DCT 245

Pavement Condition Surveys – Overview of Current Practices

By

Nii Attoh-Okine
Offei Adarkwa

June, 2013

Delaware Center for Transportation
University of Delaware
355 DuPont Hall
Newark, Delaware 19716
(302) 831-1446

The Delaware Center for Transportation is a university-wide multi-disciplinary research unit reporting to the Chair of the Department of Civil and Environmental Engineering, and is co-sponsored by the University of Delaware and the Delaware Department of Transportation.

DCT Staff

Ardeshir Faghri
Director

Jerome Lewis
Associate Director

Ellen Pletz
Business Administrator I

Earl "Rusty" Lee
T^2 Program Coordinator

Matheu Carter
T^2 Engineer

Sandra Wolfe
Event Coordinator

DCT Policy Council

Robert McCleary, Co-Chair
Chief Engineer, Delaware Department of Transportation

Babatunde Ogunnaike, Co-Chair
Dean, College of Engineering

Delaware General Assembly Member
Chair, Senate Highways & Transportation Committee

Delaware General Assembly Member
Chair, House of Representatives Transportation/Land Use & Infrastructure Committee

Ajay Prasad
Professor, Department of Mechanical Engineering

Harry Shenton
Chair, Civil and Environmental Engineering

Drew Boyce
Director of Planning, Delaware Department of Transportation

Ralph Reeb
Planning Division, Delaware Department of Transportation

Executive Director, Delaware Transit Corporation

Representative of the Director of the Delaware Development Office

James Johnson
President, JTJ Engineers, LLC

Holly Rybinski
Rybinski Engineering

Delaware Center for Transportation
University of Delaware
Newark, DE 19716
(302) 831-1446

Project Report for

Pavement Condition Surveys – Overview of Current Practices

Prepared for

Delaware Department of Transportation

by

Nii Attoh-Okine
Offei Adarkwa

Delaware Center for Transportation

College of Engineering
University of Delaware
Newark, DE 19716

June 2013

This work was sponsored by the Delaware Center for Transportation and was prepared in cooperation with the Delaware Department of Transportation. The contents of this report reflect the view of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Delaware Center for Transportation or the Delaware Department of Transportation at the time of publication. This report does not constitute a standard, specification, or regulation.

2013

PAVEMENT CONDITION SURVEYS

OVERVIEW OF CURRENT PRACTICES

OFFEI ADARKWA & PROF. NII ATTOH-OKINE

JUNE 2013

PAVEMENT CONDITION SURVEY

EXECUTIVE SUMMARY

Pavement Condition Surveys refer to activities performed to give an indication of the serviceability and physical conditions of road pavements. These activities have three main aspects namely data collection, condition rating and quality management. In recent times, most state agencies are inclined towards automated and semi-automated means of collecting pavement data. Condition rating involves quantifying the condition of pavement assets based on a chosen scale or index. The rating index selected by an agency depends on the agency's available resources and its ability to address pavement issues prevalent in the area. There are two main groups of condition indexes; estimated and measured condition indexes. Estimated condition ratings are based on observed physical conditions of the pavements while the measured condition rating systems are not only based on observations by trained raters but are also backed by physical measurements such as roughness and mathematical expressions. Quality management is done to ensure that the data collected meets the needs of the pavement management process. It involves activities such as specification of data collection protocols, quality criteria, responsibilities of personnel, quality control, quality acceptance, corrective action and quality management documentation.

There is room for improvement in all aspects of the pavement management process. Quality criteria need to be updated periodically using basic statistical tools. All quality management procedures must be well documented to help improve future data quality control and assurance procedures. With quality and reliable data, pavement management will be improved and this will ultimately lead to efficient use of pavement assets.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Pavement condition surveys form the core part of pavement management. The overall goal of pavement management is to ensure efficient use of resources by assisting management in making informed decisions. In other words, pavement management reduces the level of subjectivity in decision making. Condition surveys have three main aspects namely; data collection, condition rating and quality management. This document examines the evolution of various aspects of condition ratings. It also takes a closer look at current practices by some transportation agencies in the United States.

1.0 INTRODUCTION

Pavements form a greater part of our society's infrastructure system whose proper functioning is essential for development. Similar to other types of infrastructure assets, pavements deteriorate over time. Therefore, there is the need to find ways to preserve these capital intensive assets to ensure they perform as expected. This need resulted in the development of periodic and routine maintenance activities undertaken by Departments of Transportation (DOTs) nationwide.

The level of repair and rehabilitation done on the roads depends on the physical condition of the road at a particular time in relation to its acceptable and operable condition. Thus, the condition of pavements is monitored regularly and this is known as pavement condition monitoring. These condition monitoring surveys play a vital role in pavement management since it provides valuable information that forms the basis of repair and rehabilitation activities. The information given to management staff is usually in the form of condition ratings of specific sections or an entire pavement network based on which sound and informed decisions are made.

Pavement condition rating refers to a score that quantifies the performance of a pavement section or an entire network. The score is based on visual inspection and or measures such as roughness, skid resistance, deflection among others. Condition Rating systems used by states as part of their pavement management systems differ as a result of different requirements by State DOTs as well as the rating system's cost of implementation and ease of understanding. This report investigates all aspects of pavement condition surveys and rating systems in use nationwide.

1.1 Background

Pavement condition surveys give an indication of the serviceability of the road pavements and also the physical condition of the assets. It is referred to as the collection of data to determine the ride quality and structural integrity of a road segment [iv].They are based on observations by trained staff as well as measurements of pavement roughness, surface distress, skid resistance, deflection, among others. Condition ratings may be done manually or through automated means. The choice of whether automated or manual depends on an agency's priorities and its available resources. The condition rating for a particular section is chosen from a scale which may range from 0 to 100, 0 to 5 or even 0 to 99. There are three main aspects of condition surveys which will be looked at in detail in this document. They are data collection, condition rating and quality management.

1.2 Importance of Condition Rating Surveys

Pavement Condition Surveys are vital to the operations of DOTs due to several reasons.

First, pavement condition monitoring helps agencies to schedule maintenance and rehabilitation works efficiently [i]. As a result, the DOTs have an idea as to when to carry out maintenance in order to effectively utilize the assets during its useful lifespan. This is done by setting a threshold level of performance which will indicate acceptable and non-acceptable operating conditions.

Second, pavement condition ratings are used as a fair basis of comparison for different pavements. In other words, pavement condition ratings allows for a more objective comparison of two or more pavement sections. This becomes important when prioritizing maintenance and rehabilitation projects.

Third, condition ratings enable DOTs and all stakeholders to estimate the level of repair and rehabilitation required in terms of costs and extent of deterioration. This is because the condition ratings reflect the current condition of the pavement.

Lastly, data obtained from condition surveys can be used for long-term budget planning. The survey data of past and present conditions can be used to project future conditions and this serves as a guide for management during allocation of funds for future works. With condition ratings, management decisions are no longer based on sentiments and hunches but rather on the valuable and reliable information provided by the condition ratings.

1.3 Objectives

This report will seek to:

1. Identify issues in Pavement data collection;
2. Identify the types of equipment used in data collection;
3. Identify types of condition rating systems and the variables and factors affecting performance; and
4. Address various data quality management procedures.

1.4 Layout of Report

This report has 5 main chapters. The first chapter is the introduction. The second chapter sheds light on the three main aspects of pavement condition surveys. The third chapter takes a look at current condition rating practices in the country. Chapter four contains the evaluation of the various aspects of condition rating such as the equipment and indices used and chapter five is the concluding chapter.

2.0 CONDITION RATING PROCESS

2.1 Brief History

The main purpose of highways is to serve the highway users by giving a comfortable and safe ride to their destinations. As such, DOTs were charged with the responsibility of ensuring the needs of the public are met when using the highways. In order to perform their tasks, DOTs needed to define what comfort was for the general public. This was and still is a difficult question to answer since what may be comfortable to an individual may not be comfortable for others. State departments relied on the personal knowledge and experience of their staff to maintain their highways [ii]. As a result, condition surveys were done by engineers and trained inspectors who identified distresses on the roads based on visual inspections. The manual means of conducting condition surveys were found to be subjective, time-consuming and often times hazardous for the staff. Efforts were made to automate the entire condition survey and rating process. Currently, some state DOT's, for example Maryland, employ fully-automated condition survey systems. In the 1960's, a condition index was developed by the American Association of State Highway Officials (AASHO) in order to make pavement condition surveys more objective. This index was based largely on the Present Serviceability Rating (PSR) which was also based on ride quality as experienced by a panel of raters riding in a vehicle on the road.

Condition ratings are done periodically by the state DOTs. The data accumulated serves as a valuable source of information for assessing and predicting the performance of the pavement over time. See figure 1. This helps in anticipating rehabilitation needs and prioritizing competing projects [iii].

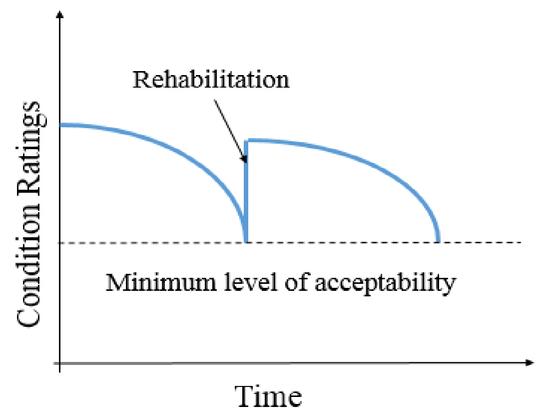

Figure 1: Pavement performance in terms of condition ratings over time

The condition survey process is composed of three main activities, namely; Data collection, Quality Control (QC)/Quality Assurance (QA), and Condition rating. QC/QA can also be referred to as Quality Management. It is worth noting that the condition survey process is part of the larger Pavement Management process which involves decision making. See figure 2. Information obtained after the condition surveys is then packaged and sent to management. Decisions are then made based on this information. The decision making process may be optimized using Pavement Management Software (PMS) and other optimization tools. These tools make use of models that predict the pavement performance over time and influence decisions to be taken. QC activities are performed before data collection, during data collection and after data collection. QA is performed before data is delivered to management for decisions to be made.

