in AACRA, that are mandatory for recommending the best maintenance option?

Frequencies for the best ranked factors which described the main problems for practicing different pavement evaluation methods in AACRA from the listed factors are 'Lack of appropriate pavement management system, Absence of Appropriate machinery, Budget constraint whilst the least ranked is the Limited skilled man power at 3.9, 3.6, 3.5 and 3.3 of average index respectively.

5.2.3. Section 3 - Pavement Evaluations;

3.1. Did AACRA apply alternative pavement treatment types different from overlay and patching?

Among the respondents, 77 % of them disagrees that AACRA currently carries out overlay and patching showing that AACRA did not use other alternative pavement treatment types.

3.2 AACRA uses overlay and patching as preventive and rehabilitation maintenance strategy. Are those strategies adequate for preserving pavement in good condition and reducing expensive maintenance work?

Among the respondents, 80% of them disagrees the above hypothesis showing that AACRA is not practicing different alternatives of preventive and rehabilitation maintenance strategies that are good pavement preserving capacity and also known by their cost effectiveness.

3.3 In your opinion did AACRA apply different types of maintenance treatment selection techniques that are mandatory for recommending specific and cost effective remedial maintenance measures to be taken?

Among the respondents, 87% of them disagrees the above hypothesis showing that AACRA did not apply specific treatment selection methods to propose specific cost effective remedial action to be taken.

3.4 Do you consider the quality of maintenance and rehabilitation work in AACRA is sufficient?

Among the respondents, 91% of them disagrees the above hypothesis showing that Accra's quality of maintenance and rehabilitation work is not sufficient.

3.5 What are the main constraints for implementation of effective road maintenance and rehabilitation work in AACRA?

Frequencies for the best ranked and the least ranked factors which described the main constraints for implementation of effective road maintenance and rehabilitation work from the listed factors which are important to be considered. The most important constraints for of effective road maintenance and rehabilitation work in AACRA is Lack of appropriate

pavement management system the second is the Absence of Appropriate machinery the third is Lack of monitory and quality control the forth Limited Skilled manpower whilst the least ranked is Budget constraint at 4.2 ,3.9,3.7,3.0 and 2.9 of average index respectively.

5.2.4. Section 4 - Pavement maintenance management

4.1 Is there well established road maintenance management system in AACRA for effective planning and management of pavement network?

Among the respondents, 72% of them disagrees that there is no well established road maintenance management system in AACRA for effective planning and management of pavement network, showing that AACRA did not have well established road maintenance management system.

4.2 There are different alternate maintenance prioritizing methods to insure the limited available resource to be utilized in most effective manner. Did AACRA have well defined organizational maintenance prioritizing method?

Among the respondents, 77 % of them disagree the above hypothesis showing that AACRA did not have well defined organizational maintenance prioritizing method that can insure the limited available resource to be utilized in most effective manner.

4.3 AACRA outsources rehabilitation and maintenance works to other private contracting companies.

Among the respondents, 96 % of them disagrees that AACRA outsources rehabilitation and maintenance works to other private counteracting companies showing that AACRA did not give contract to other maintenance contractor; it works by its own force.

4.4 What are the main constraints to establish Pavement maintenance management system (PMMS) in AACRA?

Frequencies for the best ranked and the least ranked factors which described the constraints to establish Pavement maintenance management system (PMMS) in AACRA from the listed factors which are important to be considered. The First most important constraint to establish Pavement maintenance management system (PMMS) in AACRA is Lack of awareness for its benefits and costs of PMMS ,the second is Limited Skilled manpower the third Political

influence or involvement, the forth Budget constraint whilst the least ranked is the Absence of Appropriate machinery at 4.4 ,3.7,3.6,3.4 and 2.8 of average index respectively.

5.3. Summary

One of the objectives of this research is to assess the existing challenges on pavement maintenance and rehabilitation practice of AACRA. To achieve this objective ten hypothesized questions and three questions to be ranked based on the degree of importance for the listed problems or constraints so that to understand and mitigate the encountered problems. The responses for hypothesized and questions to be ranked have been analyzed. (The summery of response is included in appendix II).

