BE CIVIL ENGINEERING
PROJECT REPORT

DEVELOPING A FRAMEWORK FOR PAVEMENT MANAGEMENT SYSTEMS IN PAKISTAN

Project submitted in partial fulfillment of the requirements for the degree of

BE Civil Engineering

SUBMITTED BY

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This is to certify that the

BE Civil Engineering Project entitled

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Has been accepted towards the partial fulfilment of the requirements for

BE Civil Engineering Degree

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Dr.Muhammad Irfan, PhD
Syndicate Advisor

Dedication

Special dedication to our parents
Supervisor, beloved friends,

And all faculty members

For all support, encouragement and believe in us. Thank you so much.

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We are thankful to **ALMIGHTY ALLAH** Who gave us the strength, ability and wisdom to achieve everything in our lives. Our **Parents** and **Families** who are a source of constant support to us and without whose prayers we may have never achieved anything. Our **Friends** and **Course Mates** for helping us through thick and thin. Our Project Supervisor **Lt. Col. Dr. Muhammad Irfan** for his guidance, encouragement, patience, knowledge and for providing us the freedom of action.

All Syndicate members

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LIST OF ABBREVIATIONS/SYMBOLS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AASHO	American Association of State Highway Officials
AC	Asphalt Concrete
AC	Agency Cost
AMP	Annual Maintenance Programme
AOC	Area Over The Curve
AMS	Asset Management System
APTECH	Applied Pavement Technology
AUC	Area Under The Curve
AVO	Average Vehicle Occupancy
BMS	Bridge Management System
CDA	Cumulative Difference Variable
CE	Cost Effectiveness
CPI	Construction Price Index
CRF	Capital Recovery Factor
dTIMS	Deighton Transportation Infrastructure Management System
ESALs	Equivalent Single Axle Loads
EUAC	Equivalent Uniform Annual Cost
FHWA	Federal Highway Administration
FWD	Falling Weight Deflectometer
GDP	Gross Domestic Product
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HDM	Highway Development And Management
HMA	Hot Mix Asphalt
INDOT	Indiana Department Of Transportation
IPENZ	Institution Of Professional Engineers New Zealand
JPCP	Jointed Plain Concrete Pavement
JRCP	Jointed Reinforced Concrete Pavement
IRI	International Roughness Index
LCC	Life Cycle Costing

LCA	Life Cycle Analysis
LCCA	Life Cycle Cost Analysis
MOEs	Measures Of Effectiveness
M & R	Maintenance and Rehabilitation
NAPA	National Asphalt Pavement Association
NHAI	National Highway Authority Of India
NPMS	Nebraska Pavement Management System
PCA	Principal Component Analysis
PCC	Plain Cement Concrete
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
PI	Performance Indicator
PJ	Performance Jump
PMS	Pavement Management System
POP	Pavement Optimization Programme
PSI	Pavement Serviceability Index
RAMS	Road Asset Management System
RDB	Road Data Base
RIMS	Road Information Management System
SC	Structural Capacity
SD	Standard Deviation
SE	Standard Error
SHAs	State Highway Agencies
SN	Structural Number
TMH	Technical Methods For Highway
UKPMS	United Kingdom Pavement Management System
WSDOT	Washington State Department Of Transportation
WZ	Work Zone
WZUC	Work Zone User Cost
VMT	Vehicle Miles Travelled
VOC	Vehicle Operating Cost

EXECUTIVE SUMMARY

Pakistan has 12131 Kilometres long National Highway and Motorway network which is 4-6 % of the total road network but carries 80% of the country's total traffic. Over the past few years, road traffic both passengers and freight has grown significantly faster than National economy. Owing to these facts management and preservation of existing road systems has become a major activity for the government. Currently National highway authority is using HDM-IV decision support software whose results and reports are used to prepare annual maintenance planes but shortage of funds to maintain the pavement system exists. Therefore funds that have been designated for pavement preservation must be used as effectively as possible. Hence key to a successful pavement management programme is to develop a reasonably accurate performance and cost models of the road way, and then identify the optimal timing and strategies for cost effective maintenance of rehabilitation whichever is applicable.

In this study a framework for pavement management has been developed for better management of flexible pavements of Pakistan. A review of the existing systems for different countries has been carried for comparison of existing practices. The idea revolves around the fact that pavement managers seek cost effective maintenance or rehabilitation profiles over the pavement life cycle. For this first a network level analysis of the pavement is done to determine which pavements sections are below the agency's minimum performance level. That is followed by project level analysis of the deteriorated section. For this purpose Software has been developed which aids in structural evaluation of the pavement. Then an activity profile is selected, the benefit of profile can be measured as the service life, increase in average performance or area bounded by the performance curve that corresponds to that profile, may be monetized or non-monetized. For this purpose treatment specific performance and cost models were formed. The cost effectiveness evaluation is ultimately done to determine the most feasible activity profile, thus increasing the overall effectiveness and optimum utilization of available resource.

Chapter 1

INTRODUCTION

1.1 Background

The first forms of road transport were horses, oxen and even humans carrying goods over tracks that often followed game trails, such as the Natchez Trace (John 1915). The first improved trails were at fords, mountain passes and through swamps. The first improvements consisted largely of clearing trees and big stones from the path. As commerce increased, the tracks were flattened and widened to accommodate human and animal traffic. Some of these dirt tracks were developed into fairly extensive networks, allowing communications, trade and governance over wide areas (John 1915).

Wheeled-transport were developed in ancient Sumer in Mesopotamia in 5000BC (John 1915), originally for the making of pottery. Wheeled-transport then created the need for better roads. Generally natural materials could not be both soft enough to form well-graded surfaces and strong enough to bear wheeled vehicles, especially when wet, and stay intact. It began to be worthwhile to build stone-paved roads and in fact, the first paved roads were built in Ur in 4000 BC (John 1915).

Since then, a strong needs to have a system for management and maintenance of roads surfaced. Engineers throughout the world invested funding in developing a system that could solve the problem at hand, until Pavement Management System (PMS) was adopted as an effective solution to pavement management in the 1950s (The American Association of State Highway and Transport Officials 1985).

Prior to the development of PMS, countries typically established yearly road maintenance budgets that emphasized maintenance improvements on a worse-case first basis, or in response to citizen complaints and political priorities. This approach worked satisfactorily for most communities, as long as sufficient funding was available. However, while funding sources dried up and maintenance budgets decreased or stayed constant, the need for improvements increased due to greater traffic volumes, aging of pavements and inflated material costs. Instead of providing preventative maintenance at an early stage, roads were left until much more expensive reconstruction was needed. Unfortunately, the short span of extra service years, during the delay of maintenance, was purchased at a very high price in terms of increased upgrade costs. It is for that reason that PMS was needed to orderly prioritize roads for maintenance at the earlier, cost-effective time.

1.2 Pavement Management System (PMS)

Pavement management is a systematic method to assess pavement condition, to identify M&R needs, and to plan pavement maintenance and rehabilitation (M&R) activities. A pavement management system (PMS) is a tool to track pavement inventory and condition, estimate future condition, determine M&R requirements and costs, and develop and prioritize M&R projects.A PMS, which analyses pavement condition and optimizes the use of available funding, is one source of necessary information for effective decision making regarding transportation infrastructure investment trade-offs. Pavement management system through the use of information regarding pavement inventory and condition in conjunction with pavement analysis and performance models, can be used to determine cost-effective strategies for preserving the pavement network and to determine the level of funding required to support agency goals for targeted levels of service.

1.3 Pavement Management System In Pakistan

Pakistan, with 177 million people, has a reasonably developed transport infrastructure. The growth in demand for transportation services is considerably higher than the growth in GDP. Road transport is the backbone of Pakistan's transport.

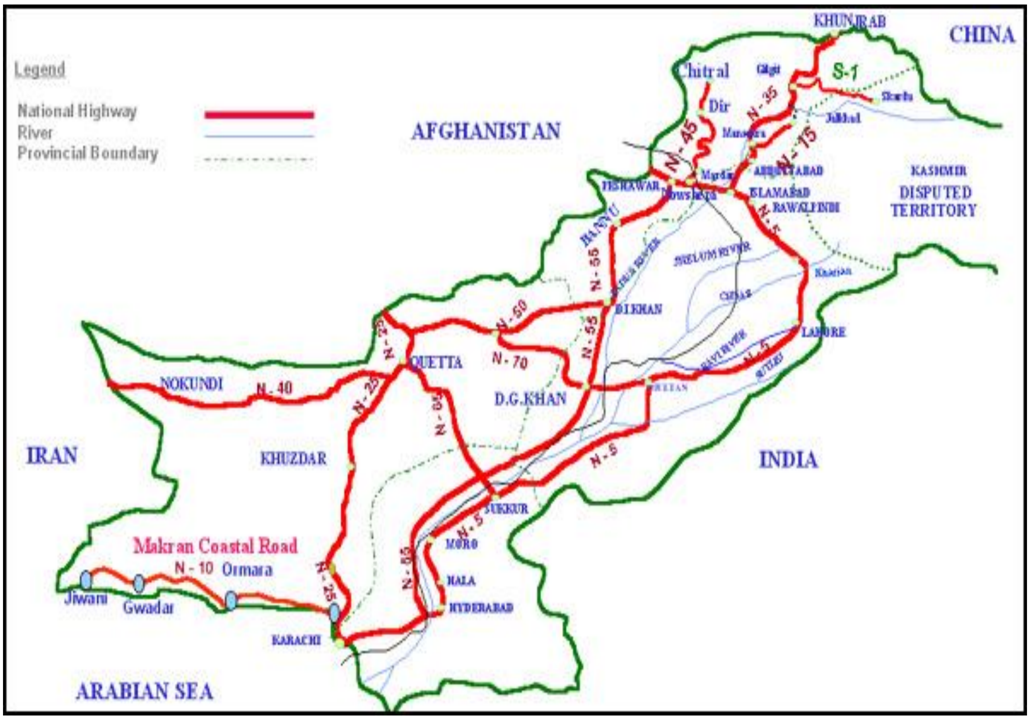


Figure 1.1: Road infrastructure of Pakistan

National Highway Authority is the central body responsible for road asset management in Pakistan. Based upon available resources and the priorities of serviceability, an annual program of care, conservation and upgrading of the road network takes place. This program of works is the investment being made in the road network. An analysis at the end of the following year of the road conditions and hence the prevailing asset values reflects the downward valuation of roads that have deteriorated further (due to no intervention) and the upward valuation of those sections receiving investments in the form of conservation or improvement programs and gives an overall picture of increase or decrease in remaining service life of the road network.

National Highway Authority follows the following strategy for the asset management.