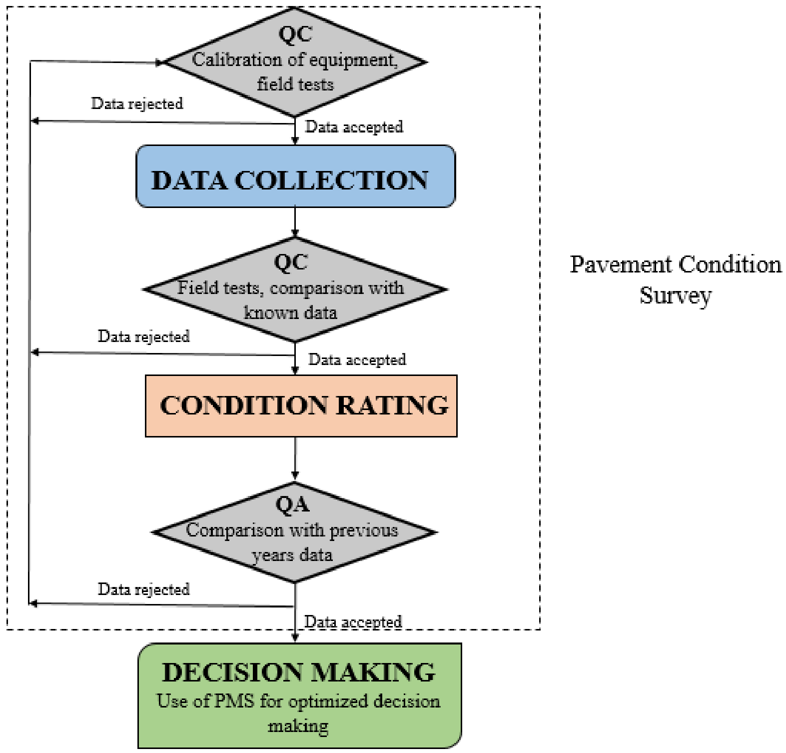

Figure 2: Pavement Management Process

Figure 2 above shows that pavement condition survey is a part of the pavement management process which includes the decision making procedures. The scope of this study is pavement condition survey. The first step is the QC step which requires calibration of equipment and random field tests. After the results of the field tests are accepted, data collection takes place. QC is done after data collection to ensure acceptable data quality. Corrective actions involving calibration and rating is done when results of QC are not acceptable. Condition ratings are then carried out on the data. Before data is fed to decision-making and optimization tools or sent to management, quality assurance is done again to ensure that the results are coherent.

2.2 Data Collection

Data collection is a very important part of the condition survey process. The type of data that is collected by DOTs varies nationwide. This is because different DOTs consider different factors as indicators of pavement performance and deterioration. Examples of data collected during surveys are rut depth, International Roughness Index (IRI), faulting, among others. Data that is collected during condition surveys depend on the type of pavement, whether rigid or flexible. The types of data collected can be categorized into four groups. They are distress data, structural capacity, ride quality data and skid resistance data.

Ride quality data refers to IRI, profile data and Present Serviceability Rating (PSR) data. It is data that gives an indication of how comfortable it is to ride along a particular section. Ride quality data is sometimes referred to as roughness data. This type of data is associated with the quality of the ride as experienced by road users. The ride quality is quantified using the IRI or PSR.

Distress data also refers to the data that describes the types, extent and severities of distresses on the pavement surface. This type of data is usually in the form of pavement images and videos which are analyzed by trained engineers who identify the distresses present. Similarly, the data can also be collected through visual inspections during condition surveys. Pavement distresses are major signs of deterioration and usually manifest as distortions, disintegrations and fractures [xiii]. Distortions refer to corrugations and rutting. Disintegrations also refer to spalling, stripping and raveling. Fracture is the broad term referring to cracking as a result of traffic loadings and changes in temperature. This is the data that is mostly used as a basis to determine the type of maintenance work that is required for a particular section of pavement.

Structural Capacity data gives an indication of the load carrying capacity of the pavement. This type of data collection is usually conducted at the project level using destructive and nondestructive methods. Deflection measurements are typically used to calculate the load transfer capabilities of the structural layers and hence, the structural capacity of the pavement [xiii]. Deflection at a point is defined as the vertical deflected distance as a result of dynamic or static loading at a specific point.

Skid resistance refers to the force developed when a wheel slides along a pavement surface when it is prevented from rotating. It is dependent on the microtexture and macrotexture of pavements. It is generally expressed in terms of friction factor, f or skid number, SN[xiii].

$$f=F/L \qquad (1)$$

$$SN=100*f \qquad (2)$$

where F=frictional resistance opposing motion in the plane of the interface and L=load perpendicular to interface.

There must be some level of skid resistance in order to prevent skidding accidents. Skid resistance decreases over time as the aggregates used in the pavement construction become polished. Skid resistance varies seasonally and so this must also be taken into consideration during measurement.

It is worth mentioning that the condition ratings of pavements are based on the aforementioned data types. Some condition rating systems are based on only one category of data or a combination of all the four types.

2.2.1 Data Collection Methods

There are two approaches to collecting pavement data. They are automated and manual pavement data collection methods. Currently, most state DOTs are gravitating towards the automated approach due to several reasons. For example, Maryland has a fully automated pavement condition survey system. However, the manual methods have unique characteristics that make DOTs continue to rely on them. The characteristics of both approaches are tabulated in table 1. The two methods are compared in terms of time, safety of staff, objectivity of measurements, cost, data size, handling and employers' point of view. An agency's preference for one of these approaches or even a combination of them is based on the amount of financial resources and human capital it has as well as the level of detail and accuracy of data required.

Table 1: Comparison of Automated and Manual Pavement Data Collection Methods

	Automated Data Collection	**Manual Data Collection**
Time	Reduces data collection times	Longer data collection times
Safety	Much safer means of collecting data	Personnel at risk collecting data
Objectivity	Objective measurements	Usually subjective since it depends on experience of personnel
Cost	Very expensive equipment costs	Relatively less expensive
Data Size	Vast amounts of data collected & stored depending on capacity of equipment	Agencies may only be able to collect smaller amounts of data at a time
Data Handling	Not subject to transcription errors	Subject to transcription errors
Employers	Suitable in agencies seeking to downsize number of employees	Source of employment for rating staff
Coverage	May cover footprint of data collection vehicle. Multiple runs sometimes needed to cover entire road width	Inspectors can cover entire width of road section relatively easier

2.2.2 Data Collection Equipment

Recent improvements in data collection equipment technology have been very beneficial. The cost of storing data is not as high as it used to be and processing speeds have improved to ensure computers function efficiently even when high resolution equipment is used.

The manual walking survey procedure mentioned earlier is one method of data collection which has been used for many years. It is done on selected inspection units in the management section. An inspection unit is a small segment of a management section with a convenient size that is selected and inspected in detail. Typically, inspection units may range in lengths from 50 to 200 feet and may also be up to four lanes wide. Inspection units may be selected at random or through a defined sampling procedure. In a typical windshield survey, the survey is done from a vehicle travelling at a speed of about 5 to 15 miles per hour. The distresses are visually identified by the rater and the area affected is estimated as a percentage of the road surface [iv]. The manual distress surveys are slow, labor-intensive and subject to errors. Consistency between classification and quantification of the distresses observed by the raters can also be a major problem. After the data has been summarized and corrected, the only recourse for checking apparent anomalies in the data is to return to the field. Safety of field crews is also another major concern. Some of the equipment used are rod and level survey instruments, dipstick profilers and California type profilometers.

The rod and level instrument are used in measuring pavement profiles. Two persons are needed to complete data collection with this instrument. One individual holds the rod while the other holds the level instrument and records the readings. In some cases, a third person, solely responsible for recording data is added to the crew. Measurements are usually taken at 0.3m intervals [xxii]. Experienced personnel usually take 10s to acquire one data point. Rod and level must be stored and carried in shockproof packaging and they must be cleaned before storing in case when wet.

Data collection using the rod and level must not be done in windy conditions as it may lead to errors. See figure 3.

Figure 3: Auto Rod and Level Device

Source: APR Consultants, http://www.aprconsultants.com/Pavement-Profile-Measurement.html, Date accessed: July 20, 2013

The Dipstick profiler is also another instrument used for measuring pavement profiles. The name 'Dipstick' is the trade name of the company that manufactures the profilers. The company is Face Construction Technologies of Norfolk, VA. This device is currently being used in about 63 countries. Federal Highway Administration (FHWA) and the World Bank have established guidelines and procedures for using the dipstick profiler. The Dipstick measurements record data at rates greater than the rod and level instrument. The dipstick profiler's main body is composed of an inclinometer, LCD panels and a battery for providing power supply

[xxiii]. See figure 4. The sensor is unbalanced as the device is pivoted on one leg as the other leg moves down the pavement. The relative elevation is read from the display as the sensor gains equilibrium. Experienced personnel can obtain 500 readings per hour.

Figure 4: Dipstick 2000

Source: http://www.pavementinteractive.org/article/roughness/, Date accessed: July 20, 2013, 3:10pm

The 25-foot California profilograph is also another important device used by some agencies for acquiring data on pavement profiles. This equipment is basically a rolling straight edge. It measures vertical deviations using the instrument as a 25-foot reference plane recording the readings on a profilogram. The instrument is a 25-foot aluminum truss with a recorder located at center top of the device. Profilographs are pushed by personnel at walking speeds along the pavement section. Advanced profilographs may have small propulsion units of about 3 horsepower pushing them [xxiv]. A necessary precaution that must be taken is that the speed at which the equipment is pushed along the pavement must be reduced when there are excessive spikes in the readings which affect the quality of the data. See figure 5.

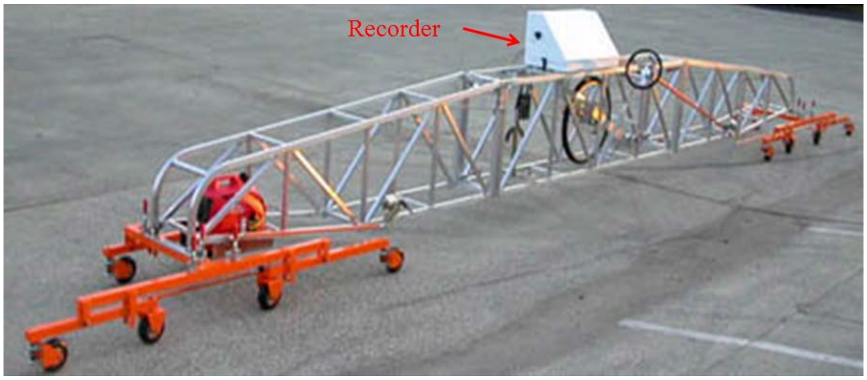

Figure 5: Computerized Profilograph

Source: Surface Systems & Instruments, Inc.
http://www.smoothroad.com/products/profilograph/, Date accessed: July 20, 2013, 4:00pm

To minimize the errors and standardize the survey process, agencies employ automated methods in recording, reduction, processing and storage of pavement data. An automated distress survey can be defined as any method in which distress data is entered directly to the computer in the field during the survey. This type of survey can reduce greatly errors associated with transferring data from paper forms used in the field to computer systems for analysis. Other benefits of automated distress surveys include safety for survey crews, faster and more objective surveys. Most states now use automated means to collect data on pavement friction, roughness, profile, rut depth and deflection.

