<u>Pavement management system development for Mekelle city road network and prioritization of roads for maintenance based on their performance index</u>

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Pavement management system development for Mekelle city road network and prioritization of roads for maintenance based on their performance index

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The thesis is submitted to School of Graduate studies of Mekelle University in partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering

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Declaration

I hereby declare that all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Confirmation

The thesis can be submitted for examination with my approval as an Institute`s advisor.

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Abstract

Pavement represents an important asset which is a pillar for the economy of one nation and this demands well-organized asset management. In Mekelle city, intensive investment has been made on constructing and maintaining roads at a network level. The current maintenance strategy followed by Mekelle city municipality is reactive. It responds to a problem after it has occurred. Instead of providing preventative maintenance at an early stage, roads are left until much more expensive reconstruction is needed and this maintenance delay will induce rising cost. This, in turn, causes spending a large amount of money to maintain extensively distressed pavements. The network needs great caution through periodic evaluation of pavement conduction and timely maintenance to keep the network operating under an acceptable level of service.

This research work is intended to develop web-based flexible pavement management system software for Mekelle city road networks which will support the local road agency on road maintenance decisions. The developed decision supporting tool software compiles the basic components of a pavement management system using MySQL as a database creating quarry language and PHP software creating platform. The components of the pavement management system are framed as input data, analysis part and reporting tool for the outputs of the analysis section. The software uses road inventory data, road condition assessment data, road section data, and road traffic survey data as input. Storing all this data on its database the software utilizes those data to make pavement performance evaluation analysis employing the pavement condition index as a performance indicator. A case study of 6 km main access road segmented to eight sections was inspected to analyze the proposed pavement management system software.

Finally, the software reports the results of the analysis part in the form of road Id, pavement condition index, rating scale, repair alternatives, and maintenance strategy as end results of the analysis for each road on the network then a priority for maintenance is made based on PCI value. In addition to this, the developed system can perform life cycle cost analysis for each road on the network employing net present value as economic evaluation criteria. According to the analysis result of the developed software, Alula Street i.e. form commercial bank of Ethiopia to Romanat roundabout is with least pavement condition index value, a PCI value of 11.17, a rating scale of very poor, and the corresponding maintenance strategy is reconstruction.

Key Words: Pavement Management System, Pavement Condition Index (PCI), Priority, and Net present value (NPV)

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Contents

Abstract 1
Acknowledgements 2
List of figures 5
List of tables 6
Abbreviations 7
CHAPTER-ONE 8
Introduction 8
1.1 Background 8
1.2 Problem Statement 11
1.3 Research Objective 12
1.4 Research Utilization 12
1.5 Research Organization 12
1.6 Study Area 13
CHAPTER-TWO 15
Literature Review 15
2.1 Introduction 15
2.2 Pavement Management System 15
2.2.1 Pavement Management System Components 15
2.2.2 Pavement Management System Process 16
2.2.3 PMS Benefits 17
2.2.4 Pavement Distresses 18
2.3 Pavement Performance Evaluation Methods 18
2.3.1 PSI Method 19
2.3.2 PCI Method 19
2.4 Treatment Selection 20
2.4.1 Scheduled Approach 20
2.4.2 Condition Responsive Approach 21
2.5 Prioritization 22
2.6 Integrating Software and Database into PMS 23
CHAPTER-THREE 26
Materials and Methodology 26

3.1 Introduction 26
3.2 Materials 26
3.3 Methodology 26
3.3.1 Introduction 26
3.3.2 Data Collection 27
3.3.3 Database Development 29
3.2.3 Procedures to Analyze Pavement Data 32
3.4.2 Phase one: Frame Work Design for the Software 37
3.4.3 Phase two: Integration of PMS components to the software 38
CHAPTER - FOUR 40
Result and discussion 40
4.1 Structure of the Developed Web Based PMS Software 40
4.1.1 Database 40
4.1.2 Analysis Scheme 47
4.1.3 Report Scheme of the Software 52
4.2 Repair Alternatives 54
4.3 Maintenance Priority Ranking 57
CHAPTER-FIVE 58
Conclusion and Recommendation 58
5.1. Conclusion 58
5.2 Recommendation 59
References 60
Appendices 63
Appendix-1: Road condition survey datasheet format 63
Appendix-2: Repair alternative for each distress type and severity 64
Appendix-3: Equations developed to estimate deduct value form ASTM curve 76
Appendix-4: Demonstrative example on basic PCI calculations and result interpretation 97
Appendix-5: Deduct Values determining ASTM standard curves 99
Appendix-6: Distress Type and Description 1

List of figures

Figure 1: Asphalt road development over series of time Mekelle city 10
Figure 2: Study area description as case- study 14
Figure 3: Components of MC-PMS 27
Figure 4: Activities involved in MC-PMS 30
Figure 5: Flexible database for deduct value computation 31
Figure 6: Flexible database for maintenance need selection 32
Figure 7: PCI calculation procedure 34
Figure 8: Frame-work design for MC-MPS 38
Figure 9: Login system for MC-PMS 41
Figure 10: Inventory data entry interface 43
Figure 11: Section data entry interface 43
Figure 12: Condition survey data entry interface 45
Figure 13: Traffic survey data entry interface 45
Figure 14: LCCA data entry interface 46
Figure 15: Corrected deduct value curve 48
Figure 16: CDV calculation interface 48
Figure 17: PCI calculating interface 49
Figure 18: Outputs of the software 52

List of tables

Table 1:Infrastructure development over series of time Mekelle city 9
Table 2.Study area description as case study.. 13
Table 3.PCI value and corresponding rating scale (ASTM D6433 Rating Scale (ASTM 2007)) 35
Table 4.PCI value and corresponding maintenance strategy. According to World Bank, (2003).36
Table 5: Flexible pavement rating and evaluation scheme.. 50
Table 6: PCI value vs Maintenance strategy.. 54
Table 7: Distress type vs repair alternatives 55

Abbreviations

AACRA	Addis Ababa City Road Authority
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transport Officials
AC	Asphalt Concrete
ASTM	American Society for Testing and Materials
CDV	Corrected Deduct Value
DV	Deduct Value
DV-L	Deduct Value Low
DV-H	Deduct Value High
DV-M	Deduct Value Medium
ERA	Ethiopian Road Authority
ID	Identification
HDM-4	Highway Development and Management
LCCA	Life Cycle Cost Analysis
PHP	Hypertext Preprocessor
MC-PMS	Mekelle City Pavement Management System
MCRN	Mekelle City Road Network
MySQL	My structured Quarry Language
PCI	Pavement Condition Index
PMS	Pavement Management System
PSI	Pavement serviceability Index
TDV	Total Deduct Value

CHAPTER-ONE

Introduction

1.1 Background

Transportation infrastructure plays a vital role in the economic, social, political development of all countries. The impact of growth and prosperity achieved in this sector extends to include other sectors, and therefore, there is a strong relationship between growth in the transportation sector and the growth of a country's economy as a whole. Pavements are huge investments and demand well-organized institutions and management systems to preserve them to the desired service life.

According to American Association of State Highway and Transportation Officials (AASHTO) pavement management is defined as "…the effective and efficient directing of the various activities involved in providing and sustaining pavements in a condition acceptable to the traveling public at the least life cycle cost is known as pavement management system (AASHTO, 1985).

A great deal of money can be saved as a result of implementing a pavement management system in a country. For instance, in 1974, the ADOT (Arizona Department of Transportation) allocated $25 million to pavement preservation and by 1978 the preservation budget had increased to $52 million. The development in ADOT has resulted in huge cost savings. The $600,000 spent on research, including outside contracts and staff time and expenses, was recovered more than 20 times over during the first year of its implementation (TRB, 1983). The state saved more than $200 million in five years by applying the Pavement Management System (PMS) to pavement preservation programming (Mandanat, 1997).

Mekelle city

Mekelle city is one of the fast-growing cities in Ethiopia and is becoming an ideal place of visiting and investment hub. The city has more than a 518 km network of road transport, of which 96.7 km is asphalt road, 187 km of cobblestone, and the rest 234 km is gravel and earthen road. (Mekelle municipal office, 2018).

Table 1: Infrastructure development over series of time Mekelle city

Infrastructure development over series of time Mekelle city						
Year	Asphalt(km)	Cobble stone (km)	Gravel road(km)	Drainage (km)	Number of bridges	Open dich(km)
1997	10		45	---	6	3.5
1998	20		60	---	10	45
2007	40		80	5.96	14	5.53
2008	45	3.05	108	21.36	20	
2009	---	7.5	---	21.9	24	
2010	---	14.5	114	2.66	30	
2011	54.6	23	152	---	36	
2012	55.3	60.6	154.5	28.51	40	
2013	55.3	88	157	---	46	
2014	65	112	159.5	47.9	50	
2015	72	134.5	162	51.6	55	
2016	80	135	164	3.4	55	
2017	81.2	167	189.3	60.3	63	
2018	78.2	177	209	60.58	65	
2019	96.7	187	234	67.38	69	

Source: (Mekelle city construction and design office).

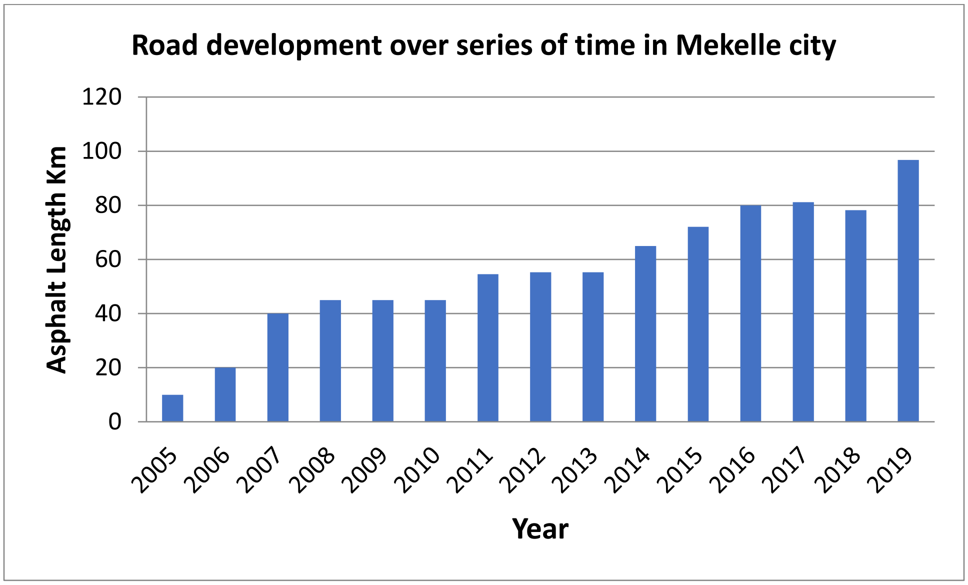


Figure 1: Asphalt road development over series of time Mekelle city

1.2 Problem Statement

According to Mekelle city construction and design office, huge investments have been made in constructing asphalt roads. AS the infrastructure development program of the city indicates there was only 10 km asphalt concrete road in 2005, this stretch of road is extended to 96.7 km in 2019. Even though there is a good road infrastructure extension program, the city is facing a challenge in dealing with the aging of pavements and the quality of the road network.

The current pavement maintenance practice of Mekelle city municipal reveals that:

1. There is a lack of documentation
2. There is no use of database programs in storing and processing the system data in the Road Management and Maintenance Department.
3. The system is poor to assist in making decisions.

Roads are not preserved well but instead left to prematurely deteriorate due to lack of adequate maintenance practice. Instead of providing preventative maintenance at an early stage, roads are left until much more expensive reconstruction is needed. Consequently, the short span of extra service years during the delay of maintenance, maintenance resource is being purchased at a very high price in terms of increased upgrade costs.

From the above mentioned points, there is a strong need for a comprehensive Pavement Maintenance Management System (PMMS) that involves:

1. Databases: To facilitate the physical data of the system to be managed and allow data storing, retrieving, displaying, updating, and getting information and queries.
2. Evaluation System: To assist in making timely and cost effective decisions related to the maintenance and rehabilitation of pavements
3. Modeling system: To provide information about maintenance needs, cost, priorities, etc.

This research sought to address the maintenance problem of the city road network by providing an automated maintenance system by replacing the current manual method of pavement management.

1.3 Research Objective

The main aim of the study is to develop a web-based pavement management system for road network maintenance to serve as a decision support tool for Mekelle city road agency to improve the efficiency of making decisions on maintenance work.

The specific objectives of this study are:

- ✓ To review information about the pavement management system and design the framework for the software based on the information about PMS components.
- ✓ To select an evaluation method for pavements performance on the network.
- ✓ To develop a database that is easily accessible and web-based software for facilitating the pavement management process.
- ✓ To prioritize the pavements in the city for maintenance based on performance indicator and to provide maintenance treatment strategies

1.4 Research Utilization

A pavement management system is not well developed in our cities. This research will be a reference for further studies in this area. And also, the Mekelle city municipality can use the predicted distress density to allocate the required budget and materials to maintain the roads. Not only this but also some other researchers can get information regarding MCRN which can save time and energy to collect information about the network partially. Therefore, we have full hope that this study will have full utilization by others.

1.5 Research Organization

This thesis consists of five chapters. Chapter one is an introduction chapter where need of a pavement management system for Mekelle city. The problem statement, the research objectives and the proposed utilization of the research are also stated.

The pavement management process, pavement evaluation and pavement performance model are reviewed in chapter two, while the research methodology, the description of the research database development, Analysis of pavement distress data and the developed model, analysis of pavement condition data and developed models, and application of the developed model, is addressed in chapter three. Finally, chapter 4 points out results and discussion finally chapter 5 contains conclusions and recommendations resulting from this research.

1.6 Study Area

The study is conducted on only eight road of the city due to time and resource constraints. Surface type, distress type of each road segments and extent of the distresses is estimated.

Table 2.Study area description as case study

Road ID	Road Local Name	Road Start	Road End
04-002	04-002	Adihaki campus main entrance	Abrha Castle
01-139	Alula Avenue	Abrha Castle	Romanat Roundabout
01-111	Hawzen Avenue	Romanat Roundabout	Hawzen Roundabout
01-092	01-092	Hawzen Roundabout	Dedebit Micro-finance head office
01-127	Selam Avenue	Romanat Roundabout	Atse yohannes Hotel
01-144	Ageazi Avenue	Milano Hotel	Romanat Round About
01-174	01-174	Commercial Bank of Ethiopia (CBE)	Aksum Hotel
01-169	Guna Avenue	Dove Café	Mekelle Health Center (MHC)

Figure 2: Study area description as case- study

Source (esri open Street Map contributor, online ArcGIS)
Link; https://arcg.is/9rnSq

Legend

Road-04-002 (green)	Road-01-127 (yellow)
Road-01-139 (red)	Road-01-144 (dark blue)
Road- 01-111 (dark red)	Road-01-174 (black)
Road-01-092 (light orange)	Road-01-169 (purple)

CHAPTER-TWO

Literature Review

2.1 Introduction

This chapter introduces a general components of pavement management system, pavement evaluation, and methods of scoring pavement condition, treatment selection approaches used to select treatment, prioritization and different prioritization methods and database system and software methods have also been discussed.

2.2 Pavement Management System

A PMS is a tool that can be used to make informed decisions about the maintenance and rehabilitation of a pavement network. The Ethiopian Road Authority (ERA) defines a pavement management system as a set of tools or methods that assist decision makers in finding optimum strategies for providing, evaluating, and maintaining pavements to prolong their service life. PMS is defined as a systematic method for routinely collecting, storing, and retrieving the kind of decision-making information needed to make use of limited maintenance (and construction) dollars according to the American Public Works Association (APWA). The American Association of Highway Transportation Officials (AASHTO,1985) states that 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 same organization."
Pavement management is expressed as well-organized set of activities all directed toward achieving the best value possible public funds in providing and operating smooth, safe, and economical pavements (Hudson et al,1997).

2.2.1 Pavement Management System Components

Pavement management systems differ in detail from road authority depending upon their specific needs. However, the typical components and processes as inputs to the PMS are as follows: -

- ✓ *Data storage*. The database is the key element of a PMS, which is continually updated with pavement surveillance measurements, traffic data and as-built information. Much of the effort developing the PMS is in the building of the database and the manner in which large amounts of data are stored and retrieved.

- ✓ *Data acquisition*. There is an amount of data to be collected and periodically updated. With current practices, large amounts of data can be collected at high speed using sophisticated surveillance vehicles. Location referencing of all data is done using GPS technology. The processes of these data gathering devices, their accuracy and limitations, have a substantial impact on the results and analysis using the data.
- ✓ *Criteria*. These are employed in the evaluation of pavement condition and subsequent identification of maintenance or rehabilitation options. Minimum and maximum levels of threshold for the various criteria are defined, and form the basis of performance-based contracts.

Generally speaking the pavement management system should comprise the following main components (Prakash A, 1995).

1. An information system to collect, store and manage and information. It should be able to treat road inventory data, road condition data such as distress survey data, and traffic survey data which are key for pavement performance evaluation and maintenance priority analysis.
2. A decision support system to process the data and information for decision making. This include pavement condition, pavement performance, and economic analysis.
3. Feedback and report scheme process which uses on-going field observations to improve the reliability of PMS analysis and the report tool gives an output of the analysis in table or chart formats.

2.2.2 Pavement Management System Process

The application and implementation of the pavement management system to a specific road agency are completed with a systematic procedure that involves a variety of tasks on a periodic basis. This procedure is used worldwide with little variation and modification on the basis of system customization regarding the need for road agencies.

A pavement management system process tasks include:

1. Defining the city road network by breaking into manageable segments and creating road inventory for each road segment.
2. Gathering and inspecting the pavement condition of each road segment.
3. Calculating the pavement condition by the selected evaluation criterion.
4. Determining the treatment strategy based on the pavement condition.
5. Developing a method of prioritizing segments for maintenance when funding constraints exists in a pavement maintenance program.
6. Documenting and reporting analysis results.

2.2.3 PMS Benefits

There are a number of benefits in using a PMS instead of using engineering experience and judgment a lone. A PMS can (Prakash, 1995).

1. Provide an inventory of pavements that includes data on location, type of pavement functional classification, mileage, pavement area, etc.
2. Provide a comprehensive database containing information relating to pavement condition, traffic levels, construction, maintenance and rehabilitation histories, and any additional quantifiable information that may be needed or specified.
3. show the current condition of the pavement network based on systematic and sound engineering procedures for obtaining objective pavement condition information
4. define an estimated budget required to bring the total roadway network from its current condition to desired condition levels
5. help to predict the projected condition of the network over time, as a function of the funds available to make improvements

2.2.4 Pavement Distresses

Damage and deterioration of pavements are made apparent as a result of traffic, pavement and climatic or environmental factors. These factors cause surface fatigue, consolidation or shear, developing in the subgrade, subbase, or pavement surface (Yoder E. et al, 1976).

Traffic factors include traffic volume, heavy axle load repetitions, accelerating and decelerating traffic while pavement factors may include excess asphalt, poorly graded mix, inadequate particle interlock and poor subgrade drainage. Temperature variation and rainfall are examples of climatic factors. The deterioration of a pavement is also apparent by various external signs and indicators called pavement distresses. Pavement distresses fall into one of the following categories

1. Cracking
2. Distortion
3. Disintegration
4. Loss of skid resistance

For detailed description of each distress type look on appendix-6.

2.3 Pavement Performance Evaluation Methods

The essential function of the PMS at the network level is to evaluate the acquired data, using predefined performance criteria, so that a maintenance and rehabilitation program can be produced. Various analyses are carried out to obtain the following: -

- ✓ Present needs of the network.
- ✓ Distress distribution of the sections.
- ✓ Maintenance and rehabilitation alternatives for the network.
- ✓ Technical and economic evaluation of the appropriate or acceptable maintenance and rehabilitation alternatives.
- ✓ Priority analysis

Evaluation is a key part of PMS because it provides the means of seeing how well the PMS components have been satisfied. Pavement Condition Score quantifies pavement performance. Based on measurements of surface distress that are collected from survey pavements can be assigned a score that reflects their overall condition. Different agencies and organizations have different names for the scores but the purpose is similar everywhere.

By carefully selecting the rating scale, pavement condition scores can be used to (Deighton, 1997).

- ✓ *Trigger treatment;* once a pavement condition index rating reaches a certain level, it can be scheduled for maintenance or rehabilitation.
- ✓ *Determine the extent and cost of repair;* A pavement condition index score is a numerical representation of a pavement overall condition and can thus be used to estimate the extent of repair work and likely cost.
- ✓ *Determine a network condition index*; by combining pavement condition scores for an entire road network, a single score can be obtained that gives a general idea of the network performance condition as whole.
- ✓ *Allow equal comparison of different pavements*. It can be used to compare two or more pavements with different problems on equal ground.
- ✓ *Develop a network preventive maintenance strategy*
- ✓ *Develop a network preventive maintenance strategy*
- ✓ *Evaluate a pavement materials and designs*

2.3.1 PSI Method

The present serviceability index (PSI) is based on the original AASHO Road Test PSR (Pavement Serviceability Rating). Basically, the PSR was a ride quality rating that requires a panel of observers to actually ride in an automobile over the pavement in question. Then the panel of observers provides their judgment about the pavement. This method is then modified and some objective ratings such as Slope variance, Rut depth and Cracking and patching where included. PSR estimated from objective physical measurement are termed as PSI. The measure of roughness was also used to determine PSI of the pavement (Hass et al, 1979). PSI ranges from 5 (excellent rating) to 0 (essentially impossible).

2.3.2 PCI Method

The Pavement Condition Index (PCI) is a numerical index between 0 which is the worst possible and 100 which is the best. It is a statistical measure and requires a manual survey of the pavement. PCI computing processes and calculation methods have been standardized by ASTM for both roads and airport pavements. PCI method of performance evaluation is a simple, convenient and inexpensive way to monitor the condition of the surface of roads, identify maintenance and rehabilitation needs, and ensure whether road maintenance budgets are spent wisely or not (ASTM, 2007).

