CHAPTER ONE

Introduction

Pavement distresses are visible imperfections on pavement surface. They are symptoms of the deterioration of pavement structures. Most, if not all, agencies that have implemented a Pavement Maintenance Management System (PMMS) collect periodic surface distress information on their pavements through distress surveys. Distress evaluation, or condition survey, includes detailed identification of pavement distress type, severity, extent, and location. To combine these details, an index is assigned to each pavement which is transferred to a general rating. Every highway agency either develops pavement distress evaluation procedure or selects a developed one for its pavement condition survey. Regardless of the size of the highway network or the sophistication of the PMS procedure, most PMS strategies can offer assistance at two levels: the network level and the project level. Network level information provides management with broad-based data about the entire system. Information for planning purposes and fiscal analysis is often provided by the network data. On the other hand, project level information can include specific details about engineering design, construction and cost accounting. Obviously the data required for each level differs considerably. Network level required disaggregate data that reflects the general pavement condition. However, project level needs detailed and specific data on expected distresses.

In general, distress density starts its propagation process very slowly, but it accelerates more at a later stage. There are factors that affect rate of propagation. These factors may include pavement condition, traffic levels and distress severity. The distress density propagation on a new or recently overlaid pavement sections having excellent condition is expected to be slower than on pavement sections with poor condition. A distress is expected to behave differently on pavement sections subjected to different traffic levels. Also, the distress severity levels have an effect on behavior and propagation of distress density. The Pavement Maintenance Management System (PMMS) of Khartoum city perform comprehensive pavement visual survey prior to each maintenance program . In the condition survey, detailed information related to type, severity and density of existing distresses was collected.

The collected data was then used to determine needed maintenance activities on a project level. This process is usually very expensive and time consuming.

Pavement Maintenance Management System (PMMS) provides systematic objective and consistent procedure to evaluate existing and future pavement condition.

A PMMS also provides a mean to help mange pavement maintenance expenditure more economically and efficiently. They provide a

A PMMS also provides a mean to help mange pavement maintenance expenditure more economically and efficiently. They provide an objective approach to pavement maintenance and allow for multiple budget options and scenarios to be run quickly and assist in project formulation for maintenance and rehabilitation works. A PMMS typically uses a pavement rating system, called pavement condition index (PCI) as the basis from which current and future pavement condition. Within the process of implementing a PMMS there are two distinct areas which need to be examined. The first is defining the PMMS to be adopted and the second is implementation of the PMMS on a pavement network basis.

PMMS in Khartoum State : Centre of Khartoum, has applied Distinctive pavement management maintenance system which was depend on roughness measurement, visual surveying of the pavement condition and skid resistance and dynamic cone penetrometer to assesses the state of the pavement. The assessment of pavement situation before implementing any program of rehabilitation and repairing. The assessment procedure concentrated on realizing the type , density and the severity of pavement distresses. An index for pavement condition were utilized to represent the data which is called index of urban distress in which is composed of fifteen kinds of pavement distresses existed in the pavement maintenance management system of Khartoum State in addition to that fact urban distress index is considered is as a numerical leveling method for different distresses and this rating procedure is depending on the numerical index ranging from 0-100, where 100 symbolize excellent condition of pavements. The measurement of urban distress index depends on the kind of distresses, density and distress severity for each network level and project.

1.1 Objective

The main objective of this study is to implement a system to monitorroad maintenance expenditure of the urban road for Khartoum State network and to proposeframework policyof Khartoum roads.

1.2 Scope of work

The above objective can be detailed into the required scope of work items which contributed in making better decision with respect to expenditures of pavement maintenance and rehabilitation in Khartoum State. These items were identified and evaluated and are follows:

- Assessment of road classification and adopting numbering system for Khartoum State (centre of Khartoum) paved road network.
- Carrying out road inventory survey.
- Undertake visual condition survey for paved road network.

1.3 Methodology

Firstly all distress types, severities and density in Khartoum State paved road were identified using up to date and state of the art pavement condition index method selected and customized as one main scope of the research. This study was carried out as part of a comprehensive road inventory study which will divide the road network into group each one consists of 15 km, then the collected data.

The final result of pavement condition survey, and selection of maintenance standards for paved roads in Khartoum State

Finally adopting of the suitable PMS for Khartoum State

1.4 Study Outcomes

- Identification of treatment selection for each road.
- PCI rating for some of the street located at urban centre.
- Propose of PMS policy framework for Khartoum State.
- The recommendation for the application of the PCI in Khartoum State.

1.5 Outlines of the thesis

The thesis was divided into seven chapters. The first chapter is an introduction and the last chapter is conclusion and recommendationsthe others chapter from two to Seven were briefly described below.

In chapter two pavement management literature review, pavement management system is composed of two levels project and network level, the purpose is to provided, cost effective, original design,, maintenance, rehabilitation and reconstruction.

In this chapter describes the importance management, data in providing for management decision in assessing limit level for road condition.

Chapter three explains the pavement condition rating study, and methodologies used. The detailed explanation of the ASTM and the adopted methodology is given, including the road numbering and identification system, tools needed to carry out the study, types of distresses, method of their management and analysis and scale of surface rating. The chapter represents all the study results including, pavement distresses quantity, density and severity.

The findings of this study are:

24,5 % of the road length (7.4 km) subjected to visual condition evaluation is condition is "Fair" condition.

31.7% of road length (9.5 km) is in" good" condition.

25.0% of the road length (7.5 km) is in "Very good" condition.

18.2 % of road length is (5.65 km) is in excellent condition to very good condition.

In chapter Four discuss structural evaluation of pavement of roads in Khartoum State,like Dynamic Cone Penetrometer(DCP),Pit test and Non- Destructive test (NDT)Roughness,Skid resistance and level of service

DCP tests are particularly useful for identifying the cause of road deterioration when it is associated with the one of the unbound pavementlayer eg, shear failure of the road base or sub base. A comparison betweenDCP test results from subsection that are failing and those that are sound will quickly identify the pavement layer which is cause of the problem. In this chapter also skid resistant including the factor affecting it and correlation between PCI and skid number (SN) is discussed.Finally in this chapter the level of service is estimated Using HCS software which is valid procedure to estimate the level of service (LOS), for Khartoum urban center streets. According to the procedure shown in appendix D the data in table 4.9 is entered to the software, analyzed and the results were obtained for each road including report.

Chapter Five overview pavement management system order to select some items for the implementation of pavement management system in Khartoum State , detailed in this chapter . How to implement pavement management system and how to apply this system, including , barriers , institutional issues. Constrain and system design or selection

And in chapter Six types of maintenance will be with recommendation for urban Khartoum State Network according to practice. This types of maintenance including, preventive, corrective maintenance, crack sealing, thin overlay, chip sealing, Fog sealing and slurry sealing. ,

Chapter Six focus that quantitative the performance of various preventive maintenance treatments, including the effect of these treatments have on pavement performance. Preventive measures examined in this thesis.Include Crack sealing

Thin overlays, chip sealing, fog sealing and slurry sealing. To the extent possible, this synthesis identifies the adequacy of the existing data and methodologies in terms of. Establishing appropriate preventive maintenance treatments, evaluating the effectiveness of these treatments and examine the reported life.

Chapter Seven described conclusions and recommendations

The references list is shown after Chapter Seven and before the Appendices. The reference list is organized according to the appearance of references in the text, in alphabetical order.

CHAPTER TWO

Pavement Management Overview

2.1 GENERAL

Pavement management and pavement management systems (PMS) have been defined several ways, but the AASHTO has published two definitions that are very similar: “The Federal Highway Administration has defined a PMS as ‘a set of tools or methods that can assist decision-makers in finding cost-effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition.”’(AASHTO 1990)

“A pavement management system (PMS) is a set of tools or method that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time. “(AASHTO 1993) The Organization for Economic Cooperation and Development (OECD) used the following definition:“Pavement maintenance management is the process of coordinating and controlling a comprehensive set of activities in order to maintain pavements, so as to make the best possible use of resources available, i.e., maximize the benefits for society.” (OECD 1987) There is a key difference between pavement management and pavement management system (PMS) . Pavement management is a management approach used by personnel in an agency to make decision, hopefully cost-effective decision as identified in one of the definitions above. A PMS is a set of tools used to assist decision-makers at all levels in making better and more informed decision. For the state-level person involved in day-to-day pavement management activities, these two may be synonymous. However, senior management personnel who are involved in pavement management activities often will not be directly involved with the details of PMS.

2.2. Importance of Pavements

State, local, and federal agencies have spent billions of dollars construction the current system of over 45,000 miles of interstate highways, over 111,000 miles of other national highway system (NHS) roads, and over 3,700,000 other roads and streets in United State. Over $87 billion were spent on highways, roads, and streets in the United States in 1993 (U.S.DOT 1997b). It is estimates that approximately one half that amounts goes directly into pavement construction, maintenance, and rehabilitation. The private sector dedicates about 15 percent of its plant and equipment investments to transportation.The highway industry is not only a huge part of the public agency funding, it accounts for about 11 percent of the gross national product (GNP), and nearly 10 million people are employed in transportation related industries. Taxes paid by the transportation industry amount to 14 percent of all federal taxes and 23 percent of all state taxes (AASHTO 1988). The 1995 Travel Survey (U.S. DOT 1997a) showed the importance of highway transportation to the families living in the United States. About 100 million households took about 685 million long trips traveling about 827 billion miles. This is in addition to the normal daily travel that they complete on roads, streets, and highways to get work, school, shopping, worship, medical facilities, etc. All of this shows importance of the highways, roads, and streets to the United States. The amount of money spent on the roads in the United States is in fair, mediocre, or poor condition. The funds currently being spent on them is much less than most leaders say is needed, which indicates a need for spending the available funds effectively.

2.3 Importance of Pavement Management

Engineers often hear questions such as: “why are you always working on the roads?” Those who work with pavements know that as soon as a pavement is built it starts to deteriorate. After some period of time, work is required to keep the pavement in a serviceable condition.

The old colloquial saying of “pay me now, or pay me later” applies to the life of pavements. Figure 2.1 shows a typical pavement deterioration rate with relative costs needed to maintain, or return, the pavement in a serviceable condition. It is evident from figure 2.1 that even when the earlier treatments must be applied more often, the overall costs will be less if the pavements are repaired earlier than later. There are a number of assumptions in this analysis; the most important being that the pavement is structurally adequate allowing the less expensive treatments to be effective. Analysis indicates that it costs the maintaining agency less to have good roads than bad roads, assuming that the roads are kept at any reasonable level of serviceability over some reasonable analysis period (Peterson 1977). This conclusion is based on the assumption that the roads and streets will respond to preventive maintenance. Preventive maintenance is defined a treatments applied to prevent or reduce the rate of deterioration, and it is limited to treatments which have traditionally been considered maintenance such as surface seals and thin overlays.

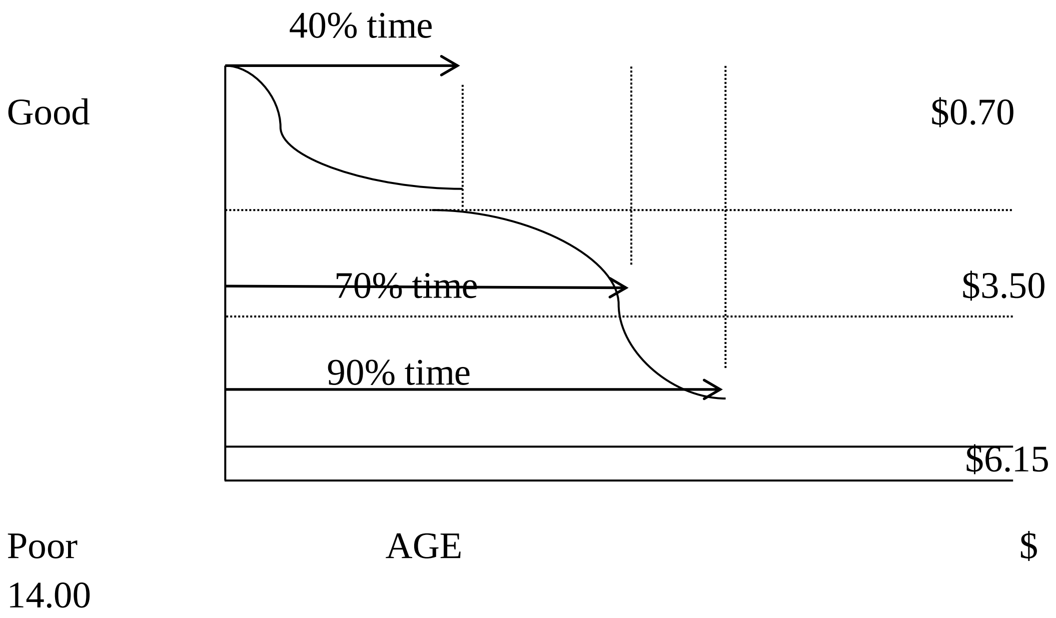

Figure 2.1. Effect of treatment timing on repair costs

which do little to change the structural capacity of the pavement. For preventive maintenance to be effective, roads and streets must be adequately designed to withstand traffic loadings initially. Preventive maintenance treatments applied to inadequately designed road surfaces may delay the required rehabilitation for a short period of time, but in the long run they will not be very cost-effective. Many agencies have highways, roads, and streets that carry traffic loads for which they were never designed, and these must be structurally improved before they will provide the desired performance. Several agencies have a backlog of maintenance and rehabilitation needs that must be corrected before they can fully adopt a preventive maintenance approach. These agencies must develop a program that works to improve those pavements in poor condition and those that are structurally inadequate while also trying to keep those pavements in good condition from deteriorating to the point where the less expensive treatments will not be effective. Pavement management practices provide a rational approach to assist in finding a cost-effective combination of treatments to apply at any given time to provide the level of service selected by the managing agency. Pavement management systems that evaluate various strategies use the expected impact of maintenance and rehabilitation treatments on the future performance of the pavements to identify those that need treatment and identify the mixture of preventive maintenance and rehabilitation that will provide the desired overall condition within imposed constraints. Pavement management systems provide a means to organize the massive amount of data that develops with a road and street network facilitating data storage, retrieval, and the complex calculations needed to identify cost-effective alternative quickly and efficiently. They also provides the information needed to support fund requests and justify maintenance and rehabilitation programs. Maintenance addressed in pavement management is primarily programmed or planed maintenance such as surface seals and crack seals. Pavement management systems normally do not try to predict where a pothole will appear nor the frequency of routine maintenance activities such as pothole filling, temporary repairs, etc. However, information from pavement management systems indicating deferred rehabilitation work provides information to maintenance personnel on which segments are likely to have significant maintenance needs. Maintenance management systems normally address routine, emergency, and other unprogrammed maintenance work requirements. Some programmed maintenance activities such as surface seals may be controlled and the work managed through a maintenance management system, but the location and timing of the programmed maintenance treatments should be determined based on the pavement management system so that the pavement management system addresses the entire pavement preservation program. The maintenance management systems should interface with the pavement management system so that each system knows of the work completed and programmed by the other.

2.4. Pavement Management Level

Pavement management is generally described, developed, and used in two levels-network level and project level (AASHTO 1990). These two levels differ in both management application and data collected. However, the cost of data collection has normally forced a distinct separation between the two levels (FHWA 1995).There are several difference between network-level and project level management processes (AASHTO 1990,Haas, Hudson, and Zaniewski 1994; Peterson 1987). Although the differences very among agencies depending on the size, organization, and other factors in the agencies, some or all of the following differences are generally found:

1. Goals or purposes of the decisions;

2. Groups or levels within the organization making the decision;

3. Number of groups, or individuals, who must develop and review the recommendation prior to submittal to the decision authority;

4. Number of management segments considered in the analysis; and

5. Detail of the data and information needed to support the decision.

The first four are of interest because they identify the decision support needed at each level, while data is needed to provide the information used to support those decisions.

2.4.1 Network Level Purposes

The purposes and goals of the network level management process are normally related to the budget process and include (FHWA 1995).

1- Identifying Pavement Maintenance, Reconstruction and rehabilitation needs.

2- Selecting feasible funding options and strategies to be tested.

3- Determining funds needed to adverse these needs.

4- Determining the impact of these funding options.

5- Developing a recommended funding options and funding strategies.

6- Selecting sections to be recommended for funding.

7- Funding options strategies.

2.4.2. Project-Level Purposes

At the project level, the purpose is to provide the most cost-effective, feasible, and original design, maintenance, rehabilitation, or reconstruction, strategy possible for a selected section of pavement within available funds and other constraints (Haas, Hudson, and Zaniewski 1994). This generally includes:

1. An assessment of the need for construction or cause of deterioration leading to the need for maintenance, reconstruction, or rehabilitation;

2. Identification of feasible design, maintenance, rehabilitation, and reconstruction strategies;

3. Analysis of the cost-effectiveness of the feasible alternative or treatments;

4. Definition of imposed constraints; and

5. Selection of the most cost-effective strategy within imposed constraints.

This generally provides support at the analysis and design levels, and the results are primarily used by technical users. Some agencies call this stage preliminary design, primarily because it does not include the final development of plans and specification. Depending on the detail of the analysis, it can include the complete alternative selection and design process. Although some authors include construction and quality control/quality assurance in project-level management, most pavement activities, as currently practiced, place those activities under different management systems related to construction.

2.5. Differences between Network and Project-Management Levels

In many agencies, different groups within the agency are responsible for the network-level and project-level management activities and decisions. Those who make the final network-level decisions are relatively high within the organization , and they generally have some level of authority in allocating the specific funds being managed. Even where decisions are decentralized, the senior district personnel with final authority for allocating funds make the final decisions. At project level the decision about which segment will be funded generally were already made. Engineering or maintenance staffs who must keep the final costs for the treatment within the funds previously established generally make treatment selection.

Before the network-level recommendations are submitted to the decision-makers, they often must be reviewed and approved by a series of individuals at different levels among the pavement management staff and the funding authorities. This review and approved process can be quite extensive in alarge agency, or it can be relatively informal in a small agency. In the project-level analysis, the group responsible for designing pavement maintenance or rehabilitation normally completes the work under a design supervisor with a technical background who makes the final decision about the specific treatment. In politically sensitive situations, this design may be reviewed by the senior engineering staff.

In network-level management activities, agencies can include all of the pavement segments under their jurisdictions; however, many agencies manage subset because of funding requirements. In many state highway agencies, specific funds are defined that can only be spent on selected groups of highways. Many agencies must group pavement segments into subsets such as the interstate highways, the farm-to-market roads, the pavements on the national highway system or the U.S. highways with asphalt concrete surfaces. The quantity of pavement considered in project-level analysis is normally single management section, which also often corresponds to an original construction section. However, in the analysis some management section may

be combined into a single project for contracting purposes, and other sections may be subdivided into more than one segment so that different treatments can be applied to individual portions of an original management or construction section.
Each purpose, decision level, and review level needs different amounts of information and detail in data. In general, as the purpose becomes broader, less detail is needed and more summarized information is used (FHWA1991). Information presented to funding authorities must be general.

Although few agencies discuss pavement management as having a research level, information from the pavement management process should influence the research program in several ways. Effective management requires a number of components including the ability to efficiently assess the condition of the pavements, to predict the future condition without treatment, to determine the benefits from applying treatments, to efficiently prioritize segments needing work, etc. When the PMS is deficient in any of those areas, then they are prime candidates for research to develop the procedure, tools, and techniques to remedy those deficiencies. The information in the database prepared for the PMS provides a source of information that can be used as the basis for research on such items as which treatment or what materials perform better in on situation compared to another. However, the data may not be complete enough to answer all of the questions, but the information can be used to develop a sampling design based on which additional data can be collected and analyzed to answer such questions.

Although the network-level pavement management elements provide information for senior management at the legislative and administrative levels, the senior management often wants to have the pavement information integrated with information from other management systems. In some agencies, this has been called an administrative management system. Recently, agencies have adopted Asset Management Concepts or Infrastructure Management Systems to assist with this strategic-level management, and later sections of this chapter discuss those topics.

2.5.1 Inventory

Information is needed as the basis of decisions supported with the PMS. The network-level inventory, or database of basic information, includes information on the pavements the agency is responsible for managing. It is impossible to manage the pavement network as a whole, and the agency must divide the network into management sections, or segments, to facilitate the management process. These management sections do not necessarily have to correspond to data collections sections. However, it is expected that they will generally be considered as single entities during the management process, and provisions must be made for sections to change over time. Some agencies are considering using dynamic segmentation techniques to define management sections, but most agencies use fixed management sections that must be adjusted when changes occur that require adjustments in section limits. The inventory generally includes information that defines the management sections and information about the location, limits, size, connectivity to other sections, and number of traffic lanes, route designations, and functional classification for each management section. This type of data is normally entered into the database once, and it is only changed when some significant change occurs in the data. Management sections generally have similar pavement layers, material types, past rehabilitation activities, past maintenance activities, and past traffic loading. This type of information is often stored in database for each individual management section. Since these can change over time but the previous information may influence later decisions, the data is often stored in history type files where the initial information is retained, and subsequent information is added over time providing a “history” of activities. Data should never be collected because “it would be nice to have the data” or because “ it might be useful someday . “Each data item collected requires time, effort, and money to collect, store, retrieve, and later use. Many agencies have found that it is more difficult to keep data current than it is to collect the data initially. Inaccurate or outdated data will reduce the credibility of any decision support based on that data. Data should only be collected when what data element is important to the agency in making pavement maintenance and rehabilitation decisions at the level it is to be used and when it cant be kept current (FHWA 1991). Different types, amounts, and accuracy levels can be used for network-and project-level analysis. Information not vital to the decision at hand should be avoided. The items generally included are selected to provide enough information to support effective management without burdening the agency with collecting an excessive amount of data.

2.5.2. Condition Assessment

Pavement condition assessment begins with collecting data to determine the type, amount, and severity of surface distress, structural integrity, ride quality, and skid resistance of the pavement. Pavement condition data are necessary to determine maintenance and rehabilitation needs, project future condition, and identify the impacts of treatments. They are also used to identify feasible maintenance and rehabilitation strategies, prioritize work, and help optimize maintenance and rehabilitation fund expenditures. Pavement condition is normally measured using the following factors (AASHTO 1990; Peterson 1987):

1. Surface Distress----damage to the pavement surface, distress survey are performed to determine the type, severity, and quantity of surface observable distress. This information is often used to determine a pavement condition index (PCI), which can be used to compute a rate of deterioration and is often used to project future condition. Surface distress and the current or future PCI values are often used to help identify the timing of maintenance and rehabilitation as well as the funds needs in the PMS process. Distress is the measure most used by maintenance personnel to determine the type and timing of needed maintenance.
2. Structural capacity-----the maximum load and number of repetitions a pavement can carry. Structural analysis is normally conducted to determine the current pavement load-carrying capacity that can be compared to the capacity needed to accommodate projected traffic. Non-destructive deflection testing of the pavement is a simple and reliable method to assist in making this evaluation; however, coring and component analysis techniques may be used as well.
3. Roughness (ride quality)----a measure of pavement surface distortion or an estimate of the ability of the pavement to provide a comfortable ride to the users. Roughness is often converted into an index such as the present serviceability index (PSI) or the international roughness index(IRI). Pavement roughness is considered the most important indicator of pavement condition by the using public and it especially important on pavements with higher speed limits, those above 70 kph (45 mph). it is also needed to calculate vehicle-operating costs.
4. Surface Friction or Skid Resistance----the ability of the pavement surface to provide sufficient friction to avoid skid-related safety problems, especially in wet weather. Skid resistance is of most important for pavements where vehicles operate at higher speeds. It is generally considered a separate measure of the condition of

the pavement surface, and it may be used to determine the need for remedial maintenance by itself to address safety.

The first two measures are generally considered measures of the engineering properties of the pavement while the last two are generally considered measures of the functional performance of the pavement. Other measures that may be used include the noise and water spray created by traffic. These pavement condition measures can be used to determine the overall pavement condition and to identify the most cost-effective and optimum maintenance and rehabilitation treatment. The pavement condition measures discussed above very in their degree of importance in terms of pavement performance and maintenance and rehabilitation needs. It is obvious that any treatments recommended to correct the structural load-carrying capacity of the pavement can take care of all other deficiencies that might be present, including roughness. Also, any treatment selected to correct pavement roughness can also be used to improve the surface skid resistance and correct any surface distress as well. Several methods can be used to collect each of the condition measures (Hicks and Mahoney 1981; Epps and Monismith 1986). Each method has advantages and disadvantages. In general, those procedures the require the least effort and cost the least are also accurate. Those that are most accurate and provide the most detail are also the most expensive and time consuming. The agency must carefully consider the type and level of decision being made along with the resources available to determine the measures that should be collected at each level and the best method to collect them. The measures to be collected and the collection methods are interconnected, because as less expensive, more rapid, non-destructive testing methods become available, more measures can be collected for the same expenditure of resources. Most state agencies collect at least distress and roughness at network level. Many state agencies also collect friction data, and a few collect deflection data at network level. Noise and spray information are not collected by most agencies in the United States at this time. In general, most agencies use less accurate methods for network-level analysis and more detail measures for project-level analysis. Data can be collected and stored for data collection sections that do not have a same limits as management sections, or data can be collected for each management section. As more high-speed data collection techniques are used, more agencies collect and store data by data collection sections that are later analyzed in relation to the management sections. Data analysis can prepare collected condition information in several different ways (Peterson 1987; Hicks and Mahoney 1981).

Some agencies use individual measures, including individual distress types, severities, and quantities, at network level. Other agencies combine distress information into single or multiple distress indexes such as cracking and pavement condition indexes. Other agencies combine several measures together into composite indexes such as the present serviceability index (PSI) and road condition index (RCI) (Haas, Hudson, and Zaniewski 1994). Combining data into indexes provides single numbers that can be used to compare the condition of one section of pavement to another. However, this comparison is based on the concepts incorporated into the particular index used. Some indexes are primarily oriented to how the traveling public views the pavement (e.g., PCI) while others are oriented primarily toward what engineers think should be done to the pavement (e.g., PCI). Those who use indexes must understand the basis of the indexes, and they should be only be used to represent the conditions upon which they are based. Specific PMS software programs often require the use of a particular set of measures. Changing those measures may require that the decision support algorithms in the software also be changed.

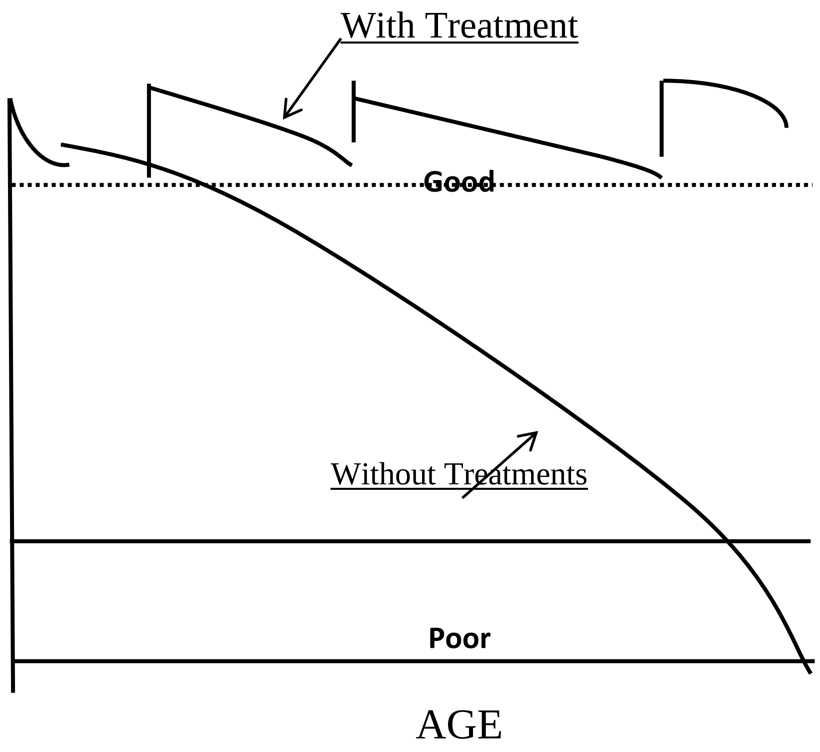

Figure 2.2.projected condition with and without treatment

Once the pavement network have been defined, basic information known, and the condition data has been collected, most agencies then want to know what work is needed and the resources needed to complete that work. This process should identify the work needed over some defined analysis period to support the level of service that the agency wants to provide to their highway users without respect to available funds. This provides a base value of needs that can be used to show the work and resources needed to meet the agency work. In general, this requires that the condition of individual management sections without maintenance or rehabilitation be projected to a common period and into the future in terms of individual distresses, PCI, PSI, or some combination index as illustrated in Figure 2.2 (FHWA 1991). The projected condition of all sections in the network can then be used to determine the overall condition of the network at any time with or without treatment. The projected condition without treatment gives a base condition of pavement sections being analyzed, or network as a whole, if no funds are spent. A common method used to identify sections that need work is to compare the condition of each management section during each year over the analysis period to established decision criteria (trigger values) that are normally based on condition, surface type, functional classification, and traffic loading (FHWA 1991). Figure 2.3 shows a condition index scale (0 to 100 where 0 is low) with four different network-level treatment categories, preventive maintenance, light rehabilitation, moderate rehabilitation, and heavy rehabilitation (or reconstruction). The dividing lines between preventive maintenance, light rehabilitation, preventive maintenance, light rehabilitation, moderate rehabilitation and between moderate rehabilitation/reconstruction would be the trigger values. When the condition of a pavement is projected to cross from one

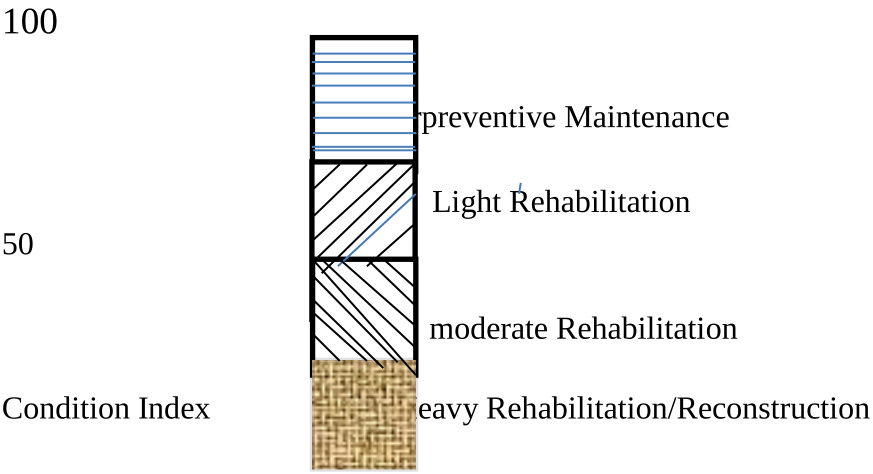

Figure 2.3 Trigger value examples

Level to another, a specific treatment is identified or triggered. For rural collector highways, those values might be 70, 50, and 25, respectively. If a segment of rural highway has a condition index projected to reach 70 in the analysis year, then that segment of pavement would be identified as needing a light rehabilitation in that year. For urban interstate highways, the break points or trigger values might be 80, 65, and 40, respectively. Different break points can be established for each functional classification or traffic grouping the agency uses in the management process. Normally different break points are also established for different types of pavements or pavements with significantly different layer materials; break points of flexible pavement are often different than those for rigid pavements. Agencies that use several condition indicators generally establish a set of break points for each different condition indicator, such as rutting, cracking, roughness, and surface friction. When one of the indicators for a segment of pavement research a trigger value, then that segment is scheduled for the appropriate level of treatment. There is no trigger value for preventive maintenance in this approach; instead a cyclic time sequence application of treatments can be used to reach the first trigger value when it would then be scheduled for the appropriate treatment category. Figure 2.4 shows a projected performance for an asphalt surface pavement with a seal coat projected on an eight-year cycle. The first two would be applied, but the third is projected to reach a trigger point before the eight-year cycle is completed; it would then be scheduled for the appropriate treatment instead of another seal coat. As sections are selected for treatment, the condition of each is increased in that year based on the expected affect of the treatment, and future work identified through the analysis period is based on that changed condition. When managers identify the pavement sections for treatment, they can use information from network level data (treatment category and unit cost). The treatments and funds needs are summed

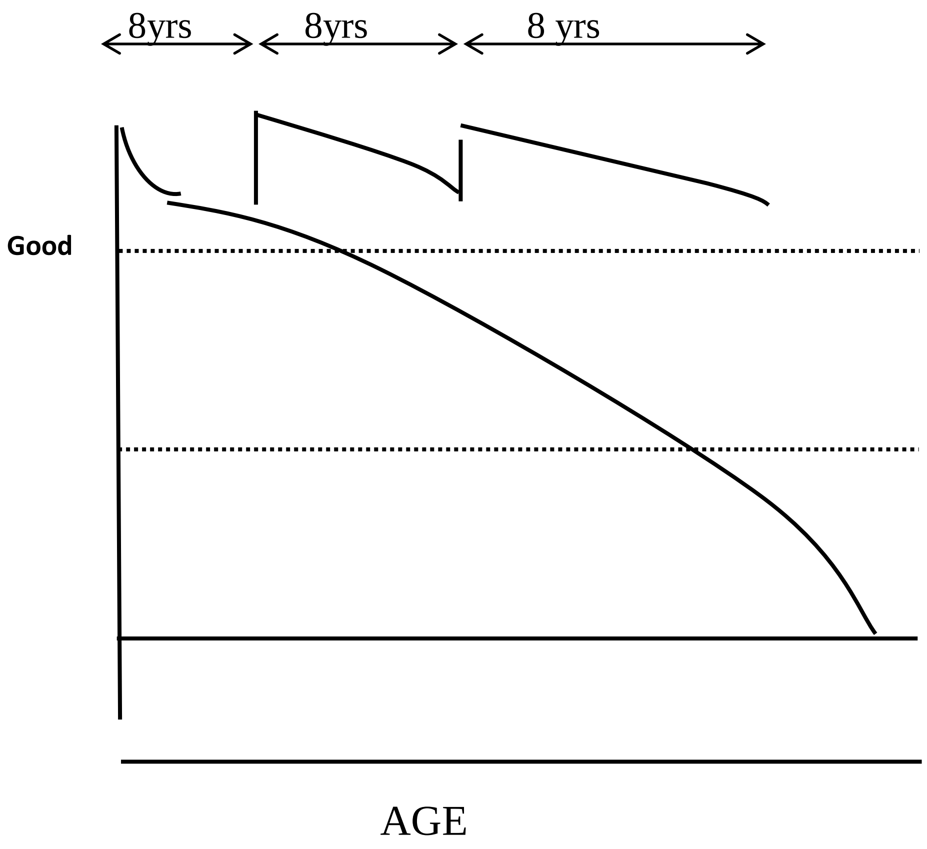

Figure 2.4.Projected performance with projected preventive maintenance

For each year to determine annual work and budget needs over the analysis period. The condition of each management section and the overall network condition with all needed maintenance and rehabilitation applied projected over that analysis period gives a second base condition if all funds needed were applied. The trigger values and the cost categories associated which each level should be selected based on an analysis of the most economical levels of service the agency can provide based on the agency goals within existing constraints. The cost category treatments should be selected based on a life-cycle cost analysis to provide the best life for the least money. However, since these are only network-level planning treatments, they should provide a reasonable first cost as well.

The purpose of the network-level budget planning treatment is to assign a cost to each section of pavement that has reached a selected threshold value. These treatments should generally consider cost categories rather than actual treatments; the actual treatment will be selected during the project-level analysis. Treatments and costs should generally be reviewed and changed on a periodic basis. However, at the network level, the costs are the most important. The network-level system is defined by trying to identify candidate sections and the pot of money needed to achieve some department-define goals. Some sections will require more money than estimated while others will require less. The project-level analysis is used to adjust the treatments when more detailed data can be collected to allow a more detailed look at the sections to come up with the most cost-effective treatment for each specific section of pavement. If an agency has a backlog of unfinished work, the needs analysis will often show that a large amount of work is needed in the first year of the analysis; although the agency cannot complete the work on that schedule, this does not invalidate the usefulness of the information. Assignment procedures that connect the condition of the pavement with the cost category for the needs analysis often use just one cost category for each condition level. PMS programs which use full optimization techniques may look at several named treatments for each condition level; however, this selection is based on construction funds and resources. The needs should be based on the level of service that the agency wants to provide to the user. The decision support algorithm requires models that project the condition of pavement without treatment, the impact of treatments on the condition, and the condition of pavements with treatments. It must be able analysis to identify sections needing work in each analysis year, and it must be able to estimate the costs of applying those treatments over that analysis period. In many cases, multiple treatments will be required for individual sections during the analysis, and reflect the agency values. They must be able to support the decision that would be considered by the agency

2.6 Determine the Impact of Funding Decisions

The general goal of government agencies is to provide the maximum social benefit for the money provided to them by the public. However funds are usually allocated to a managing agency by elected officials who must run for election every few years. These elected officials are often more interested in solutions that show immediate impacts rather than long-term solutions that do not show immediate impacts, even if the long-term solutions are most cost-effective. It generally requires considerable justification to get funds for long-term solutions that either do not show immediate impacts or that cost more than short-term solutions. One of the best ways to justify funding requests is to show the impact of alternate funding levels and strategies on the health of the network, the backlog of needs, future funds needs, and user costs. The health of the network can be shown by projecting the average condition of the pavement network over some reasonable analysis period with various levels of funding and various funding strategies, e.g., higher and lower percentage of funds directed at preventive maintenance (AASHTO 1993, U.S.DOT 1997b). However, many of those allocating funds often will not understand what change in condition is significant; they generally think in financial terms. It is often best to describe the current quality of service being provided and discuss how the funding strategies under consideration will increase or decrease the condition with an emphasis on the percentage of each type of road in one of several levels. The change in percent of highways in poor condition with the current and alternative funding levels may be more appropriate.

For instance, the amount of pavement in poor condition will increase from 5 percent to 10 percent over the next five years with the current funding level, but the amount in poor condition would remain constant over that period with a 7 percent increase in funding. Possible even more applicable to those allocating funds is to show the current fund needs, backlog of fund needs, and amount spent on stop-gap maintenance activities and how they will change over time for different funding alternatives. The change in number of pavements that need rehabilitation or maintenance and have been deferred because of funding limitations may also help in discussion with funding authorities. The remaining life of the existing network and changes in remaining life with different funding strategies are also helpful to some agencies. Changes in user costs may be useful those officials who are interested in the financial impact on their constituents. Even though there are problems with the user costs for the whole network, or some large portion of the network, give the order of magnitude of the impact of different funding strategies on the using public.

2.7 Description of Project-Level elements

Most engineers have more experience in project- level activities than network-level management. After the network-level management elements identify candidate projects for programmed maintenance, rehabilitation, and reconstruction, the engineering staff generally prepares the final list of segments for work along with plans, specifications, and cost estimates during project-level analysis.

Project-level management is the process of analysis and design to determine the layer material types and thickness needed for a pavement structure to serve the public (Peterson 1987). Although computer programs may be used in designing layer thicknesses of specific materials and in economic analysis, much of the process must be completed outside a computer program. The complete project-level analysis can require considerable materials sampling and testing both in situ and in laboratories. Project-level pavement management activities usually include new design, rehabilitation design, reconstruction design, and programmed maintenance that requires some level of design. New design needs may be generated by the congestion management, planning activities, or other management processes. Rehabilitation, reconstruction, and programmed maintenance needs should be generated from the network-level PMS functions, or some other management process such as the safety management processes. Maintenance treatment development and design may be completed by a different group within the agency than the group that completes the development and design of the new, reconstruction, and rehabilitation pavement design. The purpose of project-level management is to determine the most cost-effective design or treatment for a section of pavement selected for work. The layers and materials selected for the segment of pavement needing work must be designed and constructed within constrained fund levels and meet other applicable constraints.

2.8 New Design

The purpose of a pavement is to provide the public with an economical, safe, and comfortable surface on which to drive. Although engineers often consider pavements one of the simplest types of structures, the design is quite complex (ERES Consultants 1987). Most pavements are constructed using layers of materials, and eventually all of the imposed traffic loads are transmitted to the underlying natural soils as suggest by Figure 2.5. The stringer materials are placed nearer the surface so that they can resist the applied traffic load, both dynamic and static. Each successive layer distribution of load reduces the load-induced vertical compressive strains and stresses on subsequent layers. A thicker layer of the same material, such as the top layer in Figure 2.5B compared the top layer in Figure 2.5A, will distribute the load over a wider area reducing the vertical stress and strain. Stronger materials provide more distribution causing the load to be distributed over a larger area than the same

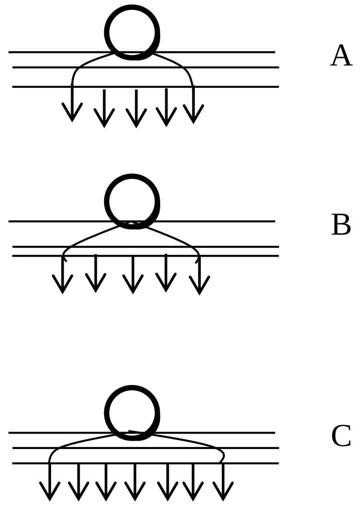

Figure 2.5.Load distribution

Thickness of weaker material as illustrated in Figure 2.5C compared to Figure 2.5A. Excessive vertical compressive stress and strain can cause permanent deformation in the pavement structure leading to rutting in flexible pavements or faulting in rigid pavements. The materials must also have adequate stability to resist the imposed wheel loads without experiencing shear failure (excessive lateral movement of layer material under load) or other forms of deformation. The materials must also be able to resist the applied traffic loads without developing excessive tension (tensile strain) in the bound layers. Excessive tension leads to fatigue cracking (alligator in flexible pavements and corner breaks in rigid pavements). The thickness of the layers, the stiffness of the layers, and load transfer across joints affect the load distribution and fatigue resistance of the pavement layers. The stiffness and thickness of the pavement layers are generally considered in pavement design; however, most of the pavement design procedures do not directly consider the material stability needed to resist deformation. It is assumed that material specifications adequately control material stability. The Strategic Highway Research Program (SHRP) developed a mixture design procedure (SUPERPAVE for superior performing asphalt pavements) that was supposed to be able to predict the performance of an asphalt concrete mixture in terms of cracking and rutting (Grauberger 1987). One goal of such a procedure is to allow the mixture properties of each layer to be fully realized in the design of the pavement layer thicknesses. However, at the time researcher procedure prepared this report, programmers were still modifying and adjusting the SUPERPAVE procedure.

In the future such a procedure will be available, but at the current time, thickness design and materials stability requirements are separate. We know many of the factors that affect pavement performance, although we may not be able to fully characterize all of them (AASHTO 1993). A rational design procedure forces the designer to consider each of the major factors that affect performance. This process leads to a better design compared to selecting a standard thickness of a single material that does not consider the important design variables, even when many of the design variables are estimated.

One of the most commonly used pavement design procedure used by state agencies is the AASHTO procedure (AASHTO 1993); however, there are several others available (NSA 1985; Packard 1984). Some state highway agencies use their own design procedures. All pavement design procedures should address several basic factors that are known to affect pavement performance including (AASHTO 1993):

1. Support provides by the in-place soil(Subgrade);
2. Traffic loads expected to be applied (primary trucks and other heavy loads);
3. Environmental factors (especially the impact of rainfall, changing moisture levels; extreme temperatures, and freeze-thaw cycles);
4. Drainage;
5. Available materials;
6. Capabilities of construction forces; and costs.