- Conducting Annual Network Analysis
- Development of Existing central Road databank.
- Development of Annual Business plans.
- Target all Maintenance Activities
- Developing the current Asset Value of the Network.
- Financial and Technical Audit (performance indicators evaluation) for each Annual Maintenance plan

The annual maintenance plan of NHA can be divided into the following components

- Routine Maintenance Plan
- Periodic Maintenance Plan
- Rehabilitation Plan

1.4 Problem Statement

Pavement Management Systems (PMS) are important to all levels of government due to the deteriorating condition of our nations' highway infrastructure. Government officials are looking to maximize the benefit of every rupee spent on the road infrastructure because smooth functioning of a road and highway network is very important in the development and growth of any state. Determining when, where, how and to which level the maintenance will be performed is a complex question to be handled through various types of analysis such as Structural and Functional Capacity analysis can accurately describe the present condition and predict the future life of a pavement asset, and Life Cycle Costing (LCC) that considers not only the current cost but also that to be resulted from the future maintenance. We cannot rely too much on individuals' experience and sense in determining the maintenance requirements with such diverse and complex problems. Any judgment made based on economic efficiency in terms of an individual sense can be inefficient in the aspect of LCC. To find such unreasonableness and manage pavement in an efficient method, it is required to systemize overall management of pavement. The Pavement Management System (PMS) is the reification of this concept. PMS largely relies on development of the fast and safe testing equipment, the computer technology and the optimization technique as the cost for maintenance of road pavement increases sharply. As the technologies advance, the PMS technology is also under development. This research develops a framework for the management of pavement assets in Pakistan to make it easier for the decision makers to select the best M&R alternative for any road.

1.5 Objective of the Study

The objectives of study is to carry out an analysis of existing Pavement Management System being followed across the world and to develop a decision framework for determining the optimal timing and type of treatment for highway networks of

Pakistan with special focus on motorway networks which should maximise the benefits (monetized and non- monetized) and minimize the cost (Agency and user cost)

1.6 Organization of the Report

The thesis is ordered in six chapters; brief description of each is as follows:

- Chapter 1 elaborates a short overview related to background and evolution of Pavement Management system, Problem statement and objective of the study.
- Chapter 2 comprises of review of the past researches carried out regarding the development and implementation of Pavement Management System around the world.
- Chapter 3 explains the framework of Pavement Management system which we have proposed in this research which includes data collection techniques, data storage and data management, quality control and quality assurance of data, structural capacity evaluation, identification of maintenance and rehabilitation treatments, performance modeling, cost modeling and overlay design procedure.
- Chapter 4 explains structural evaluation and overlay design. It mainly includes evaluation of structural capacity, Destructive and Nondestructive testing for flexible pavements, categories of overlay design procedure, overlay design using AASHTO 1993 procedure, different approaches for design of overlay along project and structural capacity evaluator and overlay thickness calculator.
- Chapter 5 explains treatment specific effectiveness analysis (Performance models). It includes mainly model classification, why pavement performance modeling is important, steps for building regression models, pavement maintenance and rehabilitation techniques, pavement performance indicators, performance jump and short term measures of effectiveness, long term measures of effectiveness (Non- monetized & Monetized) and a detailed explanation of cost models.

- Chapter 6 summarizes the conclusions of this research. The recommended work for future and suggestions are also discuss

Chapter 2

LITERATURE REVIEW

2.1 Introduction

It is hard to say exactly when the idea of systematically managing pavement networks first started but it is believed to have started sometime after the building of the first stone-paved roads in Europe in 4000 BC (John 1915). The building of stone-paved roads developed a strong need for their management and maintenance.

According to AASHTO 2001, a Pavement Management System (PMS) consists of a large no of activities including programming and planning of funds on design of pavement, construction, maintenance and evaluation of performance. It consists of documented and established processes concerning all activities which come under the domain of PMS. The concept of PMS requires clear and detailed understanding in order to apply it for practical purposes. Implementation process within a specified organization is a complex and cumbersome task.

The beginning of PMS occurred in mid of 1960’s. It was based on integration of system principles, engineering technologies and economic evaluation. Early contributions involved a system approach to pavement design (Hudson et al. 1968; Scrivener et al. 1968) and a management system for highways (Haas and Hutchinson 1970) followed by development of technologies in individual components of pavement management (RTAC 1977; Haas and Hudson 1978). Although perhaps arguable, the modern era began with the explosion of Post-World War II road building in the late 1940’s and continuing on for the next several decades, the AASHO Road Test, 1958-61, and researchers associated with it, made an enormous contribution to the technology base of PMS (Hudson *et al.* 1979).

The following years saw literally an explosion of interest in PMS and further implementation in many countries around the world. Much of that experience was summarized in the first two conferences on pavement management in Toronto in 1985 and 1987 (Hudson *et al.* 1979). The Third International Conference on Managing Pavements, in San Antonio in 1994 reported further major advances, as did the Fourth

International Conference in 1998 in Durban, Republic of South Africa (Hudson *et al.* 1979). The Fifth Conference was held in Seattle in 2001 and illustrated many contributions that pavement management is dynamic and continually evolving with new and better technologies and real efforts to achieve integration with the broader spectrum of asset management (Hudson *et al.* 1979).The initiatives (and risks) subsequently undertaken by a number of pioneering agencies were most instrumental towards expanded acceptance and further development of pavement management. Some of the first published records of implemented PMS began to appear about 1980, and by 1982, for example Session IV of the Fifth International Conference on the Structural Design of Asphalt Pavements was devoted to PMS. It provided descriptions of implemented, working systems in the Netherlands, United Kingdom and United States (Hudson *et al.* 1979).

The development of network level prioritization methods and life cycle analysis (LCA) were given consideration after the identification of major operational levels of pavement management in late 1960's (Haas and Hutchinson 1970).

Performance prediction modelling is a vital and critical element of pavement management since 1960's. A huge consideration is given to the development of reliable and improved pavement performance prediction methods. Establishment and application of life cycle analysis is a noteworthy breakthrough in PMS, beginning in 1970. During 1980's improved maintenance treatments and their importance in enhancing pavement performance was realized. Now most agencies stress a lot on maintenance treatments (FHWA 2001). The importance of asset valuation in PMS is a concept of mid 1990's (Yeaman 1997; Cowe et al.2001).

2.2 Development and Improvement of Pavement Management System around the World

The development and implementation of pavement management system has been studied quite critically in past few years at international level. Some transportation organizations and departments emphasize on the engineering problems while some focus on technological and administrative aspects of PMS. Some of studies carried out on development, implementation and up-gradation of PMSs in different parts of the world are presented here.

PMS in Australia, like in other countries across the world, is managed at the district and state level, only. It was developed as in-house software to serve as a decision support tool for the road asset maintenance policy and strategy at the state and district levels. Data gathered includes, but is not limited to roughness, rutting, strength, texture, cracking; skid resistance and seal coat age (Anderson *et* al. 1994). Australia uses long-term (10-year) maintenance contracts to turn over total control and responsibility for roadway system maintenance, rehabilitation, and capital improvements to private contractors.

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

In December 1998, New Zealand (NZ) embarked on an ambitious project to implement a National Pavement Management System (NPMS).A software called Deighton Transportation Infrastructure Management System (dTIMS) was chosen as the software application for multi-year programming road works. A pragmatic approach was selected and followed in the implementation of the NZ NPMS. The main aim or benefit of this approach was that it manifested an evolutionary progression. In adopting this approach, a preliminary NZ dTIMS system was developed within a relatively short time-frame during the first seven months of the project using available information and systems (Phase I). This system was then further refined from feedback from the system users and the refined system was released in October 2000, marking the end of Phase II of the project. Phase II included further research and development. Phase III of the project was also developed and has brought about further refinements, operational research and enhancements, continued training and support for users. NZ PMS has even awards at home and internationally and is recognized all engineering institutions in NZ, including the Institution of Professional Engineers New Zealand (IPENZ) (Wilson *et al*. 2002).

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

PMS in SA occurs through the Asset Management System (AMS) and is maintained, with guidance from the SA PMS Plan, independently by different road network agencies, i.e. local and metropolitan levels (National Department of Transport 2006). By local level, it is referred to local and district municipalities. AMS process refers to a systematic method of information collection and decision making support to permit the optimization of resources for maintenance, rehabilitation and construction of new roads, generating a programme of works and corresponding budget which match a defined level of service (National Department of Transport 2006). The SA PMS applies a two-step process of generating strategies and their optimization. The optimization process aids in selection of the most economical strategy within budget parameters. Even though the PMS determines optimum strategies, a field panel selects the final construction work program. This selection is then reviewed and final project selection may be modified to meet local needs and considerations. A key component of SA PMS road condition analysis is the annual visual evaluation, which is based on the Technical Methods for Highways (TMH) 9 handbook. Rates are trained and certified to ensure consistency among the provinces. The annual evaluation is combined with mechanical measurements for use in the calculation of road condition indices. Mechanical measurements of the road, done every two to three years, include traverse and longitudinal profiling. The road indices are then used to formulate optimization of preventative maintenance based on available funds.

The Spanish Ministry of Public Works and Transport has implemented a PMS for its road network. Studying the experience of other authorities had been extremely important in selecting a method. The aim was to adapt the system to the circumstances of the network. The system was implemented in stages in order to produce results as soon as possible and to not lose the advantages of a rigorous approach. The existing requirements and resources available were considered in selecting the data to be collected. Some of the problems that had arose during the work had been successfully solved, and it is hoped that others would be solved in the future. The first stage has been implemented, and work is under way on the second stage (Gutierrez-Bolivar &Achutegui 1994). Pavement inventory, models for analysis and deterioration prediction, procedure of administrative follow-up and analysis, and the models of optimization and planning are main components of PMS in Spain. In general, the different inventories have an objective catalogue with description and quantification of the different variables (Gallant 1999). The prediction models are useful at the network level for pavement design, analysis of the cost of service life, selection of appropriate design and to determine the appropriate time and pavement condition for the selection of optimal strategy of maintenance at the project level. The planning models are used to evaluate strategies before identifying projects or precise maintenance works. PMS of Spain deals with the varied functions that are derived from planning, emphasis is given to those that have to deal with the design and elaboration of information instruments to support the strategic road infrastructure planning. The analytical software of management system is integrated with the geographical information, used for representing results, future condition forecasted optimization models, using the modern technology of “Dynamic Segments”. Pavement management philosophy in Spain places a reasonable consideration for conciliation of operational organization of maintenance works with optimal needs (Victor and Teresa 2008).

In India, National highways (NH) are the primary system of road transportation. Although NH constitute about two percent of entire road network but it accommodates about forty percent of road traffic. Due to limited funds for road maintenance and violation of axle load limit, the existing highway network is deteriorating exponentially and resulting in pavement failure before design life. The pavement preservation strategies were based on heuristic approach of pavement engineers. The deteriorating road network and unsatisfactory results of heuristic decisions called for the need of developing a scientific approach towards pavement management and maintenance management systems. Now the modified methodology used for the development of network level pavement management system consists of pavement inventory and its identification, data collection and database, models for predicting pavement performance, selection of alternative maintenance strategies, life cycle cost analysis, optimization of investment allocations and prioritization of road segments based on economic evaluation (Aggarwal et al.2004). Internationally recognized HDM-4 model is being employed for development of network level PMS using some segments of NH network in India, after its calibration according to local conditions. The network level pavement management analysis has been carried out using the “Program Analysis” application module of HDM-4. The National Highway Authority of India (NHAI) is contemplating the development of a Road Information Management system (RIMS) for the National Highway (NH) network in the country using HDM-4. The methodology adopted for the development of PMS may be extended to include whole of the NH network to achieve this objective.