PCI measures two conditions. These are the type, extent, and severity of pavement surface distresses and the smoothness and ride comfort of the road. It's a subjective method of evaluation based on inspection and observation. Manageable road sections, a road inventory and a classification and rating system for road defects is everything that is required to undertake this method. Due to these reasons, PCI is chosen as the best method of scoring the pavement condition.

2.4 Treatment Selection

Treatment selection is process by which appropriate type of remedial for pavement distress is selected based on cost-effective principles. There are two approaches of selecting the appropriate treatment for pavement once the decision has been made to maintain it.

2.4.1 Scheduled Approach

It is an approach in which a fixed amount of maintenance work is specified at a fixed interval of time. In scheduled approach activities are performed to protect the pavement and decrease the rate of deterioration of the pavement quality. This method is used when the deterioration rate is stable and treatment selection issues are related to engineering decisions about the treatment method rather than to fundamental decisions about which treatment to apply.

When this approach has followed the maintenance, works are called preventive maintenances. There are two types of preventive maintenances:

i) Surface Seal**s**: These are activities consisting of applications of asphalt alone continuously to the whole surface of a traffic lane.

- ✓ *Fog seals:* Involves a light application of a slow setting emulsion sprayed directly to an oxidized pavement surface. The primary objective is to restore/ rejuvenate the asphalt cement at the surface of the roadway and seal minor surface cracks and voids.
- ✓ *Rejuvenators***:** They are made from tar products to make the surface resistant to fuel spillage.

- ✓ *Chip Seal***:** A chip seal consists of a sprayed application of asphalt binder followed by a thin layer of aggregate which is rolled as soon as possible. They provide several benefits, such as providing a new wearing surface, waterproofing the surface, sealing small cracks, protecting the original surface from solar radiation, and improving surface friction.
- ✓ *Sand seal:* is a type of single surface treatment that use sand as a cover aggregate. Sand seals are low cost treatments.
- ✓ *Slurry seals***:** slurry seal is a mixture of asphalt emulsion, well-graded fine aggregate (sand), mineral filler, additives as needed, and water. Slurry seals are used to seal minor surface cracks and voids, slow weathering and raveling, and improve surface friction characteristics.

ii) Crack Sealing: Crack Sealing is a routine maintenance activity which involves cleaning out the cracks and filling the clean cracks with a sealant in order to prevent water and non-compressible from entering the pavement structure.

2.4.2 Condition Responsive Approach

In this approach work is conducted or triggered when the pavement condition indicators reach a critical threshold known as an 'Intervention interval'. The treatment selection method involves the use of a larger number of indicators and the use of more detailed rules. When this type of approach is used to select the feasible treatment, the maintenance works are called corrective maintenances.

Corrective maintenance consists of:

i) Patches**:** This is a repair method for localized areas of intensive cracking, whether the cracking is a load associated or environmental or construction related. The affected area of pavement is removed and replaced by new material.

ii) Chip Seals**:** This is a sprayed application of asphalt binder followed by a layer of aggregate. The advantages of chip seals includes providing a new wearing surface, waterproofing the surface, sealing small cracks, protecting the original surface from solar radiation, and improving surface friction.

2.5 Prioritization

Prioritization is a process of selecting, ranking, and prioritizing a pavement for maintenance based on the budget allocation, the functional classification of the road and the traffic hierarchy. Priority analysis is systematic process that determines the best ranking list of candidate sections for maintenance based on specific criteria such as pavement condition, traffic level, and functional class of the road, etc. Various methods are used for priority analysis ranking from simple listing based on engineering judgement to true optimization based on mathematical formulations (Shah et al, 2012).

All road work agencies need to factor in budgetary limitations when planning their maintenance program. Engineers responsible for road maintenance faces an additional challenge that available funds are never sufficient. It is there for necessary to assess the importance of various work interventions to ensure that available resources are utilized in the most effective manner (Chris et al, 2007)

In most cases during budget allocation, 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 depending on several factors such as present condition of the road i.e. quantity and level of deterioration, increasing rate of deterioration, importance of selected road, and traffic load (Agarwal, 2006). The following is a list of methods for establishing priorities. However, alternate methods can be used based on an agencies policies and administrative decisions to select its own prioritization routine over time.

A. ***Matrix method;*** 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 (worst) to 100 (for best).Priories can combine condition score with such factors as functional class or traffic in order to develop a final project list.
C. Benefit -cost ration; the segments with highest benefit to cost ratio would have the highest priority. Whereas the precious methods are likely to favor a worst first approach.

The benefit to cost ratio can provide high priorities for pavements in fair to poor condition rather than always starting with the pavements in the worst condition.

The most known method that used to calculate the PI value using defect indices is rational factorial method. It uses, PCI, traffic, condition rating as a variable to develop the equation: All the prioritization analysis of Mekelle city road has been done using the PCI value.

2.6 Integrating Software and Database into PMS

Different countries have implemented pavement management system to their major cities by developing software and databases specific to their road networks. Some of the developed software and some of their future are as follows (Kiema et al, 2009)

HDM-4

The Highway Development and Management system (HDM-4, 2003) which was developed by the World Bank and other international organizations, has been widely used in over one hundred countries including developing countries. Also, HDM-4 is recognized as a state-of-the-art system for the analysis of road management and investment alternatives because of the following advantages:

1) HDM-4 incorporate both agency costs and road user costs in life-cycle cost analysis,
2) HDM-4 uses calibration parameters for broad-based applicability in diverse climates and conditions, and
3) HDM-4 includes an appropriate design tool for pavements, if properly calibrated, especially for developing countries (Tsunokaw and Ul-Islam,2003)

HDM-4 has been used for a pavement management system (PMS) by various major projects such as the highway management capacity improvement project (HMCP, 2002) and the road network improvement project in Vietnam (RNIP, 2003). These studies showed the potential and promise of using this advanced tool, incorporated with the existing tools in the PMS database, to establish the strategic management plan for the national road network (Tsunokawa and Ul-Islam, 2003).

PAVER^{TM}

Provides pavement management capabilities to inspection data and a pavement condition index (PCI^{TM}) rating from zero (failed) to 100 (excellent) for consistently describing a pavement's condition and for predicting its M&R needs many years into the future. The PCI for roads and parking lots became an *ASTM standard* in 1999 (D6433-09). The PAVER^{TM} program performs multiple levels of analysis to show where to best allocate scarce M&R dollars (Tsunokawa and Ul-Islam, 2003). This Pavement Maintenance Management System gives an output of PCI values and quantity of distress of all sample sections surveyed, as well as PCI of the all roads network.

STREETSAVER®

The Metropolitan Transportation Commission's Pavement Management Program (PMP) Street Saver® is a computer-assisted decision-making process designed to help cities and counties prevent pavement problems through cost effective maintenance approach.

The benefits of using StreetSaver include the following:

- This computer based application can predict the future condition of pavement for different levels of funding and show the effects of under-funded road programs.
- StreetSaver works as an effective tool for local jurisdictions to both manage and generate street and road revenues.
- MTC is able to document the Bay Area's needs and shortfalls and use the data to build support in the state Legislature for increased funding, as more and more jurisdictions complete their pavement needs analysis using StreetSaver, .

The systematic procedure that involved in PMS are following tasks on a periodic basis:

1. Defining the roadway network by breaking it into management segments and creating an inventory for each segment.
2. Inspecting and Gathering the pavement condition and maintenance data of each segment in the network.
3. Estimating the pavement condition by selecting an evaluation criterion.
4. Determine the treatment strategy and cost for each segment based on pavement condition. Condition.

5. Developing a method of prioritizing segments when funding constraints exist in a pavement maintenance program.
6. Documenting and reporting results.

PCI measures two conditions. These are the type, extent, and severity of pavement surface distresses and the smoothness and ride comfort of the road. It's a subjective method of evaluation based on inspection and observation. Manageable road sections, road inventory and a classification and rating system for road defects is everything that is required to undertake this method. Due to these reasons PCI is chosen as the best method of scoring the pavement condition.

CHAPTER-THREE

Materials and Methodology

3.1 Introduction

This chapter discusses the material and methodology used to develop the proposed Pavement Management System Software for Mekelle City. It illustrates the basic system components and framework design which are key to develop the system. The chapter is divided into three main sections; the first section presents the materials used and procedures followed to prepare the database required for the management system. The second section explains the method and procedures used to measure pavement performance. The last section presents the architecture of the developed software and complementary analysis to validate the software.

3.2 Materials

To developed the decision supporting tool software database, I used the following

- ✓ MySQL as database creating quarry language
- ✓ PHP and sublime as web-based software creating platform
- ✓ MS-excel and ASTM manual to develop deduct value equation as function of density of distress

While conducting pavement condition survey on the study area

- ✓ Metric tape to measure extent of distress
- ✓ Ruler to measure depth and permanent deformations
- ✓ PMS guideline to measure severity of pavement distresses

3.3 Methodology

3.3.1 Introduction

This research aims to develop a pavement management system which is powerful tool for storing, organizing, manipulating and analyzing data. The system incorporates a database system with a treatment models for the road networks owned by Mekelle City Municipality. Inventory, condition assessment and traffic survey are essential data used for the data analysis in the database system. The following figure shows the components of the developed PMS.

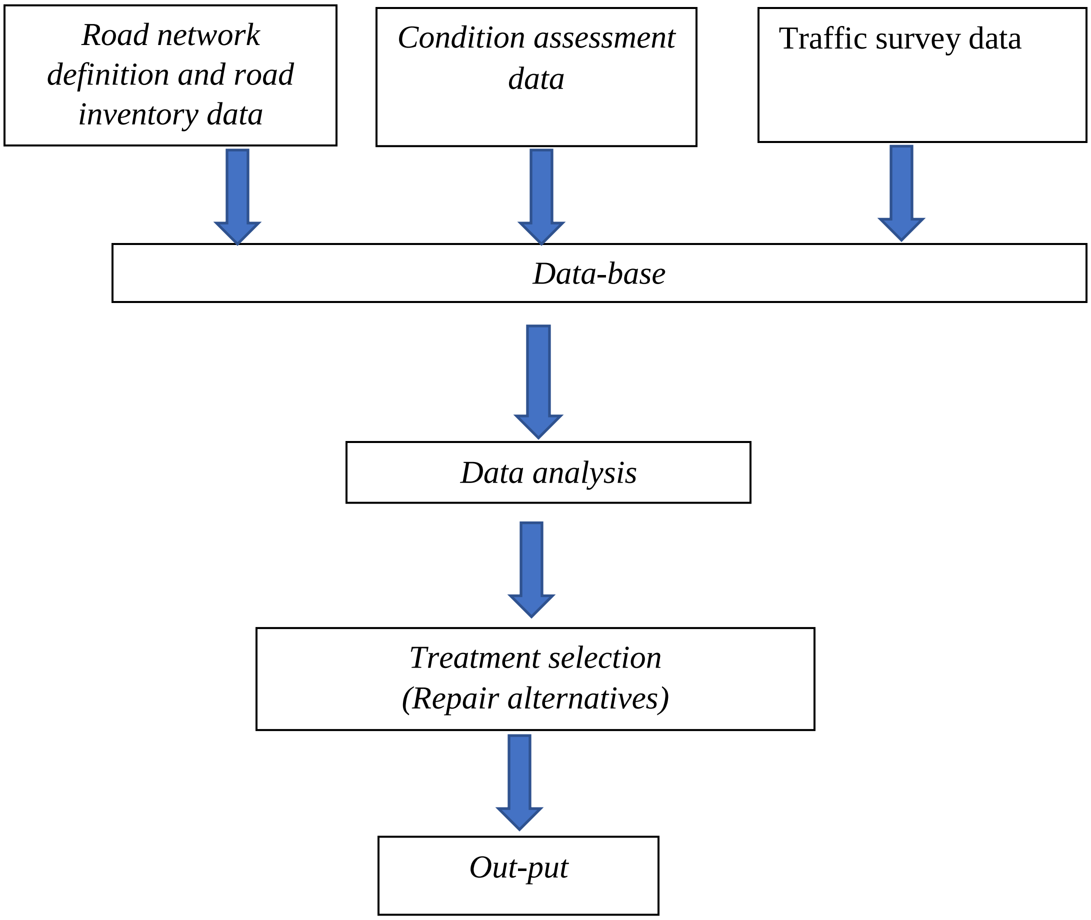


Figure 3: Components of MC-PMS

3.3.2 Data Collection

Four type of data are incorporated in the Mekelle City Pavement Management System (MC-PMS). These are

i. Road inventory data
ii. Condition assessment data
iii. Traffic survey data
iv. Life cycle cost analysis data

Road inventory and condition survey

In order to evaluate the pavements understudy, first, the surface conditions need to be assessed. It took one month to complete the assessment of the eight-road network of paved roads in Mekelle city. To achieve this goal the roads are segmented and named. The following section explains the segmentation and naming. Road inventory and condition assessment data are placed in the appendix in table format.

Condition assessments were conducted by walking through every road segment. When a distress is encountered first its type is identified then its severity and extent are decided and/or measured. ERA manual is used as a guideline to identify type, severity and extent of pavement distresses. Surface condition assessment format and the road inventory data collected are available in the appendix 1.

Traffic Survey data

The purpose of the traffic survey is to collect information on the number and type of vehicles using each part of the road network. This information is used in the system to model the deterioration and upgrading requirements of the roads.

The deterioration of pavement is mainly caused by traffic results from both the magnitude of the individual wheel loads and the number of repetition of these loads are applied. Especially in Mekelle which is an urban area repetition is the major cause of deterioration of the roads. Hence, for pavement design purposes it is necessary consider not only the total number of vehicles that will use the road but also the wheel loads. As a result, the survey shall include AADTs and classification of the traffic among the various vehicle categories.

3.3.3 Database Development

The database is developed by MySQL. MySQL provides a powerful set of tools that allow to quickly start tracking, reporting, and sharing information in a manageable environment. With its, interactive design capabilities, prebuilt library of tracking application templates, and ability to work with data from many data sources, MySQL allows to rapidly create attractive and functional tracking applications using advanced programming tools like java script and mySQL.

The Developed data base contains tables and queries. The tables are useful for storing datas while queries are usefull in storing data and calculating values by interacting with code builder PHP. Froms and reports are useful to display datas for the user with an interactive ways. The condition assesment data, the road inventory and the traffic survey are insereted by the user and stored in the database in a table format. These datas will be analysed using the database analysis tool. The anlysis tool contains queries equiped with PHP and expression builder equations to perform the required calculations. Then the calculated values are sorted and organized to be displayed to the user in the usre interactive forms.The activities involved in MC-PMS are illustrated by flow chart below.

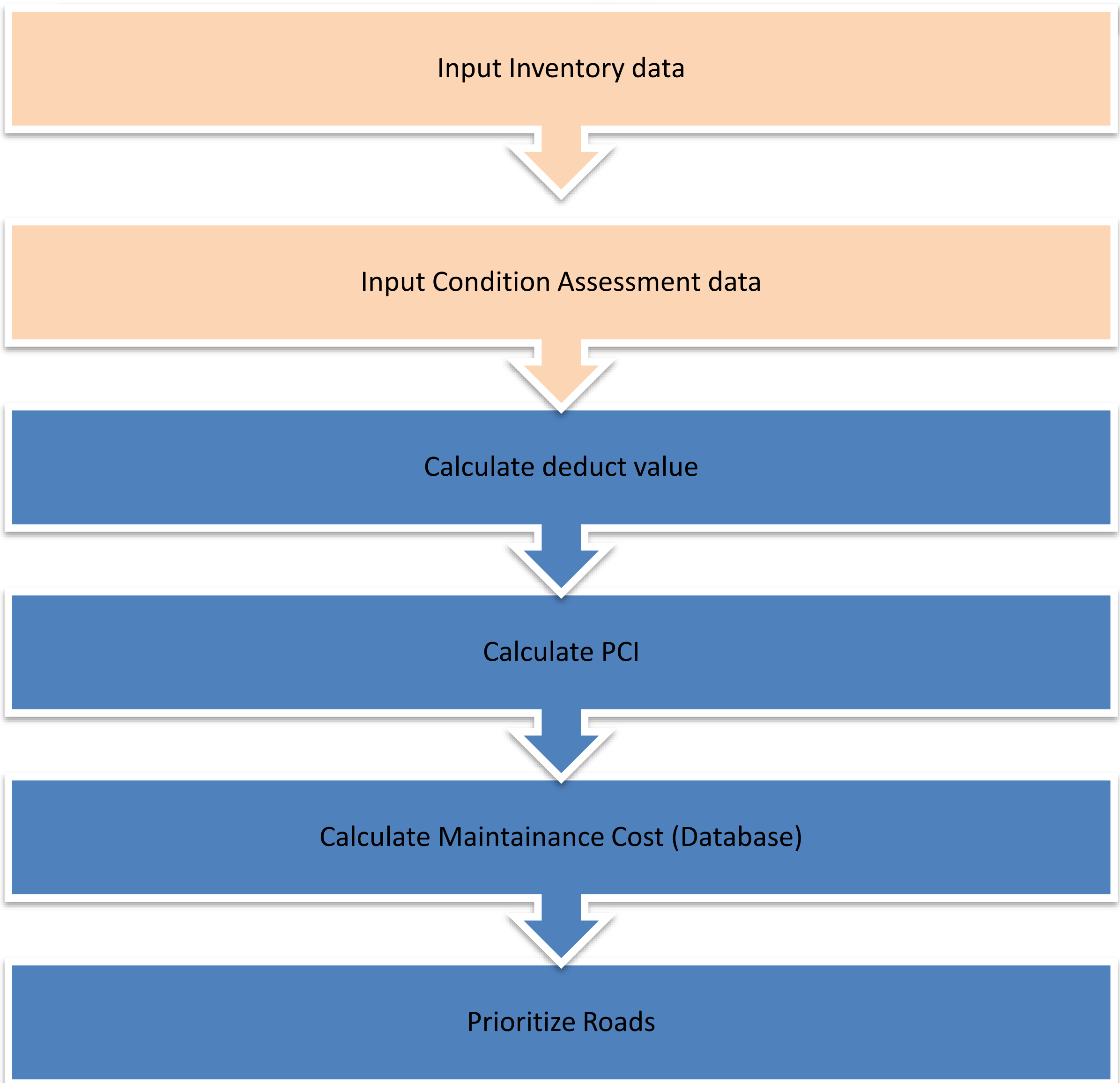


Figure 4: Activities involved in MC-PMS

The first step was to determine the equations for the deduct values as well as the corrected deduct value curves. The process of developing the curves was empirically based without any strict mathematical equations defining them as described in the ASTM D6433 document. Therefore, curves were replotted by estimating the coordinate values along with them. With the DV and CDV curve equations (see appendix -5) obtained they are programmed into the MySQL as a function of distress type and severity level.

Browse | Structure | SQL | Search | Insert | Export | Import | Privileges | Operations | Triggers

+ Options

←T→	Id	type	severity	a1	b1	a2	b2	a3	b3	a4	b4	a5	b5	a6	b6	a7	b7	c	d	k	m
Edit Copy Delete	1	Bleeding	Low	0	0	0	0	0	0	0.000001	3	-0.0011	2	0.306	1	0	0	0	0	0	0
Edit Copy Delete	2	Bleeding	Medium	0	0	0	0	0	0	0.0001	3	-0.0232	2	1.4361	1	0	0	0	0	0	0
Edit Copy Delete	3	Bleeding	High	0	0	0	0	0	0	0.0002	3	-0.032	2	2.3974	1	0	0	0	0	0	0
Edit Copy Delete	4	Block Crack	Low	0	0	0	0	0	0	0.00007	3	-0.0134	2	0.8889	1	0	0	0	0	0	0
Edit Copy Delete	5	Block Crack	Medium	0	0	0	0	0	0	0.0001	3	-0.0256	2	1.5976	1	1.507	0	0	0	0	0
Edit Copy Delete	6	Block Crack	High	0	0	0	0	0	0	0.0003	3	-0.0534	2	2.9935	1	3.2856	0	0	0	0	0
Edit Copy Delete	7	Corrugation	Low	0	0	0	0	0	0	0.000001	3	-0.0201	2	1.3864	1	0	0	0	0	0	0
Edit Copy Delete	8	Corrugation	Medium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13.292	0.4063
Edit Copy Delete	9	Corrugation	High	0	0	0	0	0	0	0	0	-0.2697	2	10.322	1	0.2273	0	0	0	0	0
Edit Copy Delete	10	Depression	Low	0	0	0	0	0.000003	4	-0.0003	3	0.0082	2	1.616	1	2.3455	0	0	0	0	0
Edit Copy Delete	11	Depression	Medium	0	0	0	0	-0.000001	4	0.0005	3	-0.06	2	2.9391	1	5.688	0	0	0	0	0
Edit Copy Delete	12	Depression	High	0	0	0	0	-0.0000094	4	0.0019	3	-0.1341	2	4.333	1	11.817	0	0	0	0	0
Edit Copy Delete	13	Edge Crack	Low	0	0	0	0	-0.00008	4	0.0043	3	-0.0987	2	1.6668	1	0	0	0	0	0	0
Edit Copy Delete	14	Edge Crack	Medium	0	0	0	0	0	0	0.0073	3	-0.2985	2	4.2809	1	3.767	0	0	0	0	0
Edit Copy Delete	15	Edge Crack	High	0	0	0	0	0	0	0.011	3	-0.4619	2	6.9654	1	6.69	0	0	0	0	0
Edit Copy Delete	16	Longitudnal Crack	Low	0	0	0	0	0	0	0.0017	3	-0.1076	2	2.6762	1	-0.771	0	0	0	0	0
Edit Copy Delete	17	Longitudnal Crack	Medium	0	0	0	0	-0.0005	4	-0.0321	3	-0.721	2	7.501	1	0.4023	0	0	0	0	0
Edit Copy Delete	18	Longitudnal Crack	High	0	0	0	0	-0.0007	4	0.0483	3	-1.129	2	12.947	1	4.0276	0	0	0	0	0
Edit Copy Delete	19	Transversal Crack	Low	0	0	0	0	0	0	0.0017	3	-0.1076	2	2.6762	1	-0.771	0	0	0	0	0

Figure 5: Flexible database for deduct value computation

In addition to the above deduct value computation equation, treatment action for each type of distress is incorporated on the database based on the extent and severity level of the distresses. The developed database size depends on the hosting server, it is apparent that the MySQL server is large and worldwide. Thus, the size of the developed system is unlimited it can store and retrieve large size data.