Chapter- 6

Discussion on Critical Identified Points

6.1. Introduction

The response for hypothesized and questions to be ranked based on their significance have been analyzed in the previous section. Based on responses of the hypothesized questions, questions to be ranked, informal interview and site visit, the following discussion and conclusions are drown

6.2. Pavement evaluation

Even though AACRA reported in its special edition magazine in 2014, road pavement condition of Arterial and sub arterial roads are situated in very good condition and collector and local roads are in good conditions [4]. Most of respondents agree that Addis Ababa city road status is not in good condition, this shows the city road needs intensive maintenance; in contrary the asphalt maintenance progress report from 2001 to 2005 EC as illustrated in fig.3.1 shows us the maintenance activities are decline from year to year ,this has direct impact in increasing maintenance backlog.

Pavement condition surveys are very important in pavement management. Most respondents agrees that road condition evaluation method currently used by AACRA is only visual condition survey and this is inadequate for evaluating the pavement for its structural, functional and safety of the city road. Even though visual condition surveys cover aspects of both functional and structural pavement condition, but generally serve as a qualitative indicator of overall condition. Specialized equipment is used to quantify both functional and structural properties of the pavement structure. Ideally, for any given section of highway, two or more evaluators would arrive at the same assessment of the section's current condition. However, there are still many aspects of pavement evaluation that are highly subjective[20].To avoid this subjectivity it has to be supported by other qualitative condition assessment methods listed in the literature review Chapter Two, so that to recommend specific effective and efficient maintenance treatments and strategies.

Currently, in AACRA condition survey has been done by the Authority primarily based on public and government body's request rather than defined schedule that aimed regular inspection to cover the entire city roads; this shows that the pavement will be evaluated and maintenance activates will be proposed to be done after the worst condition has come. During the condition survey they will not consider the past maintenance and construction history of the road more over the data collection format is not consistent.

From the condition survey report gathered from Road Asset Management ,after they carry out condition survey they will define distress types and categories the pavement condition as very good, good, fair, poor, very poor, fail. Finally the maintenance options will be set with its respective unit price and sent to construction department. They did not explicate probable causes of pavement deterioration and not consider traffic data. From 193 km conducted condition survey in the year 2006 E.C; among different distress types, they identify only crocodile cracking, pothole, reveling and failure this shows the subjectivity of their visual condition survey moreover they did not adhere their pavement design manual. The department has no centralized data collection unit that has all road asset condition data.

6.2.1. Problems for practicing different pavement evaluation methods.

There are different pavement evaluations methods used worldwide listed in the literature review chapter two, but AACRA is currently using only visual method of condition survey. The problems for practicing different pavement evaluation methods so that to improve Accra's current pavement evaluation method .This analysis was conducted on the data gathered through questionnaires. From the data gathered using questionnaires, the frequencies for the most and the least ranked problems practicing different pavement evaluation methods is Lack of appropriate pavement management system' whilst the least ranked is the 'Limited skilled man power'. The finding shows that the most respondent agreed on the problem.

This shows pavement management is a key component in the effective planning and management of a pavement network .AACRA has to establish sound pavement management system adequate methods to evaluate and implement different pavement evaluation methods

so that the condition data can be reliable impute for further treatment selection comparisons, maintenance prioritization, resource allocation and the like.

6.3. Pavement maintenance and rehabilitation

Among different pavement maintenance treatment types that can be used; most respondents agree AACRA is currently practicing overlay and patching these treatments are not adequate more over AACRA did not apply specific maintenance treatment selection techniques that are mandatory for recommending specific and cost effective remedial maintenance measures to be taken.

Even though there are alternative maintenance types applicable for different distress types that can enhance the durability and serviceability of the road; AACRA use patching and overlay. Those treatments are decided based on the visual condition survey they perform. There is no material specification, design, work methodology etc; every maintenance detail like depth of path and overlay thickness is decided on site. Fekir (2006) in his study pointed out that in AACRA there is no proper material and construction quality control for the road maintenance and rehabilitation works. As a result, repeated and premature failures are observed [3].

As it was discussed in previous section 5.2 the pavement evaluation practiced by AACRA has limited relevance to assist pavement treatment selection. This shows that the maintenance activities performed by AACRA is traditional and they didn't apply maintenance treatment selection technique that have technical and financial consideration.

Different countries use alternative types of treatment types specific for distress and failure types. Davis city uses crack sealing, fog sealing, sulery seal and cape seal as preventive maintenance and cold in-place recycling and asphalt overlays as rehabilitation techniques [44].Singapore used different asphalt mixes that are appropriate under different traffic conditions based on research and field work experience more over there countries like Singapore , Finland , Quebec develop their own national maintenance and rehabilitation standard [45] .California transport agency determine specific maintenance treatments that

answer the questions whether the selected treatment can address the distresses present, be carried out, be cost effective, can be performed before the situation being addressed changes[30].