Several technologies hold great promise in the area of automated high-speed distress data collection. Examples are laser technology, film-based systems and video systems.

The Road excellent automatic logging system (Real) is a system that is from the PASCO Corporation. PASCO is one of the renowned companies which specializes in the measurement and collection of geospatial data for use by government agencies and private sector organizations. The Real system conducts surveys on road images as well as providing geographical characteristics. It has the ability to also capture images on the entire road environment which makes it more useful for conducting a road management system. With Real, it is possible to gain stereoscopic information on road texture conditions through the captured images and 3D data. Figure 6 shows the Real system from PASCO.

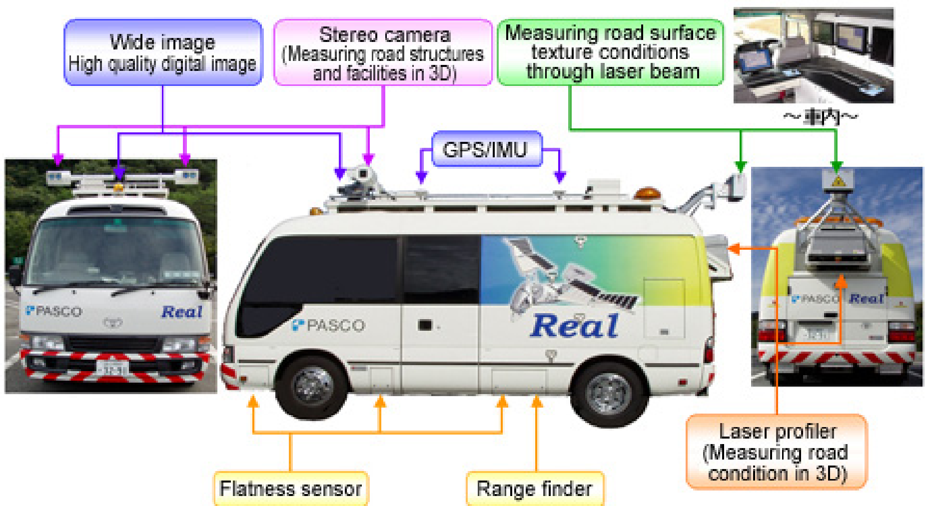

Figure 6: Real System from PASCO

Source: PASCO Corporation, http://www.pasco.co.jp/eng/products/real/, Date accessed: June 14, 2013, 11:01am

Another type of equipment is the ARAN, and it is a high-speed, multi-functional and diverse road/ infrastructure data acquisition vehicle. It measures pavement condition and distresses for comprehensive pavement management. User agencies include about 20 countries worldwide and about 30 states in the United States. Two on-board geometric systems are used. The POS/LV onboard geometric and orientation system utilizes state-of-the-art military aircraft grade gyroscopes, accelerometers and global positioning system (GPS) receivers all work together to provide enhanced precision survey measurements. The ARAN employs GPS to continuously monitor the ARAN's absolute position in the XYZ space with an accuracy of 50 to 100m. ARAN employs two road roughness profile measuring systems. The laser SDP employs the use of lasers instead of ultrasonic sensors. The second road roughness profile measuring system is an inertial roughness profilometer. The ARAN also uses a smart bar for road rutting measurements. This smart bar employs up to 37 ultrasonic sensors positioned at 4-inch intervals across the entire transverse profile. The rut is then measured to an accuracy of 1/32 of an inch. Video logging is used to collect the data. The ARAN can employ up to six video cameras. The onboard video logging subsystems are the Right-of-Way (ROW) windshield video and the Pavement View (PV) video. The ROW video consists of a full color video camera mounted between the driver and the passenger and looks forward out of the vehicle's front window to record a continuous video as seen through the windshield. See figure 7.

Figure 7: ARAN vehicle

Source: Spar Point Group, "FugroRoadware lands two-year, $3m mobile data collection contract" http://www.sparpointgroup.com/uploadedImages/Images/08.22.11.ARAN.png?maxwidth=800&maxheight=600&bgcolor=white ,Date accessed: June 14, 2013, 11:20am

The MHM Automated Road Image Analyzer (ARIA) which is another automated pavement distress collector is capable of measuring faulting, grooving, pavement distress and rut depth. The user vehicle is generally a van, which operates at speeds of about 5-10 mph. The system components consist of a video camera collecting data, a distance measuring device (DMI) and an automated digitized processor for analyzing the data collected. It can detect crack widths of about 1/8”-1/16”. The ARIA is used at the local level such as the city of Coriscana, Texas and LaPorte County, Indiana.

Pavedex Inc. is the supplier of the PAS-1, which is another automated pavement distress collector. The user vehicle for the PAS-1 is a van that has the capacity to operate at speeds from 0 to 55mph. The system components consist of five video cameras, 2 on the front, 2 on the rear and one top and center mounted. The cameras can each cover a span of about 30 square feet with a 50% overlap at 55mph [i]. The cameras record pavement distress and the system utilizes automated digitized processing through video imaging to determine cracks. The DMI employed in this system can measure with an accuracy of about one foot. It is currently being used in 4 cities in western United States.

Pathway Services Inc. also has the Digital Inspection Vehicle (DIV) which is used by the Minnesota Department of Transportation (Mn/DOT) for pavement data collection [ixx]. It has three lasers in the front for profile measurements. There are two lasers in the rear for rut measurements and four digital cameras mounted on top of the vehicle for capturing distress images as well as right-of-way images. See figure 8. Measurements are taken at 1/8 of an inch of the roadway at highway speeds.

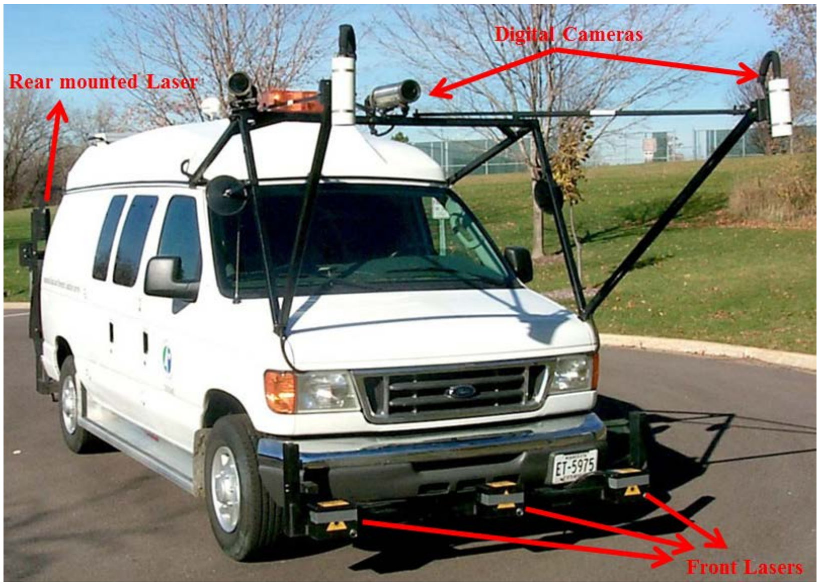

Figure 8: Pathway Services Inc., Digital Inspection Vehicle (DIV)

Source:http://www.stlouiscountymn.gov/Portals/0/Departments/PublicWorks/internet_files/pathway_van.jpg, Date accessed:7/11/2013, 12:24pm

The images captured by the system are then analyzed using a workstation by two qualified engineers allowing for better rating consistency.

Table 2 is a summary of some of the automated equipment used and their unique characteristics.

Table 2: Summary of automated equipment used in pavement evaluation

EQUIPMENT	Data Output	Minimum Crack width	Identified Line	Laser	Film-Based	Photometric	Video System
Pasco Road Survey	Continuous film: digitized in office	1/16”			√		
Pathway Services, Inc.	Video Record						√
ARAN	Video Record	1/16”					√
AREV		1/16”					√
ARIA System (MHM Assoc.)	Video Imaging	1/8”					√
PAS-1 (Pavedex, Inc)	Video Imaging	1/16”					√
VIV (PaveTechInc)		1/16”					√
VideoComp	Crack map	1/10”					√
Roadman PDI-I (PCES Inc)	Continuous line video log	1/20”	√				
ITX Stanley Road Tester	Video record	1/16”					√
Laser RST (IMS)	Crack characteristics- ASCII file	1/16”		√			
GIE System	Crack characteristics	1/8”		√		√	

Source: Module 5, http://www.cee.mtu.edu/~balkire/CE5403/Lec%204A.pdf

2.3 Condition Rating Systems

The condition rating of a pavement section refers to a score that quantifies the performance. This rating is based on measures such as roughness, skid resistance, deflection among others obtained during the data collection process. The condition ratings are used as a basis for comparing the performance of two road sections. Most importantly, they help agencies to determine the extent and severity of pavement defects and estimate the cost of repair and rehabilitation and prioritize treatment procedures. They are also used as a basis for planning budgets. Condition rating indexes have also in a way reduced the political pressure that formed a greater part of the decision making process.

2.3.1 Evolution

In the 1950s, pavement condition ratings were done by a panel of raters who drive along the pavement and subjectively rate the condition of pavements based on a numeric scale or verbal description. This form of rating, developed by the American Association of State Highway Officials (AASHO), used a 0-5 scale. It was known as the Present Serviceability Rating (PSR). Despite the fact that this was simple, the ratings did not provide adequate engineering basis for prescribing the type and extent of repair and rehabilitation work to be done on damaged pavements. To deal with this issue, researchers developed mathematical expressions that were able to give the condition of pavement sections based on the type, severity and extent of distresses. This led to the development of a more objective means of condition rating in the late 1950s. This index, known as the Present Serviceability Index (PSI) was based on the relationship between panel ratings and measurements such as rutting and roughness [xvii]. The equation used to calculate the PSI is shown in (3) below. This provided an index that can be calculated from objective measurements of roughness, cracking, patching and the slope variance of the pavement section under consideration.

$$PSI = 5.03 - \log(1 + SV) - 1.38(RD)^2 - 0.01(C + P)^{1/2} \qquad (3)$$

where PSI= Present Serviceability Index

SV=slope variance of section obtained using CHLOE Profilometer

RD= mean rut depth (in)

C=cracking (ft/1000 sq. ft)

P=Patching (sq. ft/1000 sq. ft)

The PSR and PSI were widely accepted among several states. However, during the late 1960s, states began developing unique indexes to address diverse pavement issues. The US Army Corps of Engineers also developed the Pavement Condition Index (PCI) in 1976 which is still being used by several state DOTs. The scales of the condition indexes vary and may sometimes range between 0-5, 1-5 or in some cases 0-100.