Browse | Structure | SQL | Search | Insert | Export

+ Options

	Id	type	distribution	severity	action
Edit Copy Delete	1	Alligator crack	Localized	Low	Crack seal
Edit Copy Delete	2	Alligator crack	Localized	Medium	patch
Edit Copy Delete	3	Alligator crack	Localized	High	patch
Edit Copy Delete	4	Alligator crack	Extensive	Low	Crack seal
Edit Copy Delete	5	Alligator crack	Extensive	Medium	Surface recycle
Edit Copy Delete	6	Alligator crack	Extensive	High	Thick overlay
Edit Copy Delete	7	Bleeding	Localized	Low	No action
Edit Copy Delete	8	Bleeding	Localized	Medium	Patch
Edit Copy Delete	9	Bleeding	Extensive	Low	No action
Edit Copy Delete	10	Bleeding	Extensive	Medium	Burn & sand seal
Edit Copy Delete	11	Bleeding	Extensive	High	Burn & sand seal
Edit Copy Delete	12	Corrugation	Localized	Low	No action
Edit Copy Delete	13	Corrugation	Localized	Medium	Patch
Edit Copy Delete	14	Corrugation	Localized	High	Patch
Edit Copy Delete	15	Corrugation	Extensive	Low	No action
Edit Copy Delete	16	Corrugation	Extensive	Medium	Surface recycle
Edit Copy Delete	17	Corrugation	Extensive	High	Surface recycle
Edit Copy Delete	18	Depression	Localized	Low	No action
Edit Copy Delete	19	Depression	Localized	Medium	patch
Edit Copy Delete	20	Depression	Localized	High	patch

Figure 6: Flexible database for maintenance need selection

3.2.3 Procedures to Analyze Pavement Data

This section tries to elaborate the mechanisms used in analyzing data that are obtained from primary and secondary sources calculation, treatment selection and prioritization methods of analysis have been briefly described.

a) Basic steps to calculate PCI

The following are the necessary steps that have been followed in calculating PCI

Step 1: Inspect sample units. Determine distress types, severity levels and measure density.

Step 2: Determine deduct values – it depends on the density of each severity distress

The distress type and severity are already decided by the condition survey. The density is calculated depending on the distress types.

- *For longitudinal wheel path cracking, edge crack and meandering cracks*

$$\text{Density} = \frac{\text{sum of Length of cracks}}{\text{number of crack times length of section}} * 100 \tag{1}$$

- *For Traverse Cracks*

The level depends on the average crack spacing

$$\text{Density} = \frac{\text{Length}}{\text{Number of crack}} * 100 \tag{2}$$

- *For Alligator Cracks,*

$$\text{Density} = \frac{\text{sum of area of cracks}}{\text{area of the section}} * 100 \tag{3}$$

- *For rutting, shoving and bleeding*

$$\text{Density} = \frac{\text{sum of Length}}{\text{n times length of section}} * 100 \tag{4}$$

- *For raveling*

$$\text{Density} = \frac{\text{sum of Length}}{\text{length of section}} * 100 \tag{5}$$

- *For potholes*

Level of severity depends on the number of potholes in the section of 50 meters It's Few, Frequent and throughout. It can also be quantified as distress area divided by the section area, but higher weighting factor must be used.

After the densities are calculated for each type of distress, the deduct values are read from graph for the given distress, density and severity. The deduct graph are available in the annex section.

Step 3: Adjust total deduct value, TDV = a + b sum of each type

In a given section of the road there may be more than one distress types hence more than deduct values. These deduct values are summed and total deduct value (TDV) is obtained.

Step 4: Adjust Total Deduct Value to Corrected Deduct Value:

Corrected deduct value is in between 0 and 100 while the total may be greater than 100.

Step 5: Compute Pavement Condition Index

$$\mathrm{PCI} = 100 - \mathrm{CDV} \tag{6}$$

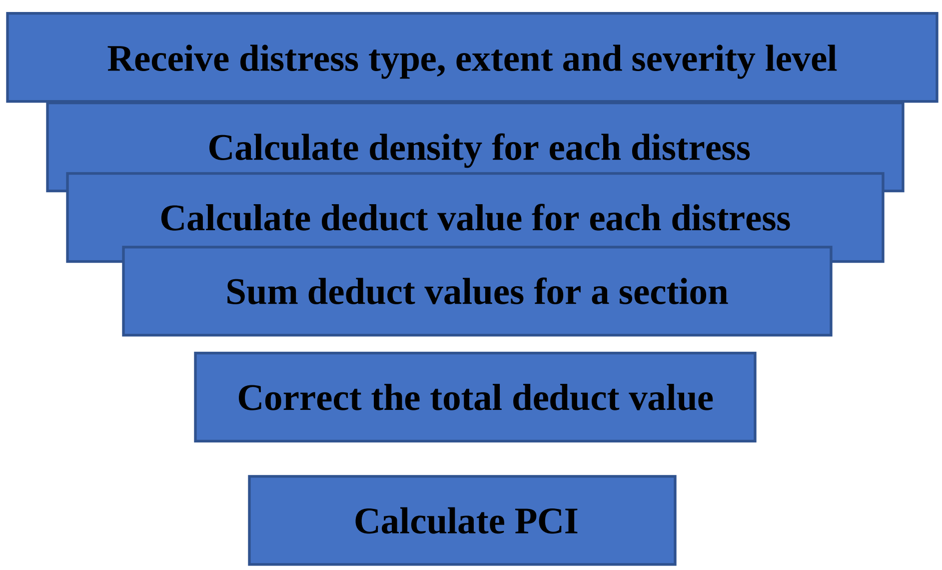


Figure 7: PCI calculation procedure

The road Id, width of road ,section length,distress type, length and width of distress, severety level of distress are values which are inserted by the users. The extent, density and deduct value is calculated by the database itself.

The developed software first idenfies which type of distress type and the severity level is selected by the user. Then the it calculates the extent, density, and deduct values for each type of distress using the predefined expressions or equations.

The calculated deduct values are summed and stored for each road section in the database. Then the deduct values will be corrected and the PCI of each road sections will be found by deducting the corrected deduct value from 100.

PCI and corresponding rating

Table 3. PCI value and corresponding rating scale (*ASTM D6433 Rating Scale (ASTM 2007))*

PCI	Rating
0 to 10	Failed
10 to 25	Very Poor
25 to 40	Poor
40 to 55	Fair
55 to 70	Good
70 to 85	Very Good
85 to 100	Excellent

PCI and corresponding maintenance strategies

Table 4.PCI value and corresponding maintenance strategy. According to World Bank, (2003).

PCI	Rating	General treatment strategy
0 to 10	Failed	Reconstruction
10 to 25	Very Poor	Reconstruction
25 to 40	Poor	Reconstruction
40 to 55	Fair	Rehabilitation
55 to 70	Good	Resurface
70 to 85	Very Good	Preventive Maintenance
85 to 100	Excellent	Do nothing/corrective

a) Life cycle cost analysis

Life cycle cost analysis is a process for evaluating the total economic cost of an asset by analyzing the initial costs and discounted future expenditures such as maintenance, repair and renewal cost, and user and social costs over the service life of the asset. The most common method of life cycle cost analysis method is the net present value method since it considers the time value of money.

Net Present Value – NPV

In order to estimate whether an investment could bring positive results, economic evaluation should be conducted. In the decision-making process, this is achieved by the net present value. This criterion can also be used to help the analysis about which investment option would be the most profitable one. The net present value (NET) is simply the difference between the discounted profits and costs in the course of the period of analysis.

$$NPV = \sum_{i=0}^{n-1} (bi - ci) / \left(1 + \left(\frac{r}{100}\right)\right)^{i} \quad (7)$$

n- is period of analysis related to the number of years

i- is current year, i = 0 in the basic year

bi- sum of all profits in the year and

ci- sum of all costs in the year and

r- discount rate expressed in percentages

NPV is a measure of the economic efficiency of an investment. Its positive value indicates that the investment is economically justifiable for the given discount rate and the pure net profit in higher by the increase of NPV. Thus, the selection should be based on NPV, meaning that priority should be given to projects where NPV is higher.

Economic analyses are essential from the viewpoint of planning of the sufficient funds for all activities envisaged within the management system and, ultimately, for making the correct decisions on the highest level of decision-making. As a whole, the management system cannot function without adequate cost-benefit analyses, that is, without Life Cycle Cost Analyses and appropriate comparisons of the invested funds and the profits hence the software employs NPV as economic evaluation criteria.

3.4.2 Phase one: Frame Work Design for the Software

A review was conducted regarding pertinent PMS components and data types for modeling pavement management structure. In addition, data organization and integration issues were examined, as well as analytical methods for modeling and presenting performance related data. Based on the review the following observation are made;

1. Data types collected for pavement performance evaluation and modeling varies from agency to agency depending on needs but the most common ones include inventory, road condition, traffic volume, and maintenance and rehabilitation data.
2. Adoption of common referencing system between various data collection systems can facilitate data integration for pavement performance modeling. The literature suggest that there is major barrier for achieving full data integration by agencies is lack of common referencing system compounded by the use of different data formats

Once pertinent issues to be considered on developing pavement management system is reviewed, the software modeling process can begin. The basic features of PMS are identified and they should be designed in such a way that the system is simple to users.

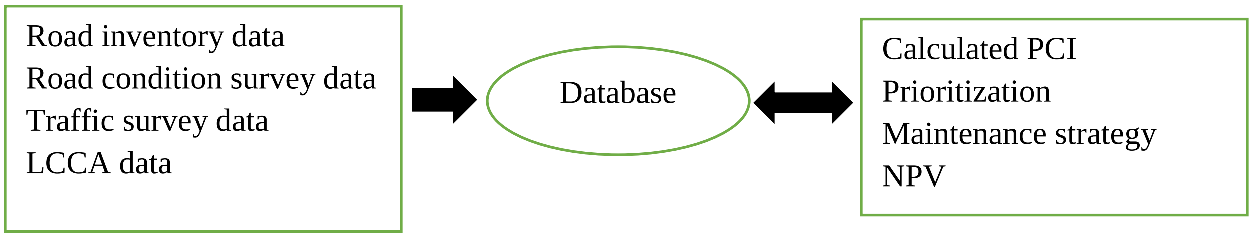


Figure 8: Frame-work design for MC-MPS

3.4.3 Phase two: Integration of PMS components to the software

The pavement management system should be comprehensive and easy to implement for data collection, entry, processing, and report generation. In addition to this the system should be modular and upgradable for new addition of capabilities in the future.

Based on these requirements,network coding,Road inventory data collection ,distress data collection,pavement performance evaluation,maintenance activity selection,maintenance priority ranking procedure, and other system activites will be formalized and coded in the form of computer package called ‘’Mekelle City Pavement Management System”. A computer program will be coded and complied using the PHP language and customized as a Web-based software.

System Parameters

Corrected Deduct Value

To estimate the performance indicator i.e. PCI first we should have to determine the deduct values for each distress. Deduct value is computed by applying the deduct value equations which are as a function of distress density and distress severity. The next step is, to sum up all deduct values of each distress on the road segment under study. Once we sum up all deduct value the total deduct value can result above 100, this value should be corrected unless the PCI value will be negative, applying the corrected deduct value curve shown below we estimate the CDV and we deduct this from 100 to obtain the PCI value of the corresponding road segment.

Pavement Condition Index

Pavement condition index is a numerical rating of the pavement condition based on the type and severity of distresses observed on the pavement surface. This value of the pavement condition is represented by a numerical value between 0 and 100, where zero is the worst possible condition and 100 is the best possible condition. The general procedure how to compute PCI is expressed on chapter three in section 3.2.3.

Maintenance Cost

The main purpose of the maintenance cost estimation is to determine the cost required to restore the pavement surface condition to its as constructed state. This cost information is important as feedback for planning and reconstruction need for the agency while prioritizing roads for maintenance. The developed system estimates the maintenance cost as function of distress area and unit cost of maintenance.

Net Present Value

In order to estimate whether an investment could bring positive results, economic evaluation should be conducted. In the decision-making process while maintenance priority is made the economic importance of prioritized link should be significant. The developed system can estimate NPV using the LCCA data feed on its database.

CHAPTER - FOUR

Result and discussion

4.1 Structure of the Developed Web Based PMS Software

The developed web based pavements management systems consist mainly of three major components: the first one is the database which is an information system to collect, store and manage road network data and information. It could be able to treat inventory data of the pavement segments, condition survey data, traffic data including AADT and life cycle cost analysis related data. The second section is analysis tool which is decision support systems to process the data and information for decision making. This include pavement condition and performance evaluation, maintenance and repair alternative, life cycle cost analysis and priority analysis based on pavement condition index. The last section contains report tool which display the outputs of the analysis section of the developed PMS software. One of the main features of the developed PMS software is its flexibility since it can be customized for different local pavement authority's need.

4.1.1 Database

The database is the first building block of any management system, since the analysis used and recommendations made by a management system should be reliable and current information, and the developed database behaves all these basic characteristics of database. The developed database system is very flexible, data can be edited, upgraded or deleted if accessed by authorized person. The developed PMS software supports SQL server database. This product represents the latest technology in relational database management systems. It has virtually no size limit and it can grow with the clients as the need arises. The developed database can store all inputs for pavement management system namely

a. Road inventory data
b. Road condition assessment data
c. Road traffic survey data
d. Life cycle cost analysis data
e. 39 equations for deduct value computation, 7 equations for determining the corrected deduct value and constants while estimating distress density and NPV.

Basic Features of the developed database and PMS software

1) Login system

System user management

The developed PMS software has secured user account management system. New users can be added to the system, each with a specified password. The authorized road asset administrator can utilize and update all PMS system parameters and data management.

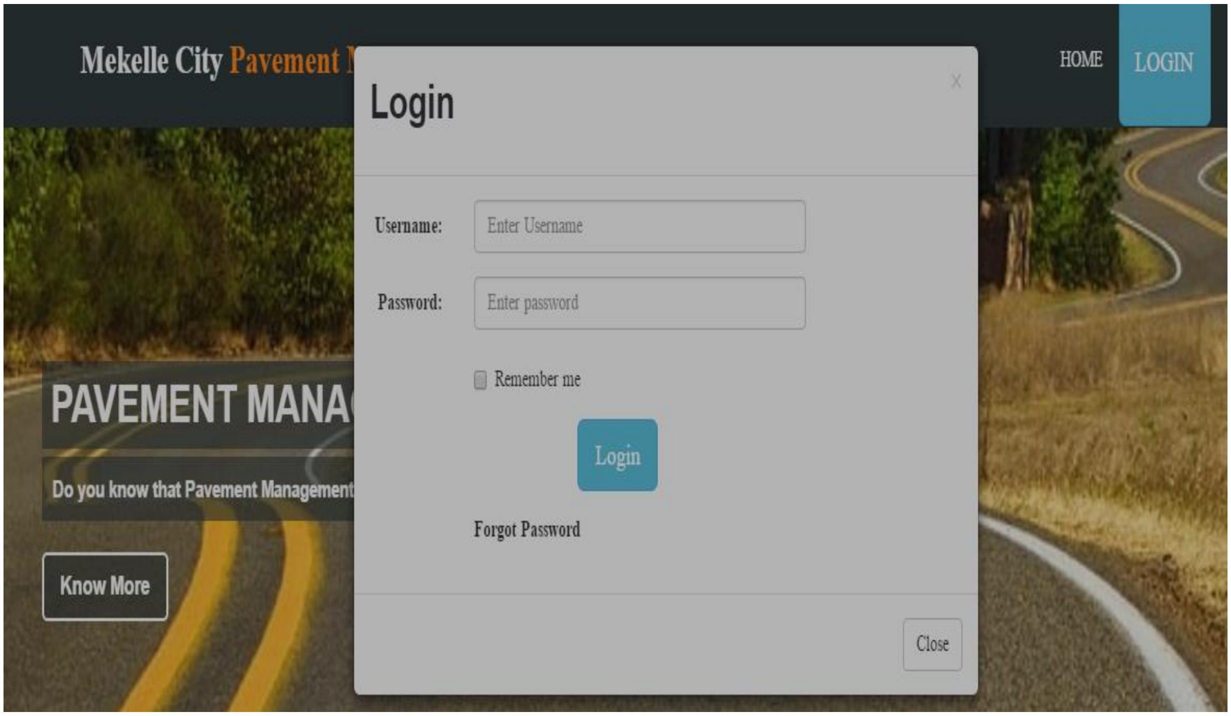


Figure 9: Login system for MC-PMS

2) Input Sections

This contains five basic input data entry interfaces

a. Road Inventory Data Entry Interface
b. Road Section Data Entry interface
c. Road Condition Assessment Data Entry Interface
d. Traffic Survey Data Entry Interface
e. Life Cycle Cost Analysis Data Entry Interface

Road Inventory Data Entry Interface

Road inventory data define the physical geometry of road sections. Each roadway segment is assigned a computer generated unique identification number. A roadway section (also known as an anchor section) is defined as a section of roadway connecting two or more nodes. This database contains node number, but also uses a Unique ID for each individual node, which eliminates any duplicate numbers in the system. A roadway section is defined as a section of roadway (line segment) connecting two points or nodes. Street Name is the name of each respective road as supplied by municipalities. The basic road inventory data parameters that define the physical feature of the road on this developed database are:

- Road Id (unique identification number)
- Road local name
- Road class
- Road Surface type
- Road start node
- Road end node
- Road length
- Road width
- Drainage characteristics
- Walk way characteristics
- Median characteristics
- Number of section on the road segment.

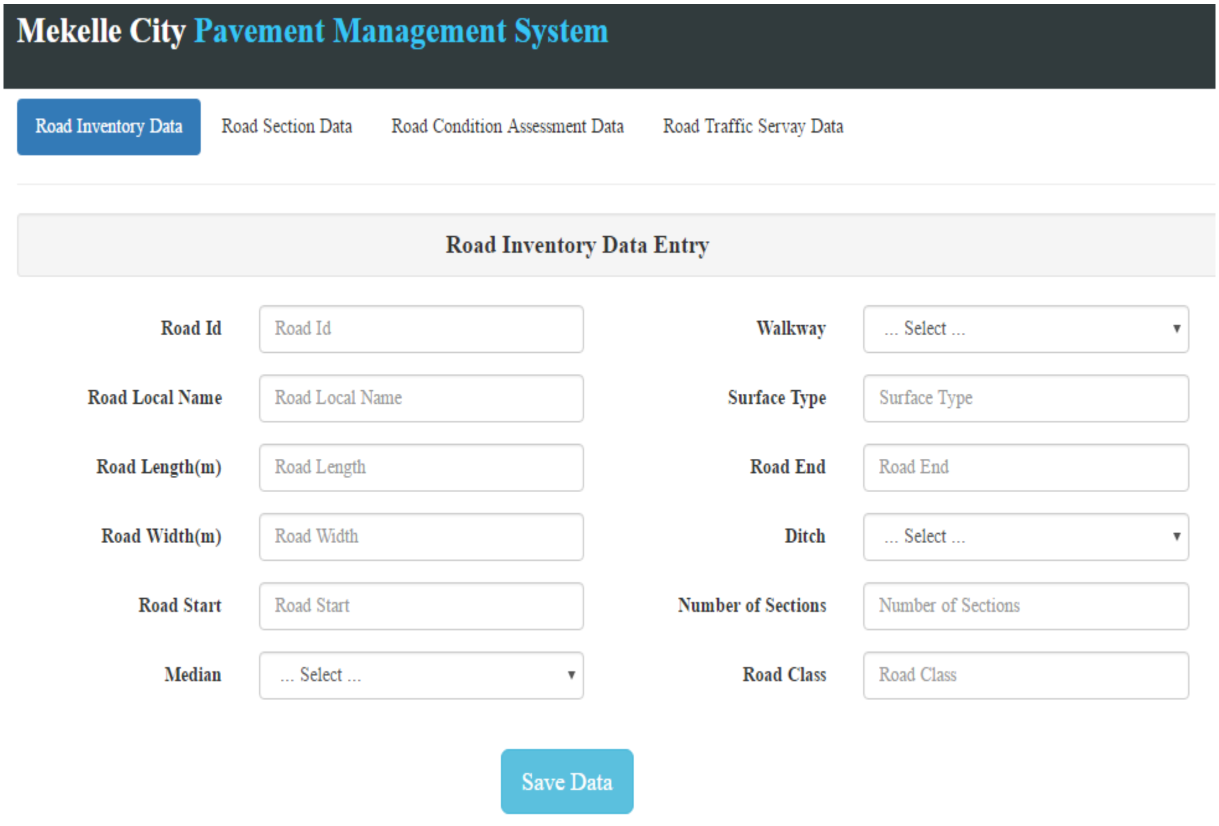


Figure 10: Inventory data entry interface

a) Road Section Data Entry interface

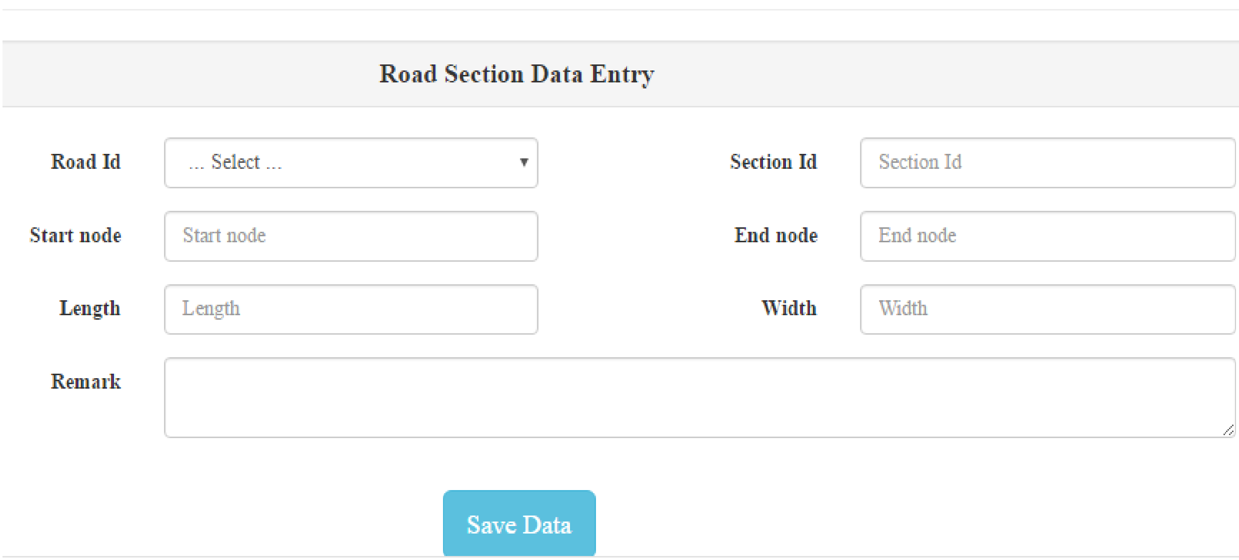


Figure 11: Section data entry interface

Road Condition Assessment Data Entry Interface

Once the pavement management inventory has been performed and all the data has been collected for each segment, pavement condition evaluation can begin. The major types of pavement distress to be recorded on the database for the pavement management system are described below. These are the principal condition indices that provide important information in predicting the pavement performance, and hence the road, life which enables long term strategies for maintenance to be determined. For the condition survey a form has been designed according to ASTM manual which will enable the major distresses to be recorded when the form is correctly completed. The basic road condition assessment dataset to be collected and Stord on the developed database are:

- Section Id
- Distress type
- Distress distribution
- Distress severity
- Distress length
- Distress width
- Distress density

Pavement condition data are collected by agencies to support pavement management system (PMS) for decision-making purpose as well as to construct performance model, perform cost-effectiveness analysis, conduct maintenance, rehabilitation analysis. Pavement condition and distress are analyzed using the combination of standard practices and procedures developed by ASTM. PCI is calculated for each road section form the profile data collected. The value of PCI indicates the condition of the road whether it is at good or worst level.

