ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Assessing Ethiopian Roads Authority's (ERA) Pavement Management System

An Independent Project submitted to the School of Graduate Studies of the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

(Road and Transport Engineering)

By

Kalid Ali Seid

Advisor: Mr. Asres Simeneh (Msc. In Road and Transport Engineering)

April, 2016

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Kalid Ali Seid

Approved By Board of Examiners

Mr. Asres Simeneh ______ ____________________

Advisor

____________________ ____________________

Internal Examiner

____________________ ____________________

Chairman

Declaration

I, Kalid Ali, declare that this case study is my original work. The findings presented in this paper are not found in any other previous research works.

Kalid Ali

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April, 2016

Acknowledgment

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Abstract

Pavement management systems can assist the engineers in identifying the most appropriate treatment on selected sections of the road network through the use of economic analysis, predictive models and time-series information.

The objective of this case study was to review the Pavement Management System's PMS of Ethiopian Roads Authority (ERA).

To meet the above mentioned objective interview and reviewing of archival data at ERA head office were conducted.

From the interview and archival data, it can be concluded that Ethiopian Roads Authority was not utilizing its Pavement Management System in full capacity in order to be beneficiary from the system due to different reasons such as luck of sufficient trained staff, breakdown of data collection equipments and lack of its maintenance.

Key Words: ERA Pavement Management System,

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Abbreviations

AASHTO---------- American Association of State Highway and Transportation Officials

CI -----------Condition Index (CI)

dTIMS ----------- Deighton Total Infrastructure Management System

ERA------Ethiopian Roads Authority

FWD------Falling Weight Deflection

HDM-4-------- Highway Development and Management system

IRI------------ International Roughness Index

MR&R------maintenance, reconstruction and rehabilitation (MR&R)

PMS-----Pavement Management System

QCP --------------Quality Control Plan

QMP --------------Quality Management Plan

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Chapter One ---Introduction

1.1. Background

Pavement Management System (PMS) is a coordinated and systematic process for carrying out all activities related to providing and maintaining pavements. The primary goal of the PMS is to predict the pavement condition and the cost associated with its maintenance and rehabilitation over a given time frame, and aid in the planning and programming of works. With a properly developed and implemented PMS, it is possible to make good, well informed, and consistent decisions on maintenance, rehabilitation or reconstruction of pavements. Pavement management systems can assist the engineer in identifying the most appropriate treatment on selected sections of the road network through the use of economic analysis, predictive models and time-series information.

The Pavement management must be capable of being used in whole or in part by various technical and administrative levels of management in making decisions regarding both individual projects and an entire highway network. All functions are essential, but not all functions need to be active at same time.

Mostly a PMS works at two separate levels, network and project level, though a hard dividing line between the two is difficult to draw. For the most part, the same type of data is needed for both types of activities but more detail is beneficial for project analysis. The pavement management at the project level deals with detailed design decisions, for an individual project. Project level work comes "on stream" at the appropriate time in the schedule and incorporates detailed engineering applications to address individual pavement sections and their specific problems. Network level pavement management has its primary purpose of using engineering applications to develop a priority program and schedule of rehabilitation, maintenance or new pavement construction work, within overall budget constraints. The network level of pavement management, as commonly used, incorporates the project selection and program levels. The project selection level involves prioritization to identify which projects should be carried out in each year of the program period. At the program level, budgets are established and general allocations made over an entire network.

Nonetheless, in our country Ethiopia PMS does not implemented in full capacity in assisting pavement managers to predict future economic, technical, social and environmental outcome of possible investment decisions concerning maintenance management of pavements.

Taking this into account, this research assessed the main public body for roads, Ethiopian Roads Authority's (ERA's), Pavement Management System (PMS) by focusing only on its availability and extent of implementation.

1.2. Statement of the Problem

Road Construction in Ethiopia is increasing rapidly. In relation with this, use of Pavement Management System (PMS) as a tool to predict the pavement condition and the cost associated with its maintenance and rehabilitation over a given time frame, and aid in the planning and programming of works are vital. Different experienced pavement managers said that with a properly developed and implemented PMS, it is possible to make good, well informed, and consistent decisions on maintenance, rehabilitation or reconstruction of pavements.

Nonetheless, it is noted that there are some federal road projects its maintenance, rehabilitation or reconstruction program are not viable with the current situation of the country's road demand. This indicates that the PMS is not given due attention in the Ethiopian road construction industry. Therefore, this research has been initiated to review the Pavement Management System's (PMS) of Ethiopian Roads Authority (ERA) which is the main responsible public body in charge of administering the Federal Roads.

1.3. Objectives of the Study

The objective of the study is to review the Pavement Management System's (PMS) of Ethiopian Roads Authority (ERA) and its implementation level in federal road network.

1.4. Scope of the Study

The scope of study for achieving the goals was focus on ERA Road Asset Management Branch because this branch was implementer for the Pavement Management System and also due to time and budget constraints the study is mainly focus in evaluation of the implementation of ERA PMS manual in Ethiopian Federal Road Network.

1.5. Methodology

In order to achieve the aforementioned objectives of the paper, the following methodologies have been applied;

1) Literature review to get background information on the Pavement Management System (PMS) that will be used as basic variable of the paper.
2) Critical analysis and review of Ethiopian Roads Authority's (ERA) Pavement Management System (PMS) using interview and archival data.
3) Assessing the draw backs /short comes encountered while implementing this PMS in Ethiopian context.
4) Finally conclusion and recommendation has been drawn based on the findings resulted from the case study.

Chapter Two ------- Literature Review

2.0 Introduction

The purpose of literature review was to study the theoretical background on about Pavement Management System through the journals, books, references, internet and articles. The study was related to the objectives of this study.

This chapter discuss on the definition of Pavement Management System (PMS), PMS in the World Over, function of PMS, Pavement Management System (PMS) process, the problems and approach for improving Pavement Management System and etc.

2.1. Definition of Pavement Management System

PMS is a tool that can be used to make informed decision about the maintenance and rehabilitation of a pavement work.

The American Association of State Highway and Transportation Officials (AASHTO) defines pavement management 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*** *(AASHTO, 1985[2]).*" This concept of providing pavements and maintaining them in acceptable condition is as old as the first pavement. As pavement networks grew slowly in the first half of the twentieth century and then quickly in the 1950s and 1960s, simple procedures or experience that had worked previously was no longer able to manage these burgeoning networks. Instead, a more holistic systems approach was needed.

Originally described as "a systems approach to pavement design", the term "pavement management system (PMS)" came into popular use in the late 1960s and early 1970s to describe decision support tools for the entire range of activities involved in providing and maintaining pavements (OECD, 1987 and Peterson, 1987[20]). Hudson et al. (1979[12]) describe a "total pavement management system" as

"…a coordinated set of activities, all directed toward achieving the best value possible for the available public funds in providing and operating smooth, safe, and economical pavements."

Haas and Hudson (1978[21]) expand on this by defining "activities" as those actions associated with pavement planning, design, construction, maintenance, evaluation and research.

On the same manner Dr. Nick Vitillo [17] defines **Pavement Management** as *"Pavement Management is a program for improving the quality and performance of pavements and minimizing costs through good management practices"* and **Pavement Management Systems** as *"A Pavement Management System is a set of defined procedures for collecting, analyzing, maintaining, and reporting pavement data, to assist the decision makers in finding optimum strategies for maintaining pavements in serviceable condition over a given period of time for the least cost."*

A Pavement Management System (PMS) is designed to provide objective information and useful data for analysis so that road managers can make more consistent, cost-effective, and defensible decisions related to the preservation of a pavement network. While a PMS cannot make final decisions, it can provide the basis for an informed understanding of the possible consequences of alternative decisions.

In general a PMS is a very powerful tool for storing, organizing, manipulating, and analyzing data. It takes raw data puts it into a form that the pavement manager and other users can quickly use to help make pavement related repair and funding decisions. A PMS provides consistent, accurate, and objective information to the decision maker.

There are numerous different pavement management systems (PMS) from which to choose, each one with its own level of complexity. For a small town or rural county a simple system based on visual inspection and maintained in a Microsoft Excel or Access database may be more than sufficient. For a state road network a more complex PMS is usually appropriate.

2.2. Levels of Pavement Management System

Based on the level of complexity there are two levels of PMS implemented now a day in the world. Which are Network and Project levels of PMS. Dr. Nick Vitillo [17].

1. **Network Level**

It is bird's eye view of network pavements as a whole and statewide pavement condition summary which used to estimate budget and predict performance of a pavement.

2. **Project Level**

It assists designers in constructing, maintaining, or rehabilitating a section of roadway. It also useful for preventive maintenance, resurfacing or reconstruction and treatments options along the project.

The detail of the two levels of PMS we will discuss in the under listed section of this chapter.

2.3. Pavement Management Systems in the World Over

a) PMS in Australia, like in other countries across the world, is managed at the district and state level, only. It was developed as an in-house software to serve as a decision support tool for the road asset maintenance policy and strategy at the state and district levels. Other states use commercially available software for this purpose. All states use pavement data collection systems. Data gathered includes, but is not limited to roughness, rutting, strength, texture, cracking, skid resistance and seal coat age (Anderson *et* al. 1994)[10].

b) By 2005, 1,900,000 km roads had been constructed in China, among them 40,000 km roads were expressways, another 15,000 expressways would have been constructed by 2010 (Liu, 2006) [19]. By 2020, a national highway network would be completed with 85,000 expressways. Clearly, China needed a pavement management plan to address past and future pavements. In 1984, China initialized and developed a PMS and since its introduction significant progress, in terms of pavement management, has been made. The implementation of this PMS has not gone so well, due to less focus and acceptance. Most transportation departments in China are more focused on road construction and not maintenance (Liu 2006) [19].

c) Australia uses long-term (10-year) maintenance contracts to turn over total control and responsibility for roadway system maintenance, rehabilitation, and capital improvements to private contractors. In 1992 the managing authority of the French National Roads Network decided to modernize the means of evaluating the condition of its roads, i.e. develop a PMS. The tool set up to do this was based primarily on a systematic survey of pavement surface damage, completed by skidding resistance measurements. For the evaluation tool to have the expected qualities, there had to be a special effort to make the damage survey a means of investigation as reliable as a measurement. The laboratories used a highly formalized method that precisely fixed the conditions in which the survey had to be performed, the type of information recorded, and its codification. Asset management programs for pavements have been used as effective methods for determining maintenance needs and increasing funding (Federal Highway Administration 2008)[23].

d) In Germany the design of a new, complete pavement management system is under way. Major components are already operational. Meanwhile, data on road conditions have been collected with high-speed monitoring systems over the national road network, including the Autobahn. The data is assembled according to evenness, skid resistance, and surface damage and subsequently classified via a special grading system. By applying special algorithms, a service value, a structural value, and an overall condition value are being developed. The results of the survey are then presented in lists, route section graphs, and network graphs with different colors indicating where specific target, warning, and threshold values are exceeded. By means of continuous feedback, the information collected is used to improve and adjust the system's components and the plausibility of the output. There is an agreement that for an effective PMS application, repeated automated network monitoring is necessary. To minimize necessary monitoring and evaluation efforts, the use of multifunctional automated monitoring systems is used to collect all necessary data during a single pass (Burger et al. 1994) [29].

e) The first experience of PMS in Italy was through the Province of Milano. Following the adoption of a new law in 2001, major portions of the interurban state road network had been transferred from the national road agency (ANAS) to the jurisdiction of the provincial governance. This transferrable of competences brought up a number of consequences in the field of maintenance and management and in particular the need for the Provinces to optimize budget funds dedicated to the new additions to their road network. The latter situation led the Province of Milano to the adoption of a new approach for the task of pavement maintenance aiming at a more rational solution based on objective criteria for intervention planning (Crispino et al 2004)[6].

f) In December 1998, New Zealand (NZ) embarked on an ambitious project to implement a National Pavement Management System (NPMS). A software called Deighton Transportation Infrastructure Management System (dTIMS) was chosen as the software application for multi-year programming road works. A pragmatic approach was selected and followed in the implementation of the NZ NPMS. The main aim or benefit of this approach was that it manifested an evolutionary progression for everyone rather than perfection of a system for a few and at much later date. In adopting this approach, a preliminary NZ dTIMS system was developed within a relatively short time-frame during the first seven months of the project using available information and systems (Phase I). This system was then further refined from feedback from the system users and the refined system was released in October 2000, marking the end of Phase II of the project. Phase II included further research and development. Phase III of the project was also developed and has brought about further refinements, operational research and enhancements, continued training and support for users. A year after the beginning of the NZ dTIMS project, more than 84 systems were being used by about 47 different RCAs throughout NZ. To date, the system is being used by all RCA's in NZ, with success. NZ has reported that its NPMS has been successful since its implementation. NZPMS has even awards at home and internationally and is recognised all engineering institutions in NZ, including the Institution of Professional Engineers New Zealand (IPENZ) (Wilson et al. 2002)[3].

g) The Spanish Ministry of Public Works and Transport has implemented a PMS for its road network. Studying the experience of other authorities had been extremely important in selecting a method. The aim was to adapt the system to the circumstances of the network. The system was implemented in stages in order to produce results as soon as possible and to not lose the advantages of a rigorous approach. The existing requirements and resources available were considered in selecting the data to be collected. Some of the problems that had arose during the work had been successfully solved, and it is hoped that others would be solved in the future. The first stage has been implemented, and work is under way on the second stage (Gutierrez-Bolivar & Achutegui 1994)[9].

h) The United Kingdom Pavement Management System (UKPMS) is a computer system that was designed for the economic management of the structural maintenance budget of a road network and dates back to the early 1980's. It incorporates a new system of visual data collection, data analysis, and budget allocation for all roads and has combined data from different types of condition surveys. Other significant features include the ability to project condition data into the future; this enables the user to take account of the economics of alternative maintenance treatments when deciding where and what treatments should occur. The core philosophy of UKPMS is to defer treatments where it is cost-effective and safe to do so and to give priority instead to preventive maintenance. The UKPMS provides standards for the assessment and recording of network condition and for the planning of investment and maintenance on roads, kerbs, footways and cycle-tracks within the UK. UKPMS provides a framework for combining the systematic collection of data with the decision-making processes necessary to optimize resources for the maintenance and renewal of pavements, including the generation of programs of works and corresponding budgets. It is used by local authorities in the UK for the management of roads, and for the production of performance indicators that are used nationally (Scott Wilson Group OLC 2007)[13].

i) The South African Pavement Management Systems (SAPMS) is a data-intensive system that uses state-of-the-art technology, computer programs and global positioning system (GPS) technology. The information is used for measuring system condition, predicting service life and selecting future projects. The program is used to validate cost benefits of pavement preservation and maintenance activities. The South African PMS applies a two-step process of generating strategies and their optimization. The optimization process aids in selection of the most economical strategy within budget parameters. Even though the PMS determines optimum strategies, a field panel selects the final construction work program. This selection is then reviewed and final project selection may be modified to meet local needs and considerations. A key component of SA PMS road condition analysis is the annual visual evaluation, which is based on the Technical Methods for Highways (TMH) 9 handbook. Rates are trained and certified to ensure consistency among the provinces. The annual evaluation is combined with mechanical measurements for use in the calculation of road condition indices. Mechanical measurements of the road, done every two to three years, include traverse and longitudinal profiling. The road indices are then used to formulate optimization of preventative maintenance based on available funds [5].

2.4. The Purpose of Pavement Management System (PMS)

The purpose of Pavement Management System (PMS) is to have;

- Precise knowledge of the road network its present condition. This step requires data collection and management together with pavement engineering for data interpretation
- Technical & economic analysis of maintenance and rehabilitation strategies such as;
    - ✓ Consequences of maintenance and rehabilitation strategies on the overall quality of the road network
    - ✓ Choice of the optimum maintenance and rehabilitation strategy from a technical and economic point of view

This step can be considered as the heart of the PMS itself. It can be efficiently achieved by using "Decision Support Models".

- Budget planning and programming in accordance with the chosen maintenance and rehabilitation strategies. These are outputs from the decision support models like HDM-4.

2.5. Costs and Benefits of PMS

Considering the benefit of PMS, it tempting to say "of course, the benefits of PMS outweighs the costs." however, at minimum the Authority should identify qualitatively the costs and benefits of implementing and maintaining its PMS.