Nebraska Pavement Management System (NPMS) developed by the Department of Roads. It represents an organized approach to prove the Department’s administration with the necessary information to efficiently manage its highways. In 1973 Nebraska initiated a program for measuring the roughness of pavement for present serviceability index (PSI) on all state maintained highways. There were two controlling factors used for Nebraska’s sufficiency rating at that time which include pavement condition, safety and service. The condition rating was derived from structural adequacy and roughness data. The structural adequacy was derived from the deflection information using the Dynaflect and the roughness from measurement obtained using a PCA response type road meter. This system provided general information for management regarding programming for the rehabilitation of pavements. In 1984 the Program Management Division was created to upgrade and implement a more operational Pavement Management System. Initially, a great deal of time and effort was expended in determining what information was required to achieve above mentioned goals. Finally Surface condition, present serviceability index, age, maintenance and life cycle costs, pavement design (thickness and material) and deflection data for resurfacing were established as important factors for evaluations and achievement of above mentioned goals. This finally led to development of basic components of NPMS. They comprise a computer master file and interpreting programs. The master file provides the information for the computer system's pavement management record. The interpreting programs summarize the information and provide reports listing candidate sections of pavement suitable for rehabilitation. In 1985 a method was developed for measurement of surface condition of pavement of Nebraska (Heinemann 2012). In 2004 the pavement optimization program (POP) was developed. The program allows investigating current pavement ratings and also incorporates life cycle cost analysis (LCCA). By now a number of versions of this program with additional functions have been released.

In the mid -1980s, the Illinois Department of transportation pioneered the use of PMS at the state level. In 1999, the division retained technology, Inc. (AP Tech) to update their system and enhance its usefulness. During that project, APTech worked to develop an innovative approach to maintaining the Division's pavement management system that would minimize costs and enable the Division to maintain a high level of involvement in the process. The first step in this process was converting the existing pavement management system into MicroPaver database to enable the rapid communication of information to the staff of agencies involved and division employees. Next, APTech performed pavement evaluations using the pavement condition index (PCI) procedure to assess current pavement conditions. Finally APTech established a system that facilitated the effective communication of pavement and made the information readily accessible to users with a variety of technical backgrounds. APTech developed an interactive pavement management data access CD to provide instant access to the most commonly requested pavement management information PCI maps, distress photographs, and maintenance and rehabilitation recommendations without requiring the user to own and operate pavement management software. Due to the Division's satisfaction with APTech's wok, it has retained several projects to re-evaluate the condition of pavements and to update the pavement management system and data access CD. Throughout these projects, APTech maintained a unique teaming relationship with the Division. Each year, the division is assisted by APTech for obtaining system's inventory information pertaining to the projects, development of treatments, the project base maps and their implementation.

2.2.1 Pavement Management System Adopted by National Highway Authority Pakistan

Pakistan has an average transport infrastructure. Road transport is the backbone of Pakistan's transportation system. To keep the National Road Network at an optimum level, NHA has developed a Pavement Management System. Currently, PMS of NHA is based on computerized road database (RDB) integrated with PMS, HDM-IV and bridge management system (BMS). Pavement condition data, pavement roughness, geometric data, traffic data are collected by visual inspection and using machines like Falling Weight Deflectometer (FWD), BI units and laser profilometer. The collected data is used in the World Bank recommended decision support tool HDM. The results and reports of HDM are used to prepare an annual maintenance plan (AMP), which is then disbursed to regional offices of NHA for implementation. Strategy followed by NHA is as under:-

- Conducting Annual Network Analysis process.
- Development of Existing central Road databank.
- Development of Annual Business plans.
- Target all Maintenance Activities as investments making them to be cash specific.
- Developing the current Asset Value of the Network.
- Financial and Technical Audit (performance indicators evaluation).
- Annual Maintenance plan.

2.2.2 Rispave Pavement Design And Analysis Computer Program

Rahmanet al. 2014; developed a computer program at Military College of Engineering Risalpur in order to simplify the design and analysis process for flexible and rigid pavements. The RISPAVE computer program was named after the place of origin, Risalpur. RISPAVE was developed using Microsoft Visual Basic. NET language for designing and analysing flexible and rigid pavements based on AASHTO empirical design procedures of 1993. The program provides an easy-to-use user interface, which has been augmented with supplementary tools to work out the Equivalent Single Axle Loads (ESALs), Effective Modulus of subgrade reaction, etc. The Computer Program considers the four design factors – traffic and loading, environment, materials and failure criteria – based on the AASHTO Design Guide (AASHTO, 1993) as input parameters to compute the layer thicknesses for both flexible and rigid pavement along with steel reinforcement (longitudinal, transverse steel, ties, dowels etc). Furthermore, the Computer Program analyses one-layer, two-layer and three-layer flexible pavements and rigid pavements as well caters for the design of Asphalt Course overlay on Flexible Pavements. This Computer Program help in saving valuable time ensure accuracy in design/analysis and can be utilized to check designs/analysis done by hand. The Computer Program finds its place as an integral component of the broader Pavement Management Systems utilized by Highway and other construction authorities.

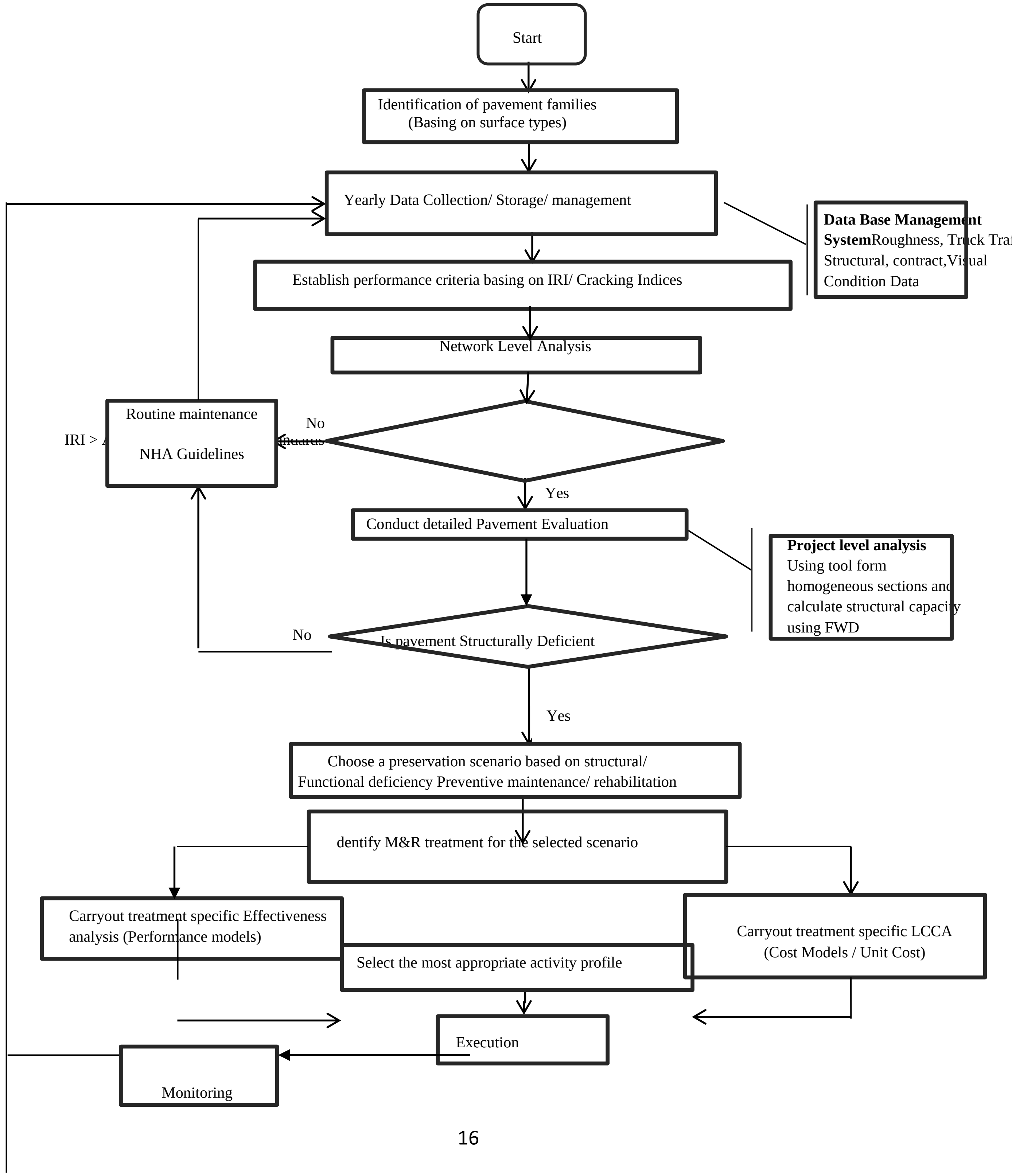
2.2.3 Summary

It is apparent from the literature review above that since PMS emergence in the early 1960s, road authorities throughout the world have adopted PMS as a solution to road network management. Its development and implementation has had successes and shortcomings to different extents.

In this chapter an endeavour is made to explain pavement management system. Main focus of this chapter is on the development and up-gradation of pavement management systems across the world including the ones that are similar to road asset management system (RAMS) of Pakistan e.g South Africa and India. The decision support tool used by Pakistan and India is HDM as both these follow the same guidelines of World Bank. A study conducted to develop the life cycle activity profile for the state of Indiana is also included that highlights and demonstrates the techniques to be used to increase the cost effectiveness of individual treatments and performance standards at project level analysis. The pavement management practices and the techniques for development and up-gradation used in different parts of the world compared with the current pavement management practices of Pakistan will help identify the areas for improvement of RAMS of Pakistan. There are a number of key problem areas with the existing PMS that are being used by the international road authorities namely the high establishment costs, high maintenance costs, complicated in terms of its format and in data collection, unreliable in pavement performance modelling, need for training and expensive. There is therefore a need for a cost effective and easy to use pavement management system.

PROPOSED METHODOLOGY

Proposed Framework of Pavement management system



3.1 Identification of Pavement Families

Pavements like other assets are grouped into families basing on common features which may include, material type, traffic levels, functional classes & geographical location. But most of the time the pavements are classified on the basis of surface type and functional class. For the purpose of this research we have considered the grouping of pavement basing on surface material type and in that restricted ourselves only to flexible pavements. This grouping is explained in subsequent sections.