2.9Developing Maintenance, Rehabilitation, and Reconstruction Treatments

Like initial pavement construction, rehabilitation and reconstruction are costly construction activities (ERES Consultants 1993). Design of maintenance, rehabilitation, and reconstruction can take more time, effort, and funds than the design of a new pavement, because the properties of the existing pavement layer materials are needed and the complex interactions of different options possible to address existing problems. An analysis of the existing pavement to determine the cause of deterioration is necessary to identify cost-effective maintenance, rehabilitation, or reconstruction treatments that can correct the problem that created the need for repair rather than just treating a symptom of problem. This can be approached as a series of steps to determine the cause of deterioration and identify relevant constraints. The answers to the set of questions are then used to identify feasible treatments. A question-answer oriented project-level evaluation should include the following questions (AASHTO 1993):

1. Is the pavement structurally adequate for future traffic?
2. Is the pavement functionally adequate?
3. Is the rate of deterioration abnormal?
4. Are the pavement materials durable?
5. Is the drainage adequate?
6. Has pervious maintenance been abnormal?
7. Does the condition vary substantially along the length of the project or between lanes?
8. Does the environment require special consideration?
9. What traffic control options are available?
10. What geometric factors will impact on the design?
11. What is the condition of the shoulders?

Survey may be approaching two years old by this time), an analysis of the drainage situation, a first look at traffic control options, etc. Analysis of these data would give the designer a reasonable idea of the types of treatments that would feasible. With this, the second field survey can be planned, which would normally include most of the field testing such as coring, soil testing, and materials sampling. If it is determined early in the analysis that the asphaltic layers must be removed and replaced, data on the existing asphalt properties would be of little use; however, if in-place recycling of the asphaltic layers is being considered, properties of the asphalt would be vital. Knowing feasible alternatives is important in planning the field testing and sampling. Appropriate laboratory testing can then be completed, the results analyzed, and final recommendations developed. The size of the project and importance of the highway to the agency also influences the amount of time and funds that will be expended in project-level evaluation. Pavements on high-volume major highways will generally be subjected to more testing and evaluation than those on low-volume roads. The concepts and questions described above are valid for pavements with any volume of traffic; however, the amount of testing and time expended in reaching the conclusions should vary. There are a large number of maintenance, rehabilitation, and reconstruction alternatives available for both flexible and rigid pavements, and recycling has increased that number of options (AASHTO 1993; ERES Consultants 1993). Surface seals such as aggregate seals and slurry seals combined with localized repairs are often used as preventive maintenance treatments for flexible pavement, and they are also used as rehabilitation treatments on lower volume flexible pavements when structural improvements are not required. Although many asphalt overlays are considered structural improvements, many of the overlays currently in place were never designed; rather a standard thickness is used in some agencies without regard to the structural adequacy of the pavement. Overlays have become more versatile by combining them with interlayer's such as fabrics, milling full or partial widths, and recycling part of an existing layer prior to applying the overlay. Other types of rehabilitation and reconstruction include the following for flexible pavements:

1. Cold in-place recycling followed by a new surface
2. Hot in-place recycling with or without an overlay;
3. Reworking and stabilization of foundation materials followed by a new surface;
4. partial or full depth removal and replacement;
5. Full depth recycling; and
6. overlay with PCC.Other types of rehabilitation for rigid pavements include:

1.a series of maintenance treatments such as partial depth patching, full depth repair, grinding, and joint sealing, often referred to as concrete pavement restoration (CPR);
2. Break and seat with asphalt concrete overlay; and
3. Bonded or unbounded PCC overlay

2.9.1. Thickness Design

Since most rehabilitation are overlays, most engineers will think of overlay design when they determine layer thicknesses for rehabilitated pavements. Overlay design procedures are used when a new layer is to be added to an existing pavement; AASHTO (1993) describes a common overlay design procedure. Even when other treatments are used, whenever some portion of an existing bound layer is to be left in place, an overlay design procedure should be used to design the thickness of the new layer because overlay design procedures try to account for damage in the existing pavement layers. New thickness design procedures are also often used in rehabilitation design. When the existing bound layers (asphalt concrete, Portland cement concrete, or stabilized material) of a pavement are to be removed dures can be used to design required layer thicknesses. The material properties and layer thicknesses of the existing layers that will be left in place, such as an existing base or subbase, are first determined. The properties of the reworked materials after the reworking and their reworked thickness are also determined.

The properties and thicknesses of these layers are then fixed in the design procedure, and the thickness of additional layers of new material can be determined using the expected material properties in this new material. If no additional layer thicknesses are needed, then the reworked material can be surfaced with a wearing course, such as a double-chip seal or cape seal.

2.9.2. Selecting the Best Strategy

The analysis and design procedures discussed above will define a series of alternative treatments. The impact of future maintenance and rehabilitation should also be included to develop overall strategies. However, there is seldom a single alternative or set of materials and layer thicknesses combined with future activities that is immediately obvious as the best choice. The durability of the materials and the cost-effectiveness of each combination must be considered. Pavement failure is difficult to define, and once defined, different levels of damage are considered "failure" for different levels of usage. Some agencies prefer to consider useful life of the pavement based on some preset condition level below which the pavement is no longer useful; it can still carry traffic but at a reduced level of service. Because of the large areas covered by pavements they must be constructed of relatively inexpensive materials. This generally leads to using locally available materials, some of which may need to be upgraded through chemical stabilization. The imposed traffic loads are often relatively difficult to predict. The pavement materials, especially the surface layers, are exposed to the environment resulting in changing moisture and temperature conditions. The strength or stiffness of most materials used in pavements changes when the temperature and moisture content change. Some of the materials experience long-term material property changes due to the effects of the environment, and many have stiffnesses that change when the load-induced stress changes. The process of selecting the combination of treatments, materials, and layer thicknesses for the design, maintenance, rehabilitation, or reconstruction is an integral step of the project design process (ERL Consultants 1993). The approach followed in project-level analysis should include completing a preliminary thickness design using all of the available materials and treatments that are considered feasible under the circumstances. The designer should then try to identify the combination of treatments, material types, layer thicknesses, and future maintenance and rehabilitation activities that give the least life-cycle costs for the design period analyzed while providing the desired condition. However, several factors that are difficult to include in the economic analysis may have a direct impact on the type of pavement selected. Properly designed and constructed rigid pavements generally last longer than properly designed and constructed flexible pavements until the first major rehabilitation is required, but asphalt concrete pavements have more rehabilitation options. Portland cement concrete pavements generally cost more initially, but asphalt concrete generally has more frequent rehabilitation requirements. In many instances, the actual cost difference when considered over long analysis periods will be small, and other factors often influence the selection of pavement or treatment type. Many pavements can be kept serviceable beyond their original design life by applying appropriate maintenance and rehabilitation treatments in a pavement preservation program. Programmed future maintenance and rehabilitation treatments expected to be applied to the pavement surface should be combined into reasonable sequenced strategies when completing both new and rehabilitation design. For example, in new design two strategies might include:

1. construct with an asphalt concrete surface followed with a surface seal at seven years, an overlay at 15 years, another surface seal at 22 years, followed by milling and overlay at 30 years; and
2. Construct with Portland cement concrete surface with joint resealing at eight years and 16 years, a concrete pavement restoration at 24 years, and an asphalt concrete overlay at 30 years.

Life-cycle costing concepts should be used to determine the differences in costs of the different strategies to account for the time value of funds spent (Peterson 1085). The costs should include construction costs, traffic control costs, and other costs to the agency. The analysis should also consider the impact of the construction and future maintenance and rehabilitation operations on users.

2.10 Project Selection Level

Some agencies that decentralize decision authority include a third management level between the network-and project-level analysis, which has been called the project-selection level. Haas et al.identify this as a part of the network-level analysis with the remainder being considered program-level analysis (Haas, Hudson, and Zaniewski 1994). The purpose of the project-selection level is to complete the process of prioritizing or optimizing the segments that will be programmed for work with constrained funding. This includes assigning the level of treatment and the timing of the treatment for pavement segments over the analysis period. It requires more data than might be collected at network level but probably less data than needed for full project-level design and analysis.

After completing the normal network-level analysis, those segments that are obviously not candidates for maintenance, rehabilitation, or reconstruction in the analysis period can be removed from further analysis. Those segments for which the appropriate levels of treatment needed are obvious can have the level of treatment established. The remainder of the segments are then identified for additional data collection and analysis. However, the agencies are generally collecting a minimum amount of additional data and using that to adjust the treatment level, resulting cost, and timing of treatment. It is generally used at the network level. It is particularly helpful when he pavement analysis drives the decisions about which sections should be considered primary candidates for work but where other costs, such as traffic control, safety improvements, and drainage can become quite large compared to the actual pavement rehabilitation costs.

2.10.1 Interfacing Network and Project Level Elements

Network-level pavement management activities should identify and prioritize pavement sections needing work. They should also identify fund needs and show the impact of different funding strategies providing information so that requests for funding can be justified and explained to funding authorities. Project-level activities should use that prioritized list as the starting point of project-level analysis. Additional data will normally need to be collected to better define the need of work, determine the cause of deterioration, and identify feasible treatments. The project-level analysis should determine more accurate cost estimates for each alternative strategy and select the most cost-effective treatment for application within imposed constraints. All of this illustrates that the project-level analysis should use the network-level analysis as the first phase of the analysis and build on that step.

2.10.2 Relationships of Data

It should be readily apparent that, if the data necessary to determine the need for work, define the cause of deterioration, identify feasible treatment strategies, and select the best treatment needed for project-level analysis are available, that data would also be adequate to make network-level decisions. However, it is not cost-effective or feasible to collect all of the data needed to make project-level decisions on all of the pavement segments in a network; it is even less feasible to keep that data current. To reduce the cost of implementing a PMS, only the minimum data required are normally collected at network level. By adopting project-level data collection processes that complement the network-level system, the minimum required data can be collected. During the network-level surveys, more complete data can be developed and captured by the PMS over a long time period through project-level analysis when those data are necessary to support the decisions being made. Detailed data collection is spread over a longer time frame that makes the PMS more adaptable to an agency. During subsequent project-level analyses, time and effort would be spent on verifying and updating the more detailed data collected during previous project-level analysis efforts; it probably will not be completely accurate at the subsequent analysis. As an example, distress may be collected for network level using a sample of each management section, automated distress collection techniques, or a windshield survey. At project level, detailed distress maps with distress information for the entire management section might be collected to facilitate calculation of repair quantities for comparison of rehabilitation strategy costs. The types of distress, the definitions of severity, and the measurement of quantities should be the same for all major distress types collected at both levels. The difference should primarily be in the accuracy of the density measurements due to a full survey of the entire section and more accurate determination of severity levels due to a slower or more detailed inspection. It may also be necessary to collect additional distress types at project level than at network level, as long as those collected at network level are adequate to support the ‘decisions being made at that level. Some measures of condition may only be collected at project level. For example, deflection testing accompanied by coring or radar surveys to determine the structural adequacy of the pavement may only be collected at project level while at network level, the layer thicknesses from plans and assumed layer coefficients may be used.

2.10.3 Decision Support

Since the results of the network-level programs should be used as the starting point for the project-level analysis, the project-level analysis should use the same basic decision support concepts that are applied to the network-level process. When the same data for a pavement section is considered in both network- and project-level systems, they should project the same lives with and without the same treatments. The treatments selected at project level should be more detailed, but should come from the same category used at network level. The differences should occur because more complete and more accurate data is available during project-level analysis.

2.11. Real World Factors Not Considered at Network Level

Some factors that influence the selection and timing of treatments can only be handled at project level because they will not be known until a more detailed data collection has been completed. For instance, traffic control during construction can limit the number of feasible treatments to those that can be completed during hours of lower traffic, or to minimize traffic problems. The treatment timing may be deferred, advanced or set up with periods in which no roadway work is allowed. These constraints are often not known until project-level analysis determines that the adjacent street system cannot be used because of citizen objections or some other limitation is present. Some projects are so large that the work cannot be completed in a single season or they cannot be fully funded in a single year. These sections must then be programmed into future years restricting the funds available for other projects in those future years. All of these require that the project-level system allows forced treatment strategies, forced treatment dates, forced treatment deferral, and multiple strategies. Sections not selected by the network-level programs should be allowed to be added, and those selected should be allowed to be deferred. The project-level system should support a more complete cost analysis. Network-level analysis uses relatively gross unit costs based on averages for many sections within a certain condition and pavement type category. Many cost items are combined into this single unit cost value. At project level, detailed cost estimates should be completed. They will often need to consider costs of concurrent construction activities outside the pavement maintenance arena, which may or may not have an impact on pavement performance. In some projects, the cost of traffic control, addition of safety appurtenances, new signs and signals, and landscaping may cost more than the pavement costs. Separate accounting may need to be maintained of these additional costs that should be considered in the cost-effectiveness or benefit-cost analysis of pavement performance and the costs which are required by policy or management decision, but which do not affect performance. (e.g., traffic signalization may be included in the project cost but should not be considered in any cost-effectiveness analysis of the pavement).

2.12Developing Contract or Construction Packages

The network-level analysis will often identify a large number of sections for the same treatment spread over the network for each analysis year or several diverse treatments to small sections within a small geographic area. To gain efficiencies of scale, some agencies prefer to apply the same treatment to several management sections in a geographic area at one time. For example, they might combine several surface seal jobs into a single contract package for a selected geographic region and consider it as a single entity for the remainder of the analysis. Few agencies will apply an overlay to 2 mi, heater scarify and overlay 1 mi, skip 2 mi, apply a chip seal to 1 mi, and skip 2 more miles before reconstructing 3 mi, all in the same year. This could then be followed within the next three years with treatments to those sections left out in the first year. Instead, most agencies will try to find a treatment which will be appropriate for all of those adjacent sections with minor changes in surface preparation, base repairs, or overlay thickness. If two management sections need a treatment in one year and the management section connecting them is identified as needing a similar treatment in the near future, the agency may apply a treatment to all three sections in the same year. This type of combination of sections into a single contract package is generally not handled by most network-level software.

These processes lead to considerable modification in management section selection in the development of final projects by grouping management sections into “contract or construction packages” based on geographic location, type of treatment, or date of treatment. The project-level system should assist the user in defining these packages. The basic information can be retained on individual management sections in the database; however, the management sections would be combined for final analysis and strategy development.

2.13. Feedback from Project Level to Network Level

Once the project-level analysis is completed and a project is programmed for work, this information should be entered into the network-level data so that the same section will not be selected in the next analysis period. Sections that are actually under construction should also be identified so that the network-level analysis will not select them again. The data collected during the network-level analysis about the pavement layers and their properties should be made available for subsequent network-level analysis.

Actual treatment costs from the construction should be used to update the projected costs used in the network-level analysis.

Data collected during the actual application of the maintenance treatment and construction of the rehabilitation treatment or new construction should be collected in a form that allows it to be used in pavement management activities. It should be made available to those responsible for pavement management. This can be in the form of the original data set that will be permanently maintained by the responsible group. However, if construction and maintenance data will only be maintained for a short period, then a subset of that should be extracted on a periodic basis and maintained by the pavement management group as a part of the network-level pavement management database.

2.14. Feedback from Network Level to Project Level

The performance data collected at network level should be used to validate the life values used in project-level life-cycle-cost analysis. If appropriate data are collected and stored at network level, then the lives of selected pavement designs, maintenance treatments, and rehabilitation treatments can be determined. The overall performance of various designs, material types, and construction processes under similar or different conditions can be compared using the data in the PMS database, assuming adequate information is collected and maintained so that these parameters are available. Agencies can use this database to update network-and project-level performance projections based on these available parameters and to help determine the most cost-effective designs, maintenance treatments, and rehabilitation strategies. These feedback processes may not be program elements, and some of the analysis may require considerable research and analysis before the information is adequate for updating current department information.

2.15 The Move to Infrastructure Management

As the costs to operate and maintain the highway transportation system in the U.S. have increased and the funds available have been reduced, there is an increased need to support fund requests with relevant justification, not just for pavements but for all expenditures. Infrastructure management systems and to start the move towards integrating the management of all physical facilities managed by the agency. Grigg (1986) prepared the first text available on infrastructure management; however, it was more oriented towards local agency planning activities than highway agencies and engineering aspects. Other areas became involved in the infrastructure area including the Building Research Board (Grant and Lemer 1993). Recently Hudson et al. (2000) prepared a text that is more directed towards the activities of state agencies. Several academics have started developing course material for use in teaching infrastructure engineering and management. Pavement and bridge management were some of the first decision support systems developed in highway agencies for their physical infrastructure (Hudson, Haas, Uddin 1997). Many highway agencies also use maintenance management systems(MMS), and the federal government requires highway agencies to provide information to support the highway performance monitoring system (HPMS). The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) required the implementation of a PMS, bridge management (BMS), congestion management (CMS), safety management (SMS), intermodal management (IMMS), and transit (or public transportation management systems (TMS); however, those requirements were later removed. In addition to transportation facilities, some local agencies are developing other infrastructure decision support systems for water supply, waste water, and other facilities.

Most of these various decision support systems have developed independently. For them to be truly effective, they need to be integrated, or at least coordinated, to provide the information needed by administration and funding authorities to support their strategic planning and budgeting activities. As implemented in most agencies, the network-level PMS addresses only the rehabilitation and preventive maintenance of the existing pavement system; pavements needed to increase capacity and on new alignments are not addressed. It was expected that the CMS would address capacity improvement needs for the highway system; although not explicitly stated, it is assumed that the normal planning process would be used to identify the need for new pavements to provide better access to undeveloped areas. The IMMS concept was interpreted differently by several agencies, but it was assumed that it would affect the highways by defining the need for highway links to other transportation modes including air, rail, light rail, sea, inland waterways, and pipelines. Although many of the actual transfer facilities are built and maintained by other agencies, they must be linked by highways. The BMS would address the maintenance and rehabilitation needs for both the on- and off-system bridges; however, as with the PMS, the need for new bridges and increased width to address capacity needs would be accomplished through the CMS and planning processes. The SMS was to address all safety needs, and it was expected to address all types of facilities; it was expected to identify needs for new pavements, maintenance, or rehabilitation. The MMS normally address the routine maintenance applied by force account or contract forces to all components of every highway or public works facility. The existing MMS tend to be more work management systems than planning and programming systems. However, information from the MMS should provide each of the other systems with the maintenance effort applied to the affected elements.

The more numerous and the more complex the infrastructure systems become, the more there is a need for coordination of data management. Data collection, storage, and retrieval are the most costly part of infrastructure management systems. When management systems for several different highway facilities are developed separately, some data will be duplicated and similar data will be collected differently. It is likely that economies can be found by combining some of the data collection activities. Needs analysis for one facility will not reflect the impact of the needs generated by another facility management system. Prioritization will not reflect the impact the decisions by one facility management system have on another. The fund needs analysis from each system will each compete for funds from the same source without providing those who allocate funds a common measure of the impact of funding decisions on the health of the highway network overall.

Sinha and Fwa(a987) outlined a concept of total highway management that addresses the relationships among some of the various factors. Although it does not address all management systems, per se, the authors address several of the coordination and interaction issues. They discuss example elements of a highway system as related to total facilities management. They prepared a three-dimensional matrix structure of the highway management systems. While this methodology is incomplete, it illustrates many of the interactions among the various system components. Hudson,Haas, and Uddin(1997) developed recommendations for infrastructure management that would address the need for overall integration of various individual management systems.

Coordination can occur at several levels, but it should generally include some or all of the following:

1. Donation referencing;
2. Data definitions including standardized terms and syntax;
3. Data collection processes;
4. Conflict analysis;
5. Needs analysis; and
6. Fund allocation.

2.15.1 Location

To coordinate construction, rehabilitation, maintenance, and other activates, a common location method is needed. It becomes even more important if other management systems are to coordinate with PMS. All of the activities are generally completed in relation to some physical location along a highway. Since pavements are located on these highway routes, either a route-based or coordinate-based location referencing system can be used, as long as the PMS and all other management systems either use the same referencing system or can be easily translated to the other location referencing systems.

Although a geographic information system (GIS), or spatial database, is not required to define a location, it will be especially helpful to display locations. A GIS can be used to show the location of separate activities along a highway and display their spatial relationships. If several groups are planning work, all of the plans can be shown on a GIS, and conflicts can be resolved prior to encountering them on the ob site. Even if separate management systems use different location systems is related to a single base map location system defined on a GIS. However it is done, a method to relate location of activities in one system to those in another system is essential to support coordinated management activities.

2.15.2. Definitions

Data definitions must be coordinated among the various management systems. It is impossible for one group in an agency to use information collected by another group if they cannot understand what the other group is doing. If one group within the agency calls work "after construction rehabilitation" and another group calls it "repair", the decision support software of one group will not be able to find the work because they are asking for the data with a name the other group does not use. If the PMS needs to know the thickness of asphalt concrete and the lanes on which it is placed and the construction management system only reports total tons of asphalt concrete purchased, the two systems cannot share meaningful information. It is essential that a common set of terminology and definitions be established that will facilitate transfer of information needed among the management systems.

2.15.3. Data Collection

There are two general kinds of data collection that need to be considered. The one that is most commonly considered is the dedicated condition assessment. In this process, a team of inspectors or a piece of specialized data collection equipment travels along the highway and collects data. When this process is developed for each management system individually, there may be more than one team traveling the same highway collecting similar data. For instance, the pavement management team, or equipment, may be collecting roughness, rutting, and cracking data. The crew for safety management may be traveling the same highways collecting edge drop-off, guide-rail, and marking data. The maintenance management group may be traveling the highway a third time collecting data on drainage, signs, markings, and signals. By coordinating these activities, it may be possible to reduce the number of passes and collect the data with few crews of specialized pieces of equipment.

The data collected to define the condition of individual segments of pavement by the various management systems is often collected using different methods and equipment. Roughness measurements are often collected using automated equipment that summarizes the data in one-tenth mile or one-tenth kilometer increments. Distress may be collected and summarizes in one-half mile or one kilometer increments. If a common location referencing system is used, data transformation techniques can be used to match the data with pavement segments in a dynamic way to make the best use of the data without requiring it to be collected and stored for predefined segment lengths. This process allows each separate data collector to collect the data as best fits the needs of the equipment or process while allowing the analysis to be performed on sections independently defined by the analyzer to fit those requirements. This allows transformation of data with differing section limits by an orderly process of accumulation or averaging as best suits each separate data field. This is extremely helpful when operating in a shared data environment where many different data collectors provide data for separate analysis processes.

The other type of data is that which is produced by one management system and is needed by another. Most agencies have some type of construction or contract management procedures that record progress of work and authorize payment to the contractor. The pavement, bridge, etc. management systems need information about the work completed on the appropriate facilities. If the contract and maintenance management systems use the same location system and same definitions as the pavement, bridge, and other management systems when work is completed on the facilities, the related management systems would know how much and what work has been completed on the facility at any given time. Data like that stored in pavement layer databases would be kept current on a routine basis.

2.15.4. Conflict Analysis

The lowest level of decision support, and probably the first needed, is conflict or constraint analysis. At this level, each management system could still operate separately. Each system would identify needs and select lists of candidate projects independently. The results from each management system would then be compared to identify conflicts. As an example of the conflict analysis, if pavement rehabilitation is planned for 2004, but a bridge with new approaches and alignment are planned within the pavement management section in 2006, the schedule of the work should be coordinated and the pavement treatment plans integrated into the plans for pavement work involved in the bridge work. As another example, if extensive rehabilitation work is identified as being needed for a section of highway in 2005 but that section of pavement is scheduled for more significant work (widening, reconstruction, etc.) in 2009 to increase highway capacity, the type of treatment to be applied in 2005 should be adjusted to a more moderate treatment. This treatment will hold the condition of the pavement at a reasonable level until the more complete work is completed in 2009.

2.15.5. Needs Analysis

The second level of coordination among separate management systems is coordination of the needs analysis. In this level, the needs analysis of the individual management systems would interact requiring considerable integration of the decision support software. Bridge construction is affected as much by the need to improve the highway capacity as by the condition of bridges. Highway capacity is not truly changed if only the road surface or only the bridge capacity is increased; both must be increased together. If a farm-to-market road is being strengthened to allow heavier traffic, any structurally deficient bridges alsoneed to be strengthened. If the congestion must be relieved by changing the highway from two lanes to four lanes for a given corridor, both the bridges and pavements must be widened.

2.15.6. Fund Allocation

A third level of coordination among the various management systems is allocation of funds. This can be done in two ways. One way is to allocate funds to each group of facilities addressed by the individual management systems. This is normally a strategic management decision made at the highest management levels in most highway agencies. In this approach, each management system would compete for a share of the total available funds. In the past, the allocation among these systems by state transportation agencies was heavily influenced by how funds were allocated through federal programs. With changes in the ISTEA and other federal fund allocation policies, state agencies have more flexibility in allocation of funds among programs. The methods used by some state agencies to allocate funds among the different programs re often difficult to explain and justify to the elected officials and it is sometimes difficult to directly compare the benefits of funds allocated among different types of facilities. This would require a method to define the costs and benefits of the facilities supported by each management system so that impacts of tradeoffs among the supported systems could be analyzed. It should also address the interacting of the facilities supported by each management system.

A second approach would be to allocate funds to each individual project needing work. This would require each management decision support system to identify needs. All projects needing work, whether pavement, bridge, signals, etc. would then be combined together into a group for prioritization. This would require a common method of defining the benefit derived from spending funds on any project considered by the agency. This type of overall prioritization is probably some way off in the future, but there are some approaches such as multi-variate utility analysis techniques that should be investigated to determine if they could provide assistance in this area in the future (Canada and Sullivan 1989)

This listing broadens the scope of asset management from the physical assets identified in the first definition to include several non-physical items. Since asset management is new to transportation agencies, we can expect further changes in both the definition and scope.

Just as there are similarities and differences between network-level and project-level pavement management, there are similarities and differences among pavement, infrastructure, and asset management.

Pavement management focuses on pavements, infrastructure management focuses on physical facilities, and asset management can include all elements managed by the agency, including many non-physical facilities, and asset management can include all elements managed by the agency, including many non-physical assets (financial capabilities, methods, and technologies). However, the basic management concepts are the same in all three, to provide the best return for the funds spent. Network-level pavement management, infrastructure management, and asset management have the same general goals for the facilities and assets managed, and they require the same basic components that were earlier described for network-level pavement management. The focus of the decision support from these three systems seems to be different; although, this is not well defined. The pavement management decision support is generally directed towards those who make decisions about the pavements; the infrastructure management systems are more directed towards those who must allocate funds among the different types of infrastructure facilities; and asset management systems are more directed at the policy making level. All of these systems are a cross between engineering and planning, but of the three, pavement management seems to be most closely related to engineering while asset management seems to be more closely related to planning.

One of the implementation problems encountered in pavement and infrastructure management has been developing information in a form and format that can be easily communicated with senior management and funding authorities. In his presentation to the second asset management workshop, Lemer (1997) suggested that an infrastructure balance sheet and infrastructure income statement be developed as part of an integrated infrastructure asset management system. This type of focus allows those funding authorities who are more familiar with private industry to view the allocation of funds and resulting benefits in a form that many of them are familiar with.

As asset management matures, it appears that it will attempt to better integrate the management of physical assets and possibly non-physical assets. Pavement management is one of the tools that most transportation agencies have in place, and it should be one of the first that is integrated into an overall management approach. The lessons learned from implementing and using PMS should be helpful in asset management, and the lessons learned in developing tools to better communicate with policy makers in transportation agencies should help guide future developments in pavement management.

2.16 The Move to Pavement Preservation

The 1994 Federal Highway Administration Policy Memorandum on ISTEA Pavement Management Systems includes reference to “developing the statewide pavement preservation program”; however, pavement preservation was not well defined (FHWA 1994). Pavement preservation has been used in other documents, but a clear definition was not developed until recently. At the Kansas City, Missouri workshop the following definition was used, “Pavement Preservation is a program of activities aimed at preserving our investment in the Nation’s highway system, enhancing pavement performance, extending pavement life, and meeting our customers’ needs. It is the sum of all activities undertaken to provide and maintain serviceable roadways; this includes corrective maintenance, preventive maintenance, as well as minor and major rehabilitation. It excludes capacity improvements and new or reconstructed pavements.”However, in another part of the same publication, it stated that major rehabilitation was excluded (FHWA 1999). One state gave the following definition, “Pavement reservation is the planned strategy of cost-effective pavement treatments to an existing roadway to extend the life or improve the serviceability of the pavement. It is a program strategy intended to arrest deterioration, retard progressive failure, and improve the functional or structural condition of the pavement. It is a strategy for individual pavements and for optimizing the performance for a pavement network” (Schober and Friedrichs 1998).

Pavement preservation is an inclusive program that identifies the treatment for each section of pavement in the managed network that will give the greatest pavement life for the least money. The treatments include corrective maintenance, preventive maintenance, and rehabilitation. A method to identify appropriate treatments for consideration for each section of pavement is required. Reasonable models that can project pavement performance and the impact of the considered treatments are required. These must be combined together in a decision-making process that will identify the costs and benefits of each alternative for each section of pavement and the network as a whole must be available. These must look at the long-term effects of the treatments for impact of preventive maintenance treatments as well as rehabilitation treatments to be considered. A database of information about each pavement section is necessary to identify candidate projects and select “the right treatment at the right time”. As pavement management systems, pavement preventive maintenance, and pavement preservation programs are each described, there is a tendency to identify them as three different, independent programs. However, if we look deeper at these three programs, we can see definite interrelationships that will allow us to use one set of data and one set of analysis tools for all three.

Although the definitions for pavement management and PMS include identifying cost-effective alternatives, some agencies with a PMS use it to assist in finding the worst sections of pavement so they can be selected for treatment. This results in a structured approach to insuring the worst pavements in the network are repaired first. Most of these agencies us some priority number that is function of condition and traffic usage, so that some of those with the highest traffic are repaired while in better condition than those in poorer condition with lower traffic. However, this is still repairing the worst first but adjusting to repair the more important before repairing the less important roads. No one can argue that this is not a structured PMS that is used to achieve a set of defined goals; however, this approach will not meet the goal of applying the right treatment to the right pavement as defined in a preventive maintenance or pavement preservation program. Pavement preservation, including preventive maintenance treatment as part of the pavement preservation treatments, is a particular approach to managing pavements that stresses selecting the most cost-effective treatments for each section of pavement in the network to minimize long-term network costs while maximizing the service provided to the using public.

2.17 Organization Impacts

There are several methods that can used for each element in a network-level PMS, and there are many different data collection procedures that can be used. There are a number of conditions and situations in any organization that affect the PMS elements and procedures that are most appropriate for the agency. Agency size, organizational structure, past management and decision-making practices, stability, planning horizons, resources, and fixed investments will all have an impact. Selecting the appropriate PMS procedures and decision support software can have major impacts on the difficulty and success of the implementation process, whether it is implementation of a new PMS or implementation of a revised component in an existing PMS.

2.18 Past Management and Decision-Making Practices

Some agencies have developed good management practices even though they have not made effective use of software to support pavement management decisions. For them, the conversion to a structured PMS is a natural evolution of management practices. Other agencies may have PMS software, but because they react only to the latest emergency and they feel that planning for pavement maintenance and rehabilitation is an “exercise in futility,"they do not use it in the decision-making process. It is difficult to implement a structured management approach in organizations where planning and programming are foreign concepts, even if they have the decision support software available.

2.18.1. Planning Horizons

Some agencies plan pavement maintenance and rehabilitation one year at a time. Others must plan work for four or five years in advance. Those with longer planning horizons need methods to predict future condition and the impacts of treatments they plan to apply. Those with longer planning horizons generally are more accepting and understand the need for decision support tools better than those who have done little planning in the past.

2.18.2 Fixed Facilities and Process

Some agencies have invested resources into a particular computer system, a location referencing system, a specific data collection process, an existing database management system, or a spatial database that constrains the decisions that can be made in the development, selection, implementation, and use of pavement management components. The PMS must make use of these existing facilities such as an information systems infrastructure because of prior management decisions and resource allocations.

2.18.3 Resources

Pavement management cannot be developed, implemented, or effectively used if resources are not available. This includes both the resources for those responsible for the PMS and funds for implementing the programs developed through the effective use of a PMS.

Those responsible for the selection, implementation, and use of PMS must have funds and resources to complete hose activities. Larger organizations may find this easier than smaller agencies because, in larger agencies, it is often easier to find some resources to allocate to pavement management development and implementation than in a small local agency; however, it is more difficult to coordinate the activities on an agency-wide basis. In smaller agencies, funds are often difficult to allocate to pavement management and pavement management may be only one of several activities for which the manager is responsible. Some agencies have much more personnel resources than funds. Others can contract for work easier than they can hire staff. This constrains the resources available to support pavement management development, implementation, and continued use.

Effective pavement management requires the application of treatments at the most cost-effective pavement network. If an agency has a backlog of funding needs and sections that are in extremely poor condition, much of the funds available may have to be spent on stopgap type maintenance to reduce the liability exposure of the agency. This can prevent the effective use of PMS-supported decisions to improve the condition of the network unless the PMS is structured to support backlog analysis and shows the impact of this type of fund allocation on funding needs. If adequate funds are not allocated to apply appropriate preventive maintenance to good elements and gradually reduce the backlog, PMS cannot improve the situation.

Several agencies have invested their pavement management knowledge experience in one or two people in the organization. The PMS positions often are at a relatively low pay level, but they often are filled with young, bright individuals with skills such as computer expertise that are in high demand. These talented individuals often only stay for a limited time. When a promotion, transfer, or job change removes that person from responsibility for pavement management, it often takes several months to replace the person. By the time the position is filled, the pavement management knowledge from the preceding PMS Manager may be lost. The problem is one of the most troublesome found because it is so difficult to address.

2.18.4 Completion of Funding Needs

Almost every agency has more funding needs than resources, and there are always many competing funding needs. In some agencies, certain funds are dedicated to specific highway categories or maintenance needs. This used to be heavily influenced by federal funding allocations; however, the ISTEA and more recent federal funding has given state agencies more control of how funds are distributed. This allocation can reduce the effectiveness of pavement management activities and require sub-optimal decisions because the group responsible for allocation among pavements has no control over how the funds are distributed among these different funding categories.

2.18.5 . Structure

Effective pavement management decisions cross the boundaries of many traditional divisions within most transportation agencies. The structure of the organization can have a significant impact on the effective use of pavement management. Some organizations encourage intercommunication among the various central office functional departments and the regional or field groups. Others require that communications go up the chain before they cross areas of responsibility. The lack of effective direct communication among pavement management users can have a detrimental effect on implementation and effective use of pavement management.

Agencies can have several different types of structures. Some agencies have organizational structures that were developed when constructing new facilities was their primary activity. In many of those agencies, maintenance received the lowest priority for staffing and funding. As the need to maintain, rehabilitate, and retrofit the existing pavement network became more important, there was no realignment in the structure of the agency to better address these functions. If the structure of the agency does not match the functions they must fulfill, there will not be an adequate allocation of resources to address the problems that the agency must face. When this occurs, implementation and effective use of pavement management will be more difficult.

Some agencies have centralized decision-making processes. In those agencies, the subdivisions, such as districts or maintenance areas, are responsible for effective implementation of the program developed by the central office. In other agencies, the central office allocated funds to each subdivision, and the subdivision then determines how to spend that money. Decentralized organizations require a different type of decision support outputs for pavement management than for centralized organizations. In decentralized programs, all of the decision-makers in the subdivisions must be convinced that effective pavement management is beneficial to them before it will be effectively used.

2.19 Benefits of Pavement Management

There are many benefits of having a structured pavement management system implemented in a highway agency. Some of the benefits that have been identified include:

1. More efficient use of available resources (Van Ness 1987;Rizenbergs and Deen 1987),and

2. quantified condition of network;

3. Ability to track the performance of selected treatments;

4. Supportable needs analysis;

5. Ability to show impact of funding decisions;

6. Selection of more effective maintenance and rehabilitation strategies;

7. improved communication between different groups working with pavements in the organization and with the public;

8. Ability to answer pavement questions from management, elected officials, and the public;

9. Better coordination of work with utility agencies;

10. Improved credibility when dealing with management, elected officials, and the public; and

11.a sense of satisfaction from knowing that the agency is doing the best possible job with the available funds.

Until recently, it has not been possible to document monetary benefits. A recent study conducted in Arizona documented a conservative benefit-cost ratio to the Arizona DOT of 30 dollars of savings in pavement expenditures for every one dollar spent on PMS development, implementation, and operation (Hudson et al. 2000). If user costs were included, the savings would be considerably higher, about

2.20 The policy framework

Management and policy

The concept of the management cycle has already been introduced. The first step in the cycle is to determine policy and objectives. In essence, this process aims at defining the policy framework which provides the context within which decision can be taken about all aspects of road management. At its simplest, policy may be defined as a "definitive course of action selected from alternatives to determine present and future decisions" (Howe, 1996).

Howe, (1996). Notes that roads policy should be part of an overall vision for transport that indicates how the supply of infrastructure and vehicle is to be provided, regulated and managed in relation to given demands. Supply policies are determined by a specific, often implicit philosophy defining the role that transport is expected on play in development.

A policy framework lays down the basic rules and requirements within which the professional and technical decision can be made about the road network. If this framework is well defined.The role of professionals in the road administration one of providing the appropriate technical solutions to implement the defined policy.

2.20.1 Components of the policy framework

1-Mission statement

2- Objectives

3- Standards and intervention levels.

A mission statement outlines, in broad terms, the nature of the operation being managed by the organization responsible for the road network. Objectives set specific goal to be a achieve within the short to medium term. Standard and intervention levels provide the detailed operational targets to be worked on by individuals in the organization. Standards may be supported by the legislation or regulation; intervention levels may be set internally by the road administration itself.

Relationship between the components of the framework, figure () below.

2.20.1.1Mission statement

The mission statement is recognition of the fundamental purposes for which the road organization has been set up, and the responsibilities with which it is charged. Historically, the focus of attention of most road in terms of the designs and specifications and structures of the pavements. The mission statement should then relate to needs of customers and other stakeholders. In this case , the customers are the road users, so the mission statement should operate its business to meet their needs. it should normally define how the organizations.

The mission statement may relate to those areas that were identified before, the work activities on the road network:

- Level of service or road condition
- National development and socio economic impacts
- Road user costs
- Accident levels and costs
- Environmental degradation
- Road administration costs

2.20.1.2 Objectives

An objective must be:

- Measurable
  Quantified in such away that it is possible to determine whether or not the objective has been achieved; normallyrelated to achievement within stated time scale.
- Relevant
  Being pertinent and applicable to the administrations mission , and having a direct bearing or influence on the item from the mission statement being considered.
- Achievable

Such that it is actually possible for the administration to accomplish the requirement in the time available or defined for response, with the recourses available.

The objectives in the different areas of the mission statement are given below:

1 Level of service objectives, the road network will be broken down into a functional hierarchy or road classes, each with a defined purpose.

2- User cost objectives, Arterial roads will be maintained, so far as budgets will allow minimizing the sum of user and road maintenance costs in the longer term.

3- Environmental, Materials used for road construction and maintenance will only be obtained from sources approved by the Ministry of Infrastructure and Transport.

4- Safety, Road work will be carried out in such a manner as to minimize the hazard caused to road users, pedestrian and workers during the course of the works.

2.20.1.3 Standard and intervention levels

The determination of standards and intervention levels differs between road administrations. In some cases, standards are the targets that the broad administration should aim to achieve; whereas intervention levels are the minimum level of service that is allowed. In other cases, standards are defined levels of condition or response that the road administration is obliged by law to achieve in its management activities; intervention levels have a similar purpose, but are norms set by the administration itself.

The following are examples of the formulation of maintenance standards and intervention levels:

Safety,

This requires, for example, that a standard is available for sig

10- Provide an acceptable level of service that economic and safe for road users.

11- Minimize the sum of road user and road administration costs within the budget available.

12- Undertake all work effectively, efficiently and safety and in such a way that minimizes damage to the environmental

The policy framework which provides the context within which the decisions can betaken about all aspects of road management, policy may be defined as a "definitive course of action selected from alternatives to determined present and future decisions" (Howe, 1996). Policies should also Provide an acceptable level of service that economic and safe for road users.

- Reduce of accident about 40%
- Zero potholes
- Roughness max 4m/km.