2.5.1. Benefits

The literature on Pavement Management lists the following general list of benefits obtained from using PMS

- ✓ Facilitates decision making; increases chance of making optimal decision.
- ✓ Provides timely and accurate information for the use in need assessment.
- ✓ provides a means to monitor pavement network condition and provides a quantifiable assessment of network condition
- ✓ Provides a means for evaluating various rehabilitation strategies and option trade-offs.
- ✓ Improves the prioritization of pavement repair work, which in turn reduces excessive costs of rehabilitation costs caused by delayed action
- ✓ Provides a way to analyze the quensequenses of various funding levels.
- ✓ Provides a sound basis for allocating resources
- ✓ Provides objective information to balance political (subjective) input.
- ✓ Improves the effectiveness of money spent on the pavement network.
- ✓ Provides a saving in user costs.

- ✓ Provides valuable feedback on pavement design, maintenance, rehabilitation, materials, and construction; in the long term, this improves engineering and results in better pavements.
- ✓ Improves communications.
- ✓ Allows the authority to answer "what-if" type of questions regarding pavement repair programs and funding level.

Notice that these benefits, while they are very real and recognized and being valid, they are very difficult to quantify.

2.5.2. Costs

The costs of PMS directly relates to the implementation and upkeep of the PMS itself, including the software and data collection costs, and the actual expenditure made on the pavement network. These costs may be broken out as follows:

- ✓ Data collection (initial and future updates)
- ✓ Software acquisition (initial and future updates)
- ✓ Hard ware acquisition (initial and future updates)
- ✓ Consultant services.
- ✓ In-house staff time (data processing, data analysis, system maintenance, and training).
- ✓ Actual expenditure on the pavement for maintenance and rehabilitation.

Overhead and other indirect costs, such as work done by the authority staff, need to be included for an accurate evaluation of costs. Otherwise best estimate should be made.

2.6. Functions of Pavement Management System

Research has shown that it is far less expensive to keep a road in good condition than it is to repair it once it has deteriorated. This is why pavement management systems place the priority on preventive maintenance of roads in good condition, rather than reconstructing roads in poor condition. In terms of lifetime cost and long term pavement conditions, this will result in better system performance. Agencies that concentrate on restoring their bad roads often find that by the time they have repaired them all, the roads that were in good condition have deteriorated.[14]

In general, the typical tasks performed by pavement management systems include:

1. Inventory of pavement conditions, identifying good, fair and poor pavements.
2. Assign importance ratings for road segments, based on traffic volumes, road functional class, and community demand.
3. Schedule maintenance of good roads to keep them in good condition.[4]
4. Schedule repairs of poor and fair pavements as remaining available funding allows.[11]

2.7. Pavement Management System Components

Most formal definitions of a "pavement management system" agree on five key components (Peterson, 1987[15]):

1. **Pavement Condition Surveys**

Pavement condition surveys were probably the first PMS component to be adopted on a large scale by any transportation agencies. Condition survey research is largely concerned with advancing or refining measurement and data collection.

2. **Database Containing All Related Pavement Information**

Databases have evolved along with the pavement condition survey data they are designed to house. Computer databases gained prevalence in the 1970s and as adequate, cost effective computing power and storage became available. Recent research has concentrated on implementing more robust databases (e.g., Microsoft SQL server, Oracle, etc.) and better user interfaces including GIS-based spatial interfaces. These interfaces are as important as the data itself because they enable users to view and manipulate data in a meaningful way.

3. **Analysis Scheme**

Analysis schemes are those algorithms used to interpret data in meaningful ways. The late 1960s and early 1970s saw the introduction of computer-based optimization algorithms (Haas et al., 1979[11]). Recent software can combine the database, analysis scheme and decision criteria in one package. Recent research has focused on advancing or refining life-cycle costing analysis, optimization algorithms and performance prediction.

4. **Decision Criteria**

Decision criteria are those rules developed to guide pavement management decisions. As pavement management systems have evolved, decision criteria have become more complex and now account for items such as user delay, vehicle operating costs and, in limited cases, environmental effects. Research is ongoing to develop and refine appropriate decision criteria and the ability to automatically apply these criteria.

5. **Implementation Procedures**.

Implementation procedures are those methods used to apply management decisions to roadway sections. Implementation is often thought of as a political, budgetary or procedural issue and is not often dealt with in research.

2.8. Pavement Management Processes

There are many ways to do pavement management. Many cities and towns hire an outside engineering firm or pavement management consultant that incorporates advanced software products, while others choose to perform the duties in-house. In the latter case, communities may use technology as simple as spreadsheet software.

One approach to pavement management includes the following steps (William Scarpati and Jerry Guerra [28]):

1. **Project Initiation Meeting:** Consultants meet with key community officials (e.g., Road Director, town/city manager, town/ city engineer) to establish goals, collect existing data and prioritize the work areas.

2. **Database Construction:** The project team collects and enters existing data into the software, configuring the program to prepare it for additional data entry.

3. **Pavement Data Collection:** An inventory and evaluation of pavement conditions is conducted for the agreed-upon roadway miles. Factors considered include material type, age, geometry, drainage, substructure conditions and construction history, as well as basic geophysical segmentation, average daily traffic (if available), functional class, curb reveal, and thickness (if available). The comparative measure of this information is the Pavement Condition Index, which is rated on a scale of 0 (worst) to 100 (best). PCI surveying practices and calculation methods have been standardized by ASTM International and accepted by the American Association of State Highway Transportation Officials. Typically, communities strive for a PCI in the low 80s on their major arterial/collector streets and high 70s on their local roadway network.

4. **Quality Assurance, Strategy Meeting and Data Analysis:** After ensuring the integrity of the data, the consultant and municipal officials meet to review the findings, discuss the community's repair policies and prioritize objectives to develop a long-term pavement management strategy. The consultant then determines what the repair "backlog" is and establishes priorities, costs and alternatives for stemming the pavement network's deterioration and moving toward improvement.

5. **Report of Findings:** Data, costs and alternatives are condensed into a report, expressed in layman's terms and incorporating graphs, charts, tables and other illustrations to better explain the findings and proposed solutions.

6. **GIS Integration:** If a community has a geographic information system available, analysts develop a linear route system to aid in the development of a new pavement data layer in the system.

7. **Training and Guidance:** Consultants will train community officials to understand and use the software, while remaining available to assist with the implementation of the program. In many cases, when the consultation is ongoing, an annual status report is also part of the process.

2.9. Comparison of PMS Approaches

This section discusses the advantages and disadvantages of both network-level and project-level approaches to pavement management by listing the principal advantages of each approach (Article launched on www.pavementinteractive.org[8]).The disadvantages of each approach correspond to the advantages of the other; for instance, one advantage of the network-level approach is that it can optimize solutions for the entire network. The conjugate disadvantage of the project-level approach is that it may not be able to optimize solutions for the entire network.

2.9.1. Network-Level Approach Advantages

The network-level approach is characterized by top-down logic, system optimization, aggregate data, large data and resource requirements, and sophisticated models. Its chief advantages are that it can:

- **Optimize Solutions for The Entire Network;** By definition, this is what a network-level approach does. For instance, a network-level approach can optimize the cost-benefit ratio for the entire network. This would seem the most logical since the system, rather than an individual project, is the overarching concern. Project-level approaches attempt to replicate this ability by assigning project priorities that are commensurate with network-level programs, decisions or budgets. However, because projects are already planned before high-level decisions are made, project-level decisions and priorities may not be consistent with network-level decisions and priorities. This can lead to a suboptimal system solution that is driven by individual project-level decisions instead of network-level decisions.

- **Quickly and Accurately Produce Conditional Scenarios;** Software models using a network-level approach allow the user to adjust top-level budget and policy inputs and then quickly calculate the resulting network-wide effects because these models are driven by top-level (network-level) decisions. For example, a network-level model could calculate the economic and pavement conditions effects of a proposed lower axle load limit law or the long-term network performance under varying levels of funding. Conversely, project-level software is generally driven by low-level inputs and thus, a change in top-level budget or policy would be input into the system by adjusting the multitude of lower-level inputs which is a more laborious process.
- **Prioritize Broad Areas of MR&R**; since network-level analysis provides target MR&R treatments and costs, these targets can be easily and consistently applied to individual projects. In order to accomplish the same thing with a project-level approach, network-level targets need to be provided in advance such that project-level decision can be made with network-level targets in mind.
- **Use Consistent Inputs In Scenario Comparisons**; using a network-level model, different scenarios can be modeled on the same system. This helps if each scenario is modeled using consistent assumptions models, outcomes may still be able to reflect appropriate qualitative and comparative results. Project-level approaches have more difficulty in this area because basic assumptions must be input on the lower, project level. As this is done agency-wide, communication problems and personal/geographic bias may have a substantial effect on input consistency.
- **More Easily Obtain Top Management Attention**; At the 1997 New Orleans pavement management workshop, many pavement management practitioners raised the following issues: (1) pavement management had lost the attention of top

management because they did not understand its capabilities or importance, and (2) some managers haphazardly overrode pavement management recommendations with little or no though to network implications (Zimmerman, Botelho and Clark, no date given). With its conditional scenario capability, a network-level approach could easily show the fiscal importance of pavement management as well as the implications of various decisions.

2.9.2. Project-Level Approach Advantages

The project-level approach is characterized by simpler models, less data aggregation, fewer data and resource requirements, less reliance on feedback for success and better understanding. Its chief advantages are:

- **Relies less on aggregate data;** The network-level approach relies on aggregate data to drive its models. There is an inherent risk involved when using aggregate data to drive network-level decisions. First, the aggregate data, if not carefully chosen, may not be representative of actual conditions, which could lead to incorrect decisions at the highest level. Second, aggregate data is sometimes difficult to translate into specific project-level results (e.g., overlaying all pavement above a certain IRI on a particular route may be costly if these high-IRI sections are small isolated segments).
- **Able to be used with little data**; Project-level systems can be used in situations where data availability/requirements are small making them ideal for smaller agencies. Network-level systems require large amounts of data and resources (such as computers, trained personnel, advanced algorithms), which smaller municipal agencies may not be able to afford. Additionally, the networks managed by these smaller municipal agencies may be simple enough that they do not require a network-level analysis. For instance, a small city with perhaps 40 km (25 miles) of roadway could probably use a simple pavement condition analysis method to meet all their information needs. Project-level systems can, however, require a significant amount of data depending upon their complexity and how they are modelled.

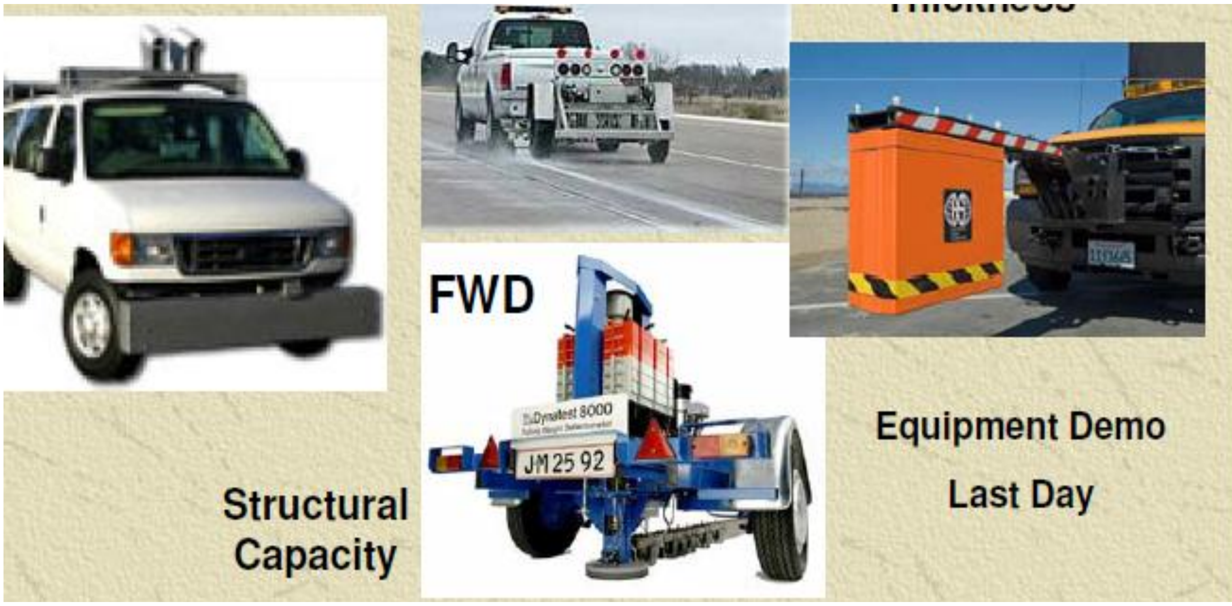
- **Better link between network-level and project-level management decisions**; because decisions flow from the bottom up, the high-level network decisions, although somewhat limited in scope, in essence must be based on low-level project decisions. However, in a network-level approach it is sometimes difficult to translate broad network-level decisions into specific project actions. For instance, a decision to improve all IRI>3.0 m/km roadways by overlay may be made at the network level, but these segments of roadway may be located in small sections over a wide area making for inefficient construction.
- **Less dependent upon feedback for success**; Political sentiment, budgets, pavement condition and MR&R strategies are highly dependent upon the local environment. Because of this, network-level models will invariably need calibration, which can only occur through continual feedback and updating. If this feedback/update process is interrupted or halted (e.g., through budget cuts, personnel transfers) a network-level model's utility can quickly degrade. Additionally, un-calibrated network-level models that are used will produce erroneous results.
- **Easier to obtain buy-in from others**; Project-level approaches can be simpler and more easily understood. Network-level approaches typically use sophisticated models that make many generalizations and assumptions. Those who are unfamiliar with the model may be unwilling to use its results because (1) they do not understand how it works or (2) they do not agree with its generalizations and assumptions.

2.10. Pavement Condition Survey Equipment

Some of the pavement condition survey equipments are;

Profiler; it is used to determine roughness, distress, rutting, noise and pavement cracking
Skid Trailer; it is used to determine Pavement friction
GPR; it is used to determine Layer Thickness

Figure 1 picture of condition survey equipment



2.11. PMS Data Collection

It is extremely important to collect all the pavement-related information for their effective management. Because of the sheer size of the highway network, the PMS has required a huge amount of data. While collecting data it should be aimed that the collected data, directly or in its derived form should meet the requirements of HDM-4 system or PMS in general. The data types can be categories as;

- Inventory data,
- Pavement Condition data,
- Traffic/Loads,
- Costs - Construction, Rehabilitation, Reconstruction
- History – Initial Construction, Rehabilitation, Reconstruction, (Last Treatment) and etc

1. **Inventory Data**; the inventory data includes the following details about the selected pavement sections: Name of road, category of road, carriageway and shoulder width and its number of lanes, drainage conditions, surface type and thickness, pavement layer details , Country, legislative district and etc.