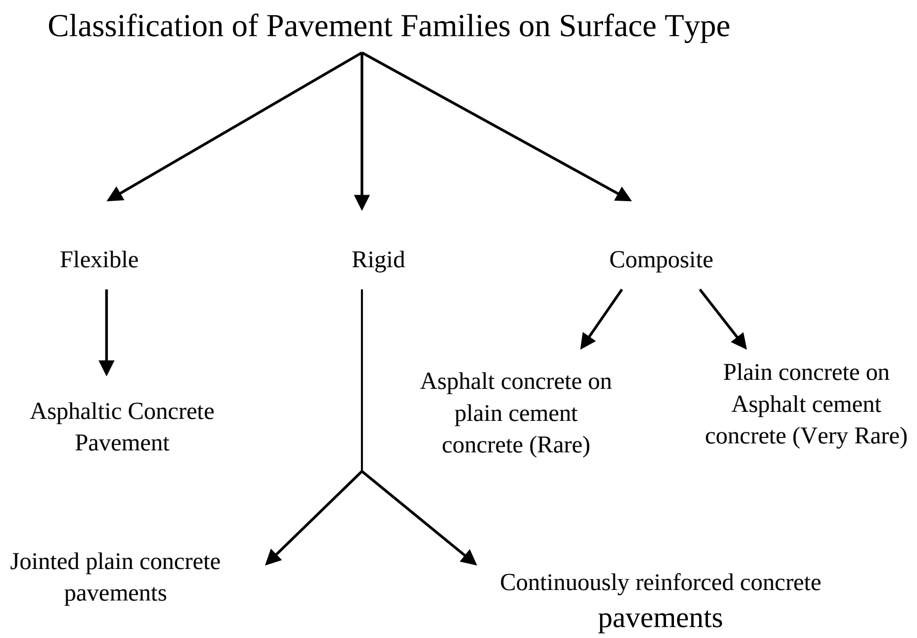


Figure 3.2: Classification of Pavement Families

The main difference between Rigid & Flexible pavements is the structural response upon vehicular loading. The flexible pavements are called flexible owing to the fact that all the pavement layers bend on application of vehicular loads, thus showing flexibility. They may have inherent advantage such as low cost and ease of repair compared to their counter parts. On the other hand rigid pavements are stiffer than the flexible pavement, and have higher modulus of elasticity of Plain Cement Concrete (PCC) material. They deflect very little on vehicular loading application. Therefore they are used for the areas subjected to heavy loadings. They are further classified as:-

- Jointed Plain Concrete Pavement (JPCP) which as the name implies have joints to control natural cracks

- Continuously Reinforced Concrete Pavements (CRCP) does not have transverse contraction joints and cost more than JRCP.

Rigid Pavements have higher initial cost and are comparatively difficult to repair, whereas Composite Pavements as the name implies combine the elements of flexible and rigid pavements. Their rehabilitation activities are not always the same as of those two types explained earlier

3.2 Data Collection

Data collection is the first and foremost step in the evaluation of pavement performance and predicting suitable maintenance strategies. Frequency of data collection varies across the world. For example in USA nearly all State Highway Agencies (SHAs) collect pavement performance data at 1-, 2-, or 3-year frequency. Some SHAs such as the Washington State Department of Transportation (WSDOT) survey the pavement network each year. Others survey half the pavement network each year and still others survey one third of the pavement network each year. Regardless of the data collection frequency, most agencies use semi- or fully-automated means of data collection along the outer traffic (driving) lane (McGhee 2004). Further, some SHAs use sampling techniques where the pavement performance data are collected along a short pavement segment (such as 100, 200, 300 feet, 0.1 mile, etc.) of each one mile and the data are assumed to represent the pavement conditions along the entire mile (Zimmerman 1995).

In Pakistan NHA collects data on annual basis for formulation of strategy of maintenance for National Highways. Here we will discuss types of data collected for pavement evaluation, data collection techniques and quality control & quality assurance of data.

3.2.1 Types of data

Five major types of data are collected for the analysis, design and formulation of strategy of maintenance for National Highways.

- Pavement condition data which includes inventory, cracking, rutting, edge erosion, edge stepping, ravelling, size and number of potholes and drainage condition. Survey form of NHA is attached as annexure A. (show the form on slide)

- Road roughness data as the roughness of the surface is pre-dominant condition which effects VOC on road network
- Traffic data includes AADT, ESAL, % Trucks, etc.
- Structural data includes deflection data which is collected using manual as well as automated techniques like FWD. Deflection data is used for calculation of residual pavement strength. The deflection values of pavement are very useful in determining the existing structural number (SN) and analysing the remaining service life (RSL) of the pavement, employing which, maintenance strategies are formulated.
- The Contract data provides information on project location, type of pavement treatment, the total construction cost, the project size (length & no of lanes), the date of letting and completion, the fiscal year, the type of contract (fixed, available days or fixed deadline), the project duration, the initial (pre-treatment) performance, the surface type, the functional class,etc.

3.2.2 Data Collection Techniques Followed In Pakistan

Data is collected using pavement condition surveys. Different techniques are used for data collection which include manual as well as automated Condition Surveys. In Pakistan NHA Conducts Condition Surveys after every moon soon for the collection of data. Here are some examples of how data is collected by NHA using different equipment:-

- Roughness data is collected using laser profilometer
- Pavement Condition Surveys are performed by Visual Surveys
- Deflection data is collected usingFalling Weight Deflectometer (FWD)
- Traffic data including truck traffic data is collected every year from the record maintained by NHA

3.2.3 Quality Control/ Quality Assurance of Data

Quality control includes these activities necessary to asses and adjusts production processes to obtain the desired level of quality of pavement condition data. This includes checks on the equipment used to collect the data, the personnel responsible for the data collection, and the data collection process itself conducted before and after the data collection. Quality acceptance includes those activities conducted to verify that the collected pavement condition data meets the quality requirements. Quality acceptance tools are used for testing both the pavement condition data that are collected by the agency and those that are collected by a service-provider. Common methods include testing of controls or verification sites, use of software to check for errors such as incorrect asset data or ratings outside of an expected range, and checking a certain percentage of data by quality assurance personnel. Major factors and reasons that contribute to doubtfulness of credibility of data are listed below:-

- Visual pavement condition survey is conducted by individuals who do not possess requisite qualification, information and knowledge to conduct this critical job. Further there are few quality training programs for teams who perform visual pavement condition survey.
- As per guidelines and requirements of World Bank (Donor), all the pavement surveys are carried out every year; this makes the process hectic and reduces quality of observed data. This can be overcome by developing a sample methodology and its rigorous implementation, which will require prior approval of World Bank.
- Although the deflection survey is carried out to determine the structural integrity of pavement and calculation of remaining service life but destructive testing is not carried out to compliment the visual pavement condition survey.
- The idea of audits and spot checks is missing in the process. Further due to limited resources drainage survey is not a part of pavement survey.

3.3 Data Storage and data Management

Data storage and management is one of the important aspects of PMS. Agencies have developed their data banks of the storage and management of data. Various types of software/ decision support tools are used for data management for example HDM-IV adopted by NHA and Arc GIS etc are mainly used. Many countries like New Zealand, Australia and UK have developed their own data storage and management software. Incorporation of GIS in PMS includes procedures for data input, either from maps. Aerial photographs, satellites, surveys or other sources; data storage, retrieval, and querying;

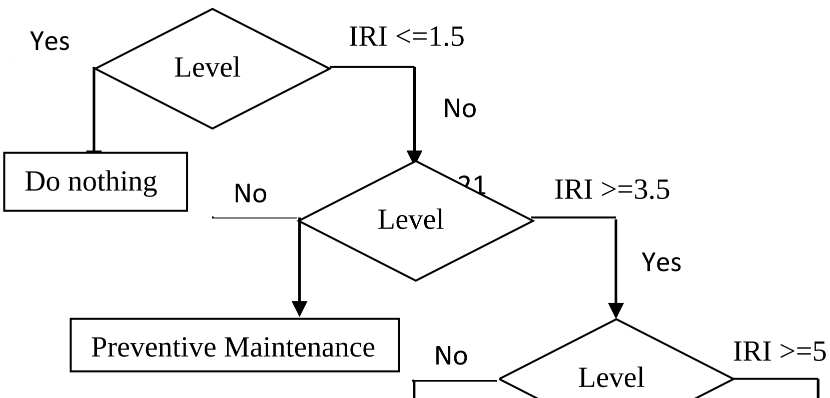
data transformation, analysis and modelling; and output generation including maps, reports and plans. Current state of practice of GIS in PMS includes use of spatial tools for map generation and database integration. RAMS, NHA, Pakistan is also developing itself for incorporating GIS in its road maintenance system, but the process is in its elementary stages. To begin with, its implementation will be utilized for improvement of location referencing consistency and will then move towards maximization of benefits and optimum utilization of GIS application. As pavement management decisions require information from myriad sources GIS is very useful for facilitating the integration of data with graphic information and with different data sets

3.4 Network level analysis

Network level analysis is required for system wide management. It utilizes aggregate data on the basis of which prioritization of maintenance, rehabilitation and reconstruction techniques is done. In network level analysis top management attention is easily obtained.

3.5 Establish Levels of Service

Based on the performance standards set by any agency, and their treatment specific performance models, levels of service are formulated which include target levels of service and minimum levels of service which provide necessary guide line for selecting maintenance and rehabilitation strategies (M&R). When the value of any performance indicator reaches or exceeds the threshold (as already set by the agency), the option to carry out particular M&R becomes available for the decision makers. The performance indicators used mostly in Pakistan are IRI and cracking as a percentage of pavement area. Different threshold levels set by NHA for these two above mentioned performance indicators are as follows, corresponding to various traffic bands:-



Pavement Life Cycle

Figure 2.3: M&R Activity Decision Tree (Based on NHA Standards)

3.6 Pavement Structural Capacity Evaluation

3.6.1 Deflection, a Function of Structural Capacity

Pavement surface deflection measurements are the primary means of evaluating a flexible pavement structure and rigid pavement load transfer. Although other measurements can be made that reflect (to some degree) a pavement's structural condition, surface deflection is an important pavement evaluation method because the magnitude and shape of pavement deflection is a function of traffic (type and volume), pavement structural section, temperature affecting the pavement structure and moisture affecting the pavement structure. Deflection measurements can be used in back calculation methods to determine pavement structural layer stiffness and the subgrade resilient modulus. Thus, many characteristics of a flexible pavement can be determined by measuring its deflection in response to load. Furthermore, pavement deflection measurements are non-destructive.

3.6.2 Deflection Measurement:

Surface deflection is measured as a pavement surface's vertical deflected distance as a result of an applied (either static or dynamic) load. The more advanced measurement devices record this vertical deflection in multiple locations, which provides a more complete characterization of pavement deflection. The area of pavement deflection under and near the load application is collectively known as the “deflection basin”.