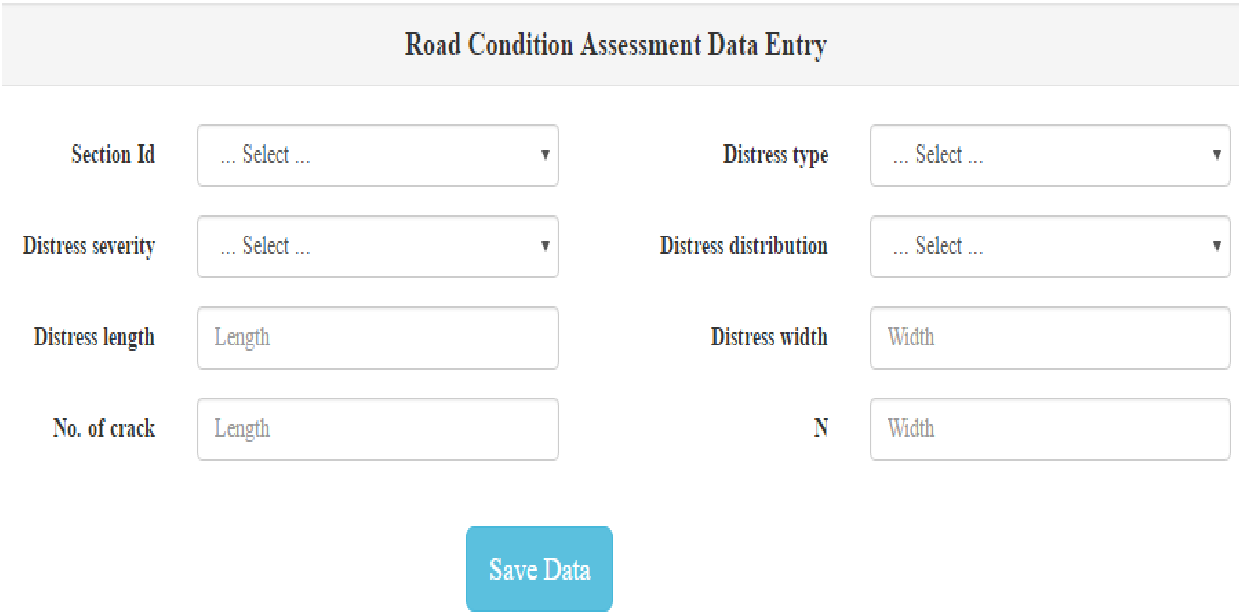


Figure 12: Condition survey data entry interface

b) Traffic Survey Data Entry Interface

Road Traffic Data becomes an essential element in decision-making traffic data is needed for planning maintenance.

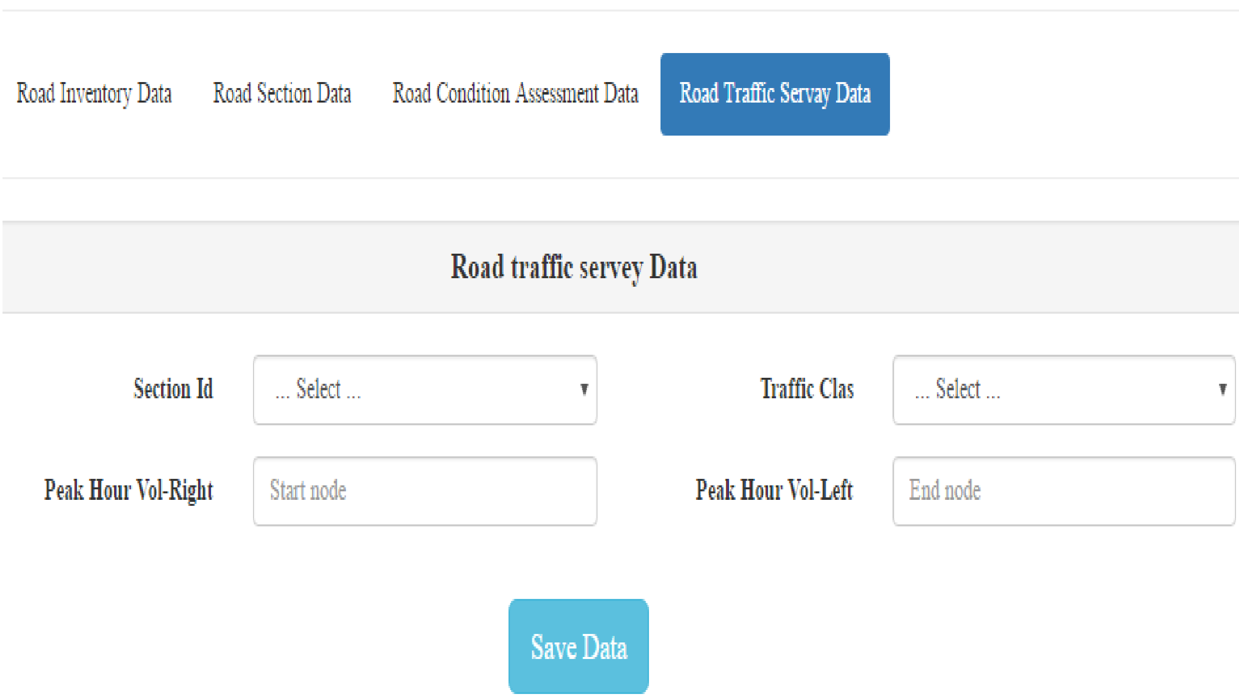


Figure 13: Traffic survey data entry interface

c) Life Cycle Cost Analysis Data Entry Interface

The developed system can estimate NPV using the LCCA data feed on its database. The cost and benefit data inputs for the software are as follows:

Cost elements	Benefit elements
Construction cost Maintenance cost Time cost Accident cost Fuel cost Spare part cost Cost of human fatal Loss due to injury damage to property vehicle	VOC saving Value of travel time saving Value of saving in accidents

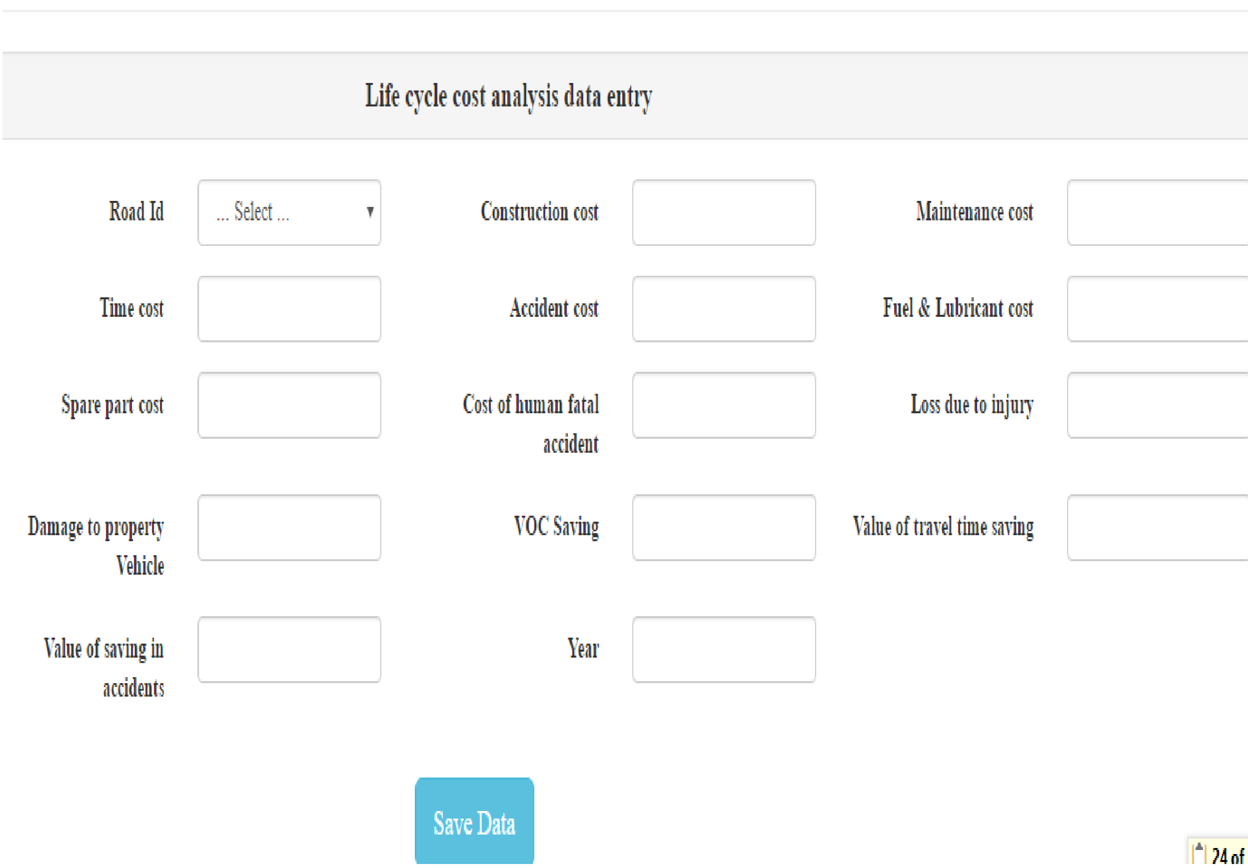


Figure 14: LCCA data entry interface

4.1.2 Analysis Scheme

The analysis section of the developed system comprises

a. Distress density calculation
b. Deduct value calculation for each distress type
c. Total deduct value calculation
d. Corrected deduct value calculation
e. Pavement condition index calculation
f. Maintenance cost estimation
g. Economic evaluation/NPV

Analysis Section

This section of the software developed comprises corrected deduct value calculating interface, pavement condition index calculating interface, maintenance cost estimation interface and economic evaluation applying NPV as evaluation criteria.

On the internally built database distress density is calculated as function of distress type and severity level. Once distress density is determined internally the deduct value for each distress type and severity level is calculated employing equations derived from ASTM curve as described in appendix-3.

In a given section of the road there may be more than one distress types hence more than deduct values. These deduct values are summed and total deduct value (TDV) is obtained. This total deduct value should be adjusted corrected deduct value applying the ASTM corrected deduct value as shown below in figure 17.Seven equations are extracted from this corrected deduct value curve and incorporated on the inbuilt database.

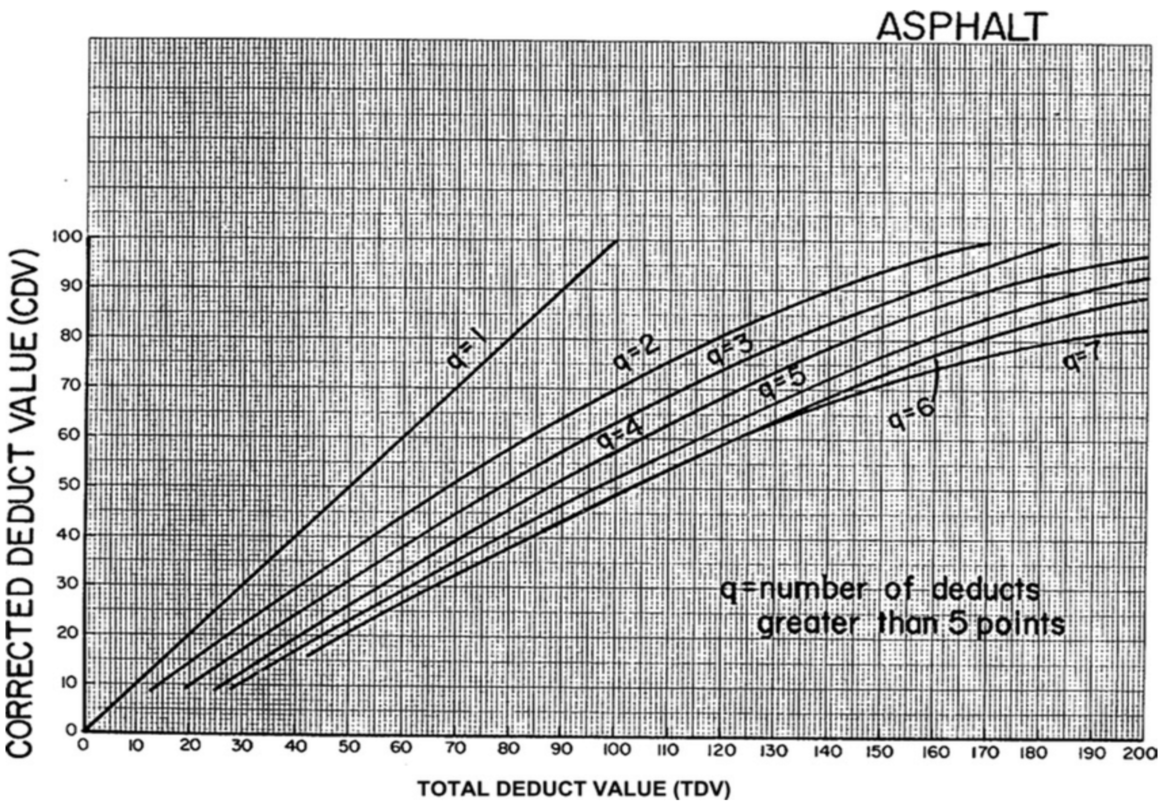


Figure 15: Corrected deduct value curve

1. Corrected Deduct Value Calculating Interface

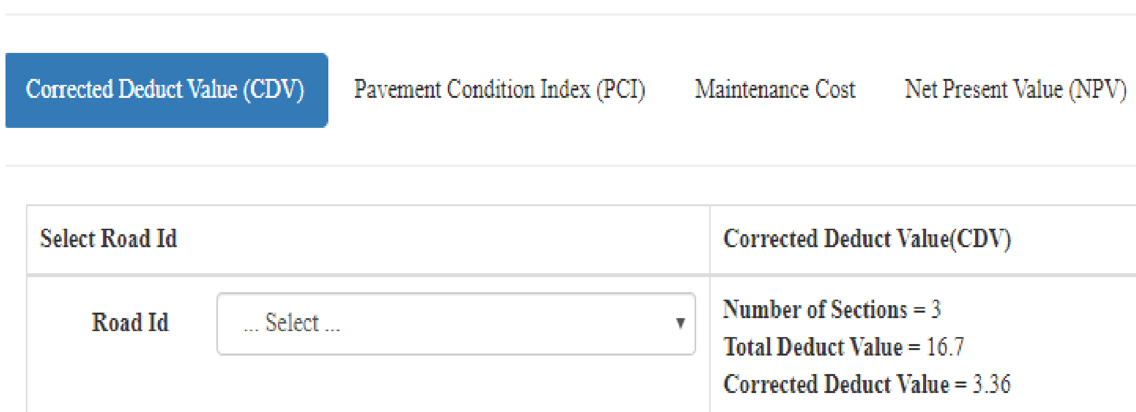


Figure 16: CDV calculation interface

2. PCI calculating interface

Flexible pavement performance rating and evaluation scheme is based on the pavement condition index value. The software calculates the PCI value for each road segment designated with unique identification number and it provides corresponding rating scale and repair alternative for each distress type and severity level.

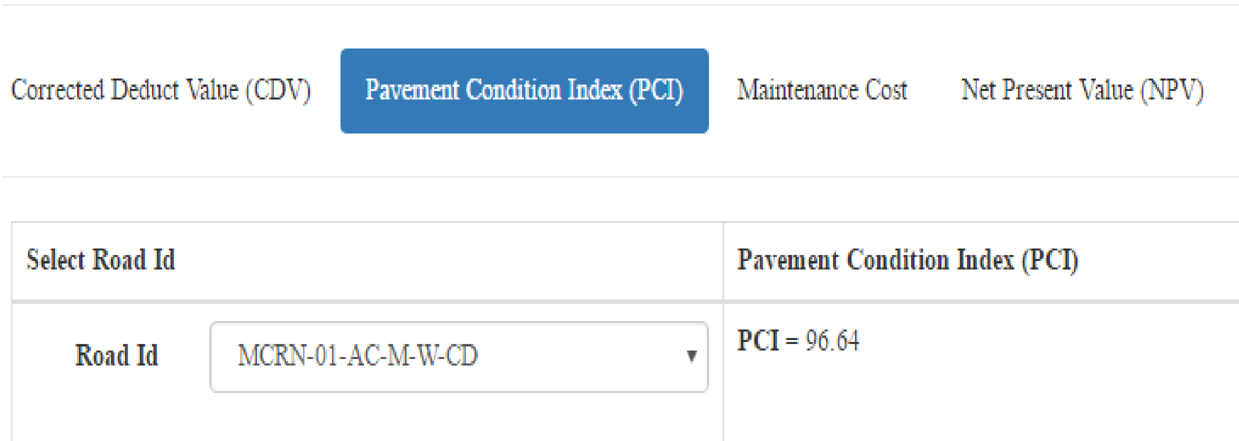


Figure 17: PCI calculating interface

Flexible Pavement Rating and Evaluation Scheme

Table 5: Flexible pavement rating and evaluation scheme

PCI value	Rating	**Surface Condition Description**
100 to 86	Excellent	The pavement surface is in excellent condition. The pavement appears to be very smooth and is generally free from any distress As the pavement surface a rating closer to the lower end of this category, some oxidation of the pavement surface may be present and minimal amounts of low severity hairline cracks or depressions may be visible.
85 to 71	Very Good	Even though the pavement surface is in very good condition, but surface deterioration is evident to exist. Transvers and longitudinal cracks are visible, and width are generally less than 3mm wide. Block cracking patterns may be appearing but cracks not deteriorated greatly. Along the cracks some minor faulting may be present. Additional type of surface deterioration. Along the outer wheel paths Minor rutting may be noticeable.
70 to 56	Good	The pavement surface is generally in good condition. Raveling may be present and the surface is noticeably oxidized. Transverses and longitudinal cracks are between 6 and 12 mm wide and may exhibit some deterioration. Depression in cracked area or around utility repairs may be noticeable. Along the wheel path alligator cracking may be evident. Rutting is becoming more pronounced and some shoving may occur at intersections. Minor patching may present as a result of surface distress or utility settlements.
55 to 41	Fair	The pavement is in fair condition. Pavement deterioration is much more advanced. Block cracking is common with detrimental effect the pavement cracks may be faulted or have medium to high severity spalls.
40 to 26	Poor	The pavement is in poor condition with poor readability. Alligator cracking is sever and potholes present. Rutting become common
25 to 0	Very poor to failed	The vast majority of the pavement surface is severely cracked and disintegrated and the pavement condition is in very poor condition. Traffic operations are severely affected.