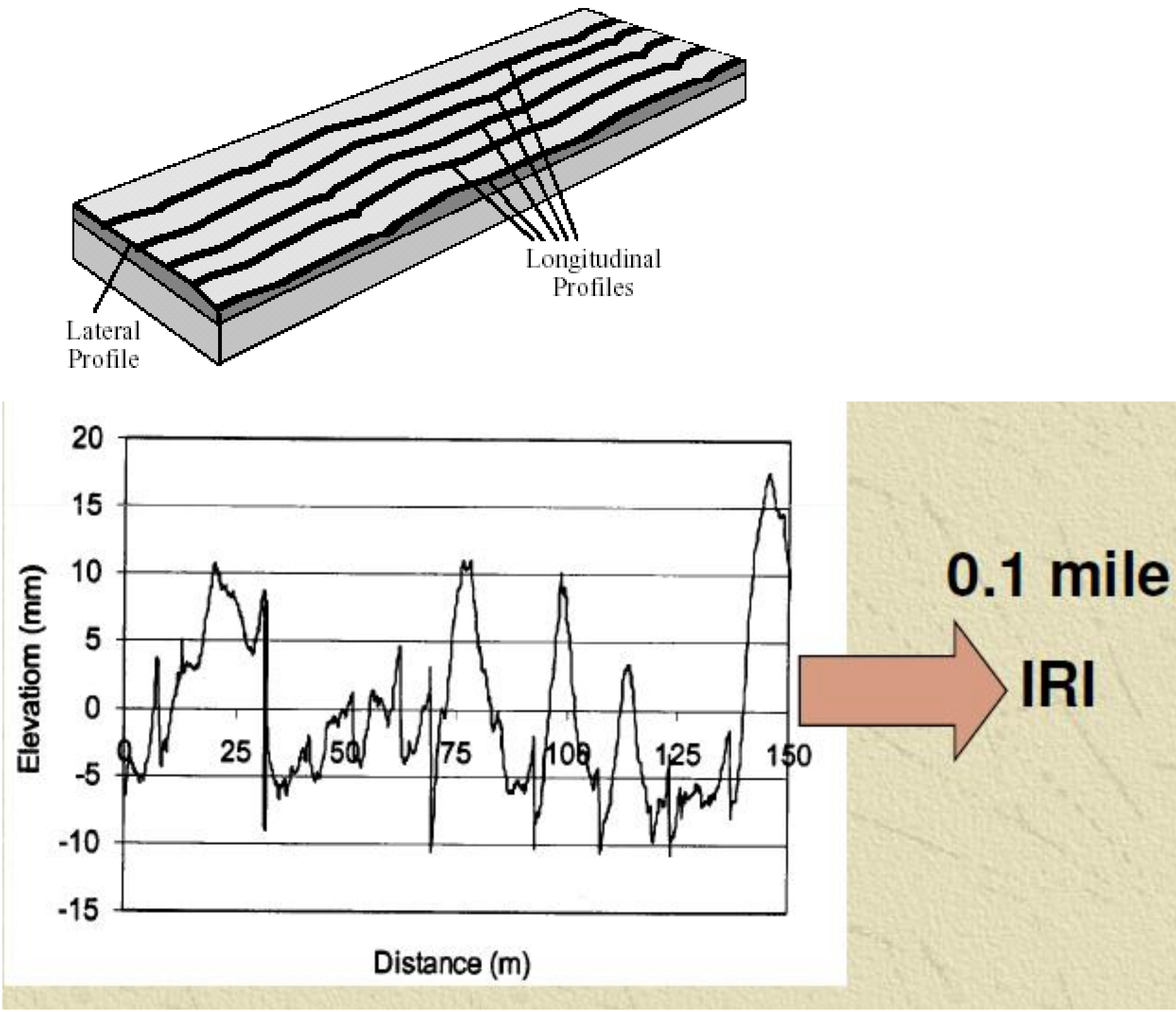
2. **Pavement Condition Evaluation;** in general under this data collection type the Pavement Roughness or Ride Quality, Surface Distress, Rutting, Skid Resistance and Structural Capacity can be determined. These data can be used to determine the need for annual condition surveys, ride quality, surface distress, rutting, friction, and to evaluate the current condition of pavement, determining rates of deterioration, project future conditions and to determine current and future maintenance & rehabilitation needs and its future cost of repairs. In general term it can be sub divided into two categories;

   Structural Evaluation: The magnitude of pavement rebound deflection is an indicator of the ability of the pavement to withstand traffic loading. Higher the rebound deflection, poor is the structural capacity and performance. The practice hitherto is to use the Benkelman Beam deflection method for evaluating the structural condition of the flexible pavement.

   Functional Evaluation: Functional evaluation of pavements consists of collection of road data pertinent to surface distress (crack area, raveled area, pothole area), rut depth, surface roughness etc. having observed the type and extent of distress developed at the surface i.e. cracking, raveling, patch work, potholes, rut depth, edge break and etc based on the visual condition survey. The extent and type of distress developed in quantitative terms will also be measured, in addition to the visual recording of the pavement surface condition.

3. **Road Roughness;** is the irregularities in the pavement surface affecting user comfort and safety due to variations in horizontal, vertical, and transverse profiles ride quality - user perception of Pavement Roughness. This roughness can be measured using profiler. The instrument measure pavement wheel path profile(s) to assess pavement ride quality and convert pavement wheel path profile (l&r) to Pavement Ride Quality Indices (IRI).

Figure 2 International roughnesses Index



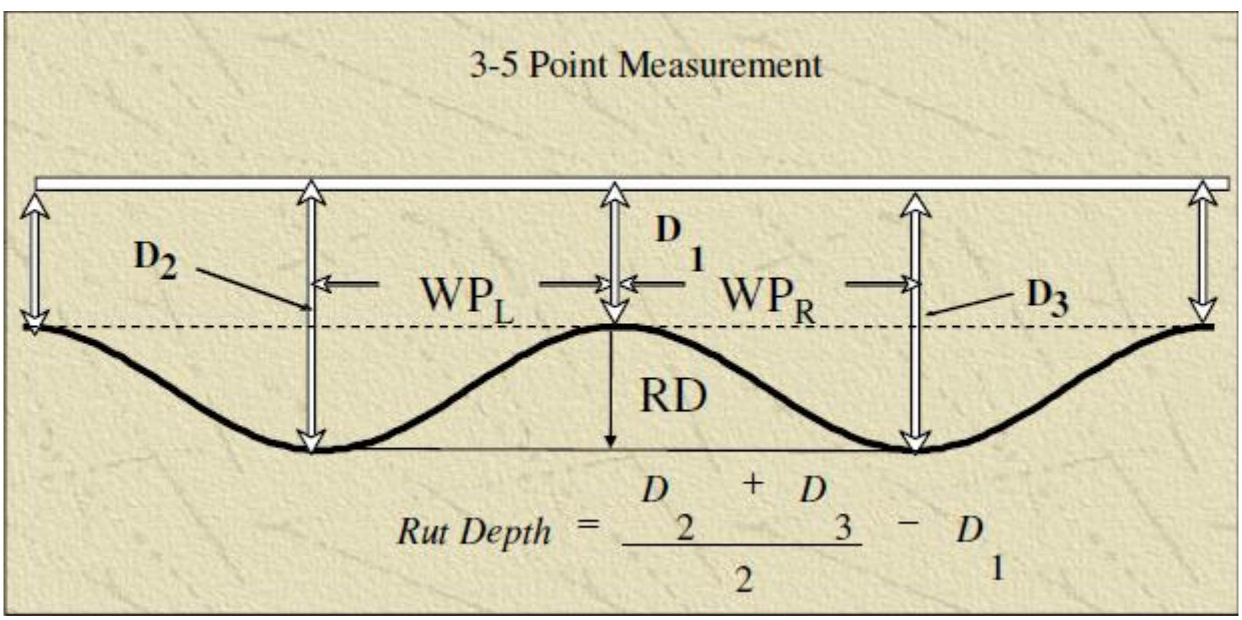
4. **Surface Distress;** while evaluating and collecting data on surface distress one has to consider;

- ✓ Type of Distress *(Cracking, Patching, Rutting)*
- ✓ Severity (Crack Width, Condition Assessment)
- ✓ Extent (Percentage of the Pavement Length)

Figure 3 Picture of Distress

5. **Rut Depth Measurement;** the transverse deformation across the wheel path is defined as the rut. The rut depth can be measure as shown in the figure 4 below.

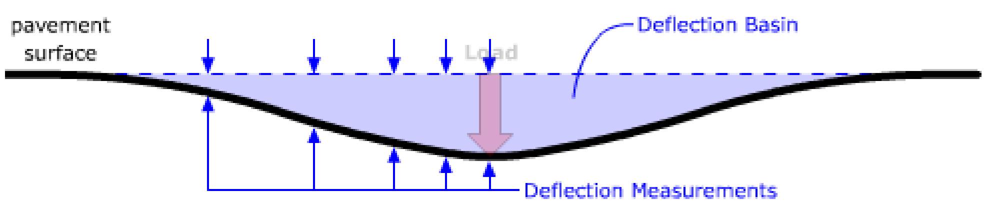
Figure 4 rut depth measurement



6. **Skid Resistance ;** *It is assessment of the coefficient of friction of the pavement surface using* (Lock Wheel) Skid Trailer

7. **Structural Load Capacity;** It is assessment of the load carrying capacity of the pavement structure using coring/borings/lab tests (destructive type) or Falling Weight Deflectometer (fwd) (non-destructive test)

Figure 5 Deflection measurement



2.12. Challenges and Opportunities in PMS Implementation

Given the ever-increasing pavement rehabilitation needs and limited available budgets, most highway agencies are using PMSs in one form or another to preserve the huge investment in pavements and to maximize the use of limited resources. However, even after 2 decades of usage, implementing a comprehensive, yet practical, PMS that will realize its full potential in terms of wide usage among not only pavement engineers, but also executives involved in setting policies, and financial planning and accounting is still challenging. The awareness of each challenge also presents an opportunity to improve the state of pavement management practice. Herein below are the main challenges in PMS implementation and the opportunity to improve the PMS practice in the process by meeting each of the challenges (Ram B. Kulkarni and Richard W. Miller, 2003[1]).

- ***Systematic updating of pavement performance prediction models***; No prediction model can be perfect in predicting future conditions. As data from ongoing pavement condition surveys become available, one can check whether significant deviations exist between model predictions and on-ground truth. Such deviations may indicate a problem with either the model or the data. Data problems may include a gross error, for example, in recording a particular data item, or unreported maintenance activities that have changed the expected pavement condition. If the data are confirmed to be accurate, model parameters or the model formulation may need to be updated to resolve observed deviations between the data and the model predictions. Yet, few systems have incorporated systematic procedures for validating and updating pavement performance prediction models based on the data from pavement condition surveys. With time, the reliability of model predictions can become poor and result in selecting strategies that are necessarily the most cost-effective. Recent concepts of artificial intelligence and neural networks provide an opportunity to put in place automated alerts to identify model deviations and to update the models.

- ***Access to data and reports***; most modern PMSs have electronic databases that contain such data as pavement conditions, traffic, and construction and maintenance history. However, the database is often not readily accessible to all potential users, particularly to the local maintenance supervisors and field personnel who need to be well aware of trends in pavement distresses, recent maintenance history, and planned rehabilitation actions in the near future. The recent advances in information technology provide the ability to design database applications that are user-friendly and readily accessible to users in different locations, including field personnel. Web-enabled applications can be used to improve user access through local computers or smart terminals. Databases used in different management systems such as pavement management, bridge management, and traffic congestion management can be readily linked so as to avoid duplication of common data and to coordinate programming decisions for different facilities in an overall asset management system.
- ***Tracking of PMS effectiveness;*** If a PMS has been in place for several years, is it working the way it was intended? Has it improved the cost-effectiveness of the agency's maintenance budgets, i.e., improved the 'health' of the highway network for a given amount of expenditure? Few systems systematically track and document

PMS effectiveness. With the linking of various databases on pavement conditions, traffic, and maintenance expenditures, PMS effectiveness can be tracked using automated procedures.

- ***Documentation of maintenance activities***; Data that records ongoing maintenance activities, particularly when performed with in-house agency forces, are continually lacking. The lack of such data creates problems in properly defining the current pavement conditions, identifying the remaining serviceable pavement life, and consequently, predicting future pavement conditions. Furthermore, data on the cost of various maintenance actions are often recorded only at the aggregate level (e.g., for a given maintenance area) and, hence, costs of maintenance actions for individual segments are often not available. With recent advances in hand-held devices and GPS systems, the type, amount, and location of routine maintenance activities can be recorded much more easily by simply pushing some buttons on small, hand held machines. No paperwork is needed and the chances of field personnel consistently recording the maintenance activities they perform are improved.
- ***Coordination with other systems/programs/personnel;*** Pavement rehabilitation decisions cannot be made in isolation; they must be coordinated with other planning and programming decisions that a transportation agency needs to make. Such decisions include bridge maintenance and rehabilitation, highway system modernization and expansion, and maintenance and improvement of other transportation modes. In current practice, little coordination exists among various management systems for different facilities in a transportation network. Furthermore, while engineers and planners may routinely use the output of PMSs, financial personnel (accountants and financial VPs) often do not access PMS output to help in making agency-wide budgeting and asset management decisions. Again, recent advances in system integration should provide the opportunity to achieve seamless integration of various management systems and to improve the access to data and results of analysis to all users.

- ***Capability for efficient sensitivity ("what if") analysis;*** Many current management systems lack the capability to perform efficient sensitivity analysis to address many "what if " questions of interest to planners and managers. For example, what are the budget implications of higher performance standards? What is the impact of reduced pavement rehabilitation budgets on the overall health of the system and on user costs? With the linkage of databases and wide access to multiple user groups, one can significantly improve the ability to perform sensitivity analysis such that many budget and performance scenarios can be analysed rapidly online, thus providing the basis for more informed decisions.

2.12.1. Keys to Success In PMS

Even communities that invest the time and money in a pavement management system can falter in the process. Turnover in key positions or a shift in funding priorities can spell trouble. There are, however, some prescribed steps that can improve a community's chances of benefitting from an investment in pavement management (William Scarpati and Jerry Guerra [28]).

- Ensure buy-in at the top. If a municipality's governing bodies and officials don't support the pavement management system or worse, don't understand why they're doing it. It will more than likely run off the rails. Communities with the best pavement management results tend to have political leadership with a strong commitment to changing for the better their approach to pavement repair and maintenance.
- Identify project champions. Change is often met with fear and resistance. The person in the organization charged with ensuring implementation of the pavement management system must also be its greatest advocate, stopping at nothing until it is accepted and considered the guiding force behind the pavement repair and maintenance process. The higher in the organization this person is, the better. It is also critical to identify additional champions to carry on this leadership should the primary person move on to another job.

- Select a software package that is best suited for your organization. Employing technology to solve problems can sometimes complicate a process, especially in the short term. As noted earlier, small and rural communities with a relatively low number of roadway miles can use a simple spreadsheet program. Larger and more urbanized municipalities should consider investing in a comprehensive asset/work order management software program that can address not only pavement, but also water, sewer, sidewalks, ramps, signs, signals and other systems. Whichever approach a community takes, officials should ensure that the program is robust enough to address issues such as short- and long-term prioritization, spending optimization, reporting and querying capabilities, and so on. And don't skimp on training; the best system in the world is useless if the people who matter don't know what it can do or how to use it.
- Conduct a quality assurance review of pavement management data. Proper analysis and planning require accurate data. Identify what you're going to collect, why you need the information, how you will use it and so on. Identify the appropriate data and models required to produce the desired output. Conduct a pilot—select a snow route, district or ward to test data collection and modeling. Perform tests to ensure that the collected data is uniform and consistent, especially when multiple personnel are gathering and entering data.
- Deliver a readable and useful report. The people reading the data are likely to have a range of technical knowledge, so it is imperative to use language that is understandable to a wide audience. Express data and recommendations with terms such as dollars, miles, and months or years. Recommendations should be clear and candid. Tell it like it is.
- Continually update the pavement management database. Pavement/asset management is a living process. It should not be done once and then followed or worse, forgotten. If pavement management is to be beneficial, the community needs to maintain accurate and up-to-date records of repairs, costs, schedules

and so on. One rule of thumb is to inspect between one-quarter and one-third of the roadway network every year.

Long-Term Benefits

It's tempting to look at pavement management as a quick fix or a silver bullet for all of a community's roadway woes. While pavement management does offer some immediate benefits, this is not the primary motivation. A pavement management system is a long-range plan that will stretch a roadway repair budget and will eventually result in a vastly improved system. The plan typically covers a period of three to five years, with a focus on the work that is necessary to bring the roadway system up to more acceptable standards.
Identifying a community's backlog of work, and the costs associated with addressing these needs, helps the community effectively manage the finances of its roadway infrastructure program. The pavement management system becomes the blueprint for a proactive, cost-effective preservation and maintenance program, as well as the foundation for a strategic capital infrastructure improvement plan. The benefits don't end with roads, however. Pavement management systems can be shared and coordinated with utility companies, for example. Before a city or town invests in a resurfacing project, it can ensure that any conflicts with utility infrastructure are addressed.

A pavement management plan overlaid with other condition assessments can help communities make better decisions about all of their assets. One example is sidewalk condition data, which allows a community to address issues related to compliance with the Disabilities Act by identifying problem areas. This includes costs and a timetable for corrective measures (William Scarpati and Jerry Guerra [28]).