2.3.2 Classes of Condition Indexes

Different States across the country use different approaches towards pavement condition rating. The condition rating systems can be grouped into two main groups namely estimated condition ratings and measured condition ratings. The estimated condition rating systems are based on observed physical conditions of the pavements while the measured condition rating systems are not only based on observations by trained raters but are also backed by physical measurements such as roughness and mathematical expressions. Most of the state agencies use the measured rating systems since they provide a more objective rating of the performance of the pavements. See figure 9 for examples of rating systems in the two categories.

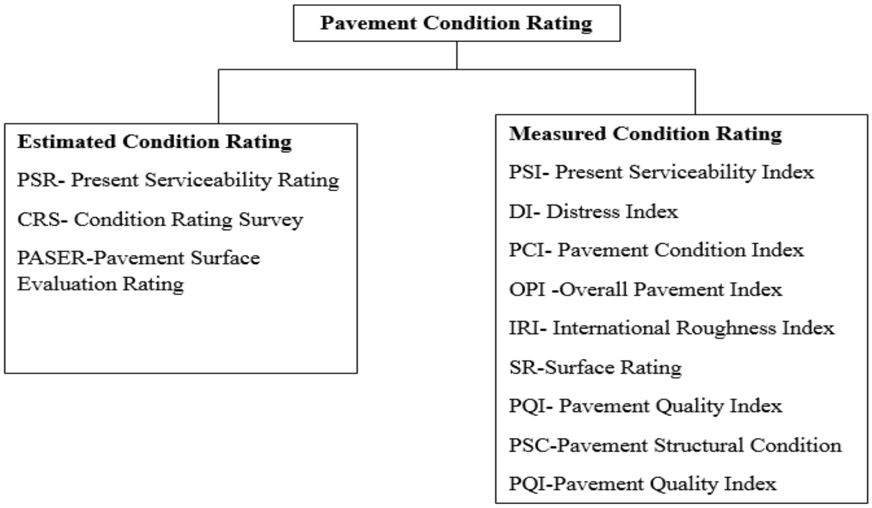

Figure 9 Pavement Condition Rating Systems

2.3.2.1 Estimated Condition Survey

Present Serviceability Rating (PSR)

The most common and fundamental pavement condition rating index is Present Serviceability Rating (PSR). This is from AASHO and is based on the ride quality as experienced by a panel of observers riding in a vehicle on a particular section of pavement. The rating scale used is from 0 to 5 as shown below in figure 10. The mean of the individual ratings is the present serviceability rating [vii].

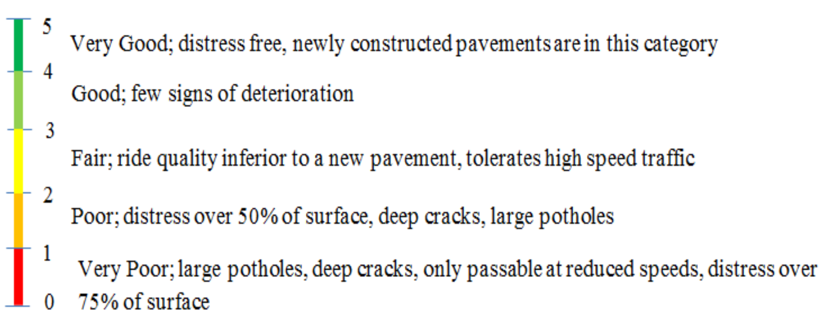

Figure 10: Present Serviceability Rating

Condition Rating Survey (CRS)

The Condition Rating Survey (CRS) is also another estimated condition rating system used by the Illinois Department of Transportation (IDOT) [vii]. The scale is a 1.0-9.0 scale with increments of 0.1. A value of 1.0 represents total failure while a value of 9.0 represents a newly constructed pavement. The values are assigned based on a CRS Manual developed in 2004. The manual has several images that guide the inspector in assigning appropriate values. CRS has evolved over the years into a measured condition rating at the state level since algorithms have been developed to incorporate the measured defects into the calculation of condition rating values. Some agencies at the local level still use the original form of the CRS.

Pavement Surface Evaluation and Rating System (PASER)

Another estimated rating system is the Pavement Surface Evaluation and Rating System (PASER). It comes under the estimated rating systems since it is also a visual rating of the pavement conditions based on a 1-10 scale. Similar to the CRS, there is a manual with photographs and descriptions that guides inspectors to choose the appropriate value on the scale that captures the conditions accurately. Table 3 shows a general translation of the PASER ratings [vii].

Table 3: PASER ratings and maintenance requirements

PASER Ratings	**Description of Maintenance**
9-10	No maintenance needed
8	Little maintenance
7	Routine maintenance, crack sealing, minor patching
5-6	Seal Coating
3-4	Overlay
1-2	Reconstruction

2.3.2.2 Measured Condition Rating

Present Serviceability Index (PSI)

For the measured condition ratings, the Present Serviceability Index (PSI), a 0-5 index is considered as a measured rating system since it is based on physical measurements of pavement characteristics in addition to observations from trained raters. The information from the panel of raters who rated roads in Illinois, Minnesota and Indiana was correlated with the roughness, rut depth, cracking and patching measurements of the pavement to produce this index. This test and analyses were carried out by AASHO (American Association of State Highway Officials) between 1958 and 1960 with the aim of providing a much more objective means of establishing pavement conditions[i]. The pavement measurements were correlated with the observations from the raters to develop expressions for calculating the PSI.

Distress Index (DI)

Distress Index (DI) is also considered as a measured condition rating system. This is used by the Michigan Department of Transportation (MDOT). A survey for every 0.1 mile of the pavement is collected by MDOT through a video survey. The Distress Index is simply a weighted score of the distress points which are the result of assigning the distresses points based on their type, extent and severity from the video survey. The expression for DI is

$$DI = \sum DP / L \tag{4}$$

where DI = distress index, DP= distress points and L= number of 0.1 mile sections. The DI starts from a rating of zero with no upper bound. Generally, a DI less than 20 is considered low whilst a

DI greater than 40 is considered as high. Medium DI ranges between 20 and 40. A DI of 50 may indicate zero remaining service life [viii].

Pavement Condition Index (PCI)

The Pavement Condition Index is also a measured condition rating system developed by the US Army Corps of Engineers and adopted by the American Public Works Association and American Society for Testing and Materials (ASTM). It is based on a 0-100 scale. See figure 11 for an illustration [vii]. Each distress identified on the pavement is assigned a value based on the type, severity and extent. The points are then summed up and deducted from a score of 100 to give the pavement condition rating. The weighted average of the PCIs for multiple sub-sections is then the condition of the entire section. There are 39 distresses with 3 levels of severity namely high, medium and low. There are 20 distresses for asphalt concrete (AC) pavements and 19 distress types for Portland Cement Concrete pavements (PCC).

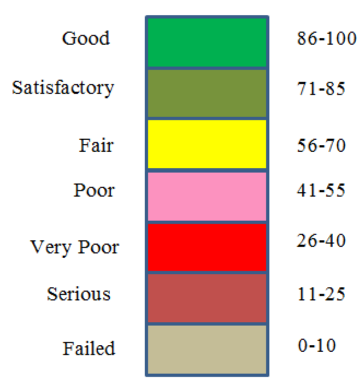

Figure 11: PCI Ratings (Illinois Center for Transportation, Implementing Pavement Management Systems for Local Agencies-State-of-the-Art/ State-of-the-Practice)

Overall Pavement Index (OPI)

Some agencies also use the Overall Pavement Index which is based on the Modified Distress Rating (MDR). The MDR is also based on the PSI which in turn is derived from the IRI. This was employed in the PMS Implementation for Nigerian Federal Roads [ix]. The following equations will further explain the OPI.

$$PSI = 5e^{0.198-0.000261(IRI)} \tag{5}$$

$$MDR = 20(PSI) \tag{6}$$

$$OPI = MDR(PSR/5)^{0.22} \tag{7}$$

Surface Rating

This is an index used by the Minnesota Department of Transportation (MNDOT). It is a 0.0-4.0 rating scale. Similar to the PSR the higher ratings correspond to better pavement conditions. Two raters categorize and measure the distresses on the pavement. This is then converted to percentages of distresses. The percentages are then weighted according to the type of distresses with the appropriate weighting factor. The total percentage weighted distress is then converted to Surface Rating (SR). Table 4 shows the weighting factors for distresses in bituminous pavements. Table 5 and 6 show the weighting factors for concrete pavements and continuously reinforced concrete pavements respectively. Table 7 shows the total weighting and the corresponding Surface Ratings.

Table 4: Bituminous Pavement Weighting Factors

Distress Type	**Severity**	**Weighting**
Transverse Crack	Low	0.01
	Medium	0.10
	High	0.20
Longitudinal Crack	Low	0.02
	Medium	0.03
	High	0.04
Longitudinal Joint Deterioration	Low	0.02
	Medium	0.03
	High	0.04
Block Cracking		0.15
Alligator Cracking		0.35
Rutting		0.15
Raveling and Weathering		0.02
Patching		0.04

Table 5: Concrete Pavement Weighting Factors

Distress Type	**Severity**	**Weighting**
Transverse Joint Spalling	Low	0.10
	High	0.20
Longitudinal Joint Spalling	Low	0.10
	High	0.20
Cracked/Broken/ Faulted Panel		0.07
Faulted Joints		0.10
100% overlaid Panels		0.00
Patched Panels		0.14

D-cracking		0.10

Table 6: Continuously Reinforced Concrete Pavement Weighting Factors

Distress Type	Weighting Factor
Patch deterioration	0.30
Localized Distress	0.40
D-cracking	0.05
Transverse cracking	0.25

To convert to the SR, table 8 is used.

Table 7: Total weighting and SR

Total Weighting	**SR**	**Total Weighting**	**SR**
0	4.0	21	1.6
1	3.8	22-23	1.5
2	3.6	24	1.4
3	3.4	25-26	1.3
4	3.2	27	1.2
5	3.0	28-29	1.1
8	2.9	30-33	1.0
7	2.8	34-40	0.9
8	2.7	41-47	0.8
9	2.6	48-54	0.7
10	2.5	55-61	0.6
11	2.4	62-68	0.5
12	2.3	69-75	0.4
13	2.2	76-82	0.3
14	2.1	83-89	0.2
15	2.0	90-96	0.1
16-17	1.9		
18	1.8		

19-20	1.7		

Pavement Quality Index (PQI)

PQI is used by the MNDOT and is a combination of the PSR and the SR. It is the square root of PSR multiplied by SR. It ranges on a scale of 0.0 for failed pavements to 4.5 for no defects.