2. Maintenance cost estimation

The main purpose of the maintenance cost estimation is to determine the cost required to restore the pavement surface condition to its as constructed state. This cost information is important as feedback for planning and reconstruction need for the agency while prioritizing roads for maintenance. The developed system estimates the maintenance cost as function of distress area and unit cost of maintenance

3. Economic evaluation/NPV

In the decision-making process while maintenance priority is made the economic importance of prioritized link should be significant. The developed system can estimate NPV using the LCCA data feed on its database. The cost and benefit data inputs for the software are as follows

Cost related data

i) construction cost

ii) Maintenance cost

iii) Road user cost

The road user cost includes

1. Vehicle operating cost
2. Time cost
3. Accident cost

Costs under vehicle operating cost includes

1. Fuel and lubricant cost
2. Spare parts cost

Accident cost includes

1. Cost of human fatal
2. Loss due to injury
3. Damage to propriety vehicle

Benefit related data

1. Vehicle operating cost saving
2. Value of travel time saving
3. Value of saving in accident

Once the cost and benefit related data are filled to the life cycle coast analysis data entry database, the developed system computes NPV for each road segment with respective of their corresponding maintenance cost. The software estimates NPV using equation-7 and we should set the constants. The two constants are analysis period and discount rate. Those two constant are stored on the database once filled by the user but they can be updated.

4.1.3 Report Scheme of the Software

The calculated deduct values are summed and stored for each road section in the database. Then the deduct values will be corrected and the PCI of each road sections will be found by deducting the corrected deduct value from 100.

#	Road Id	PCI	Rating	Maintenance Stratergy
1	MCRN-01-AC-M-W-CD	96.64	Execellent	Do nothing (Corrective Maintenance)
2	MCRN-03-AC-NM-W-CD	61.28	Good	Resurface
3	MCRN-02-AC-M-W-CD	11.17	Very Poor	Reconstruction
4	MCRN-04-AC-NM-W-CD	62.37	Good	Resurface
5	MCRN-05-AC-M-W-CD	53.64	Fair	Rehablitation
6	MCRN-06-AC-M-W-CD	36.22	Poor	Reconstruction
7	MCRN-07-AC-NM-W-CD	80.42	Very Good	Preventative Maintenance
8	MCRN-08-AC-M-W-CD	34.75	Poor	Reconstruction

Figure 18: Outputs of the software

Based on the calculated pavement condition index value most of the roads are under poor performance and they need to be rehabilitated. The riding quality of the roads is in a poor and uncomfortable state. This is due to the presence of deformations namely raveling, depression, corrugation, potholes and patching.

Due to the severity of the degree of distresses, especially in the prioritized link, and the safety risk threat posed to road users an urgent attention is required in the rehabilitation of the road network. After the rehabilitation process has taken place, continuous maintenance activities should be applied to ensure that the life span of the road network is enhanced and increased.

The observed pavement distresses are raveling, alligator crack, potholes, transverse crack, bleeding, depression and corrugation. Among these distresses raveling, alligator crack and potholes are the most frequent ones.76.6% of the distresses in the pavement are raveling

The cause of this raveling could be construction defect or aging i.e. being exposed to weathering for a long period of time. Construction defect, loss of the asphalt binder aggravated by poor drainage is the reason why raveling has been observed this much.

Finally, as the result indicates there is late or insufficient maintenance and this leads to

- Increase ultimate repair cost
- Increase road user cost
- Reduce safety due to poor riding quality.

To ensure that the roads remain serviceable throughout its design life they should be maintained early. The important result of good maintenance that should be achieved are

- Prolong the life of the road by reducing the rate of deterioration.
- Decrease the cost of operating vehicle on the road by providing smooth running surface.
- Sustain social and economic benefits of the city.

4.2 Repair Alternatives

The data base will provide a possible repair alternative for each type of distress. The possible repair alternatives for each distress and severity level is embeded on the data base.Once you feed the system with road condition data i.e. the existing distress type and severity level,then the software provides you corresponding repaire alternative for each distress type in accordance to their severity level. The developed pavement management system allows the user to update the M&R selection strategies for any specific distress by selecting the specific pavement distress and updating its corresponding M&R treatments.

Table 6: PCI value vs Maintenance strategy

PCI value	Rating	Typical Repaire	Level of rapaire (Maintenace strategy)
100 to 86	Excellent	Crack sealing	Preventive maintenace
85 to 71	Very Good	Pothole reapires,crack sealing and sureface treatments	Routine/preventive maintenance
70 to 56	Good	Chip seals, non-structural overlays	Minor rehabilitation
55 to 41	Fair	Structural overlays and partial depth reconstruction	Major rehabilitation
40 to 26	poor		
25 to 0	Very poor to failed	Reconstruction	Reconstruction

Table 7: Distress type vs repair alternatives

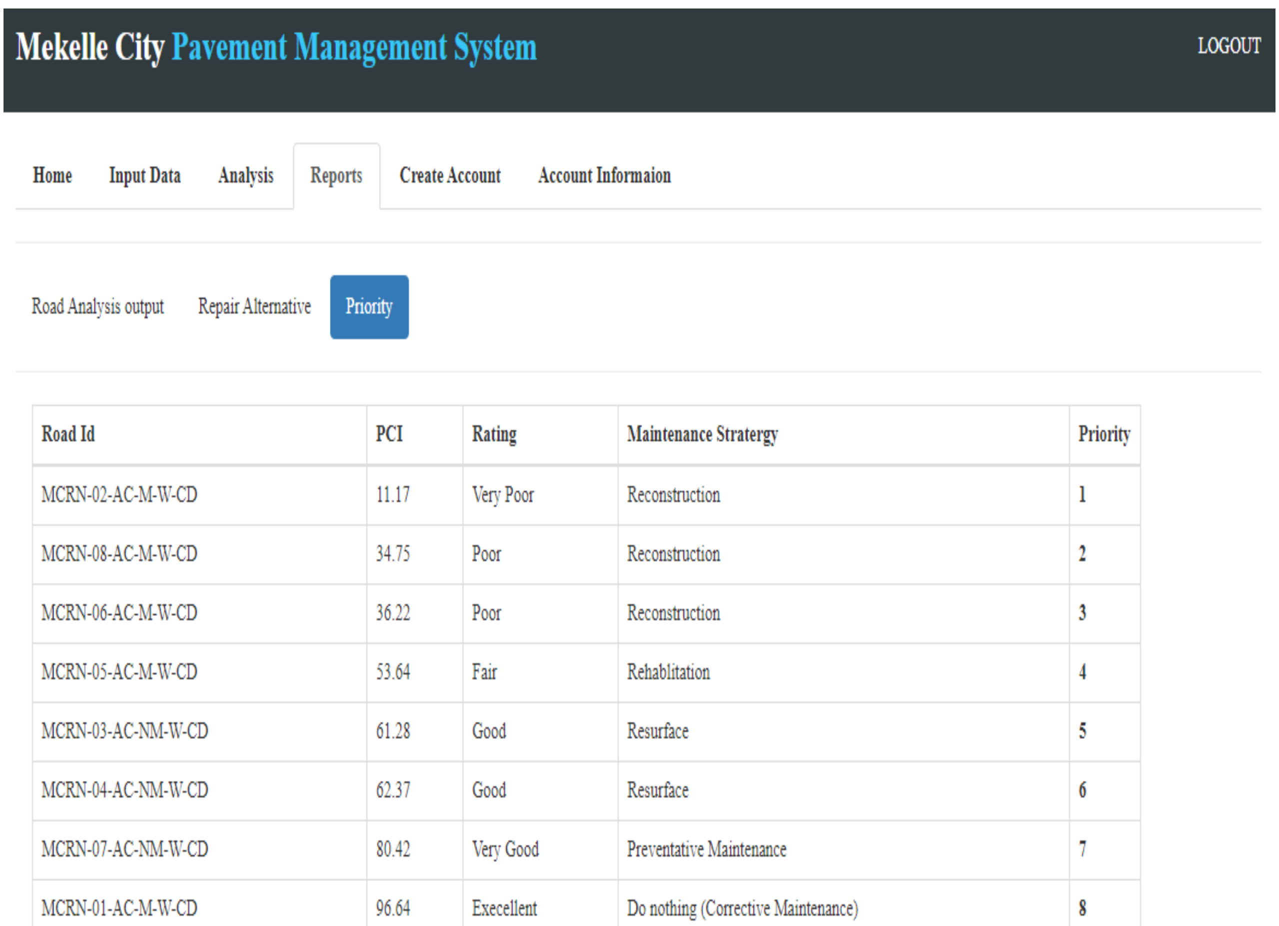
Distress type	Distribution	Severity	Repair Action
Alligator crack	Localized	Low	Crack seal
		medium	patch
		High	patch
	Extensive	Low	Crack seal
		medium	Surface recycle
		High	Thick overlay
Bleeding	Localized	Low	No action
		medium	Patch
		High	Heat &Roll sand
	Extensive	Low	No action
		medium	Burn & sand seal
		High	Burn & sand seal
Corrugation	Localized	Low	No action
		medium	Patch
		High	Patch
	Extensive	Low	No action
		medium	Surface recycle
		High	Surface recycle
Depression	Localized	Low	No action
		medium	patch
		High	patch
	Extensive	Low	No action
		medium	patch
		High	Full depth recycle
Edge crack	Localized	Low	Crack seal
		medium	Crack seal
		High	Patch
	Extensive	Low	Shoulder seal
		medium	Crack seal
		High	Thin overlay
Longitudinal &transverse crack	Localized	Low	Crack seal
		medium	Crack seal
		High	Crack seal
	Extensive	Low	Chip seal/slurry seal
		medium	Crack seal
		High	Thin overlay
Potholes	Localized	Low	patch
		medium	Patch
		High	patch
	Extensive	Low	Full depth recycle
		medium	Thick overlay

		High	Thick overlay
		severity	Repair Action
Rutting	localized	Low	No action
		medium	Patch
		High	Patch
	Extensive	Low	No action
		medium	Thin overlay
		High	Surface recycle
Raveling	localized	Low	No action
		medium	patch
		High	patch
	Extensive	Low	Fog seal
		medium	Slurry seal
		High	Thin overlay
Shoving	Localized	Low	No action
		medium	Patch
		High	patch
	Extensive	Low	No action
		medium	patch
		High	Reconstruct
Shoulder drop off	Localized	Low	No action
		medium	No action
		High	Patch
	Extensive	Low	No action
		medium	Add aggregate& grade
		High	Level shoulder &chip seal

4.3 Maintenance Priority Ranking

The sections are then prioritized within funding category in worst first order. When ranks are equal, pavements with higher functional class and higher traffic volumes would prioritize a head. Repair strategies are determined without regard to the available funds. In this stage the road manager compares the funds required with the funds available. Within the funding parameters, the road manager identifies the section for repair which will yield the highest return for the available funds. The goal is to provide the greatest overall network condition for the funds expended.

According to the analysis result of the developed software, Alula Street i.e. form commercial bank of Ethiopia to Romanat roundabout is with least pavement condition index value, a PCI value of 11.17, a rating scale of very poor, and the corresponding maintenance strategy is reconstruction.



Road Id	PCI	Rating	Maintenance Stratergy	Priority
MCRN-02-AC-M-W-CD	11.17	Very Poor	Reconstruction	1
MCRN-08-AC-M-W-CD	34.75	Poor	Reconstruction	2
MCRN-06-AC-M-W-CD	36.22	Poor	Reconstruction	3
MCRN-05-AC-M-W-CD	53.64	Fair	Rehablitation	4
MCRN-03-AC-NM-W-CD	61.28	Good	Resurface	5
MCRN-04-AC-NM-W-CD	62.37	Good	Resurface	6
MCRN-07-AC-NM-W-CD	80.42	Very Good	Preventative Maintenance	7
MCRN-01-AC-M-W-CD	96.64	Execellent	Do nothing (Corrective Maintenance)	8

Figure 19: Priority ranking based on worst first scenario

CHAPTER-FIVE

Conclusion and Recommendation

5.1. Conclusion

The main objective of this research study was to develop web-based pavement management system for Mekelle city road network maintenance to serve as a decision support tool, to assist and improve the efficiency of making decisions for pavement maintenance and management.

1. Basic information about pavement management system is reviewed and frame work for the software is designed based on this information obtained.
2. Pavement condition index (PCI) is selected as performance evaluation criteria, because it is a simple, convenient and inexpensive way to monitor the condition of the surface of roads, identify maintenance and rehabilitation needs. This parameter considers distress type, distress extent and distress severity. Thus, its good representative of performance of pavements
3. PMS database in this study is developed as an integrated system with four major modules. Road Inventory, Conditions Survey, Traffic Survey and Analysis for decision making. The developed PMS software store input data on its database system and analyses the distress extent, density and the pavement performance based on performance indicator. However, the PMS database can be modified when more data of distress surveys and related information are available especially traffic and condition survey data since the study area is limited to eight road sections of the total road network of the city.
4. A case study of eight road segments were inspected to analyze the proposed pavement management system software. According to the analysis result of the developed software, Alula Street i.e. form commercial bank of Ethiopia to Romanat roundabout is with least pavement condition index value, a PCI value of 11.17, rating scale of very poor, and the corresponding maintenance strategy is reconstruction.

5.2 Recommendation

Once a pavement has been constructed, it needs continuous management but this trend is not widely practiced in developing country especially in our country. Mekelle city municipality uses old system of management which leads the municipality to an extra expense.

Automated PMS should be initiated to serve and protect Mekelle pavements and this will encourage other cities in enhancing the management process and to maximize the benefits to the society**.**

As the output of the software indicates, most of the roads are under poor performance and they need to be rehabilitated. Especially in the prioritized link, the safety risk threat posed to road users an urgent attention is required in the rehabilitation of the road network. Unless, this late or insufficient maintenance leads to increase ultimate repair cost and road user cost.

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Appendices

Appendix-1: Road condition survey datasheet format

Mekelle City Road Condition Survey

Kebele: ____________________ Road start: ______________Road length: _______________
Road Id: ____________________ Road end: ____________________ Surface type: _______________
Road local Name: ______________ Road width: ______________ Date of survey: _______________

1. Alligator Cracking	6.Raveling	11. Traverse Cracking	16. Joint Crack
2. Bleeding	7.Rutting	12. Shoving	17. Utility defect
3. Corrugation	8.Lacy Edge	13. Subsidence	
4. Potholes	9.Low Shoulder	14. Stripping	
5. Patching	10.Longitudinal Cracking	15. Edge Crack	

No	Start Node	End Node	Section Length	Distress Type	Distress Severity	Distress Extent	Remark

Appendix-2: Repair alternative for each distress type and severity


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- Version 4.1.14
- http://www.phpmyadmin.net
-
- Host: 127.0.0.1
- Generation Time: Jul 18, 2019 at 10:46 AM
- Server version: 5.6.17
- PHP Version: 5.5.12
-->

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    - Structure schemas
    -->
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                  `Type` varchar (100) NOT NULL,
                  `Distribution` varchar (100) NOT NULL,
                  `Severity` varchar (100) NOT NULL,
                  `Action` varchar (100) NOT NULL,
                  PRIMARY KEY (`Id`)
                ) ENGINE=MyISAM AUTO_INCREMENT=73 DEFAULT
CHARSET=latin1;
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        </pma: database>
    </pma: structure schemas>

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        <column name="type">Transversal Crack </column>
        <column name="distribution">Extensive</column>
        <column name="severity">Low</column>
        <column name="action">Chip seal/slurry seal</column>
    </table>
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        <column name="type">Transversal Crack</column>
        <column name="distribution">Extensive</column>
        <column name="severity">Medium</column>
        <column name="action">Crack seal</column>
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        <column name="action">Thin overlay</column>
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```

```xml
    <column name="type">Potholes </column>
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    <column name="severity">Low</column>
    <column name="action">patch</column>
</table>
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    <column name="distribution">Localized</column>
    <column name="severity">Medium</column>
    <column name="action">Patch</column>
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    <column name="distribution">Localized</column>
    <column name="severity">High</column>
    <column name="action">patch</column>
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</table>
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    <column name="severity">Medium</column>
    <column name="action">Thick overlay</column>
</table>
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    <column name="severity">High</column>
    <column name="action">Thick overlay</column>
</table>
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    <column name="type">Rutting </column>
    <column name="distribution">Localized</column>
    <column name="severity">Low</column>
    <column name="action">No action </column>
</table>
```

```
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    <column name="severity">Medium</column>
    <column name="action">Patch </column>
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    <column name="severity">High</column>
    <column name="action">Patch </column>
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    <column name="severity">Medium</column>
    <column name="action">Thin overlay</column>
</table>
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    <column name="severity">High</column>
    <column name="action">Surface recycle </column>
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    <column name="type">Raveling </column>
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</table>
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    <column name="severity">Medium</column>
```

```
        <column name="action">Patch</column>
    </table>
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        <column name="action">Patch</column>
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        <column name="action">Fog seal</column>
    </table>
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        <column name="action">Slurry seal</column>
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        <column name="action">Thin overlay</column>
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        <column name="severity">Medium</column>
        <column name="action">Patch </column>
    </table>
    <table name="repair alternative">
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        <column name="type">Shoving </column>
```

```
        <column name="distribution">Localized</column>
        <column name="severity">High</column>
        <column name="action">patch</column>
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        <column name="severity">Medium</column>
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        <column name="distribution">Extensive</column>
        <column name="severity">Medium</column>
        <column name="action">patch</column>
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        <column name="type">Shoving </column>
        <column name="distribution">Extensive</column>
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        <column name="action">reconstruct</column>
    </table>
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        <column name="type">Shoulder drop off </column>
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        <column name="action">No action </column>
    </table>
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        <column name="Id">68</column>
        <column name="type">Shoulder drop off </column>
        <column name="distribution">Localized</column>
        <column name="severity">Medium</column>
        <column name="action">No action </column>
    </table>
    <table name="repair alternative">
```

```
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            &lt;column name="severity"&gt;High&lt;/column&gt;
            &lt;column name="action"&gt;Patch &lt;/column&gt;
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            &lt;column name="type"&gt;Shoulder drop off &lt;/column&gt;
            &lt;column name="distribution"&gt;Extensive&lt;/column&gt;
            &lt;column name="severity"&gt;Low&lt;/column&gt;
            &lt;column name="action"&gt;No action &lt;/column&gt;
        </table>
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            &lt;column name="severity"&gt;Medium&lt;/column&gt;
            &lt;column name="action"&gt;Add aggregate amp;
grade&lt;/column&gt;
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            &lt;column name="Id"&gt;72&lt;/column&gt;
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            &lt;column name="distribution"&gt;Extensive&lt;/column&gt;
            &lt;column name="severity"&gt;High&lt;/column&gt;
            &lt;column name="action"&gt;Level shoulder &amp; chip
seal&lt;/column&gt;
        </table>
    &lt;/database&gt;
&lt;/pma_xml_export&gt;
```

Appendix-3: Equations developed to estimate deduct value form ASTM curve

General equation

$$Y=a_1x^{b1}+a_2x^{b2}+a_3x^{b3}+a_4x^{b4}+a_5x^{b5}+a_6x^{b6}+a_7x^{b7}+c\ln x+d+kx^m$$

$$where\ y = deduct\ value\ and\ x = distress\ dendity$$


```
- PhpMyAdmin XML Dump
- Version 4.1.14
- http://www.phpmyadmin.net
-
- Host: 127.0.0.1
- Generation Time: Jul 26, 2019 at 03:41 AM
- Server version: 5.6.17
- PHP Version: 5.5.12
-->

<pma_xml_export version="1.0" xmlns:
pma="http://www.phpmyadmin.net/some_doc_url/">
    <!--
    - Structure schemas
    -->
    <Pma: structure schemas>
        <pma: database name="mcpms"
collation="latin1_swedish_ci" charset="latin1">
            <pma: table name=" distress details">
                CREATE TABLE ` distress details` (
                  `Id` int (11) NOT NULL AUTO_INCREMENT,
                  `Type` varchar (200) NOT NULL,
                  `Severity` varchar (200) NOT NULL,
                  `a1` float NOT NULL,
                  `b1` float NOT NULL,
                  `a2` float NOT NULL,
                  `b2` float NOT NULL,
                  `a3` float NOT NULL,
                  `b3` float NOT NULL,
                  `a4` float NOT NULL,
                  `b4` float NOT NULL,
                  `a5` float NOT NULL,
                  `b5` float NOT NULL,
                  `a6` float NOT NULL,
                  `b6` float NOT NULL,
                  `a7` float NOT NULL,
                  `b7` float NOT NULL,
                  `C` float NOT NULL,
                  `d` float NOT NULL,
```

```
                  `k` float NOT NULL,
                  `m` float NOT NULL,
                  PRIMARY KEY (`Id`)
                ) ENGINE=MyISAM AUTO_INCREMENT=40 DEFAULT
CHARSET=latin1;
            </pma: table>
        </pma: database>
    </pma: structure_schemas>

    <!--
    - Database: 'mcpms'
    -->
    <database name="mcpms">
        <! -- Table distress details -->
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            <column name="type">Bleeding</column>
            <column name="severity">Low</column>
            <column name="a1">0</column>
            <column name="b1">0</column>
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            <column name="b2">0</column>
            <column name="a3">0</column>
            <column name="b3">0</column>
            <column name="a4">0.000001</column>
            <column name="b4">3</column>
            <column name="a5">-0.0011</column>
            <column name="b5">2</column>
            <column name="a6">0.306</column>
            <column name="b6">1</column>
            <column name="a7">0</column>
            <column name="b7">0</column>
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            <column name="d">0</column>
            <column name="k">0</column>
            <column name="m">0</column>
        </table>
        <table name=" distress details">
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            <column name="type">Bleeding</column>
            <column name="severity">Medium</column>
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            <column name="a2">0</column>
            <column name="b2">0</column>
            <column name="a3">0</column>
            <column name="b3">0</column>
```

```
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        &lt;column name="a7"&gt;0&lt;/column&gt;
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        &lt;column name="type"&gt;Bleeding&lt;/column&gt;
        &lt;column name="severity"&gt;High&lt;/column&gt;
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        &lt;column name="b1"&gt;0&lt;/column&gt;
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        &lt;column name="b3"&gt;0&lt;/column&gt;
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        &lt;column name="b4"&gt;3&lt;/column&gt;
        &lt;column name="a5"&gt;-0.032&lt;/column&gt;
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```