Chapter Three ------- Case Study on ERA Pavement Management System (PMS)

3.0 Introduction

This chapter discuss on data analysis obtained from the archival data and interviews made with the Officers of ERA Road Asset Management Department. All information required is collected from the Road Management Team of ERA Road Asset Management Department. The purpose of the analysis was to obtain information from ERA Road Asset Management Department on the standard, content/organization of Pavement Management System, the current implementation level of ERA Pavement Management System including its manuals in Ethiopian Federal Road Network, the problems in implementation of Pavement management system and the basic approach to improve the implementation level of Pavement management system at Ethiopian Roads Authority (ERA).

The interview was conducted on the officers of Road Management Team of ERA Road Asset Management Department. Most officers have less than three years experience on PMS. This observation is important to show lack of experienced/trained personnel on PMS. The aim of the interviews is to attain the main objective of the study which is to know the present implementation level of ERA Pavement Management System in Federal road Network.

For reporting purpose this chapter divided in two parts;

Part I Overview of ERA Pavement Management System (PMS), this section will discuss the overall structure of ERA road asset department, the manuals, supporting documents and equipments utilized for ERA PMS and others; and,

Part II Case Study on ERA PMS, this section will discuss the result/findings of the data obtained from the interviews and archival data. The findings of the case study will discuss into two sub-sections, which are problems occurred during the process of PMS System and basic approach in improving the Pavement Management System.

Part I Overview of ERA Pavement Management System (PMS)

3.1. Introduction

ERA has been implementing asset management to maintain, upgrade, and operate the physical assets systematically through cost-effective methods [1]. As per organizational chart of Ethiopian Roads Authority; Road Asset Management Department is the responsible party to administer the federal road network. In this chapter will discuss about ERA Pavement Management System. It explains the detail procedure for Pavement Management System which was applied at Ethiopian Roads Authority (ERA). The manual utilized for PMS of ERA is elaborated including its procedures.

3.2. Role and Task of ERA Road Asset Management Department

Road assets are economic resources that provide services to the public. Asset management is the process for managing these assets. Accordingly, the main Objectives of ERA road asset management department are [1];

- To ensure continued and effective provision of road network to road users and
- Support of national economic development.

On the other hand, ERA Road Asset Management Department has been performed the following Tasks [1];

- Collect and organize data required for road network management,
- Make road condition assessment and gap identification,
- Prioritize and optimize works based on network classification,
- Administer and improve PMS and road classification system,
- Administer and improve BMS,
- Collect bridge condition Data,
- Prepare Bridge maintenance and replacement plan,
- Protect road and bridge from damage due to excessive loads,

- Control and manage the situation that interrupt road transportation,
- Network administration,
- Prepare annual maintenance plan and budget requirement,
- Administer Road maintenance projects and
- Conduct seasonal Traffic count.

In general, in order to perform the above mentioned tasks (implementing asset management), ERA has launched the current Pavement Management System since 2011 as a tools to implement asset management. The ERA PMS structured with different user manuals and equipments. In the following subsequent topics ERA Pavement Management System has been discussed.

3.3. Over view of ERA Pavement Management System

ERA Pavement Management System organized with different PMS user manuals. Among these user manuals, PMS User Manual for PMS Operations is the leading one which includes all procedures in PMS. This PMS User Manual describes the operational actions necessary to maintain and support the data management of the Pavement Management System of ERA [15].This manual refers to all other manuals in the suite of documents supporting the PMS of ERA. Herein below describes all supporting documents for ERA's PMS.

- **ERA PMS User Manual for dTIMS and HDM4 Operations;** This manual describes the customized PMS systems of ERA in the dTIMS and HDM-4 software applications. It includes database operations in dTIMS and life cycle cost analyses in HDM-4.
- **ERA PMS User Manual for HAWKEYE Data Processing;** This manual describes the processes to be followed after a road survey has been completed with the HawkEye equipment. The manual has details on how to process and export the profile and distress data, and how to further manipulate the surveyed into the correct format for importing into ERA's dTIMS database.
- **Official set of HDM-4 Manuals;** This manual suite contains the following documentation on the HDM-4 series: Applications Guide, Software Users Guide,

Analytical Framework and Model Descriptions, A Guide to Calibration and Adaptation, Modelling effects.

- **WE 751-4-4 Processing Toolkit & Data Viewer User Manual, and WE 751-4-3 Hawkeye Data Viewer Quick Start Guide (18.11.2010);** This is the official manual of the HawkEye Processing Toolkit application that is used to process and view the ERA's surveyed data.
- **dTIMSV8 User Guide March 2011;** This is the official User's Guide of the Dtims software application. It describes all aspects of the dTIMS software application that are necessary to maintain a road network database in dTIMS.

3.4. Overview of ERA's PMS Operations

3.4.1. Data Collection Equipment of ERA

Data collection for the PMS is done through the Hawkeye 2000 (on paved roads) and Hawkeye 1000 (on unpaved roads) systems [Quality Management Plan, page 2&3[27]].

The Hawkeye 2000 system is installed in the Mercedes Benz Vito vehicle and provides the following:

- Roughness from laser measured longitudinal profiles processed through the Hawkeye Toolkit software,
- Rutting from laser measured transverse profiles processed through the Hawkeye Toolkit software,
- Texture from laser measured texture in right wheel path and processed through the Hawkeye Toolkit software,
- Pavement video files from two pavement view cameras, from which defects such as cracking, ravelling, potholes and structural failures are extracted through the Hawkeye Toolkit software rating form approach and
- Asset view video files from one asset view camera facing forward for measuring of defects such as edge break, measurement of pavement dimensions, recording of side

drainage facilities, evaluating side drainage condition, kerbing through the Hawkeye Toolkit software rating form approach.

The Hawkeye 1000 system is installed in the Nissan Patrol station wagon vehicle and provides the following:

- Roughness from the Roughometer III and
- Asset view video file from one asset view camera facing forward for rating of items such as wearing course quantity, wearing course quality, road formation, measurement of road dimensions, recording side drainage facilities, evaluating side drainage condition through the Hawkeye Toolkit software rating form approach.

Once all data has been processed in the Hawkeye Toolkit software, and validated, merged / combined in the special pre-processing software application, they are imported to the dTIMS database. A special conversion application is then executed to convert the data to HDM-4 input file requirements. Life cycle strategic and programme analysis then follow in HDM-4 for decision support to ERA Management on maintenance strategies and long-term programmes.

Apart from the above equipment ERA also operates a Falling Weight Deflecto-meter (FWD), trailer mounted and towed by another Nissan patrol station wagon vehicle. The FWD provides structural strength information about road pavements. The structural strength information is captured in HDM-4 to represent the current strength of the pavements.

3.4.2. Day to day operations

The maintenance of any PMS is an on-going continuous task. For the majority of time, the PMS personnel will be tasked with the activities to process surveyed data; however the maintenance of ERA's dTIMS database should be done on a day-to-day basis when possible [24].

The data in ERA's dTIMS database is imported from various sources and after being verified to ensure the road elements the data are complete for ERA's road network. Any changes to the road network (new roads, etc.) could also have the result that some perspectives in ERA's dTIMS database have incomplete or "missing" data.

ERA follow the following steps to verify and confirm the validity of data in ERA's dTIMS database.

Step 1. In dTIMS: Select one perspective at a time and export the Data Sheet View to Excel or Access. ERA uses the manual, ERA PMS User Manual for dTIMS and HDM4 Operations, to validate the value of each attribute.

The properties of each attribute can also be consulted in ERA's dTIMS database.

This will be performed for all perspectives, except HDM4 perspective.

Step 2. In dTIMS: Use the Tools/Database Reports item on the menu to investigate all roads with "missing pieces". Select one perspective at a time and generate the Database Report and export to Excel or Access. This step generates a list of road segments with no elements for a specific perspective. The "Missing Pieces" report can then be used to obtain data for from an appropriate source before importing the elements/data into dTIMS.

The Tools/Database Reports item will be repeated until you are satisfied with the contents on each perspective.

This will be performed for all perspectives, except the HDM4 perspective.

3.4.3. The start of a new survey cycle

At the start of each survey cycle, ERA's road network to be surveyed should be identified in a list of paved and unpaved roads. The list of roads can then be distributed to the surveyors and PMS personnel involved with the monitoring of the annual surveys.

ERA follow the following steps to generate road lists of the current road network of ERA. The road lists also contain the steps to be followed during the processing stages.

Step 1 Using chapter 2 of ERA PMS User Manual for HAWKEYE Data Processing determine the "YEAR OF THE SURVEY".

Step 2 Using chapter 2 of ERA PMS User Manual for HAWKEYE Data Processing three road lists will be generated:

- A Road list to process the surveyed data for paved roads. This list contains the necessary steps to be taken to generate the import data of paved roads for the "SURVEY perspective" in dTIMS.
- A Road list to process the surveyed data for unpaved roads. This list contains the necessary steps to be taken to generate the import data of unpaved roads for the "SURVEY perspective" in dTIMS.
- A Road list to process the inventory data for both paved and unpaved roads. This list contains the necessary steps to be taken to generate the import data of paved and unpaved roads for the "INVENTORY perspective" in dTIMS.

Step 3 Create the directory for the "survey year" and store all processed data.

Annually the paved and unpaved roads of ERA are surveyed using the HawkEye 2000 equipment for paved roads and the Roughometer equipment for unpaved roads. After a survey has been completed for a road, the surveyed data and videos require further processing, analysis and importing into ERA's dTIMS database. The "field" survey is thus completed and the subsequent data processing should now be completed for each road that was surveyed as soon as possible to prevent backlog of survey processing.

Using the processes of Chapter 3 of ERA PMS User Manual for HAWKEYE Data Processing, the inventory data for a specific paved or unpaved road will be processed and stored in the "Survey" perspective of ERA's dTIMS database. These processes will take the user through the steps:

- to process all profile data,
- to complete automatic crack detection,
- to identify distresses from the video surveillance data,

- to combine the data of different lanes for a road and
- Finally to import the data into the "Survey" perspective in dTIMS. On completion of this step, the survey data for a specific paved road will be stored in the "Survey" perspective of ERA's dTIMS database.

On the other hand, using the processes of chapter 5 of ERA PMS User Manual for HAWKEYE Data Processing, the INVENTORY data for paved and unpaved roads will be processed and stored in the "Inventory" perspective of ERA's dTIMS database.

3.4.4. Traffic data in the "Traffic" perspective in dTIMS

Traffic data is an important component into the strategic analysis of ERA's road network in the HDM-4 software. It influences road user costs in an economic analysis, it influences the rate of deterioration on roads and it plays an important role in the strategic planning of road works under constrained budget scenarios.

The Traffic data shall be obtained from the "Traffic Information System" of ERA at least once a year, after the survey shave completed and before an analysis in HDM-4 is done. Typically the traffic data will be obtained for a specific year and the data will be traffic counts for the eight vehicle classes adopted for ERA (i.e. CAR, LAND ROVER, SMALL BUS, LARGE BUS, SMALL TRUCK, MEDIUM TRUCK, LARGE TRUCK and ARTICULATED).

The Data Sheet View of the "Links" perspective can be exported from ERA's dTIMS database to provide the TIS with a list of all roads in the PMS.

Once the most recent set of traffic data has been obtained from ERA's traffic information system, the data can be imported into dTIMS database and verify the data is complete for the entire road network or not.

3.4.5. Falling Weight Deflection (FWD) data

Deflection data collected from the FWD equipment should be stored in the "FWD" perspective of ERA's dTIMS database. The FWD data collected for any portion of the road network should be imported into ERA's dTIMS database and will then automatically be included in the HDM-4 analysis. The collection of FWD data will grow on a yearly basis until all paved roads have FWD data. If a paved road is surveyed for the second time, the existing FWD data of such a road should be removed from the "FWD" perspective in dTIMS and the "new" FWD data should be imported.

The Adjusted Structural Number (SNP) is an important parameter that is derived from the FWD data for input into the HDM-4 software for a strategic/programme analysis.
Steps to take to import FWD data in dTIMS are:

- Identify the roads with new FWD data.
- In dTIMS: Open the Data Sheet View of the FWD perspective.
- Verify if any of the roads with new FWD data have existing (old) elements (points) on the FWD perspective. If elements exist: Deleted the old existing elements from the FWD perspective.
- Continue to import the elements and data of the roads with new FWD data.

3.4.6. Details on the Condition Index (CI)

The Condition Index (CI) describing the overall condition of road.

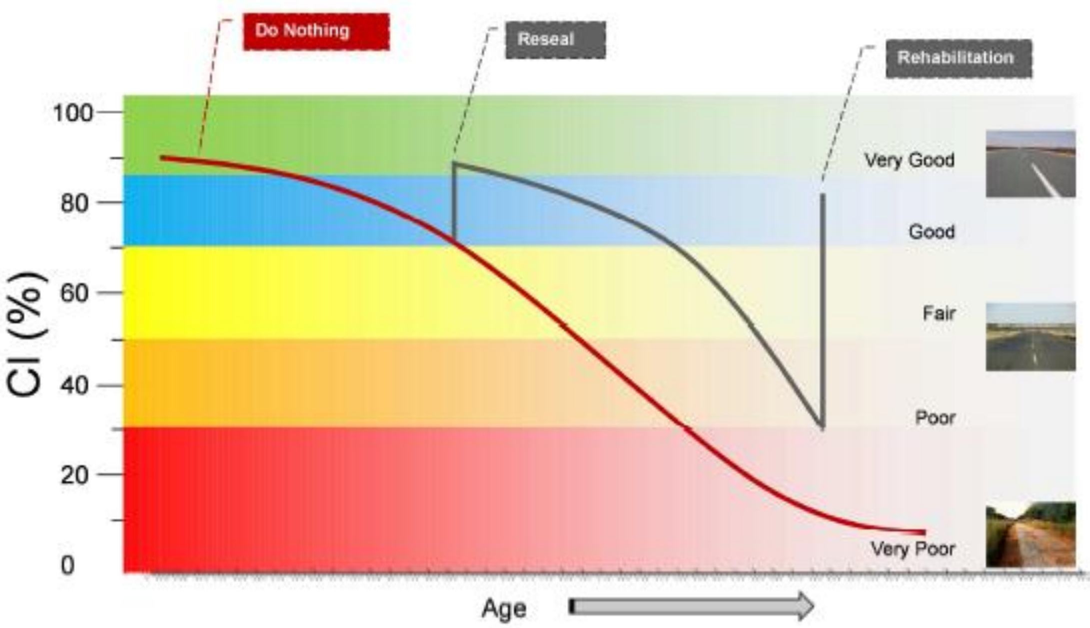
The processed profile and distress data is used to calculate a single Condition Index (CI) describing the overall condition of a road segment, for a specific year. This CI, calculated for each surveyed road segment, is a percentage index ranging between 0 and 100; 0 representing a road segment in very poor condition and 100 representing a road segment in very good condition. The CI percentage is calculated and stored in the dTIMS database after the surveyed data was imported.

The CI is used as follows in ERA's PMS:

- An average network CI is calculated representing the average condition of the paved road network for a specific year. This average network CI is weighted by length.

- An average network CI is calculated representing the average condition of the unpaved road network for a specific year. This average network CI is weighted by length.
- The CI is furthermore grouped into five condition categories that are used to categorise the condition of the paved or unpaved road network into very good, good, fair, poor and very poor categories. The categories adopted are:
  - ✓ Very Good = 86% to 100%
  - ✓ Good = 71% to 85%
  - ✓ Fair = 51% to 70%
  - ✓ Poor = 36% to 50%
  - ✓ Very Poor = 0% to 35%
- The colours RED, ORANGE, YELLOW, BLUE and GREEN are universally used to condition information on road networks.

Figure 6 the CI Scale and Typical road deterioration for paved road



The following formula is used to calculate the CI:

$$CI = (0.02509 * CI_p + 0.0007568 * CI_p^{2})^{2}$$

Where

CI_p = Preliminary CI

$CI_p = 100 * (1 - C * \Sigma (Fn))$

Fn = Rn x Wn

Rn = The rating of the condition distress, subject to a maximum (MAXn) as in the table below, and normalized to a value between 0 and 4.

MAXn = Maximum allowable value of each distress rating

Wn = Weight of the defect, i.e. the contribution of each distress in the CI calculation. See table below.

C = The normalizing factor

$$C = 1 / \sum_{n=1}^{N} Fn(\max)$$

Fn(max) = MAXn x Wn

N = The number of distresses contributing to the CI.

It is crucially important that the same factors as the ones supplied in the table below are applied for future surveys too, in order to be able to compare like with like and to determine whether the overall network condition has deteriorated or improved between surveys.