3.6.3 Determination of SN_{eff}

Based on the assumption that the structural capacity of a pavement is a function of its total thickness and overall stiffness, the effective structural number can be calculated as:

$$SN_{eff} = 0.0045D\sqrt[3]{E_p} \quad 3.1$$

Where,

E_p = Effective modulus of pavement layers above subgrade in psi

D = Total thickness of all pavement layers above subgrade in inches

It must be noted that the constant 0.0045 used in equation 7.2 has been computed as:

$$0.0045 = \frac{0.14}{30000} = \frac{a_i}{M_R} \quad 3.2$$

3.6.4 Determination of E_p from NDT

The resilient modulus may be determined through performing a Falling Weight Deflectometer (FWD) test on the existing pavement using a load magnitude of approximately 9000 pounds (40 kN) and measure deflections at the *center of the load* and at least at *one other location* at a sufficient distance from the load. Back calculate subgrade modulus using the equation.

$$M_R(\text{psi}) = \frac{0.24P}{d_r r} * C \quad 3.3$$

Where,

d_r = FWD deflection at a distance ‘r’ from the center of the load in inches

P = Applied FWD load in pounds

r = distance from center of FWD load to deflection sensor in inches

C = constant with a value of 0.33 (include pic below)

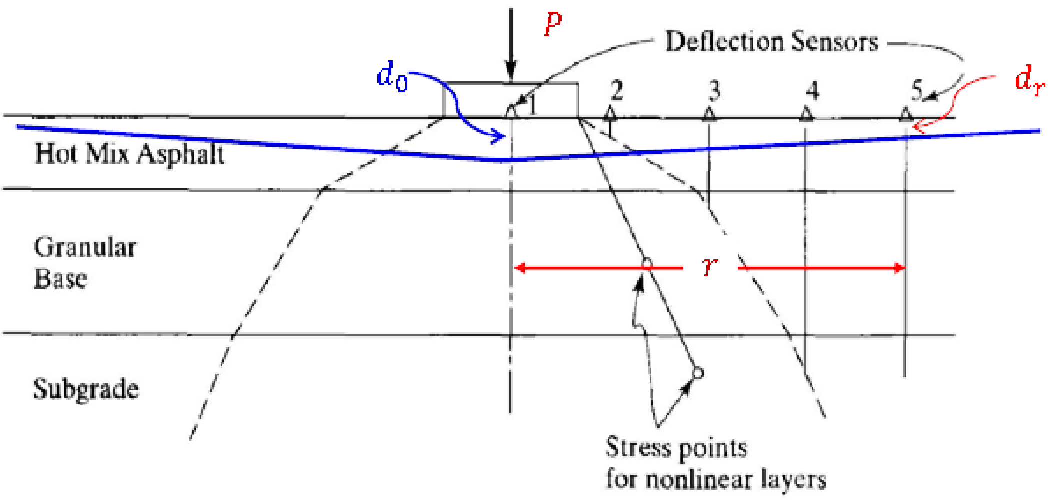


Figure 3.4 : Deflection at Centre and Distance 'r' during Falling Weight Deflectometer Test

The distance "r" should be far enough such that the measured FWD deflection would be independent of the effects of the pavement layers above the subgrade, but close enough such that the deflection would not be too small to be measured accurately. The minimum distance is given as

$$r = 0.7\sqrt{\left[a^2 + \left(D\sqrt[3]{\frac{E_p}{M_R}}\right)^2\right]} \qquad 3.4$$

Modulus of Rigidity of Pavement (E_p) can be calculated using an iterative process as follows:

$$d_o = \frac{1.5qa}{M_R}\left\{\frac{1}{\sqrt{1+\left[\left(\frac{D}{a}\right)\sqrt[3]{\frac{E_p}{M_R}}\right]^2}} + \frac{1-\frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}}{\left(\frac{E_p}{M_R}\right)}\right\} \qquad 3.5$$

Where, d_o for granular or asphalt treated base has to be adjusted for the Asphalt Course Mix Temperature if the temperature is other than *68 °F* using the following graph.

3.6.5 Overlay Design Procedure

This procedure consists of a component and a deflection-based analysis method based on the concept that the structural capacity of a flexible pavement can be quantified by a SN (Structural Number). The required overlay thickness is the amount that will increase the effective SN of the existing pavement (after the necessary milling and repair before the overlay) to the required SN to meet the future traffic demand.

$$SN_{ol} = a_{ol}D_{ol} = SN_f - SN_{eff} \quad 3.6$$

Where,

SN_{ol} = required overlay structural number

a_{ol} = structural coefficient for the AC overlay

D_{ol} = required overlay thickness in inches

SN_f = required structural number for future traffic demand

SN_{eff} = effective structural number of the existing pavement to be overlaid.

3.6.6 Structural Capacity Evaluator

This tool will be used to evaluate the structural capacity of the flexible Pavement.

3.6.6.1 Steps to calculate Structural Capacity

- Data obtained from FWD will be imported to the application.
- The entire length of pavement is divided into sections.
- Using Cumulative Difference Variable (CDV) approach, each section will be divided into uniform subsections.
- Average deflection, Standard Deviation and Co-efficient of Variance will be calculated by pre fed formulae in the tool.
- Calculate Mr using average maximum deflection.
- Calculate Ep from Mr calculated above
- Calculate SNeff
- Calculate D_{OL}

3.7 Preservation Scenario basing on Structural/ Functional deficiency and Agency standards

A preservation scenario is agency's pavement preservation plan which aid in making a decision as to which M&R strategy is applied i.e whether to carry out preventive maintenance wherever designated level of service is crossed or to let the level of service fall within the category where rehabilitation option for the pavement is triggered. Mostly developed countries with less budgetary constraints follow the practice of doing preventive maintenance whenever threshold level for ‘do nothing’ scenario is crossed. Some countries follow this strategy of allowing the pavement to cross the threshold level where rehabilitation becomes necessary depending upon the economic circumstances. For the purpose of this research and keeping in view the practices followed in our country vis a vis NHA standards, we will resort to either the maintenance strategy designated by NHA’s trigger matrix or if structural deficiency is also found (as a result of above mentioned procedure)will resort to rehabilitation techniques.

3.7.1 Identify Maintenance and Rehabilitation Treatment for Selected Scenario

On the basis of threshold matrix, and treatment performance models, a set of candidate maintenance and rehabilitation strategies is established. An important fact is that there could be as many as hundreds of candidate strategies for each pavement family and a number of combinations, depending upon the number of maintenance and rehabilitation treatment types and selected threshold values.A maintenance and rehabilitation strategy or activity profile is simply one of the large number of permutations of treatment applications within the analysis horizon and set of performance standards. A hypothetical schematic of maintenance and rehabilitation is shown in figure below in which two treatments are applied subsequent to the new construction. PI(s,i) is the post treatment performance of ith stage treatment ‘s’ at time ‘t’. PI(s,0) is the do nothing or new construction performance. ts(trig)is the time of triggering of subsequent treatment ‘s’, tps(trig) is the time at which pre-treatment is triggered and is ‘0’ for new construction. tps (max) is the time at which pre-treatment performance reaches the absolute performance threshold, PI(max). t(i-1)is the actual service life of the(i-1)th stage treatment (the time span between the triggering of two consecutive treatments (i.e.,ithstage treatment and previous stage ((i-1)th)treatment).such as t(0) is the service life of new construction until the time of triggering the first treatment.(including figure please)

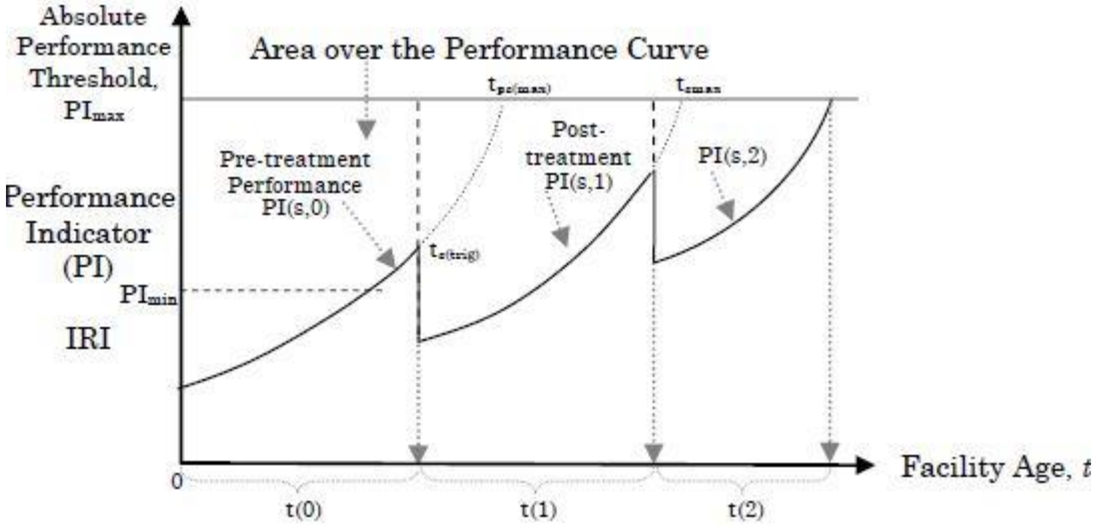


Figure 3.5 : Treatment-Triggering Phenomena Based on Predefined Performance Standards

3.8 Pavement Maintenance and Rehabilitation Techniques

3.8.1 Preventive Maintenance

Pavement preventive maintenance is a pre-emptive effort to arrest the onset of significant deterioration and often corrects minor defects as a secondary benefit.

3.8.2 Rehabilitation

Rehabilitation is the act of repairing portions of an existing pavement to reset the deterioration process. The various preventive maintenance and rehabilitation techniques that can be considered are shown below:-

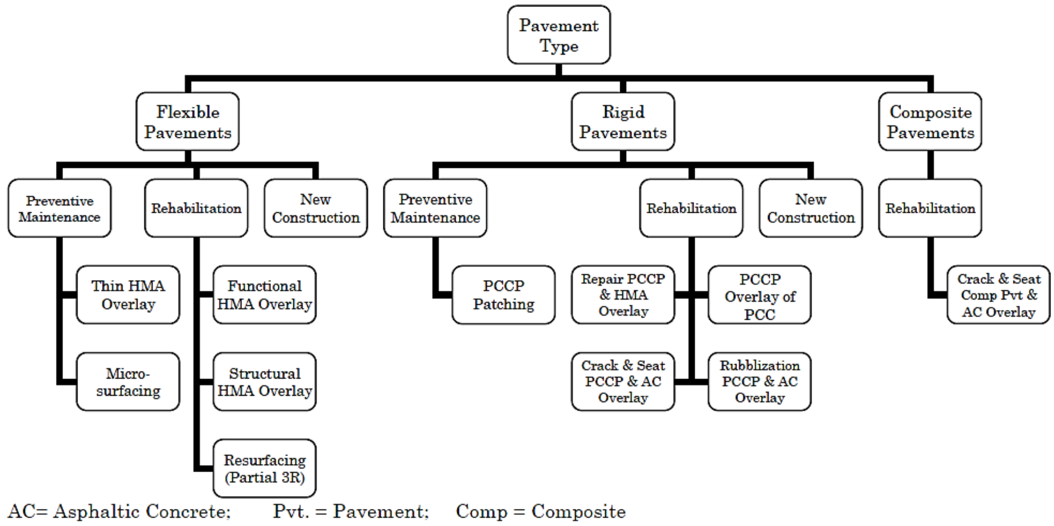


Figure 3.6: Different types of M&R Treatments

3.8.3 Thin Hot Mix Asphalt (HMA) overlay

It is a traditional method for protecting a deteriorated pavement surface where strengthening the pavement structure is the primary objective. However, thin HMA overlays do not involve extensive structural enhancement and generally contribute little, if anything, to a pavement's structural capacity [Roberts et al., 1996]. These overlays are generally thin surface overlays on the order of 12.5 mm (0.5 in.) to 37.5 mm (1.5 in.) that often are intended to address problems of surface roughness, rutting, and surface cracking, ride quality improvement, correction of minor surface defects, safety characteristics such as skid resistance and drainage, appearance enhancement, and road-tire noise reduction [NAPA, 1995; Labi et al., 2005; Irfan et al., 2009a]. Thin HMA overlay varies widely in composition, depending on the local practice, the volume of traffic and the general purpose.