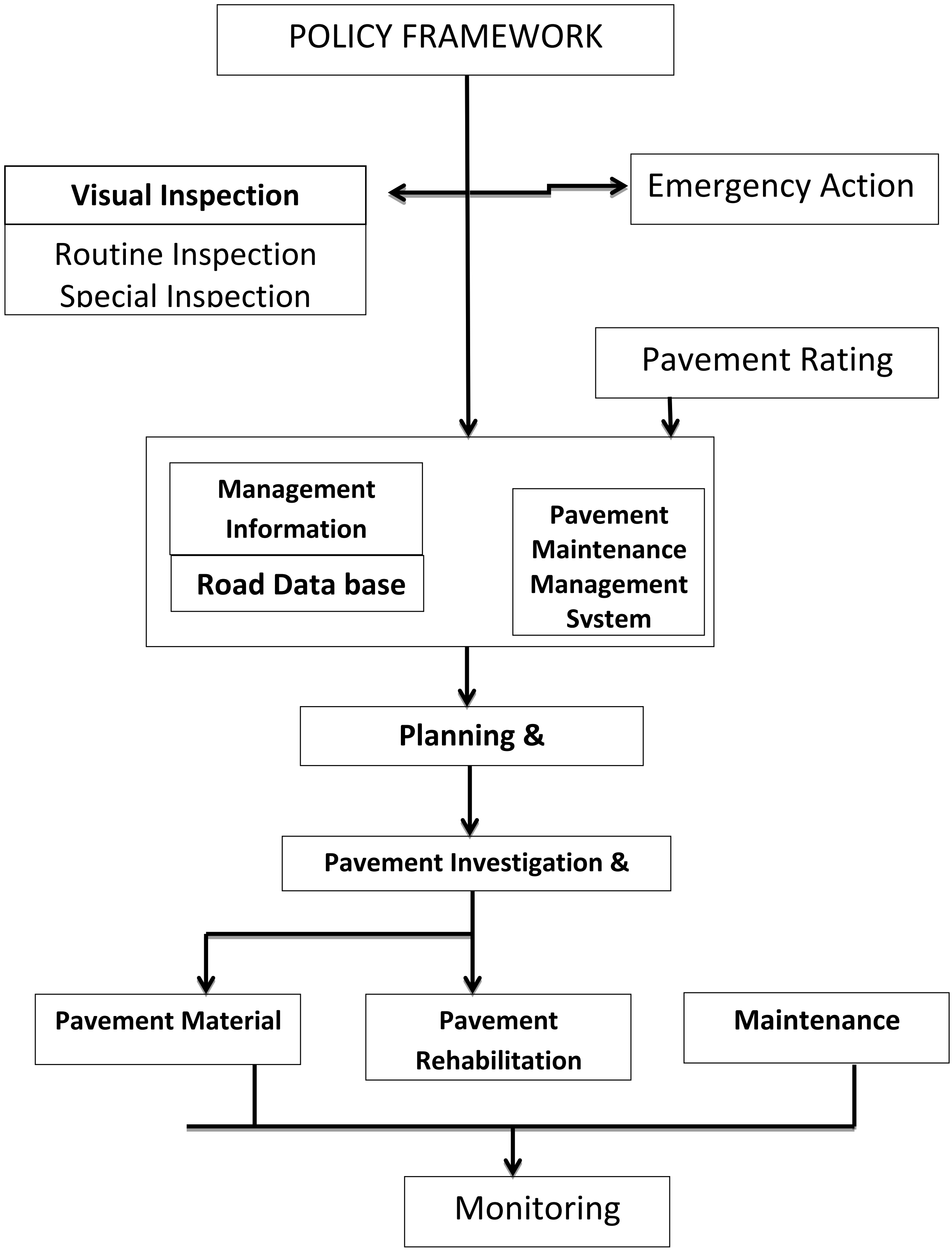

Figure (2.6) proposed policy framework for Khartoum State paved road

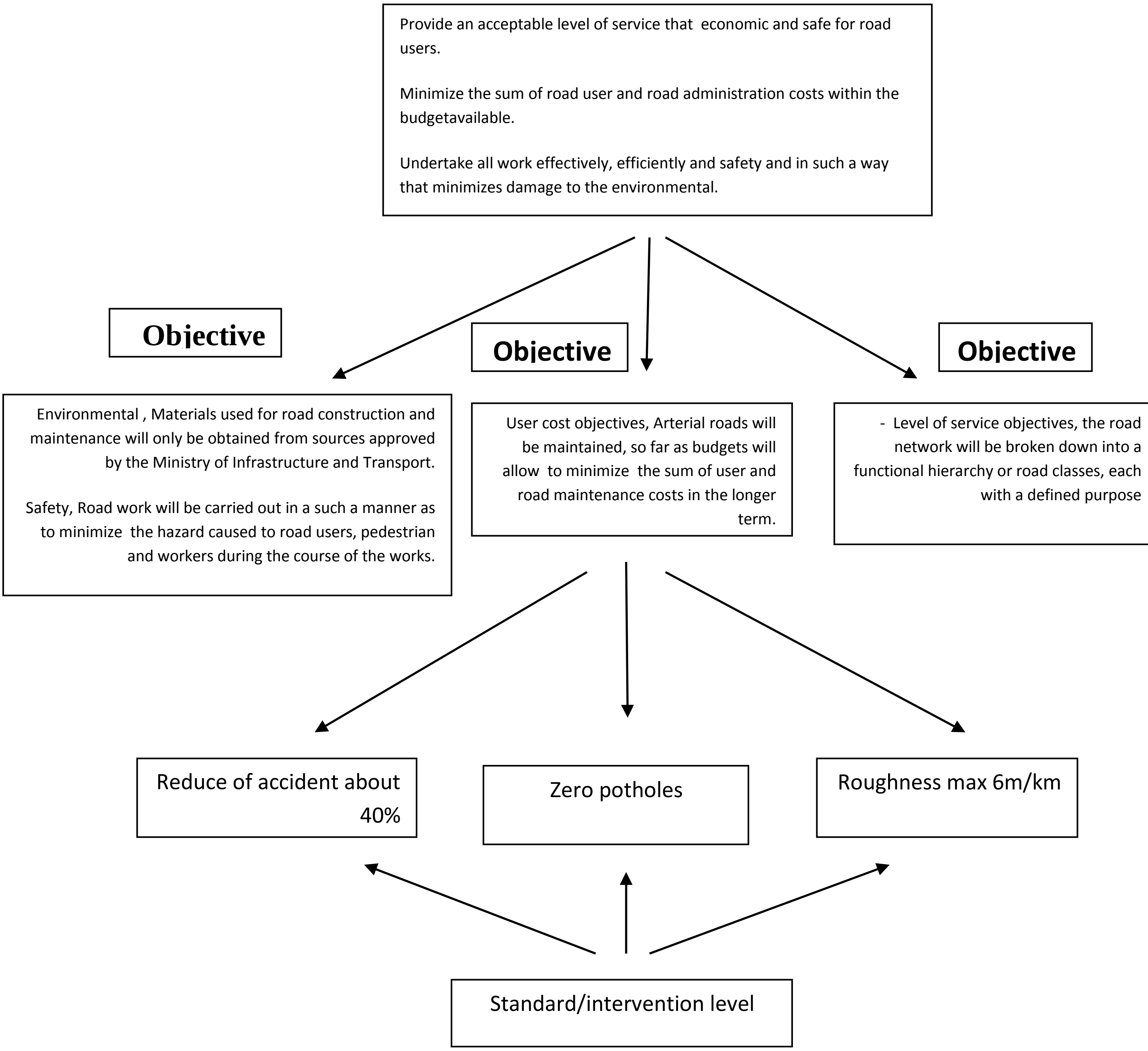

figure (2.7) Mission statement

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CHAPTER THREE

PavementCondition Survey Methodologies

The pavement condition survey and rating systems was implemented in KhartoumState (capital), study during 2012. The study s to certain road and all of them depend in rating system adopted y the American Asphalt Institute in the Information Series No. 169.

The 2012 PMS data collection methodology is including visual condition assessmentof potholes , cracking and raveling.

In coming pages brief description for the asphalt Institute rating method is presented, then full details for the adopted methodology implemented in this study is described and the results were analyzed.

3.1. Asphalt Institute Pavement Condition Rating Procedure

The asphalt Institute developed Pavement Condition Rating and issued this procedure in information series number (IS-169) during 1980th, Which is also attached into (MS-17) manual series as appendix. In that procedure pavement distress types like Rutting, corrugations, raveling, shoving, potholes, bleeding, polished aggregate and deficient drainage is identified and rated using scale ranged from 0 to 10.

An effective way of inspecting a pavement according to this procedure is to drive slowly over the road to get an overall impression of its condition. Then, make a thorough inspection on foot, taking rough notes on the type and extent of distress as one goes along. When the inspection is completed, the rating form is filled out. It may be useful to drive again slowly over the pavement after filling out the rating form. Since the system is based on personal judgment, better results are obtained when two or more experienced individuals independently rate the pavements and the results are averaged.

This method assumes that some distresses affect the performance of a pavement more than others. Under this rating system, the less serious observations are assigned values between zero (0) and five (5). Distress of a more serious nature – those directly related to the strength of the pavement – are rated on a scale of zero (0) to Ten (10). A rating of zero (0) means that the pavement is free of that particular type of distress.

When assigning a rating to a particular type of distress, it is important to consider both its extent and severity. For example, a rating of 10 for "rutting" would indicate that it occurs on most or all of the pavement, the ruts are probably deep enough to be a safety hazard (especially during rain), and it is an impediment to traffic at all times. On the other hand, a rating of 1 for "corrugations" would indicate that corrugations, although evident, are not numerous and that at present the distortions are not very large.

After each distress is rated, the individual distress ratings are added. This "Sum of Distresses" is then subtracted from 100, and the result is simply called the "condition rating," as shown in Figure (2.1).

3.1.1 Interpreting of the Condition Rating

There are two ways that the condition rating can be used. First, as a relative measurement, it provides a rational method for ranking paved streets or roads according to their condition. Secondly, as an absolute measure, the condition rating provides a general indicator of the type and degree of repair work necessary. As a very general rule, if the condition rating is between 80 and 100, normal maintenance operations such as crack sealing using emulsified asphalt like RS-2 and AC3, or crack filling, pot hole repair, or surface treatment like Fog seal using emulsions CSS-1 and SS-1 are usually all that is required. If the condition rating falls below 80, it is likely that an overlay will be necessary. And if the condition rating is below 30, major reconstruction is necessary, as illustrated by Figure (3.2).

HOT-MIX ASPHALT PAVEMENT RATING FORM

STREET/ROUTE NAME---

CITY COUNTY------------------------------------ DATE---

LENGTH OF PROJECT --------------------------- WIDTH--..

LOCATION OF SURVEY -------------------------WEATHER ---------------------------------------...

PAVEMENT TYPE --

NOTES --

(a rating of "0" indicates that the distress does not occur)

DISTRESS	RATING	SCORE
Transverse Cracks ---	0 to 5	---------------
Longitudinal Cracks --- -------	0 to 5	---------------
Alligator Cracks ---	0 to 10	---------------
Shrinkage Cracks --	0 to 5	---------------
Rutting --- ------	0 to 10	---------------
Corrugations ---	0 to 5	---------------
Raveling ---	0 to 5	---------------
Shoving and Pushing ---	0 to 10	--------------
Potholes ---	0 to 10	---------------
Excess Asphalt binder ---	0 to 10	---------------
Polished Aggregate --	0 to 5	---------------
Deficient Drainage ---	0 to 10	---------------
Overall Riding Quality (0 IS EXCELENT AND 100 IS VERY POOR) --	0 to 10	---------------

SUMM OF DISTRESS = -------------

Condition Rating = 100 – SUMM OF DISTRESS

= 100 - ----------------------

RATING = [ ]

Source: Information Series No. 169 (IS-169), asphalt institute

Figure (3. 1): Inspection Form, Asphalt Institute

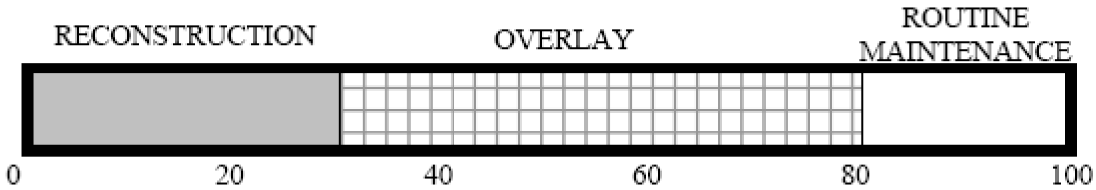

Figure (3 2): Condition Rating as Maintenance Indicator, Asphalt Institute

TRANSVERSE CRACK: A crack that follows a course approximately at right angles to the pavement centerline. This frequently is caused by movement in the pavement beneath the HMA layer (reflection cracking). It can also result from stresses induced by low-temperature contraction of the pavement. It may require sealing or filling with asphalt material. At a later date, this may be followed by an overlay or mill and fill over the entire surface.

LONGITUDINAL CRACK: A crack that follows a course approximately parallel to the centerline. This usually results from a weak joint between paving lanes. These cracks can also result from earth movements, particularly on embankments. Two closely-spaced longitudinal cracks in the wheel path usually indicate bending stress induced by rutting.

Longitudinal cracks can also occur as a result of movement in the pavement beneath the HMA layer (reflection cracking or stripping). For repair, see "Transverse Crack."

ALLIGATOR CRACKING: Interconnected cracks forming a series of small polygons, the pattern resembles an alligator's skin. It is caused by excessive deflection of the surface over unstable pavement base or subgrade layers that lead to fatigue failure. The unstable support usually is the result of saturated layer or layers or an unstable pavement design. It requires deep patching with HMA.

SHRINKAGE CRACKS: Interconnected cracks forming a series of large polygons, usually having sharp angles at the corners. It is caused by volume change in the base or subgrade. It requires monitoring of the hairline cracks, crack sealing, or fog treatment with asphalt material possibly followed by a surface treatment over the entire surface.

RUTTING: longitudinal depressions with a minimum length of at least 600 cm which formed under traffic, in the wheel paths, it is caused by consolidation or lateral movement under traffic in one or more of the underlying courses, or by displacement in the surface layer itself.

Ruts should be filled with HMA to restore proper cross-section. This should be followed by a thin overlay of HMA.

CORRUGATIONS: Transverse undulations at regular intervals in the surface of the pavement consisting of alternate, closely-spaced valleys and crests. It is caused by a lack of stability in the surface layers and requires repair before resurfacing. If the corrugated pavement has an aggregate base with a thick surfaced treatment, a satisfactory corrective measure is to mill off the surface, and replace with HMA. If the pavement has more than three inches (3”) of HMA, shallow corrugations can be removed with a pavement milling machine, better known as “cold milling.” This can be followed with a surface treatment or HMA overlay.

RAVELING: The progressive disintegration from the surface downward, or edges inward by the dislodgement of aggregate particles. It is caused by the original mix type, compaction capability during construction, construction during wet or cold weather, or overheating of the asphalt mix. It usually requires a surface treatment of some type.

SHOVING: A lateral displacement of paving material appears due to traffic, which generally resulting in the bulging of the surface. It is caused by lack of stability in the subgrade, base, or surface layers. It requires the removal of the affected area followed by deep patching with HMA.

POT HOLES: Bowl-shaped holes of varying sizes in the pavement, often resulting from the progressive deterioration of other distresses such as alligator cracking. It usually is caused by a combination of weaknesses in the pavement for the given traffic resulting from insufficient HMA surface thickness, too many or too few fines, and/or poor drainage. It requires removal of the affected area followed by deep patching with HMA.

EXCESS ASPHALT/BINDER (BLEEDING):

Free asphalt/binder on the surface of the pavement. It is caused by too much asphalt/binder in one or more of the surface layers. In many cases, bleeding can be corrected by repeated applications of hot sand, hot screenings, or hot rock screenings to blot up the excess asphalt/binder. Sometimes, when bleeding is light, a plant mixed surface treatment or an aggregate seal coat using absorptive aggregate is the only treatment needed. In rare instances of heavily over-asphalted surfaces, the surface should be completely removed and replaced with HMA.

POLISHED AGGREGATE:

Aggregates in the surface of the pavement that have been polished smooth. It is caused by naturally smooth, non-crushed gravels and/or crushed rock that wears down quickly under action of traffic. It requires covering the surface with a HMA treatment that has good frictional characteristics.

DEFICIENT DRAINAGE:

Drainage problems may be considered in two categories: surface and subsurface. Proper surface drainage efficiently removes runoff from the pavement and the nearby ground. Standing water on the pavement or in the side ditches indicates a drainage deficiency. Proper subsurface drainage keeps groundwater from the pavement structure. Two indicators of deficient subsurface drainage are: (1) constant water in the side ditch, possibly with cat tails growing, and in the absence of precipitation, or (2) alligator cracking with moisture in the cracks.

3.2 Pavement Condition Evaluation - ASTM Method

3.2.1 General

The coming pages describe the visual condition survey methodology adopted to determine the pavement condition for Khartoum State paved road Network, the one of the scope of this thesis. it provides a common method for describing distress on asphalt pavement in State of Khartoum road (centre of Khartoum) network like cracks, bleeding, bump and sags, potholes, patching, raveling, swelling, etc…, it improve communication within pavement community, by fostering more uniform and consistent definitions of pavement distress. Administration of public utilities in the state, airports, parking facilities and others will benefit from adaptation of common distress language. It can play an important role in developing of the strategic planning of road maintenance, and when detailed surveys were conducted, the inventory data can be used at project level.

This methodology is based on ASTM Standard D6433, 2003, which in turn is a verification of Paver system developed by U.S army of Engineers in 1997. {1}

This chapter includes the required instructions for conducting the visual study for all the paved roads classified as primary or secondary. These instructions provide a procedure for evaluating the surface condition of all paved roads in State of Khartoum (centre of Khartoum).

It is well known that the function of Pavement management system (PMS) is to improve the efficiency of decision making, expand its scope, provide feedback on the consequences of decisions, and insure the consistency of decisions made at different management levels within the same organization. This PMS has some essential requirements one of them is pavement condition, basic inventory, traffic data and others.

This chapter address two of the four major elements of deterioration contributes to pavement management systems, ride quality and distress, using visual inspection, the other components of pavement management system (PMS), which are Skid resistance and deflection or structural capacity and automated roughness measurements are not discussed here. It is clearly seen that, the use of this methodology will provide vital road condition data for researchers, decision makers and maintenance engineers to generate strategy, to develop PMS framework and data base and to select the suitable maintenance treatment at the project level.

The purpose of this methodology is to increase the awareness of importance of road maintenance and rehabilitation of Khartoum State paved road network and to provide a tool for formulating rational bases for assessment of pavement condition and evaluation options.

The methodology covers the determination of pavement condition, through visual surveys using the Pavement Condition Index (PCI) method, for quantifying pavement condition, and provides necessary information for scheduling pavement rehabilitation strategies for Khartoum State paved road network.

3.2.2 Approach

The Khartoum State paved road network is subdivided into links which are uniform in respect of traffic, environment, geometry, and pavement type and construction history. The links were subdivided into sections which are uniform in respect of pavement condition then the sections were subdivided in to sample units each of which of 100 linear meter length. For the purpose of this analysis the sample units were selected randomly in such way that not less than 60 % of each road section should be surveyed, and all type and severity of pavement distress were assessed by visual inspection for each sample unit and road section.

The distress data are used to calculate the PCI for each sample unit. The PCI of the pavement section is determined based on the PCI of the inspected sample units within the section.

The PCI is a numerical indicator that rates the surface condition of the pavement is adopted to measure the present condition of the pavement based on the distress observed on the surface of the surveyed sample units.

This procedure cannot measure directly the structural capacity nor does it provide direct measurement of skid resistance or roughness. It provides an objective and rational basis for determining Maintenance and repair needs and priorities. Continuous monitoring of the PCI is used to establish the rate of pavement deterioration, which permits early identification of major rehabilitation needs. The PCI provides feedback on pavement performance for validation or improvement of current pavement design and maintenance procedures.

Finally the list of links with some key parameters in respect of geometry, pavement structure, construction and rehabilitation has been developed as described here after.

3.2.3 Road Identification System

Road identification numbering system is considered one of the essential parts in the road management systems and related information systems, in order to link each road link or section with their information files containing geometric properties, history, traffic pavement and non-pavement elements, pavement condition and other necessary information used for road maintenance and rehabilitation or improvement programming or prediction of road pavement condition in the future and generating of maintenance and rehabilitation strategies using software.

The total road network in the State of Khartoum (Centre) is estimated to be 30 kilometers, 50 % (15 kilometers) of them are considered to be as urgent needs.

3.2.3.1 Methodology of Road's Identification

The existing roads network in transverse and longitudinal direction were identified, then the road network is classified in to two groups:

- East- West routes, parallel to Blue Nile
- North – South routes, perpendicular to Blue Nile

The number of main roads in all direction is 11, each of which composed of many sample units.

The road branch is a major road which has same history, construction year, and year of opening which linked between two major other roads, while the section is a subdivision from it which have similar traffic counts or maintenance history linking towns and small cities along the alignment.

The sample unit is a subdivision of sections of certain length, which should be decided by maintenance and planning directorate for the purpose of visual condition evaluation of pavements.

It is decided to assign odd numbers for the East – West (transverse) roads starting from extreme Northern of the center, and the even numbers for North-South (longitudinal) roads starting from extreme eastern of the center. As shown in Figure 3.1: location map

The road identification code (ID) is composed from two characters:

- First character is letter R which indicates word “Road”.
- The second digit is number (1, 2, …n) shows the road location with respect to the city center.

Map Figure (3.3) Network of Paved Road of Khartoum Centre

For example the identification number of the main Nile road is R1, while the next road parallel of the Nile road and south of it is Al Gamma road having ID number R.

Raters should thoroughly familiarize themselves with the visual survey methodology in order to establish reliable data for ratings, it will not be necessary to survey all entire length of street at one time. Each rater should carefully familiar with the area to be covered for a given study.

The following Table 3.1 reveals the Identification Number (ID) for the road section included in this thesis.

3.2.4 Definitions of Terms

1. Additional sample: Non-representative sample unit inspected in addition to the random sample units to include in the determination of the pavement condition. This includes very poor or excellent samples that are not typical of the section sample units, containing unusual distress (e.g. utility cut). If a

sample unit containing an unusual distress is chosen at random it should be counted as an additional sample unit and another random sample unit should be chosen. If every sample unit is surveyed, then there are no additional sample units.

2. Asphalt concrete (AC) surface: aggregate mixture with an asphalt cement binder. It includes all surfaces constructed with hot mix asphalt.
3. Pavement link: a link is an identifiable part of the pavement network that is a single entity and has a distinct function. For example, each roadway is a separate link.
4. Pavement condition index (PCI): a numerical rating of the Pavement condition that ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition.
5. Pavement condition rating: a verbal description of pavement condition as a function of the PCI value that varies from "failed" to "excellent"
6. Pavement distress: external indicators of pavement deterioration caused by loading, environmental factors, construction deficiencies, or a combination thereof. Typical distresses are cracks, rutting, and weathering of the pavement surface. Distress types and severity levels detailed in this methodology for AC pavements must be used to obtain an accurate PCI value.

Table 3.1: Road Name and ID Number

NUMBER	SECTION NAME	SECTION ID	LENGTH (km)
1	Nile avenue	R 1	5.9
2	Al Gamma street	R3	4.15
3	El Gamhoria street	R5	1.5
4	El Baladia street	R7	3.85
5	El Said Abdel Rahman	R9	2.65
6	El imam El mahdi south	R11	3.45
7	El mak Nimir	R4	1.5
8	El Gasr	R6	1.45
9	Abdel Moniem mahammed	R8	1.5
10	E l Horia	R10	1.45
11	Ali Abdel Lateef	R12	1.4

7. Pavement sample unit: a subdivision of a pavement section that has a standard length of 5000 contiguous linear meter, if the unit lies at the end of pavement section, its length should be selected to accommodate field condition.

8. Pavement section: a contiguous pavement area having uniform construction, maintenance, usage history, and condition. A section should have the same traffic volume and load intensity.

9. Random sample: a sample unit of the pavement section selected for inspection by random sampling techniques, such as a random number table or systematic random procedure.

10. Spalling: Refer to further breaking of pavement or loss of materials around cracks and joints.

3.2.5 Tools

Data Sheets: or other field recording instruments that record at a minimum the following information, date, location, link, section, sample unit size, distress types, severity levels, quantities, and names of surveyors. Example data sheets for pavements are shown in Table 3.2.

- Hand Odometer: Wheel that reads to the nearest 30 mm.
- Straightedge 3 m
- Scale, 300 mm that reads to 3 mm or better
- Layout Plan, for network to be inspected.
- Digital camera.
- Safety tools.

3.2.6 Types of distress on asphalt pavement

During the field condition surveys and validation of the PCI, several questions are commonly asked about the identification and measurement of some of the distresses. The answers to these questions for each distress are included under the heading “How to Measure.” For convenience, however, the most frequently raised issues are addressed below:

1. If alligator cracking and rutting occur in the same area, each is recorded separately at its respective severity level.

2. If bleeding is counted, polished aggregate is not counted in the same area.
3. Spalling as used herein is the further breaking of pavement or loss of materials around cracks or joints.
4. If a crack does not have the same severity level along its entire length, each portion of the crack having a different severity level should be recorded separately. If,
5. However, the different levels of severity in a portion of a crack cannot be easily divided, that portion should be rated at the highest severity level present.
6. If any distress, including cracking and potholes, is found in a patched area, it is not recorded, and however, its effect is considered in determining the severity level of the patch.
7. A significant amount of polished aggregate should be present before it is counted.
8. A distress is said to be raveled if the area surrounding the distress is broken (sometimes to the extent that pieces are removed).

To properly measure each distress type, the inspector must be familiar with its individual measurement criteria.

Nineteen distress types for asphalt-surfaced pavements are listed alphabetically in Appendix (A) and their severity and method of measurement is given in details in Table 3.4, at the end of this chapter.

3.2.6.1 Ride Quality

Ride quality must be evaluated in order to establish a severity level for the following distress types:

- Bumps.
- Corrugation.
- Railroad crossings.
- Shoving.

To determine the effect of these distresses on ride quality, the inspector should drive at the normal operating speed and use the following severity-level definitions of ride quality:

Low Severity (L): Vehicle vibrations, for example, from corrugation, are noticeable, but no reduction in speed is necessary for comfort or safety. Individual bumps or settlements, or both, cause the vehicle to bounce slightly, but create little discomfort.

Medium Severity (M): Vehicle vibrations are significant and some reduction in speed is necessary for safety and Comfort. Individual bumps or settlements, or both, cause the vehicle to bounce significantly, creating some discomfort.

High Severity (H): Vehicle vibrations are so excessive that speed must be reduced considerably for safety and comfort. Individual bumps or settlements, or both, cause the vehicle to bounce excessively, creating substantial discomfort, safety hazard, or high potential vehicle damage.

The inspector should drive a car at the normal speed in a representative section during normal traffic flow. Pavement sections near stop signs should be rated at a deceleration speed appropriate for the intersection.

3.2.6.2 Alligator Cracking (Fatigue)

Alligator or fatigue cracking is a series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading. Cracking begins at the bottom of the asphalt surface, or stabilized base, where tensile stress and strain are highest under a wheel load. The cracks propagate to the surface initially as a series of parallel longitudinal cracks. After repeated traffic loading, the cracks connect, forming many sided, sharp-angled pieces that develop a pattern resembling chicken wire or the skin of an alligator. The pieces are generally less than 0.5 m on the longest side. Alligator cracking occurs only in areas subjected to repeated traffic loading, such as wheel paths. Pattern-type cracking that occurs over an entire area not subjected to loading is called “block cracking,” which is not a load associated distress.

3.2.6.3 Bleeding

Bleeding is a film of bituminous material on the pavement surface that creates a shiny, glasslike, reflecting surface that usually becomes quite sticky. Bleeding is caused by excessive amounts of asphalt cement or tars in the mix, excess application of a bituminous sealant, or low air void content, or a combination thereof. It occurs when asphalt fills the voids of the mix during hot weather and then expands onto the pavement surface. Since the bleeding process is not reversible during cold weather, asphalt will accumulate on the surface.

3.2.6.4 Block Cracking

Block cracks are interconnected cracks that divide the pavement into approximately rectangular pieces. The blocks may range in size from approximately 0.3 by 0.3 m to 3 by 3 m. Block cracking is caused mainly by shrinkage of the asphalt concrete and daily temperature cycling, which results in daily stress/strain cycling.

It is not load-associated. Block cracking usually indicates that the asphalt has hardened significantly. Block cracking normally occurs over a large portion of the pavement area, but sometimes will occur only in non-traffic areas. This type of distress differs from alligator cracking in that alligator cracks form smaller, many-sided pieces with sharp angles. Also, unlike block, alligator cracks are caused by repeated traffic loadings, and therefore, are found only in traffic areas, that is, wheel paths.

3.2.6.5 Upheaval and Settlements

Upheavals are small, localized, upward displacements of the pavement surface. They are different from shoves in that shoves are caused by unstable pavement. Bumps, on the other hand, can be caused by several factors, including:

Infiltration and buildup of material in a crack in combination with traffic loading (sometimes called “tenting”).

Settlements are small, abrupt, downward displacements of the pavement surface. If bumps appear in a pattern perpendicular to traffic flow and are spaced at less than 3 m, the distress is called corrugation. Distortion and displacement that occur over large areas of the pavement surface, causing large or long dips, or both, in the pavement should be recorded as “swelling.”

3.2.6.6 Corrugation

It is a series of closely spaced ridges and valleys (ripples) occurring at fairly regular intervals, usually less than 3 m along the pavement. The ridges are perpendicular to the traffic direction. This type of distress usually is caused by traffic action combined with an unstable pavement surface or base.

3.2.6.7 Depression

Depressions are localized pavement surface areas with elevations slightly lower than those of the surrounding pavement. In many instances, light depressions are not noticeable until after a rain, when ponding water creates a “birdbath” area; on dry pavement, depressions can be spotted by looking for stains caused by ponding water. Depressions are created by settlement of the foundation soil or are a result of improper construction. Depressions cause some roughness, and when deep enough or filled with water, can cause hydroplaning.

3.2.6.8 Edge Cracking

Edge cracks are parallel to and usually within 0.3 to 0.5 m of the outer edge of the pavement. This distress is accelerated by traffic loading and can be caused by weak base or Subgrade near the edge of the pavement. The area between the crack and pavement edge is classified as raveled if it is broken up (sometimes to the extent that pieces are removed).

3.2.6.9 Lane/Shoulders Drop-off

Lane/shoulder drop-off is a difference in elevation between the pavement edge and the shoulder. This distress is caused by shoulder erosion, shoulder settlement, or by building up the roadway without adjusting the shoulder level.

3.2.6.10 Longitudinal and Transverse cracking

Longitudinal cracks are parallel to the pavement's centerline or lay down direction. They may be caused by:

- A poorly constructed paving lane joint.
- Shrinkage of the AC surface due to low temperatures or hardening of the asphalt, or daily temperature cycling, or both.
- Transverse cracks extend across the pavement at approximately right angles to the pavement centerline or direction of lay down. These types of cracks are not usually load-associated.

3.2.6.11 Patching

A patch is an area of pavement that has been replaced with new material to repair the existing pavement. A patch is considered a defect no matter how well it is performing (a patched area or adjacent area usually does not perform as well as an original pavement section). Generally, some roughness is associated with this distress.

3.2.6.12 Polishing

This distress is caused by repeated traffic applications. Polished aggregate is present when close examination of a pavement reveals that the portion of aggregate extending above the asphalt is either very small, or there are no rough or angular aggregate particles to provide good skid resistance. When the aggregate in the surface becomes smooth to the touch, adhesion with vehicle tires is considerably reduced. When the portion of aggregate extending above the surface is small, the pavement texture does not significantly contribute to reducing vehicle speed.

Polished aggregate should be counted when close examination reveals that the aggregate extending above the asphalt is negligible, and the surface aggregate is smooth to the touch. This type of distress is indicated when the number on a skid resistance test is low or has dropped significantly from a previous rating.

No degrees of severity are defined; however, the degree of polishing should be clearly evident in the sample unit in that the aggregate surface should be smooth to the touch.

3.2.6.13 Potholes

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

3.2.6.14 Railroad Crossings

Railroad crossing defects are depressions or bumps around, or between tracks, or both. in this Methodology shows degree of severities and how to measure this type of distress

3.2.6.15 Raveling

Weathering and raveling are the wearing away of the pavement surface due to a loss of asphalt or tar binder and dislodged aggregate particles. These distresses indicate that either the asphalt binder has hardened appreciably or that a poor-quality mixture is present. In addition, raveling may be caused by certain types of traffic, for example, tracked vehicles. Softening of the surface and dislodging of the aggregates due to oil spillage also are included under raveling.

3.2.6.16 Reflection Cracks

This distress occurs only on asphalt surfaced pavements that have been laid over a PCC slab and include reflection cracks from any other type of base, that is, cement- or lime-stabilized; these cracks are caused mainly by thermal- or moisture-induced movement of the pavement layer beneath the AC surface. This distress is not load-related; however, traffic loading may cause a breakdown of the AC surface near the crack. If the pavement is fragmented along a crack, the crack is said to be spelled.

3.2.6.17 Rutting

A rut is a surface depression in the wheel paths. Pavement uplift may occur along the sides of the rut, but, in many instances, ruts are noticeable only after a rainfall when the paths are filled with water.

Rutting stems from a permanent deformation, in any of the pavement layers or Subgrade, usually, caused by consolidated or lateral movement of the materials due to traffic load.

3.2.6.18 Shoving

Shoving is a permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic loading. When traffic pushes against the pavement, it produces a short, abrupt wave in the pavement surface. This distress normally occurs often in unstable liquid asphalt mix (cutback or emulsion) pavements.

3.2.6.19 Slippage Cracks

Slippage cracks are crescent or half moon shaped cracks, usually transverse to the direction of travel. They are produced when braking or turning wheels cause the pavement surface to slide or deform. This distress usually occurs in overlaps when there is a poor bond between the surface and the next layer of the pavement structure.

3.2.6.20 Swell

Swell is characterized by an upward bulge in the pavement's surface, a long, gradual wave more than 3 m long. Swelling can be accompanied by surface cracking.

This distress usually is caused by frost action in the Subgrade or by swelling soil.

3.2.7 Distress Measurements

Excluding Bumps, Corrugation, Railroad crossings and Shoving all other types of distress either measured in linear meter or square meter, Table (3.4) shows the method of measurements of the different distress types of asphalt pavement

3.2.8 Distress Identification and Rating Procedure

3.2.8.1 Sampling and Sample Units

The following procedure shall be followed in order to identify branches of the pavement with different uses such as roadways on the network layout plan.

Divide each branch into sections based on the pavements design, construction history, traffic, condition and according to network coding and numbering system.

Divide the pavement sections into sample units. Individual sample units to be inspected should be marked or identified in a manner to allow inspectors and quality control personnel to easily locate them on the pavement surface. Paint marks along the edge and sketches with locations connected to physical pavement features are acceptable. It is necessary to be able to accurately relocate the sample units to allow verification of current distress data, to examine changes in condition with time of a particular sample unit, and to enable future inspections of the same sample unit if desired.

Select the sample units to be inspected. The number of sample units to be inspected may vary from the following: all of the sample units in the section, a number of sample units that provides a 95 % confidence level, or a lesser number.

All sample units in the section may be inspected to determine the average PCI of the section. This is usually precluded for routine management purposes by available manpower, funds, and time. Total sampling, however, is desirable for project analysis to help estimate maintenance and repair quantities.

The minimum number of sample units (n) that must be surveyed within a given section to obtain a statistically adequate estimate (95 % confidence) of the PCI of the section is calculated using the following formula and rounding (n) to the next highest whole number (see equation Eq. 3.1 below).

$$n = NS^2 /((e^2 / 4)(N-1) + S^2) \qquad \text{- Eq (3.1)}$$

Where, = acceptable error in estimating the section

PCI; commonly, e = ±5 PCI points;

s = standard deviation of the PCI from one sample unit to another within the section. When performing the initial inspection the standard deviation is assumed to be ten for AC pavements. This assumption should be checked as described below after PCI values are determined. For subsequent inspections, the standard deviation from the preceding inspection should be used to determine n; and,

N = total number of sample units in the section.

If obtaining the 95 % confidence level is critical, the adequacy of the number of sample units surveyed must be confirmed.

The number of sample units was estimated based on an assumed standard deviation. Calculate the actual standard Deviation as follows (see equation Eq.3.2 below)

$$S = (\sum_{t=1}^{n} (PCI_i - PCI_s)^2 /(n-1))^{1/2} \qquad \text{- Eq. (3.2)}$$

Where:

PCI_i = PCI of surveyed sample units i,

PCI_s = PCI of section (mean PCI of surveyed sample units), and n = total number of sample units surveyed.

Calculate the revised minimum number of sample units (Eq.3.1) to be surveyed using the calculated standard deviation (Eq.3.2).

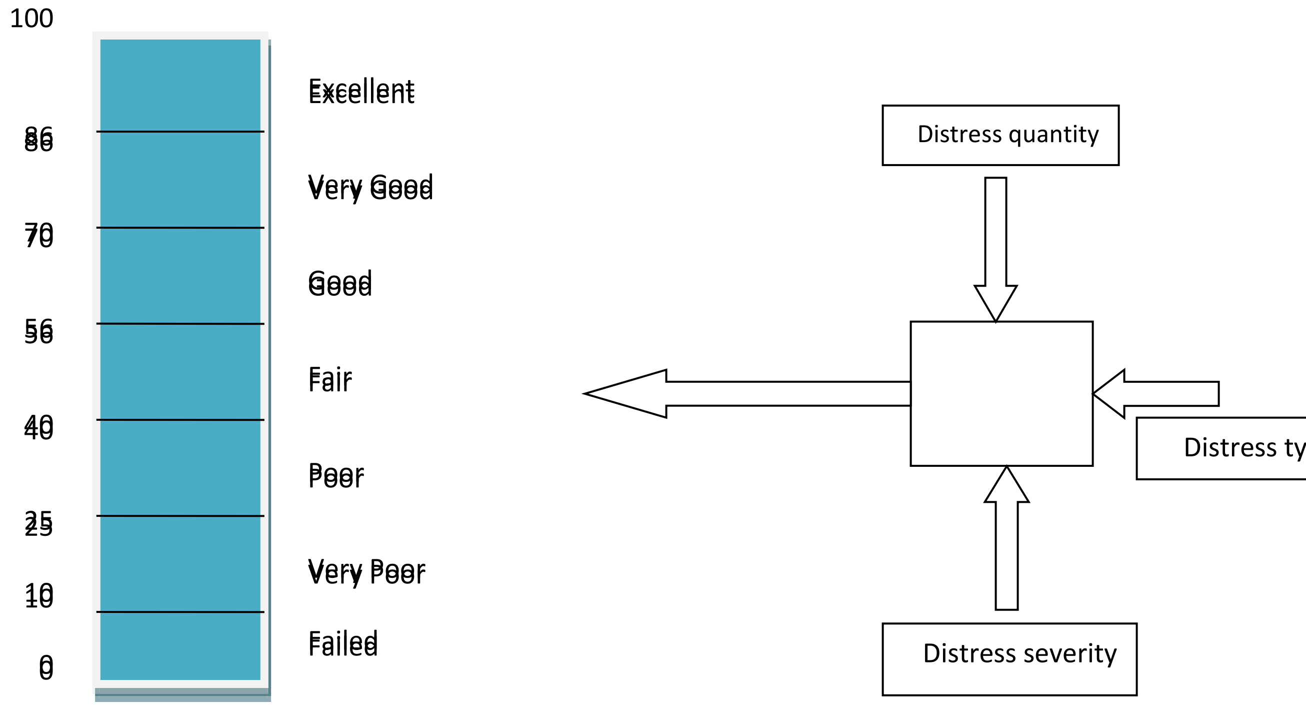

Fig 3.4 : Pavement Condition Index (PCI) and Rating

If the revised number of sample units to be surveyed is greater than the number of sample units already surveyed, select and survey additional random sample units.

These sample units should be spaced evenly across the section. Repeat the process of checking the revised number of sample units and surveying additional random sample units until the total number of sample units surveyed equals or exceeds the minimum required sample units (n) in Eq 1, using the actual total sample standard deviation.

3.2.8.2 Inspection Procedure

Individually inspect each sample unit chosen. Sketch the sample unit, including orientation.

Record the branch and section number and the number and type of the sample unit (random or additional). Record the sample unit size measured with the hand odometer or measuring tape.

Once the number of sample units to be inspected has been determined, compute the spacing interval of the units using systematic random sampling. Samples are spaced equally throughout the section with the first sample selected at random.

The spacing interval (I) of the units to be sampled is calculated by the following formula rounded to the next lowest whole number:

$$I = N / n \qquad \text{- Eq. (3.3)}$$

Where:

N = total number of sample units in the section, and

n = number of sample units to be inspected.

The first sample unit to be inspected is selected at random from sample units 1 through i. The sample units within a section that are successive increments of the interval i after the first randomly selected unit also are inspected.

A lesser sampling rate than the above mentioned 95 % Confidence level can be used based on the condition survey Objective. As an example, one agency uses the following table for selecting the number of sample units to be inspected for strategy or programming analysis purposes rather than project analysis: Given Survey.

Table (3.2) No of unit in section and sample inspected

No of sample unit in the road section	No of sample units to inspected
1 to 5	1
6 to 10	2
11 to 15	3
16 to 40	4
Greater than 40	Greater than 10

Additional sample units only are to be inspected when no representative distresses are observed as defined before. These sample units are selected by the user.

Conduct the distress inspection by walking over the sidewalk/shoulder of the sample unit being surveyed, measuring the quantity of each severity level of every distress type present, and recording the data. Each distress must correspond in type and severity to that described in this methodology the method of measurement is included with each distress description. Repeat this procedure for each sample unit to be inspected. A copy of a Blank Flexible Pavement Condition Survey Data Sheet for Sample Unit is included in Table 3.3 at the end of this chapter.

3.2.8.3 Calculation of PCI

1. Add up the total quantity of each distress type at each severity level, and record them in the "Total Severities" section. For example, Table 3.4 shows five entries for the Distress Type alligator cracking, edge cracking, patching, potholes and rutting with different severities. The distress at each severity level is summed and entered in the "Total Severity" of low severity or medium severity or high severities. The units for the quantities shall be in square meters, linear meters, or number of occurrences, depending on the distress type.

2. Divide the total quantity of each distress type at each severity level as determined above by the total area of the sample unit and multiply by 100 to obtain the percent density of each distress type and severity.

3. Determine the deduct value (DV) for each distress type and severity level combination from the distress deduct value curves showed in Appendix (A),

4. Determine the Maximum Corrected Deduct value (CDV) according to the following procedure:

- If none or only one individual deduct value is greater than two, the total value is used in place of the maximum CDV in determining the PCI; otherwise, maximum CDV must be determined using the procedure described in the following.
- List the individual deducts values in descending order. For example, in **Table 3.7** this will be 25, 20, 8,7,5,4 and 3.
- Determine the allowable number of deducts (*m*), using the following formula (Eq3.4):

$$m = 1 + (9/98)(100 - HDV) \leq 10 \quad \text{- Eq. (3.4)}$$

Where:

m = allowable number of deducts including fractions (must be less than or equal to ten), and

HDV = highest individual deduct value.

(For example in Table 3.7,)

m = 1 + (9/98) (100-25) = 7.9).

The number of the individual deduct values is reduced to the *(m)* largest deduct values, including the fractional part. For example in Table 3.6, the values are 25, 20, 8, 7, 5, 4 and 3 (the number of deduct values available in this example is less than *(m)* deduct values, in this case use all of the deduct values without a reduction of the last deduct value (Ex. 1, Table 3.5).

In the second case (using data Table (3.5), the number of deduct values will be greater than the *(m)* value, the reduction shall be calculated as follows: reduce the last value by multiplying it with the difference between calculated *(m)* value and the number of deduct values less than the allowable ones. (See Ex.2, Table(3.6).

1. Determine total deduct value by summing individual deduct values. The total deduct value is obtained by adding the individual deduct values in Example (1) is 72 and in Example (2) is = 88.7.
2. Determine q as the number of deducts with a value greater than 2.0. For examples in Table 3.5 = 7 and in Table 3.6, q =8.
3. Determine the CDV from total deduct value and q by looking up the appropriate correction curve for asphalt concrete pavements in Fig. 20 in Appendix (B).
4. Reduce the smallest individual deduct value greater than 2.0 to 2.0 and repeat the last three steps until q = 1, (see Ex. 2).
5. Maximum CDV is the largest of the CDV.
6. Calculate PCI by subtracting the maximum CDV from 100: PCI = 100-max CDV.

Table 3.7 shows PCI calculation for the asphalt concrete pavement example data presented in Table 3.6, and Table 3.7 shows PCI calculation for the asphalt concrete pavement.

3.2.8.4 Determination of Section PCI

If all surveyed sample units are selected randomly or if every sample unit is surveyed then the PCI of the section is the average of the PCI of the sample units. If additional sample units, as defined in before, are surveyed then a weighted average is used as follows:

$$PCI_S = (N - A)(PCI_R)/N + A(PCI_A)/N \qquad \textbf{Eq. 3.5}$$

Where:

PCI_S = weighted PCI of the section,

N = total number of sample units in the section,

A = number of additional sample units,

PCI_R = mean PCI of randomly selected sample units, and

PCI_A = mean PCI of additional selected sample units.

Determine the overall condition rating of the section by using the section PCI and the condition rating scale in Fig. 3.3.

A summary report shall be developed for each section. The summary shall lists all section location, size, total number of sample units, the sample units inspected, the PCIs obtained, the average PCI for the section, and the section condition rating these data shall be stored on the available data base.

3.2.9 Results of Visual Condition Survey

The survey covers the road network with total length of 30km; the survey covers at least 60 % from the length of each section in order to assure the reliability of the data. The visual condition survey is completed, and the row data were collected analyzed and interpolated and the results are as follows:

Table 3.7 at the end of this chapter shows the PCI values for the road sections included in this study, Figure 3.1(Map) shows road link subjected to visual condition survey, Figure 3.7 shows the average pavement condition index (PCI) value in each road link, table 3.8 shows the percentage of road length covered with visual condition survey with respect to the total length and Figure 3.5 shows the relative percentage of each distress compared to the paved surface area of all length covered by the visual survey.