The values below were established during 2011 when ERA's PMS was customized; it is highly recommended that the exact same parameter values are applied to future surveys.

Table F-1: CI calculation formula for PAVED roads: Input weights and factors

Distress	Weight (Wn)	Range used for CI calculation	Maximum Allowable Contribution to CI ($MAX_{n)}$)	Maximum Value when Normalized
Narrow Cracks (%)	15	0-25	25	4
Wide cracks (%)	10	0-20	20	4
Thermal Cracks (No / km)	5	0-20	20	4
Potholes (no)	15	0-50	50	4
Ravelling (%)	4	0-30	30	4
Roughness (IRI)	20	0-9	9	4
Rutting (mm)	15	0-25	25	4
Texture (micro mm)	10	5 – 0.3	Min = 0.3	4
Edge Break (m^2 / km)	3.5	0 - 300	300	4
Side_Drain (0-4)	3	0 - 4	4	4

Table F-2: CI calculation formula for UNPAVED roads: Input weights and factors

Distress	Weight (Wn)	Range used for CI calculation	Maximum Allowable Contribution to CI ($MAX_{n)}$)	Maximum Value when Normalized
Formation rating	10	1-5	5	4
Gravel quality rating	10	1-5	5	4
Gravel quantity rating	10	1-5	5	4
Roughness (IRI)	10	1-5	5	4

3.4.7. Strategic/Programme Analysis in HDM-4

A strategic/programme analysis in HDM-4 entails the medium to long term planning of required road network expenditure and the forecasts of long term road network performance under varying funding levels. Multi-year works programs are part of the output.

A HDM-4 strategic/programme analysis should be completed at the end of a year's survey cycle when all surveyed data have been processed and imported into the dTIMS database.

The following information and data should be available:

- The survey data for all paved and unpaved roads should have been processed and imported into dTIMS. The "SURVEY" perspective in ERA's dTIMS database should have been updated with the most recent surveyed data.
- The "TRAFFIC" perspective should have been updated with the most recent data from the Traffic Information System (TIS)·
- Costs regarding ERA's Vehicle Fleet and ERA's Maintenance Works should be updated.

3.5. Quality Management Plan for Data Collection

'Good' data are very important in providing effective pavement management. In this respect, ERA has quality management plan for data collection which describes the Quality Management Plan (QMP) for data collection for the PMS of ERA [27].

A QMP provides a comprehensive, systematic approach to data collection and processing. It contains detailed quality acceptance procedures and established guidelines to monitor the entire process.

The QMP is described in two components:

- A quality control plan; and
- A quality acceptance plan.

'Quality control includes actions and considerations necessary to assess and adjust production processes to obtain the desired level of quality of pavement condition data' (refer NCHRP 401). These activities will then include checks on the equipment used to collect the data, the personnel responsible for the data collection and the data collection process itself.

'Quality acceptance activities are those that govern the acceptance of the pavement condition data' (refer NCHRP 401).

The purpose of the Quality Control Plan (QCP) is to ensure that the people, processes and equipment are all aimed at collecting quality data. The QCP thus has to do with the actual data collection exercise, detecting problems as soon as possible, before large quantities of data have to be re-collected.

The contents of a comprehensive QCP typically include the following elements:

- Clear delineation of responsibilities;
- Documented (and available) manuals and procedures;
- Training of survey personnel;
- Equipment calibration, certification and inspection procedures;
- Equipment and/or process quality verification procedures before starting and during production testing; and
- Checks for data reasonableness, consistency and completeness.

Thus, using this manual ERA has implementing quality control mechanisms on the data used for PMS.

3.6. Model Calibration

ERA has developed HDM-4 calibration of RD manual. This manual describes the procedures for calibration of the Road Deterioration and Works Effects (RDW) models of HDM-4 as incorporated in the Pavement Management System of the Ethiopian Roads Authority (ERA).

It is well known that the only way to complete calibration of the HDM pavement deterioration models is by conducting a study into the rate of pavement deterioration. Such studies provide time series deterioration data that are used to compare predicted and observed pavement behavior in terms of various deterioration characteristics. The HDM-4 models contain 'calibration factors' that can then be determined from the data comparisons to adjust the predicted behavior towards the observed behavior.

The calibration of HDM-4 will run for a number of years (minimum 5 years), it is therefore necessary to consider the following [7]:

- The long-term vision for the calibration
- How many calibration sites to establish
- What data to collect
- Data acquisition methods
- Calibration database
- Resources
- Methodology for calibration, e.g long-term monitoring or slice in time.

3.7. Evaluation of Sample Condition Survey Conducted by ERA

ERA being develops PMS system and launching the necessary manuals for PMS as depicted in the above sections of this chapter in order to examine the implementation level of the system in ERA I have tried to assess the sample condition survey conducted for the purpose of ERA PMS system in the subsequent sub-sections of this section it was discussed.

3.7.1. Condition Survey

Pavement condition data are used as a basis for every decision made with the PMS. If the condition data are not reliable, none of the recommendations of the system will be reliable. Based on this principles in ERA condition survey carried out every year after rainy season

- Collects information on the condition of road network
- Collets data based on the severity and extent of a condition item

The intention of the survey is to produce quantifiable & comparable data set to identify the condition of the road network (poor, fair, good). The severity index determines how bad the selected item or part of the road and the extent index determines the quantity of the distress.

While evaluating the archival data at ERA I found that till to date after the launching of revised ERA PMS i.e 2011 ERA has been conducted the first cycle of condition survey for about 5,670 km of Road (most are paved) and currently they are started second cycle condition survey using data collection equipments i.e Hawkeye 2000 (for paved roads) and Hawkeye 1000 (for unpaved roads). Nonetheless, due to the break dawn of the Hawkeye 2000 the survey is stacked.

3.7.2. Equipment used for Condition Survey

ERA currently conducting condition survey at district and network level.

At district level the data collector personnel conduct condition survey (visual Condition survey) every three months for budgeting purpose to maintain the damaged roads or spots at the section. In this level of condition survey the personnel uses visual inspection to determine/survey the extent and type of distress and etc. The visual Condition survey used to measure various types and degrees or severity of distress. The components which can be measure using visual Condition survey are surface defects (such as longitudinal joint cracks, potholes, raveling, bleeding and lacy edge), permanent deformation or distortion, fatigue cracking and patch deterioration.

At network level using Hawkeye 2000 (on paved roads) and Hawkeye 1000 (on unpaved roads) systems ERA has been conducted/conducting condition survey and collects Roughness, Rutting, Texture, Pavement video files from which defects such as cracking, ravelling, potholes and structural failures are extracted and Asset view video files from which defects such as edge break, measurement of pavement dimensions, recording of side drainage facilities, evaluating side drainage condition, kerbing are extracted as input for PMS. On the other hand ERA also use Falling Weight Deflection (FWD) equipment to collect pavement deflection data. The FWD data collected for any portion of the road network used to derive the Adjusted Structural Number (SNP) which is an important parameter for input into the HDM-4 software for a strategic/programme analysis.

The sample data collected for the purpose of PMS input attached as annex i.e. ***Appendix No.3***

Table No.3 Paved road Condition Survey Form 1

Paved Road Condition Survey Form 1
Road Side, Side Drains and Shoulders

District: __________________ **Section:** ___________________ **Date:** _____________ **Weather:** _______ **Survey Dir.** ***from*** _________ ***to*** ___________

Road Seg. No. ______ **Road Segment:** ***from*** _____________ ***to*** _____________ **Start Km :** _________ **End Km:** _________ **Subsegment No.:** ______

Km			Sever	0.000 - 0.500	0.500 - 1.000	1.000 - 1.500	1.500 - 2.000	2.000 - 2.500	2.500 - 3.000	3.000 - 3.500	3.500 - 4.000	4.000 - 4.500	4.500 - 5.000
Left	Road Side Brush		1										
			2										
			3										
	Side Drains	Brush	1										
			2										
			3										
		Scour	1										
			2										
			3										
		Silt	1										
			2										
			3										
	Shoulder	Deformation	1										
			2										
			3										
		Scour	1										
			2										
			3										
		Edge Step	1										
			2										
			3										
Right	Shoulder	Edge Step	1										
			2										
			3										
		Scour	1										
			2										
			3										
		Deformation	1										
			2										
			3										
	Side Drains	Silt	1										
			2										
			3										
		Scour	1										
			2										
			3										
		Brush	1										
			2										
			3										
	Road Side Brush		1										
			2										
			3										

Prepared By: ______________________ Checked By: _____________________
Name & Signature Name & Signature

Table No.4 Gravel road Condition Survey Form 1

Gravel Road Condition Survey Format

District: _________ Section: ________ Date: ________ Weather: _______ Survey Dir. *from* __________ *to* ___________

Road Seg. No. _____ Road Segment: *from* ___________ *to* ____________ Start Km : ______ End Km: ______ Subsegment No. ____

Km	___________		Sever	000 - 500	500 - 1.000	1.000 - 1.500	1.500 - 2.000	2.000 - 2.500	2.500 - 3.000	3.000 - 3.500	3.500 - 4.000	4.000 - 4.500	4.500 - 5.000
Left	Road Side Brush		1										
			2										
			3										
	Side Drain / Turnout	Brush	1										
			2										
			3										
		Scour	1										
			2										
			3										
		Silt	1										
			2										
			3										
Carriageway	Gravel Thick.												
	Camber		1										
			2										
			3										
	Erosion Gully		1										
			2										
			3										
	Potholes		1										
			2										
			3										
	Corrug.		1										
			2										
			3										
	Stoniness		1										
			2										
			3										
Right	Side Drain / Turnout	Silt	1										
			2										
			3										
		Scour	1										
			2										
			3										
		Brush	1										
			2										
			3										
	Road Side Brush		1										
			2										
			3										

Prepared By: ______________________ Checked By: ______________________

Name & Signature Name & Signature

Table No.5 Paved road Condition Survey Form 2

Paved Road Condition Survey Form 2

Carriageway

District: _________________ **Section:** _________________ **Date:** ____________ **Weather:** _________ **Survey Dir.** ***from*** _________ ***to*** _________

Road Seg. No. ______ **Road Segment:** ***from*** ___________ ***to*** _____________ **Start Km :** ________ **End Km:** _________ **Subsegment No.:** ____

Km		Sever	0.000 - 0.500	0.500 - 1.000	1.000 - 1.500	1.500 - 2.000	2.000 - 2.500	2.500 - 3.000	3.000 - 3.500	3.500 - 4.000	4.000 - 4.500	4.500 - 5.000
Left	Edge Damage	1										
		2										
		3										
Carriageway	Rutting	1										
		2										
		3										
	Corrugation	1										
		2										
		3										
	Linear Cracks	1										
		2										
		3										
	Area Cracks	1										
		2										
		3										
	Ravelling	1										
		2										
		3										
	Depression	1										
		2										
		3										
	Potholes	1										
		2										
		3										
	Bleeding	1										
		2										
		3										
	Lane Marking	R										
		C										
		L										
Right	Edge Damage	1										
		2										
		3										

Prepared By: ____________________ Checked By: ____________________

Name & Signature Name & Signature

Table No.6 Gravel road Condition Survey Form 2

Paved Road Condition Survey Form 2

Carriageway

District: ________________ **Section:** ________________ **Date:** ____________ **Weather:** _________ **Survey Dir.** *from* _________ *to* _________

Road Seg. No. ______ **Road Segment:** *from* __________ *to* ____________ **Start Km :** _______ **End Km:** ________ **Subsegment No.:** ____

Km		Sever	0.000 - 0.500	0.500 - 1.000	1.000 - 1.500	1.500 - 2.000	2.000 - 2.500	2.500 - 3.000	3.000 - 3.500	3.500 - 4.000	4.000 - 4.500	4.500 - 5.000
Left	Edge Damage	1										
		2										
		3										
Carriageway	Rutting	1										
		2										
		3										
	Corrugation	1										
		2										
		3										
	Linear Cracks	1										
		2										
		3										
	Area Cracks	1										
		2										
		3										
	Ravelling	1										
		2										
		3										
	Depression	1										
		2										
		3										
	Potholes	1										
		2										
		3										
	Bleeding	1										
		2										
		3										
	Lane Marking	R										
		C										
		L										
Right	Edge Damage	1										
		2										
		3										

Prepared By: ____________________ Checked By: ____________________

Name & Signature Name & Signature

3.7.3. Type of Maintenances applied in ERA for Road distresses

Maintenance is Preservation of roads such that they maintain their functions, including daily simple repair works. Among the purpose of PMS providing means for evaluating various maintenance strategies and option trade-offs is the main one. In order to realize this advantage, currently; ERA based on inventory and condition survey assessment the type and severity of the road distress there are three types of road maintenance;

- Routine maintenance
- Periodic maintenance
- Emergency maintenance

Routine maintenance; it is a small scaled maintenance (operations) with limited resource requirement and done at least once per year. Which is consists of relatively unskilled activities, except grading. These types of maintenance include the following activities;

- ✓ Inspection and removal of obstacles
- ✓ Cleaning of drainage structures and their inlets and outlets (culverts, fords, etc)
- ✓ Repair culvert headwalls, approaches and aprons of fords, etc.
- ✓ Repair culvert drains/off-shoot drains/catch water drains and excavation to original sizes
- ✓ Cleaning of side drains and excavation to original size
- ✓ Cleaning of catch water drains and excavation to original size
- ✓ Maintenance of erosion controls in drains
- ✓ Cutting of grass on shoulders and side drains
- ✓ Clearing bush

Periodic maintenance; is a type of maintenance need to be carried out on the road segment after a number of years and requires extra resources to implement. In addition funds have to be specifically requested as they are not part of the normal maintenance allocations activities are usually not carried out by ordinary routine maintenance labour. These types of maintenance include the following activities;

- ✓ Heavy reshaping of road or road section (by labour, drag, towed grader)
- ✓ Installation or reconstruction of small drainage structures
- ✓ Rehabilitation of road or road section
- ✓ Rehabilitation of major structures (bridges, drifts)
- ✓ Reshaping and re-gravelling /resealing of road or road section
- ✓ Provision of gravel stacks along the road use for routine maintenance activities.

Emergency maintenance; this type of maintenance is implemented for distress caused due to sudden and unforeseen damages. In most cases it requires the deployment of additional resources. These types of maintenance include the following activities;

- ✓ Reconstruction or repair of damage to structures resulting from washouts, erosion, breakage or damage from high floods,
- ✓ Clearing of landslide, tree fall or rocks fall,
- ✓ Reconstruction or repair of damage to road section resulting from washout or serious erosion,
- ✓ Reconstruction of damage to drainage systems resulting from serious silting up or erosion,
- ✓ Reconstruction or repair of damage to erosion protection resulting from serious washout, landslide, etc.

Part II Case Study on ERA PMS

3.8. Data Analysis (Interview and Archival data)

To achieve the objective of this study interview was made with the Engineers of ERA Road Asset Management Department who are working on ERA PMS at head office level (i.e .they are responsible to coordinate data collecting process and overall ERA PMS operations). Among the Engineers in ERA Road Asset Management Department only four Engineers including the Team Leader directly/indirectly involve in ERA PMS at head office. Based on this information interview was made to all four Engineers (annex 1) and more or less their response were similar.

Besides, in order reinforce the study the ERA archival data in relation to its Pavement management system in this regard ERA PMS user manuals, reports, data collected (inventory survey and conditional data) for the purpose of PMS and other documents have been reviewed and analyzed.