Hence, taking in to consideration the above cited experience, AACRA has to strengthen the pavement evaluation method that can assist treatment selection methods furthermore has to determine alternative treatment options and sort out in terms cost feasibility, treatment's ability to the functional and structural condition of the pavement while also meeting any future needs. More over AACRA has to carry out routine road maintenance activities regularly and properly that are known by their relatively inexpensive has major cost savings.

6.3.1. The main constraints for implementation of effective road maintenance and rehabilitation work?

From the listed factors which are important to be considered. This analysis was conducted on the data gathered through questionnaires. From the data gathered using questionnaires. The most important constraints for of effective road maintenance and rehabilitation work in AACRA is 'Lack of appropriate pavement management system' whilst the least ranked is the 'Budget constraint'.

This shows pavement management system is vital for effective and efficient road maintenance works in AACRA. In Korea research has been conducted to analyze the situation before and after introduction of PMS. As a result, it was analyzed that traffic volume was dramatically increased, but the pavement condition was improved and rehabilitation budget is decreased after introduction of PMS [46].

6.4. Pavement maintenance management

Most respondents agreed that AACRA didn't have well established road maintenance management system for managing the city roods and they did not apply alternative maintenance prioritizing methods for proper utilization of the limited resource. Also majority of respondents agree AACRA did not outsource rehabilitation and maintenance works to other private counteracting companies.

Since the yearly budget of road maintenance is very limited which cannot cover all roads to be maintained .The Federal Road Fund office allocates 415milion birr for the last fifteen years (1990-2005 EC). The allocated fund is not sufficient and it will not cover 50% of the maintenance demand of the city [4].Figure 6.1 illustrates the budget allocated by the City administration and road fund for road construction and maintenance respectively. Considering the budget allocation and the reduction of maintenance activities shown in figure 3.1; road maintenance has given negligible consideration.

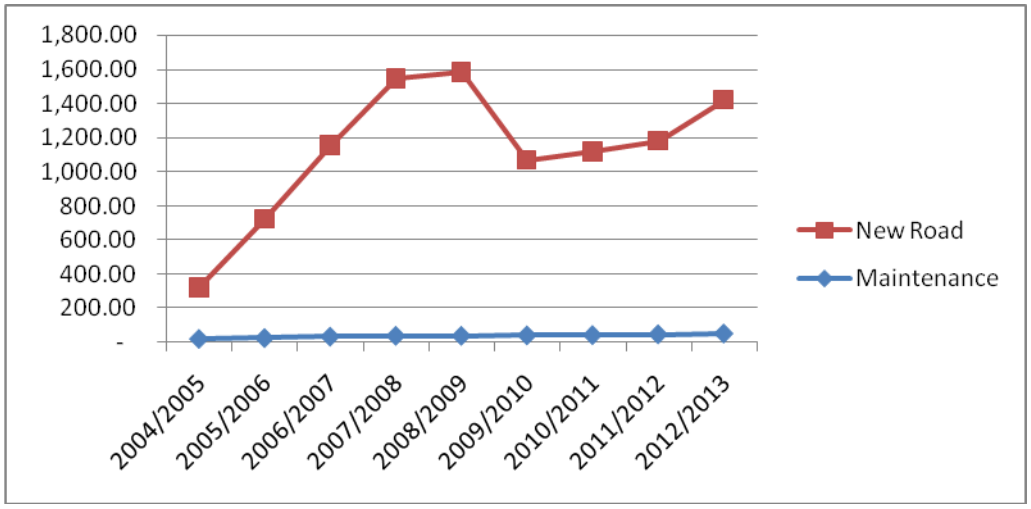


Figure 6.1 budget allocated for road construction and maintenance [1]

The south African national road agency ltd. (SANRAL) estimates that repair costs rise to six times that of maintenance costs after three years of neglect and to 18 times after five years of neglect[45].this implies currently AACRA has huge maintenance demand backlog and in future this gap will further increase and rich worst situations.