Pavement Structural Condition (PSC)

The PSC is rating system used by the Washington State DOT to rate pavement conditions [viii]. The scale ranges from 0 for poor conditions to 100 for no distress. Similar to most of the rating systems, the PSC is also a single value that is used to give an indication of the pavement conditions in terms of the severity and extent of all distresses. The PSC is calculated differently in rigid and flexible pavements. The expressions for calculating PSC are below

$$Flexible\ Pavements: PSC = 100 - 15.8EC^{0.5} \tag{8}$$

$$Rigid\ Pavements: PSC = 100 - 18.6EC^{0.43} \tag{9}$$

where PSC=Pavement Structural Condition; EC= equivalent cracking

Each distress type is converted to an equivalent cracking number based on the extent and severity. The EC is the sum of the defects obtained after summing up the defects that have been assigned numerical values. See table 8. PSC values are categorized as follows in table 9.

Table 8: Equivalent Cracking Valuation for Asphalt Concrete

Distress	**Type Coefficient**	**Coefficient**	**Power**
% Length Patching High*	0.75	1	1
% Length Patching Medium*	0.75	0.445	1.15
% Length Patching Low*	0.75	0.13	1.35
% Both Wheel Paths of Alligator Cracking High	1	1	1
% Both Wheel Paths of Alligator Cracking Medium	1	0.445	1.15
% Both Wheel Paths of Alligator Cracking Low	1	0.13	1.35
% Length Transverse Cracking High	0.8	1	1
% Length Transverse Cracking Medium	0.8	0.445	1.15
% Length Transverse Cracking Low	0.8	0.13	1.35
% Length Longitudinal Cracking High	0.1	1	1
% Length Longitudinal Cracking Medium	0.1	0.445	1.15
% Length Longitudinal Cracking Low	0.1	0.13	1.15

Table 9: PSC Categories

Condition	**PSC Rating**

Excellent	75-100
Good	50-75
Fair	25-50
Poor	0-25

2.4 Quality Management

Many transportation agencies are developing procedures and guidelines for managing the quality of pavement data collection activities to ensure that the data collected meets the needs of the pavement management process. Pavement data quality is receiving increased attention due to fact that the data quality has a critical effect on the pavement management decisions.

The most efficient way to achieve high-quality pavement condition data collection is to adopt a comprehensive and systematic quality management approach that includes methods, techniques, tools and model problem solutions. Quality management involves the specification of data collection protocols, quality standards, responsibilities of personnel, quality control, quality acceptance, corrective action and quality management documentation.

Quality control (QC) refers to activities performed to ensure that the equipment and processes involved in data collection are under control which will in turn ensure that high quality results are obtained. Quality assurance (QA) is a term that refers to all activities conducted to verify that the collected pavement condition data meet the quality requirements and specifications. It is usually conducted by a quality assurance auditor, who checks data management spreadsheets, verifies that the data is complete and checks a random sample of 2-10% of the data collected. Ideally, QC procedures must be performed at all phases of the data collection process [x]. At the pre-project phase, QC procedures ensure the equipment's accuracy and precision match industry standards.

During post-processing, QC is also done to ensure completeness and accuracy. After which QA is done to further ensure reliability and accuracy of delivered data. Purpose of quality control is to quantify variability in the process, maintain it within acceptable limits and to take the necessary actions that can minimize controllable variability. Sources of variability include rater or operator's training skills and environmental conditions. Approximately 64% of state and provincial highway agencies have a formal data collection quality control plan.

The AASHTO Standards, ASTM Standards, Long Term Pavement Performance (LTPP) Guide are a few of the standards which serve as guidelines for agencies performing data quality management. These guidelines address quality assurance and control with respect to the qualification of personnel, validation sections, equipment calibration and additional checks using previous years' data. However, the guidelines are not very specific but have served as the basis for agencies to create detailed state-specific data quality management guides.

A key feature of quality management that must be noted is that the variability of the data must be less than the yearly change of the data. Otherwise, this indicates a high level of "noise" and or bias which may not yield meaningful results from analysis. Data quality management is the responsibility of both data collectors and the end user of the data.

Due to the fact that there is always some level of bias and error inherent in the data, quality assurance guidelines outline tolerance limits to ensure permissible variability of data. Variability can also be caused by rater inconsistencies and during data referencing, data handling and processing [xv]. Table 18 shows some of the tolerance limits for data collection used by PENNDOT. The limits may be in the form of absolute values or percentages.

Extensive work has been done in the quality control and quality assurance of data. However, the quality management of sensor-collected data is more established than distress data. This is due to the inherent variability in the equipment used in acquiring pavement images as well as the processing of the images [x].

2.4.1 Quality Management of Distress Data

In most cases, the data collector (whether in-house or outsourced) performs pilot runs and the data obtained is compared with data obtained from manual surveys. This is the quality management that is done before data collection and it is used to ensure the equipment is functioning. During data collection, random sections are chosen and data is compared with manual survey data. Agencies therefore need to define their limits for acceptable variability in data. This may be done through in-depth statistical analyses as well as examination of sources of variability.

2.4.2 Quality Management of ride quality data

Ride quality data refers to roughness and profile measurements (See page 5). These are measured with sensors and lasers. The AASHTO standards for quality management give little detail and so the agencies are responsible for their own requirements. As a result of extensive studies, guidelines have been provided to ensure reduced errors in profile data collection [xi]. The tire pressures must be checked and the lenses must be cleaned before the runs. The profile data must be collected at speeds recommended by the manufacturer. The measuring devices such as the sensors, accelerometers and distance measuring devices must be calibrated using the manufacturer's specifications. Wet pavements must be avoided during data collection season. Similar to distress data, pilot runs are also conducted on validation segments before actual data collection takes place. This is a way of ensuring the equipment's ability to collect data.

In summary, the importance of quality management cannot be overlooked by engineers and other professionals. Quality management of data and procedures can lead to:

1. Consistent and accurate data;
2. Improved decision support for stakeholders and managers;
3. Reduced costs; and
4. Higher credibility ratings within and outside the organization.

3.0 CURRENT PRACTICES IN THE US

DOTs across the nation have different ways of managing their pavement infrastructure. They employ different methods of data collection during condition monitoring and condition evaluation. The choice of a particular method depends largely on financial constraints and the qualification of personnel. It also depends on whether those methods for evaluation and data collection reflect the needs of the agency. The following sections summarize the methods adopted by some state agencies in the US. Almost all the states avoid data collection during wet conditions.

Delaware

DelDOT performs pavement condition surveys once every two years. Currently, the data collection process has been outsourced to Data Transfer Solutions. Data collected depends on the type of pavement. Tables 10-17 show the types of pavements, pavement defects considered and the levels of severities and extent. These are used for evaluating the condition of the pavements based on the Overall Pavement Condition (OPC) which is on a 0-100 scale. IRI and rutting data are collected but are not factored into OPC calculations. Detailed QA/QC procedures including equipment calibration, data verification and office data checks are also performed.

Severity Levels Describing Failure in Pavements

Table 10: Flexible Pavement Defects and Severity Levels (DelDOT)

	Severity		
Deficiency	*LOW*	*MEDIUM*	*HIGH*
Fatigue Cracking	Fine parallel hairline cracks	Alligator crack pattern clearly developed	Alligator crack pattern clearly developed with spalling and/or distortion
Transverse Cracking	Crack < 1/4 inch wide	Crack Width > 1/4 and < 3/4 inch and/or spalls less than 3 inches in width or sealed crack with sealant in good condition	Crack Width > 3/4 inch and/or spalls greater than 3 inches in width or significant loss of material
Block Cracking	Crack < 1/4 inch wide	Crack Width > 1/4 and < 3/4 inch and/or spalls less than 3 inches in width or sealed crack with sealant in good condition	Crack Width > 3/4 inch and/or spalls greater than 3 inches in width or significant loss of material
Patch Deterioration	Patches showing little or no defects with a smooth ride	Patches showing medium severity defects (e.g. cracking) and/or notable roughness	Patches showing high severity defects and/or distinct roughness
Surface Defects	Aggregate has begun to wear away	Aggregate has worn away and surface is becoming rough and/or minor rutting occurring from horse & buggy traffic (less than 1 inch average depth)	Aggregate has worn away and surface is very rough and/or major rutting occurring from horse & buggy traffic (greater than 1 inch average depth)

NOTES: Transverse Cracks – For Medium or High Severity Cracks – Raters will have to Note if Cracks are Sealed or Not Sealed
Bleeding Flushing – When present, it will be recorded as a comment

Table 11: Surface Treated Pavement Defects and Severity Levels (DelDOT)

	Severity		
Deficiency	*LOW*	*MEDIUM*	*HIGH*
Fatigue Cracking	Fine parallel hairline cracks	Alligator crack pattern clearly developed	Alligator pattern clearly developed with spalling and distortion
Bleeding	Area of pavement discolored by excess asphalt cement	Area of pavement is losing surface texture due to excess asphalt cement	Excess asphalt cement gives pavement a shiny surface, aggregate is not exposed
Surface Defects	Aggregate has begun to wear away	Aggregate has worn away and surface is becoming rough and/or minor rutting occurring from horse & buggy traffic (less than 1 inch average depth)	Aggregate has worn away and surface is very rough and/or major rutting occurring from horse & buggy traffic (greater than 1 inch average depth)
Edge Cracking	Fine parallel hairline cracks	Crack pattern clearly developed	Crack pattern clearly developed with spalling and/or distortion
Roughness/ Crown	N/A	Roughness is severe enough to require a leveling course	Roughness is severe enough to require reconstruction of the base

Note: Roughness/Crown Distress should be rated as being defective if the road requires a new base or leveling course to re-establish the cross-section and profile. Medium and high severity levels of distress are defined in the table above. There is no low-level severity for this distress.