The objective of this study was to evaluate implementation level of PMS in ERA. So as to understand the overall implementation level of PMS in ERA, precautions taken while interview were made. Most of the respondents respond for "interview question" number 5 of the interview are problems occur during the process of Pavement Management System (PMS) in ERA is similar. Incorporating other information extracted from archival data it is presented herein;

- ✓ Shortage of Trained Staffs (i.e. only one staff trained on PMS)
- ✓ No sufficient training for the staffs.
- ✓ Data of Road: the data was not too accurate and also the problem to keep the data in systematic manner.
- ✓ Do not fully implement the Standard Manual in PMS. In this regard, since the revised PMS launch in 2011, ERA has been conducted only level 1 calibration of HDM-4, level 2 and 3 are not yet conducted.
- ✓ Breaking dawn of data collector Equipment and delay of its maintenance

- ✓ Lack of awareness of data collector personnel
- ✓ Lack of timely Model calibration and validation
- ✓ Not timely perform PMS (i.e since 2012 they have performed 1st cycle PMS for about 6000km only).
- ✓ For the already surveyed 6000 km major roads HDM-4 was not analysed,
- ✓ A report (Ten years annual maintenance plan and etc) not produce for the already surveyed 6000 km major roads.
- ✓ **Hawkeye 2000 Series**
  - One of the laser sensors were damages on a survey
  - Error was encountered and the whole system froze.
  - Upon launching all necessary modules, the status of the profiler stays on "not connected"
  - "***Profiler module1, a sensor has been configured incorrectly! Reconfigure sensor and start again.***"
- ✓ **Hawkeye 1000 Series**
  - Currently operating for roughness measurement of asphalt roads. (Having difficulty with gravel roads but it is designed for unpaved road.)
  - Stops operation after 2-10 km
  - There is some problem with the DMI (disconnected from the wheel)
- ✓ **FWD**
  - Hydraulic system failure

Despite the current ERA PMS system launched since 2011, the above mentioned problems affect the implementation level of ERA Pavement Management System. Hence, Problems occur during the implementation of Pavement Management System need to define by ERA in order to improve its current Pavement Management System.

3.9. Basic Approach to Improve ERA Pavement Management System

Each system must have their strength and weakness. From the study, I was defined problems in Pavement Management System at Ethiopian Roads Authority. Based on the findings (problems) from the current ERA PMS the under listed basic approaches has been drawn to improve the current Pavement Management System in ERA.

- ✓ Hire Consultant (outsource) to manipulate (fully implement) the PMS. If ERA outsourcing its PMS the relevant manipulation of the system in general will be effective and ERA staff can focus on its other assignments. However, it must be recognized that for outsourcing to succeed there needs to be strong management and quality assurance of the nominated consultant.
- ✓ The people in ERA PMS (including all computer systems, data, policies and procedures) should be driven by a dedicated group within the agency, probably in the Road Asset Management Department or equivalent. This dedicated group should actively seek to promote the system within the agency, especially to higher level management; raise awareness of the system; manage data collection; constantly look for ways of improving data collection procedures and data quality assurance; research off-the-shelf packages and systems on the market; create and maintain technical and functional requirements for improving the PMS system; and coordinate all efforts related to the PMS in terms of other applications. To ensure these, in ERA an appropriate staff environment must exists with the following devices;
    - There should be an organizational unit established with specific responsibility for the PMS.
    - There should be enough budgets for the operation of the system, including all staffing, equipment, data collection, field travel, quality assurance and etc.
    - There should be clear job descriptions for the various activities, and a career path for those in the unit.

  - There should be a continual training and development program (and enough budgets) for staff to deal with staff turnover and re-training where necessary. This should potentially include Master's or other post-graduate degrees in abroad which will increase the attractiveness of working in this area.
  - Jobs should be filled with appropriately qualified personnel(i.e. in area of Management of the road network referencing system, data collection, data quality management, Management reporting, good basic management principles, covering procedures and records), experienced with PMS, having good technical and management skills, and with access to and control over their budget.

- ✓ Technical audits should be carried out on data and systems (internal and/or external and the recommendations acted on. If there is appropriate audit mechanisms on the implementation of the data quality assurance procedures so that all system users have confidence in the data and analyses provided to them.
- ✓ Should develop and adhere to a specific IT section, with explicit IT technology standards and directions and also a long-term IT budget strategy; these IT budgets should cover procurement of all new hardware and software, operation of the network (including costs of leased lines *etc.*), warranty and maintenance agreements, support etc.
- ✓ Better to build capacity of branch network (district) department in order to implement PMS at branch (district) level,
- ✓ Equipment-driven Surveys should be conducted after assessment of the suitability of the road condition for the equipment.
- ✓ **Special care should be given to the survey vehicles.**

  - How to operate and maintain the vehicles?
  - Is the road suitable for the equipment?
  - Train personnel for survey vehicles maintenance

- ✓ Seek support from Equipment supplier
- ✓ Hire supporting consultant for data collecting equipment maintenance. If ERA has specialist on operation and maintenance of data equipment in-house, then timely collection of the relevant condition survey data for PMS will be easy. However, it must be recognized that for outsourcing to succeed there needs to be strong management and quality assurance of the contractor.
- ✓ Produce a report after compiling previous condition survey data of the already surveyed 6000 km major roads.
- ✓ Provide PMS dedicated computers and servers.
- ✓ Protect data from virus and corruption
- ✓ Timely conduction of Level 2 and 3 calibration for HDM-4 software.
- ✓ No system is static. All systems can be improved. Hence, continual Quality Improvement on the system is critical.

Chapter Five--- Conclusion and Recommendation

4.0 Introduction

This is the last chapter of this report in which it will conclude the case study conducted in Chapter 3. The recommendation of further Pavement Management System for the future study is also included to improve The Pavement Management System at Ethiopian Roads Authority.

4.1. Conclusion

From this study conclusions related to the objectives of the study are made.

The main objective of the study was to review the Pavement Management System of ERA has been achieved. The Pavement Management System for the current practice at ERA can be concluded that ERA is not implementing PMS in full capacity in order to be beneficiary from the system due to different reasons such as luck of sufficient trained staff, breakdown of data collection equipments and lack of its maintenance. In general, it seems ERA top management does not give the required attention for the Pavement Management System.

Nevertheless, ERA top management have perceived some of the drawback of its PMS implementation and started exercising some improving mechanisms like; hiring of external consultant to assist him in improving and strengthening ERA road asset management department in general.

4.2. Recommendation

From the study of assessing ERA Pavement Management System, I have noted that being the equipments utilized in PMS are new technology, computerized and sophisticated on top of the ERA road asset management team staffs' engaged another different assignment besides PMS jobs, ERA should either recruit new teams working on PMS alone or hire external consultant in order to utilize/implement ERA Pavement Management System as tools in decision making process for maintenance and rehabilitation options.

On the other hand, ERA has to re-visit its PMS current implementation level. In this respect, ERA has to build capacity of its staffs.

Currently Level 2 and 3 calibration of HDM-4 were not conducted which might biases the outcomes. Hence, ERA should establish calibration sites in order to conduct calibration of the system.

In general, as adopting PMS requires major commitment from the road agency. This commitment needs not only to be for the fulfillment of the required equipments and software (computer programs), initial implementation, but also to ongoing refinements, often through operational research. There needs to be full ownership of the system, its models and its outputs along with the necessary expertise to undertake the necessary improvements over time. A lack of commitment will lead to dissatisfaction by the users, and potentially an abandoning of the PMS. Hence, ERA besides giving the required attention to improve the current implementation level its executives and top Management (high ranking decision-makers) has to promote asset management principles and developed an 'asset management' mindset.

References

1. *A Risk-based Optimization Methodology for Managing County Paved Roads.* In Transportation Research Board 94th Annual Meeting (No. 15-1916), by Saha, P., & Ksaibati, K. (2015).
2. *AASHTO (1985). Guidelines on Pavement Management*, American Association of State Highway and Transportation Officials, Washington D.C., 9p.
3. *Appropriateness of Data in Pavement Management Systems: A New Zealand Experience.* By Wilson, D.J., Pradhan, N.K. & Henning, T.J. 2002. Transportation Research Board, Washington DC 2001.
4. *Development and Implementation of Washington ... 177-A, Sept., 1982.* by Nelson and LeClerc.
5. *Development of Pavement Management System for Road Network Maintenance*. By David Mapikitla.
6. *Development of Pavement Management System: The Validation of Pavement Performance of Curves.* By Crispino, M., Olivari, G., Poggioli, M. & Scazziga, I. 2004. Available at: http://sed.siiv.it/documenti/63_2848_20080821110123.pdf. Assessed: 17/09/2007.
7. *ERA HDM-4 Calibration of RD Manual 5'.* ERA, Nov 2011.
8. http://www.pavementinteractive.org/article/pavement-management-systems
9. *Implementation of PMS in Spain State Road Network.* By Gutierrez-Bolivar, O. & Achutegui, F. 1994. Transportation Research Board, Washington DC 2001. USA.
10. *Implementation of VIC Roads Pavement Management Systems.* By Anderson, D., Kosky, C., Stephens, G. & Wall, A.R. 1994. Transportation Research Board, Washington DC 20001. USA.
11. *Introduction of computer-based optimization algorithms* (Haas et al., 1979)
12. *Pavement Management System Development.National Cooperative Highway Research Program Report 215:* NCHRP, TRB, National Research Council. Washington, D.C.
13. *Pavement Engineering: United Kingdom Pavement Management System*. Scott Wilson Group Plc. 2007. Available at: http://www.scottwilson.com. Assessed: 15/09/2007.
14. *Pavement Management Methodologies to Select Projects and Recommend Preservation Treatments.* Synthesis 222: National Cooperative Highway Research Program Transportation Research Board, National Research Council. Washington, D.C.
15. *Pavement Management Practices.* Synthesis of Highway Practice 135: National Cooperative Highway Research Program NCHRP, TRB, National Research Council. Washington, D.C.
16. *Pavement Management Primer (PDF).* Federal Highway Administration, U.S Department of Transportation. Retrieved 9/1/2011
17. *Pavement Management System Overview*. By Dr. Nick Vitillo
18. *Pavement Management System Summer Intern Program*. Volume XXX Number 3, Cornell Local Roads Program, summer 2011, page 4. by Nuggets and Nibbles.
19. *Pavement Management Systems in China*. By Liu, W. 2006. Available at: http://www.pavement.com.au/downloads/papers/PMS%20Development%20in%20China-Pre sentation%20in%2010th%20SPT)-.pdf. Assessed: 20/10/2007.

20. *Pavement management systems.* A report prepared by the OECD scientific expert group. OECD, Paris, 1987.
21. *Pavement Management Systems.* McGraw-Hill Book Company. New York, NY.
22. *Pavement Management Systems: Past, Present, and Future,* TRB Annual Meeting 2003, page 11&12. By Ram B. Kulkarni and Richard W. Miller.
23. *Pavement Preservation Technology in France, South Africa and Australia.* Federal Highway Administration, Department of Transport, US, 2008.
24. *PMS User Manual for PMS Operations*. ERA, October 2011.
25. *Presentation on Road Asset Management Performance and the way forward*. ERA Road Asset Management Department, August 2013.
26. *Quality Management of Pavement Condition Data Collection.* NCHRPSYNTHESIS 401, Washington DC, 2009.
27. *Quality Management Plan for Data Collection.* ERA, November 2011.
28. *The Pavement Management Process. Investing in Pavement Management CAN IMPROVE ROADS, SAVE MONEY.* By William Scarpati and Jerry Guerra. Municipal Advocate Vol. 27, No. 2
29. *Towards a New Pavement Management System in Germany: Organisation, Data Collection, Experience and Innovations.* By Burger, W., Canisius, P. & Sulten, P. 1994. Transportation Research Board, Washington DC 2001.

Appendix

APPENDICE 1

Pavement Management System (PMS) – A Case Study at Ethiopian Roads Authority

INTERVIEW FORM

Name : ....

Designation : ....

Question 1

Experience and role at ERA, Road Asset Management Team

Question 2

When did ERA PMS launched? ....

Question 3

Explain the current procedure for ERA Pavement Management System which applied at ERA.

Question 4

At what level do you conduct Pavement Management? (i.e project level and network level) why?

Question 5

Problems occur during the process of Pavement management system (PMS).

Question 6

Propose to improve the road Pavement management system (PMS) at ERA.

Question 7

What your expectations for Pavement management system (PMS) in the future?

APPENDICE 2

Photos of Data Collection Instrument

30. Hawkeye 2000 Series

31. Hawkeye 1000 Series

H1000 Digital Laser Profiler

H1000 Digital Imaging System

32. Falling Weight Deflectometer

APPENDICE 3

The sample data collected by ERA for the purpose of PMS input

Table Addis - Weliso IRI sample data															
Section	Distance (km)	Sub Distance (km)	IRI Right	IRI Left	IRI Avg	IRI Lane	IRI Centre Lane	HATI Right	HATI Left	HATI Avg	RN Right	RN Left	RN Avg	NAASRA	GPS position is calculated
1	0.1	0.1	7.92	8.21	8.06	X	X	X	X	X	X	X	X	X	FALSE
1	0.2	0.2	10.97	9.75	10.36	X	X	X	X	X	X	X	X	X	FALSE
1	0.3	0.3	7.54	15	11.27	X	X	X	X	X	X	X	X	X	FALSE
1	0.4	0.4	1.29	1.29	1.29	X	X	X	X	X	X	X	X	X	FALSE
1	0.5	0.5	1.35	1	1.17	X	X	X	X	X	X	X	X	X	FALSE
1	0.6	0.6	1.18	1.13	1.16	X	X	X	X	X	X	X	X	X	FALSE
1	0.7	0.7	1.35	1.15	1.25	X	X	X	X	X	X	X	X	X	FALSE
1	0.8	0.8	1.45	1.21	1.33	X	X	X	X	X	X	X	X	X	FALSE
1	0.9	0.9	2.92	2.56	2.74	X	X	X	X	X	X	X	X	X	FALSE
1	1	1	2.15	1.44	1.8	X	X	X	X	X	X	X	X	X	FALSE
1	1.1	1.1	5.44	6.32	5.88	X	X	X	X	X	X	X	X	X	FALSE
1	1.2	1.2	4.03	4.33	4.18	X	X	X	X	X	X	X	X	X	FALSE
1	1.3	1.3	4.55	4.82	4.68	X	X	X	X	X	X	X	X	X	FALSE
1	1.4	1.4	5.71	6.17	5.94	X	X	X	X	X	X	X	X	X	FALSE
1	1.5	1.5	1.21	1.1	1.15	X	X	X	X	X	X	X	X	X	FALSE
1	1.6	1.6	1.62	1.27	1.44	X	X	X	X	X	X	X	X	X	FALSE
1	1.7	1.7	1.47	1.46	1.47	X	X	X	X	X	X	X	X	X	FALSE
1	1.8	1.8	1.15	1.24	1.19	X	X	X	X	X	X	X	X	X	FALSE
1	1.9	1.9	1.19	1.29	1.24	X	X	X	X	X	X	X	X	X	FALSE
1	2	2	1.06	1.42	1.24	X	X	X	X	X	X	X	X	X	FALSE
1	2.1	2.1	1.52	1.58	1.55	X	X	X	X	X	X	X	X	X	FALSE
1	2.2	2.2	1.36	1.46	1.41	X	X	X	X	X	X	X	X	X	FALSE
1	2.3	2.3	1.57	1.51	1.54	X	X	X	X	X	X	X	X	X	FALSE
1	2.4	2.4	2.86	1.83	2.35	X	X	X	X	X	X	X	X	X	FALSE
[illegible]	2.5	2.5	2.73	3.0[illegible]	2.8[illegible]	X	X	X	X	X	[illegible]	X	X	X	FALSE