At present, they implement the all maintenance and road improvement works done by their own force methods. The international experience tells us some countries benefited fom outsourcing maintenance activities to private contracting parties using alternative maintenance delivery systems. By introducing Performance-Based Management and Maintenance of Roads parts of Australia benefited and gate saving from the cost incurred for maintenance; Sidney 35%, Tasmania 20%, western Australia15-35% ,south wells3 7% and

similarly New Zealand and Virginia saves 15-40% and 15% respectively [47]. Considering the above international experience and facts AACRA has to be flexible and asses alternative maintenance delivery options.

By now AACRA did not have defined organizational prioritizing methods which is practical for the Addis Ababa city roads. So the program for prioritizing road links has to be selected for the road maintenance needs to be done. A prioritizing methodology needs to be used for selecting prioritized road links for road maintenance. AACRA has to define and use organizational prioritizing methods like Matrix and Condition index methods for effective utilization of limited resource and funding. SANRAL allocates available funding for maintenance based on the following order of priority; optimized preventative asset preservation actions, more extensive reconstruction and improvements and new construction [44].

6.4.1. The main constraints to establish Pavement maintenance management system in AACRA?

From the listed factors, the most important constraint to establish Pavement maintenance management system (PMMS) in AACRA is 'Lack of awareness for its benefits and costs of PMMS' whilst the least ranked is the 'Absence of Appropriate machinery.

This shows the main constraint to establish pavement management system is lack of awareness for its cost and benefit of PMS. As it was mentioned before AACRA was established and stared using PMS before years but it was very expensive, not practical and sustainable. During the interview it is found that the Managers and Engineers working in Road asset management assumes implementation of PMS in AACRA is expensive and impractical; the failure of the past PMS has great negative impact and puts stigma in professionals for introducing the new system and convincing the higher officials.

Hence, considering the above international experience AACRA has to asses and develop sound PMS that can provide a rational engineering decision for selecting projects, helps to identify the right treatments for the right roadways at the right time, rational and objective

method to identify resource allocation. Optimal use of available funds, reduction in pavement rehabilitation costs over time, identification of accurate treatment for the pavement segments through roadway assessment [34].and generally to be benefited from its merits discussed in chapter 2.

Chapter - 7

Conclusions and Recommendations

7.1. Conclusions

1. The study elucidates that, the condition survey conducted by AACRA is done by visual condition survey only, they did not apply none destructive and destructive tests that have great role in identifying causes of failure. There is no defined schedule for road condition survey; mostly it is done by public request after the worst condition has come. Even though traffic data, axle load are among the factors of road deterioration; there is no traffic data axle load collected and used for recommending maintenance and rehabilitation options.

2. The finding implies, the maintenance and rehabilitation work done by AACRA is restricted to overlay and pouching. Moreover they are performing overlay and pouching without defining and understanding the route causes of road failure or distress. Hence, the traditional maintenance techniques being carry out by AACRA simply treating the symptoms than the actual cause of distress, this results wastage of budget resource ;because it will fail obviously soon and rework will follow.

3. Based on the study, AACRA did not perform pavement maintenance selection techniques to select cost effective and specific maintenance options at project level and also it have no organizational maintenance prioritizing methods to optimize the available scarce resource, more over there is no quality control and quality assurance system while performing data collection and maintenance.

4. The study identifies the greatest challenge for road rehabilitation and maintenance in AACRA is the absence of well established pavement management system. The maintenance and rehabilitation work force is not properly organized with adequate resource such as finance, equipment and skilled manpower as the result the scope of the work performed is limited to the inadequate budget allocated by road fund and some subsidy from the city administration moreover there is no adequate central data

collection system, this has resulted in the maintenance operation not to be efficient and effective.

7.2. Recommendations

Based on the findings of the study, the following recommendations are put forward for the improvement of the current road maintenance and rehabilitation practice of AACRA.

a) Pavement condition surveys are very important in pavement management. Condition surveys inform management of the actions that need to be taken in order to ensure effective and efficient use of resources .AACRA shall asses alternative pavement condition survey methods and apply the right method or combination of methods, equipment and labor with the required skills must be in use more over the activities to be deploy has to be done with plan and schedule. Quality Management has to be integrated at all stages in pavement condition surveys to ensure accurate information that has to be given to the management.

b) The city Administration and Authority has to give adequate consideration to road maintenance works and seek for various funding options to fill the rehabilitation and maintenance backlog. AACRA has to focus on conducting preventive maintenance for pavements before they deteriorate into poor conditions; this can save a considerable amount of pavement maintenance budget.