These figures and graphs reveal the following:

-Two streets subjected to visual condition evaluation their condition is fair, it

Needs cut and patch of pothole and alligator crack areas, then, asphalt oerlay urgently (Al gasr and Nile Avenue)

- There is in good condition they should be under closed jurisdiction (Al gamohria, Albaladia and Al mak nimr). When they fall to fair condition and overlay should be constructed

-The other streets should be monitored by condition evaluation continued every three years.

-A routine maintenance should be applied to the network every year including pothole, patching and crack sealing.

Table3.3: Condition Survey Data Sheet

<table>
<tr><td colspan="12">Asphalt Road Condition Survey Data Sheet</td><td colspan="3" rowspan="4">Sketch</td></tr>
<tr><td>Link ....</td><td colspan="4">Section……………………</td><td colspan="7">Sample Unit………………………………</td></tr>
<tr><td>Surveyed by:…..........</td><td colspan="4">Date ……………………...</td><td colspan="7">Sample area………………………………</td></tr>
<tr><td>1. Alligator cracks
2. Bleeding
3. Block cracks
4. Upheaval & Settlement</td><td colspan="4">5. Corrugation
6. Depression
7. Edge cracks
8. Lane/shoulder drop off
9. Long. & Trans. Cracks</td><td colspan="4">10. Patching
11. Polishing
12. Potholes
13. Rail/Road cross.
14. Raveling</td><td colspan="3">15. Reflection Cracks
16. Rutting
17. Shoving
18. Slippage cracks
19. Swell</td></tr>
<tr><td>Distress Severity</td><td colspan="11">Quantity</td><td>Total</td><td>Density
%</td><td>Deduct value</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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</table>

Table 3.4: Distress Severity and Method of Measurements

No.	Type	Severity levels			How to Measure
		Low (L)	**Medium (M)**	**High (H)**	
1	Alligator Cracking	Fine, longitudinal hairline cracks running parallel to each other with no, or only a few interconnecting cracks. The cracks are not spalled	further development of light alligator cracks into a pattern or network of cracks that may be lightly spalled	Network or pattern cracking has progressed so that the pieces are well defined and spalled at the edges. Some of the pieces may rock under traffic	Alligator cracking is measured in square meters of surface area. The major difficulty in measuring this type of distress is that two or three levels of severity often exist within one distressed area. If these portions can be easily distinguished from each other, they should be measured and recorded separately; however, if the different levels of severity cannot be divided easily, the entire area should be rated at the highest severity present. If alligator cracking and rutting occur in the same area, each is recorded separately as its respective severity level.
2	Bleeding	Bleeding only has occurred to a very slight degree and is noticeable only during some part of the year. Asphalt does not stick to shoes or vehicles	Bleeding has occurred to the extent that asphalt sticks to shoes and vehicles during only a few weeks of the year	Bleeding has occurred extensively and considerable asphalt sticks to shoes and vehicles during at least several weeks of the year	Bleeding is measured in square meter of surface area. If bleeding is counted, polished aggregate should not be counted.

No.	Type	Severity levels			How to Measure
		Low (L)	**Medium (M)**	**High (H)**	
3	Block Crack	1.If unfilled cracks ≤ 13 mm, or 2.filled cracks of any width with the filler in satisfactory condition. No faulting exists	1. unfilled crack with a width >13 and ≤50 mm. 2.unfilled crack of any width ≤ 50 mm with faulting of <10 mm, or 3. filled crack of any width with faulting <10mm	1.unfilled crack with a width >50 mm, or 2.filled or unfilled crack of any width with faulting >10 mm	Block cracking is measured in m2 of surface area. It usually occurs at one severity level in a given pavement section; however, if areas of different severity levels can be distinguished easily from one another, they should be measured and recorded separately
4	Upheaval & settlement	causes low-severity ride quality	causes medium-severity ride quality	causes high-severity ride quality	Measured in linear meters. If the bump occurs in combination with a crack, the crack also is recorded.
5	Corrugation	Corrugation produces low-severity ride quality	Corrugation produces medium-severity ride quality	Corrugation produces high-severity ride quality	Corrugation is measured in square meters of surface area
6	Depression	13 to 25 mm	25 to 50 mm	More than 50 mm	Depressions are measured in square meters of surface area.
7	Edge Cracking	Low or medium cracking with no breakup or raveling	Medium cracks with some breakup and raveling	Considerable breakup or raveling along the edge	Edge cracking is measure in linear meters.

No.	Type	Severity levels			How to Measure
		Low (L)	Medium (M)	High (H)	
8	Lane / Shoulder Drop-off	the difference in elevation between the pavement edge and shoulder is > 25 mm and< 50 mm	the difference in elevation is > 50 mm and < 100 mm	the difference in elevation is > 100 mm	Lane/shoulder drop-off is measured in linear meters.
9	Longitudinal / Transverse Cracking	1.filled crack width is less than 10 mm, or 2.filled crack of any width (filler in satisfactory condition).	1. .non-filled crack width is greater than or equal to 10 mm and less than 75 mm; 2. non-filled crack is less than or equal to 75 mm surrounded by light and random cracking; or, 3. filled crack of any width surrounded by light cracks	1. any crack filled or unfilled surrounded by medium- or .high-severity random cracking; 2. unfilled crack greater than 75 m; or, 3. a crack of any width where approximately 100 mm of pavement around the crack is severely broken.	Longitudinal and transverse cracks are measured in linear meters. The length and severity of each crack should be recorded. If the crack does not have the same severity level along its entire length, each portion of the crack having a different severity level should be recorded separately.
10	Patching	Patch is in good condition and satisfactory. Ride quality is rated as low severity or better	Patch is moderately deteriorated, or ride quality is rated as medium severity, or both	Patch is badly deteriorated, or ride quality is rated as high severity, or both; needs replacement soon	Patching is rated in m2 of surface area; however, if a single patch has areas of differing severity, these areas should be measured and recorded separately. For example, 2.5 m2 patch may have 1 m2 of medium severity and 1.5 m2 of low severity

<table>
<tr><th>No.</th><th>Type</th><th>Severity levels</th><th>How to Measure</th></tr>
<tr><td>11</td><td>Polishing</td><td>No degrees of severity are defined; however, the degree of polishing should be clearly evident in the sample unit in that the aggregate surface should be smooth to the touch</td><td>Polished aggregate is measured in square meters of surface area. If bleeding is counted, polished aggregate should not be counted.</td></tr>
<tr><td>12</td><td>Potholes</td><td>
<table>
<tr><td rowspan="2">Max. depth of pothole</td><td colspan="3">Average diameter</td></tr>
<tr><td>100 - 200 mm</td><td>200 - 450 mm</td><td>450 to 750 mm</td></tr>
<tr><td>13 to ≤ 25 mm</td><td>L</td><td>L</td><td>M</td></tr>
<tr><td>> 25 and ≤ 50 mm</td><td>L</td><td>M</td><td>H</td></tr>
<tr><td>> 50 mm</td><td>M</td><td>M</td><td>H

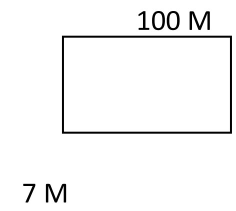
If the pothole is more than 750 mm in diameter, the area should be determined in square meter and divided by 0.5 m^2 find the equivalent number of holes. If the depth is 25 mm or less, the holes are considered medium-severity. If the depth is more than 25 mm, they are considered high-severity</td></tr>
</table>
</td><td>Potholes are measured by counting the number that are low-, medium-, and high-severity and recording them separately.</td></tr>
</table>

No.	Type	Severity levels			How to Measure
		Low (L)	**Medium (M)**	**High (H)**	
13	Rail-Road Crossings	Railroad crossing causes low-severity ride quality	Railroad crossing causes medium-severity ride quality	Railroad crossing causes high-severity ride Quality	The area of the crossing is measured in square meters of surface area. If the crossing does not affect ride quality, it should not be counted. Any large bump created by the tracks should be counted as part of the crossing
14	Raveling	Aggregate or binder has started to wear away. In some areas, the surface is starting to pit. In the case of oil spillage, the oil stain can be seen, but the surface is hard and cannot be penetrated with a coin.	Aggregate or binder has worn away. The surface texture is moderately rough and pitted. In the case of oil spillage, the surface is soft and can be penetrated with a coin.	Aggregate or binder has been worn away considerably. The surface texture is very rough and severely pitted. The pitted areas are less than 10 mm in diameter and less than 13 mm deep; pitted areas larger than this are counted as potholes. In the case of oil spillage, the asphalt binder has lost its binding effect and the aggregate has become loose.	Raveling are measured in square meters of surface area

No.	Type	Severity levels			How to Measure
		Low (L)	**Medium (M)**	**High (H)**	
15	Reflection Cracks	1.Unfilled crack width is less than 10 mm , or 2. filled crack of any width (filler L satisfactory condition).	1.Unfilled crack width is greater than or equal to 10mm and less than 75 mm; no 2. filled crack less than or equal to 75 mm surrounded by light secondary cracking; or, filled crack of any width surrounded by light secondary cracking	1.Any crack filled or unfilled surrounded by medium or high-severity secondary cracking; unfilled cracks greater than 75 mm or, 2. a crack of any width where approximately100 mm of pavement around the crack are severely raveled or broken	Reflection cracking is measured in linear meters. The length and severity level of each crack should be identified and recorded separately. For example, a crack that is 15 m long may have 3 m of high severity cracks, which are all recorded separately. If a Bump occurs at the reflection crack, it is recorded also.
16	Rutting (mean rut depth)	6 to 13 mm	>13 to 25 mm	>25 mm	Rutting is measured in square meters of surface area, and its severity is determined by the mean depth of the rut. The mean rut depth is calculated by laying a straight edge across the rut, measuring its depth along the length of the rut to compute its mean depth in millimeters.
17	Shoving	Shove causes low-severity ride quality	Shove causes medium-severity ride quality	Shove causes high-severity ride quality	Shoves are measured in square meters of surface area. Shoves occurring in patches are rating with the patch, not as a separately

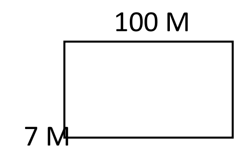
No.	Type	Severity levels			How to Measure
		Low (L)	**Medium (M)**	**High (H)**	
18	Slippage Cracks	Average crack width is < 10 mm	One of the following conditions exists average crack width is ≥ 10 and < 40 mm, or the area around the crack is moderately spalled, or surrounded with secondary cracks.	One of the following conditions exists the average crack width is > 40 mm, or the area around the crack is broken into easily removed pieces.	The area associated with a given slippage crack is measured in square meters and rated according to the highest level of severity in the area.
19	Swelling	Swell causes low severity ride quality. Low severity swells are not always easy to see but can be detected by driving at the speed limit over the pavement section. An upward motion will occur at the swell if it is present.	Swell causes medium-severity ride quality.	Swell causes high-severity ride quality.	The surface area of the swell is measured in square meters

Table 3.5: Example (1)

Asphalt Road Condition Survey Data Sheet				Sketch
Link	Section……………………	Sample unit………………………………		
Surveyed by:…...........	Date ……………………...	Sample area………………………………		
1. Alligator cracks 2. Bleeding 3. Block cracks 4. Upheaval & Settlement	5. Corrugation 6. Depression 7. Edge cracks 8. Lane/shoulder drop off 9. Long. & Trans. cracks	10. Patching 11. Polishing 12. Potholes 13. Rail/Road crosses. 14. Raveling	15. Reflection Cracks 16. Rutting 17. Shoving 18. Slippage cracks 19. Swell	

Distress severity	Quantity											Total	Density %	Deduct value
1L	1X1.5	1X1.2	1X1.2									3.9	0.56	7
1H	1X2.7	1X2										4.7	0.67	25
8L	7	5	6	4								22	3.1	4
10H	3X1.2	2X1.5										6.6	0.94	20
12L	1											1	0.14	3
18L	1X1.2	3X1	2.5X1									6.7	0.96	8
14L	84X1											84	12	5

Table 3.6: Example (2) Calculation

Asphalt Road Condition Survey Data Sheet				Sketch
Link	Section……………………	Sample unit………………………………		
Surveyed by:….........	Date ……………………...	Sample area………………………………		
5. Alligator cracks 6. Bleeding 7. Block cracks 8. Upheaval & Settlement	5. Corrugation 6. Depression 7. Edge cracks 8. Lane/shoulder drop off 9. Long. & Trans. Cracks	10. Patching 11. Polishing 12. Potholes 13. Rail/Road cross. 14. Raveling	15. Reflection Cracks 16. Rutting 17. Shoving 18. Slippage cracks 19. Swell	

Distress severity	Quantity											Total	Density %	Deduct value
1L	1X1.5	1X1.2	1X1.2									3.9	0.56	7
1H	1X2.7	1X2										4.7	0.67	25
8L	7	5	6	4								22	3.1	4
10H	3X1.2	2X1.5										6.6	0.94	20
12L	1											1	0.14	3
18L	1X1.2	3X1	2.5X1									6.7	0.96	8
14L	84X1											84	12	5
7H	3	2	5									11	1.6	17

Table 3.7: Follow Example (1) Calculation

No.	Deduct Values							Total	Q	CDV
1	25	20	8	7	5	4	3	72	7	34
2	25	20	8	7	5	4	2	71	6	32
3	25	20	8	7	5	2	2	69	5	35
4	25	20	8	7	2	2	2	66	4	37
5	25	20	8	2	2	2	2	61	3	39.5
6	25	20	2	2	2	2	2	55	2	41
7	25	2	2	2	2	2	2	37	1	35
8										
9										
10										

Note:

m = 1+ (9/98) (100-25)-7.9 < 8

Use highest 7 deducts without a reduction of the eighth deduct

Max CDV = 41

PCI = (100-Max CDV) = 59

Rating =Good

Table 3.8: Follow Example (2) Calculation

No.		Deduct Values							Total	Q	CDV
1	25	20	17	8	7	5	4	2.7	88.7	8	42
2	25	20	17	8	7	5	4	2	88	7	41
3	25	20	17	8	7	5	2	2	86	6	45
4	25	20	17	8	7	2	2	2	83	5	48
5	25	20	17	8	2	2	2	2	78	4	44
6	25	20	17	2	2	2	2	2	72	3	47
7	25	20	2	2	2	2	2	2	57	2	42.5
8	25	2	2	2	2	2	2	2	39	1	37
9											
10											

Note:

$m = 1 + (9/98)(100-25) - 7.9 < 8$

Max CDV = 48

PCI = (100-Max CDV) = 52

Rating =Fair

Table3.9: PCI Result for Road Sections

STREET NAME	STREET ID	T. UNIT SAMPLE	S.U.SAMPLES	LENGTH KM	MEAN PCI	RATING	%OF SURVEYED. LENGTH
Nile avenue	R 1	10	3	5.9	52	Fair	60
Al Gamma street	R3	8	3	4.5	60	Good	60
El Gamhoria street	R5	3	1	1.5	96	Excellent	67
El ssBaladia street	R7	7	3	3.85	60	Good	60
El Said Abdel Rahman	R9	5	3	2.65	86	Excellent	70
El imam El mahdi	R2	8	3	4.65	70	V. good	68
El mak Nimir	R4	3	1	1.5	60	Good	67
El Gasr	R6	3	1	1.45	52	Fair	67
Abdel Moniem mahammed	R8	3	1	1.5	86	Excellent	67
E l Horia	R10	3	1	1.5	78	V. good	67
Ali Abdel Lateef	R12	3	1	1.45	78	V. good	67
STANDARD DEVIATION OF PCI							
AVERAGE PCI					70		
TOTAL LENGTH, KM					30		

Table 3.10: Distress Percentages Compared to total surface area of All Surveyed Street

Type of Distress	relative% of Distress compared toTotal Surface Area of all Roads
ALLIG. CRACKS	7.4
BLOCK CRACKS.	18.4
CORRUGATIONS	4.2
UPHEVAL.& SETTLEMENT	4.7
BLEEDING	0.1
DEPRESSION	9.6
EDGE CRACK	0.0
LANE /SH.DROP	4.2
LONG.& TRANS. CR.	23.4
PATCHING	8.4
POLISHING	0.0
RAIL/ROAD CROS.	0.0
POTHOLES	17.9
RAVELING	0,0
REFLECTION CR.	0.0
RUTTING	0.05
SHOVING	0.0
SLIPAGE CRACKS	0.0
SWELLING	0.0

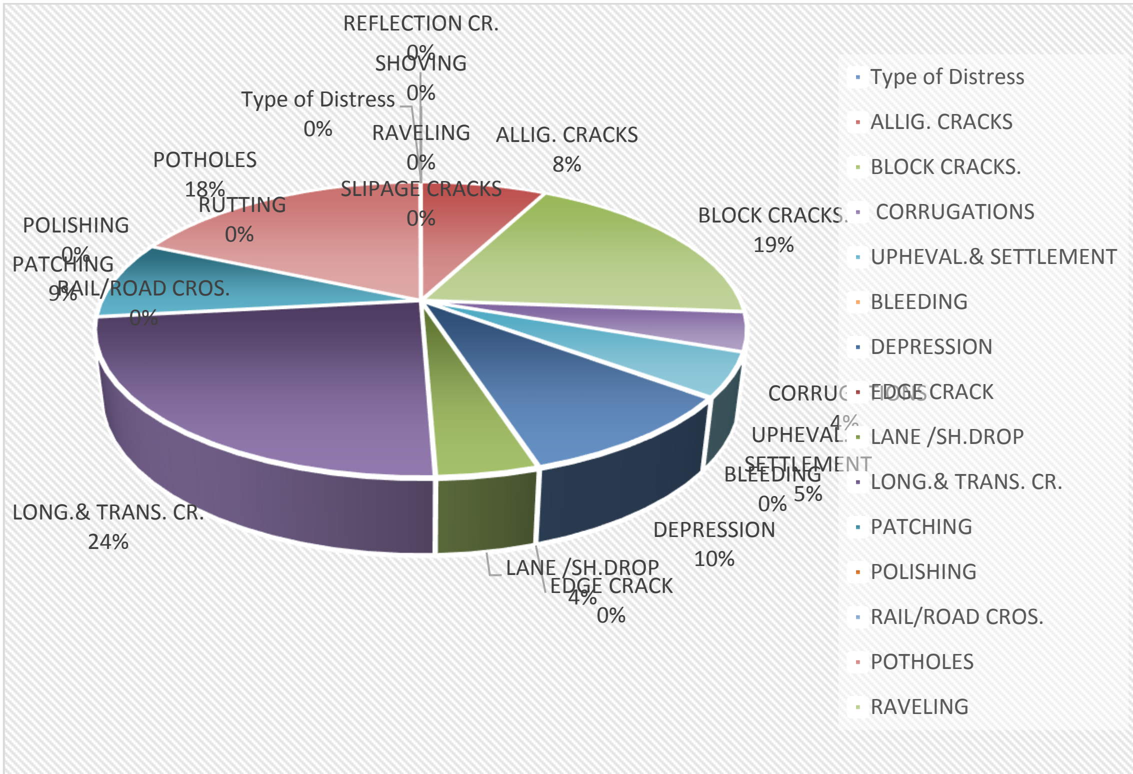


Figure 3.5: Distress Percentages Compared to total surface area of All Surveyed Street

The Figure (3.6) reveals the following:

- Two streets subjected to visual condition evaluation their condition is fair, it needs cut and patch of pothole and alligator crack areas, then, asphalt overlay urgently (Al gasr and Nile Avenue).
- Three is in good conditions they should be under closed jurisdiction (Al gamoria, Al baldia, and Al mak nimr) when they fall to fair condition an overlay should be constructed.
- The other streets should be monitored by condition evaluation continued every three years.
- A routine maintenance should be applied to the network every year including pothole patching and crack sealing.

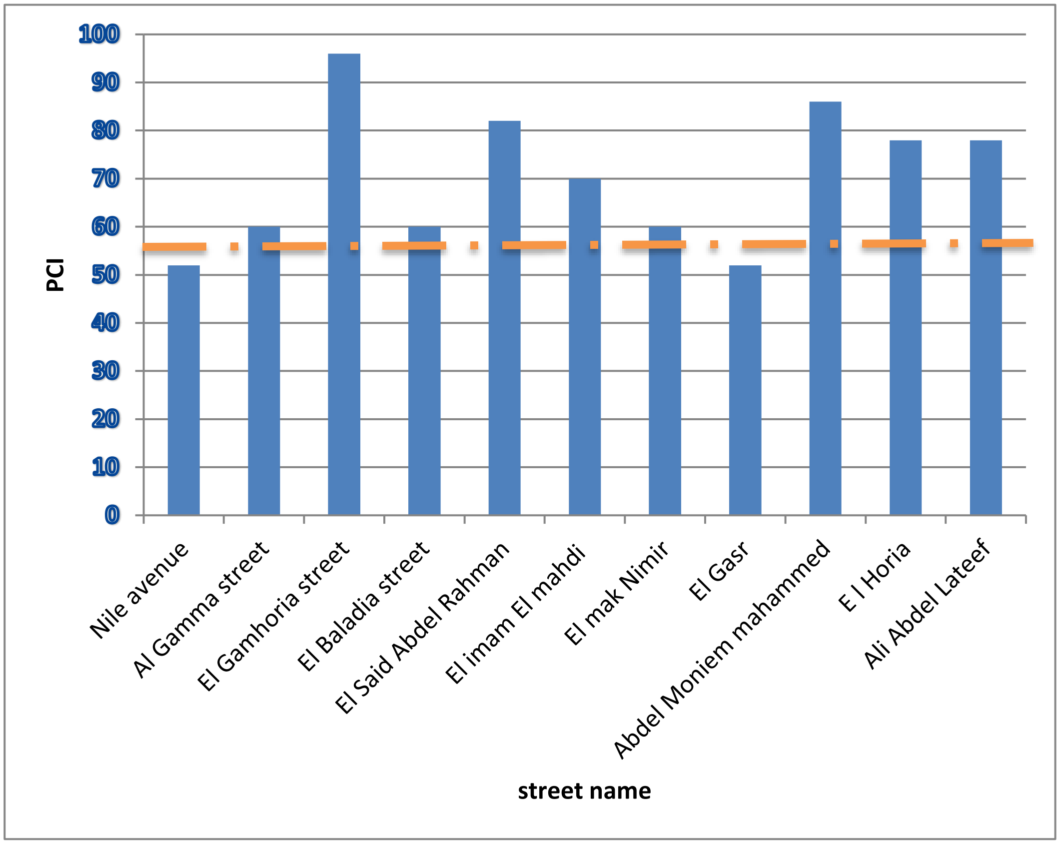


Figure 3.6: the average pavement condition index (PCI) values

This Figure reveals the following:

- Two streets subjected to visual condition evaluation their condition is fair, it needs cut and patch of pothole and alligator crack areas, then, asphalt overlay urgently (Al gasr and Nile Avenue).
- Three is in good conditions they should be under closed jurisdiction (Al gamoria, Al baldia, and Al mak nimr) when they fall to fair condition an overlay should be constructed.
- The other streets should be monitored by condition evaluation continued every three years.
- A routine maintenance should be applied to the network every year including pothole patching and crack sealing.

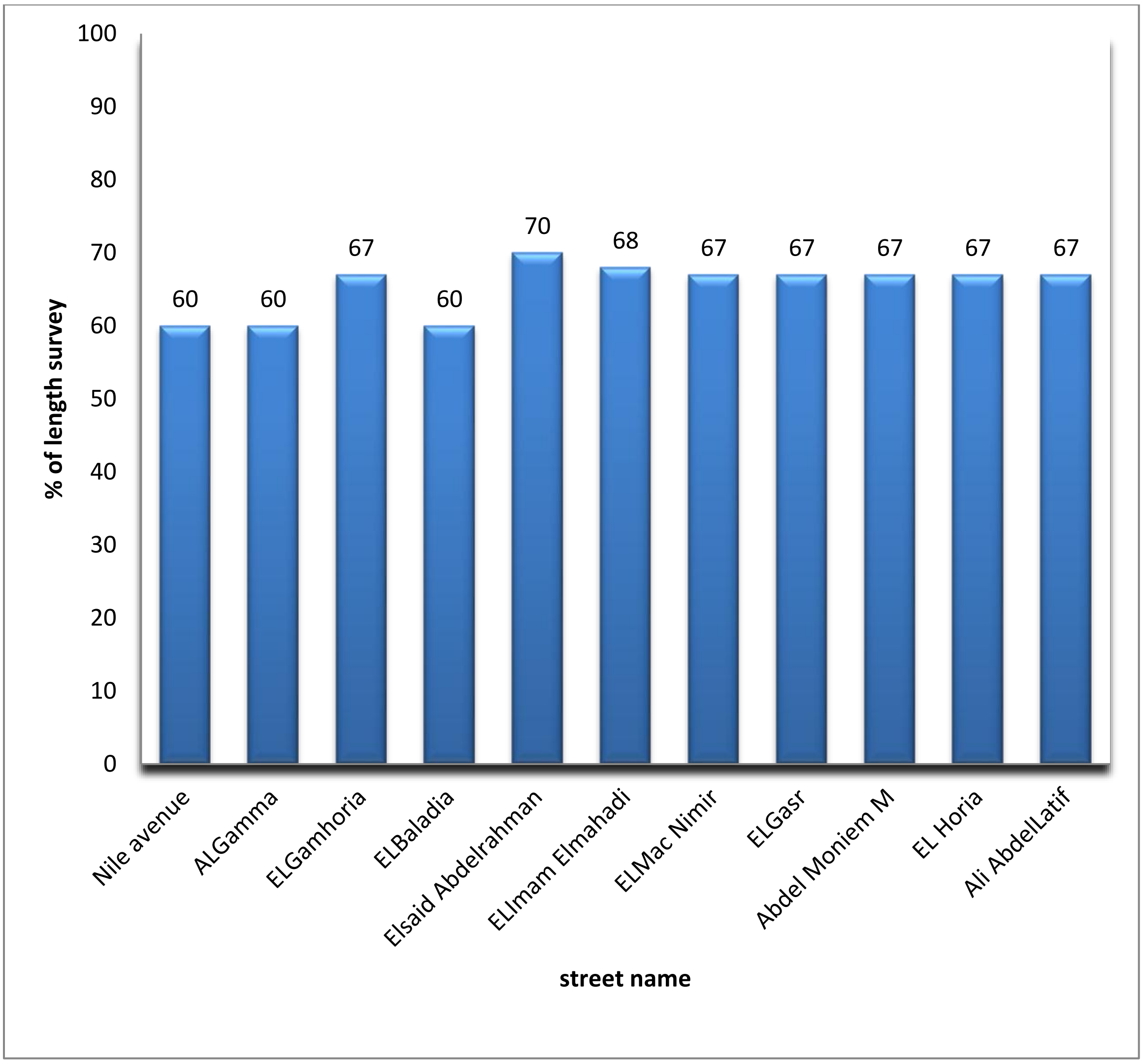


Figure 3.7: Percent of surveyed length of all roads

CHAPTER FOUR

Functional and Structural Evaluation

In order to carry out design of final stage of pavement rehabilitation, the existing pavement condition must be evaluated. Such evaluation usually involves the assessment of the existing pavement structural adequacy, Dynamic cone penetration, Test pits, Non destructive test,Roughness and Skid resistance.

4.1 Dynamic Cone Penetration:

_ The DCP was initially developed in Ssouth Africa for in-situ evaluation of pavements strength or stiffness in the 1960s. Dr. D. J. van Vuuren designed the original DCP with

a 30 degree cone (van Vuuren, 1969). The tTransvaal Road Department in South Africa began using the DCP to investigated road pavement in 1973(Kleyn, 1975), Kleyn reported the relative results obtained using a 30 degree cone and a 60 degree coneIn 1982, Kleyn described another DCP design, which used a 60 cone tip, 8 kg (17,6 ib) hammer, and 575 mm (22.6 in) free fall (Kleyn, 1982), This design was then gradually adopted by countries around the globe. In 2004, the ASTM D6951- 03 Standard Test Method for use of the Dynamic Cone Pentrometer in Shallow Pavement Applications described using a DCP with this latest design (ASTM, 2004). Since then, it has been used in South Africa , United Kingdom , Australia, New Zealand and several states in the United States, such as California, Florida, ***Illinois***, Minnesota, Kansas, Mississippi and Texas for site characterization of pavement layers and sub grades. The U.S.

Corps of Engineers has also used the DCP. DCP has proven to aneffective tool for assessing in –situ strength/ stiffness of pavement and sub grade

The DCP is simple and economical ; it requires minimum maintenance, easy to access . The DCP is an instrument which can be used for the rapid measurement of the in situ strength of existing pavements constructed with unbound materials. Measurements can be made down to a depth of approximately 800 mm or when an extension rod isfitted to a depth of 1200 mm. Where pavement layers can be identified and the thickness of each layer estimated

DCP tests are particularly useful for identifying the cause of road deterioration when it is associated with the one of the unbound pavementlayer e.g., shear failure of the road base or sub base. A comparison betweenDCP test results from subsection that are failing and those that are sound will quickly identify the pavement layer which is cause of the problem.

In some circumstances it is convenient to convert the individual pavementlayer thickness and strengths measured in the DCP test

4.1.1 DCP test Procedure

TRL DCP uses an 8 kg hammerdropping through a height of 57 mm and a 60 cone having a maximum diameter of 20 mm.

The instrument isassembled as shown in figure () . It is supplied with two spanners and a tommy bar to ensure that the screwed joints are kept tight at all time. To assist in this the following joints should be secured with a non hardening threadlocking compound prior to use.

*Handle / Hammer shaft

*Coupling / hammer shaft

*Standard shaft / cone

The instrument is usually split at the joint between the standard shaft and the coupling for carriage and storage and therefore it is not usual to use locking compound at this joint . However , it is important that this joint is checked regularly during use to ensure that is does not become loose . Operating the DCP with any loose joints will significantly reduce the lifeof.the instrument.

The DCP is driven into soil by dropping either the 8 kg or 4.6 sliding hammer from height of 575 mm. The 8 kg hammer is converted to 4.6 kg hammer by removing thehexagonal set screw and removing outer steel sleeve hammer. This procedure can be accomplished duringtest since the outer sleeve isdesigned to slide over the DCP handle. The cone penetration causedby one blow of the 8 kg hammer isessentially twice that caused by one blow of the 4.6 kg hammer. The 4.6 kg hammer is more suitable for use and yields better test result in weaker soils having CBR of 10% or less

The depth of the cone penetration is measured at selected penetration or hammer drop intervals and the soil shear strength is reported in terms of the DCP index .The DCP index is based on the average penetration depth resulting from one blow of the 8 kg hammer .The average penetration per hammer blow of the 4.6 kg hammer must be multiplied by 2 in order to obtain the DCP index value . The DCP is designed to penetrate soil s to a depth of 1 meter

4.1.2 Terminology

During the early stages of DCP development, many indexes were derived from DCP sounding data to percent DCP results. The following paragraphs discuss the resulting terminology. Kleyn et al. defined The DCP Structure Number (DSN) as the number of blows required to penetrate a layer of material (Kleyn, Maree, and Savage, 1982)

They further defined the DSN of number layers , DSN, as the number of blows required to penetrate the layer thickness h in mm (or in) at an average PR of DN mm (or in) per blow.

DSN = h/DN

The pavement DSN was defined as the number of blows required to penetrate the whole pavement structure.

DSN = sum DSN1

The pavement strength balance N DCP was defined as the number of blows required to penetrate 10 cm (3.9 in).

DCP readings have been presented in the following chart formats (Kleyn, 1975):

- The Foundation balance graph: a plot of depth over PR with both axes in log scale
- The DCP Factor: the area enclosed by the foundation balance graph

DCP readings have also been represented in these formats (Kleyn, Maree, and savage, 1982):

- The strength balance curve
- The layer Strength Diagram: the depth in natural numbers and the PR in the log scale.
- The DCP Curve: the number of blows needed to reach a certain depth.

The DCP reading is a measure of the amount of penetration per blow. Over the years, different agencies have used various terms for this measurement. The following are some of the most common names for DCP readings, which measure the depth of penetration per below:

- Penetration rate (PR)
- DCP number (DS) (Kleyn, 1975)
- DCP Index (DI or DCPI) (Harison, 1989)
- Blow Number (BN)

Consulting Webster Third New International Dictionary to help determine the best term for our use yielding the following definitions:

- Index:",,,a ratio or other number derived from a serious of observations and used as an indicator or measure…"
- Rate: "… quantity, amount, or degree of something measured per unit of something else…"
- Number: the enumerative aspect of things existing in countable units…"

The DCP reading is an actual measurement rather than a countable natural number or ratio. Rate is a more appropriate and self –explanatory term. Therefore this report uses PR, which is expressed in millimeters per blow.

4.1.3Developing Correlationsbetween DCP Readings and CBR Value

Base, sub grade soil, and paving material strength values derived from cone penetration resistance can be converted into CBR, Limestone Bearing Ratio (LBR), sub grade modulus K, resilient modulus E, and Soil Support Value (SSV). The most common conversion is expressed in the form of equations for CBR as a function of PR (in mm/blow). The following are some of empirical correlations developed by various agencies.

The Australian Road Research Board (ARRB) (Smith and Pratt, 1983) developed an empirical correlation between PR and CBR, which is:

$$\text{Log (CBR)} = 2.56 - 1.15 \text{ Log (PR)}$$

The North Carolina Department of transportation (NCDOT) (Wu, 1987) developed the following DCP and CBR relationship, based on the field CBR and the average of the three DCP readings taken within an area with a radius of less than 1 ft (0.3 m) around the CBR test location:

$$\text{Log (CBR)} = 2.64 - 1.o8 \text{ Log (PR) or}$$

$$\text{CBR} = 435/(\text{PR}^{1.08}) \qquad (R^2 = o.79) - (\mathbf{4.1})$$

Livneh presented the following relationship during the Southeast Asian Geotechnical Conference in Bangkok, Thailand in 1987:

$$\text{Log (CBR)} = 2.20 - 0.7 (\text{Log(PR)})^{1.5} \quad (\mathbf{4.2})$$

Harison (Harison, 1989) of ARRB developed another equation:

$$\text{Log (CBR)} = 2.81 - 1.32 \text{ Log (PR)} \quad (\mathbf{4.3})$$

The U.S Army Corps of Engineers (USACE) (Webster, Grau and Williams, 1992) developed another equation representing the relationship between the CBR and the DCP reading, used by many state departments of transportation (DOTs) and federal agencies:

$$\text{Log (CBR)} = 2.465 - 1.12 \text{ Log (PR) or CBR} = 292/(\text{DCPI})^{1.12} — (\mathbf{4.4})$$

The USACE study was based on lab CBR values, while the NCDOT study was based on field CBR values. It is known that a field CBR value is generally twice as large as a lab CBR value. Considering this characteristic, the results of these two independent studies actually match very well.

In 1994, Webster (Webster, Brown and Porter, 1994) further refined this equation to fit specific soil types:

$$\text{CBR} = 1/(0.002871\text{DCPI})^2 \text{ for high plasticity clay (CH)} \quad (\mathbf{4.5})$$

$$\text{CBR} = 1/(0.017019\text{DCPI})^2 \text{ for low plasticity clay (CL)} \quad (\mathbf{4.6})$$

Klyen deve loped a similar equation in 1992:

$$\text{Log (CBR)} = 2.62 - 1.27 \text{ Log (PR)} \quad \textbf{(4.7)}$$

Livneh et al. (Livenh, Ishai, and Livenh, 1992) used automated DCP readings to develop the following equation:

$$\text{Log (CBR)} = 2.20 - 0.71 \text{ Log (PR)} \quad \textbf{(4. 8)}$$

Where

CBR = 0.84 CBRa

CBRa is the CBR derived from the automated DCP reading

Ese, (Ese, Myre, Noss, and Vaernes, 1994) presented the following equation during the Fourth International Conference on the bearing Capacity of Roads andAirfields:

$$\text{Log (CBR)} = 2.669 - 1.065 \text{ Log (PR)} \quad \textbf{(4.9)}$$

Ese, of the Norwegian Road Research Laboratory, then correlated field DCP readings with lab CBR values. The result is:

$$\text{Log (CBR)lab} = 2.438 - 1.65 \text{ Log (PR) field} \quad \textbf{(4.10)}$$

Where

(CBR) lab is the CBR value obtained in the lab

And (PR) field is the DCP reading obtained in the field

In 1999, Coonse presented the following correlation (Coonse)

$$\text{Log (CBR) field} = 2.53 - 1.14 \text{ Log (PR) field} \quad \textbf{(4.11)}$$

In the work leading to Equation **(4.4**)

4.1.4 Manual DCP Operation

A two person team is needed to operate a manual DCP, one serves as the operator and the other is recorder. In addition to the DCP, the team must also have a hammer on hand. After locating a test point, the operator follows these steps.

1. Gently place the DCP tip at the test point

2. Use one hand to hold the handle (that is, the rod above the upper stopper). Keep the DCP vertically (with the help of the recorder if needed). Picking a fixed reference object around you is a good way to keep the DCP plumb.

3. Record the initial height of the bottom of the lower stop (the marker) with a marking stick (the stick)

4. With one hand holding the DCP, use the other hand to raise the weight to the bottom of the upper stop (be careful not to hit the upper stop), then let the weight fall freely to hit the top of the lower stop.
5. Mark the new position of the marker on the stick.
6. Repeat step 4 and 5 until the maximum depth of the penetration is reached. Attention : Keep the DCP vertical all the time and take care to avoid hitting your thumb,
7. Extract the DCP from the testing hole by hitting the upper stop with a hammer.

Stop DCP testing when one of the following conditions is satisfied:

1. Penetration depth reaches 1m (39)
2. Penetration depth is greater than 0.6 m(24 in) and at least 10 consecutive blows return a PR of less than 1 mm/ blow (0.04 in/blow)

To record your results for reporting, measure the marks on the stick and record the results in a DCP Record Form. Here are a few suggestions to make field data recording easy.

- Cover a 4 ft (1.22 m) survey stick with masking tape. Use it to mark the height of the marker and below number. Up to eight tests can be marked on one stick. Penetration depth can be measured and recorded in the office, and the stick is reusable afer being covered with new tape.
- When the penetration rate is less than 2.5 mm (0.1 in) per blow, do not Use project number and stations to identify data points. If two or more tests are performed at one station, add A,B, etc., at the end of the station number. For surcharge testing add "S" to the end of the identified
- mark Marking every 5 or 10 blows is sufficient.

4.1.5 Automated DCP Operation

Operating an automated DCP is like operating amanual DCP, except the DCP penetration and extraction are done using machine power and the computer records the data. One person can operate an automated DCP. The time needed to complete a test is much shorter with an automated DCP than with a manual DCP.

Following are the steps to perform when using an automated DCP.

1- Before testing a project, input the information necessary to set up the header for the data record and files.
2- Establish a file naming convention
3- Locate the trailer so the DCP tip is aimed precisely at the test point.
4- Ensure the DCP rod is vertical.
5- Lower the DCP tip to the ground surface and start data collection. The computer records the penetration depth after every blow.
6- When data collection at this test point is done and the DCP is extracted from the ground, move the DCP trailer to the next location.
7- At the end of the day testing, be sure to save the data file to a disk. Name the file using the naming convention.

4.1.6 Practical use of Dynamic Cone Penetrometer

This chapter deals with the practical use of DCP in evaluation of pavements

One project is selected for evaluation of pavements (Khartoum streets).

The results obtained are described and discussed

4.1.7 Evaluation of pavements--- Khartoum Roads

4.1.7.1 Introduction

Performed in a normal or abnormal way. A pavement normally deteriorates as traffic loads accumulate .When the rate of deterioration is unacceptable high, the pavement behavior is considered abnormal. Abnormal behavior can have numerous causes and special care should be taken to determine the reason for the abnormality and to prevent its recurrence.

In this case study selected roads in the national capitalist Khartoum were evaluated. The work undertaken includes visual classification according to physical condition.

DCP survey and trail pits. It was therefore decided to study the roads in more details in order to select appropriateengineering design and improvement standards to establish the technical and economic feasibility of rehabilitation.

4.1.7.2 Roads included in the study

The road selections included in this study consisted of the following:

Gasr south street(6.5 km), Africa street (3.7 km), Elsayid Abd elrahman street (2.5 km), Tabia street (2.25 km), Al morrada street (4.00 km)

Wadi saidna street (6.5 km)

4.1.7.3 Visual classification

At the beginning, a visual survey of the project roads has been carried out, the various types of pavement distresses were recorded.

Cracking, Rutting, Potholes, Patching, andRaveling

The results were then assessed using a rating system describing extent and severity of defects, as follows;

Extent**,**No Significant defects, Slight not more than 10% of length or area Moderate, 10- 25% affected, Extensive, over 40% affected

Severity, No significant defects, Minor defects of non urgent nature

Severe defects where urgent action is needed

4.1.7.4 Dynamic Cone PenetrometerTests

DCP tests were carried out in the wheel path on all roads sections. The DCP used for this study was modified version of the instrument designed at**TRRL**, in this study the thickness and strengths of the pavement layers has been expressed in terms **CBR** from the results **DCP** tests. Show in Tables **(4.1, 4.2, 4.3, 4.4, 4.5, 4.6**) In Appendix **(B)**.

Table (4.7)Summary of Trail Pits Laboratory testing for different roads in Khartoum State

Street and chain age	Thickness of layer(mm)	Atterberg limit			Classification	Compaction		Soaked .CBR %
Gasr South		L.L	P.L	P.I		MDD	OMC%	
0+800	450-650	30	10	20	CL	1.97	12	7
6+400	700-900	40	19	21	CL	1.95	12	12
Africa	-							
1+400	450-600	36	20	16	CL	2.02	11	10
2+700	450-600	35	24	11	CL	2.11	9	8
Al said A Rahman								
0+600	500-700	26	14	12	CH	2.01	10	2
+8001	500-700	52	12	40	CH	1.84	14	2
Tabia								
0+200	550-700	19	14	5	CH	1.95	11	3
1+350	450-600	35	17	18	MH	1.84	16	4
Murrada								
0+250	400-600	23	16	7	CL	2.12	9	5
Alwai								
8+000	450-600	34	26	8	CL	2.19	9	14

4.1.7.5 Laboratory Soaked CBR / Field DCP Relationship

To establish a relationship between field DCP values and soaked CBR values a comparison was made between DCP test at Gasr South, Africa, Al sayid A/ Rahman, Tabia, Murrada and Al wadi roads. The tests were carried out adjacent to locations where samples for soaked for CBR testing in the laboratory were taken (CBR values at field density after 4 days soaking).

The result of the tests are shown in Table (4.7) and Table (4.8)

The relationship Soaked CBR versus DCP field thus found is plotted in Figure (4.1). The regression line is placed graphically as the assumed best fit curve as shown in figure(4.1) and the equation is.

CBR (DCP) =2.121 $e^{0.235CBRLab}$

The regression coefficient $(R)^2$ = o.622

The rate of penetration of the DCP is related to the strength of the materials through which cone is passing, if the penetration depth after, say, every five blows is plotted on a graph The thickness of the pavement layers was also obtained from the DCP measurements. Provided there was a reasonable The results of the thickness measurement are shown in table(4.7) In this study the strength of the pavement layers has been expressed in terms of CBR using the relationship Therefore a computer programmed was made to the work . The DCP programmed automatically generates and input data file for (Africa street) with the number of blows against penetration (depth) and the also CBR against penetration (depth) . Atypical printout from the DCP programmed is shown in Figure (4.4 and 4.5) . And Table (4.8)

4.1.7.6 The intended use of DCP test results was as follows:

For substantial intact road pavements the requirement was to be determining the strength and thickness of the pavement layers and the subgrade CBR. This information would serve as an input to the overall assessment of the current pavement strength and residual life for the design and rehabilitation strengthening measures; if required. In the case of pavement in very poor condition the information provided by the DCP testing was used to assess the thickness and strength characteristics of the pavement layer materials with the view to their re-use in pavement rehabilitation .