```
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```

```
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        <column name="b3">0</column>
        <column name="a4">0</column>
        <column name="b4">0</column>
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```

```
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```

```
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    &lt;column name="d"&gt;0&lt;/column&gt;
    &lt;column name="k"&gt;0&lt;/column&gt;
    &lt;column name="m"&gt;0&lt;/column&gt;
</table>
<table name=" distress details">
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Appendix-4: Demonstrative example on basic PCI calculations and result interpretation

The validity of the developed software is checked by compering results calculated manually with results calculated.

Pavement condition index calculation

1, Adihaki campus –Abreha castle

N<u>o</u> of section -3 L= 1450m W= 13m

A, Adihaki campus – Debrdamo hotel

Distress type: Raveling Severity: Low Extent: (8*3) m L=729m

$$\text{Density} = \frac{length\ of\ distress}{length\ of\ section} * 100\%$$

$$= \frac{8}{729} * 100 = 1.1\%$$

$$DV_L = 4E^{-0.5}(Densit)^3 - 0.007(Density)^2 + 0.7716(Density)^2 + 0.4838(\text{Density}) + 0.7716$$

$$= 1.29\%$$

B, Debredamo hotel – Michael Bridge

Distress type: Raveling severity – Low, Extent= (5*3) L=350m

$$\text{Density} = \frac{\text{length of distreee}}{\text{length of section}} * 100\%$$

$$DV_L = 4E^{-0.5}(1.43)^3 - 0.007(1.43)^2 + 0.7716(1.43)^2 + 0.4838(1.43) + 0.7716$$

$$= 1.45\%$$

C, Michael Bridge –Abreha castle

Distress type	severity	Extent	L=371m
Bleeding	M	(9.6*2.2) m	
Raveling	M	(11*9.5) m	

Bleeding: Density $=\frac{\text{length of distreee}}{\text{length of section}} * 100\%$

$=\frac{9.6}{371*1} * 100\% = 2.59\%$

$DV_{M=0.001(den)^3-0.0232(den)^2+1.4361(den)}$

$DV_{M=0.001(2.59)^3-0.0232(2.59)^2+1.4361(2.59)}$

= 3.58%

Raveling: density$=\frac{11}{371} * 100$ = 2.96%

$DV_M = 0.0001D^3 - 0.0208D^2 + 1.2918(D) + 6.7402$

$DV_M = 0.0001(2.96)^3 - 0.0208(2.96)^2 + 1.2918(2.96) + 6.7402$

=10.4%

TDV=3.58+10.4=13.98%

∑DV =1.29+1.45 +13.98 =16.72%

Corrective deduct value

$CD_V = -0.014X^2 + 0.838(X) - 6.7309$

Where, x=∑TDV – 16.72

$CD_V = -0.014(16.72)^2 + 0.838(16.72) - 6.7309$

=3.37%

Pavement condition index (PCI)

PCI = 100-CDv=100-3.37

=96.63%

Rating: Excellent

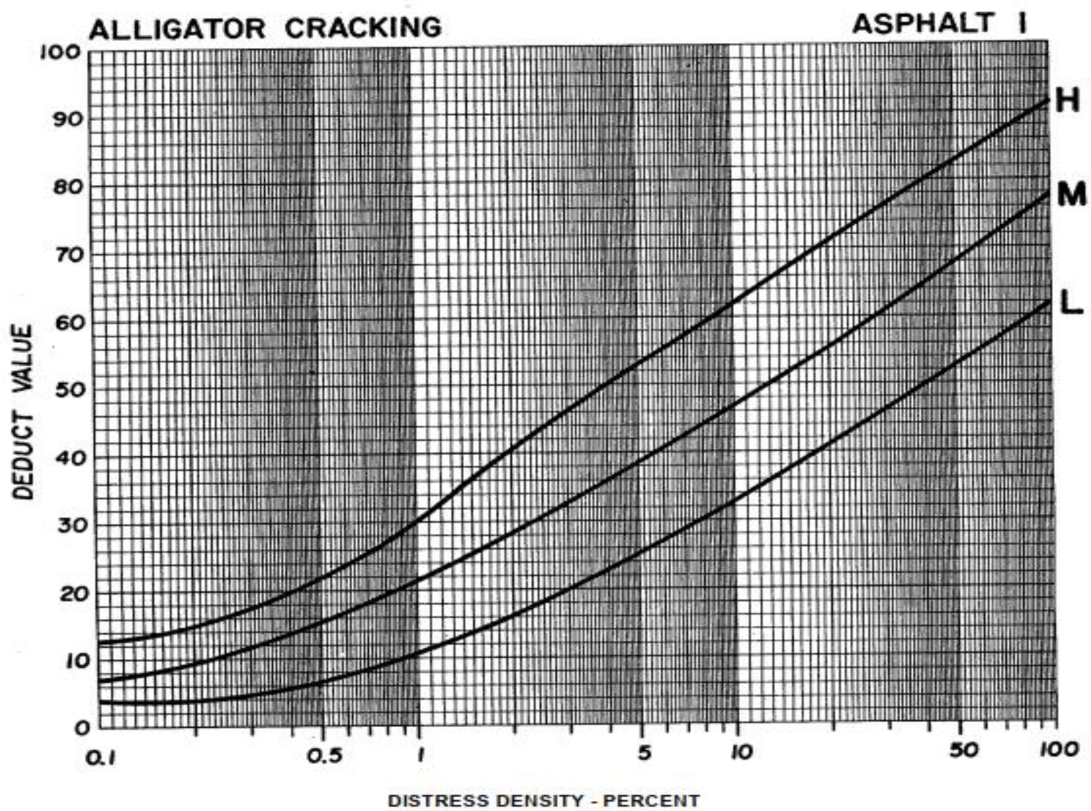
Treatment action: do nothing

For this road section the outputs of the software are as follows
Road id: MCRN-01-AC-M-W-CD
PCI: 96.64 ***Rating: Excellent*** ***Maintenance strategy: Do nothing***

Appendix-5: Deduct Values determining ASTM standard curves

- (Y) Parameter in the following equations is the required deduct value and the (X) parameter is the log of the distress density at each case of severity low, medium and high.
- The degree of reliability between the original ASTM standard curves and the curves drawn by derived equations, is illustrated by the R^2 values for each curve which is minimum value is 99%.

Deduct Value curve for each distress type and severity level

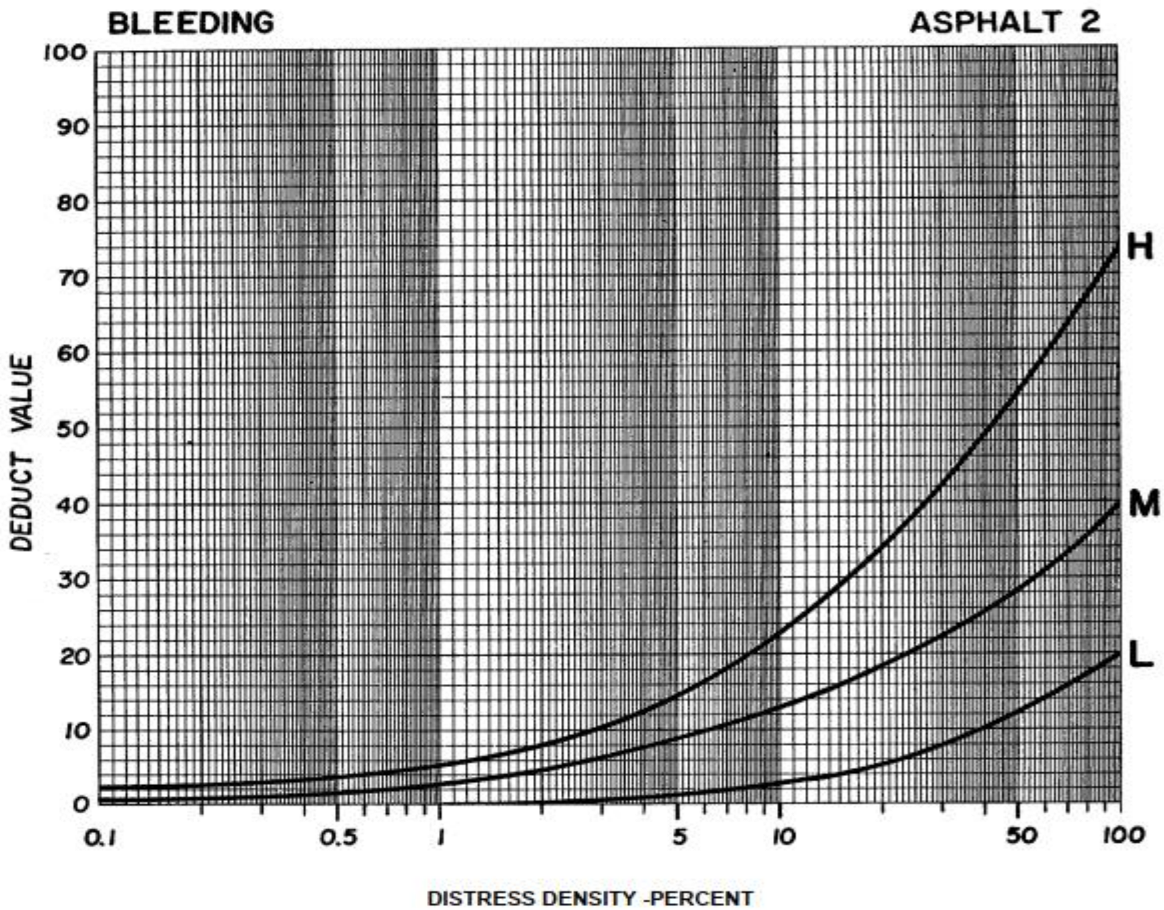


1. Alligator Cracks Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

$$yL = 1.397x^4 - 4.6379x^3 + 6.8218x^2 + 19.384x + 10.585$$

$$yM = -0.0638x^4 - 0.5927x^3 + 5.2326x^2 + 20.517x + 21.755$$

$$yH = 1.5001x^4 - 5.5434x^3 + 5.0192x^2 + 30.77x + 30.71$$



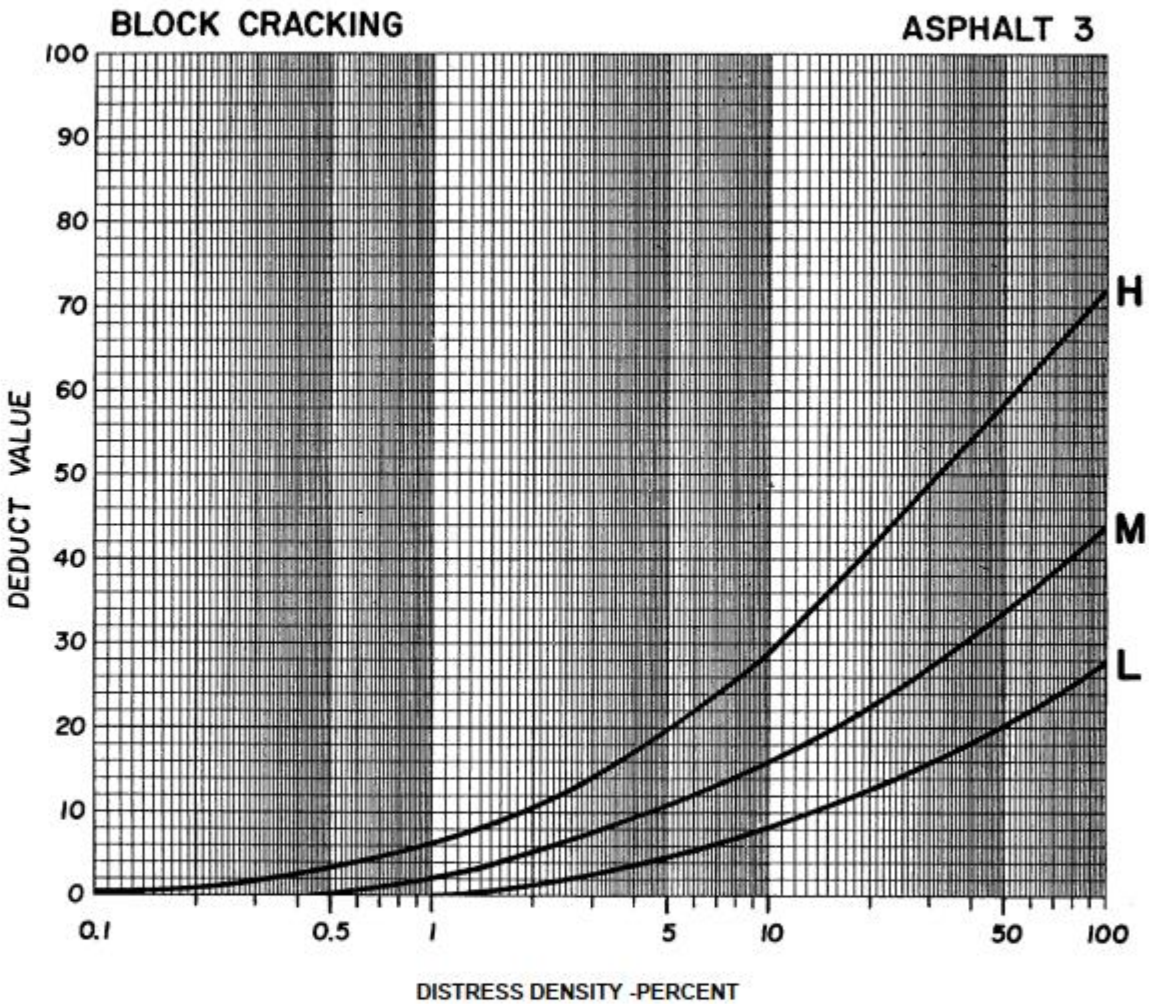
2. Bleeding Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity

   Equations

   Low $y = 0.000001\, x^3 - \ 0.0011x^2 + 0.306x$

   Medium $y = 0.0001x^3 - 0.0232x^2 + 1.4361x$

   High $y = 0.0002x^3 - 0.032x^2 + 2.3974x$



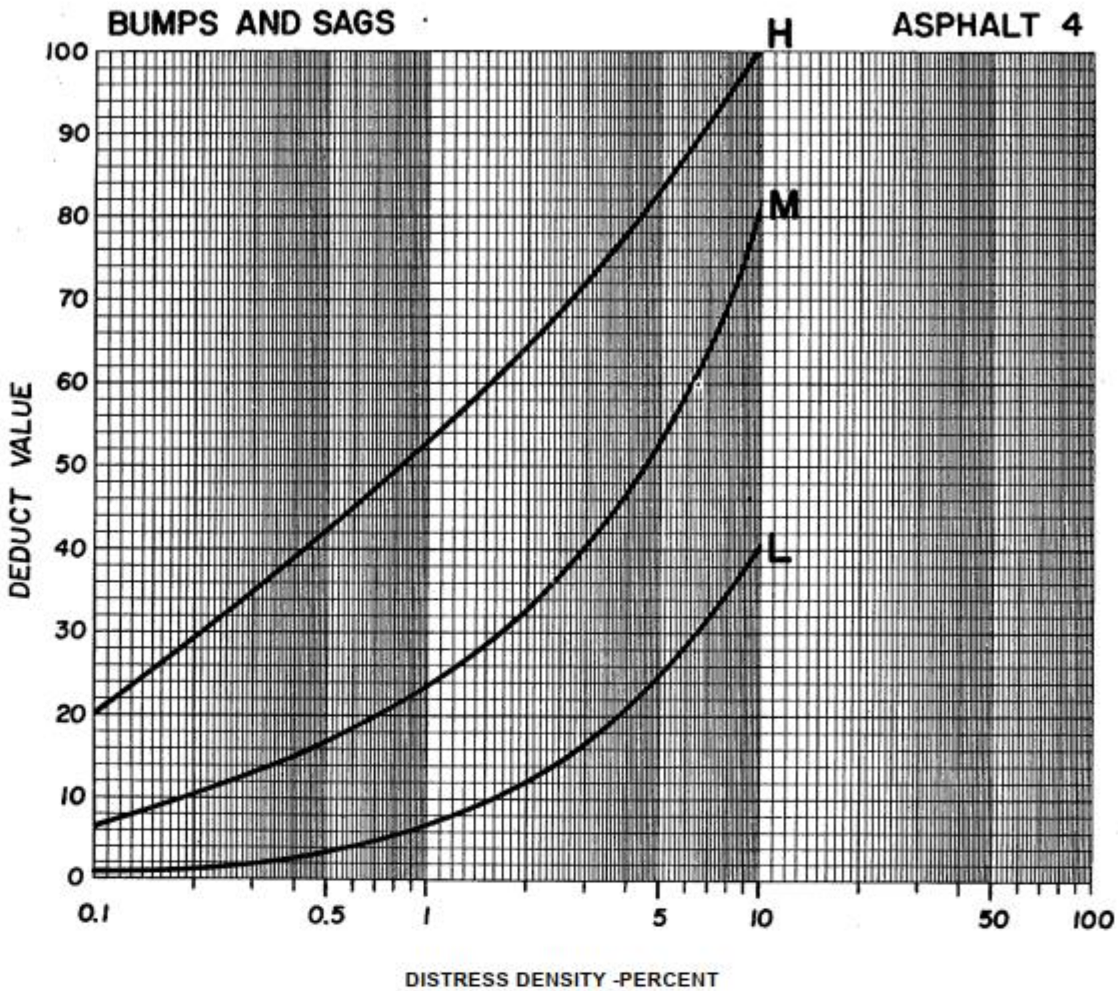
3. Block Cracks Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity

   Equations

   Low $y = 0.00007x^3 - 0.0134x^2 + 0.8889x$

   Medium $y = 0.0001x^3 - 0.0265x^2 + 1.5976x + 1.507$

   High $y = 0.0003x^3 - 0.0534x^2 + 2.9935x + 3.2856$

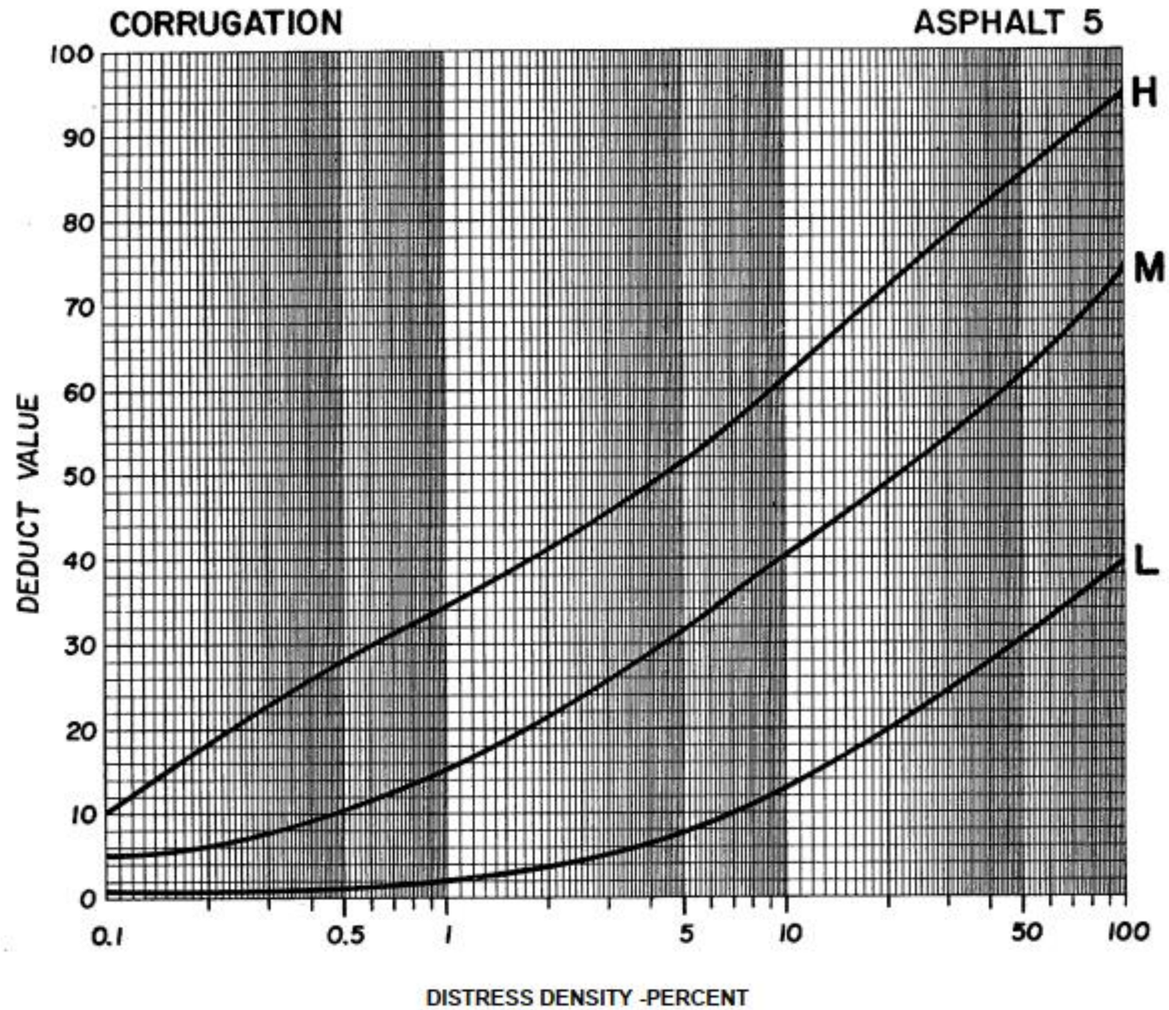


4. Upheaval and Settlement Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

$$yL = 0.2632x^4 + 7.4952x^3 + 0.7129x^2 + 6.0943x + 3.3233$$

$$yM = 9.4947x^4 - 7.8903x^3 + 8.3794x^2 + 18.892x + 12.065$$

$$yH = -1.0613x^4 + 6.6118x^3 + 1.6375x^2 + 29.948x + 34.919$$

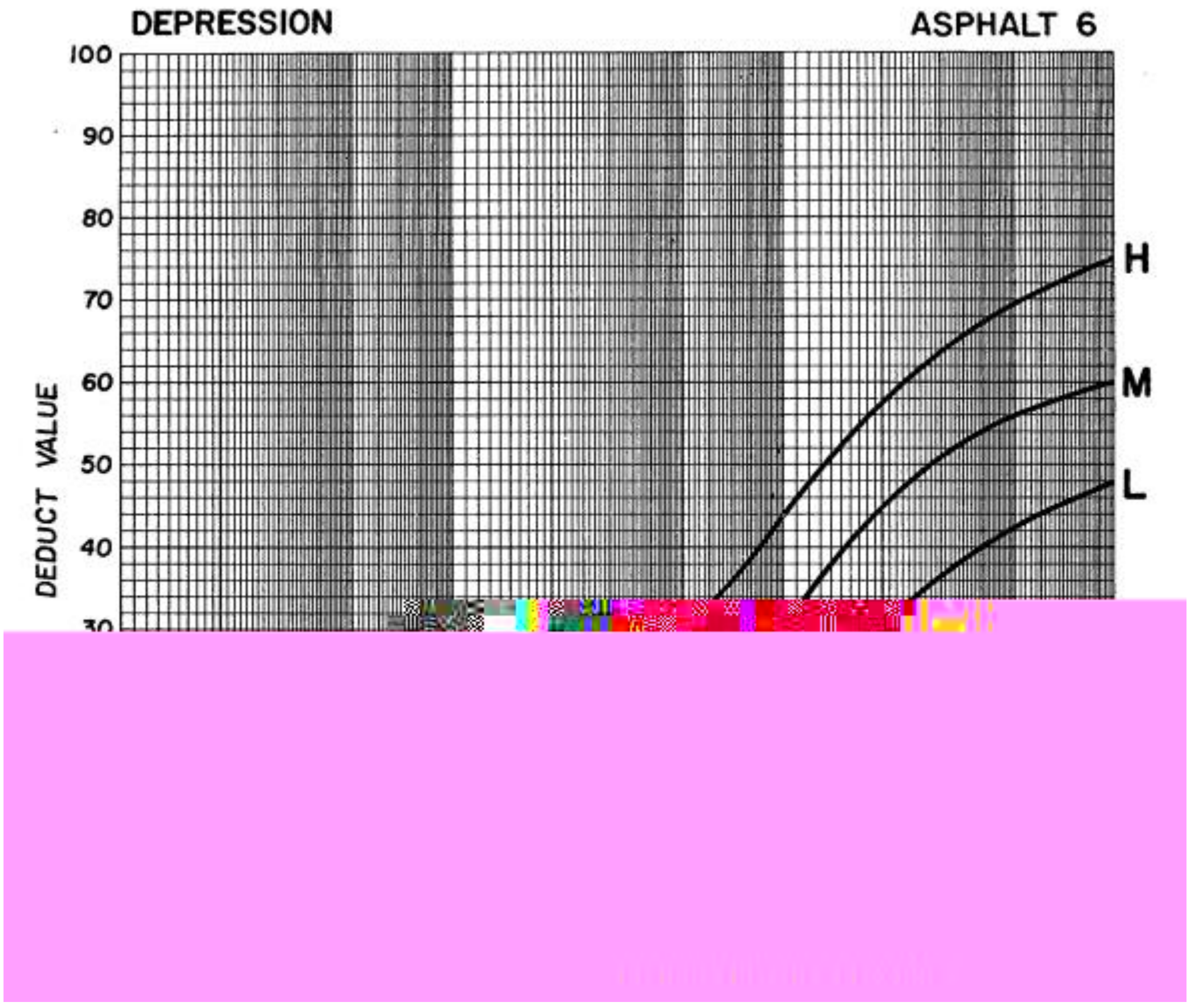


5. Corrugation Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

   Low $y = 0.000001x^3 - 0.0201x^2 + 1.3864x$

   Medium $y = 13.292x^{0.4063}$

   High $y = 12.382\ln(x) + 36.064$

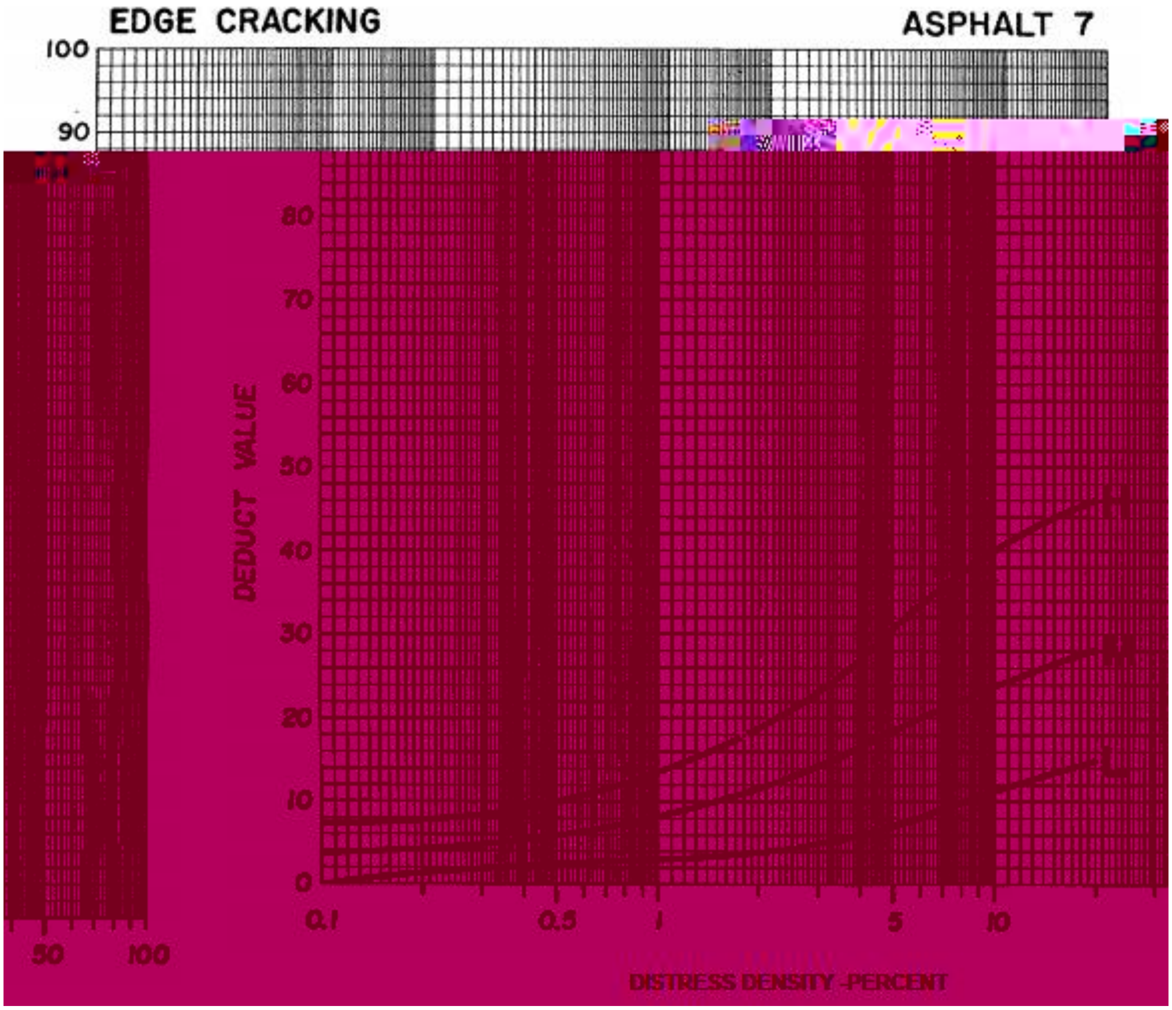