c) AACRA shall asses and adopt alternative maintenance strategies and maintenance treatment selection techniques to withstand scarcity of resources required and has to develop his own organizational maintenance prioritization methods for efficient use of available resources more over it has to investigate and exercise by evaluating alternative maintenance delivery systems for the city roads.

d) It is recommended that AACRA has to organize the asset management and maintenance department by adequate skilled manpower, equipments and, machineries and has to establish Pavement maintenance management systems. PMS has to be designed to manage maintenance and rehabilitation activities to optimize pavement condition with available funds, considers current and future pavement condition,

priorities, funding, and can reduce pavement deterioration. Moreover, the PMMS has to be simple, easy and sustainable and suited to local conditions.

7.3. Recommendations for further studies

1. Development and Implementation of pavement management system in AACRA
2. Alternative funding options for maintenance and rehabilitation of Addis Ababa city roads.
3. Pavement treatment selection and maintenance alternatives in Addis Ababa city roads
4. Application of alternative and innovative maintenance delivery systems in AACRA

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Appendices I

ADDIS ABABA UNIVERSITY INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

M.S.C Thesis on Road pavement Rehabilitation and Maintenance Case Study in Ababa City Roads Authority (AACRA)

Dear, Sirs

This research is being conducted as partial fulfillment of Master of science (M.S.c) in Addis Ababa University and the information is required for the academic research entitled Asphalt Road pavement Rehabilitation and Maintenance Case Study in Ababa City Roads Authority (AACRA). The main objective of the research is to assess the current Addis Ababa City Roads Authority (AACRA) road maintenance strategy and maintenance management in Addis Ababa City Roads. Based on the finding recommendation will be forwarded to assist the maintenance and management of the city road.

The questionnaires asses the existing practice and challenges on pavement maintenance and pavement management practice of AACRA. They are divided into four sections, which include the respondent background, Pavement evaluation, pavement maintenance, and pavement maintenance management system.

Your response, in this regard, is highly valuable and contributory to the outcome of the research.

All feedback will be kept strictly confidential, and utilized for this academic research only.

Thank you in advance for your willingness to fill the questionnaires and returning them back on time

Temesgen Girmay
Post graduate student,
A.A University, Technology Faculty, School of Civil and Environmental Engineering
Tel: 0911 912160
Addis Ababa

Section 1: **General Background**

The questions below are related to your organization and yourself. please indicate your response by ticking (x or √) the appropriate box(es),and also filling the blank spaces provided as appropriate.

1.1 Respondent's Name (optional) :_____

1.2 Name of organization :_____

1.3 Type of organization Employer ☐ Contractor ☐ Consultant ☐

1.4 Address (optional) : _____

1.5 Designation: _____

1.6 Experience: ☐ < 5 years ☐ 5-10 years ☐ > 10 years

1.7 Level of Academic: Diploma ☐ First Degree ☐ Second Degree ☐

☐ Other, please specify _____

Section 2- Pavement evaluation

2.1 In your opinion is Addis Ababa's city road condition status is good?

Strongly agree	Slightly agree	Neutral	Slightly disagree	Strongly disagree
☐	☐	☐	☐	☐

Please specify reason_____

_____

2.2. Did AACRA currently carries out destructive and none destructive tests other than visual pavement condition evaluation method?

Strongly agree	Slightly agree	Neutral	Slightly disagree	Strongly disagree
☐	☐	☐	☐	☐

2.3. Does the present pavement evaluation method used by AACRA is adequate for evaluating the pavement for structural, functional and safety of road condition?

Strongly agree	Slightly agree	Neutral	Slightly disagree	Strongly disagree
☐	☐	☐	☐	☐

Why _____

_____

2.4 What are the main problems for practicing different pavement evaluation methods in AACRA, that are mandatory for recommending the best maintenance option?

1. Very Important 2. Important 3. Average 4. Least Important 5. Not Important

A.	Limited Skilled manpower	1	2	3	4	5
B.	Lack of appropriate Pavement management system	1	2	3	4	5
C.	Budget constraint	1	2	3	4	5
D.	Absence of Appropriate machinery	1	2	3	4	5
E.	Otherspecify_____					

_____

Section 3- Pavement Rehabilitation and Maintenance

3.1. Did AACRA apply alternative pavement treatment types different from overlay and patching?

Strongly agree ☐ Slightly agree ☐ Neutral ☐ Slightly disagree ☐ Strongly disagree ☐

3.2 AACRA uses overlay and patching as preventive and rehabilitation maintenance strategy. Are those strategies adequate for preserving pavement in good condition and reducing expensive maintenance work?