Table 12: Composite Pavement Defects and Severity Levels (DelDOT)

	Severity		
Deficiency	*LOW*	*MEDIUM*	*HIGH*
Fatigue Cracking	Fine parallel hairline cracks	Alligator crack pattern clearly developed	Alligator pattern clearly developed with spalling and distortion
Reflective Cracking	Crack < 1/4 inch wide	Crack Width > 1/4 and < 3/4 inch and/or spalls less than 3 inches in width or sealed crack with sealant in good condition	Crack Width > 3/4 inch and/or spalls greater than 3 inches in width or significant loss of material
Surface Defects	Aggregate has begun to wear away	Aggregate has worn away and surface is becoming rough and/or minor rutting occurring from horse & buggy traffic (less than 1 inch average depth)	Aggregate has worn away and surface is very rough and/or major rutting occurring from horse & buggy traffic (greater than 1 inch average depth)
Block Cracking	Crack < 1/4 inch wide	Crack Width > 1/4 and < 3/4 inch and/or spalls less than 3 inches in width or sealed crack with sealant in good condition	Crack Width > 3/4 inch and/or spalls greater than 3 inches in width

NOTES:

Reflective Cracks – For Medium or High Severity Cracks – Raters will have to Note if Cracks are Sealed or Not Sealed

Bleeding Flushing – When present, it will be recorded as a comment

Table 13: Rigid Pavement Defects and Severity Levels (DelDOT)

	Severity		
Deficiency	*LOW*	*MEDIUM*	*HIGH*
Joint Deterioration	Spalls < 3 inches wide with no significant loss of material	Spalls 3-6 inches wide with loss of material	Spalls > 6 inches wide with significant loss of material
Slab Cracking	Crack < 1/4 inch wide	Crack width > 1/4 and < 3/4 inch , spalling < 3 inches wide or sealed cracks with sealant in good condition	Crack width > 3/4 inch or spalling > 3 inches wide
Patch Deterioration	Patches showing low severity defects and no measurable faulting	Patches showing medium severity defects and/or faulting up to 1/4 inch	Patches showing high severity defects and/or faulting up to 1/4 inch
ASR	Cracks are light with no loose or missing pieces	Cracks are well defined and some small pieces are loose or missing	Cracks are a well developed pattern with a significant amount of loose or missing pieces
Sealant Loss	0-9 % of Joint Loss	10-50 % of Joint Loss	> 50 % of Joint Loss

NOTE:
Slab Cracks – For Medium or High Severity Cracks – Raters will have to Note if Cracks are Sealed or Not Sealed

Extent Levels describing Failure in Pavements

Table 14: Flexible Pavement Defects and Levels of Defect Extents (DelDOT)

	Severity		
Deficiency	*LOW*	*MEDIUM*	*HIGH*
Fatigue Cracking	0 - 9% (wheel path)	10 - 25%	> 25%
Transverse Cracking	> 50 ft spacing	25 ft < spacing <50 ft	< 25 ft spacing
Block Cracking	0 - 9%	10 - 25%	> 25%
Patch Deterioration	0- 9%	10 - 25%	> 25 %
Surface Defects	0- 9%	10 - 25%	> 25 %

Table 15: Surface Treated Pavement Defects and Levels of Defect Extents (DelDOT)

	Severity		
Deficiency	*LOW*	*MEDIUM*	*HIGH*
Fatigue Cracking	0- 9% (wheel path)	10 - 25%	> 25%
Bleeding	0- 9%	10 - 25%	> 25%
Surface Defects	0- 9%	10 - 25%	> 25 %
Edge Cracking	0- 9% (3 ft Edge)	10 - 25%	> 25%
Roughness/Crown	0- 9%	10 - 25%	> 25 %

Table 16: Composite Pavement Defects and Levels of Defect Extents (DelDOT)

	Severity		
Deficiency	*LOW*	*MEDIUM*	*HIGH*
Fatigue Cracking	0- 9%	10- 25%	>25%
Reflective Cracking	> 50 ft spacing	25 ft < spacing <50 ft	< 25 ft spacing
Surface Defects	0- 9%	10- 25%	> 25%
Block Cracking	0- 9%	10- 25%	> 25%

Table 17: Rigid Pavement Defects & Levels of Defect Extents (DelDOT)

	Severity		
Deficiency	*LOW*	*MEDIUM*	*HIGH*
Joint Deterioration	0- 9% of joints	10- 25% of joints	>25% of joints
Slab Cracking	0- 9% of slabs	10- 25% of slabs	>25% of slabs
Patch Deterioration	0- 9% of area	10-25% of area	>25% of area
ASR	N/A	N/A	N/A
Joint Sealant Damage	0- 9% of joints	10- 25% of joints	>25% of joints

Maryland

IRI, rutting, friction and cracking data are collected by the Maryland Department of Transportation (MDOT). MDOT has been using automated means of data collection since 1995. It is done annually. MDOT does not use a composite rating but provides condition reports and preservation needs reports to management.

Pennsylvania

Pennsylvania Department of Transportation (PENNDOT) uses automated means to collect data on IRI, rutting, fatigue cracking, edge deterioration, bituminous patching, transverse joint spalling, longitudinal joint spalling, transverse joint faulting, broken slab and concrete patching. Data collection is outsourced to external consultants. Surveys are carried out on all of the National Highway System (NHS) annually and half of the non-NHS roads. The Overall Pavement Index (OPI) is used. The OPI for asphalt concrete pavement is calculated from equations below [xviii].

$$OPI = (0.15 * FCI) + (0.125 * TCI) + (0.10 * MCI) + (0.10 * EDI) + (0.05 * BPI) + (0.05 * RWI) + (0.175 * RUT) + (0.25 * RUF) \quad (10)$$

PENNDOT also has a well-structured QA program which specifies limits and criteria for accepting and rejecting data collected. See table 18 below.

Table 18: PENNDOT Data discrepancy tolerances

Data Type	**Initial Criteria**	**% Within Limits**	**Recommended Action**
IRI	±25%	95	Reject
Individual Distress Severity	±30%	90	Feedback on potential bias
Total fatigue	±20%	90	Reject
Total non-fatigue cracking	±20%	90	Reject
Total joint spalling	±20%	90	Reject
Transverse cracking, JCP	±20%	90	Reject

Source: Practical Guide for Quality Management of Pavement Condition Data, USDOT, FHWA

New York

New York State Department of Transportation uses both manual windshield surveys and automated surveys in collecting data. Distress data is collected manually while ride quality data are collected using the automated road analyzer system. Windshield surveys conducted annually on all state highways. The automated survey is also conducted annually on interstates and biannually on roads with lower functional classes. During QA, 5% of the weekly mileage covered by the automated surveys are examined. 10% of the mileage covered by windshield surveys are also examined. A 15% variation is considered acceptable for automated surveys while a 1% variation is considered for the windshield surveys.

Georgia

Similar to DelDOT, Georgia Department of Transportation (GDOT) also conducts surveys on the entire network annually. However, data collection is not outsourced.Data is collected by trained staff from the agency. Data collection is done through manual walking surveys. Data collected include rut depth, load cracking, reflection cracking, block cracking, bleeding, corrugations and loss of section. GDOT makes use of the Georgia Pavement Management system (GPAM) to report information to management level staff. The rating index is based on a 0 to 100 scale with a threshold level of 70.

Minnesota

Mn/DOT uses a Pavement Quality Index (PQI) for condition rating. The PQI is made up of Surface Rating and Ride Quality Index (RQI). RQI is based on a 0.0-5.0 scale while SR is on a 0.0-4.0 scale. The PQI is also based on a 0.0-4.5 scale. It is calculated as:

$$PQI = \sqrt{SR * RQI} \quad (11)$$

RQI is obtained using a correlation between IRI measurements and the perception of roughness by a rating panel. IRI is converted to PQI using expressions that depend on the type of pavement. See (12) and (13).

$$RQI = 5.697 - 0.264(IRI^{0.5}) \quad (12)$$

$$RQI = 6.634 - 0.353(IRI^{0.5}) \quad (13)$$

where IRI is in in/mile.

In order to determine SR, pavement images taken by the DIV are analyzed at a workstation by two engineers. Some of the defects considered are Transverse, longitudinal, alligator, multiple cracking, longitudinal joint distress, longitudinal and transverse joint spalling, D-cracking, faulted, cracked, broken, patched and overlaid panels. Rating is done on the first 500 ft of sections which represents 10% of a typical section. The percentage of each distress is then weighted and summed to obtain the total weighted distress (TWD). The SR can then be calculated from the TWD as shown in (14)

$$SR = e^{(1.386 - 0.045(TWD))} \quad (14)$$

Texas

Texas Department of Transportation (TxDOT) collects data annually using a combination of manual and automated survey techniques. Ride quality data such as IRI and rutting are collected using specialized vans while distress data is collected primarily using manual windshield surveys. Work is being carried out to transition to a fully-automated method. Data collected include IRI, ride quality, texture, deflection, patching, rutting, raveling, average crack spacing and apparent joint spacing. Condition indexes used are the distress score (DS) and the condition score (CS) [xviii]. The rating scores are obtained from utility functions using (15) and (16) below.

$$DS = 100 \times \prod_{i=1}^{k} U_i \quad (15)$$

$$CS = U_{ride} \times DS \quad (16)$$

whereU_i is the utility value for distress type i

DS is the distress score

CS is the condition score

$U_i$is the utility value obtained from (12) below

$$U_i = \begin{cases} 1.0 \; when \; d_i = 0 \\ 1 - \alpha e^{-\left(\frac{\rho}{d_i}\right)^{\beta}} \; when \; d_i > 0 \end{cases} \tag{17}$$

d_i is the density of the distress in the pavement section and α, β and ρ are maximum loss factor, slope factor and prolongation factor that control the shape of the utility curve. These coefficients depend on the type of pavement.

Figure 12 shows a typical utility curve.

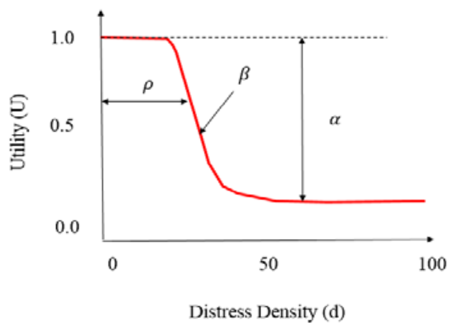

Figure 12: Typical utility curve

Virginia

VDOT outsources its data collection to Fugro-Roadware[xii].Data collection is fully automated using the Automatic Road Analyzer (ARAN) van with an annual collection frequency for the Interstate system, primary system. The secondary system data is collected on a 5-year cycle. Data collected include alligator cracking, longitudinal cracking, transverse cracking, patching, bleeding, rutting, and delamination. For QC/QA, a third party consultant known as Quality Engineering Solutions (QES) reviews results from the control sites. QA is done by Fugro-Roadware, QES and VDOT.

West Virginia

West Virginia Department of Transportation (WVDOT) collects IRI and rutting, faulting and cracking data. Collection of data follows a 1-year cycle. WVDOT's QC/QA is based on field surveys. 1% of the data is selected for auditing using a 3-5% tolerance level for discrepancies. Data collection is outsourced by WVDOT.

Vermont

Vermont Agency of Transportation (VTran) outsources data collection. It collects IRI, rutting, wheelpath cracking, transverse and non-wheel path cracking data. The process is fully automated and is performed every two years using a summary index.This index is reported to management with the percentage of roads in very poor conditions. The data from the consultants are verified on selected field sections.