6. Depression Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

   Low $y = 0.000003\,x^4 - 0.0003x^3 + 0.0083x^2 + 1.616x + 2.3455$

   Medium $y = -0.000001x^4 + 0.0005x^3 - 0.06x^2 + 2.9391x + 5.688$

   High $y = -0.0000094 \qquad + 0.0019x^3 - 0.1341x^2 + 4.333x + 11.817$



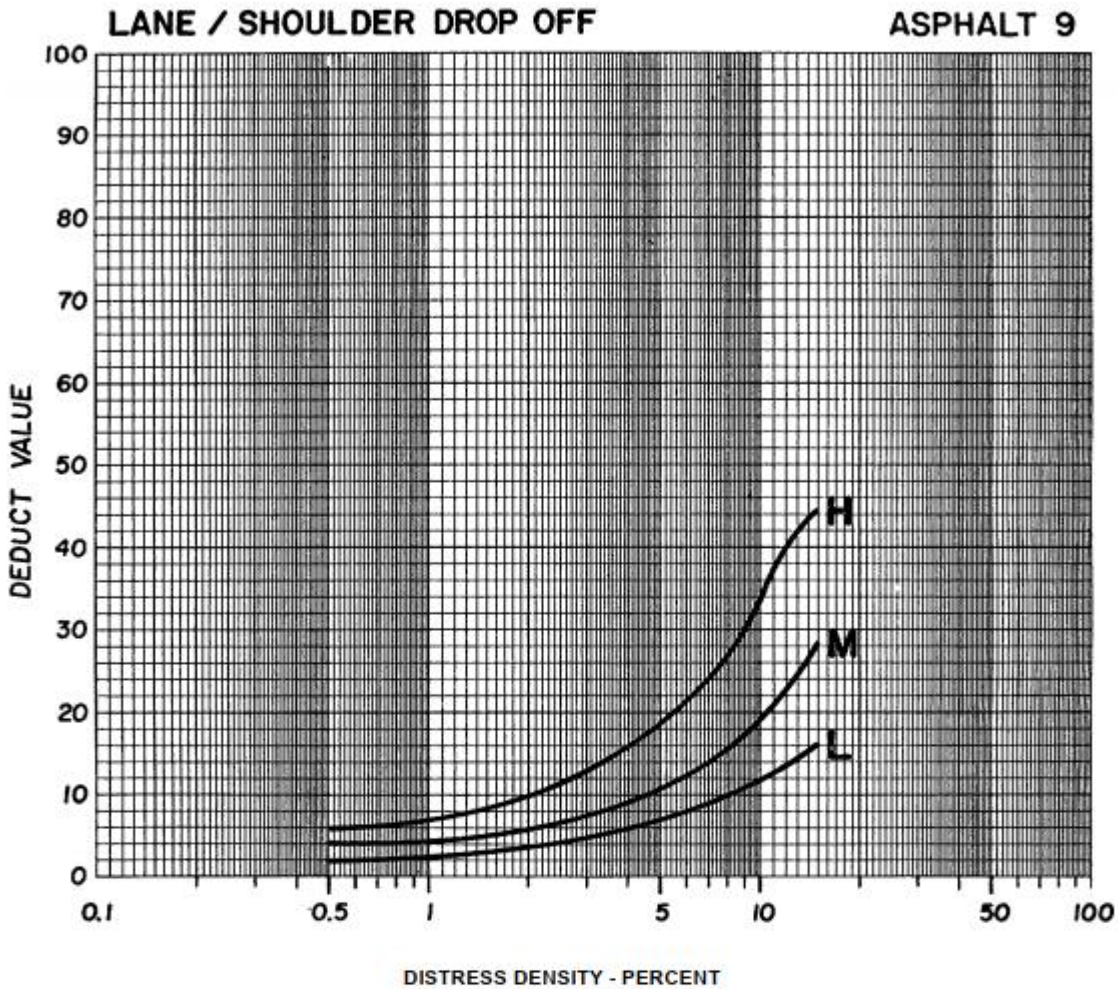
7. Edge Cracks Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity

Equations

Low $y = -0.00008\,x^4 + 0.004x^3 - 0.0987x^2$

Medium $y = 0.0073x^3 - 0.2985x^2 + 4.2809\,x + 3.767$

High $y = 0.011x^3 - 0.46191x^2 + 6.9654x + 6.69$

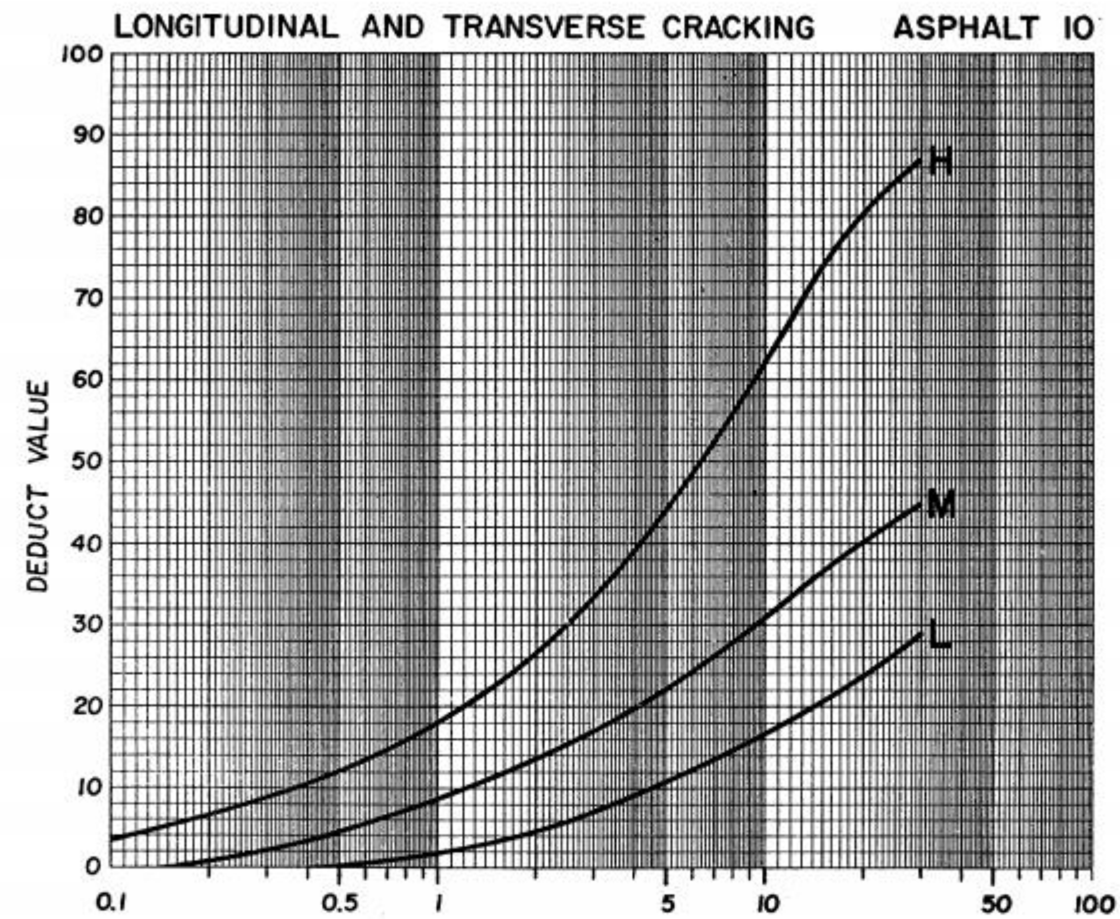


8. Lane Shoulder Drop off Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

$yL = -6.8547 x^4 + 28.066 x^3 - 30.342 x^2 + 13.471 + 0.1248$

$yM = 8.0818 x^4 - 19.476 x^3 + 22.092 x^2 - 7.2014 x + 4.6611$

$yH = 0.0774 x^4 + 5.766 x^3 + 3.4491 x^2 - 0.6096 x + 6.0547$



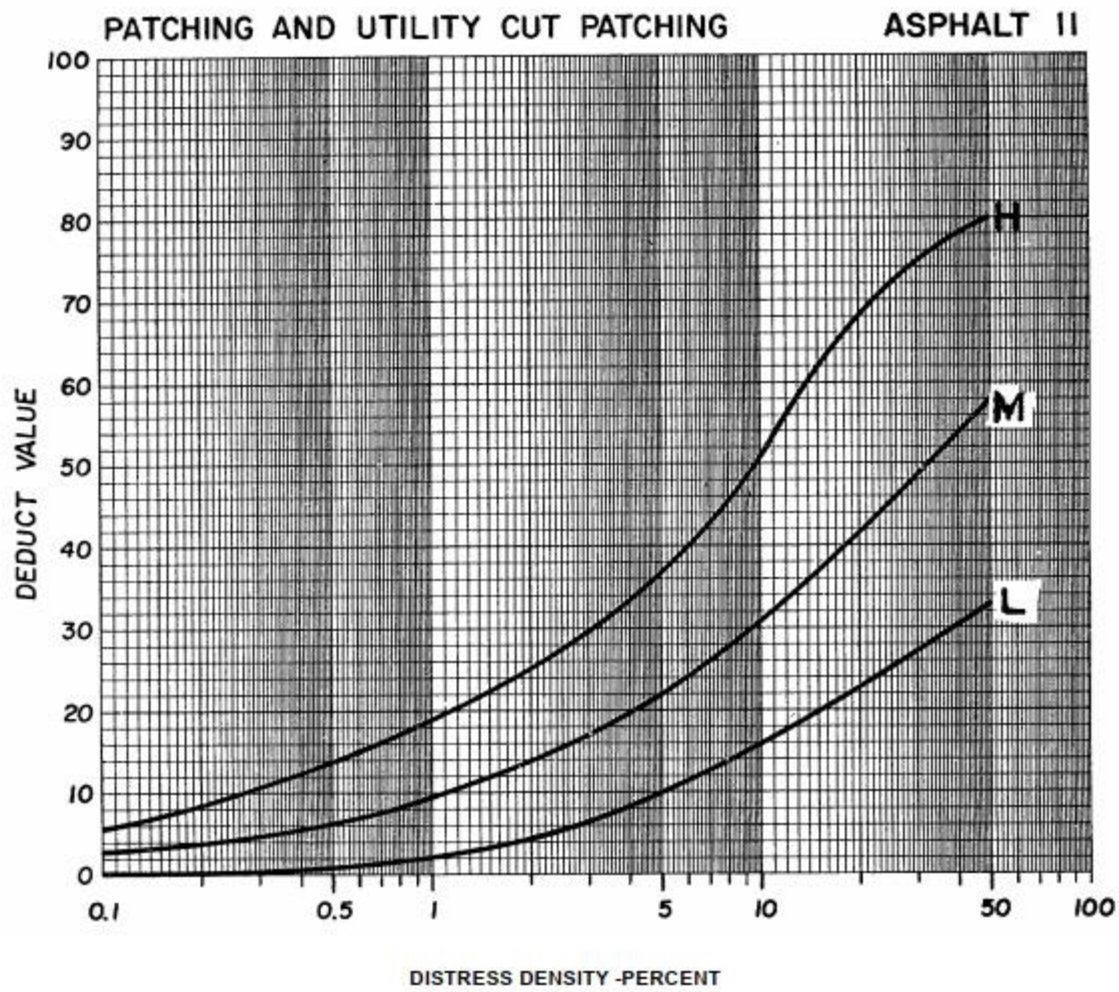
DISTRESS DENSITY - PERCENT

9. Longitudinal and Transverse Cracks Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

   Low $y = 0.0017x^3 - 0.1076x^2 + 2.6762x - 0.771$

   Medium $y = -0.0005x^4 - 0.0321x^3 - 0.7217x^2 + 7.5401x + 0.40233$

   High $y = -0.0007x^4 + 0.0483x^3 - 1.1298x^2 + 12.947x + 4.0276$



10. Patching Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

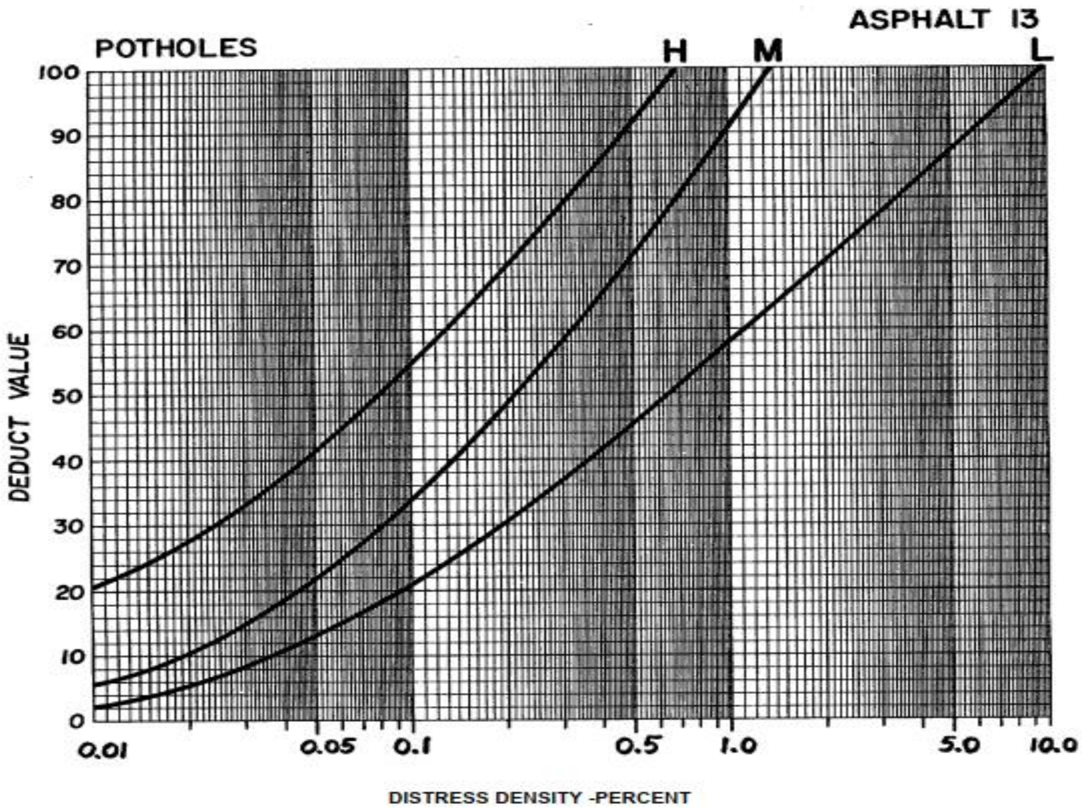
    Low $y = 0.0006x^3 - 0.0636x^2 + 2.2302x$

    Medium $y = 0.0012x^3 - 0.1191x^2 + 3.9359x + 4.3721$

    High $y = 0.0018x^3 - 0.179x^2 + 5.8943x + 10.23$

11. Polishing Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

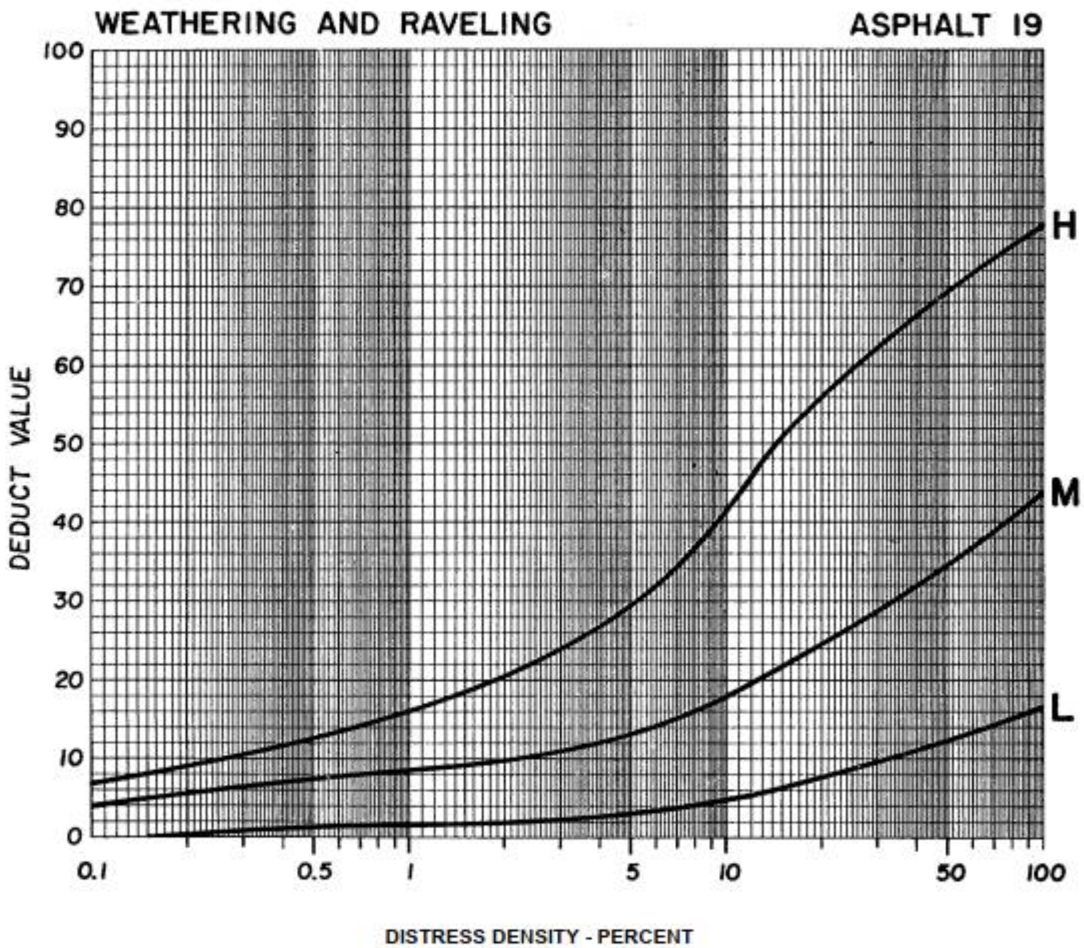
$$y = -0.7507x^4 + 5.5488x^3 - 4.1908x^2 + 2.6503x - 0.5929$$



12. Potholes Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity

Equations

Low $y = 14.791\ln(x) + 60.842$
Medium $y = 19.7891\ln(x)$
High $y = 19.5661\ln(x) + 104.47$

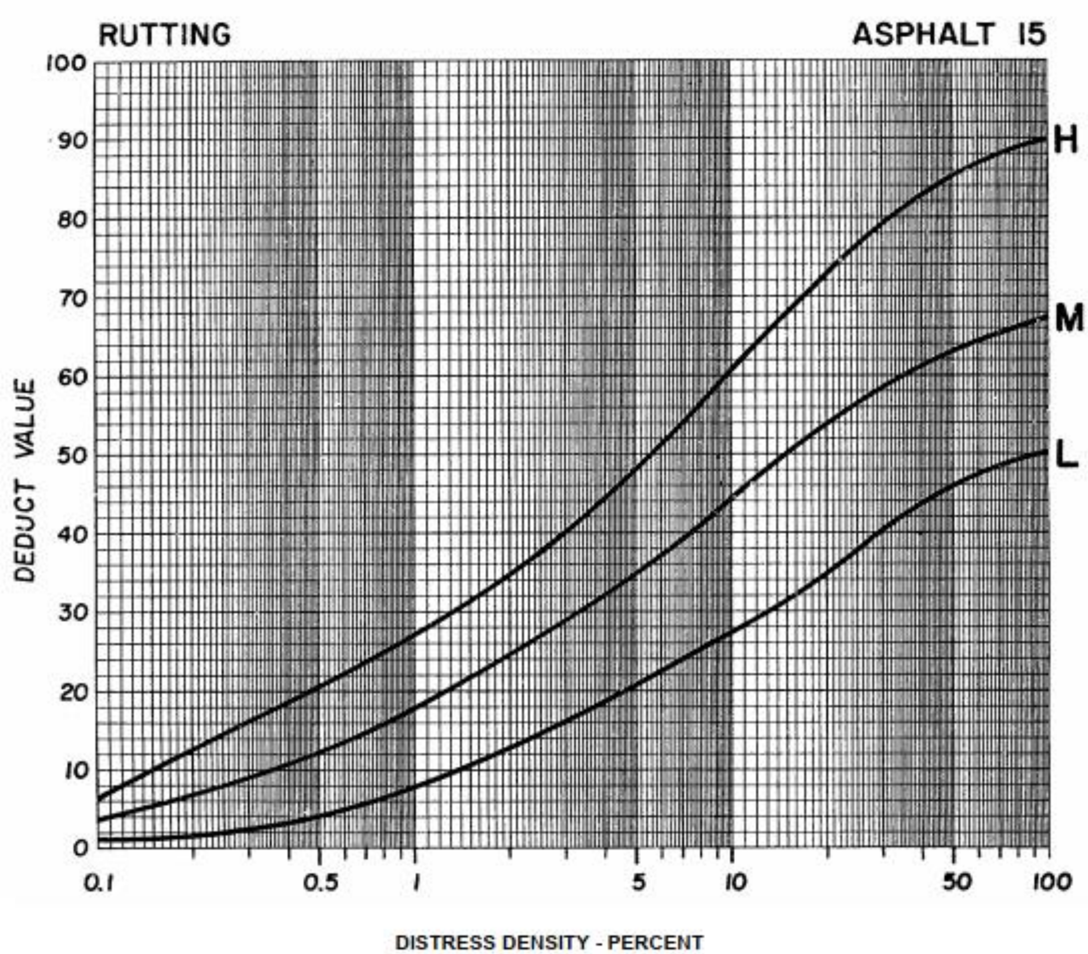


13. Raveling Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

    Low $y = 0.00004\,x^3 - 0.007x^2 + 0.4838x + 0.7716$

    Medium $y = 0.0001x^3 - 0.0208x^2 + 1.2918x + 6.7402$

    High $y = 0.00004x^3 - 0.007x^2 + 0.4838x + 0.7716$



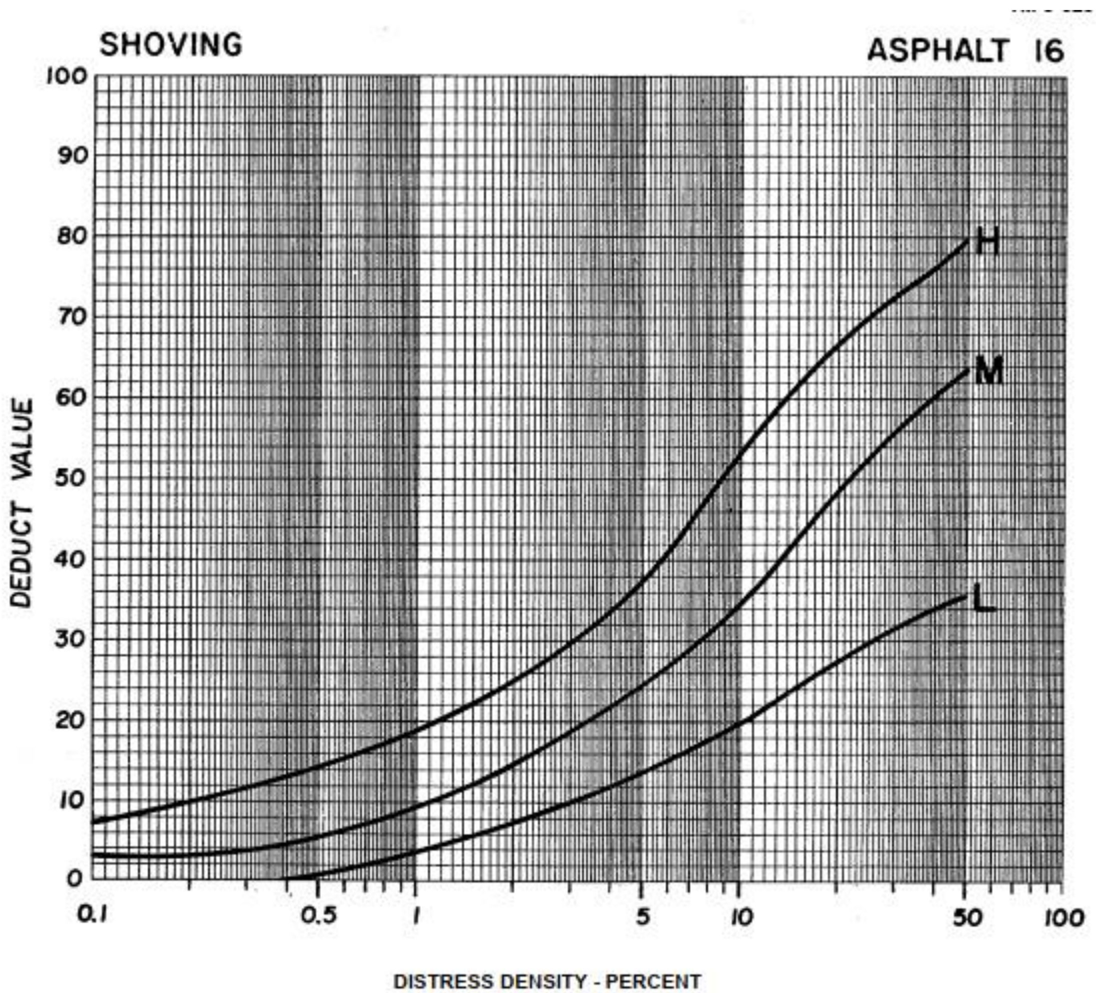
14. Rutting Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity

    Equations

    Low $y = 0.00004\,x^3 - 0.007x^2 + 0.4838x + 0.7716$

    Medium $y = -0.00000002x^6 + 0.000004x^5 - 0.0005x^4 + 0.0238x^3 - 0.6179x^2 + 8.188x + 7.0476$

    High $y = 0.0002x^3 - 0.032x^2 + 2.3974x$

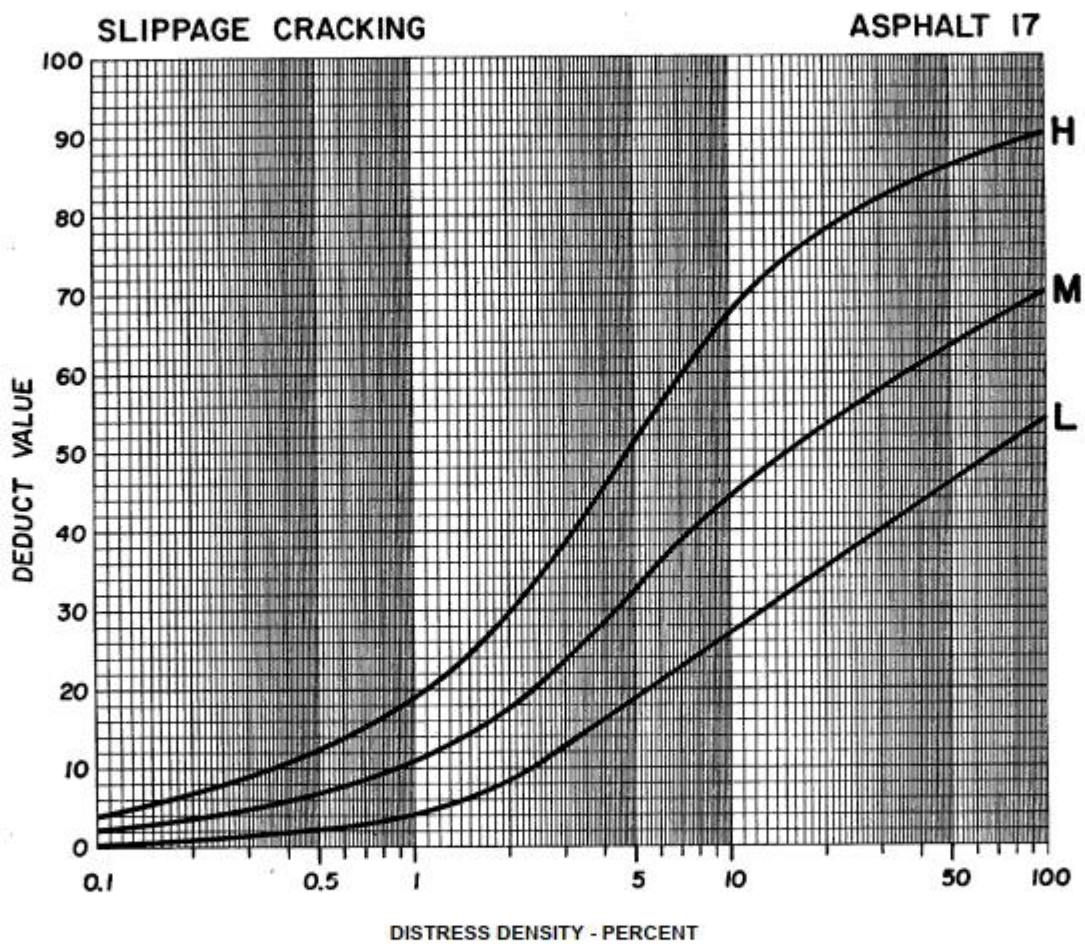


15. Shoving Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

    Low $y = 0.000005\,x^5 - 0.0006x^4 + 0.0259x^3 - 0.5027x^2 + 5.0717x - 1.5597$

    Medium $y = 0.000007x^5 - 0.0008x^4 + 0.035x^3 - 0.6721x^2 + 7.1521x + 2.0687$

    High $y = 0.000006x^5 - 0.0007x^4 + 0.0345x^3 - 0.7473x^2 + 9.0722x + 8.6384$



16. Slippage Cracks Deduct Values Calculation at Low (L), Medium (M) and High (H) Severity Equations

$$yL = 1.492x^6 - 2.436x^5 - 5.5809x^4 + 5.5352x^3 + 13.593x^2 + 10.681x + 4.2723$$

$$yM = 0.3841x^6 + 2.0804x^5 - 10.367x^4 + 1.2921x^3 + 22.393x^2 + 17.285x + 10.248$$

$$yH = 0.7493x^6 + 1.5562x^5 - 10.762x^4 - 3.0824x^3 + 26.416x^2 + 32.464x + 18.53$$

Appendix-6: Distress Type and Description

No	Type	Severity Levels			How to Measure
		Low(L)	**Medium(M)**	**High(H)**	
1	Alligator Cracking	Fine, longitudinal hairline cracks running parallel to each other with no, or only a few interconnecting cracks. The cracks are not spalled	Further development of light alligator cracks into a pattern or network of cracks that may be lightly spalled	Network or pattern cracking has progressed so that the pieces are well defined and spalled at the edges. Some of the pieces may rock under traffic	The major difficulty in measuring this type of distress is that two or three levels of severity often exist within one distressed area, measured in square meters of surface area. If the alligator cracking and rutting occur in the same area, each is recorded separated as its respective severity level.
2	Bleeding	Bleeding only has occurred to a very slight degree and is noticeable only during some part of the year. Asphalt does not stick to shoes or vehicles	Bleeding has occurred to the extent that asphalt sticks to shoes and vehicles during only a few weeks of the year	Bleeding has occurred extensively and considerable asphalt sticks shoes and vehicles during at least several weeks of the year	The unit of measurement is square meters of surface area.