It should be noted that the equivalent CBR values obtained for with the DCP are natural moisture content condition of the materials at the time of the test which are normally in practically condition.

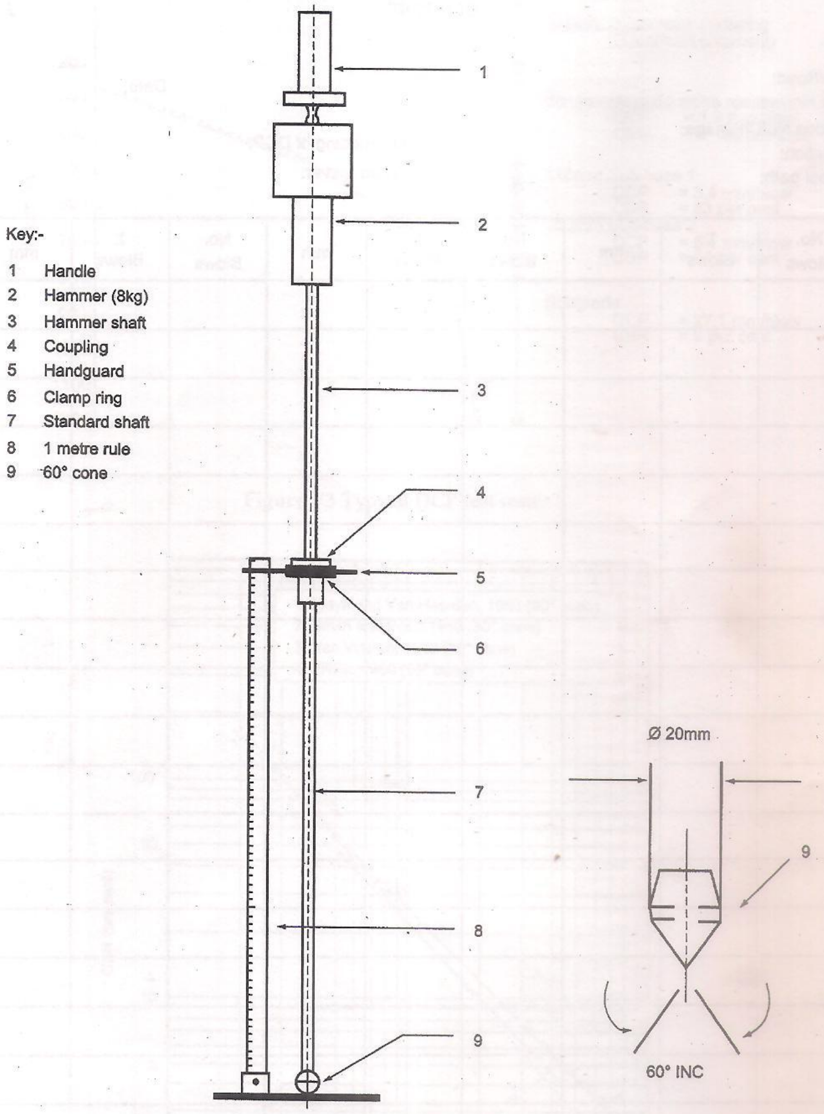


Figure Fl TRL Dynamic Cone Penetrometer

Figure 4.1 Dynamic Cone Penetrometer

Summary

The Nondestructive equipmentincludes the DCP device. The results of the field and laboratory investigation are presented, DCP – CBR relationship were developed and compared with the published. Use of DCP tests to predict in – situ CBR was emphasized.

Conclusions

The following conclusions can be disclosed from the results of this investigation:

1- The experiments proved that the DCP has a high degree of repeatability under control conditions, and is sufficiently sensitive for used in practice.

2- A definite relationship exists below DCP and CBR such a calibrated allows the determination of pavement layer strength.

3- the most significant factors that influence the DCP- CBR

- Correlation is: Clay content of a soil, passing sieve No 200 content of a soil. Moisture content and soaking condition (degree of saturation) for clay soils
- 4- It is clear that the DCP measures a variety of material properties. According to experimental data it appears that the following are the most important properties: grading. Density and moisture content

5-The application of the DCP can before seen in the following fields. Control of earthwork and Evaluation of pavements

6- The lab. Soaked CBR/ Field DCP relationship can be used for

Estimating the soaked CBR values for high and low plasticity from DCP investigation.

7-The field DCP/ in –situ CBR relationship; should make it possible to evaluate with greater ease the in- situ condition of pavement.

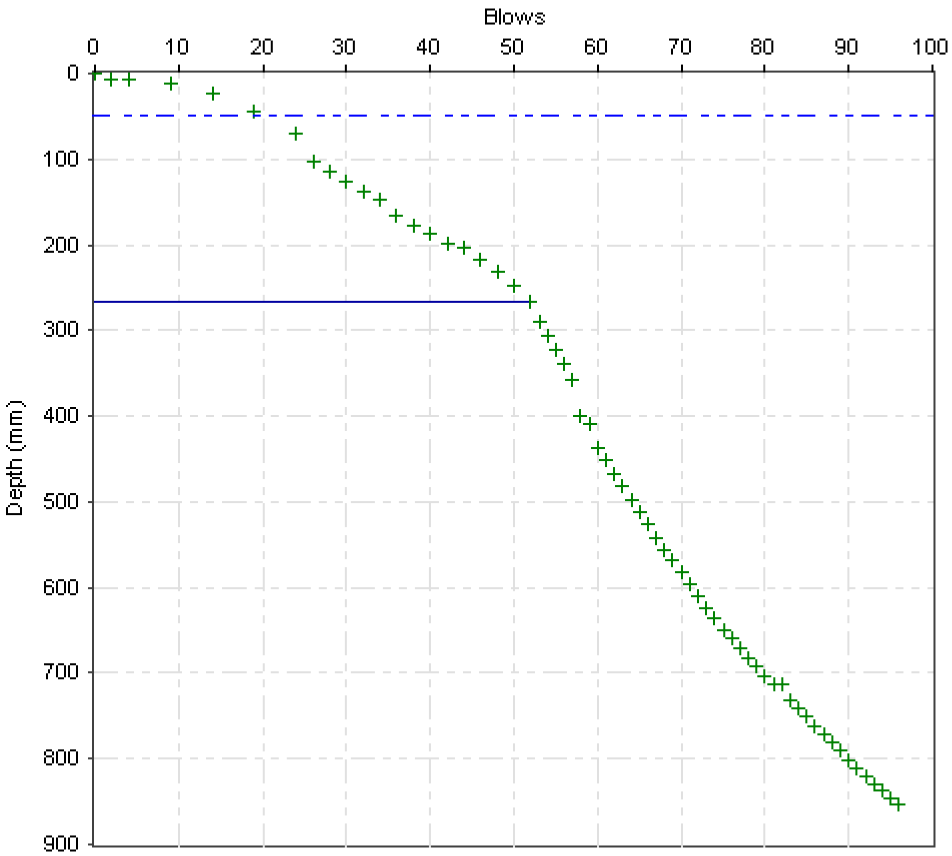
Table (4.8) :Atypical Printout of Data Analysis By TRRL DCP Computer Programme

UK DCP V3.1	Penetration Data Report		
Project Name	africa street		
Chainage (km)	0+200	Surface Type	Hot Mixed Asphalt
Direction	R.H.S	Thickness (mm)	50
Location/Offset	Lane 1	Strength Coeff.	0.3
Cone Angle (degrees)	60	Base Type	Granular
Zero Error (mm)	53	Thickness (mm)	200

No.	Blows	Cumulative Blows	Penetration Depth	Penetration Rate
1	0	0	53	0
2	2	2	59	3
3	2	4	60	0.5
4	5	9	64	.8
5	5	14	77	2.6
6	5	19	97	4
7	5	24	123	5.2
8	2	26	155	16
9	2	28	167	6
10	2	30	180	6.5
11	2	32	192	6
12	2	34	201	4.5
13	2	36	220	9.5
14	2	38	231	5.5
15	2	40	241	5
16	2	42	251	5
17	2	44	256	2.5
18	2	46	270	7
19	2	48	284	7
20	2	50	300	8
21	2	52	320	10
22	1	53	344	24
23	1	54	359	15
24	1	55	375	16
25	1	56	392	17
26	1	57	411	19
27	1	58	452	41
28	1	59	462	10
29	1	60	490	28
30	1	61	505	15

No.	Blows	Cumulative Blows	Penetration Depth	Penetration Rate
31	1	62	520	15
32	1	63	535	15
33	1	64	551	16
34	1	65	566	15
35	1	66	580	14
36	1	67	595	15
37	1	68	610	15
38	1	69	622	12
39	1	70	636	14
40	1	71	650	14
41	1	72	664	14
42	1	73	677	13
43	1	74	690	13
44	1	75	703	13
45	1	76	713	10
46	1	77	724	11
47	1	78	735	11
48	1	79	746	11
49	1	80	756	10
50	1	81	766	10
51	1	82	766	0
52	1	83	785	19
53	1	84	795	10
54	1	85	804	9
55	1	86	814	10
56	1	87	824	10
57	1	88	833	9
58	1	89	844	11
59	1	90	854	10
60	1	91	863	9
61	1	92	873	10
62	1	93	882	9
63	1	94	891	9
64	1	95	900	9
65	1	96	907	7

Layer Boundaries: Chainage 0.200



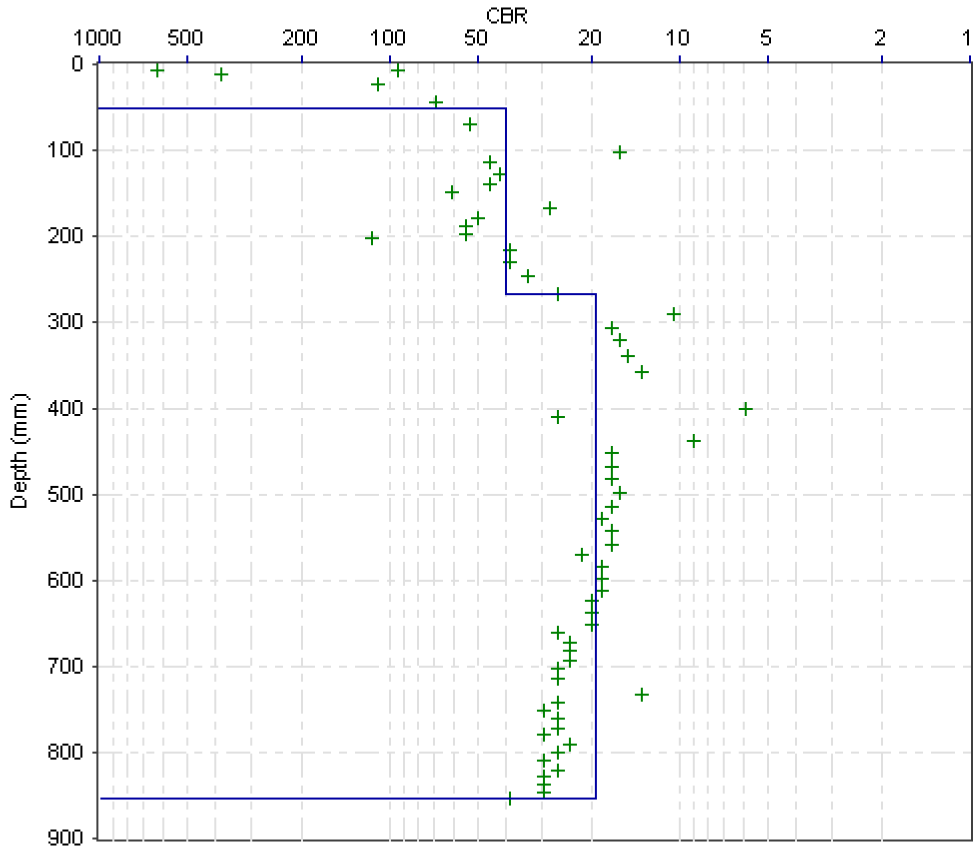


Table (4.9) Street and chain age CBR% and DCP (CBR)

Street and chain age	Thickness of layer (mm)	Soaked CBR%	DCP (CBR)
Gasr South			
0+800	-450650	7	42
6+400	700-900	12	7
Africa	-		
1+400	450-600	10	11
2+700	450-600	8	11
Al said A Rahman			
0+600	500-700	2	3
+8001	500-700	2	3
Tabia			
0+200	550-700	3	3
1+350	450-600	4	7
Murrada			
0+250	400-600	5	2
Alwai			
8+000	450-600	14	11

Table (4.10)CORRELATION BETWEEN CBR (DCP) AND LABORATORY CBR

Insitu CBR(DCP)	CBR
40	7
42	12
11	10
12	8
3	2
3	2
3	3
19	4
2	5
58	14

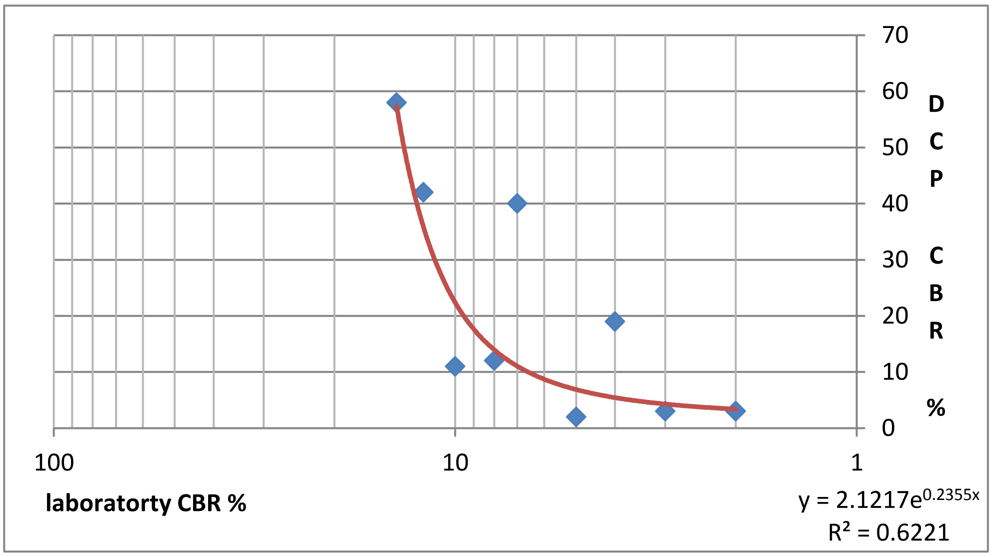


Figure (4.2))CORRELATION BETWEEN CBR (DCP) AND LABORATORY CBR

4.2 Pit Test Procedure

4.2.1 Purpose

The purpose of carrying out a test pit investigation is to confirm the engineers understanding of the information from surface condition, deflection and DCP surveys. It is a time consuming and expensive operation, and for this reason the location of each test pit should be carefully selected to maximize the benefit of any data collected. The collection of the road pavement and the primary purpose for the pit investigation should be recorded on the Test Pit Log(see figure below).

4.2.2 Labour, equipment and materials

Test pit can be excavated either by machine or manually. The choice will normally be determined by the availability of plant and the test pit programme, as machine operations are usually more productive but more costly than manual methods.

The following personnel are required:

- Traffic controllers- a minimum of one at each end of the site;
- 2 (if machine excavation) or 3 (if manual excavation laborers;
- 1 machine operator if applicable;
- 1 driver for vehicle ; and
- 1 supervising technician.

4.2.3 Equipment and materials requirements are as follows:

- 1 backhoe (for machine excavation);
- 1 jack hammer with generator (to assist with manual excavation);
- 1 pick;
- 1 or 2 spades (a fence post hole digger can also be useful);
- 1 tamper or plate compactor for backfilling test pit;
- Material to backfill and seat test pit : gravel, cement for stabilizing gravel, water and cold mix for resurfacing;
- 1 broom to tidy area on compaction;
- 1 chisel is often useful to assist with inspecting the wall of the test pit;
- Equipment necessary to complete any required on site testing;
- 1 tape measure and thin steel bar to span pit (to assist with depth measurements)
- Sample bags and containers, with some means of labeling each;
- Test pit log form and clipboard; and
- Sample log book.

4.2.4 Sampling and testing

Before commencing the survey in the field, the engineer should be clear as to the information required from each test pit. This will depend on the results of the previous surveys, the materials specifications in use and as understanding of the pavement behavior. Some field testing might be necessary as well as subsequent laboratory testing of samples extracted from the pit. the various tests that may be required and references the relevant standards with which the tests should comply. Not all these tests will be necessary and the engineer must decide on those which are required.

4.2.4.1 Procedure

A safe working environment should be maintained at all times. Many organizations will have on site safety procedures which should be followed. Where there are no local safety procedures those described in Overseas Road Note 2 are recommended (TRRL, 1985)

Once it has been decided what testing is to be carried out and the location of the trail pits has been confirmed, the following procedure should be adopted.

1- Sep traffic control
2- Accurately locate position of test pit and record this on the Pavement Test Pit LogUsually, the position of a pit will be apparent after completion due to the patched surface. However, if long term monitoring is required, a permanent location marker should be placed at the roadside. Record any relevant details such as surrounding drainage features, road condition and weather.

4.3 Non-Destructive Deflection Testing

One of the most reliable methods for determining the structural condition of an in service pavement is to use nondestructive deflection testing (NDT). NDT has two major advantages over destructive testing. First destructive testing by definition disturbs the under lying. Paving layers or required removed of the pavement materials of laboratory for testing. Whereas NDT truly an in- situ test that evaluates the pavement without any material disturbance or modification. The second advantages of NDT is that the tests are relatively quick and inexpensive allowing more tests to be completed while causing less disruption to traffic than destructive testing. Be performed in association with NDT to verify layer thickness for accurate back calculation of the layer moduli. Ingeneral, however, the amount of destructive testing needed to evaluate a pavement in conjunction with NDT in minimal.

NDT equipment operates by applying a load to the pavement and measuring the resulting maximum surface deflection or the surface deflection basin. NDT results are used to determine the following:

4.3.1- Asphalt pavement

- Elastic modulus of each of the structural layers
- Allowable loads for a specified number of load applications
- Overlay thickness design

4.3.2- Concrete pavement

- Concrete elastic modulus and subgrade modulus of reaction
- Load transfer across joints
- Voids detection
- Allowable loads for a specified number of load application
- Rehabilitation design

NDT data can be used in conjunction with the information from the distress survey to select the best maintenance and rehabilitation (M& R) alternative. It is recommended that NDT be conducted prior to destructive testing to better select the location for coring and material sampling , if required. For pavement, NDT results can be used to determine the Aircraft Classification Number (ACN)/Pavement Classification Number (PCN) ratio (ACN/ PCN)

4.3.3 Pavement Deflection Measurement Devices

At present, there are many different commercially available deflection testing devices. The devices group based on loading mode as: impulse, steady state dynamic, and static. The impulse NDT devices are the most recently developed. They better simulate the load from a moving tire and are currently use by highway and airport agencies more than any other devices.

4.3.3.1 Impulse Deflection devices

The Falling Weight Deflectomet (FWD) is the most commonly used impulse deflection device. FWD is based on the concept of dropping a weight (W) from a known height (H), thus producing a kinetic energy that is equal to W*H. The resulting force pulse transmitted to the pavement approximates the shape of a half sine wave. The load pulse shape and duration have a significant impact on measured deflection as discussed The integration of the force applied to the pavement (F) multiplied by the composite compression of the falling weight and the pavement is equal to the produced kinetic energy as follows

4.3.3.2 Dynatest FWD

- Dynatest offers two models (Dynatest 2004). Once of the models can apply peak impact loads in the range of 1500 Ibf To 27000 Ibf (7 KN to 120 KN). The second model also known as heavy FWD (or HWD) can apply peak impact loads in the range of 6500 Ibf to 54000 Ibf (30 KN to 240 KN)

The Dynatest FWD is a trailer- mounted system and the operation is produced by a single – mass falling weight striking a buffer system which, in turn, transfers the energy to the loading plate. The automated operation control performs several functions including the lowering and raising of the loading plate and deflection sensor bar to and From the surface of the pavement being stated.

Other optional equipment for the Dynatest FWD include:

- Video System
- Automated Differential Global Positioning System (GPS)
- Automated Air Temperature Probe
- Automated Non – contact Infra Red Temperature Transmitter

4.3.3.3 KUAB FWD

KUAB manufactures two types of FWDs (KUAB 2004). Once type uses a single mass system for load generation similar to the Dynatest described above. The other type uses a KUAB patented two mass force generating.

Deflections are measured using absolute seismic displacement transducers (seis-mometers) or velocity transducer. One sensor is placed at the center of the plate. Other sensor are mounted on a bar and automatically lowered to the pavement surface with the loading plate. The most common number of deflection sensors is 7; however up to 16 deflection sensor can be delivered in various configurations.

There are several options available with the each of the models, including temperature measuring gauges, distance measuring systems, core drill video camera and GPS devices.

4.3.3.4 Dynaflect Equipment

The Dynaflect was one of the first commercially available steady- state devices. The Dynaflect is an electromechanical system "The cycle force generator utilizes a pair of unbalanced flywheel, rotating in opposite directions at speed of 480 rpm or 8 cycles per second. The vertical component of the acceleration of the unbalanced mass produces the cycle force" (Dynaflect 2004). The Dynaflect has static weight of 2000 Ib and produces a 1000 Ib peak- to peak dynamic force at a fixed frequency of 8 cycles/ second. The load is applied through two rigid steel wheels and the resulting deflections are recorded by five velocity transducers (geophones). The transducers are suspended from a placing bar and are normally positioned with one located between the two wheels and the remaining four placed at 1- ft intervals.

4.3.3,5 Benkelman Beam

The Benkelman Beam is a simple hand operated deflection device. And is It consists of a support beam and a probe arm. The probe arm is 10 ft long t a point 8 ft from the probe which rests upon the pavement surface. It is used by placing the tip of the probe between the two tires of a loaded truck, typically an 18000 Ib axle load. As the loaded vehicle moves away from the beam, the rebound or upward movement of the pavement is recorded.

Some problems encountered with his device include:

- The need to ensure that the front supports are not in the deflection basin
- The difficulty or in ability to determine the shape and size of the deflection basin.

4.3.4 Factors Affecting Deflection Values

4.3.4.1 Pavement Structure

The deflection of a pavement in response to an applied load represents

An overall response. It is important to remember that the complete pavement system consists of all constructed layered (i.e , subbase, base and surfacing) plus subgrade . The deflected surface profile is commonly referred to as the deflection "basin" or "bowl".

The surface fatigue life of a pavement is directly proportional critical load induced strains in the asphalt, with the higher strain values indicating shorter lives.

4.3.4.2 Load Magnitude:

A second factor that affects recorded deflection values is the magnitude of load. Load levels ranging from a little as 1000 Ibf to over 50000 Ibf are available. Some NDT units offer the potential to vary the applied load while others used constant value. Many researchers have found that light loads do not sufficiently stress the underlying layers of heavy highway and airport pavements (Bush,Alexander, and Hall 1985; FFA 1976; Hall 1975; Ullidtz and Stubastal 1985

4.3.4.3 Load Distribution:

Most mechanistic analysis routines assume a full contact between the loading plate of the NDT device and the pavement being tested, thus assuming a circular uniform stress distribution under the loaded area.

Placed under two FWD devices, one with segmented load plate and the other with a solid load plate.

The testing was conducted on three pavements: a smooth, newly paved asphalt pavement, a relatively strong asphalt pavement that had a rut depth of the field 1/8 in, and a measured pressure distribution under the segmented and solid plates. Mechanistic analysis using that the field data showed that if full contact is assumed when in reality it did not occur, significant errors reaching 100% may result in the back- calculated layer moduli.

4.3.4.4 Pavement Temperature

Another factor that must be closely monitored during testing is the pavement temperature. When testing a pavements asphalt pavements, the deflection changes as temperature varies because the stiffness of the asphalt layer reduced, is stiffness is a function of its temperature. At higher temperature, the asphalt stiffness is reduced, thus increasing deflections

The bearing capacity of a pavement is generally evaluated through non-destructive load testing (NDT). Based on the deflections measured in situ and taking into account the pavement layer thickness and material characteristics a response model of the pavement is established. The layer thicknesses are normally obtained through cores and, if available Ground Penetrating Radar (GPR) measurement. The elastic moduli of the layers are adjusted until the deflections measured during testing.

There are several methods for back calculation for layer moduli from Falling Weight Deflactometer (FWD) test results.

The pavements structural condition is one of the main factors to taken into account for pavement maintenance planning. Non-Destructive Testing (NDT) of pavements is increasingly being recognized as an effective way to obtain information about their structural behavior. In order to evaluate the bearing capacity of a pavement, using a mechanistic approach, a structural model of the pavement is required for the estimation of its residual life. This structural model is obtained through interpretation of non-destructive tests. Using layer thickness as input, the elasticity moduli (E moduli) of the pavement layers are backcalcutated from the deflection basin measured with non-destructive load testing equipment. In this way, the pavement bearing capacity is evaluated, and the remaining pavement life can be estimated, taking into account the future traffic.

The combination of results from FWD and GPR tests can provide a major improvement to the quality of the results.

4.3.4.5 Falling Weight Deflactometer

The Falling Weight Deflactometer (FWD) is presently the device for deflection testing most widely used in Europe, North America and Japan (Irwin, 2002). The test load is obtained by dropping a weight from a certain height on a set of buffers. The deflections are measured by a set of deflection transducers resting on the surface . This equipment has the advantage that the impact loads applied on the pavement can be changed by changing the weight, the height and the loading plate. In this way simulation of various loading is enabled. The equipment measure the pavement response in 6 9 points, resulting a deflection bowl that reflects the influenced of different layers on pavement response (Figure below). The measurements are performed at equal distances, chosen according to the length of the section to be tested (from 10 m to 100m)

4.3.5 Test Procedure

A safe working environmental should be maintained at all times. Many organizations will have on site safety procedures which should be followed. The safety aspects of a FWD survey are particularly difficult to manage, as it is a mobile operation, and the supervising engineer should ensure that satisfactory procedures followed. Where short lengths of road are being investigated they should be coned off. If measurements are being carried out over longer lengths of road then the operator, driver and traffic control personnel should always be extremely aware of both the movements of the testing equipment and other vehicles on the road signs, the towing vehicle should always be fitted with flashing lights and direction signs all personnel should wear high visibility safety jackets.

Typically tests should be carried at intervals of 20-100 meters in the verge- side wheel- path in each direction. Additional tests should be undertaken on any areas showing atypical surface distress.

On flexible pavements the load level should be set at a nominal load of 50 KN +/- 10%. On roads with bituminous seals, often found in the developing world, this level of load may possibly over – stress the pavement, in which case the load level should be reduced. The load should be applied through a 300 mm diameter plate and the load pulse rise time should lie between 5 and 15 milliseconds.

The deflection should be measured by at least five and preferably seven deflection sensors having a resolution of one micron, the location of the sensor depends on the stiffness of the pavement structure. The stiffness of the sub- grade has the major influence on the shape of the deflection bowl and therefore there should be at least two sensors at such a distance from the load centre as to enable the stiffness of the sub-grade to assess. In the case where seven sensors are available

4.3.6 Temperature measurement

When the road has an asphalt surfacing the deflection may change as the temperature of the surfacing changes. Also when the deflection bowl is to be used to estimate pavement layer moduli, the stiffness of the asphalt surfacing will need to correct to standard temperature. It is therefore necessary to measure the temperature of the surfacing during testing. In temperature climates measurements taken hourly may be sufficient, however, in tropical climates the pavement temperature will rise quickly during mid morning and can reach a temperature at which the asphalt surfacing is liable to plastic deformation during testing. This must be carefully monitored and temperature measurements at this critical time of the day may need to be taken every 15 or 20 minutes.

The temperature of the pavement can be measured using either a short –bulb mercury thermometer or a digital thermometer. The temperature holes should be at least 0.3 m from the edge of the surfacing. Where the asphalt surfacing is less than 150 mm the temperature should be measured at the depth of 40 mm when the surfacing exceeds 150 mm, it is recommended that temperatures should be recorded at two depths, 40 mm and 100 mm.

The measured deflection bowls together with the information on layer thickness are used for the estimation of "in situ" bearing capacity (Antunes, 1993).

4.3.7 Ground Penetrating Radar

In general information about the existing pavement structure thickness can be obtained from historical data, coring, trail pits and Ground Penetrating Radar **(GPR)**. Normally, the best approach is to gather as much information as possible, from different sources.

Layer thickness may be quite variable along a pavement structure;therefore continuous information on thickness is needed. Accurate measurements are essential for the analysis of FWD tests, particularly for the back calculation process. A continuous measurement of the layer thicknesses has become possible with the application of GPR for substructure evaluations.

Air- coupled antennas are the most widely used for pavement studies. The antennas are suspended on a van or a trailer and allow for measurements at high speed.

The GPR transmits short duration electromagnetic pulses from transmit antenna into the material being testedand picks up the reflected energy in the receive antenna. The reflected wave gives information about pavement structure. The wave amplitude is related with the difference in dielectric properties (Ei) of two adjacent layers, while the travel time gives the interface location beneath the surface.

The GPR measures the travel time, which is post- processed and converted to layer thickness. The thickness can be estimated if the relative dielectric constant is known.

LNECs equipment has two pairs of air- launched (horn) antennas (1000MHZ and 1800 MHZ), with a maximum penetration depth of 0.8 and 0.4 m, respectively .

GPR tests are undertaken along the same longitudinal profiles as FWD tests (Fontul and Anntunes, 2001).

The cores are extracted after the GPR survey, in location where the reflected signal is clear and constant along the certain distance.

GPR has become an important tool for pavement evaluation, since it allows for continuous measurement of the layer thickness (Fontul et al, 2007) and therefore, a precise identification of changes in pavements structure, taking into account that historical data are in most of the cases erroneous or incomplete, while the cores give us only local information.

4.3.8 Interpretation of Results

Pavement layer stiffness moduli can be calculated from the FWD deflections using a back calculation procedure, provided that the layer thickness is known.

Usually the layer thickness are fixed within this process, and assuming typical values for the Poisson ratios, the deflection bowls are used for back calculation of E moduli. Assuming a certain pavement structure, the values of the deflections are calculated for the FWD peak load and are compared with the measured deflections.

4.4. Roughness

Although the physical measurements used for computing PSI include the distress data of rut depth, cracking and patching, it is longitudinal profile or roughness that provides the major correlation variable . The correlation coefficient between PSR and PSI is increased by only about 5% after the addition of distress data (Zaniewski et al ,1985). Because of the relatively small contribution to PSI by physical distress and the difficulty in obtaining the distress data, many agencies rely only on roughness to estimate PSI.

Roughness is defined as the deviation of a surface from a true planar surface with characteristics dimensions that affect vehicle dynamics and ride quality (ASTM Specification E867- 2A). Many indices are developed for quantification of road roughness. Some widely used indices include International Roughness Index (IRI), Ride Number (RN), and Profile Index (PI) Etc. The International Roughness Index (IRI) was established in 1986 by the World Bank. It was first introduced in the International Road Roughness Experiment (IRRE) that was held in Brazil. The IRI is internationally accepted standard for calibration of rughness measuring instruments. The IRI is based on simulation of the roughness response of a car travelling at 80 km/h which expresses a ratio of the accumulated suspension motion of a vehicle, divided by the distance travelled during the test IRI and RN are commonly used because of their stability and reproducibility Artificial neural networks, Genetic programming and Fuzzy techniques have great variety of applications in Transportation engineering and are capable of modeling uncertain relationships. Numerous researches have been conducted to evaluate pavement condition. proposed a life cycle cost model and a cost effectiveness method for project level pavement management had done investigations on the relationship between IRI, rutting and cracking using large database.had derived a linear relationship between IRI and pavement condition based on 39 observations.had analyzed the relationships between IRI and pavement distress based on a back propagation neural network methodology. haddiscussed the capability of using neural networks for road profile estimation using neural network The objective of this (Pavement Condition Index) for construction work zones using neural network modeling**.** The predicted values are compared with actual IRI values measured using MERLIN.

4.4.1 Machine for Evaluating Roughness using Low-Cost Instrumentation

Along the construction work zones. Since poor pavement condition increases vehicle operating costs, accident costs and delay costs of the users, it is necessary to have certain guidelines for contracting work zones to calculateThe cost incurred during reconstruction. Under the existing method of reconstruction, the traffic is invariably diverted over detiorated pavement segments and shoulders which increases the vehicle operating cost and reduces safety of the road users. The Management strategies of the construction work zones can be strengthened to ensure safety and comfort for which pay index can be formulated with help study is to estimate IRI from PCI

4.4.2Methods for Measuring Roughness

Either direct or indirect method can be used to measure roughness. Direct measure to longitudinal profile can be obtained from class 1 or class II devices. Class 1 devices include the traditional longitudinal survey by rod and level or by some other by labor- saving apparatus (such as the Face Dipstick, which walked along the test path on two feet spaced 1 ft (0.305m) apart). Class II devices include various types of profilometer, such as the chloe type rolling straightedge profilometer used in the AASHO Road Test, the surface Dynamics Profilometer (SDP), designed by General Motors (Spangler and Kelly, 1964), the siometer employed by the Texas State Department of Highways and public transportation for measuring the Serviceability index (Fernando et al, 1990), and the profilometer and rut measuring device called PRORUT owned is the one most widely used.by FHWA (1987a). Indirectmeasure of longitudinal profile is those obtained from response Type Road Roughness Meters (RTRRM) system are referred to as Class III devices.

A survey of 48 state shows that the Mays ridemeter in the most popular device for roughness measurements and is used by 22 state (Epps and Monismith, 1986). The RTRRMs measure the relative movement in inches per mile (m/ km) between the body of the automobile and the center of the rear axle. They are inexpensive, simple and easy to operate at speeds of up to 50 mile /h(mph) (8o km/h). The recording systems are portable and can be installed in selected standard automobiles.The RTRRM measurements are sensitive to the types of tire, tire pressure,load, vehicle suspension system, speed of car, and factors that affect vehicle responses. Because of such sensitivity, they need to be calibrated when any of the foregoing factors changes significantly.

A recent survey of 37 state shows that most states are using laser –type

Profilometers (profilers) for roughness measurements, that only one state is still using the Mays ridemeter, and that the international roughness index (IRI) is the one most widely used.

When the response type road roughness meters are properly calibrated, the output from all the meters may be placed on acommon scale .one primary advantage of this approach is that the subjective interpretation of road roughness can be eliminated and pavement engineers will have a common scale for describing the ride quality of a road. Once the common scale is accepted , each highway agency may define where good, fair, and poor ride quality should be located on the scale. Certainly, PSR values from large panels could be correlated with the roughness scale as means for interpreting the roughness data.

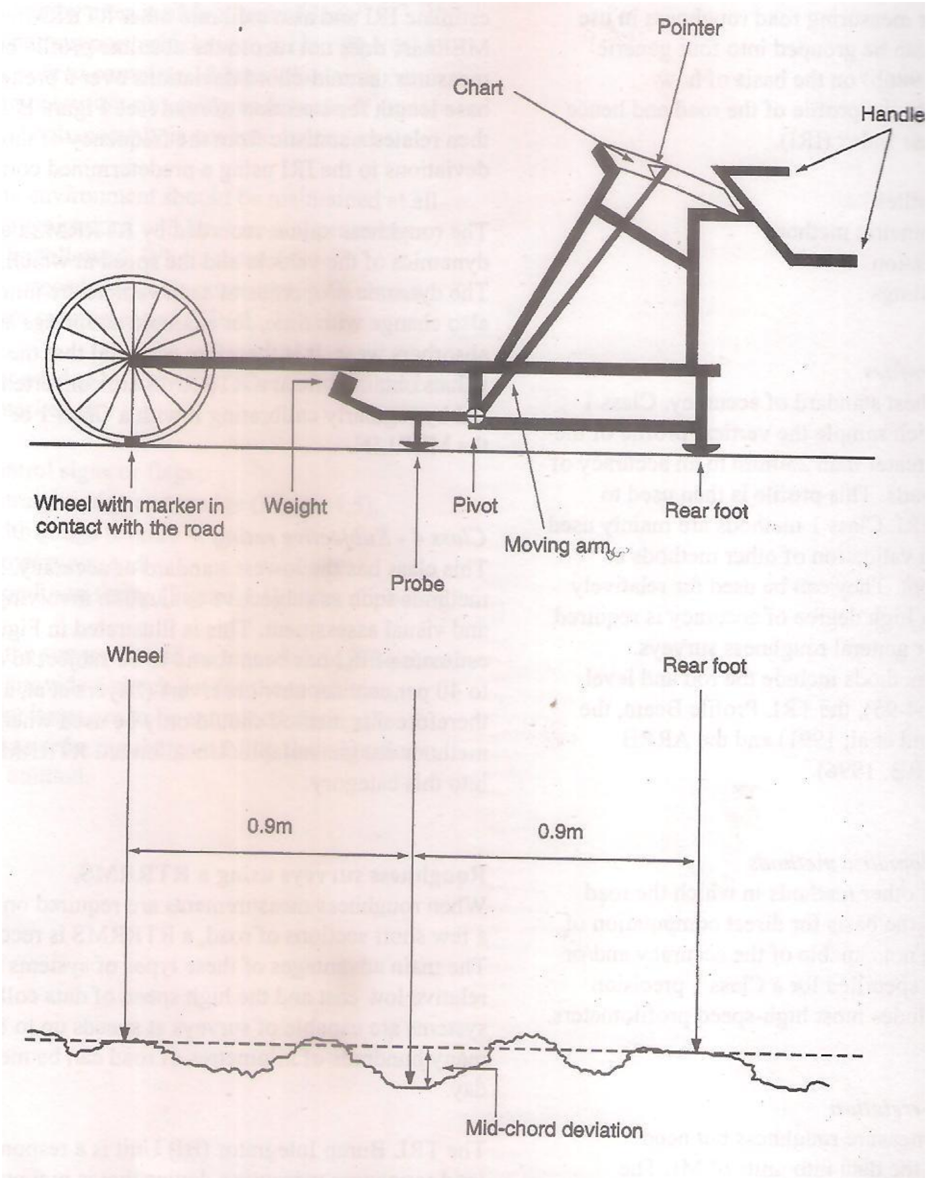


Figure B1 Operation of the MERLIN

Figure (4.3) Operation of the MERLIN

Various equipment has be developed for measurement of roughness. The equipment selected for PMS project is a vehicle a mounted Bump Integrator and MERLIN instrument , both developed by the Transport Research Laboratory (TRL, UK.) .The MERLIN instrument is used for calibrating the Bump Integrator.

Roughness may be expressed in several types of scales or indices. PEMM accepts several types of indices for input of roughness , but the program will under all circumstances convert the input figures to the International' Roughness Index (**IRI)** which expressed units **of m/km**. for this reason, it is natural to calibrate the Bump Integrator for direct conversion to **IRI**

4.4.4 Bump Integrator

The vehicle a mounted Bump Integratoris measuringthe cumulative movement (one direction only) between the body and the rear axle of the vehicle used for roughness measurements. The Bump integrator is a mechanical device fixed to the floor above the center of the rear axle of the test vehicle, a metal string with one end fixed to a hook on the rear axle and the other end winded up on a wheel on the Bump integrator, transfers the movement between the car body and rear axle to the Bump Integrator. The length of the wire must be adjusted to provide 2-2.5 turns (counter clockwise on the wheel , after prestressing by turning the wheel exactly 2.5 times , when the car is at the rest , the cumulative movement can be read on a counter unit mounted on the dash board and connected to the ?Bump Integrator by a cable. The counter units have two counters and a switch which automatically turns off one counter when starting the other. The counter unit of the Bump Integrator provided for the PMS project records the cumulative movement in centimeter (cm). The movement recorded by the Bump Integrator will depend largely on the speed and properties of vehicle in which is mounted. All reading should be made at fixed speed; the standard is 32 km/h.

4.4.5 MERLIN Apparatus

The apparatus called MERLIN, which is an acronym for a Machine for Evaluating Roughness using Low cost Instrumentation, is a simple and robust mechanical device for measuring roughness. It is a manually operated instrument which is wheeled along the wheel paths for measuring surface undulations regular interval see figure () below. The steel frame of the instrument has two legs, 1.8 m apart, with a bicycle wheel mounted on the front leg and steel plate bas footing on the rear leg. A stabilizer leg is attached to the rear leg to prevent the instrument from falling when taking readings. At the midpoint between the two legs there is a probe the vertical movement of which is transferred to a pointer via a hinged moving arm, at ratio 1:10. At each measuring point, the position of the pointer is marked on a chart which is fixed to a curved board just beneath the pointer. The chart has two boxes, one "measurement box" for making the pointer position and one tally box for counting the number of readings. The "measurement box "is divided into columns, each5 mm wide. The recommended procedure for determining the roughness on a stretch of road is to take 200 measurements at regular intervals. The spacing D, measured in millimeters, between the marks is defined as the roughness on the Merlin scale.There are formulas for converting the Merlin roughness D into the other roughness indices. for conversions to IRI, to the following formula is valid for all types of surfaces, provided that 42 less than D less than 312 which corresponds to 2.4 less than IRI less than 15.9

IRI (m/km)= 0.59 + 0.0471 * D (mm)

4.4.6. International Roughness Index (IRI)

Road roughness has been defined as the variation in surface elevation that induces vibration in moving vehicles. In particular, the International Roughness Index (IRI) is a scale for roughness based on the response of a standardised motor vehicle to the road surface. The IRI simulates response to the surface profile, and also considers the effect of vehicle suspension.