Strongly agree ☐ Slightly agree ☐ Neutral ☐ Slightly disagree ☐ Strongly disagree ☐

3.3 In your opinion did AACRA apply different types of maintenance treatment selection techniques that are mandatory for recommending specific and cost effective remedial maintenance measures to be taken?

Strongly agree ☐ Slightly agree ☐ Neutral ☐ Slightly disagree ☐ Strongly disagree ☐

Why _____

_____

3.4 Do you consider the quality of maintenance and rehabilitation work in AACRA is sufficient?

Strongly agree ☐ Slightly agree ☐ Neutral ☐ Slightly disagree ☐ Strongly disagree ☐

Please Specify reason _____

_____

3 .5 What are the main constraints for implementation of effective road maintenance and rehabilitation work in AACRA?

1. Very Important 2. Important 3. Average 4. Least Important 5. Not Important

A. Limited Skilled manpower	1	2	3	4	5
B. Lack of appropriate Pavement management system	1	2	3	4	5
C. Budget constraint	1	2	3	4	5
D. Absence of Appropriate machinery	1	2	3	4	5
E. Lack of monitory and quality control	1	2	3	4	5

F. Other (please specify) _____

_____

Section 4 - Pavement maintenance management

4.1 Is there well established road maintenance management system in AACRA for effective planning and management of pavement network?

Strongly agree ☐ Slightly agree ☐ Neutral ☐ Slightly disagree ☐ Strongly disagree ☐

Please Specify reason _____

4.2 There are different alternate maintenance prioritizing methods to insure the limited available resource to be utilized in most effective manner. Did AACRA have well defined organizational maintenance prioritizing method?

Strongly agree ☐ Slightly agree ☐ Neutral ☐ Slightly disagree ☐ Strongly disagree ☐

Please Specify reason _____

_____

4.3 AACRA outsource rehabilitation and maintenance works to other private counteracting companies.

Strongly agree ☐ Slightly agree ☐ Neutral ☐ Slightly disagree ☐ Strongly disagree ☐

Please Specify reason _____

_____

4.4 What are the main constraints to establish Pavement maintenance management system (PMMS) in AACRA

1. Very Important 2. Important 3.Average 4. Least Important 5. Not Important

A.	Limited Skilled manpower	1	2	3	4	5
B.	Lack of awareness for its benefits and costs of PMMS	1	2	3	4	5
C.	Budget constraint	1	2	3	4	5
D.	Absence of Appropriate machinery	1	2	3	4	5
E.	Political influence or involvement	1	2	3	4	5
F.	Other(please specify)					

_____

_____

Thank You

Appendices II

Summery of response

Appendices II

Q. No	Strongly Agree			Slightly Agree			Neutral			Slightly Disagree			Strongly disagree			Total Response		
	client	Consultant	Contractor	client	Consultant	Contractor	client	Consultant	Contractor	client	Consultant	Contractor	client	Consultant	Contractor	client	Consultant	Contractor
Section 2- Pavement evaluation																		
2.1	0	0	0	2	1	1	2	1	1	7	4	5	10	9	6	21	15	13
2.2	0	0	0	0	1	2	0	0	1	4	8	4	12	9	9	16	18	16
2.3	0	0	0	4	0	1	1	0	1	8	5	4	4	12	10	17	17	16
Section 3- Pavement Rehabilitation and Maintenance																		
3.1	0	2	1	0	2	4	1	0	0	7	7	7	11	3	3	19	14	15
3.2	1	0	0	2	2	2	0	3	0	4	7	6	5	12	6	12	24	14
3.3	0	1	0	1	2	1	0	0	1	6	10	11	11	3	2	18	16	15
3.4	0	0	1	1	0	0	0	1	1	3	9	2	8	9	14	12	19	18
Section 4 - Pavement maintenance management																		
4.1	1	0	1	3	1	3	2	1	2	12	6	3	5	6	4	23	14	13
4.2	0	1	4	2	1	1	1	0	1	6	7	7	4	6	7	13	15	20
4.3	0	0	0	0	0	0	1	1	0	2	6	5	18	9	7	21	16	12