North Carolina

North Carolina Department of Transportation (NCDOT) requires information on IRI, rutting, alligator cracks, raveling, transverse cracks, bleeding, patching, oxidation, longitudinal cracking, punchouts, corner breaks, Y cracks, spalling, joint seal, faulting, and skid resistance. Data collection is occasionally outsourced. Data collection is done through manual walking surveys and manual windshield surveys. The condition rating index used is based on a 0-100 scale. The collection takes place only in dry weather. The Interstate system is monitored during the spring and summer seasons while primary and secondary roads are monitored during winter and spring seasons.

South Dakota

The South Dakota Department of Transportation (SDDOT) collects data annually without any form of outsourcing. SDDOT uses a combination of automated and manual data collection methods. Data collected include IRI, rutting, cracking, patch deterioration, faulting, spalling, joint seal damage and punchouts. The Pavement Management Unit of SDDOT provides repair needs maps and project analysis reports. The index used for the condition survey is the surface condition index (SCI). It is a 0 to 5 scale with 5 representing ideal pavement conditions. The SCI is calculated as follows:

$$SCI = \mu - 1.25\sigma \quad (18)$$

$\mu$is the mean of all individual distress indexes and σ is the standard deviation of the individual distress indexes. The individual distress is calculated as:

$$I_i = 5 - D_i \quad (19)$$

Where I_i is the index value for distress I and D_i is the deduct value for distress i. The deduct value is based on its extent and severity.

4.0 EVALUATION

In this chapter, the various aspects of condition ratings will be evaluated. Comparisons will be made based on the methods and types of equipment used for data collection. The data collection and QC procedures used in the various states will also be compared with each other.

4.1 Network & Project Level Data Collection

As stated earlier, the type of data collected at the network level differs from that collected at the project level. Usually the project level data is more detailed as compared to the network level. Both types of data are used for decision-making but the project level data can also be used for refining network level management system treatment recommendations [xv]. Table 19 compares network level and project level data collection.

Generally, network level data and modeling are used for activity planning and prioritization. On the other hand, project level data and modeling are used for establishing specific intervention and corrective actions.

Table 19: Comparison of Network Level and Project Level Data Collection

	Network Level	**Project Level**
Data Collected	1. IRI 2. Rutting 3. Faulting 4. Cracking 5. Joint Condition 6. Bridges 7. Road signals 8. Geometrics 9. Events (Construction) 10. GPS coordinates	1. Base soils characterization 2. Structural Capacity 3. Joint load transfer 4. Detailed crack mapping 5. Drainage conditions 6. Signs and guard rails data 7. Geometrics
Collection Method	Usually automated	Manual and automated
Uses	1. Budgeting 2. Planning repair and rehab activities 3. Prioritization of projects 4. Mechanistic-Empirical Pavement Design Guide (MEPDG) Calibration 5. Forecast of future network conditions	1. Refining pavement management treatment recommendations 2. MEPDG calibration 3. Assessing benefits of alternatives 4. Assessing causes of deterioration

4.2 Manual & Automated Data Collection

Manual data collection involves walking surveys or windshield surveys where qualified inspectors identify the distresses present and rate the pavements. Data is recorded on paper and it may be analyzed either on paper or with a computer after being transcribed into a database. Nowadays, data can be entered directly onto handheld devices during manual inspections.

Automated surveys are mainly carried out with specialized vans equipped with lasers and high resolution cameras. These are used in acquiring images and videos. There are semi-automated and fully-automated methods depending on how the acquired data is processed and analyzed. In semi-automated methods, the acquired images are analyzed by personnel who go through them to identify the distresses. In fully-automated methods, pattern recognition software is used to classify and rate pavement distresses.

In recent times, most states are adopting automated data collection methods. This transition may sometimes result in data inconsistency issues. Other states may rather avoid the automated methods due to the high initial costs involved. Studies conducted in 2004 and updated in 2008 show that among the 50 states, Puerto Rico, 11 Canadian provinces and the Eastern Federal lands, 44 out of 65 use automated pavement collection. Table 20 is a summary of the findings.

Table 20 Summary of Pavement condition data collection methods [xv]

	Method	**Number of agencies**		
		Agencies	Vendors	Total
Collection	Automated	23	21	44
	Manual	19	2	21
Processing	Fully-Automated	7	7	14
	Semi-automated	16	14	30

4.3 Types of Data Collected & Frequency

State agencies nationwide collect different types of data during condition surveys. Table 21 below summarizes the types of data collected and frequencies for some of the state agencies.This may depend on the agency's definition for the various forms of deterioration and distresses, climate, data collection technology and the type of pavement under consideration. Generally, pavement data collection is done annually for most states. The frequency of data collection is mainly influenced by the agency's finances.

DOTs may specify different types of cracks depending on the types of distresses that are prevalent in that area. Some Agencies may outsource data collection due to financial constraints. However, other agencies strongly argue that data collection be done in-house to ensure better data quality management. Outsourcing is advantageous where contractors have advanced equipment to collect data efficiently.

Table 21: Data Collected by state agencies and Frequency of Collection

State	Data Collected	Data Collector	Frequency
Arizona (ADOT)	IRI, rutting, cracking*, friction, flushing	Outsourced	3 years
Arkansas (AHDT)	IRI, rutting, faulting, cracking*, raveling	In-house	Interstate-1 year Other roads-2 years
Colorado (CDOT)	IRI, rutting, cracking*, corner breaks	Outsourced	1 year
Delaware (DelDOT)	Patch deterioration, joint seals, bleeding, cracking*	Outsourced	2 years
Georgia (GDOT)	Rut depth, cracking*, edge distress, bleeding, corrugations, loss of section	In-house	1 year
Illinois (IDOT)	IRI, rutting, surface distress	In-house	Interstate-1 year Other roads-2 years
Indiana (INDOT)	IRI, rut, cracking*, faulting	Outsourced	Interstate-1 year Others-2 years
Kansas (KDOT)	IRI, rutting, cracking*, joint distress	In-house	1 year
Maryland (MDOT)	IRI, rutting, cracking*, friction	In-house	1 year
Michigan (MDOT)	IRI, rutting, cracking*, popouts, raveling, delaminated areas	Outsourcing	2 years
New York (NYSDOT)	IRI, rutting, faulting	In-house	Interstate-1 year Others-2 years
Oklahoma (ODOT)	IRI, rutting, cracking*, patching, faulting, corner breaks, punchouts	Outsourced	2 years
Pennsylvania (PENNDOT)	IRI, rut, cracking*, patching, edge deterioration, joint spalling	Outsourced	1 year
Texas (TxDOT)	IRI, ride quality, texture deflection, rut, patching, cracks*, raveling	Outsources manual data collection	1 year
New Jersey (NJDOT)	IRI, rutting, cracking*, shoulder condition, shoulder drop, faults,	State highway-In-house County, municipal-outsourced	2 years

	longitudinal and transverse joints		

*- refers to different forms of cracks that occur in pavements.

4.2 Consistency in Pavement Distress Ratings

The issue of consistency in distress rating is a major one in pavement condition management. Despite recent advancements in imagery technology and video capture, there is still lack of consistency in distress ratings since the technologies for identifying and determining extent and severity of distresses are not fully developed. Distress ratings are usually summarized using pavement condition indices. Pavement condition indices are a combination of distress rating and ride quality.

The focus is on distress ratings because subjectivity in measuring ride quality has been eliminated to a large extent. Ride quality is expressed mainly in terms of the IRI measurements obtained from various road profilers available on the market.

Pavement distress manifestations are visible pavement surface deterioration resulting from traffic loading and environmental factors over a period of time [xvi]. Ratings are assigned to distresses through visual inspection guided by a rating manual. Usually, there is some amount of random and or bias error. Errors are high when the severities and extents of distresses are not well defined and as a result leading to confusion on the part of the rater. There is also a high degree of errors when there are too many points on the distress and severity scales which leads to further confusion. Studies have been conducted over the years to address the accuracy and precision of pavement condition indices[xvi].

The diagrams below in figure 13 help in differentiating between precision and accuracy which is confusing at times.

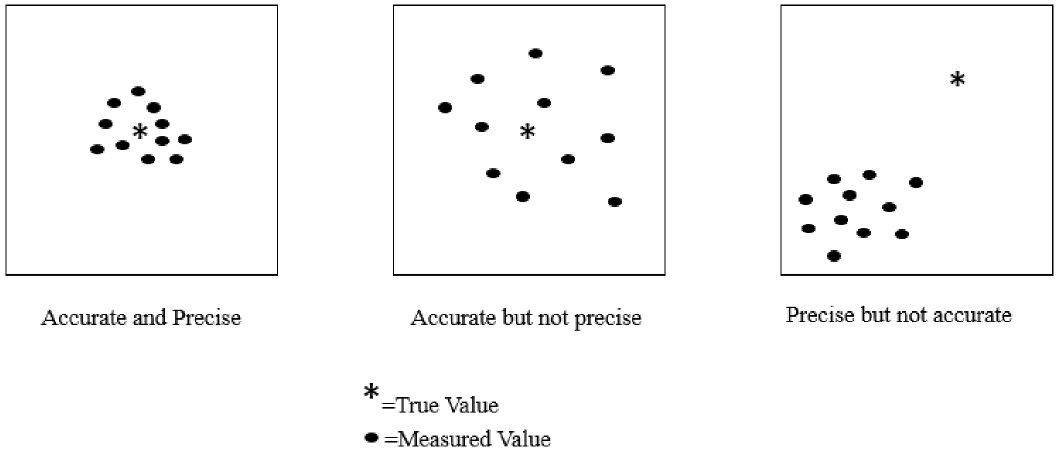

Figure 13: Accuracy and Precision

For accurate and precise measurements, the measured values are closer to the true value and the variances between the measured values are minimal. For accurate but not precise measurements, the measured values are closer to the true value but have larger variances between them. Lastly, precise but not accurate measurements have minimal variances between them but differs largely from the true value. Efforts have been made to improve the accuracy and precision of distress ratings.

In transportation agencies nationwide, these efforts can be part of the quality control protocol. Statistical analyses are made on condition ratings on calibration sites. The analyses involves t-tests and analysis of variance (ANOVA). The ratings from a group of raters with diverse levels of experience are compared to that of experienced raters whose results serve as the reference. The statistical analysis will determine whether the measurements are consistent or whether there is the need for modifications to the rating system.In the study conducted by the Ministry of Transportation of Ontario in Canada[xvi], various sources of variation and inconsistency were identified. It was observed that there was greater consistency in ratings when the points on the distress severity and density scales were reduced. It was also observed that variability among raters was high with certain types of distresses. Thus, the need to clearly define distress types as stated earlier.