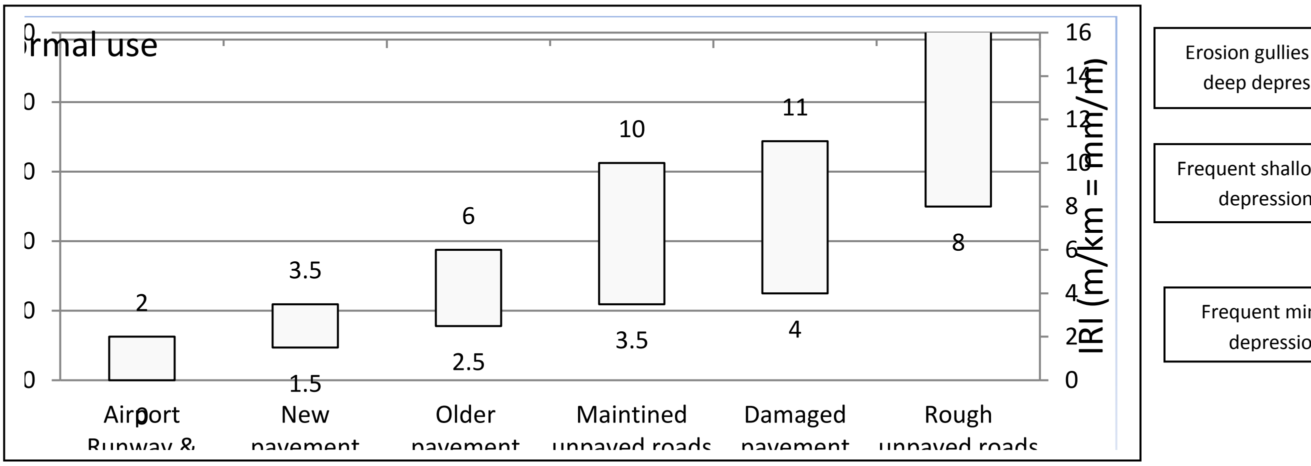


Figure (4.4): IRI roughness scale (replotted from sayers et al., 1986)

Roughness or ride quality is important . International Roughness Index

(IRI) was developed by World Bank in the 1980s (UMTRL, 1998). IRI is used to define a characteristic of the longitudinal profile of a travelled wheel track and constitutes a standardized roughness measurement. The commonly recommended units are meters per kilometer (m/km) or millimeters per meter (mm/ m). The IRI is based on the

Average rectified slope (ARS), which is a filtered ratio of a standard vehicles accumulated suspension motion (in mm, inches, etc), divided by a distance traveled by vehicle during the measurement (km, mi, etc). IRI is then equal to ARS multiplied by 1000. The open ended IRI scale as shown

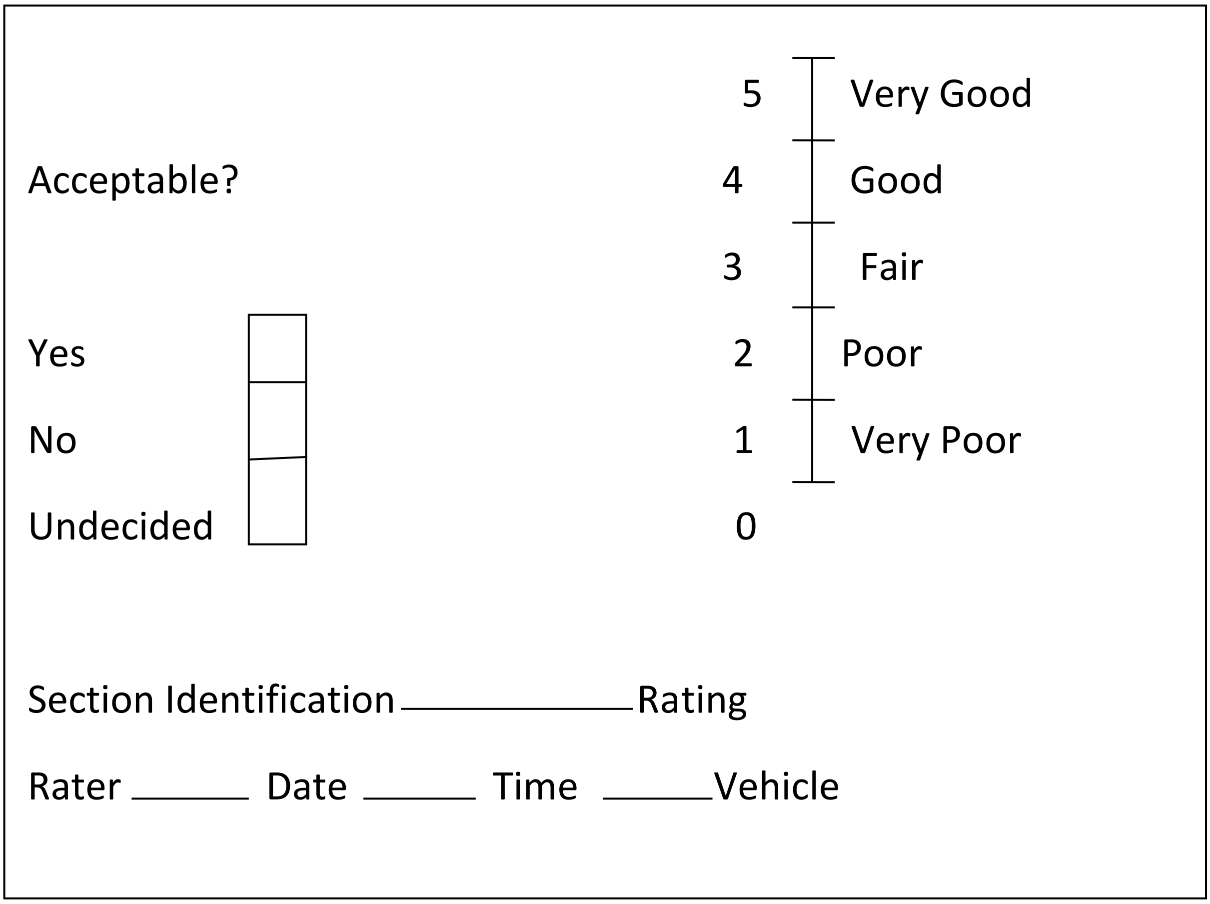


Figure (4.5) : individual present serviceability rating form

Was developed at the international road roughness experiment held in Brazil in 1982 under the sponsorship of the World Bank. The world bank published guidelines for conducting and calibrating roughness measurement (Sayers et al. ,1986a) ; the IRI has been adopted as a standard for FHWA highway performance monitoring system (HPMS)data base (FHWA, 1987).

The IRI summarizes the longitudinal surface profiles in the wheel path and is computed from surface elevation data collected by either a topographic survey or a mechanical profilometer. It is defined by the average rectified slope (ARS), which is the ration of the accumulated suspension motion to the distance traveled obtained from mathematical model of standard quarter car transversing a measured profile at a speed of 50 mph (80km/h). It is expressed in units of inches per mile (m/km). general method for use in simulation are also specified in ASTM E-1170 " standard practices for simulating vehicular response to longitudinal profiles of vehicular traveled surface."

Since no two RTRRMs are exactly alike, it is necessary to convert the measures calibration to the standard IRI scale by using the relationship established through calibration.

Calibration can be achieved by measuring ARS of the RTRRM at a standard speed on special calibration sites of known IRI roughness values. The measured ARS values are plotted against the IRI values, and a line is fitted to the data points and used to estimate IRI from the RTRRM measurements in the field.

4.4.7 Riding number

The relationship between roughness and serviceability. they found that the riding number RN, as measured with a profilometer in the band of frequencies between 0.125 and 0.63 cycle/ft (10 to 15 Hz at 55 mph), is highly correlated with the mean panel rating MPR for all three types of pavement : asphalt , concrete, and composite . Note the RN , which ranges from 0 to 5 , is equivalent to PSI and that MRP is equivalent to PSR . Resulting regression equation that transforms the longitudinal roughness.In which RN is the riding number of a given pavement section , which give the best estimate of MPR, and PI is the profile index, defined as the square root of the mean square of the profile height in the specified frequency band . The MRP of a given test section is also an accurate predictor of the public's subjective perception of whether a specific test section need repairs which NR is the percentage of drivers who think that the pavement needs repair therefore, given only longitudinal roughness measures, one can compute both the ride ability number and the exact percentage of driving population that thinks the road should be repaired.

4.5 Pavement Skid resistance Management

4.5.1 introduction

The measurement and management of pavement skid resistance is of the critical importance to highway agencies world wide . the key point of interest is the frictional resistance generated between the vehicle tires and the pavement surface that allow a moving vehicle to the brought to a stop .The greater the frictional resistance mobilized, the quicker the vehicle can be slowed or stopped.

The improvements in tire technology , including advances in tire compounds, tread patterns and tread depths. All of the improvements are aimed at ensuring maximum contact between tire and pavement surface at all speed, with generation of high age of the pavement surface

4.5.2 Factors influencing skid resistance

The critical factors are whether the pavement surface is wet or dry. Under completely dry conditions, resistance to skidding is very high, and the frictional resistance as measured by SCRIM (side way force coefficient routine investigation machine)

Frictional resistance (as measured by testing equipment) has been found to fall the speed of testing increases. Frictional resistance at lower speeds, and much shallow gradients at higher speeds.

1- Seasonal effects also can have a very significant role on the frictional resistance provided by a given pavement surface. The frictional resistance of a wet road surface is greater in winter than in Summer. The proportion of the time that the road is wet seems to influence the variation in frictional resistance more than the actual temperature. Thus wet winter produce higher friction resistance on wet road surface than cold dry winters.

2- The difference between summer and winter conditions relates to changes in micro texture. In wet winter conditions, heavy traffic polishes the aggregate faces. In wet winter conditions, the presence of salt and grit works to improve the micro texture

3- Temperature also exerts a considerable influence on the variability in skidding resistance results. Resistance to skidding tends to decrease as the temperature increases, due to mainly to temperature effects on the material properties of the vehicle tires.

4- The age of the pavement surface can also be a significant factor . Skidding resistance values can be quite low as the binder rather than the aggregate is providing the surface at the tire / surface interface.

5- Bleeding of a

4.5.3 Micro texture and Macro texture

The micro texture of the aggregate controls the contact between the tire rubber and pavement surface. The micro texture characteristics of aggregates are governed by the crystalline nature of the aggregate itself. micro texture provides the primary source of frictional resistance at low speeds (less than 50 km / h) due to the direct interaction between the tire rubber and aggregate surface.

The macro texture of the pavement surface refers to the coarser texture defined by the shape of the individual aggregate chips and by spaces between the individual aggregate chips.

The macro texture plays a critical role in tire hysteresis. Hysteresis or distortion of the tire surface occurs as the surface of the tire passes over projection and depression in the pavement surface

4.5.4 Measurement of frictional resistance

The measurement of the resistance to movement at the interface between the tire and pavement surfaces is the friction coefficient. The friction coefficient is defined as the force resisting motion divided by the vertical load. The friction coefficient is dependent on many factors:

Tire compound properties, tire tread pattern, and tread depth, the pavement surface micro texture and macro texture and the presence of the surface water or other lubricants or contaminants.

There are four categories of friction measuring devices that can be used to measure skid resistance on pavement surfaces. They are:

Locked wheel devices , Fixed slip devices, Variable slip devices, Sideway force devices

4.5.5 Locked Wheel Tester

The procedure may be summaries as follows:

The test vehicle /trailer is brought up to the desire test speed. Water is delivered ahead of the test tire. The resulting friction force is measured by some type of force transducer. The speed of the testing vehicle/trailer is also simultaneously measured. The reported out put under the ASTM standard is the skid number (SN) defined as the force required to slide locked test wheel as the stated speed , divided the effective vertical load applied to the test wheel and multiplied by 100%.

4.5.5.1 Fixed Slip Devices

Fixed slip device operating at a slip ratio of 20% if the test vehicle is moving at 65 kg/ h, the device is measuring at attire speed of 65*0.2= 13 kg/ h, these devices are measuring low speed friction resistance.

The grip tester device is representative of fixed slip devices. The operation is covered by a British Standard Specification (BS 7941-2). The grip tester is a small trailer towed device , approximate 1m in length and 0.8 m width , it has been used on roads , and because of small size , it can also be operated in manual (pushed)

I *n the roadway context , the grip tester can be operated at vehicle speeds between 5km/h and 130km/h subjected to the road being sufficiently smooth that the trailer is in constant contact with the road surface . Frictional results are measured continuously along the road section length. Results can be average and summarized over specified intervals, usually over either 5 to 10 m intervals for road applications*

SCRIM

The most common type of equipment using sideway force as a measure of frictional in resistance the Sideway Force Coefficient Routine Investigation Machine (SCRIM) the SCRIM covered by (BS 7941) . The equipment was produced originally in the early 1970 s in the Britain for measuring the skid resistance of the road network. The equipment mounted on a track chassis with the large capacity with tank (approx. 4000 L) , its especially designed to allow large length of network to be continuously tested. Daily output of approximately 200km can be expected using SCRIM

0.5mm, Mega texture is defined by PIARC as the derivation of the pavement, surface from a true planar surface is the texture wave length range of approximately 50—500mm

s4.5.6 International Friction Index

It is clear by now that there is a variety of different measures of frictional resistance at the interface between the pavement surface and the vehicle tire . Frictional resistance at the interface varies with speed, and both micro and macro texture, play significant roles in the frictional resistance, generally depending upon the speed.

High speed frictional resistance in the field can be measured with locked wheel device.

A Similar situation existed in the measurement of the unevenness or roughness of road surfaces. An international road Roughness (IRR), leading to development of the International Roughness Index (IRI)

sphalt, which covers the aggregates and obscures the effectiveness of their skid resistant qualities.

6- Polished aggregate with sooth micro texture, which reduces friction between the aggregate and the tire.

7- Smooth macro texture, which lacks suitable channels to facilitate drainage.

8- Rutting, which holds water in the wheel paths after rain and causes hydroplaning.

4.5.7 Skid resistance Policy

A road agency charges with the provision of pavements with adequate frictional resistance can use the information and available equipment in a variety of ways .essentially, however, these reduce to one of the following three:

Three main areas of interest;

Controlling the frictional resistance of the road agency pavements through specification of micro texture and macro texture.

Using field results of frictional resistance to investigate accident and to identify high risk accident locations.

Managing the in situ frictional resistance of a road agency's network of pavements through systematic network surveys.

Skid resistance tester is the high quality skid resistance testing equipment. This provides highway engineers with a routine method of checking the resistance of wet and dry surfaces to slipping and skidding, both in the lab and on site. To measure texture depth and skid resistance of the pavement. It is based on the load principle

Table (4.11) PCI and skid resistance for roads

Road NAME	PCI	SKID RESISTANCE (SN)
AL MAK NIMR	60	86
SIAD A/RAHMAN	82	83
AL BALADIA	60	84
EL JAMMAA	60	83
EL EMAM EL MAHADI	70	73
EL GASRE	52	74
EL JAMHOORIA	96	74
AL/MONIEM MHAMMED	86	67
EL HORIA	78	73
ALI A/LATIEF	78	72

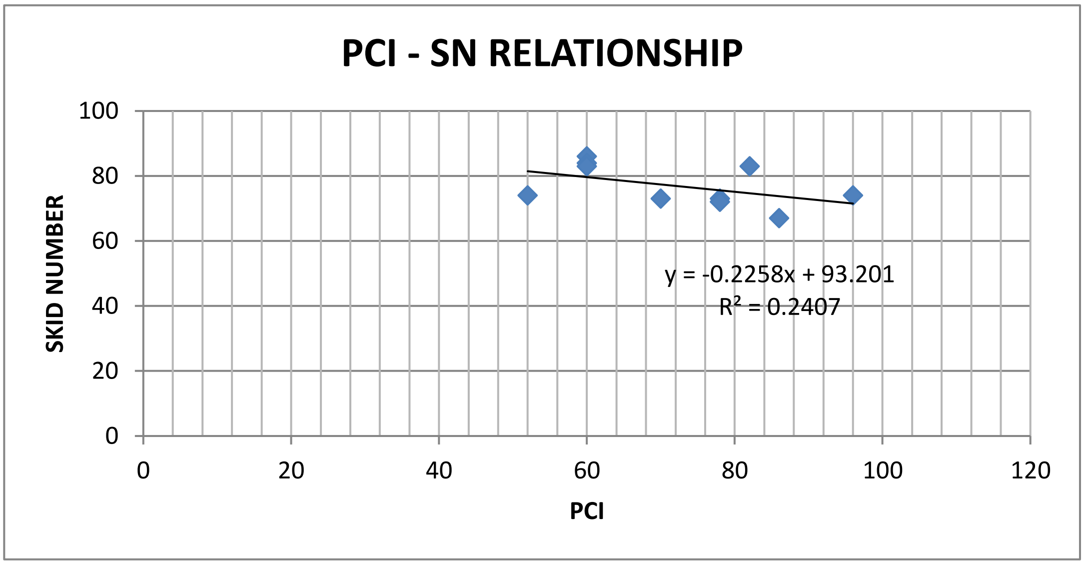


Figure 4.6:pavement condition index and skid resistant relationship

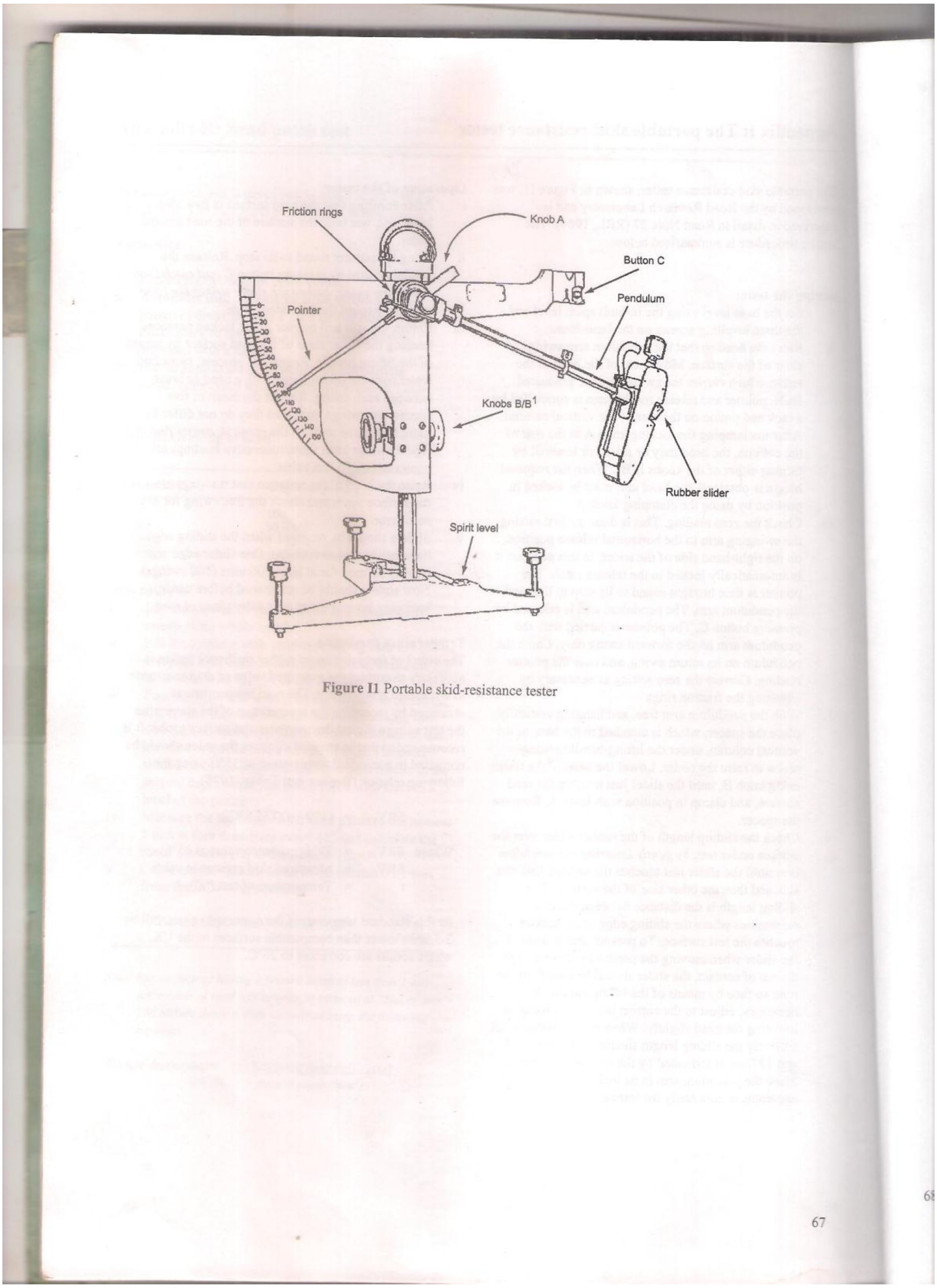


Figure 4.7SKID RESISTANCE TESTER

4.6 Level of service

The 2000 Highway Capacity Manual provides methodologies for estimating the level of service and capacity for both uninterrupted and interrupted transportation facilities. For each facility there are one or more performance measures, or measures of effectiveness (MOEs), which characterize the user's perception of the operating conditions of that facility. It is critical to understand at the outset that *users, not facilities,* experience the travel characterized by LOS in the 2000 HCM. By implication, there are different levels of service for each user, and indeed even within a travel mode there are different service qualities possible by approach or direction, as well as by time of day.

For simplicity, this study focuses solely on LOS from the perspective of drivers of motor vehicles. However, regardless of user mode, approach, or direction, each LOS representsa range of values for that facility's MOE. This range varies by a lettering system 'A'through 'F'. LOS 'A' represents a user perception of the MOE as being excellent, with'F' denoting a breakdown in the facility.

The four facilities of interest for this project are freeways, multilane highways, two-lane highways and urban streets (also known as arterials). A brief description of each of these facility's MOE and LOS follows. A detailed summary of the HCM procedures for determining the LOS of each facility type can be found in Appendix A.

4.6.1 Freeways

A freeway is an uninterrupted flow facility comprised of two or more lanes per direction with complete access control and no signals or at-grade intersections involving mainline (through) traffic. A basic freeway segment is not influenced by ramp or weaving segments and operates under uniform conditions. Pedestrians and bicycles are not permitted to travel on freeways in North Carolina.

The measure of effectiveness for a basic freeway segment is density, in units of passenger-cars per mile per lane (pc/mi/ln). It is a function of flow rate and average passenger-car speed. This is shown as a graphical representation in the HCM in Exhibit23-3, which is seen below in Figure (4.8). The various LOS can be seen as breaking points, or thresholds, on the basis of density boundary values.

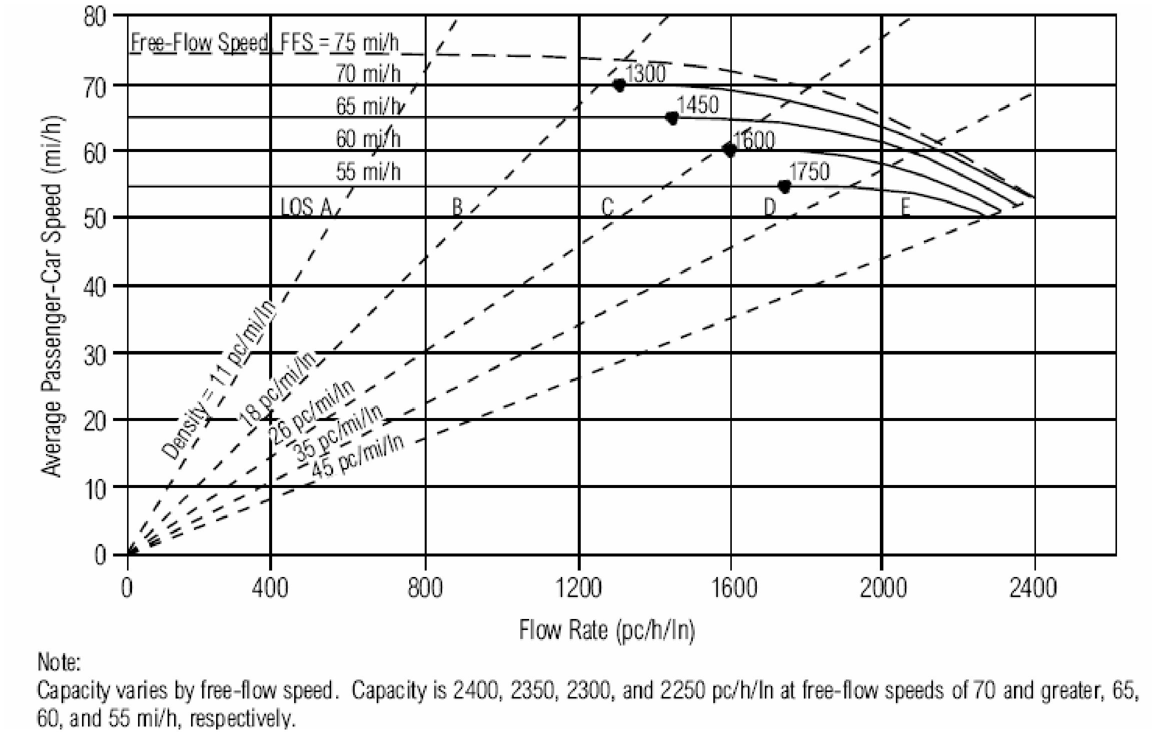


Figure (4.8). Speed Flow Curves and LOS for Basic Freeway Segments (HCM Exhibit 23-2)

Table (4.12) The specific LOS thresholds for a freeway facility are shown below in Table

LOS	Density range (pc/mi/in)
A	0-11
B	>11-18
C	>18-26
D	>26-35
E	>35-45
F	>45

Density is the preferred MOE because it is easily measured in the field and is more sensitive to the level of comfort and convenience that freeway users experiencing than are speed or travel time. In fact, as volumes increase, LOS can decrease dramatically on a freeway with speed remaining constant or decreasing minimally.Additionally, because thresholds have been established, it is important to note that actualdensities vary throughout each LOS range. Therefore, when calculating a specificfreeway density, the analyst should recognize that a density of 26 pc/mi/in (LOS C) and27 pc/mi/ln (LOS D) are really not that different even though the designated letterindicates to most analysts a large difference. This is true for all four facility types. Forfurther explanation of the methodology and calculations for obtaining the LOS for thefreeway facility, see Appendix D.

The following are the data required to be entered in the HCS software:

Table (4.13) Traffic account for Khartoum centre roads (ADT)

Name of road	ADT	% of Truck	Time Account	Speed (mile/hour)
Nile Avenue	1200	2	AM	45
Al gamma	1600	3	AM	45
El gamhoria	1000	3	AM	45
El baladia	1100	3	AM	45
El sayid A/Rahman	1000	4	AM	45
El imam Elmahdi	14oo	4	AM	45
El mak Nimir	760	3	AM	45
El gasr	940	2	AM	45
Abdel Moniem Mohmed	1050	3	AM	45
El Horia	1000	3	AM	45
Ali Abdel Lateef	64o	3	AM	45

Highway Capacity Software

This major upgrade to the Highway Capacity Software is planned for release as *HCS 2010* concurrently with the publication of the 2010 of the Highway Capacity Manual (HCM),scheduledforJanuary,2011.

Using of this software is valid procedure to estimate the level of service (LOS), for Khartoum urban center streets. According to the procedure shown in appendix D the data in table 4.9 is entered to the software, analyzed and the results were obtained for each road as in the following table report.

Table 4.14 shows the level of service summary obtained from the analysis of the the street data.

Table(4,14): level of service for the street of Khartoum urban center.

Street Name	Level of Service (LOS)
Nile avenue	C
Al Gamma	C
El Baladia	C
Said Abdel Rahman	A
El Emam El Mahadi	B
Mac Nimir	C
El Gasr	C
Abd ELmoniem mohammed	B
El Horia	B
Ali Abdelatief	B
El Gamhoria	C

AS it is seen only one street has level of service A, and four of them has level of service B and the rest six street are having level of service c which will need more access and grade separation for the junctions and to some extent some maintenance is needed for some of them.

The following are the results of HCS software

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

___OPERATIONAL ANALYSIS___

Analyst:	Abd alla
Agency/Co:	sust
Date:	24/09/2016
Analysis Period:	8-9 am
Highway:	Al gamma
From/To:	East to West direction
Jurisdiction:	Khartoum State
Analysis Year:	2015
Project ID:	

___FREE-FLOW SPEED___

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	45.0	mph	45.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	45.0	mph	45.0	mph

___VOLUME___

Direction	1		2	
Volume, V	1500	vph	1500	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	417		417	
Trucks and buses	3	%	3	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.985		0.985	
Flow rate, vp	845	pcphpl	845	pcphpl

___RESULTS___

Direction	1		2	
Flow rate, vp	845	pcphpl	845	pcphpl
Free-flow speed, FFS	45.0	mph	45.0	mph
Avg. passenger-car travel speed, S	45.0	mph	45.0	mph
Level of service, LOS	C		C	
Density, D	18.8	pc/mi/ln	18.8	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.
HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst: Abd alla
Agency/Co: sust
Date: 24/09/2016
Analysis Period: 8-9 am
Highway: Al baladia
From/To: East to Weat direction
Jurisdiction: Khartoum State
Analysis Year: 2016
Project ID:

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	45.0	mph	45.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	45.0	mph	45.0	mph

VOLUME

Direction	1		2	
Volume, V	1600	vph	1600	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	444		444	
Trucks and buses	4	%	4	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.980		0.980	
Flow rate, vp	906	pcphpl	906	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	906	pcphpl	906	pcphpl
Free-flow speed, FFS	45.0	mph	45.0	mph
Avg. passenger-car travel speed, S	45.0	mph	45.0	mph
Level of service, LOS	C		C	
Density, D	20.1	pc/mi/ln	20.1	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst:	Abd alla
Agency/Co:	sust
Date:	24/09/2016
Analysis Period:	8-9 am
Highway:	Al sayid A Rahman
From/To:	East to West direction
Jurisdiction:	Khartoum State
Analysis Year:	2016
Project ID:	

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	60.0	mph	60.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	60.0	mph	60.0	mph

VOLUME

Direction	1		2	
Volume, V	1100	vph	1100	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	306		306	
Trucks and buses	3	%	3	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.985		0.985	
Flow rate, vp	620	pcphpl	620	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	620	pcphpl	620	pcphpl
Free-flow speed, FFS	60.0	mph	60.0	mph
Avg. passenger-car travel speed, S	60.0	mph	60.0	mph
Level of service, LOS	A		A	
Density, D	10.3	pc/mi/ln	10.3	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst: Abd alla
Agency/Co: sust
Date: 24/09/2016
Analysis Period: 3-4 pm
Highway: Imam Elmahadi
From/To: East to West direction
Jurisdiction:
Analysis Year: 2016
Project ID:

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	60.0	mph	60.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	60.0	mph	60.0	mph

VOLUME

Direction	1		2	
Volume, V	1400	vph	1400	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	389		389	
Trucks and buses	3	%	3	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.985		0.985	
Flow rate, vp	789	pcphpl	789	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	789	pcphpl	789	pcphpl
Free-flow speed, FFS	60.0	mph	60.0	mph
Avg. passenger-car travel speed, S	60.0	mph	60.0	mph
Level of service, LOS	B		B	
Density, D	13.1	pc/mi/ln	13.1	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst: Abd alla
Agency/Co: sust
Date: 24/09/2016
Analysis Period: 8-9 am
Highway: Mac Nemir
From/To: North to South direction
Jurisdiction: Khartoum State
Analysis Year: 2016
Project ID:

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	45.0	mph	45.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	45.0	mph	45.0	mph

VOLUME

Direction	1		2	
Volume, V	1450	vph	1450	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	403		403	
Trucks and buses	2	%	2	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.990		0.990	
Flow rate, vp	813	pcphpl	813	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	813	pcphpl	813	pcphpl
Free-flow speed, FFS	45.0	mph	45.0	mph
Avg. passenger-car travel speed, S	45.0	mph	45.0	mph
Level of service, LOS	C		C	
Density, D	18.1	pc/mi/ln	18.1	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst: Abd alla
Agency/Co: sust
Date: 24/09/2016
Analysis Period: 3-4 pm
Highway: El gasr
From/To: North to South direction
Jurisdiction: Khartoum State
Analysis Year: 2016
Project ID:

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	45.0	mph	45.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	45.0	mph	45.0	mph

VOLUME

Direction	1		2	
Volume, V	1500	vph	1500	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	417		417	
Trucks and buses	3	%	3	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.985		0.985	
Flow rate, vp	845	pcphpl	845	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	845	pcphpl	845	pcphpl
Free-flow speed, FFS	45.0	mph	45.0	mph
Avg. passenger-car travel speed, S	45.0	mph	45.0	mph
Level of service, LOS	C		C	
Density, D	18.8	pc/mi/ln	18.8	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst: Abd alla
Agency/Co: sust
Date: 24/09/2016
Analysis Period: 3-4 pm
Highway: A moneim Mohd
From/To: North to South direction
Jurisdiction: Khartoum State
Analysis Year: 2016
Project ID:

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	45.0	mph	45.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	45.0	mph	45.0	mph

VOLUME

Direction	1		2	
Volume, V	1100	vph	1100	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	306		306	
Trucks and buses	3	%	3	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.985		0.985	
Flow rate, vp	620	pcphpl	620	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	620	pcphpl	620	pcphpl
Free-flow speed, FFS	45.0	mph	45.0	mph
Avg. passenger-car travel speed, S	45.0	mph	45.0	mph
Level of service, LOS	B		B	
Density, D	13.8	pc/mi/ln	13.8	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst: Abd alla
Agency/Co: sust
Date: 24/09/2016
Analysis Period: 3-4 pm
Highway: Elhoria
From/To: North to Southt direction
Jurisdiction: Khartoum State
Analysis Year: 2o16
Project ID:

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	45.0	mph	45.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	45.0	mph	45.0	mph

VOLUME

Direction	1		2	
Volume, V	1200	vph	1200	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	333		333	
Trucks and buses	2	%	2	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.990		0.990	
Flow rate, vp	673	pcphpl	673	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	673	pcphpl	673	pcphpl
Free-flow speed, FFS	45.0	mph	45.0	mph
Avg. passenger-car travel speed, S	45.0	mph	45.0	mph
Level of service, LOS	B		B	
Density, D	15.0	pc/mi/ln	15.0	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst: Abd alla
Agency/Co: sust
Date: 24/09/2016
Analysis Period: 3-4 pm
Highway: Ali A lateef
From/To: North to South direction
Jurisdiction: Khartoum State
Analysis Year: 2016
Project ID:

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	45.0	mph	45.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	45.0	mph	45.0	mph

VOLUME

Direction	1		2	
Volume, V	1250	vph	1240	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	347		344	
Trucks and buses	3	%	3	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.985		0.985	
Flow rate, vp	704	pcphpl	699	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	704	pcphpl	699	pcphpl
Free-flow speed, FFS	45.0	mph	45.0	mph
Avg. passenger-car travel speed, S	45.0	mph	45.0	mph
Level of service, LOS	B		B	
Density, D	15.6	pc/mi/ln	15.5	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst:	Abd alla
Agency/Co:	sust
Date:	24/09/2016
Analysis Period:	8-9 am
Highway:	Al gamhoria
From/To:	East to Weat direction
Jurisdiction:	Khartoum State
Analysis Year:	2016
Project ID:	

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	45.0	mph	45.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	45.0	mph	45.0	mph

VOLUME

Direction	1		2	
Volume, V	1600	vph	1600	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	444		444	
Trucks and buses	4	%	4	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.980		0.980	
Flow rate, vp	906	pcphpl	906	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	906	pcphpl	906	pcphpl
Free-flow speed, FFS	45.0	mph	45.0	mph
Avg. passenger-car travel speed, S	45.0	mph	45.0	mph
Level of service, LOS	C		C	
Density, D	20.1	pc/mi/ln	20.1	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

HCS+: Multilane Highways Release 5.2

Phone: Fax:
E-mail:

OPERATIONAL ANALYSIS

Analyst: Abd alla
Agency/Co: SUST
Date: 24/09/2016
Analysis Period: 8-9 am
Highway: Nile Avenue
From/To: East to West
Jurisdiction: Khartoum
Analysis Year: 2o16
Project ID:

FREE-FLOW SPEED

Direction	1		2	
Lane width	12.0	ft	12.0	ft
Lateral clearance:				
Right edge	6.0	ft	6.0	ft
Left edge	6.0	ft	6.0	ft
Total lateral clearance	12.0	ft	12.0	ft
Access points per mile	0		0	
Median type				
Free-flow speed:	Measured		Measured	
FFS or BFFS	45.0	mph	45.0	mph
Lane width adjustment, FLW	0.0	mph	0.0	mph
Lateral clearance adjustment, FLC	0.0	mph	0.0	mph
Median type adjustment, FM	0.0	mph	0.0	mph
Access points adjustment, FA	0.0	mph	0.0	mph
Free-flow speed	45.0	mph	45.0	mph

VOLUME

Direction	1		2	
Volume, V	1600	vph	1600	vph
Peak-hour factor, PHF	0.90		0.90	
Peak 15-minute volume, v15	444		444	
Trucks and buses	2	%	2	%
Recreational vehicles	0	%	0	%
Terrain type	Level		Level	
Grade	0.00	%	0.00	%
Segment length	0.00	mi	0.00	mi
Number of lanes	2		2	
Driver population adjustment, fP	1.00		1.00	
Trucks and buses PCE, ET	1.5		1.5	
Recreational vehicles PCE, ER	1.2		1.2	
Heavy vehicle adjustment, fHV	0.990		0.990	
Flow rate, vp	897	pcphpl	897	pcphpl

RESULTS

Direction	1		2	
Flow rate, vp	897	pcphpl	897	pcphpl
Free-flow speed, FFS	45.0	mph	45.0	mph
Avg. passenger-car travel speed, S	45.0	mph	45.0	mph
Level of service, LOS	C		C	
Density, D	19.9	pc/mi/ln	19.9	pc/mi/ln

Overall results are not computed when free-flow speed is less than 45 mph.

CHAPTER FIVE

How to Implement a Pavement Management System

5.1 GENERAL

Pavement management system (PMS) has been available for several years. Although many agencies have adopted a PMS, many of them are not using the systems of the fullest capabilities**.** Other has adopted PMS, but the information produced by the PMS has little impact on the decision being made by the agency. Pavement management systems are decision support tools which cannot be considered fully implemented until they affect the decision making process they were designed to support (intermodal surface transportation efficiency Act 1991).A common question among research is " Why don't they adopt the new PMS approach? It would help them address the problems that they keep talking about."

Engineers tend to think that if they develop a better way of addressing a problem, it will automatically be adopted and used. History shows that the development of improved products, methods, and systems does not ensure adoption. There is a wide gap between what is known and what is actually used in many fields (Sachs and Smith 1994).As an example, the present keyboard used to prepare this report is known as the "QWERTY" board. The layout of the keys on this keyboard was developed in 1873; a few keys have been added such as the function key and numerical pad, but the basic location of the letters remain unchanged in 1873 the keys on a typewriter returned to the key rest due to the force of gravity. If the typist pressed keys too quickly, one key would not return to the rest before the second came forward resulting in incidence of jamming keys, deliberately reducing typing speed. In 1932 Professor Dvorak conducted time and motion studies at the University of Washington to create a more efficient typewriter keyboard. The Dvorak typewriter keyboard reduces the number of keystrokes on the upper row to about 22 percent, those on the lower row to about 8 percent, and increases those the middle row to approximately 70 percent. In addition, the amount of work assigned to each finger is proportional to its strength and skill. The keys are arranged with the consonants under one hand and the vowels under the other to allow more keystrokes to be alternated from one hand to another. The Dvorak keyboard is easier to use and significantly increases typing speed. Most speed typing records were set with the Dvorak keyboard in the 1930s and 1940s; however, it has not been adopted by most typists or keyboard user, including authors Sachs and Smith (1994).Since it is better, why is it not being used? Part of the answer is that the current systems are all based on the QWERTY keyboard, and everyone would have to change. Apparently the increase in speed is not worth the effort to change.

5.2 Barriers to Adoption and use

A barrier can generally be described as a barricade, obstruction, or anything that impedes advance. Barriers can limit, obstruct, or prevent PMS adoption, implementation, or effective use. There are many barriers to adoption, implementation, and effective use of pavement management system, whether it is a full PMS or a new component. In the early years of PMS development and implementation, some of the most important barriers were technical. The PMS concept was not well developed and the analysis techniques required considerable research to find those techniques were completed on mainframe computers that were both cumbersome to use and often difficult to access.

However, over the last several years, the microcomputer revolution has provided greater access to computers and created a friendlier computational environment. The state-of-the-art in PMS analysis techniques has advanced to such a level that many techniques problems have been addresses or at least the approaches to solving them have been identified. All technical problems have not been completely solved, and there will always be a need to improve existing and develop new pavement management data collection techniques, analysis procedures, and decision support software. However, even in those early days of pavement management, there was a recognition implementation and use of pavement management system (Smith 1992; Mogavero and Shane 1982; Sachs and Smith 1994). Diffusion of innovations and technology transfer are fields of study that address how changes occur in organizations. These fields can help provide some guidance minimize the problems associated with developing and implementing new, or revised, management techniques within existing organizations.

5.2.1 .Institutional Issues

Institutional issues include people, organization, and communication situations that can act as barriers or inhibit the adoption or full use of a PMS or an improved PMS component. Not all institutional issues are true barriers. Many of them just require a different approach than if the PMS was adopted by individual. There are several different type of issues and barrier that can affect PMS implementation. Many of the most troublesome are organizational or people related. Some of these people-related barriers are built into the organization that must be addressed.

The institutional issues and barriers can be loosely grouped into three classes people related, organizational, and development/implementation related. The following sections describe several issues and barriers encountered in pavement management implementation efforts that have been placed in these three groups. It is helpful to think of them in these groups to try to develop methods to address them; however, it is apparent that some fall in more than one class. While any one of these may prevent implementation or limit use of PMS, more than one is often encountered simultaneously.

5.2.2 People Issues and Barriers

This type of issue or barrier is related to the personalities and interpersonal relationships of individuals in an organization. Personal conflicts, inappropriate competition, and communication problems often lead to barriers. These issues are not unique to PMS; they appear whenever a new decision making or decision support process is adopted.

These problems may not always be immediately apparent, especially if the PMS has been mandated. In that situation, some people appear to be adopting and implementing a new PMS component from the perspective of an outsider, but they actually inhibit the effective use of the PMS component in the actual decision making. The people problems can be some of the most difficult to address because they can show up as issues in so many places and can reappear as barriers after the issues appear to have been addressed. Sometimes it only takes one person in a critical position to prevent adoption or effective use of a new PMS component. People problems also constantly change as personal at all levels enter and leave an organization. The following are some of the people barriers that are encountered.

5.2.3 Turf Protection

A PMS provides information and analysis procedures that often cross several formal and informal lines of authority and communication within an organization. It provides information on planning for funding needs, programming and selecting segments of pavement for both maintenance and rehabilitation, and determining the impact of funding decision on the future condition of the network and funding needs.

Information is power in an organization, and access to information may influence decisions. This often affects not only the decision. This often affects not only the decisions currently being made by planning, maintenance, design, operations, and administrative groups within a single organization, but it may also affect who makes those decisions in future. When a PMS is modified in a way that is perceived as having the potential for changing the status quo, the affected groups within the especially if the PMS group appears to be preparing to make decision for which the other groups were previously responsible. The leaders of these groups may resist implementation of a PMS component to prevent a perceived loss of power.

5.2.4 Fear of Exposure

Pavement management system provides structured information that often was not widely available prior to the adoption and implementation of a PMS. Those who have been making decisions with less than complete information may resist implementation of a PMS component that provides more complete information because they fear that the PMS will show that their prior decisions were incorrect or less accurate than they have previously stated. They are afraid of possible censure by their superiors or ridicule by other who now have ready access to information that was previously unavailable or difficult to access.

A few personnel may refuse to use anything that was not thought of or developed within the agency. Because of the "If it wasn't developed here, it can't be any good" attitude, an excessive amount of money may be spent in developing a pavement management component when an available process could be adopted with a few relatively inexpensive modifications. There is a balance needed between standard pavement management components and meeting agency-specific needs. It is true that almost every highway and public works agency is somewhat differently organized than the others; however, they all have similar management needs and requirements. Some customization will be necessary in almost any implementation. However, the basic elements of pavement management are similar for similarly agencies. The components from one agency can often be modified to allow use in another agency at far less cost than developing a new one.

5.2.5 Resistance to Change

There are some people who just do not want to change. These people are present in many public agencies. Some of the other issues described above may be a part of the reason they do not want to change, but some people just do not want to expend the effort needed to reshape their thinking, decision making process, and work habits. They find all kinds of excuses for not changing and will generally try something different.