3.8.4 Micro Surfacing

Micro-surfacing, or asphalt surface treatment, is a broad term encompassing several types of asphalt and asphalt-aggregate applications [Roberts et al., 1996]. Micro-surfacing is comprised of the basic ingredients of emulsified asphalt, water, and well-graded fine aggregate and mineral filler. It is used as a preventive maintenance treatment to repair slight to moderate pavement surface defects in a variably-textured surface (filling cracks and voids, improving skid resistance, sealing weather-tight, and providing colour and texture delineation in a single pass [WSDOT, 2009]. This treatment is also useful to resist the surface abrasion by traffic. A conventional surface treatment may not be suitable for use on high volume, high speed roads due to the susceptibility of loose aggregate over the surface. When properly designed and constructed, however, they are economical and reasonably durable [Roberts et al., 1996].

3.8.5 Functional HMA Overlay

Functional (non-structural) HMA overlay is designed to add to or replace the existing pavement wearing course only. As such, it contributes relatively little to the pavement structure and is generally assumed to provide no additional structural support [WSDOT, 2009]. Such overlays can be placed on existing surfaces with or without preparatory milling [NAPA, 1995]. The application of a functional HMA overlay is normally carried out after hot surface recycling (application of heat and scarification of the existing top pavement layer) [Roberts et al., 1996]. Functional overlays restore pavement smoothness to new condition on structurally sufficient pavements and it consists of an intermediate course and a surface course. Placement of the intermediate course is generally preceded by milling.

3.8.6 Structural Overlay

Structuraloverlaysconsistofbase,intermediate,andsurfacecourses,withmillingoftheexisting pavement.Theapplicationthicknessspecificallyexceedsthethicknessofnon-structural(functional)overlays.Structuraloverlaysstrengthentheexistingstructureandrestorethepavementsmoothnessandaregenerallyconsideredasrehabilitationtreatments. Asphaltic concrete structural overlay design processes can be broadly categorized into engineering judgment (which is generally subjective and can be heavily influenced by political and budget constraints)and component analysis (which takes into account pavement condition , layer types and thicknesses of the pavement ,andnon-destructive test results)[Robertsetal.,1996].

Structural overlays consist of base, intermediate, and surface courses, with milling of the existing pavement. The application thickness specifically exceeds the thickness of non-structural (functional) overlays. Structural overlays strengthen the existing structure and restore the pavement smoothness and are generally considered as rehabilitation treatments. Asphaltic concrete structural overlay design processes can be broadly categorized into engineering judgment (which is generally subjective and can be heavily influenced by political and budget constraints) and component analysis (which takes into account pavement condition, layer types and thicknesses of the pavement, and non-destructive test results) [Roberts et al., 1996].

3.8.7 New Construction

The New construction of a flexible pavement becomes necessary when the pavement has reached the end of its service life and any further rehabilitation and maintenance will clearly not be cost-effective. Full depth HMA is comprised of a surface course (top layer that comes in contact with traffic and may be composed of one or several different HMA sub layers), a base course (layer underneath the surface layer) and generally consists of aggregate (either stabilized or un stabilized), or HMA followed by a sub base course which may not always be needed [WSDOT, 2009]. Full depth HMA pavements are often considered cost-effective due to the key benefits that make them an attractive choice over concrete, such as the speed and versatility of construction, maintenance considerations, superior smoothness, and aesthetics

3.9 Treatment specific effectiveness analysis using performance models

The effectiveness of maintenance and rehabilitation strategy can be quantified using models , thus allowing us to compare different treatments that differ in attributes such as material type, procedure etc of different agencies depending upon their policies, but the most commonly used measures of effectiveness(MOEs) are

- Asset /treatment service life
- Area bounded by performance curve
- Increase in asset performance over treatment life (long term measures)
- performance jump, (short term measures)

In effectiveness analysis both monetized and non-monetized benefits are catered for. Monetary benefits are dollar or rupees cost saving in agency's maintenance expenditures on the facility and the non-monetary benefits are similar to monetary except for the fact that in the former benefits are measured in terms of money whereas in later they are measured in terms of extension in pavement life or reduction in travel time of the user.

3.9.1 Measures of long term effectiveness non monetized

During the process of pavement management. The pavement performance trend over the service life of treatment helps in determining non monetized benefits. These can be expressed in any one of 3 MOEs explained earlier. Moreover lack of universally accepted standards in determining monetary user and agency benefits has discouraged agencies in considering user and agency cost reductions in their analysis. So, instead they use non monetized benefits which are easy to calculate. Any of these three MOEs can be determined by plotting each individual pavement segment that received treatment or by drawing the best fit performance curve which are developed by using data from many pavement segments which received treatment. In order to implement effectiveness evaluation of a maintenance and rehabilitation strategy, it requires prior formulation of performance models. Than if we know the threshold performance levels basing on agency standards we can predict service life, increase in the pavement performance over service life and area bounded by performance curve. The details of which will be presented in next chapters.

3.9.2 Measures of long term effectiveness monetized

When a maintenance and rehabilitation strategy is applied, the pavement performance is improved and a finite area is formed between projected performance with the treatment and without the treatment. We know that traffic affects the projected life and is also associated with the benefits accrued due to asset improvement; the area can be a surrogate of benefits. Even if performance model is not a function of traffic usage, the area bounded by the performance curve may be multiplied by the average daily traffic (ADT)or vehicle miles travelled (VMT) thus incorporating the benefit of each vehicle that uses the asset. The benefits of highway usage are sometimes are based on the concept of reduction in an agency's maintenance cost , vehicle operating costs(voc) travel time costs, accidents cost etc.

3.9.3 Benefits from agency's perspective-annual maintenance cost savings

Agency's annual maintenance cost saving can be determined from the monetary impact of applying a treatment at a given time versus deferring a treatment application to some future time. When the facility is improved the agency is decreased and the benefits of highway improvements thus can be quantified as a reduction in agency cost. Consumer surplus analysis explained in coming chapters can be used to evaluate the impact of maintenance and rehabilitation techniques on consumers

3.9.4 Benefits from user perspective (user cost saving)

As the asset deteriorates with time the vehicle operating cost (VOC) generally increases. The VOC component includes fuel, oil, tires, maintenance of parts, repairs etc. The primary factors which can be improved by M&R are road geometry, surface roughness, capacity etc which in turns translates into VOC savings. The relationship between VOC and pavement performance will be discussed in detail in coming chapter. Besides user cost savings there are other indirect benefits due to performance improvement which include increased mobility, reduced probability of crash and enhanced user comfort etc. There are also user costs associated with the times of intervention application during work zones, where users suffer increased travel time and increased crash livelihood, resulting in lower user benefits and vice versa when intervention is complete.

3.10 Treatment specific cost analysis using cost models

This research uses the aggregate statistical modelling approach to estimate the treatment agency cost which is expressed as a function of different factors which are believed to influence construction costs. Work zone user costs are comprised of the costs incurred by road users during periods of intervention activities that reduce roadway capacity and thus reduce normal traffic flow. The procedure of developing cost models is discussed in the upcoming chapters.

3.11 Summary

This chapter gives a bird’s eye view of the proposed methodology which is to be followed for pavement management. First of all pavements are classified on the basis of material type, then data collection and type of data is explained. Emphasis is laid on quality of data collection. Level of services is then explained on the basis of agency standards. In the pavement analysis category, first of all network level analysis is explained then project level analysis is jotted down. In the end introduction to treatment specific effectiveness analysis and cost analysis is given, details of which are explained in later chapters.

Chapter 4

STRUCTURAL EVALUATION AND OVERLAY DESIGN OF PAVEMENT

4.1 Introduction

The use of nondestructive testing has become an integral part for evaluation and rehabilitation strategies of pavements in recent years. Pavement evaluation employing the Falling Weight Deflect meter (FWD) and the Ground Penetrating Radar (GPR) can provide valuable information about the pavement structural characteristics and be a very useful tool for project prioritization purposes and estimation of construction budget at the project level. By estimating pavement layer thicknesses and stiffness properties more reliable projections of project rehabilitation strategies and needs can be established, thus resulting in cost effective use of available funds.

4.2 Evaluation of Effective Structural Capacity

The most difficult part of overlay design is the determination of Effective Structural Capacity (SC_{eff}). Following three alternative methods are used to determine the structural capacity of a pavement.

- Non-destructive deflection testing NDT
- Visual condition survey and material testing
- Remaining life from fatigue damage by traffic.

There are uncertainties involved in each method, so the three cannot be expected to provide equivalent estimates. The designers should use all three methods whenever possible and select the best estimate through their own judgment. There is no substitute for experience and judgment. But in the study we will only focus on Non-destructive Deflection Testing procedures.

4.2.1 Non-destructive Deflection Testing

The NDT procedures on flexible pavements are used to estimate the roadbed soil resilient modulus and to provide a direct estimate of SNeff. Some agencies apply NDT to back calculate the module of individual layers and then use these moduli to estimate SN_{eff}, but this approach was not recommended in the 1993 guide.

4.2.2 NDT for Flexible Pavements using FWD

The FWD is a trailer-mounted device that delivers a transient force impulse to the pavement surface. By varying the mass or the drop height or both, the impulse load can be varied between 2500 lb to 27,000 lb for regular types of FWD. Generally, seven deflection sensors measure the surface deflections caused by the impulse load. The first deflection sensor is always mounted in the center of the loading plate, while the rest are positioned at various spatial distances up to 6 feet from the load center. From all deflections recorded, peak values are stored and displayed.

The FWD is the most commonly used tool for evaluating existing pavements for asphalt overlay or rehabilitation. In most cases, the FWD is used to evaluate structural capacity and then to back calculate pavement layer module.

4.3 Categories of Overlay Design Procedure:

There are three major categories for the overlay design procedures:

4.3.1 Component Analysis Design

This design procedure involves evaluating the condition of the existing pavement layers, and comparing them to equivalent thicknesses of new pavement materials to be placed. The required overlay thickness is equal to the difference between the required total thickness and equivalent thickness of the existing layer. The procedure usually requires making an engineering judgment based on visual inspection and laboratory testing. Examples include: AASHTO, 1993, Asphalt Institute effective thickness method (AI, 2000).

4.3.2 Deflection-based Design

This method uses surface deflection to estimate the structural capacity of an existing pavement. The required overlay thickness is the additional pavement thickness required to bring the measured deflection to the desired level. This design procedure is based on the empirical correlations between certain NDT deflections and field performances. Because of the empirical nature, the applicability of this procedure is usually limited to regions of similar conditions (climate, soil type and pavement materials used), and the same NDT procedure.

4.3.3 Analytical-based Design

This overlay design procedure is based on the analysis of stresses and strains in a pavement due to the expected traffic loads, and the correlations of these stresses and strains to performance. The required overlay thickness is the additional pavement thickness that will be required to bring the expected stresses and strains to the acceptable levels to prevent failure. This procedure requires extensive evaluation of the in situ properties of all the materials to be used in the pavement structure, including their damage characteristics (creep and fatigue behaviour.)

4.4 Overlay Design using AASHTO 1993 Procedures

Pavement overlay projects can involve a number of pavement sections with length ranging from a few hundred feet to several miles. A crucial question to be asked at the outset is how to divide the project into analysis sections so that the thickness of overlay for each section can be designed.

4.5 Design of Overlay

There are two approaches to designing an overlay thickness for a project; each has advantages and disadvantages. The designers should select the approach that best fits the specific situations.