Summery of response in Percentage

Q. No	Agree				Neutral				Disagree			
	client	Consultant	Contractor	Total	client	Consultant	Contractor	Total	client	Consultant	Contractor	Total
Section 2- Pavement evaluation												
2.1	9.52%	6.67%	7.69%	7.96%	9.52%	6.67%	7.69%	7.96%	80.95%	86.67%	84.62%	84.08%
2.2	0.00%	5.56%	12.50%	6.02%	0.00%	0.00%	6.25%	2.08%	100.00%	94.44%	81.25%	91.90%
2.3	23.53%	0.00%	6.25%	9.93%	5.88%	0.00%	6.25%	4.04%	70.59%	100.00%	87.50%	86.03%
Section 3- Pavement Rehabilitation and Maintenance												
3.1	0.00%	28.57%	33.33%	20.63%	5.26%	0.00%	0.00%	1.75%	94.74%	71.43%	66.67%	77.61%
3.2	25.00%	8.33%	14.29%	15.87%	0.00%	12.50%	0.00%	4.17%	75.00%	79.17%	85.71%	79.96%
3.3	5.56%	18.75%	6.67%	10.32%	0.00%	0.00%	6.67%	2.22%	94.44%	81.25%	86.67%	87.45%
3.4	8.33%	0.00%	5.56%	4.63%	0.00%	5.26%	5.56%	3.61%	91.67%	94.74%	88.89%	91.76%
Section 4 - Pavement maintenance management												
4.1	17.39%	7.14%	30.77%	18.43%	8.70%	7.14%	15.38%	10.41%	73.91%	85.71%	53.85%	71.16%
4.2	15.38%	13.33%	25.00%	17.91%	7.69%	0.00%	5.00%	4.23%	76.92%	86.67%	70.00%	77.86%
4.3	0.00%	0.00%	0.00%	0.00%	4.76%	6.25%	0.00%	3.67%	95.24%	93.75%	100.00%	96.33%

Appendices II

Summery of response

Appendices II

Q. No	Strongly Agree	Slightly Agree	Neutral	Slightly Disagree	Strongly disagree	Total Response
	Section 2- Pavement evaluation					
2.1	0	4	4	16	25	49
2.2	0	3	1	16	30	50
2.3	0	5	2	17	26	50
	Section 3- Pavement Rehabilitation and Maintenance					
3.1	4	8	0	21	17	50
3.2	1	6	3	17	23	50
3.3	1	4	1	25	16	47
3.4	1	1	2	14	31	49
	Section 4 - Pavement maintenance management					
4.1	1	8	5	21	15	50
4.2	5	4	2	20	17	48
4.3	0	0	2	13	34	49

Q. No	Agree	Nutral	Disagree
Section 2- Pavement evaluation			
2.1	8.16%	8.16%	83.67%
2.2	6.00%	2.00%	92.00%
2.3	10.00%	4.00%	86.00%
Section 3- Pavement Rehabilitation and Maintenance			
3.1	24.00%	0.00%	76.00%
3.2	14.00%	6.00%	80.00%
3.3	10.64%	2.13%	87.23%
3.4	4.08%	4.08%	91.84%
Section 4 - Pavement maintenance management			
4.1	18.00%	10.00%	72.00%
4.2	18.75%	4.17%	77.08%
4.3	0.00%	4.08%	95.92%

Appendices III

List of machinery in AACRA Maintenance Department

S. No	Types of Machinery	Quantity	Condition		
			Good	Fair	Bad
1	Compressor	2		√	
2	Paver	3		√	
3	Roller	7		√	
4	Tractor	5		√	
5	Dump Truck	11		√	
6	Water Truck	1		√	
7	Dumper	3		√	
8	Cutter	3		√	
9	Grader	1		√	
10	Loader	2		√	
11	Asphalt Plant 3	2		√	

Appendices IV

Data collection Sheet for condition survey of Exisiting Asphalt Roads

SR.No	Street name	Total Length(m)	Road Type	Defect type	Defected area						
					Specific area	Length (m)	Width (m)	area (m^2)	Unit Price (m2)	Total Price (m2)	condition

DECLARATION

I, the under signed declares that this thesis is my original and has not been presented for a degree in any other universities and all sources of materials used for this thesis have been duly acknowledged.

Name: Temesgen Girmay

Signature:_____

Place: _____

Addis Ababa University, Institute of Technology School of Civil and Environmental Engineering.

Date of Submission: _____