5.3 Organizational Issues and Barriers

There are a number of conditions and situations in any organization that can make change difficult, or at times nearly impossible. Many of these are issues that must be addressed during implementation, especially when selecting the components to include in the decision support software, to keep them from developing into barriers to effective use. This was discussed in depth in Chapter 3. The following briefly lists some of the most common issues and barriers.it's some of the most common issues and barriers.

5.4 Management and Decision Making Practices

Use of PMS components is affected by past management and decision making practices in the agency. Several types of decision making processes are used in highway agencies when they adopt a change and often different process are used within different groups of the same agency. Since a PMS is a decision support system, it must provide information in the form needed to support the decision process in agency.

5.4.1 Structure

Effective pavement management decision cross the boundaries of many traditional divisions within most highway agencies. The structure of the agency can have a significant impact on the effective use of pavement management, and the decision-making process may be influenced by the agency structure. Agencies can have several different types of functional structures that are centralized, decentralized, mixed, or some other variant. Some highway agencies have organizational structures that are aligned with their mission while others have a historical structure that has not changed as their mission changed. Planning Horizons and Requirements. The planning cycle will influence number of years based on a funding cycle that is often fixed based on legislated policies. Long-range plane are common for complex major projects in metropolitan areas and high-volume highways in remote areas where the work must be coordinated with other activities such as bridges, utilities, est. There is often a required planning process that the agency must follow in order for projects to be eligible for certain types of funding. These planning and budget processes influence the decision support needed from a pavement management system, especially the information that proposed projects must compete with other projects for funding.

5.4.2 Constrain on Selecting Projects for Funding

Selecting projects for treatment may be constrained other work; in other cases the work must be conducted concurrently with some other activity and cannot be started until the funding is available and design completed for that other activity. Many agencies have several categories of funds that have limited applicability and are defined by legislative, policy, or administrative direction. Projects can often be funded from several different funds, but are excluded from being funded by other funds. This requires special consideration in the PMS decision support system.

5.5 Fixed Facilities and Process

Some agencies have invested resources into a particular computer system, location referencing system, data collection process, database management system, or spatial database tha*t* constrain the decision that can be made in the development, selection, implementation, and use of pavement management components. The PMS must be developed or selected that will work within theseconstrain.

5.5.1 Resources

A new or revised PMS cannot be developed, implemented, or effectively used without adequate resources, including funds personal, and equipment. These resources are needed both to support the development and implementation of the data collection and decision support system as well as resources, especially funds, for implementing the program developed through the effective use of the PMS.

5.5.2 Competing Fund Needs

Almost agency has more funding needs than resources, and there are always many competing needs for that funding. The PMS must be structured so that the decision support process pavement needs when compared with other compared with other competing fund needs.

5.5.3 Stability

Some agencies have a relatively stable personnel situation while others experience constant turnover. Stability can only be improved by changes in administration, which are normally out of the control of pavement management personnel, but other actions can be taken. In lieu of other effective actions that improve stability or insure continuity, the pavement management system may need to be kept relatively simple so that the time to learn the system by new personnel is minimized.

5.6 System Design, Development, or Selection

Although many of the hardware and management support issues should have been resolved in development, there are still many options for each component. These are discussed in some detail in Chapter 3. The following section briefly reiterates those points.

5.6.1 Matched to Agency Needs

The most important consideration in selection PMS components is selecting those components that match the agency's needs. A PMS can use a simple method to gather relatively broad information about the pavement (such as the type of the drainage system through a simple windshield survey), or it can use an extensive survey to obtain detailed information (such as information and condition about each drainage component). It is imperative that the selected PMS components provide the decision support required by the agency. It is also imperative that the resources required to effectively operate the PMS are not greater than those the agency can realistically allocate to that effort over an extended period of time. Each of the following should be considered when determining if the component meets the agency's needs.

Compatibility is the degree to which the PMS component is perceived to be consistent with the current management process, existing procedures, political realities of the agency, and agency resources. The greater the compatibility between the PMS components and agency process, the more likely the new PMS component will be adopted and effectively used. An agency may decide that they want to use the adoption of a specific PMS component change some management processes, data collection procedure, etc. in the agency. However they need to make that decision with the knowledge that this will make the adoption of the PMS component more difficult.

Relative advantage is the degree to which the PMS or PMS component are perceived to be better than the existing process or components. The greater the perceived advantage, the more likely adoption and continued use are occurring. The PMS must demonstrate the benefits it is providing to both the agency and those working in the agency.

Complexity is the degree to which the system is perceived to be difficult to understand and use. Methods that all potential users can understand and explain to others will be perceived as being less complex. Minimizing the amount of data that the system uses and the number of steps required to complete a task by the user causes the system to be perceived as fewer complexes. The format of the software interface can have a dramatic impact on perceived complexity of the PMS.

Adaptability is the degree to which the PMS component can be modified to meet individual differences in needs and required changes over time. A PMS that can be easily adopted to meet local individual requirements will be considered more useful than one that requires considerable program modifications to support simple changes.

5.6.2 Methods to Overcome Institutional Problems

There are no magic solutions to people and institutional problems. Major changes in most organizations will take considerable time and effort. Changes that affect how decisions are made and the flow of information through an organization are some of the most difficult to effectively implement (Orloski 1994). The following information can be used to address and overcome some, minimize the impact of others, and identify those that must be bypassed. The discussion is presented in general groups to help define how to approach them, although concepts often cross boundaries of these groups.

5.6.3 Communication

Several of the people problems indentified above can best be addressed by effective and repeated communication. The proponents for pavement management must take every opportunity to explain pavement management concepts and processes to all that will listen. This includes formal presentation to meetings of the agency, to management, and to the funding authorities. It includes training session for all of those that will be directly involved so that they have a thorough understanding of the PMS, and they can help pass the information to other. It includes informal discussion with all of those will be influenced by the adoption and use of PMS. It includes providing simple, understandable pamphlets and brochures that can be distributed to the public.

In some instances, pavement management concepts have been misunderstood or misrepresented. Agency personnel expected too much from the decision support software, or even though that the PMS would manage their pavement with little input from staff. The support that can be expected from the PMS decision support software must be carefully described. This can help reduce turf protection problems when the current decision-makers realize they are not being removed from the process but are being provided additional information to help them make better decision. It is extremely important to show that the software packages are prepared to provide assistance and support to an experienced public works engineer and that they may not provide the final answer.

People are more willing to take a risk in trying a new approach if the potential benefits far outweigh the potential difficulties. This means the benefits must not only be to the agency but also to those persons who will be directly involved or who may prevent acceptance or full usage of pavement management. The benefits to be gained must be identified and documented.

Development and implementation are discussed together because they are so intertwined in most implementation processes that it is difficult to separate them. The development generally includes selection of data collection processes, programming database, and decision support software, etc. A consulting or software firm may develop these and then try to implement them, however, in most public agencies, development and implementation run concurrently. In some agencies, there is a selection process but little actual development. FHWA(1991) describes one approach to implementation, developed around the principals that

5.6.4 Support and Training

Experience shows that many agencies have started implementation of PMS component but failed to make full use of its capabilities. In several instances this occurred because the "champion" in the agency responsible for selection that component was promoted, moved to a different assignment, or left the agency. Support and continuous training are two essential elements that can minimize this problem.

Management must establish long-term financial, personnel, and equipment support for the continued operation and improvement of the PMS if it is to provide effective decision support. Management should plan for and finance on-call or on-line software and pavement management process support when some of the PMS activities are decentralized.

Training is vital to implementation and effective use of a PMS. The training must address all of those who will be affected by the PMS. It must be cyclic and continue indefinitely.

5.6.5Implementation Concepts

Some agencies have made attempts to mandate PMS in some agencies (Intermodal Surface Transportation Efficiency Act of 1991). Even if pavement management is mandated, there is a big difference between "having" a pavement management system and effectively utilizing it. There is still a need to convince management that they should make effective use of the pavement management concepts and components. Implementation is not complete until the pavement management system has an impact on decision being made in the pavement management process.

The approach to pavement management implementation presented here addresses several phases of pavement management adoption and implementation that cover a much broader range of implementation activities than earlier guidelines (Smith 1994). It can be used to adopt a PMS for the first time, or adopt a revision to a component of an existing PMS. The first phase is for individuals within agencies interested in changing the current process to determine if they would like to pursue implementation of a PMS or more effective use of an existing PMS. The second phase is for the interested engineer, maintenance supervisor, or other person(s) who must get a decision from the agency management on implementation and effective use of the new or revised process. The third phase is for personnel in an agency that have decided to implement pavement management or a component but who have not selected a specific PMS, decision support software, data collection procedure, or other component being considered for adoption. The fourth phase is for those agency personnel who must try the new component or system that is being implemented in the agency. The fifth phase is for those who must complete the data collection and adoption process for the entire network. The final phase is for agency personnel after the initial implementation is complete, and the agency is trying to make the new or revised pavement management process a part of their routine management activities. When the fifth phase is complete, implementation can considered complete since the new or revised pavement management process becomes the standard method of managing the pavement network in the agency.

Although this set guidelines uses several phases with subsection in sequential order, an agency may start with any phase and at any point based on the status of pavement management implementation in that agency. For instance, if a particular component or approach to pavement management is mandated, the first phase will not be needed. On occasion, it may be necessary to back up and repeat previous steps or phases. The time it will take to implement a new or revised pavement management component will vary among agencies based on information and procedures already in place, the size of the network, and the resources available. It is impossible to define the time that will be required without a thorough investigation of the current situation of the agency and the resources available to pursue implementation.

5.7 Deciding That Pavement Management is needed in the Organization

This phase is directed at the potential pavement management “champion” in an agency. A “champion” is a person, or small group of advocates, in the agency that recognizes the need for and benefits of improving the way pavements are currently managed in the agency and works to get PMS adopted and implemented. The champion must first be convinced that the pavement management components under consideration should be adopted, and then the champion must convince the agency to adopt pavement management (Magavero and Shane 1982) in phase 2. The champion may be responding to, and have the support of, a counterpart champion in an influential external agency. The following is a series of steps the champion must generally complete to reach a positive decision about adopting and implementing a new or revised pavement management component or system.

5.7.1 First Knowledge

The champion in the agency recognizes a need to change or enhance the manner in which pavement design, maintenance, and rehabilitation planning and programming are conducted. This can occur through a perceived need to improve the process when the person encounters a problem which is difficult or impossible to address with the current system. It can also occur when the champion learns about improved pavement management techniques or components from other personnel, technical publications, professional association meetings, or other professionals. The need to change can be identified by members of the agency administration or leadership who they appoint someone to be the champion for the directed or suggested change. It can also occur when a legislative or other controlling outside body mandates the change.

5.7.2 Attitude Formation

the champion must have the knowledge necessary to decide if this change in pavement management will be good for the agency. Knowledge of the principles of pavement management and how the change under consideration uses those principles are important at this stage. The champion must be able to assure him/her that this change in the pavement management process is relevant and an improvement to the agency.

The “how-to knowledge” is also critical at this point. The champion must determine what decision support is desired by potential user in the agency, how the potential pavement management components will be used, what information must be provided, how much it will cost to implement the change considered, the benefits provided, and what other change the components necessitate within the existing agency. The champion must be able to compare advantages and disadvantages of the potential pavement component(s) with current procedures.

New approaches to decision making and decision support create uncertainty in those affected about how their jobs, authority, and responsibility will be changed. The champion must have enough information to reduce that uncertainty to the point where the champion believes that adoption of the pavement management appropriate for the agency. Demonstration of operating pavement management systems using the components under consideration, case studies, formal training sessions, and discussions with peers using the recommended components management is effective means of obtaining and presenting this information. Chapter 3 addresses evaluating pavement management system components to determine if they fit the needs of the agency.

5.7.3 Decision to Pursue Implementation and Adoption

The agency champion decides to actively pursue adoption of the new or modified pavement management component in the organization or to reject at the current time. Documented information on the benefits and costs associated with new or modified pavement management processes are important at this stage. How much it will cost to implement, the benefits it will provide, and what changes will be required in the existing agency are very important at this point, implementation efforts by other agencies using the pavement management component being considered can sometimes be used to demonstrate the costs and effects. Many times this decision point is not a single instant in time, rather the decision is reached over a period of time as attitudes as formed.

5.7.4 Develop Alliances

Pavement management usually crosses several traditional divisions of authority within an agency. This includes those groups responsible for pavement design, maintenance, and rehabilitation; planning, programming, and construction, individual pavement management system components must interface and complement other pavement management system components and other infrastructure management system used by the agency. Pavement management normally crosses functional lines and their associated management processes. The information management of the pavement management aspect is particularly important because of its central role for all management processes. Members of each group that must interact with the pavement management process may be able to prevent or retard adoption of new or modified component. A very important step needs in adopting major innovations within an agency is developing an alliance of key individuals in each affected group that would like to see change adopted. They should generally formulate an initial set of goals they hope to achieve with the new or modified pavement management component.

5.7.5 Getting Pavement Management on the Agenda

In most agencies, major innovations that affect the management efforts of several groups, such as pavement management, must be approved by at least the agency director and often by elected officials. These officials must be convinced that the current process needs to be changed and that proposed changes can provide the needed help. Before they will be convinced, the change must become a part of the agenda, formal or informal, from which the decision-makers work. Getting pavement management on the agenda focuses the attention and energy of the agency decision-makers on it as a topic to be addressed. This is many time the most difficult step and may require considerable effort and time by the champion. An alliance of the managers of the affected groups with established preliminary goals is helpful, and sometimes absolutely essential, in getting pavement management on the agenda for discussion with the leaders who must approve changes to the management process and structure.

5.8 Obtaining a Corporate Decision

In this phase, the agency management commits to implementation pavement management. One of several decision-making processes is normally used to reach the decision. The type of process used depends on the type of agency, organization structure, and personalities of the managers in the agency. Normal decision-making processes include:

1. Optional decision –choices to adopt or reject are made by an individual independent of the other members of the agency.

2. Collective decision-choices are made by consensus of the members of the agency.

3. Authoritative decision-choices are made by relatively few in the system who have the power, status, or technical expertise, and

4. Combination decision- various elements of the choices may be made by some combination of the processes described above.

In many agencies, there is some combination of all the different decision-making types. The decision to implement pavement management may be authoritative because it is forced on the agency by policies of outside agencies or agency administration. The actual selection of the pavement management system components might be based on collective decisions. Some groups within the agency may have the option of being involved or not.

Decision can also be contingent on pervious decisions. A pervious investment in a particular type of roughness measurement equipment may force use of the information from that equipment in the pavement management processes being adopted, developed, or modified. Decision may also be conditional. For instance, the decision may include a provision that new or modified pavement management processes will be implemented for a limited amount of the pavement network on a trial basis. At the end of the trial implementation, an evaluation will be made to determine whether to continue with implementation, modify the selected approach and try again, or discontinue implementation.

In this phase, the pavement management champion must convince the agency management that pavement management is appropriate for the agency. The method of decision making within the agency will have an impact on how the pavement management champion organizes the information, gets the topic on the agenda (formal or informal), and develops support for the pavement management decision, but it has little impact on information needed. The champion must guide the agency through the same steps that the champion went through to make the decision to adopted pavement management.

5.8.1 Agency Persuasion

The champion must have adequate knowledge to demonstrate to the decision-makers that the new or modified pavement management approach is better for the agency than the current management approach. Knowledge of the principles of pavement management is important at this time so the champion can explain the concepts to the decision-makers in the agency. The pavement management champion must show that there are problems which are problems which are difficult, or impossible, to address with the current system and persuade them that the new or modified pavement management processes can assist the agency in achieving their management objectives.

The “how-to knowledge is critical at this point to present the advantages of the new or modified pavement management processes compared to the current procedures. The champion must know what information is needed, how the new process is used, what answer it can provide , how much it will cost to implement, the benefits it will provide, and what changes will be required in the existing agency. All new management approaches create uncertainty about expected consequences, and the champion must have enough information to reduce that uncertainty to the point where the agency decision-makers can see that the pavement management processes, case studies, formal training session, and presentation by other agencies using pavement management components under consideration are effective means of providing this information.

5.8.2 Agencies Decision

The agency's decision-makers decide adopt (or reject) the new or modified pavement management component or process for the agency. This is the culmination of the persuasion stage described above. The decision can be conditional; a trial implementation is approved with the final implementation decision to be made after the results of the trial are available. In some instances, the decision is made to reject; however, no such decision is final in most agencies is final in most agencies. The decision to reject forces the champion to start over with the collection of information and other steps described above.

5.8.3 Form a Steering Committee

A steering committee should be formed of upper-level management personnel and possibly include elected officials. All department affected by or involved in the implementation of pavement management should be represented on this committee. This committee should provide the support needed to facilitate the changes created by the pavement management process crossing traditional lines of authority. It should prepare goals for the implementation committee or champion and provide the resources to achieve the goals. Although the committee meeting may be time consuming, it is essential to have the interaction of all affected groups to get their " buy in " of the pavement management support software and procedures selected. Otherwise, some of them are sure to erect barriers to full implementation and use of pavement management.

5.8.4 Gain Commitment for Funding

Real commitment is achieved in most agencies when funding is committed. The steering committee should ensure allocation of adequate funding to support pavement management implementation. The available funds may control the rate at which the implementation can proceed. Funding can be allocated incrementally for a pilot implementation and staged implementation for the remainder of the network.

5.8.5 Form an Implementation Group

In small agencies the implementation group may be a single person, hopefully the pavement management champion. In large agencies, this group can include formation of a separate pavement management work group. The group must convert the goals prepared by the steering committee into a work plan which details the tasks and resources required to adopt and implement pavement management in the agency. This group will be responsible for the day-to-day efforts throughout the implementation period. It should be responsible for completing the remaining steps described below; however, this group must work closely with the implementation steering committee. The working group should include representation from all of the major user groups. However, one person must be in change and have authority to make day-to-day decision.

5.8.6 Organizational Analysis

The implementation group compares the pavement management process to the existing process to determine how it can be used to facilities the pavement decision or alleviate the perceived problem. Member must review the existing organization, methods, and procedures to determine how the pavement management process will support decision making within the agency. The decision support provided by the adopted pavement management process must match the needs of agency. Location of the person or staff responsible for pavement management in the agency is often a difficult decision. A pavement management system that matches the methods and procedures currently used by the agency has a much better chance of being fully adopted and used than one that requires major changes in the organizational lines of communication, chain of authority, data collection procedure, and data storage processes. However, the opportunity to improve the efficiency of management within the organization should still be considered, since duplication of functions, like data collection, can be avoided. Changes in organizational structure, processes, or lined of communication should be developed carefully in the context of all pavement management processes and should be planned rather than allowed to happen in isolation.

This should include a review of the agency structure, the communication flow, data collection processes, existing database, other affected pavement system, data flows, and decision-making processes. The implementation group must have the information to demonstrate the problem and show how available pavement management support software, and processes provide the needed solution. Accurate, reliable information on the costs and benefits of the various pavement management systems, software, and data collection are critical at this time. Generally the implementation group must provide information and show how similar agencies have used the selected procedure, approaches, and software. They must demonstrate the relative advantage provided by pavement management system and the compatibility with existing procedure to reduce the anxiety of others.Organizational analysis is described in more detail in the section on selecting an appropriate system in chapter 3.

5.8.7 Select and Design System

This is basically the systems design that must follow organizational analysis, and it is describe more fully in the section on selecting an appropriate system. These activities should include selection or development of the decision support software, determination of data of collected, definition of data collection processes, and decision about data storage processes. Of special importance in designing the pavement management process to fit the needs of the agency are the central and common aspects of information management as they affect data processing and storage. The information management system architecture must be developed considering harmonizing data standards, definitions, and reference systems. The data to be collected, the cycle of data collection, and updating the database must be defined. In this step, basic decision about division of effort between network-level and project-level pavement management processes as well as the interface between network-and project-level management must be made. This step will determine where the pavement management support software and staff should be located and who will be responsible for insuring that data is collected on a timely basis. It should include development of requirement for training resources and software support. It may also include purchase of hardware and associated software.

This can be time consuming, and it should involve the working group with several reviews by the steering committee. The selection should ensure that it is feasible to complete or support the data collection required by the agency, that it can interface with the desired projected-level system, and that it supports the existing management structure of the agency.

5.8.8 Modify Selected Pavement Management Process

Every pavement agency its organization and problems are totally unlike those of any other agency. They will always see a need to modify any system to make it fit their perceived unique situation and problems. Many times the modification is minor changes to reports and data collection procedures, but they are important to insure acceptance of the pavement management system. Thus, still be perceived to be appropriate and affordable to implement while also being compatible with current management procedures. The systems, processes and methods selected in the previous step are modified to fit the needs of the specific agency.

5.8.9 Prepare Staged Implementation Plan

The implementation should be planned is as much detail as possible, even though it will probably be changed at later date. This is normally done by the implementation group and approved by the steering committee. It is generally not possible to implement pavement management for a large network in a short time. However, each data collection process, software system, report, and data storage method must be tried to determine if they match the needs and constrain of the agency. Changes will be needed based on trial use of the software that is considered and selected. Those changes need to be planned for and identified early to avoid costly revisions. Using a pilot implementation Staged implementation is often necessitated by available funds and time. It is important to provide adequate time for the training needed for all of those involved in using pavement management during the implementation. Pavement management is not just software; it is the management process which includes all of the decision-makers involved. They generally must make some adjustment to accommodate the new information that will come from the pavement management decision support software. They must be trained to effectively use the information from the pavement management process. Training is generally most effective when real information is available from the agency's own pavement network.

5.8.10 Implementthrough Trial Operation

The system selection is normally followed by a pilot, or trial, implementation. The system is implemented on a small percentage of the network, and is used to test the pavement management system, decision support software, data collection processes, data storage, and other activities. The trial implementation should go through every management step in the pavement management process. This allows the agency to try the system, and it permits them to identify the elements that require modification to meet agency needs. It also serves as an aid in training the various user of pavement management which should be a major part of the implementation efforts. The costs and results of the system should be thoroughly documented this helps define the implementation resources and training needed for full implementation. Feedback from pavement management users should be programmed into the implementation process from the start so that they have an investment in the system and are more likely to assist with adoption rather than develop barriers.

5.8.11 Document Results

It is very important to document the findings of the trial implementation based on the goals and work plans established earlier. This will better indentify the resources and time needed to complete information. It will help determine if the current plan can be followed or must be modified based on this more complete information. The documentation should include recommendations for modifications for the adopted pavement management system software, data collection processes, and continued implementation. The results often must then be presented to the steering committee before implementation continues.

5.9 Final Agency Decision

The agency decision-makers commit to continue with full implementation, to revise pavement management concepts, or to reject pavement management at this time. The agency may decide to repeat a few pervious steps because of problems encountered during the pilot implementation prior to continuing into full implementation. Rejection may be a temporary setback or may result in years of delay before pavement management will be considered again. That makes it imperative that every effort be directed at a successful trail implementation.

Documented information on the current and future costs of the selected system are important at this time along with expected benefits. Results of trail implementations must show that the recommended system can provide the support needed by the agency and fit benefits, but costs should some from the pilot or trial implementation within the agency. The steering committee or implementation group should present the results from the steps above to the decision-makers and convince them that pavement management processes should be continued through full implementation.

5.9.1 Revise the Goals

After the pilot implementation, the original goals developed by the steering committee should be thoroughly reviewed. Based on the organizational analysis and the information gained from the pilot implementation, goals should be revised to match the agency needs to the constraints, especially the available resources needed for full implementation and use. It is particularly important to consider training and support plans in the goals and funding needs at the point.

5.9.2 Revise the Implementation Plan

The pavement management implementation group should review the work plans, resource requirement, and time requirements. The implementation group should work from the revised goals using the information learned during the pilot implementation to revise the implementation plan. The pavement management system, the software, and the data collection methods should be thoroughly reviewed. At this point it is possible to make major changes relatively easily; after full number of years.

The revised work plan can still be staged. The staging can be by area, system, or other division that meets the needs of the agency. Training and support plans are of particular importance at this time to insure that all potential user are familiarized with pavement management concepts and how they can interact with the pavement management process. Major changes to software, data collection, or data storage should be planned to allow the implementation to continue while permitting required improvements.

5.10 Implementation for Entire Network

After the pilot implementation, the pavement management process must be implemented for the remainder of the network. At this same time, needed modification must be completed. This may require that the agency go back and collect new data or the same data in different way, for the pilot network. The steps within this phase should include revision of the system, software and data collection processes full implementation, and training.

5.10.1 Complete Required Revisions

This will include the revisions of the software, data collection processes, and data storage procedures. It may be relatively simple, or it can include major revisions. This can be completed concurrently with the following step.

5.10.2 Complete the Revised Implementation

This will include the most intensive data collection and training activities. Several tasks may run concurrently. The implementation can still be staged.

5.10.2.1Collect Data

The data collection and inclusion of various elements of the network will often be staged even after pilot implementation. The most important elements might be included in the first stage. The next most important set of pavement elements may be included in the next stage. This would continue until the entire network is included in the implementation. Chapter 4 gives guidance on data collection. A method to ensure the quality of the data collected must be established and in place at this time.

5.10.2.2 Store Data

The data collected must be entered into the selected database. The data must be evaluated to ensure that it is accurate and complete. The reports that will be used by the staff must be generated and evaluated to ensure that they provide the information needed.

5.10.2.3 Train Staff

Training should be included as an essential element of each activity. As the scope of pavement management increases and the implementation steps are completed, all of the user and operators involved in pavement management must be trained on pavement management concepts and system usage. This includes those who are seeing new or more complete reports and those who will use the information form the reports to make decisions. This may include a series of meetings with the funding authority to educate them in the new information or form of data which they will receive. The general public should also be included in the training to help them understand how their facilities are being managed.

5.11 Effective Pavement Management Operations

Once the initial data have been collected for the entire network and the first set of reports completed, many consider the system implemented. A true pavement management process in not a one-time condition survey followed by a report. Pavement management is a structured method to make decision about pavement elements and requires a long-term commitment to improve management practices. A commitment will be needed to repeat the data collection and analysis activities on a periodic basis in the future. If pavement management is to be effective. It must become a part of the routine management process and affect the decisions being made. The purpose of this phase is to institutionalize the pavement management process within the managing organization.

5.11.1 Matching Output to Management Styles and Needs

Considerable effort is often required to educate the upper-level managers about the benefits of using pavement management and the reports generated by the pavement management decision support software. No matter how good the earlier investigations are, some of the reports generated by the software will not meet the needs of the upper level manager. Pilot implementation will identify some changes, but many needed changes in reports and formats will only be found when the system starts working in earnest. The pilot implementation should have identified data problems and needs that should have been subsequently corrected. The changes identified at this point are primarily related to report structure, report format, and presentation style. These changes will be needed at this point in part because the user will not completely know what they want until they see some of the reports from the system. As they learn to use information, they will see other ways to use the same information. As new senior personnel use the system, additional requirements will be identified. It is essential that these requirements be met to maintain the credibility of the system. Some senior managers will be reluctant to use the results of the pavement management process if they do not fully understand them and believe in the accuracy of the information. Considerable training on an informal basis is often needed with some senior managers.

5.11.2 Placement in the Organization

In order to ensurecontinuity of PMS development, provision must be made to formalize pavement management into the organizational structure. Although a single champion may have led the development and implementation of pavement management in the organization, pavement manage pavement responsibilities must be formally designated to survive inevitable management and personnel changes.

The formal responsibility may become a part-time requirement for a single person in small agencies, or it may be a formal assignment of duties to several people in several areas for larger, more complex, agencies. The formal organizational arrangement should facilitate development and distribution of information to support the organization's decision making process at upper-, middle-, and lower-management levels.

Of special importance is the assignment of responsibility for data collection, data entry, and maintaining integrity of the database. Only one assigned person should be responsible for adding and modifying data for which the group is responsible. Access for retrieving, reporting, data analysis, and other uses of the data should be made as easy as possible to all interested parties.

5.11.3 Training on a Continuing Basis

Changes and improvements, especially in the reporting system, the data collection processes, and the analysis techniques will continue indefinitely, although at a much reduced rate. Training is needed when changes are made to the systems; however, cyclic training is needed even when changes do not occur.

Training must continue on a repeating cycle. Many pavements, management personnel only work with the software and report generation for a few weeks each year, and condition data are normally collected for a short period each year. These individuals need refresher training each year. The responsible staff will experience turnover, and the new members will need training on a continuing basis.Adjust and improve to keep Up With change capabilities and NeedPavement management procedures and data collection procedure continue to evolve as technology advances. Computer capabilities continue to increase which allows more complex analysis and storage of larger data sets. More easily understandable decision support processes are being developed that can replace complex, difficult to understand procedure.

The software system should be modular in form and flexible enough to allow improvements and modifications over time. However, changes made too frequently will frustrate users who feel that once they learn the system, it is changed. Training is essential to assist users in understanding the changes.

5.11.4 Assistance

Many agencies use consultants and other outside agency personnel to assist in pavement management implementation. This assistance can be helpful at almost may stage. The amount of assistance and timing of the assistance needed depends on the level of pavement management knowledge within the agency. The first phase is generally completed in house. In some cases, it may be helpful to have outside assistance during the agency profession stage. However, when assistance included at this stage, those who are providing that assistance should be selected to insure that they are not biased toward no set of software.

This can sometimes create problems, because firms have their own software and data collection procedures. Selecting those consultants often means selecting their software and data collection procedures. This means the agency should complete an investigation of their needs and select the software system and data collection processes that best fits their needs before selecting a implementation. However, some agencies need assistance in determining their needs and selecting the best system for them.

Some consulting firms will assist in defining needs and selecting a system. Some firms have a range of software that can fit most any agency's needs. However, the consulting request for proposal and contract must be properly prepared to include stages. The first stage should generally include the organizational analysis and a determination of the PMS components and data collection processes appropriate for the agency. The second stage should be for trial implementation and training. The third stage should be for modifications, training, and completion of implementation. The agency should have the option to terminate the contract at the end of any these stages. The agency should also reserve the right to continue to use the material developed and provided at the point of termination, including contracting for some other group to finish implementation.

Some agencies lack adequate personnel to collect the data needed for initial and continuing surveys. Several firms can assist in this process. The request for proposal and contract should be carefully prepared to ask for the data to be collected using the required distress survey procedure, roughness measures, etc. without unnecessarily restricting the work. If distress is to be collected, the distress survey manual that is used, the accuracy required, and the format for entry into an automated database should be identified. A demonstration that the consultant can provide the required information should be required, and the agency should have a quality assurance plan in place to check the work while it is in progress. The marketplace costs should be allowed to determine if the data will be collected manually or by automated equipment.

There are several sources of information and assistance available from government organizations. The Local Transportation Assistance Program (LTAP) Technology Transfer (T2) Centers have information from the Federal Transportation Administration and other LTAP Centers that may be helpful. These agencies can often provide training on PMS or get that training from another source. Several universities and research organizations personnel experienced in pavement management and can provide assistance. User groups can be a source of very helpful information in selecting, implementation, and using a PMS (Sachs and Smith 1994). If the PMS software is being considered and used by other agencies, the potential user should contact current users to determine how well it has met their needs. If several users are in the same area, they can form a user group. It has been helpful to have regional agencies assist in setting up and conducting user groups.User meetings can be held on a periodic basis, quarterly, or semi-annually, they can become the focal point for identifying changes and enhancements needed for PMS. Through the user group meetings, ideas can be exchanged between those supporting the software and among the users themselves. More experienced users can often assist newer users in implementing PMS. User meetings can identify problem areas that need additional training.

Summary

The overall goal is to make pavement management the standard operating procedure in agencies for pavement decisions. This occurs when the agency personnel look to pavement management for information and support when pavement questions occur, funding is planned, and sections are programmed for maintenance and rehabilitation. series of phases and steps have been prepared to guide potential adopters of pavement management systems. Each agency is different, and no single set of steps can be followed blindly. The pavement management champion will be primarily responsible for working through these guidelines and preparing implementation plans for the agency. Some steps will need to dropped, and the order of some steps may need to be changed. After initial efforts, some steps may need to be repeated. However, most of these steps are necessary for successful implementation and use of PMS.Developing an implementation plan can take considerable effort and time, but this planning is essential if the system is to be fully implemented. Failure to involve all users in the process has had dire consequences in several agencies. This implementation guide was developed to help avoid some of those pitfalls and overcome others. The Federal Highway Administration (1991) developed a series of checklists that may also be helpful implementation process.

CHAPTER SIX

Types of Maintenance

6.1 Preventive maintenance treatment

Treatment is performed to prevent premature deterioration of the pavement or to retard the progress of pavement defects. The objective is to slow down the rate of pavement deterioration and effectively increase the useful life of the pavement. The key is to apply the treatment when the pavement is still in relatively good condition with no structural damage (U.S. Federal Highway Administration, 2000). Examples of preventive maintenance treatments include:

- routing and sealing cracks to prevent water from entering the pavement structure;
- stitching cracks in Portland concrete cement (PCC) pavement to restore losad transfer; and
- applying a thin overlay to protect open and porous pavement surfaces from accelerated deterioration.

Typically, preventive pavement maintenance treatments are applied to pavement in good or very good condition. Once structural damage occurs, preventive maintenance is no longer a viable option.

6.2 Corrective maintenance treatment –

Maintenance actions are taken to correct deficiencies that are potentially hazardous and to repair defects that seriously affect serviceability. Corrective maintenance is also referred to as “reactive” maintenance. Examples of corrective maintenance treatments include:

- filling potholes to retain safe driving conditions;

The following preventive maintenance techniques are presented in this section , based on , crack seals, thin overlays, chip seals, microsurfacing, cold in place recycling, ultrathin friction course, fog seals, slurry seals,and cape seals. A description of each treatmentprovided, including its advantages and disadvantages.

6.2.1 Crack sealing

When cracks occur in asphalt pavements, these cracks must besealed to prevent water infiltration and loss of load-carrying capacity. A number of materials are available for sealing cracks.These materials include cutback asphalt, emulsified asphalt, jointsealing materials, and proprietary materials. On occasions, largecracks are sealed with sand-asphalt mixtures.

Small cracks (less than 174 inch) are difficult to seal. If there are few of these cracks, they may be routed and sealed or they may beleft unsealed. If there are many of these cracks, it is usually too expensive to route and seal. In this case, the entire area may besealed with a slurry seal, surface treatment, or overlay. Liquidasphalt should not be painted on the surface over the cracks. Thisdoes not properly seal the cracks, and it can cause a skid problem,especially in areas having many cracks. This excess asphalt may alsocause problems when overlaying the existing pavement. The asphalt onthe surface often causes slippage of the overlay when being rolled.In 1985, the cost for crack sealing at a number of Air ForceBases was $0.75 to $1.25 per linear foot (2). At that time, it wasexpected that crack sealing had to be performed every 3-5 years.There are a number of maintenance procedures includingrejuvena~ors, slurry seals, surface treatments, and crack sealing thatcan be used to prolong the life of asphalt pavements. Constructionquality will greatly decrease the need for maintenance and insureyears of satisfactory performance.Preventive maintenance procedures can increase the pavement life significantly and reduce future reconstruction costs. Thepavements to be maintained need to be investigated to select the mostappropriate maintenance procedures to optimize Crack sealing is widely used relatively low cost preventive maintenance treatment. Generally, crack sealing is performed to keep water from penetrating into the pavement structure and compromising the base layers of the pavement. Proper placement is important to ensure that the sealant maintains its integrity as long as possible. Several materials and techniques are available to do this work. According to Ohio DOT (2001), crack sealing, in contrast to most other preventive maintenance techniques, should be performed in cooler weather when crack widths have expanded.

Table (6.1) advantages and disadvantages of crack sealing

Advantages	Disadvantages
Relatively low cost when compared to other preventive maintenance treatment	Relatively short life span
Effective means to prevent water infiltration into the pavement structure	Many cause bleeding through overlay
Technology is well understood and widely used	Cost effectiveness not well established
Crack sealing indeed slows the deterioration of the pavement	Performance Structure is rare and limited

In a literature review conducted by Hand el al (2000) 100 potential references regarding crack sealing were collected and reviewed. Only 18 of these references were found to specifically address cost effectiveness of joint and /or crack sealing relatively to pavement performance, and only four of 18 contained valuable quantitative data. Furthermore, many of these studies, similar to this one, have focused on the performance of material / technique combinations rather than cost effectiveness.

The extension of pavement life provided by crack filling and sealing is less documented. A paper survey by Geoffroy (1996) was distributed to the United States, District of Columbia, Puerto Rico, Canada and 37 local agencies to determined, among other things, the average life extension provided by crack treatment. A minimum increase in the pavement life of less than 2 years, a maximum increase of 9 to 10 years is observed. Average treatment life as reported by various sources is summarized in table below.

Table (6.2) treatment Crack Life as Reported By Various Sources

Reference	Treatment life (years)	Notes
Geoffroy1996,	2.2	Crack seal in Indiana
Geoffroy, 1996	2—5	Route and seal in Ontario
Geoffroy, 1996	2	Crack fill in New York
Geoffroy, 1996	2-5	Route and seal in New York
Jonnson, 2000	7- 10	Average reported value in Minnesota

Table (6.3) Crack Seal Costs per lane Mile

Cost per lane mile(12ft width)	Location	Year Data taken	Reference
1000-4000	None specified	1999	OhioDOT,2001
2900- 11750	M1	1998	B.T.Bellner&associates2001
6900(typical)	M1	1998	B.T.Bellner&Ass 2001

6.2.2 Thin HMA Overlay

The application of hot mix asphalt (HMA) as an overlay to an existing pavement is often considered a preventive maintenance treatment when the overly is between 0.75 to 1.5 inches thick (Peshkin el al., 2004) .The HMA typically consists of plant mix asphalt cement and aggregate. The three general categories of thin overlay mixes, distinguishable by their aggregate gradations are dense graded, open graded and gap graded aggregate mixes. In a dense graded aggregate, the gradation uniformly represents the full range of sieve size, in an open graded mixture; the gradation mostly consists of particles of one size. In a gap graded aggregate, the gradation contains coarse and fine particles, gap graded aggregate is used in stone matrix asphalt (SMA). Stone matrix asphalt was developed in Germany to resist wear by studded tires and is generally considered more durable than the others mixes (Gaatchalian et al., 2006)

A thin overlay can be placed with or without milling the existing pavement. It is recommended to mill the surface when segregation, raveling or block cracking are present (Hein &Croteau, 2004). Milling also provides additional asphalt for recycling operations (more asphalts is recycled in the United State than any others material (Smith 2003)

Table (6.4) Advantage and disadvantage of Thin HMA overlays

Advantages	Disadvantage
Works well in all climate conditions (Johnson, 2000)	Subject to delimitation, reflective cracking , and maintenance problems(Johnson, 2000)
Provides minor amount of structural enhancement (Ohio DOT, 2001)	Curb and bridge clearance may be an issue without milling (Johnson, 2000)
At least marginally effective for almost all pavement conditions(Hicks el al., 2000)	

Performance

The treatment life of a thin HMA overlay is relatively long in many cases (table). The average of the service life values is over eight years.

Table (6.5) Thin HMA Overlay Treatment Life as reported by Various Sources

Reference	Treatment Life(years)	Notes
Geoffroy	6	According to NCHRP
Geoffroy	8	According to New York State DOT
Geoffroy	6-11	According to FHWA
Hicks et al, 2000	7-10	Average life in Ohio
Hicks et al , 2000	2.7-12	Min .average. Max.
Johnson, 2000	5-8	Average reported value in Minnesota
Ohio DOT, 2001	8-12	Expected life in Ohio
Peshkin et al., 2004	7-10	When placed fsor preventive maintenance
Wade et al , 2001	10-12	Interstate with OGFC in Florida

6.2.3 Chip sealing

A chip seal (also referred to as a seal coat) is an application of as asphalt followed by a layer of aggregate (typically one stone thick), which then rolled into the asphalt (Gransberg& James, 2005). A chip seal protects pavement from ultraviolet rays from sun and moisture infiltration. Double Chip seals are also common, in which a second chip is placed immediately over the first. In this application, the first chip seal uses more asphalt and larger aggregate than the second overlying chipsseal. A double chip seal provides a quieter and smoother riding surface and is better suited for pavements in poor condition. Johnson reported that a chip can be applied at any time in a pavement life (2000). (Jahren et al., 2003b, and Peshkin et al., 2004). Ohio limits chip sealing to low volume roads (less than 2500 ADT) with rutting less than (1/8) inch.

Variation to standard chip seals includes the use of choke stones, fog seal, and slurry seals. A choke stone is smaller aggregate applied without asphalt after the primary aggregate has been spread and rolled. The advantages and disadvantages of chip seals are summarized in table below.

Table (6.6) Advantages and disadvantages of chip sealing

Advantages	Disadvantages
Technology is well understood and widely used (Gransberg et al., 2005)	Loose chips can cause damage to vehicles, especially windshields.(Maher et al., 2005)
Relatively low cost for a durable treatment (Maheret al., 2005)	Associated with increased road noise (Gransberg|& James, 2005)
Treatment performs wellin many climates (Peshkin et al ., 2004)	Cause of failure for projects not always understood (Gransberg&James, 2005)
More effective at sealing medium severity fatigue cracking than other treatments (Peshkin et al., 2004)	Success requires Proper application rates of binder and aggregate(Wade et al., 2001)
Susceptible to snowplow damage(Jahern 2003b	Required reduced speeds after construction (Romero & Anderson 2005)

Performance

The study by Gransberg&James (2005) indicates that skid resistance and texture depth measurements are the primary indicators used to determine chip seal performance. These indicators are particularly suitable for the most common distresses affecting chip seals; bleeding and raveling. Quantitative measures of skid resistance and texture depth are commonly measured according to ASTM E274 and ASTM E965, respectively

Table (6.7) Single Chip Seal Treatment Life as Reported by Various Sources

Reference	Treatment life (years)	Notes
Balander , 2005	3to 6	For ADT100 to 500
Balander, 2005	4to 12	For ADT less than 100
Geoffory,1996	4	Medium life in Oregon
Geoffory, 1996	4	Average life in Indiana
Geoffory, 1996	4to 7	According to FHWA
Geoffory, 1996	1to 6	According to NCHRP
Grasberg&James,2005	5.76	US average based on asurvey
Grasberg&James,2005	5.33	Canada average based on a survey
Grasberg&James,2005	10	Australia average based on a survey
Grasberg&James,2005	7	New Zealand average based on a survey
Grasberg&James,2005	12	South Africa average based on a survey
Grasberg&James,2005	10	United Kingdom average based on a survey
Hicks et al., 2000	3 to 5	Average life in Ohio
Johnson, 2000	3 to 6	Expected service life

Table (6.8) Double Chip Seal Treatment Life as Reported by Various

Reference	Treatment life (year)	Notes
Balander,2005	5 to 15	For ADT less than 100
Balander, 2005	5 to 7	For ADT 100 to 500
Hicks et al, 2000	4 to 8	Average life in Ohio
Johnson, 2000	7to 10	Depending on type & amount of traffic
Maher et al, 2005	4 to 8	Average life expectancy

6.2.4 Fog Seal

A fog seal is an asphalt emulsion diluted with water (typically 1:1) the emulsions applied directly to the pavement surface without the addition of aggregate. A fog seal can be considered a candidate treatment to address raveling, oxidation, and the low severity fatigue cracking

Table (6.9) Advantages and Disadvantages of Fog Seal

Advantages	Disadvantages
Good treatment performance in all climates (Peshkin et al ,2004)	**U**nusually slow setting emulsions are used, resulting in longer traffic delays (Wade et al , 2001)
Inexpensive treatment to address raveling (Wade et al , 2001)	Reduces surface friction immediately after application (Wade et al ,2001)
Reduces aggregate loss when applied over a chip seal (Caltrans,2003 &Wade et al (2001)	Increased wear occurs from studded tires (Peshkin et al , 2004)
Seals small cracks (Maher et al , 2005)	Short life expectancy (Maher et al , 2005)

Performance

Fog seal is often applied when there is only a relatively minor amount of surface defects. Generally rutting should be less than 3/8 inch and cracking should be minimal,(Hicks et al, 2000).