4.5.1 Uniform Section Approach

The project is divided into sections of various lengths, each with relatively uniform characteristics. Each uniform section is considered independently and overlay design inputs representing the average of the section are obtained. To delineate an overlay length, the historical data should be consulted — construction and maintenance records, types and thicknesses of layer materials, sub - grade, traffic, pavement conditions, and so on. If accurate records have been kept, the use of historical data has more merit in delineating unique units than does a procedure that relies on current observations of condition or performance indicators, because changes in one or more design factors are not always evident through observation.

If accurate historical data are not available, the designer must rely upon the analysis of a measured pavement response for unit delineation. Although deflection measurements by NDT are effective as a performance indicator, other responses, such as pavement condition, serviceability, and rut depth, can also be used. A plot of the measured response versus station number along an actual highway system may be used to delineate units using different analytical or statistical methods. This can be done manually or through computerized data analysis–graphics systems.

4.5.2 Point-By – Point Approach Overlay

Thicknesses are determined for specific points along the uniform design section for example; every 300 ft (91 m). All required inputs are determined for each point, so that the overlay thickness can be designed. This approach produces a required overlay design thickness for each analysis point along the entire project for a given reliability level. In the selection of one thickness for the uniform section, keep in mind that each overlay thickness has already been increased to account for the design reliability level. Selection of a thickness that is greater than the mean of these values will achieve a higher level of reliability, but might not be warranted. This approach can be used to divide the project into different design sections, or one design thickness may be used for the entire project. Areas having unusually large thicknesses could be targeted for additional field investigation, and extensive repair or reconstruction might be needed before overlay.

4.6 Structural Deficiency

The overlay design procedures provide an overlay thickness to correct the structural deficiency of a pavement and increase its ability to carry loads over a future design period. Structural capacity, SC, is a general term that can be applied to flexible, rigid, and composite pavements. For flexible pavements, SC is expressed by a structural number, SN; for rigid pavements, by the PCC thickness, D; and for existing composite pavements, by an equivalent slab thickness. The original pavement has an initial serviceability of pi and a structural capacity of SC_0. As the number of load applications increases, the pavement gradually deteriorates, and its serviceability and structural capacity decrease. After Np load repetitions, the pavement reaches an acceptable serviceability level of p_2. At this time, the pavement reaches a structural capacity of SCeff, which is called the effective structural capacity of the existing pavement. The SCeff is equal to SNeff for flexible pavements, but to Deff for rigid and composite pavements.

To upgrade the pavement condition to the serviceability p_l, additional structural capacity, SC_{OL}, in the form of an overlay is required. The sum of this added structural capacity and the structural capacity of the existing pavement, SCeff, is equivalent to the structural capacity, SC_f, of a new pavement designed for the existing roadbed modulus and the projected future overlay traffic, SN_f . The basic equation for overlay design is

$$(SC_{OL})^n = (SC_f)^n - (SC_{eff})^n \qquad 4.1$$

in which n is a constant that depends on the type of pavement system used in the analysis. For unbounded rigid overlays on rigid pavements, n = 2 ; for all other types of pavements, n = 1 .

4.7 Overlay Design Procedure:

This procedure consists of a component and a deflection-based analysis method based on the concept that the structural capacity of a flexible pavement can be quantified by a SN (Structural Number). The required overlay thickness is the amount that will increase the effective SN of the existing pavement (after the necessary milling and repair before the overlay) to the required SN to meet the future traffic demand.

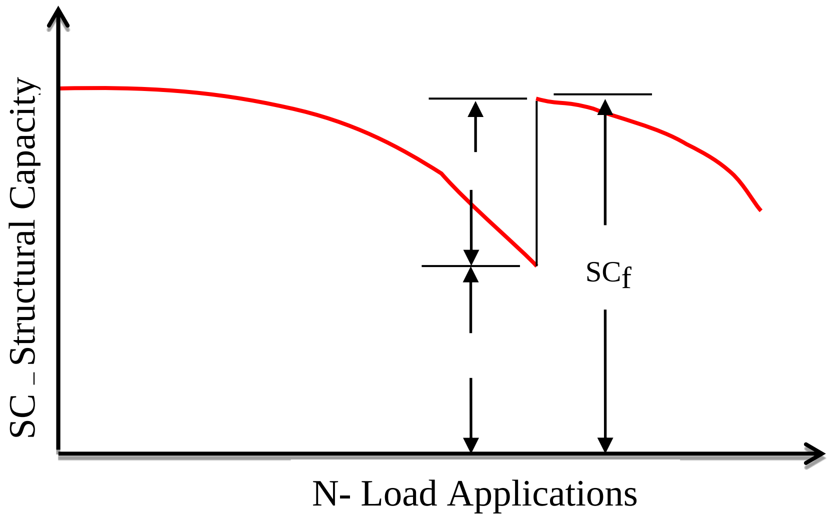


Figure 4.1: Effect of traffic on serviceability and structural capacity

SCOL

4.7.1 Determination of SN_{eff}

SCeff

Based on the assumption that the structural capacity of a pavement is a function of its total thickness and overall stiffness, the effective structural number can be calculated as:

$$SN_{eff} = 0.0045D\sqrt[3]{E_p} \qquad 4.2$$

Where,

E_p = Effective modulus of pavement layers above sub grade in psi

D = Total thickness of all pavement layers above sub grade in inches

4.7.2 Determination of E_p from NDT

The resilient modulus may be determined through performing a Falling Weight Deflect meter (FWD) test on the existing pavement using a load magnitude of approximately 9000 pounds (40 kN) and measure deflections at the *centre of the load* and at least at *one other location* at a sufficient distance from the load. Back calculate subgrade modulus using the equation.

$$M_R(psi) = \frac{0.24P}{d_r r} * C \qquad 4.3$$

where,

d_r = FWD deflection at a distance 'r' from the centre of the load in inches

P = Applied FWD load in pounds

r = distance from centre of FWD load to deflection sensor in inches

C = constant with a value of 0.33

The distance "r" should be far enough such that the measured FWD deflection would be independent of the effects of the pavement layers above the sub grade, but close enough such that the deflection would not be too small to be measured accurately. The minimum distance is given as

$$r = 0.7\sqrt{\left[a^2 + \left(D\sqrt[3]{\frac{E_p}{M_R}}\right)^2\right]} \qquad 4.4$$

Modulus of Rigidity of Pavement (E_p) can be calculated using an iterative process as follows:

$$d_o = \frac{1.5qa}{M_R}\left\{\frac{1}{\sqrt{1+\left[\left(\frac{D}{a}\right)\sqrt[3]{\frac{E_p}{M_R}}\right]^2}} + \frac{1-\frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}}{\left(\frac{E_p}{M_R}\right)}\right\} \qquad 4.5$$

4.7.3 ACO overlay of AC Pavement

The required thickness of asphalt to overlay, D_O can be determined as

$$D_{ol} = \frac{SN_f - SN_{eff}}{a_{ol}} \qquad 4.6$$

In which a_{OL}=structural layer coefficient of the overlay material. It is suggested that all three methods, if available, be used to evaluate SN_{eff} and that the most appropriate value be selected, based on the engineering judgment of the designer and the past experience of the agency.

4.8 Structural Capacity Evaluator and Overlay Thickness Calculator

This web based application is a very useful tool to evaluate the Structural Capacity of a pavement according to AASHTO 1993 procedures and then calculate the overlay thickness required. Instead of doing very complex manual calculation, just input the FWD data base file in this application and it will follow the entire procedure and give the required overlay thickness as its final output. An overview of the functionalities of the application is given below.

4.8.1 Landing page

This is the Landing page of the application which will appear once the application starts running.

Figure 4.2: Landing Page of Structural Capacity Evaluator

4.8.2 Login Screen

User names and password provide an extra tier of security for this application and make it accessible only for the authorized users. A unique "User name "and "Password" for every new user will keep this application safe and secure.

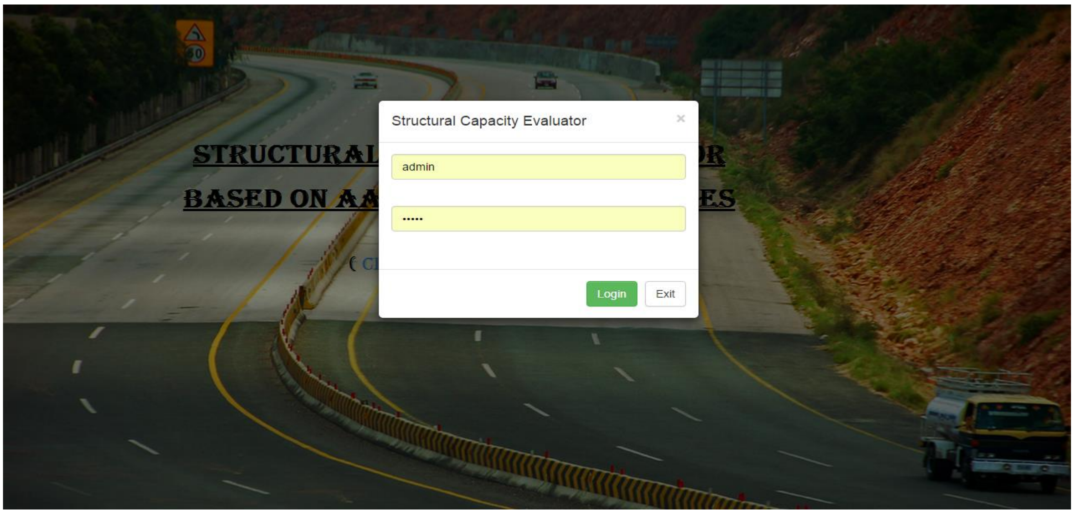


Figure 4.3: Login Screen of Structural Capacity Evaluator

4.8.3 Input the FWD data file.

In this step the file from FWD will be uploaded in the tool. The tool will use the data from that sheet for making sections, and all other calculations.