Also, control sites can be used for data verification to address the issue of inconsistency. These sample sites are carefully selected to ensure that they represent the population or entire network fully. Usually, 2-10% of the entire network is used. However, the expression below in (20) can be used to determine sample size.

$$n = \left(\frac{Z_{\sigma/2}\sigma}{E}\right)^2 \quad (20)$$

where n= sample size

$Z_{\sigma/2}$= standard normal distribution

= 1.960 (α = .05)

= 1.645 (α= .10)

E= tolerable bias

σ= standard deviation of population

4.5 Differences among Pavement Condition Indexes

Most pavement condition indexes are based on a 0 to 100 scale. Despite this fact, pavement condition indexes differ inherently and so comparing indexes from different jurisdictions may produce misleading results. Studies conducted by Texas Department of Transportation and Federal Highway Administration [xv] used t-tests and scatter plots to establish this fact. The study involved the use of selected pavement condition indexes on 9642 pavement sections. The selected indexes were the TxDOT's Distress Score and Condition Score (CS), Oregon DOT's Overall Index (OI), Minnesota DOT's Surface Rating (SR) and Ohio DOT's Pavement Condition Rating (PCR).The t-tests showed that the mean of the measurements when using different indexes were significantly different when compared. The disagreements between different indexes are due to several reasons.

Firstly, the disagreements are the result of DOTs having different methods of measuring distresses. For example, the OI uses average rut depth while the DS uses the percentage area in addition to the severity.

Secondly, the differences are as a result of different weighting factors and mathematical expressions used to define the condition of the pavements.

Last but not least, the disagreements observed may be indirectly linked to varying agency policies and climatic conditions. These in turn have an influence on the type of data collected which will eventually affect the condition rating of the pavement section.

5.0 CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusion

Pavement condition surveys are very important in pavement management. This is evident in the fact that it is performed annually by more than 50% of the state DOTs. Condition surveys inform management of the actions that need to be taken in order to ensure effective and efficient use of resources. Due to the level of importance that is associated with the surveys, engineers and management usually plan these activities in detail. Condition surveys have three main aspects which are considered namely; data collection, condition rating and quality management.

Data collection is a crucial aspect of condition surveys since the information communicated to management as to which actions they are required to take are based on it. Thus, the right equipment and labor with the requisite skills must be employed here. Currently, data collection is more automated. As a result, it is the agency's responsibility to use equipment that will meet its needs while taking into consideration its budget constraints. Data collection is outsourced by some DOTs. This may help cut down costs to an extent but may make quality control difficult. Agencies whose data collection is done in-house can monitor the collection process and perform quality control with relative ease. A greater proportion of DOTs using automated data collection methods use specialized vans such as ARAN vehicle to acquire pavement images, video and other forms of data. The data that is collected is usually categorized into four groups namely; ride quality, structural capacity, distress and skid resistance data.

Condition ratings refer to numerical representations or description of the condition of pavement sections and or entire networks. The choice of condition rating by a state DOT must be able to address the data collected by that particular agency. Most importantly, the agency's personnel must have an understanding of how the rating system works in order to use it effectively. In recent times, there has been a shift from the PSR to condition rating systems that are backed my mathematical relations between physical measurements. The condition rating indexes are divided into two main groups namely estimated and calculated condition ratings. A typical example of the estimated rating is the Pavement Surface Rating (PSR). Examples of the measured rating indexes in use are the Overall Pavement Condition (OPC) from Delaware DOT, Surface Rating (SR) from Minnesota DOT, Oregon DOT's Overall Index (OI) and Tennessee DOT's Pavement Distress Index (PDI). Most of the condition rating indexes that are being used by DOTs in the US are based on the deduct value approach. These have the ability to capture the effect of the type, extent and severity of distresses and roughness on the condition of the pavement section. Interestingly, these condition ratings are inherently different despite the fact that some of them may have similar scales such as 0-100 or 1-100 according to statistical analyses.

Quality Management is performed at all stages in pavement condition surveys to ensure the accurate information is given to management. Quality control (QC) refers to all activities performed to ensure that the equipment and processes involved in data collection are in control which will in turn ensure that high quality results are obtained. Quality assurance (QA) is a term that refers to all activities conducted to verify that the collected pavement condition data meet the quality requirements and specifications. Some state agencies employ the AASHTO guidelines as the basis for QC/QA procedures while others may have their own detailed procedures. As part of quality management, responsibilities of personnel must be stated and corrective actions such as rating or calibration must be done again when necessary. Most importantly, all quality management activities that are undertaken must be documented. This is done in order to optimize pavement management. Quality management reports must include key personnel carrying out specific tasks, initial and continuing calibration, copies of correspondences, detailed description of quality standards, analyses of verification site tests results and recommendations for improvements of the entire process.

5.2 Recommendations

It is recommended that all agencies have detailed quality control and quality assurance programs to ensure integrity of data. Quality control programs that are already in existence must also be reviewed at regular intervals since pavement condition survey is constantly evolving. Automated equipment used in data collection must also be calibrated and monitored constantly to avoid compromising the quality of the data. Agencies must also choose condition rating indexes that address issues that are relevant in their jurisdiction rather than using indexes because they are widely used by several other agencies.

Tolerance limits for data collection must also be reviewed periodically. This can be done using simple statistical tools and methods such as paired t-tests. In the case of different vendors rating in the same manner, the data can be analyzed in a time series format together with agency's data such that differences in the data are clearly visible. Lastly, all quality management procedures must be documented to ensure future optimization and enhancement of pavement management.

REFERENCES

[i] Pavement interactive. *Pavement Condition Rating Systems*. PAVIA Systems, www.pavementinteractive.org/article/pavement-condition-rating-systems/

[ii] Nakamura, V.F., and H.L. Michael. *Serviceability Ratings of Highway Pavements: Technical Paper*. Publication FHWA/IN/JHRP-62/18.Joint Highway Research Project, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 1962.Doi: 10.5703/1288284313612

[iii] Timm, D.H., McQueen, J.M. *A Study of Manual vs. Automated Pavement Condition Surveys.* Alabama Department of Transportation, Montgomery, AL, Highway Research Center, Auburn University, Alabama 36849-5337, April 2004

[iv] Pavement Condition Surveys, Module 5, http://www.cee.mtu.edu/~balkire/CE5403/Lec%204A.pdf, date accessed: 12:05 pm, June 17, 2013.

[v] PASCO Corporation, http://www.pasco.co.jp/eng/products/real/, Date accessed: June 14, 2013, 11:01am

[vi] Source: Spar Point Group, "FugroRoadware lands two-year, $3m mobile data collection contract" http://www.sparpointgroup.com/uploadedImages/Images/08.22.11.ARAN.png?maxwidth=800&maxheight=600&bgcolor=white ,Date accessed: June 14, 2013, 11:20am

[vii] Illinois Center for Transportation, Civil Engineering Studies, Implementing Pavement Management Systems for Local Agencies- State-of-the-Art/ State-of-the-Practice, Research Report ICT-11-094, UILU-ENG-2011-2020, ISSN: 0197-9191, December 2011

[viii] US Department of Transportation, Federal Highway Administration, Performance Evaluation of Various Rehabilitation and Preservation Treatments, FHWA-HIF-10-020, January 2010

[ix] Rafiah R., Advanced Pavement Management System Implementation for the Nigerian Federal Road Network, 7th International Conference on Managing Pavement Assets, 2008

[x] Ong, G., S. Noureldin, and K. C. Sinha. *Automated Pavement Condition Data Collection Quality Control, Quality Assurance, and Reliability*.Publication FHWA/IN/JTRP-2009/17.Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2010.doi: 10.5703/1288284314288.

[xi] Perera, R.W., Kohn S.D. *Profiling Errors and How to Avoid Them.* Paper Submitted for Pavement Evaluation 2002. http://pms.nevadadot.com/2002presentations/25.pdf, Date Accessed:June 19, 2013, 2:30pm

[xii] VDOT Pavement Management Program, presented at Local Government Workgroup Meeting on January 10th 2012, http://www.virginiadot.org/business/resources/local_assistance/Microsoft_PowerPoint_-_Local_Assistance_TC.pdf, Date accessed: June 20, 2013, 3:30pm

[xiii] Oregon State University Class Module. *Skid Resistance.*http://classes.engr.oregonstate.edu/cce/winter2012/ce492/Modules/09_pavement_evaluation/09-4_body.htm , Date accessed: June 21st, 2013, 2:30pm

[xiv] Oregon State University Class Module. *Surface Distress.*http://classes.engr.oregonstate.edu/cce/winter2012/ce492/Modules/09_pavement_evaluation/09-3_body.htm, Date accessed: June 21st, 2013, 2:50pm

[xv] Pierce, L.M., McGovern G., Zimmerman, K.A. *Practical Guide for Quality Management of Pavement Condition Data Collection.* US Department of Transportation, Federal Highway Administration, February 2013.

[xvi] Ponniah, J., Sharma, B.N., Kazmierowski T.J.*A Critical Review of an Existing Pavement Condition Rating System.*5th International Conference on Managing Pavements. Pavements and Foundations Section, Ministry of Transportation, Ontario, August 2001

[xvii] Pavement Condition Indices, Module 6. http://www.cee.mtu.edu/~balkire/CE5403/Lec12.pdf, Date Accessed: July 1, 2013, 11:56 am

[xviii] Gharaibeh, N.G., Zou, Y. *Assessing the Agreement among Pavement Condition Indexes.* Journal of Transportation Engineering, ASCE, August 2010, DOI: 10.1061/(ASCE)TE.1943-5436.0000141

[ixx] Janisch, D., Pavement Management Engineer. *An Overview of Mn/DOT's Pavement Condition Rating Procedures and Indices.*May 2006. http://www.dot.state.mn.us/materials/pvmtmgmtdocs/Rating_Overview_State.pdf, Date accessed: 7/11/2013, 12:27pm

[xx] Zheng, Q., Racca, D.P., *Support of Pavement Management Systems at the Delaware Department of Transportation.* Delaware Transportation Institute, Delaware Department of Transportation, Center for Applied Demography and Survey Research, College of Resources, Education and Public Policy, Newark, DE 19716, December 1999

[xxi] Prozzi, J.A., Madanat, S.M. *Development of Pavement Performance Models by Combining Experimental and Field Data.* Journal of Infrastructure Systems. Vol. 10, No. 1. ASCE, ISSN 1076-0342/2004/1-9-22. March 2004

[xxii] LTPP Manual for Profile Measurements and Processing, Chapter 4 Profile Measurements using the Rod and Level.
http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/08056/chapt4.cfm,
Date accessed: July 20, 2013, 3:00pm

[xxiii] LTPP Manual for Profile Measurements and Processing, Chapter 3: Profile Measurements Using the Face Dipstick.
http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/08056/chapt3.cfm

[xxiv] Iowa Dept. of Transportation, Office of Materials. *Method of Test Determining Pavement Profiles with the 25-foot Profilographs.*Matls. IM3H. April 2003

Delaware Center for Transportation University of Delaware Newark, Delaware 19716