3	Block crack	1. If unfilled cracks ≤13mm, or 2. Filled cracks of any width with the filler in satisfactory condition. No faulting exists	1. Unfilled crack with a width >13 and ≤50 mm 2. Unfilled crack of any width ≤50 mm with faulting of <10mm, or	1. Unfilled crack with a width >50 mm, or 2. Filled or unfilled crack of any width with faulting >10mm	This is measured in m^2 of surface area.

			3. Filled crack of any width with faulting <10		
4	Upheaval and settlement	Causes low-severity ride quality	Causes medium-severity ride quality	Causes high-severity ride quality	Measured in linear meters. .
5	Corrugation	Corrugation produces low-severity ride quality	Corrugation produces medium-severity ride quality	Corrugation produces high-severity ride quality	This is measured in square meters of surface area
6	Depression	13 to 25 mm	25 to 50 mm	More than 50 mm	This is measured in square meters of surface area
7	Edge Cracking	Low or medium cracking with no breakup or raveling	medium cracking with some breakup and raveling	Considerable breakup or raveling along the edge	Edge cracking is measured in linear meters
8	Lane /shoulder Drop-off	The difference in elevation between the pavement edge and shoulder is >25mm and <50mm	The difference in elevation is >50mm and <100mm	The difference in elevation is >100mm	Lane /shoulder Drop-off is measured in linear meters
9	Longitudinal/Transverse Cracking	1. Filled crack width is <10mm, or 2. Filled crack of any width (filler in satisfactory condition)	1. Non-filler crack width is >10mm and <75mm; 2. Non-filler crack is ≤75mm surrounded by light and random cracking; or 3. Filled crack of any width surrounded by light cracks	1. Any crack filled or unfilled surrounded by medium – or high- severity random cracking 2. Unfilled crack >75mm; or 3. A crack of any width where approximately 100mm of pavement around	Longitudinal/Transverse Cracks are measured in linear meters. Cracks with different level of service should be recorded separately.

<table>
<tr><td></td><td></td><td></td><td></td><td>the crack is severely broken.</td><td></td></tr>
<tr><td>10</td><td>Patching</td><td>Patching is in good condition and satisfactory. Ride quality is rated as low severity or better</td><td>Patching is moderately deteriorated, or ride quality is rated as medium severity, or both</td><td>Patch is badly deteriorated, or ride quality is rated as high severity, or both; needs replacement soon</td><td>Patching is rated in square meter of surface area; however, if a single patch has areas of differing severity, these areas should be measured and recorded separately. For example, 2.5 m^2patch may have $1m^2$ of medium severity and 1.5 m^2 of low severity</td></tr>
<tr><td>11</td><td>Polishing</td><td colspan="3">No degree of severity are defined; however, the degree of polishing should be clearly evident in the sample unit in that the aggregate surface should be smooth to the touch</td><td>This is measured in square meters of surface area.</td></tr>
<tr><td>12</td><td>potholes</td><td colspan="3"><table>
<tr><td rowspan="2">Max. depth of pothole</td><td colspan="3">Average diameter</td></tr>
<tr><td>100-200mm</td><td>200-450mm</td><td>450-750mm</td></tr>
<tr><td>13-≤25mm</td><td></td><td>L</td><td>M</td></tr>
<tr><td>>25 and ≤50mm</td><td>L</td><td>M</td><td>H</td></tr>
<tr><td>>50mm</td><td>M</td><td>M</td><td>H</td></tr>
</table>
If the pothole is >750mm in diameter, the area should be determined in square meter and divided by 0.5m find the equivalent number of holes. If the depth is 25mm or less, the holes are considered medium-severity. If the depth is more than 25mm, they are considered high-severity.</td><td>This type of distress is measured by counting the number that are low-, medium-, and high-severity and recording them separately.</td></tr>
<tr><td>13</td><td>Rail-Road crossing</td><td>Railroad crossing causes low-severity ride quality</td><td>Railroad crossing causes medium-severity ride quality</td><td>Railroad crossing causes high-severity ride quality</td><td>This is measured in square meters of surface area. If the crossing doesn’t affect ride quality, it should not be counted.</td></tr>
<tr><td>14</td><td>Raveling</td><td>Aggregate or binder has started to wear away. In some areas, the surface is starting to pit. In the case of oil spillage, the oil stain</td><td>Aggregate or binder has worn away. The surface texture is moderately rough and pitted. In the</td><td>Aggregate or binder has been worn away considerably. The surface texture is very rough and</td><td>This is measured in square meters of surface area.</td></tr>
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