Table (6.10) Fog Seal Treatment Life As Reported By Various Sources

Reference	Treatment life(years)	Notes
Bolander ,2005	2—4	For ADT less than 100
Bolander , 2005	1 to 3	For ADT 100 to 500
Hicks et al,2000	2, 3,4	min,average, max(respectively)
Hicks et al , 2000	1to 2	Average life in Ohio
Peshkin et al , 2004	1to 2	Generally reported range
Wade et al , 2001	1 to 2	Generally reported range

6.2.5 Slurry Seal

Slurry seal is a fluid like mixture of fine aggregate, asphaltemulsion, and water. The slurry seal is used to seal an existingasphalt surface and to provide when properly applied, it will improve surface texture in some cases. Prevent penetration of water into thepavement and, therefore, prolong the pavement life.For most projects, a special rapid-set asphalt emulsion which hasbeen specifically designed for slurry seals is used. The fineaggregate used should be crushed for best results.Slurry seals are normally used on pavements subjectedto lowtraffic volumes. When slurry seals are subjected to high trafficvolumes, the life is greatly reduced. One of the biggest problemsobserved with slurry seals is the loss of bond between the slurry andthe underlying asphalt mixture. This loss in bond can be a result ofseveral factors which may occur simultaneously or separately. Theunderlying surface must be clean prior to application of a tack coat.Construction equipment operating on a pavement to be sealed can oftentrack mud and other foreign material onto the pavement surfacepreventing the development of a satisfactory bond. The tack coat isnormally applied immediately prior to applying the slurry so dust orother debris on top of the tack is not a problem. Many timesthe slurry is placed at a time when the temperature is relatively lowresulting in poor bond. Slurry seal construction should be performedin hot weather. It generally should not be placed when the ambienttemperature is below 50 or 60 degrees Fahrenheit. For best results,slurry seals should be rolled with a rubber tire roller afterplacement. A roller is often not required by the specifications butthis can result in a slurry seal which does not provide satisfactoryperformance. Another problem that sometimes affects theperformance of slurry seals is water vapor. The slurry seal is8watertight, preventing water from passing through the sealer andevaporating. Water which might be trapped in the existing pavementmay vaporize during the hot summer months and exert sufficientpressure on the slurry to cause blisters or delimitation.Performance data determined from a number of Air Force Bases hasshown that slurry seals typically last for 3-6 years depending uponthe construction quality and environmental conditions (2). The costfor slurry seals based on 1985 data varies considerably, but generallyranges from $1.00 to $3.00 per square yard.

A slurry seal is a cold mix combination of slow setting asphalt emulsion, fine aggregate (well graded) mineral filter and water (Hick et al, 2000). The mineral filter is an insert mineral added to improve the strength and density of the slurry seal; the fine filler is completely passes through 0.002 inch sieve (USDOT)

Table (6.11) Slurry Seal Treatment life as Reported by various sources

Reference	Treatment life (years)	Notes
Bolander, 2005	5 to 10	For ADT less than 100
Bolander , 2005	5 to 8	For ADT 100 to 500
Geoffory, 1996	1 to6	According to NCRHP
Geofforry, 1996	3 to 5	According to FHWA
Geoffory, 1996	3 to 6	According to US Corps of

		Engineers
Hicks et al, 2000	2 to 5	Average e life according to Ohio DOT
Hicks et al , 2000	3 , 5, 7	Min, average, max (respectively)
Hicks et al, 2000	3 to 4	Life expectancy from Caltrans
Maher et al , 2005	3 to 8	Expected treatment life

6.3 Design of asphalt Overlay

Asphalt overlays may be used to correct both surface and structural deficiencies. Present pavement condition and estimates of future traffic dictate the thicknesses of these overlays.Surface deficiencies in asphalt pavement usually are corrected by thin resurfacings of thicknesses selected from experience. But structural deficiencies call for strengthening overlays of design thicknesses which ensure service equal to that of properly – designed new pavements at the same location. Procedures for correcting surface and structural deficiencies with asphalt overlays are presented below.

6.3.1 Correcting Surface Deficiencies in Asphalt Pavements

Need for renewing overlays –Although an asphalt pavement evaluation may predict adequate structural strength for some time to time , the condition of the pavement surface may require a thin, renewing overlay , in many cases, a thin overlay will prolong the good pavement performance, smooth out the surface and make the road safer for the user. Also a thin overlay often is used for a smooth, homogenous surface on pavements that are being widened, realigned, or improved in cross- section. They are used, too, to cover older pavements that have numerous patched areas from progressive structural improvements.Some of the major reasons for overlays otherwise adequate pavements are excessive permeability, surface raveling, surface roughness, distorted cross –section, and slippery surfaces.

6.3.2 Permeability and Raveling

The causes of excessive permeability and raveling usually are the same, surfaces containing too coarse mixtures. Mixtures that lack sufficient asphalt or pavements that have not been compacted to proper density. Any of these causes may affect pavement strength, but not necessarily to the point where structural distress will develop. The requirements for effective corrective treatment of excessive permeability and raveling are surface sealing.

6.3.4 Roughness

Surface roughness may be caused by settlement , raveling , non-uniform wear , corrugation, faulting, distress should be corrected, followed by local or general leveling of minimum thickness to ensure a smooth riding surface, leveling should be followed by a thin renewing overlay.

6.3.4 Distorted cross section

It may result in a poor riding surface on an otherwise satisfactory pavement. Correction of this deficiency involves construction of leveling wedges followed by a surface renewing overlay. Mixtures for leveling wedges should have a maximum particle size that permits "feathering" at high points in the pavement.

6.3.5 Slippery Surface

Corrective design for a slippery surface requires a skid resistant surfacing material.Properly designed sand asphalt or fine- graded asphalt concrete made with hard, polish- resistant aggregate is required. Surface treatment and slurry seals can also be used effectively.If surplus asphalt exists on the surface, it must be corrected before overlay is placed. In many cases, bleeding can be corrected by repeated application of hot sand, hot slag screening, or hot rock screenings to blot up the excess asphalt, Sometime, when bleeding is light, a plant mixed surface treatment or an aggregate seal coat, using absorptive aggregate is the only treatment needed or a hot plant mixed leveling course with a low asphalt content can be effective in absorbing the excess asphalt.

6.3.6 Surface Type Selection

The surface renewing overlay should consist of material which can be constructed in very thin layers; it must fill surface voids and provide an impervious, skid resistant surface. It must also be sufficiently resistant to traffic abrasion to provide an economical service life. Material meeting these requirements are asphalt concrete having small maximum particle size. Fine graded asphalt concrete or hot sand asphalt can be constructed in layers as thin as 13 mm, and fulfill all requirements for surface renewing overlays.

Open –graded asphalt friction courses can be used to prevent hydroplaning, to reduce tire splash and spray; and to provide skid resistant surfaces. However, surfaces on which they are placed must be impervious and reasonably smooth. They are constructed from 20 mm to 25 mm thick. In addition to using a minimum of material to provide skid resistant.

6.3.7 Correcting Structural Deficiencies

Correcting structural deficiencies calls for a thickness of asphalt overlay that will strengthen the pavement structure enough to accommodate the traffic using it for the selected design period. The overlay may be designed to serve entire 20- year design period. In all cases, the asphalt concrete overlay is designed as an integral part of the total pavement structure- thickness and strength characteristics satisfying all requirements of a new pavement structure at the same location. An effective tack coat, bonding the overlay to the existing structure, is essential to uniform stress distribution and, thus, to satisfactory performance of the pavement structure.

6.4 Asphalt Overlay Design Approach

An asphalt overlay of an asphalt pavement may be placed to improve ride quality and/or surface friction, or may be place for the purpose of substantially increasing structural capacity.

A thin asphalt overlay is appropriate for pavements with functional deficiencies only, such as excessive roughness, poor surface friction, excessive rutting, and distresses such as bleeding, weathering, raveling, bumps, settlements, and heaves. A thicker asphalt overlay is appropriate for pavements with insufficient structural capacity for the traffic anticipated over the design life of the rehabilitation. An asphalt overlay placed to correct a structural deficiency will also correct any functional deficiencies present.

As a general rule, a pavement is considered to require a structural improvement when 50 percent of the wheel path area (equivalent to about 10 percent of the total area) of the outer traffic lane has medium- to high-severity alligator cracking. A critical rutting level of one half inch is often cited as indicative of a need for structural improvement. However, rutting may have causes related not only to the load-bearing capacity of the pavement layers, but rather the stability of the mix, so the cause of rutting should be examined before deciding whether or not a structural improvement is the appropriate remedy.

6.4.1 Limitations

Functional asphalt overlays are not appropriate for pavements with little or no remaining structural life, as evidenced by the amount of medium- to high-severity alligator cracking present. And/or measured deflections. Serious materials problems, such as stripping in asphalt concrete layers, or settlement or swelling of foundations soils, can only be temporarily mitigated by an asphalt overlay. The 1993 AASHTO Guide identifies the following as conditions under which an asphalt overlay may be a feasible rehabilitation technique for an asphalt pavement when the amount of high-severity alligator cracking is so great that complete removal and replacement of the existing surface is dictated.

6.4.2 Structural Deficiency approach

The concept of the structural deficiency approach to overlay design is that the overlay satisfies deficiency between the structural capacity required to support traffic over some future design period, and the structural capacity of the existing pavement. In the 1993 AASHTO overlay design methodology. The structural deficiency concept is illustrated in Figure 1:3-4. There are eight steps in the process of determining the overlay thickness which will satisfy the structural deficiency:

1. Characterization of existing pavement design: specifically, the thicknesses and material types of each pavement layer, and any available sub grade soil information.

2. Traffic analysis: determination of the future 18-kip ESALs anticipated in the design lane over the analysis period, and if possible, the past 18-kip ESALs over the life of the existing pavement as well.

3. Condition survey: quantities of alligator cracking and transverse cracking, mean rut depth, and evidence of pumping.

4. Deflection testing: recommended to determine the *in situ* sub grade resilient modulus (as a function of deflections measured sufficiently far away from the load plate) and a deflection-based estimate of the effective Structural Number of the pavement structure.

5. Coring and materials testing: recommended to obtain sub grade soil samples for laboratory resilient modulus testing, and to obtain samples of the pavement layers for visual examination of their condition.

6. Determination of the, required Structural Number for future traffic (SNf): done using the 1986 AASHTO model for design of new asphalt pavement, with the design sub grade resilient modulus either obtained from laboratory testing or estimated from the back calculated*in situ* sub grade modulus.

7. Determination of the effective Structural Number of the existing pavement (SNeff) by one or more of three methods:

• The NDT method — SNeff is estimated as a function of the thickness and effective modulus of the pavement structure.

• The condition survey method — SNeff is estimated by assigning layer coefficients to the existing pavement layers which reflect the types and amounts of deterioration present.

• The remaining life method — SNeff is estimated as a function of the past 18-kip ESALs carried by the existing pavement as a proportion of the 18-kip ESALs a pavement of its original structural capacity would be expected to be able to carry. This approach to structural capacity determination has some significant limitations, as discussed in the 1993 AASHTO Guide.

8. Determination of the required overlay thickness: by dividing the structural deficiency (SNf— SNeff) by the layer coefficient appropriate for new asphalt overlay material.

The Asphalt Institute overlay design manual also presents a structural deficiency method for asphalt overlay design. Several State DOTs have adapted either the 1993 AASHTO or the Asphalt Institute structural deficiency method to their own purposes for design of asphalt overlays of asphalt pavements.

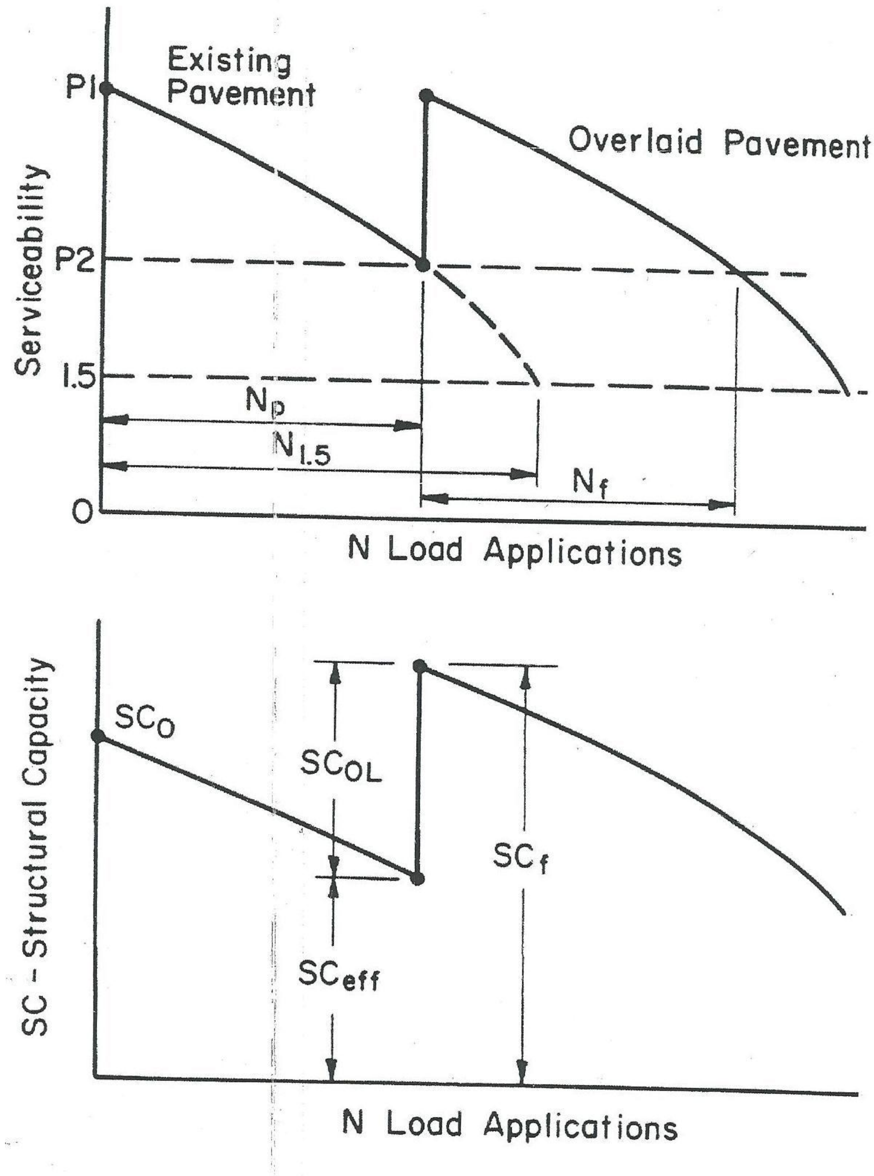


Figure B-4 Structural deficiency concept [1]

Figure 6.1 standard deficiency concrete

6.4.3 Deflection-Based Approach

The most widely known deflection-based approach to design of asphalt overlays of asphalt pavements is the Asphalt Institute procedure. State DOTs that have deflection-based procedures for design of asphalt overlays of asphalt pavements include Ohio and Arizona. The concept of the deflection approach to asphalt overlay design is that the overlay reduces load-induced deflection in the pavement to a level associated with the predicted life of the overlaid pavement. In the Asphalt Institute overlay design methodology, the design deflection level is referred to as the representative rebound deflection (RRD). There are five steps in the process of determining the overlay thickness which will reduce the representative rebound deflection to an acceptable level:

1. Select length of pavement for structural evaluation: divide the project into sections which are uniform with respect to pavement condition, subgrade strength, and drainage conditions. These uniform sections may subsequently be subdivided with respect to measured deflections.
2. Deflection survey: deflections are measured in the outer wheelpath using a Benkelman Beam and static loading. If some other deflection testing device is used (e.g., Falling Weight Deflectomoter, Road Rater, Dynaflect), the Benkelman Beam deflections must be estimated using correlations.
3. Calculate the representative rebound deflection: as the temperature-normalized mean deflection plus two standard deviations, adjusted for some climates by a critical period adjustment factor.
4. Design traffic: the expected 18-kip ESALs over the overlay design period are determined. It should be noted that unlike the 1993 AASHTO overlay design procedure, the asphalt Institute overlay design procedure does not call for the application of a reliability factor (i.e., a safety factor) to the traffic input, Instead, a safety factor is applied to the deflection input, by designing not for the mean deflection but rather the mean plus two standard deviations.
5. Required overlay thickness: a design chart is provided in the Asphalt Institute overlay design manual2 which yields the required asphalt overlay thickness as a function of the representative rebound deflection and the design ESALs. Deflection-based procedures may have been developed using mechanistic-empirical models for fatigue and/or other distresses, or they may

have been entirely empirical in their development but in either case, in their application, they go straight from deflection measurements to require overlay thickness. Other empirical parameters are often incorporated in the formula as well. These other empirical parameters may improve the prediction of the required overlay thickness but may also limit the applicability of the procedure to other locations outside the range for which the formula was developed. In Arizona's overlay design procedure, for example, the required overlay thickness is calculate as a function of design ESALs, a seasonal variation factor depending on location, the May meter roughness, the spread ability index calculated from previously FWD or Dynaflec deflections, and an outer sensor FWD or Dynaflect deflection.

6.4.4 Mechanistic-Empirical approach

In a mechanistic-empirical approach to design of asphalt overlays of asphalt pavements, performance of the overlay is predicted using mechanistic-empirical distress models. The distresses considered should include at least fatigue cracking, and ideally rutting and thermal cracking as well. The existing pavement layers and foundation are characterized using nondestructive deflection testing and back calculation of their elastic moduli. Material properties for the overlay are assured. The overlay thickness which will yield acceptable performance in terms of the distresses 'considered is determined by iteration. A conceptual overview of the mechanistic-empirical approach to design of asphalt overlays of asphalt pavements is given by MonismithThe individual tools used in mechanistic-empirical design of asphalt pavements (fatigue models, rutting models, seasonal adjustment, etc.), can be adapted to some extent to design of asphalt overlays. However, there are additional aspects of the problem that need to be considered in order to develop a full design procedure for asphalt overlays of asphalt pavements. Among these are consideration of the extent, type, and quality of pre- overlay repairs, prediction of reflection crack propagation and deterioration problem for asphalt overlays of both asphalt and concrete pavements, and calibration of asphalt overlay performance prediction models to the observed performance of asphalt overlays. Several examples of mechanistic-empirical procedures for design of asphalt pavements exist, such as the Shell procedure, the Asphalt Institute procedure, and the NCHRP 1-26 procedure fewerexamples exist, however, of mechanistic-empirical procedures for design of asphalt overlays of asphalt pavements. Among the few State DOTs that have developed a mechanistic-empirical design procedure for asphalt overlays of asphalt pavements are Washington,3° Idaho, and Nevada. The Washington State DOT procedure uses a model to predict fatigue as a function of horizontal tensile stress at the bottom of the asphalt overlay and at the bottom of the original asphalt layer, as well as a model to predict rutting as a function of vertical compressive stress at the top of the sub grade. The critical stress locations considered are illustrated in Figure B-5. A flowchart of the Washington State procedure is illustrated in Figure B-6. The overlay thickness required keeping fatigue and rutting below critical levels is determined through a process of iteration.

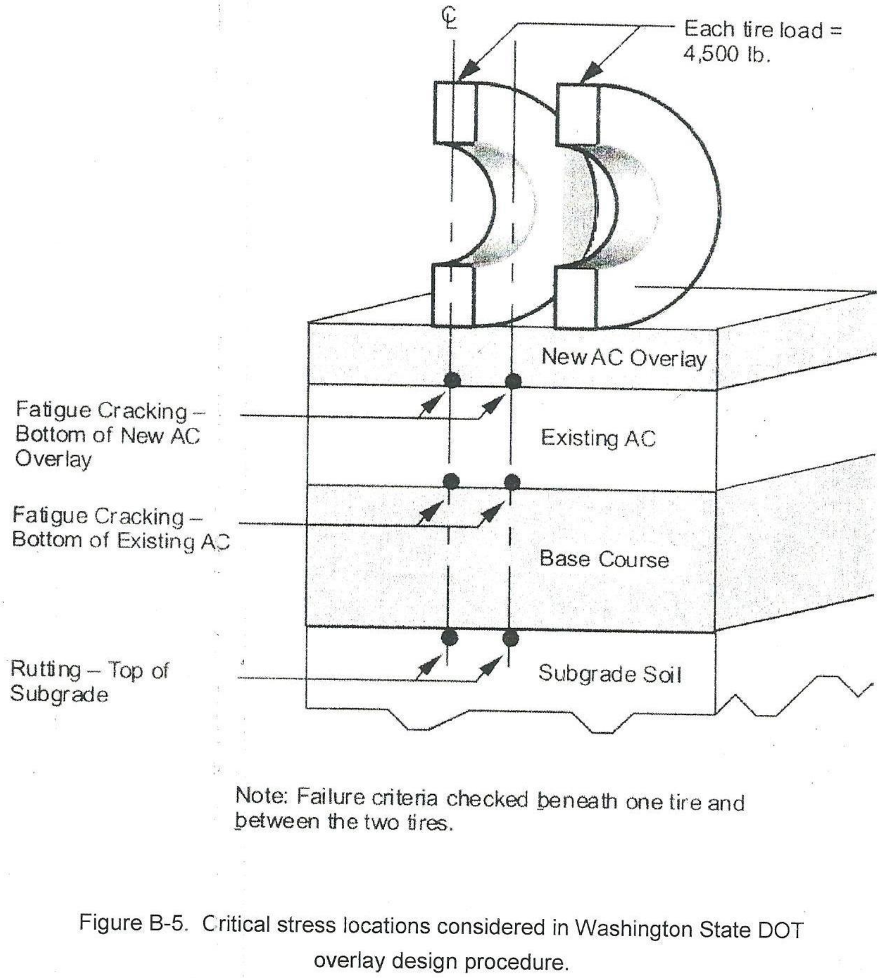


Figure 6.2 critical stress location considered in Washington state dot overlay design producer

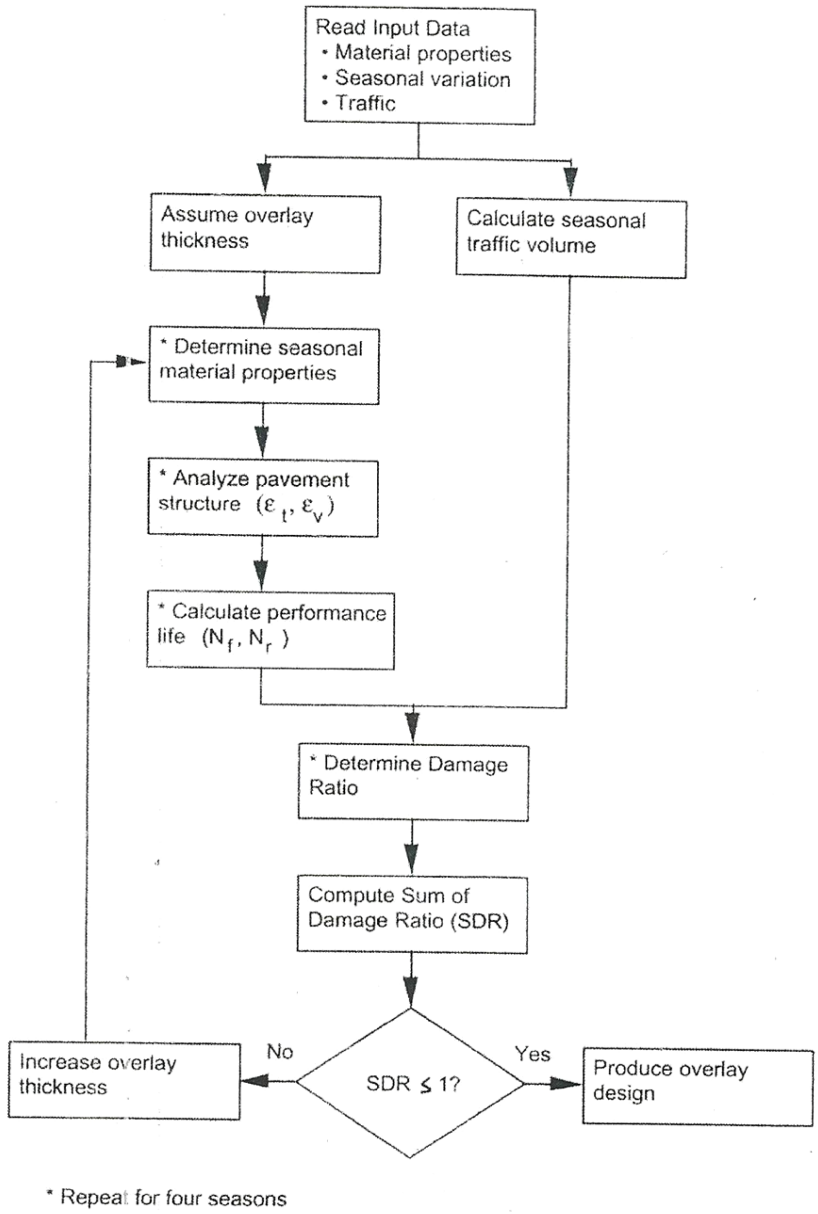


Figure B-6. Washington State DOT overlay design procedure flowchart.

Figure 6.3 Washington state Dot overlay design procedure flowchart

The Nevada DOT uses a falling weight deflectometer to measure asphalt pavement deflections, and collects the surface and air temperature data needed to adjust the measured deflections. The modulusback calculation program is used to determine the elastic moduli of the pavement layers and Vie foundation. modulus is a database back calculation program in which the deflection basin database is produced by a factorial of CHEVRON elastic layer program runs. In the Navada DOT overlay design procedure, traffic loadings are expressed in ESALs applied during each season of the year. Overlay performance is predicted in terms of rutting and fatigue cracking. The design procedure yields overlay thicknesses in the range of 2 to 5.5 inches, for design periods from 5 to 20 years.

6.4.5 Construction

Asphalt Patching

High-severity alligator cracking and linear cracking should be repaired by full-depth asphalt patching prior to placement of an asphalt overlay. How much medium-severity cracking should also be repaired to achieve the desired performance depends on the thickness of the overlay, whether or not a reflect on crack control treatment such as a fabric interlayer is used, and the unit costs of the pre overlay patching, asphalt overlay, and interlayer material.

Correcting Rutting

Rutting in the existing pavement may be removed by cold milling, filled with asphalt concrete compacted prior to placing the first overlay course, or filled with a leveling course. This last option might result in rutting occurring in the overlay at a faster rate than it would with the former two options.

Tack Coat

A tack coat is be applied to the existing or milled surface prior to the placement of the first leveling or overlay course, unless a reflection crack control treatment is used.

Reflection Crack Control

Cracking which is left unrepaired may reflect through the overlay. The rate at which reflection cracks develop and deteriorate depends on several factors, including the thickness of the overlay, the thickness of the existing pavement, the stiffness of the foundation, the number and

Magnitude of applied loads, daily and seasonal temperature variations, and the spacing of the unrepaired cracks. As reflection cracks deteriorate to medium and high severity levels, they reduce serviceability and increase maintenance needs. In addition to pre overly repair (patching and crack filling), the following reflection crack control treatment options are identified in the 1993 AASHTO Guide for asphalt overlays of asphalt pavements:

- Synthetic fabrics and stress-absorbing interlayer's,
- Crack relief layers greater than 3 inches thick,
- Sawing and sealing joints in the overlay at locations coinciding with straight (e.g., transverse thermal) cracks in the existing asphalt pavement,
- Increased overlay, thickness.

The Overlay

The asphalt overlay is placed and compacted in one or more lifts, in the same manner as for new asphalt pavement construction.

Performance

The performance of an asphalt overlay depends primarily on the thickness of the overlay, its asphalt concrete mix design, and the type and extent of pre overlay repair and surface preparation. Thin asphalt overlays are not likely to perform well or be cost-effective for pavements with little or no remaining structural life. Thicker asphalt overlays will perform well, but not be cost-effective, for pavements which have considerable remaining structural life. One reason for this is that the costs of a thicker asphalt overlay include not only the costs of the overlay itself and pre overlay repairs, but also the costs of raising guardrails and signs, overlaying shoulders, and making other geometric adjustments associated with raising the pavement grade by three or more inches. An important factor in the performance of asphalt overlays is the extent to which existing cracking is repaired prior to overlay. Asphalt pavements with extensive and severe cracking can be rehabilitated by a combination of patching and asphalt overlay, but at some point, other rehabilitation options which are not as sensitive to the pre-overlay condition of the pavement (e.g., white topping, reconstruction) may be more cost-effective. At what point this is true for a given pavement depend s on the extent and severity of cracking present, the thicknesses of the overlay and/or re constriction options considered, and the unit costs of the pre overlay repair, overlay, and/or reconstruction options. An asphalt overlay of 4 or more inches is estimated to have a service life of about 8 to 15 years on an asphalt pavement. Arizona estimates a service life of 10 years for asphalt overlays of asphalt pavements. New York estimates a service life of 15 years for 3 or more inches of new asphalt without cold milling or hot surface recycling, and for 3 or more inches of new asphalt after cold milling to a depth of 1.5 inches. These estimates apply to highways with ADT between 12,000 and 35,000, and about 5 percent trucks. Vermont estimates a service life of 6 to 12 years for 2 to 5 inches of asphalt overlay. West Virginia estimates a service life of 8 years for asphalt overlays of asphalt pavements. Wisconsin estimates a service life of 10 to 14 years for asphalt overlays of asphalt pavements.

6.5 Asphalt Patching

Appropriate Use

Full-depth or partial-depth patching of an asphalt pavement is localized repair of distresses related to structural damage, materials problems or construction problems. The repair may be full depth (down to the sub grade or intact the distress. Patching may be done in asphalt pavement either for maintenance purposes or rehabilitation purposes. Maintenance Patching is expedient and temporary repair, sometimes done in cold weather with cold-mixed Patching mixtures, and without careful construction procedures As a result, maintenance patches generally do not exhibit the same long-term stability and durability as hot-mixed Patching mixtures, carefully constructed as part of a rehabilitation strategy. Only hot-mix patching for rehabilitation purposes is described here. Patching (either full depth or partial depth) is most often thought of as the repair for potholes, but several other asphalt pavement distresses can also be repaired by patching Fatigue cracking in the wheel path, and transverse thermal cracking can be repaired by full-depth patching. Partial depth asphalt patching is appropriate for block cracking, slippage cracking, weathering, and raveling. Both full-depth and Partial-depth patching can be applied to bleeding and stripping.

6.5.1 Concurrent Work

Patching for rehabilitation purposes may be done alone, as part of restoration of the existing pavement structure, or as preparation for placement of an overlay or surface treatment.

6.5.2 Materials

Hot-mix asphalt concretes are appropriate for long-term repair of asphalt pavements Asphalt concrete mixtures for use in Patching Should be of the same aggregate gradation and asphalt cement stiffness as would be, used for asphalt paving or resurfacing.

6.5.3 Design

The major design issue related to asphalt Patching is determining the amount of Patching to be done in conjunction with an overlay. The greater the percentage of medium and high severity distress is repaired by patching, the thinner the overlay may be. However, high-quality asphalt patching requires quite bit of hand labor, so it might not necessarily be most cost-effective to repair 100 percent of the cracking present. The optimal amount of patching depends on the following:

- The amount of medium- and high-severity potholes, fatigue cracking, and other cracking present;
- The required overlay thickness as a function of the amount of distress repaired; the unit cost of pitching; and
- The unit cost of the overlay, as a function of thickness.

The condition-based 1993 AASHTO and the deflection-based 1993 AASHTO and Asphalt institute overlay design procedures permit the designer to consider the effect of extent of patching on the required overlay thickness. In the 1993 AASHTO condition-based overlay design procedure, the structural coefficients assigned to the existing surface and stabilized base may be selected to reflect the amount of medium- and high-severity alligator and/or transverse cracking left unrepaired. In the 1993 AASHTO deflection-based overlay design procedure, deflections measured in areas of the pavement that will be patched may be excluded from the calculation of the effective modulus (En) of the pavement structure above the sub grade. Similarly, iii the Asphalt Institute deflection-based overlay design procedure, deflections measured, areas to be patched may be excluded from the calculation of the representative rebound deflection (RRD) of the pavement.

6.5.4 Construction

Quantity Estimation

For the purpose of developing plans and bid documents, a field survey should be conducted to estimate the total area of patching required. The quantity of repair required may be greater than that originally estimated in the earlier pavement evaluation survey. The Asphalt Institute recommends that patch areas extend one foot on all sides beyond the edge of the visible deterioration. The total area of the required repairs — not the total area of cracking to be repaired — should be used in the estimation of the total cost of patching.

Making Repair Boundaries

Repair boundaries should be straight, to help in achieving adequate compaction of the patch material at the edges. Repair areas do not necessarily have to be rectangular.

Removal of Deteriorated Material

When resurfacing is not part of the rehabilitation strategy, partial-depth saw cuts should be made along the repair boundaries. Partial-depth sawing provides straight edges which look nice and which are easy to seal. Full-depth saw cutting of the boundaries is not recommended, because a rough face achieves better bond between the repair material and the existing pavement. When the pavement is to be resurfaced after patching, the repair boundaries may cut more expediently using flat spades on jackhammers. After the repair boundary has been cut, the deteriorated material within the repair boundary should be chipped out with jackhammers. Removal should begin at the center of the repair area and progress toward the boundaries, as illustrated in Figure *B-i.*

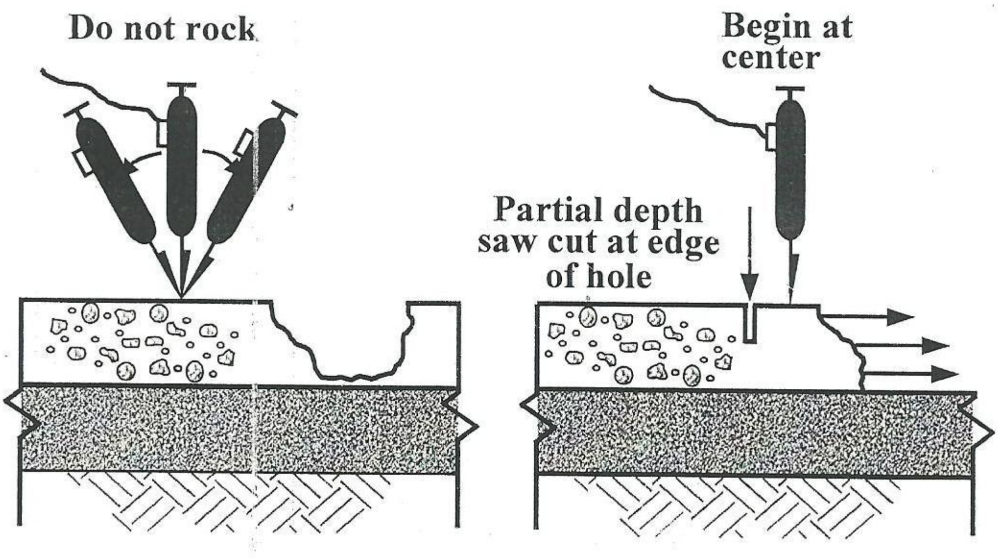


Figure B-1. Removal of material prior to aspalt patching.[4]

Figure 6.4 removal of material prior to asphalt patching

Cleaning

The exposed faces of the repair area should be thoroughly cleaned by air blasting to remove loose particles, and should be completely dry prior to placement of the patch material. Any material at the bottom of the repair area which is wet, loose, or soft should be either dried out and recomposed, or removed.

Applying Tack Coat

An emulsion, cutback, or synthetic resin tack coat should be applied to the vertical faces of the repair area, by brushing or low-pressure spraying. If the bottom of the repair area is granular or non-asphaltic treated base material, a prime coat material should be applied to this surface. If the repair extends in depth to the sub grade, it is not necessary to apply a prime coat to the bottom of the repair area.

Material Placement and Compaction

The hot-mix repair material should be placed in the repair and distributed carefully to prevent segregation. The repair material should be placed and compacted in lifts no greater than 6 inches thick. For small repair, vibratory compaction is adequate (as illustrated in Figure B-2); for larger repairs, a roller should be used for compaction. The best contact between the repair material and repair walls is achieved if compaction begins at the center of the repair area and progresses outward towards the edges. The Asphalt Institute, on the other hand, recommends that a straightedge be used to check that the final surface of the repair after compaction is level with the surrounding pavement surface.

Sealing Repair Edges

The last step in construction of an asphalt repair, the edges of the repair should be sealed. A liquid asphalt material may be poured along the edges, brushed lightly, and blotted with clean sand.

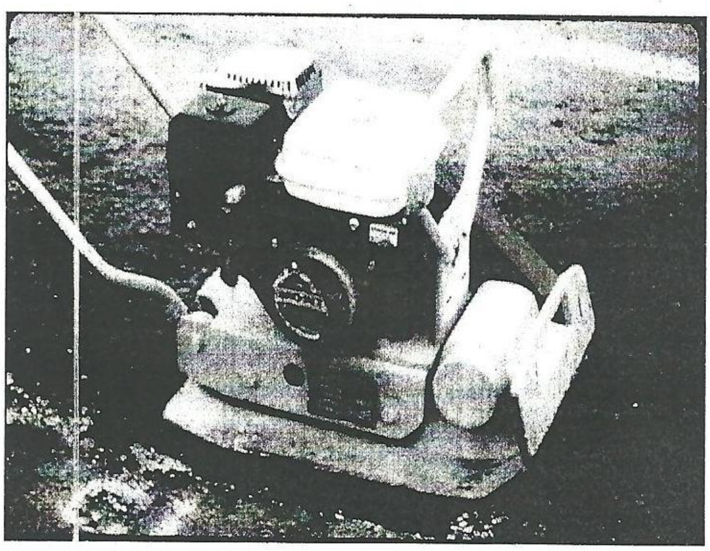


Figure B-2. Vibratory compaction of asphalt patch.[4]

Figure 6.5 vibratory compaction of asphalt patch.

6.5.5 Performance

The key factors influencing the performance of asphalt patching are the appropriateness of its use, the quality of construction, and the properties of the patch material. Asphalt patching may perform well but not be cost-effective for a pavement which has little or no remaining structural life and will soon need re-surfacing or reconstruction. Asphalt patching without overlay is estimated to have a service life of about 4 to 8 years. Although asphalt patching perhaps the most commonly used of all rehabilitation techniques, no State DOT estimates of the service life of asphalt patching were found. The American Concrete Pavement Association estimates a service life of 5 to 7 years for asphalt patching without overlay.

Table (6.12) Type of Maintenance for Pavement Distress

Distress	**Suggested Maintenance**
Pothole	Remove and clean material Fill the pothole with HMA with increase 25%ensity Compact for density Add overlay
Polished Aggregate	Slurry seal Surface treatment
Bleeding	Replace upper surface layer Surface treatment
Corrugation	Remove bitumen surface layer Surface treatment
Settlement	Clean and add tack coat HMA layer
Alligator cracking	Remove pavement layer Add HMA with increase 25% Compact up to high density
Edge cracking	Remove and clean material Fill with slurry seal
Block cracking	Remove the material near the edge Add HMA
Rutting	Level the surface with HMA Add overlay HMA

Table (6.13) Summary of Expected Lives and costs for Preventive Maintenance Treatments.

Preventive Maintenance Treatment	Treatment Life (years)			Costper Lane Mile (12 ft width) $
	Min	Average	Max	
Crack Sealing	2	4.4	10	5300
Thin overlay	2	8.4	12	146oo
Chip Seal (Single)	1	5.9	12	7800
Fog Seal	1	2.2	4	2200
Slurry Seal Cape Seal	1	4.8	10	6600
Cold in place Recycling	5	10.6	20	17700
Chip Seal (Double)	4	7.3	15	12600

CHAPTER SEVEN

Conclusions and Recommendations

7.1 Conclusions

The outcomes of this study are development of road numbering system: pavement condition survey methodology; evaluation of pavement condition

The study concluded that:

1- All the length of roads was surveyed for determining pavement distress, types, density and severity.

2- The study shows that there are 24.5% of the paved roads are in "Fair" condition, 31.7 % of roads are in "Good" condition, 25% of roads are in satisfactory condition (Excellent-- Very good) and the greatest % of distress in roads sections is found to be "Longitudinal and transverse crack.".

3- Themethodology appliedfor PCI for the road section, adopted is the visual condition survey and in calculation forindex depends on direct measurements of each distress on pavement not on just visual rating.

4- Two streets subjected to visual condition evaluation their condition is fair, it needs cut and patch of pothole and alligator crack areas, then, asphalt overlay urgently (Al gasr and Nile Avenue).

5- Three is in good conditions they should be under closed jurisdiction (Al gamoria, Al baldia, and Al mak nimr) when they fall to fair condition an overlay should be constructed.

6- The other streets should be monitored by condition evaluation continued every three years.

7- A routine maintenance should be applied to the network every year including pothole patching and crack sealing.

8- The experiments proved that the DCP has a high degree of repeatability under control conditions , and is sufficiently sensitive for used in practice .

9- A definite relationship exists between DCP and CBR such a calibrated allows the determination of pavement layer strength.

10- the most significant factors that influence the DCP- CBR:

- Correlation of Clay content of a soil, Passing sieve No 200 content of a soil, Moisture content and soaking condition (degree of saturation) for clay soils,
- It is clear that the DCP measures a variety of material properties. According to experimental data it appears that the following are the most important properties: grading, density and moisture content.

11-The lab. Soaked CBR/ Field DCP relationship can be used for Estimating the soaked CBR values for high and low plasticity from DCP investigation.

12- As it is seen only one street has level of service A, and four of them has level of service B and the rest six street are having level of service c which will need more access and grade separation for the junctions and to some extent some maintenance is needed for some of them.

7.2 Recommendations

1- As found from pavement condition survey greater percentage of distress in all road sections is found to be the longitudinal and transverse cracking.

2- All road section having PCI less than 57% should be rehabilitated. During two years, and overlay of (4-5) cm should be constructed over the road sections exhibit "Fair" condition after the third year.

3- This study shows that the current maintenance technique is not the suitable treatment selection for maintaining paved roads in the future. Crack sealing milling and replace, surface treatment and preventive maintenance technique should be considered.

5- Axleload survey should be carried out to estimate more accurate damage factors for each vehicle.

6- Level of service objectives, the road network will be broken down into a functional hierarchy or road classes, each with a defined purpose.

7- User cost objectives, Arterial roads will be maintained, so far as budgets will allow tominimize the sum of user and road maintenance costs in the longer term.

8- Materials used for road construction and maintenance will only be obtained from sources approved by the Ministry of Infrastructure and Transport.

9- Safety, Road work will be carried out in such a manner as to minimize the hazard caused to road users, pedestrian and workers during the course of the works.

10- Provide an acceptable level of service that economic and safe for road users.

14-The following mission is adopted for Khartoum road network: Minimize the sum of road user and road administration costs within the budget available.AndUndertake all work effectively, efficiently and safety and in such a way that minimizes damage to the environmental.

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