1	2.6	2.6	2.83	4.33	3.58	X	X	X	X	X	X	X	X	X	FALSE
1	2.7	2.7	1.33	1.36	1.34	X	X	X	X	X	X	X	X	X	FALSE
1	2.8	2.8	1.67	1.34	1.5	X	X	X	X	X	X	X	X	X	FALSE
1	2.9	2.9	1.72	1.53	1.63	X	X	X	X	X	X	X	X	X	FALSE
1	3	3	1.57	1.31	1.44	X	X	X	X	X	X	X	X	X	FALSE
1	3.1	3.1	14.37	15.69	15.03	X	X	X	X	X	X	X	X	X	FALSE
1	3.2	3.2	24.57	31.08	27.82	X	X	X	X	X	X	X	X	X	FALSE
1	3.3	3.3	1.89	1.87	1.88	X	X	X	X	X	X	X	X	X	FALSE
1	3.4	3.4	1.68	1.4	1.54	X	X	X	X	X	X	X	X	X	FALSE
1	3.5	3.5	1.62	1.55	1.59	X	X	X	X	X	X	X	X	X	FALSE
1	3.6	3.6	1.85	1.75	1.8	X	X	X	X	X	X	X	X	X	FALSE
1	3.7	3.7	2.48	2.54	2.51	X	X	X	X	X	X	X	X	X	FALSE
1	3.739	3.739	2.61	5.93	4.27	X	X	X	X	X	X	X	X	X	FALSE
2	3.839	3.839	1.86	2.02	1.94	X	X	X	X	X	X	X	X	X	FALSE
2	3.939	3.939	2.21	2	2.1	X	X	X	X	X	X	X	X	X	FALSE
2	4.039	4.039	1.48	1.61	1.55	X	X	X	X	X	X	X	X	X	FALSE
2	4.139	4.139	1.58	1.56	1.57	X	X	X	X	X	X	X	X	X	FALSE
2	4.239	4.239	2.11	1.93	2.02	X	X	X	X	X	X	X	X	X	FALSE
2	4.339	4.339	2.1	1.94	2.02	X	X	X	X	X	X	X	X	X	FALSE
2	4.439	4.439	1.39	1.19	1.29	X	X	X	X	X	X	X	X	X	FALSE
2	4.539	4.539	1.34	1.29	1.31	X	X	X	X	X	X	X	X	X	FALSE
2	4.639	4.639	0.86	1.14	1	X	X	X	X	X	X	X	X	X	FALSE
2	4.739	4.739	1.11	1.26	1.18	X	X	X	X	X	X	X	X	X	FALSE
2	4.839	4.839	1.57	1.43	1.5	X	X	X	X	X	X	X	X	X	FALSE
2	4.939	4.939	1.91	1.6	1.76	X	X	X	X	X	X	X	X	X	FALSE
2	5.039	5.039	1.7	1.87	1.79	X	X	X	X	X	X	X	X	X	FALSE
2	5.139	5.139	1.97	1.63	1.8	X	X	X	X	X	X	X	X	X	FALSE
2	5.239	5.239	1.61	1.43	1.52	X	X	X	X	X	X	X	X	X	FALSE
2	5.339	5.339	1.43	1.16	1.3	X	X	X	X	X	X	X	X	X	FALSE
2	5.439	5.439	2.36	1.49	1.92	X	X	X	X	X	X	X	X	X	FALSE

2	5.539	5.539	1.74	1.49	1.61	X	X	X	X	X	X	X	X	X	FALSE
2	5.639	5.639	2.16	1.88	2.02	X	X	X	X	X	X	X	X	X	FALSE
2	5.739	5.739	1.24	1.24	1.24	X	X	X	X	X	X	X	X	X	FALSE
2	5.839	5.839	2.28	1.53	1.91	X	X	X	X	X	X	X	X	X	FALSE
2	5.939	5.939	1.42	1.29	1.36	X	X	X	X	X	X	X	X	X	FALSE
2	6.039	6.039	1.55	1.51	1.53	X	X	X	X	X	X	X	X	X	FALSE
2	6.139	6.139	2.77	1.36	2.06	X	X	X	X	X	X	X	X	X	FALSE
2	6.239	6.239	2.14	1.36	1.75	X	X	X	X	X	X	X	X	X	FALSE
2	6.339	6.339	1.24	1.05	1.15	X	X	X	X	X	X	X	X	X	FALSE
2	6.439	6.439	1.13	1.14	1.14	X	X	X	X	X	X	X	X	X	FALSE
2	6.539	6.539	1.37	1.21	1.29	X	X	X	X	X	X	X	X	X	FALSE
2	6.639	6.639	1.84	2.41	2.12	X	X	X	X	X	X	X	X	X	FALSE
2	6.739	6.739	2.3	2.29	2.3	X	X	X	X	X	X	X	X	X	FALSE
2	6.839	6.839	1.54	1.5	1.52	X	X	X	X	X	X	X	X	X	FALSE
2	6.939	6.939	1.92	1.74	1.83	X	X	X	X	X	X	X	X	X	FALSE
2	7.039	7.039	1.7	1.59	1.64	X	X	X	X	X	X	X	X	X	FALSE
2	7.139	7.139	2.86	2.21	2.54	X	X	X	X	X	X	X	X	X	FALSE
2	7.239	7.239	1.73	1.57	1.65	X	X	X	X	X	X	X	X	X	FALSE

Table Addis – Weliso Rutting sample data

Section	Distance (km)	Sub Distance (km)	Rut Right	Rut Left	Rut Lane	GPS position is calculated	Speed (km/h)	Easting (m)	Northing (m)	Zone	Hemisphere
LEAD IN	-0.109	0.1	6.075	5.879	7.535	FALSE	52.5	463857	990661	37	N
LEAD IN	-0.009	0.2	5.599	3.011	5.666	FALSE	52.3	463875	990561	37	N
LEAD IN	0	0.209	7.871	2.42	7.871	FALSE	41.5	463877	990552	37	N
1	0.1	0.1	X	X	X	FALSE	14.9	463893	990453	37	N
1	0.2	0.2	X	X	X	FALSE	10.3	463910	990354	37	N
1	0.3	0.3	3.951	2.289	4.506	FALSE	20.4	463926	990258	37	N
1	0.4	0.4	10.154	2.154	10.383	FALSE	38.6	463910	990160	37	N
1	0.5	0.5	2.001	1.931	2.312	FALSE	44.9	463884	990063	37	N
1	0.6	0.6	3.423	2.833	3.692	FALSE	41.8	463861	989964	37	N
1	0.7	0.7	10.453	1.64	10.472	FALSE	37.9	463837	989868	37	N
1	0.8	0.8	3.364	1.37	3.413	FALSE	52.1	463816	989772	37	N
1	0.9	0.9	3.632	3.642	4.319	FALSE	50.3	463801	989672	37	N
1	1	1	5.234	3.465	5.528	FALSE	32.9	463785	989572	37	N
1	1.1	1.1	7.21	6.783	8.801	FALSE	30.2	463763	989476	37	N
1	1.2	1.2	7.519	5.356	8.375	FALSE	37.4	463711	989393	37	N
1	1.3	1.3	7.05	4.883	7.998	FALSE	38	463734	989298	37	N
1	1.4	1.4	5.638	5.053	6.838	FALSE	45.7	463727	989199	37	N
1	1.5	1.5	4.996	2.295	4.997	FALSE	53.5	463711	989100	37	N
1	1.6	1.6	7.187	3.236	7.192	FALSE	51	463696	989000	37	N

1	1.7	1.7	7.426	3.205	7.435	FALSE	48.3	463680	988901	37	N
1	1.8	1.8	10.26	2.988	10.266	FALSE	41.9	463666	988802	37	N
1	1.9	1.9	5.853	2.349	5.864	FALSE	39.8	463650	988705	37	N
1	2	2	8.039	2.708	8.046	FALSE	49.6	463633	988608	37	N
1	2.1	2.1	7.054	2.877	7.093	FALSE	51.2	463618	988508	37	N
1	2.2	2.2	6.174	3.192	6.183	FALSE	44.9	463602	988410	37	N
1	2.3	2.3	3.959	1.939	4.007	FALSE	43.9	463587	988312	37	N
1	2.4	2.4	5.682	3.304	5.728	FALSE	39.7	463591	988211	37	N
1	2.5	2.5	5.354	2.789	5.575	FALSE	23.3	463621	988115	37	N
1	2.6	2.6	5.81	2.296	5.871	FALSE	28.5	463582	988032	37	N
1	2.7	2.7	6.399	2.671	6.562	FALSE	44.8	463503	987971	37	N
1	2.8	2.8	6.464	2.883	6.465	FALSE	43.4	463423	987905	37	N
1	2.9	2.9	5.808	2.332	5.809	FALSE	28.6	463345	987843	37	N
1	3	3	3.966	1.775	4.031	FALSE	32.5	463269	987779	37	N
1	3.1	3.1	6.911	2.744	6.934	FALSE	6.1	463192	987714	37	N
1	3.2	3.2	3.161	3.184	4.076	FALSE	17.3	463126	987642	37	N
1	3.3	3.3	8.904	2.454	8.904	FALSE	31.2	463064	987562	37	N
1	3.4	3.4	4.876	1.055	4.876	FALSE	36.1	463001	987485	37	N
1	3.5	3.5	6.567	3.811	6.823	FALSE	34.4	462940	987405	37	N
1	3.6	3.6	6.037	1.448	6.058	FALSE	30.4	462881	987327	37	N
1	3.7	3.7	6.225	2.322	6.376	FALSE	29	462819	987245	37	N
1	3.739	3.739	1.988	1.01	2.171	FALSE	20.2	462797	987216	37	N
2	3.839	3.839	4.913	2.129	5.062	FALSE	35.3	462734	987137	37	N
2	3.939	3.939	3.235	0.728	3.245	FALSE	43.4	462673	987060	37	N
2	4.039	4.039	4.883	2.354	4.886	FALSE	47.7	462611	986981	37	N
2	4.139	4.139	5.602	4.233	6.482	FALSE	34	462548	986902	37	N
2	4.239	4.239	5.389	2.841	6.14	FALSE	49.5	462488	986823	37	N
2	4.339	4.339	8.681	7.751	12.439	FALSE	49.8	462416	986754	37	N

2	4.439	4.439	7.175	1.258	7.185	FALSE	52.5	462333	986698	37	N
2	4.539	4.539	6.517	3.352	6.532	FALSE	45.8	462247	986642	37	N
2	4.639	4.639	4.717	1.949	4.757	FALSE	40.6	462168	986587	37	N
2	4.739	4.739	5.964	2.738	5.966	FALSE	54.4	462085	986532	37	N
2	4.839	4.839	4.997	2.598	5.016	FALSE	57.2	462001	986478	37	N
2	4.939	4.939	7.148	2.667	7.175	FALSE	55.6	461916	986422	37	N

Table Addis – Weliso sample data on Surface Texture												
Section	Distance (km)	Sub-Distance (km)	MPD Texture	ETD Texture	TX R3	TX R4	GPS position is calculated	Speed (km/h)	Easting (m)	Northing (m)	Zone	Hemisphere
LEAD IN	-0.109	0.1	0.912	0.929	X	X	FALSE	52.8	463857	990661	37	N
LEAD IN	-0.009	0.2	0.95	0.96	X	X	FALSE	52	463875	990561	37	N
LEAD IN	0	0.209	0.934	0.947	X	X	FALSE	41	463877	990552	37	N
1	0.1	0.1	X	X	X	X	FALSE	14.7	463893	990453	37	N
1	0.2	0.2	X	X	X	X	FALSE	10	463910	990354	37	N
1	0.3	0.3	1.484	1.387	X	X	FALSE	22.4	463926	990258	37	N
1	0.4	0.4	1.313	1.25	X	X	FALSE	38.7	463910	990160	37	N
1	0.5	0.5	1.151	1.121	X	X	FALSE	45	463884	990063	37	N
1	0.6	0.6	1.232	1.185	X	X	FALSE	41.6	463861	989964	37	N
1	0.7	0.7	1.881	1.705	X	X	FALSE	38.1	463837	989868	37	N
1	0.8	0.8	1.87	1.696	X	X	FALSE	52.3	463816	989772	37	N
1	0.9	0.9	1.297	1.238	X	X	FALSE	50.1	463801	989672	37	N
1	1	1	1.825	1.66	X	X	FALSE	32.6	463785	989572	37	N
1	1.1	1.1	0.889	0.911	X	X	FALSE	30.4	463763	989476	37	N
1	1.2	1.2	0.917	0.934	X	X	FALSE	37.4	463711	989393	37	N
1	1.3	1.3	0.893	0.914	X	X	FALSE	38.1	463734	989298	37	N
1	1.4	1.4	0.913	0.931	X	X	FALSE	45.9	463727	989199	37	N
1	1.5	1.5	0.971	0.977	X	X	FALSE	53.5	463711	989100	37	N
1	1.6	1.6	0.926	0.941	X	X	FALSE	50.9	463696	989000	37	N
1	1.7	1.7	0.931	0.945	X	X	FALSE	48.3	463680	988901	37	N
1	1.8	1.8	0.913	0.931	X	X	FALSE	41.8	463666	988802	37	N
1	1.9	1.9	0.935	0.948	X	X	FALSE	39.9	463650	988705	37	N

1	2	2	0.899	0.919	X	X	FALSE	49.7	463633	988608	37	N
1	2.1	2.1	0.877	0.902	X	X	FALSE	51.2	463618	988508	37	N
1	2.2	2.2	0.908	0.927	X	X	FALSE	44.8	463602	988410	37	N
1	2.3	2.3	0.905	0.924	X	X	FALSE	43.9	463587	988312	37	N
1	2.4	2.4	0.93	0.944	X	X	FALSE	39.5	463591	988211	37	N
1	2.5	2.5	0.898	0.918	X	X	FALSE	22.7	463621	988115	37	N
1	2.6	2.6	0.971	0.977	X	X	FALSE	29.6	463582	988032	37	N
1	2.7	2.7	0.956	0.965	X	X	FALSE	45	463503	987971	37	N
1	2.8	2.8	0.905	0.924	X	X	FALSE	42.8	463423	987905	37	N
1	2.9	2.9	0.9	0.92	X	X	FALSE	28.6	463345	987843	37	N
1	3	3	0.873	0.899	X	X	FALSE	32.7	463269	987779	37	N
1	3.1	3.1	0.845	0.876	X	X	FALSE	6.1	463192	987714	37	N
1	3.2	3.2	0.975	0.98	X	X	FALSE	17.6	463126	987642	37	N
1	3.3	3.3	1.053	1.043	X	X	FALSE	31.1	463064	987562	37	N
1	3.4	3.4	0.986	0.989	X	X	FALSE	36.4	463001	987485	37	N
1	3.5	3.5	0.957	0.966	X	X	FALSE	34.1	462940	987405	37	N
1	3.6	3.6	0.95	0.96	X	X	FALSE	30.6	462881	987327	37	N
1	3.7	3.7	0.928	0.942	X	X	FALSE	28.6	462819	987245	37	N
1	3.739	3.739	0.917	0.934	X	X	FALSE	20.6	462797	987216	37	N
2	3.839	3.839	0.887	0.91	X	X	FALSE	35.3	462734	987137	37	N
2	3.939	3.939	0.881	0.905	X	X	FALSE	44	462673	987060	37	N
2	4.039	4.039	0.904	0.923	X	X	FALSE	47.4	462611	986981	37	N
2	4.139	4.139	0.927	0.942	X	X	FALSE	34	462548	986902	37	N
2	4.239	4.239	0.956	0.965	X	X	FALSE	49.8	462488	986823	37	N
2	4.339	4.339	0.93	0.944	X	X	FALSE	49.8	462416	986754	37	N
2	4.439	4.439	0.941	0.953	X	X	FALSE	52.6	462333	986698	37	N
2	4.539	4.539	0.881	0.905	X	X	FALSE	45.2	462247	986642	37	N
2	4.639	4.639	0.883	0.907	X	X	FALSE	41.1	462168	986587	37	N
2	4.739	4.739	0.989	0.992	X	X	FALSE	54.4	462085	986532	37	N
2	4.839	4.839	0.919	0.935	X	X	FALSE	57.3	462001	986478	37	N

2	4.939	4.939	0.86	0.888	X	X	FALSE	55.5	461916	986422	37	N
2	5.039	5.039	0.913	0.931	X	X	FALSE	52.7	461832	986367	37	N
2	5.139	5.139	0.917	0.934	X	X	FALSE	51.6	461740	986334	37	N
2	5.239	5.239	0.907	0.926	X	X	FALSE	58	461641	986333	37	N
2	5.339	5.339	0.866	0.893	X	X	FALSE	62.9	461542	986334	37	N
2	5.439	5.439	0.906	0.925	X	X	FALSE	63.8	461441	986334	37	N
2	5.539	5.539	0.926	0.941	X	X	FALSE	66.1	461341	986336	37	N
2	5.639	5.639	0.92	0.936	X	X	FALSE	54.6	461242	986326	37	N
2	5.739	5.739	0.903	0.923	X	X	FALSE	57.1	461178	986251	37	N
2	5.839	5.839	0.982	0.986	X	X	FALSE	60.1	461140	986157	37	N
2	5.939	5.939	0.888	0.91	X	X	FALSE	60	461103	986065	37	N
2	6.039	6.039	0.885	0.908	X	X	FALSE	58.7	461055	985978	37	N
2	6.139	6.139	0.901	0.921	X	X	FALSE	59.9	460979	985913	37	N
2	6.239	6.239	0.867	0.894	X	X	FALSE	60	460900	985851	37	N
2	6.339	6.339	0.85	0.88	X	X	FALSE	52.6	460822	985788	37	N
2	6.439	6.439	0.855	0.884	X	X	FALSE	50.5	460744	985726	37	N
2	6.539	6.539	0.85	0.88	X	X	FALSE	52.5	460666	985664	37	N
2	6.639	6.639	0.876	0.901	X	X	FALSE	28.8	460588	985602	37	N
2	6.739	6.739	0.873	0.899	X	X	FALSE	47.4	460510	985541	37	N
2	6.839	6.839	0.879	0.903	X	X	FALSE	43.6	460431	985477	37	N
2	6.939	6.939	0.907	0.925	X	X	FALSE	45	460336	985469	37	N
2	7.039	7.039	0.879	0.904	X	X	FALSE	44.8	460239	985495	37	N
2	7.139	7.139	0.925	0.94	X	X	FALSE	42.6	460141	985521	37	N
2	7.239	7.239	0.921	0.937	X	X	FALSE	42.9	460045	985545	37	N
2	7.339	7.339	0.937	0.949	X	X	FALSE	44.1	459947	985569	37	N
2	7.439	7.439	0.898	0.919	X	X	FALSE	36	459850	985594	37	N
2	7.539	7.539	0.938	0.95	X	X	FALSE	31.1	459762	985564	37	N
2	7.639	7.639	0.921	0.936	X	X	FALSE	30.7	459736	985467	37	N
2	7.739	7.739	0.886	0.908	X	X	FALSE	41.4	459670	985393	37	N
2	7.839	7.839	0.854	0.883	X	X	FALSE	44.1	459595	985329	37	N

2	7.939	7.939	0.888	0.91	X	X	FALSE	41.7	459499	985296	37	N
2	8.039	8.039	0.83	0.864	X	X	FALSE	31.3	459401	985281	37	N
2	8.139	8.139	0.859	0.887	X	X	FALSE	34.8	459302	985263	37	N
2	8.239	8.239	0.892	0.913	X	X	FALSE	34.1	459204	985247	37	N
2	8.339	8.339	0.832	0.866	X	X	FALSE	34.6	459106	985229	37	N
2	8.439	8.439	0.893	0.914	X	X	FALSE	30.8	459007	985213	37	N
2	8.539	8.539	1.065	1.052	X	X	FALSE	12.8	458908	985195	37	N
2	8.639	8.639	0.901	0.92	X	X	FALSE	24.6	458812	985177	37	N
2	8.664	8.664	0.927	0.942	X	X	FALSE	27.7	458787	985174	37	N
3	8.764	8.764	0.937	0.95	X	X	FALSE	31.1	458689	985157	37	N
3	8.864	8.864	0.932	0.945	X	X	FALSE	35.3	458591	985130	37	N
3	8.964	8.964	0.876	0.901	X	X	FALSE	32	458499	985095	37	N
3	9.064	9.064	0.877	0.901	X	X	FALSE	30	458403	985061	37	N
3	9.164	9.164	0.966	0.973	X	X	FALSE	19.2	458311	985019	37	N
3	9.264	9.264	0.862	0.89	X	X	FALSE	18.2	458223	984977	37	N
3	9.364	9.364	0.876	0.901	X	X	FALSE	34.1	458132	984936	37	N
3	9.464	9.464	0.9	0.92	X	X	FALSE	33.5	458041	984893	37	N
3	9.564	9.564	0.89	0.912	X	X	FALSE	38.1	457956	984846	37	N
3	9.664	9.664	0.93	0.944	X	X	FALSE	48.3	457867	984795	37	N
3	9.764	9.764	0.909	0.927	X	X	FALSE	46.7	457780	984746	37	N
3	9.864	9.864	0.892	0.914	X	X	FALSE	45.4	457693	984695	37	N
3	9.964	9.964	0.933	0.947	X	X	FALSE	47.3	457607	984646	37	N
3	10.064	10.064	0.869	0.895	X	X	FALSE	41.5	457519	984597	37	N
3	10.164	10.164	0.876	0.901	X	X	FALSE	38.9	457433	984548	37	N
3	10.264	10.264	0.879	0.903	X	X	FALSE	45.2	457343	984508	37	N
3	10.364	10.364	0.941	0.952	X	X	FALSE	62.2	457245	984513	37	N
3	10.464	10.464	0.859	0.887	X	X	FALSE	52.7	457143	984526	37	N
3	10.564	10.564	0.765	0.812	X	X	FALSE	31.5	457042	984536	37	N
3	10.664	10.664	0.852	0.881	X	X	FALSE	41.1	456945	984545	37	N
3	10.764	10.764	0.937	0.95	X	X	FALSE	44.5	456846	984553	37	N

3	10.864	10.864	0.91	0.928	X	X	FALSE	48.2	456748	984560	37	N
3	10.964	10.964	0.945	0.956	X	X	FALSE	61.5	456650	984567	37	N
3	11.064	11.064	0.836	0.869	X	X	FALSE	68.2	456550	984579	37	N
3	11.164	11.164	0.867	0.894	X	X	FALSE	60.1	456448	984586	37	N
3	11.264	11.264	0.916	0.933	X	X	FALSE	46.6	456355	984544	37	N
3	11.364	11.364	0.945	0.956	X	X	FALSE	51.8	456273	984495	37	N
3	11.464	11.464	0.848	0.879	X	X	FALSE	69.3	456185	984448	37	N
3	11.564	11.564	0.861	0.889	X	X	FALSE	71.6	456096	984399	37	N
3	11.664	11.664	0.912	0.929	X	X	FALSE	68.2	456007	984351	37	N
3	11.764	11.764	0.9	0.92	X	X	FALSE	62.5	455920	984301	37	N
3	11.864	11.864	0.888	0.911	X	X	FALSE	59.2	455833	984252	37	N
3	11.964	11.964	0.84	0.872	X	X	FALSE	67.9	455747	984205	37	N
3	12.064	12.064	0.864	0.891	X	X	FALSE	75.6	455658	984157	37	N
3	12.164	12.164	0.84	0.872	X	X	FALSE	73	455571	984109	37	N
3	12.264	12.264	0.809	0.847	X	X	FALSE	75.5	455484	984060	37	N
3	12.364	12.364	0.867	0.894	X	X	FALSE	75.2	455396	984012	37	N
3	12.464	12.464	0.853	0.882	X	X	FALSE	75.5	455309	983963	37	N
3	12.564	12.564	0.852	0.882	X	X	FALSE	75.2	455220	983914	37	N
3	12.664	12.664	0.839	0.871	X	X	FALSE	74.7	455133	983866	37	N
3	12.764	12.764	0.82	0.856	X	X	FALSE	75.1	455046	983818	37	N
3	12.864	12.864	0.82	0.856	X	X	FALSE	74.5	454960	983769	37	N
3	12.964	12.964	0.847	0.878	X	X	FALSE	73.6	454871	983722	37	N
3	13.064	13.064	0.819	0.855	X	X	FALSE	63.9	454784	983672	37	N
3	13.164	13.164	0.83	0.864	X	X	FALSE	70.3	454698	983625	37	N
3	13.264	13.264	0.807	0.845	X	X	FALSE	72.3	454609	983577	37	N
3	13.364	13.364	0.824	0.859	X	X	FALSE	75.8	454523	983530	37	N
3	13.464	13.464	0.812	0.85	X	X	FALSE	72.7	454434	983481	37	N
3	13.564	13.564	0.871	0.896	X	X	FALSE	73.6	454347	983433	37	N
3	13.664	13.664	0.838	0.87	X	X	FALSE	73.3	454259	983385	37	N
3	13.764	13.764	0.819	0.855	X	X	FALSE	62.8	454171	983334	37	N

3	13.864	13.864	0.832	0.866	X	X	FALSE	48	454082	983286	37	N
3	13.964	13.964	0.873	0.898	X	X	FALSE	57.3	453999	983241	37	N
3	14.064	14.064	0.828	0.862	X	X	FALSE	74.3	453912	983193	37	N
3	14.164	14.164	0.832	0.865	X	X	FALSE	75	453824	983144	37	N
3	14.264	14.264	0.862	0.889	X	X	FALSE	75.3	453737	983096	37	N
3	14.364	14.364	0.889	0.911	X	X	FALSE	75	453649	983048	37	N
3	14.464	14.464	0.941	0.953	X	X	FALSE	75	453561	982999	37	N
3	14.564	14.564	0.96	0.968	X	X	FALSE	75	453474	982951	37	N
3	14.664	14.664	1.031	1.025	X	X	FALSE	75	453386	982903	37	N
3	14.764	14.764	0.946	0.957	X	X	FALSE	74.9	453298	982854	37	N
3	14.864	14.864	0.915	0.932	X	X	FALSE	74.7	453210	982806	37	N
3	14.964	14.964	0.928	0.943	X	X	FALSE	74.7	453123	982759	37	N
3	15.064	15.064	0.879	0.903	X	X	FALSE	74.7	453036	982710	37	N
3	15.164	15.164	0.928	0.943	X	X	FALSE	74.6	452949	982660	37	N
3	15.264	15.264	0.9	0.92	X	X	FALSE	74.7	452861	982612	37	N
3	15.364	15.364	0.869	0.895	X	X	FALSE	74.7	452774	982564	37	N
3	15.464	15.464	0.881	0.905	X	X	FALSE	74.7	452685	982516	37	N
3	15.564	15.564	0.891	0.913	X	X	FALSE	74.7	452599	982468	37	N
3	15.664	15.664	0.971	0.977	X	X	FALSE	74.7	452512	982419	37	N
3	15.764	15.764	0.872	0.898	X	X	FALSE	74.7	452424	982372	37	N
3	15.864	15.864	0.916	0.933	X	X	FALSE	74.8	452337	982323	37	N
3	15.964	15.964	0.836	0.869	X	X	FALSE	74.8	452249	982275	37	N
3	16.064	16.064	0.86	0.888	X	X	FALSE	74.8	452162	982227	37	N
3	16.164	16.164	0.856	0.885	X	X	FALSE	74.7	452075	982179	37	N
3	16.264	16.264	0.87	0.896	X	X	FALSE	74.8	451988	982130	37	N
3	16.364	16.364	0.901	0.92	X	X	FALSE	74.8	451900	982082	37	N
3	16.464	16.464	0.861	0.889	X	X	FALSE	74.6	451813	982034	37	N
3	16.564	16.564	0.814	0.851	X	X	FALSE	74.7	451725	981985	37	N
3	16.664	16.664	0.846	0.877	X	X	FALSE	74.5	451638	981937	37	N
3	16.764	16.764	0.871	0.896	X	X	FALSE	74.4	451552	981888	37	N

3	16.864	16.864	0.861	0.889	X	X	FALSE	74.3	451464	981840	37	N
3	16.964	16.964	0.865	0.892	X	X	FALSE	74.3	451377	981792	37	N
3	17.064	17.064	0.924	0.939	X	X	FALSE	74.4	451288	981744	37	N
3	17.164	17.164	0.931	0.945	X	X	FALSE	74.4	451202	981695	37	N
3	17.264	17.264	1	1	X	X	FALSE	74.4	451114	981647	37	N
3	17.364	17.364	0.913	0.931	X	X	FALSE	74.5	451027	981599	37	N
3	17.464	17.464	0.872	0.898	X	X	FALSE	74.5	450939	981552	37	N
3	17.564	17.564	0.89	0.912	X	X	FALSE	74.5	450852	981503	37	N
3	17.664	17.664	0.868	0.895	X	X	FALSE	74.7	450764	981455	37	N
3	17.764	17.764	0.964	0.971	X	X	FALSE	74.7	450677	981407	37	N
3	17.864	17.864	0.951	0.961	X	X	FALSE	74.7	450589	981359	37	N
3	17.964	17.964	0.931	0.945	X	X	FALSE	74.8	450501	981310	37	N
3	18.064	18.064	0.881	0.905	X	X	FALSE	74.8	450414	981262	37	N
3	18.164	18.164	0.848	0.879	X	X	FALSE	74.9	450325	981214	37	N
3	18.264	18.264	0.889	0.911	X	X	FALSE	74.9	450239	981165	37	N
3	18.364	18.364	0.851	0.881	X	X	FALSE	74.9	450152	981117	37	N
3	18.464	18.464	0.867	0.893	X	X	FALSE	75	450066	981066	37	N
3	18.564	18.564	0.863	0.891	X	X	FALSE	75.2	449980	981014	37	N
3	18.664	18.664	0.864	0.891	X	X	FALSE	75.2	449895	980962	37	N
3	18.764	18.764	0.886	0.909	X	X	FALSE	75.2	449811	980908	37	N
3	18.864	18.864	0.886	0.908	X	X	FALSE	74.8	449726	980856	37	N
3	18.964	18.964	0.883	0.906	X	X	FALSE	74.8	449641	980804	37	N
3	19.064	19.064	0.875	0.9	X	X	FALSE	74.7	449556	980751	37	N
3	19.164	19.164	0.88	0.904	X	X	FALSE	74.8	449471	980700	37	N
3	19.264	19.264	0.996	0.997	X	X	FALSE	74.9	449386	980646	37	N
3	19.364	19.364	0.882	0.906	X	X	FALSE	74.7	449301	980593	37	N
3	19.464	19.464	0.851	0.881	X	X	FALSE	74.9	449217	980540	37	N
3	19.564	19.564	0.842	0.873	X	X	FALSE	74.9	449131	980487	37	N
3	19.664	19.664	0.869	0.896	X	X	FALSE	74.9	449047	980435	37	N
3	19.764	19.764	0.874	0.899	X	X	FALSE	74.7	448962	980383	37	N

3	19.864	19.864	0.875	0.9	X	X	FALSE	74.7	448877	980329	37	N
3	19.964	19.964	0.881	0.905	X	X	FALSE	74.6	448793	980276	37	N
3	20.064	20.064	0.902	0.921	X	X	FALSE	74.5	448717	980212	37	N
3	20.164	20.164	0.9	0.92	X	X	FALSE	74.4	448659	980130	37	N
3	20.264	20.264	0.903	0.922	X	X	FALSE	74.4	448622	980037	37	N
3	20.364	20.364	0.924	0.939	X	X	FALSE	74.4	448592	979942	37	N
3	20.464	20.464	0.869	0.895	X	X	FALSE	74.3	448561	979846	37	N
3	20.564	20.564	0.839	0.871	X	X	FALSE	74.4	448531	979752	37	N
3	20.664	20.664	0.85	0.88	X	X	FALSE	74.4	448500	979657	37	N
3	20.764	20.764	0.856	0.885	X	X	FALSE	74.4	448468	979561	37	N
3	20.864	20.864	0.873	0.899	X	X	FALSE	74.3	448438	979465	37	N
3	20.964	20.964	0.86	0.888	X	X	FALSE	74.4	448405	979371	37	N
3	21.064	21.064	0.85	0.88	X	X	FALSE	74.5	448360	979284	37	N
3	21.164	21.164	0.819	0.855	X	X	FALSE	74.7	448295	979208	37	N
3	21.264	21.264	0.848	0.878	X	X	FALSE	74.8	448213	979152	37	N
3	21.364	21.364	0.902	0.922	X	X	FALSE	74.6	448123	979109	37	N
3	21.464	21.464	0.986	0.989	X	X	FALSE	74.6	448031	979069	37	N
3	21.564	21.564	0.867	0.893	X	X	FALSE	74.6	447941	979027	37	N
3	21.664	21.664	0.825	0.86	X	X	FALSE	74.5	447849	978986	37	N
3	21.764	21.764	0.89	0.912	X	X	FALSE	74.7	447758	978945	37	N
3	21.864	21.864	0.885	0.908	X	X	FALSE	74.5	447666	978904	37	N
3	21.964	21.964	0.869	0.895	X	X	FALSE	74.5	447575	978863	37	N
3	22.064	22.064	0.861	0.888	X	X	FALSE	74.7	447485	978821	37	N
3	22.164	22.164	0.853	0.882	X	X	FALSE	74.7	447395	978779	37	N
3	22.264	22.264	0.873	0.899	X	X	FALSE	74.8	447304	978738	37	N
3	22.364	22.364	0.923	0.938	X	X	FALSE	74.7	447213	978696	37	N
3	22.464	22.464	0.895	0.916	X	X	FALSE	74.7	447122	978656	37	N
3	22.564	22.564	0.907	0.926	X	X	FALSE	74.6	447031	978614	37	N