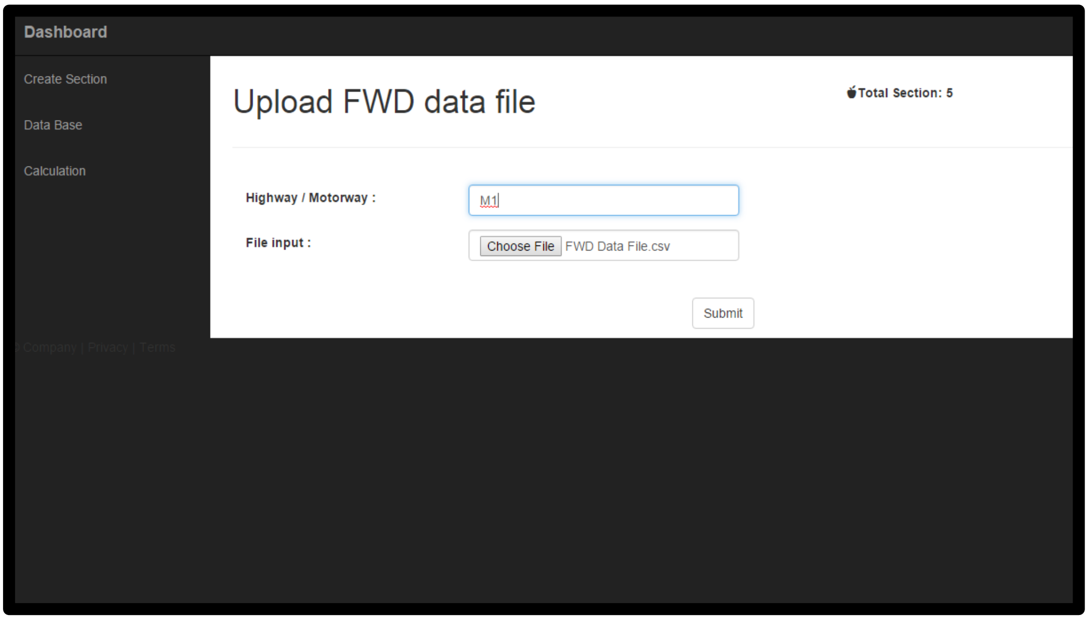


Figure 4.4: Upload FWD Data File

4.8.4 Uniform Sections

This is the screenshot of the uniform sections created by the Evaluator. The Evaluator divides the entire length of the road into many uniform sections based on uniform material properties

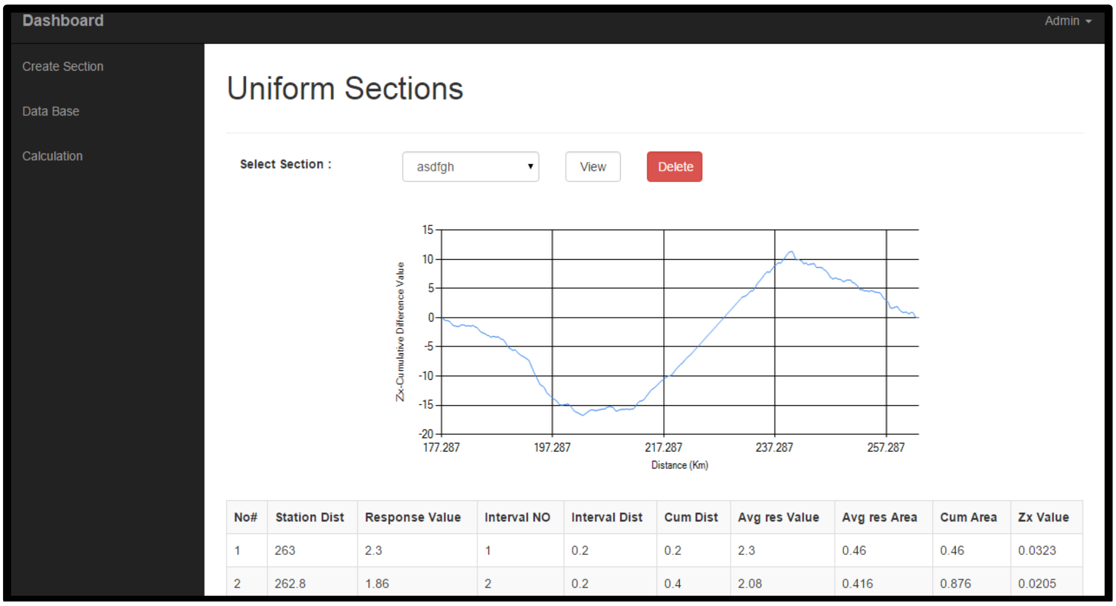


Figure 4.5 : Out Put Showing Uniform section

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4.8.5 Selection of a sub section

This step allows us to select a specific section from the entire length of the road to calculate the overlay thickness. Evaluator will calculate the maximum deflection in any section which will be used for subsequent calculations.

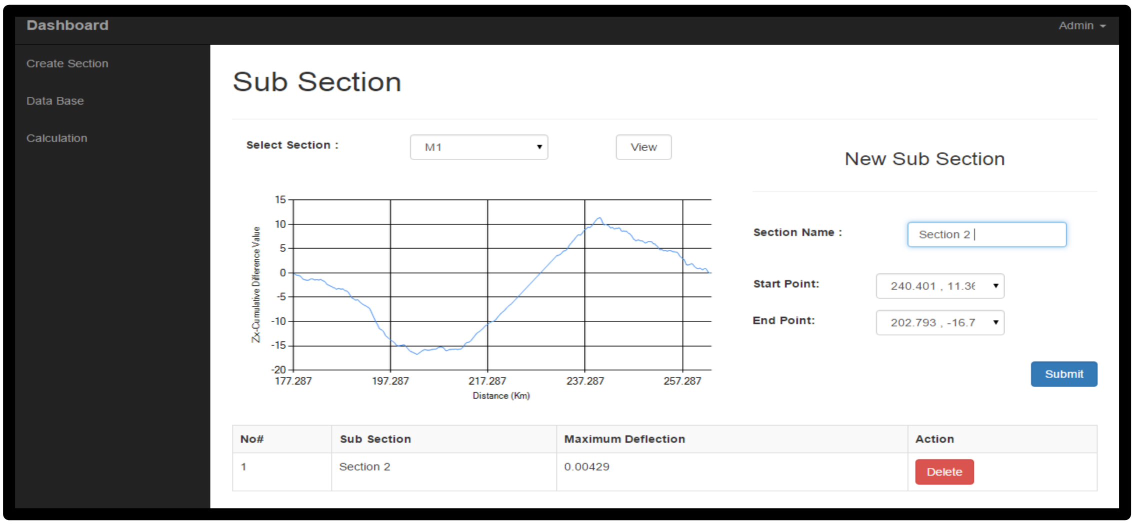


Figure 4.6: Out Put Showing Sub section

4.8.6 Calculation of Resilient Modulus (MR)

Following Input Parameters are required to be inserted in the Evaluator to calculate the value of Modulus of Resilience (Mr).

- Load Applied (P)
- Adjustment Factor (C)
- Surface Deflection (dr)
- Distance of Sensor (r)
- Resilient Modulus (Mr)

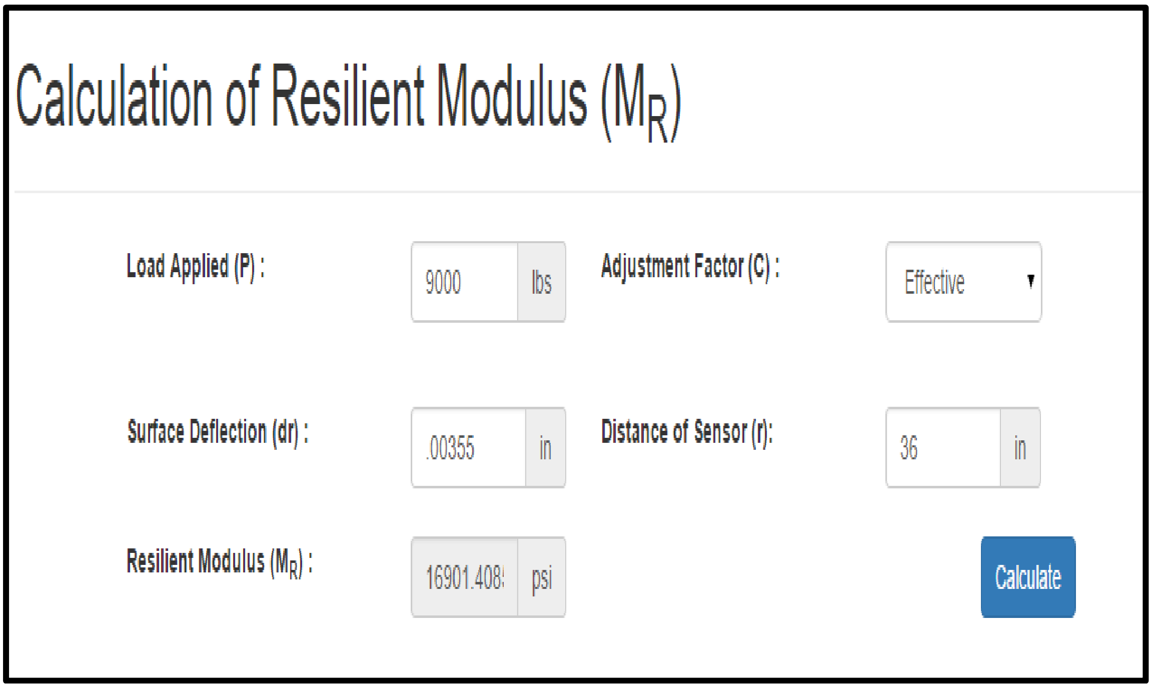


Figure 4.7 : Calculation of Resilient Modulus

4.8.7 Calculation of Effective Structural Number (SNeff)

To calculate the effective structural number (SN eff) we need to first calculate Effective Modulus of Rigidity (Ep) by using iterative functions. Then the same value of Ep is used to calculate the effective structural number. Following the input parameter required to be input in the Evaluator to get the SNeff. The Evaluator also verifies the minimum value of "r" selected in the above step so that if the value of "r" is not conforming we can change that value for further calculations.

- Max Deflection (do)Section Name

- Radius of Plate (a)
- Thickness of pavement layers (D)
- Pressure on load plate (q)
- Effective Modulus (Ep)
- Check value of ' r '
- SNeff

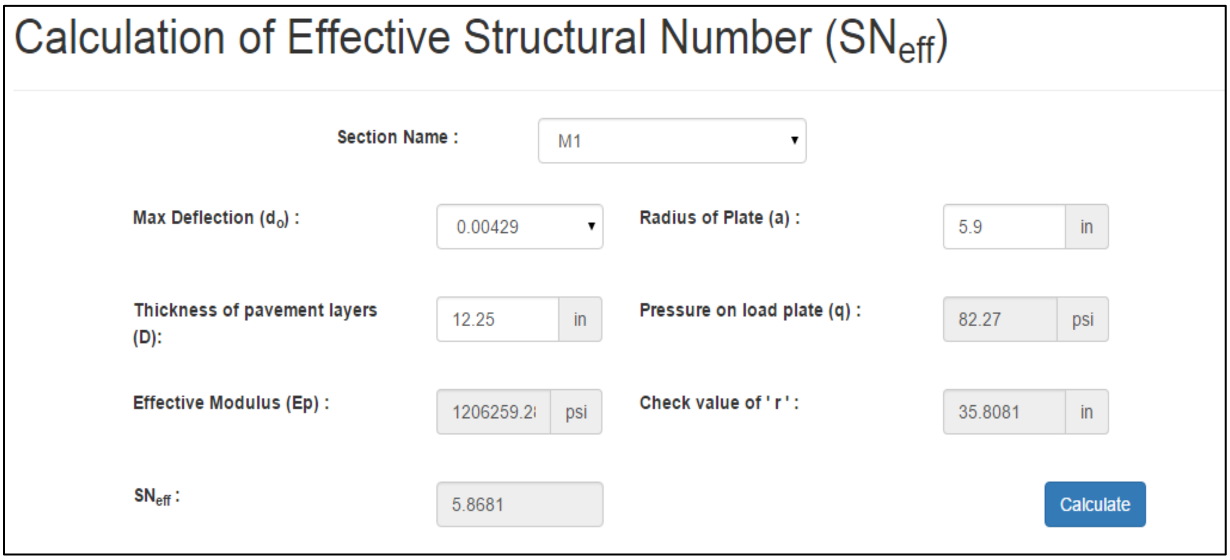


Figure 4.8 : Calculation of SNeff

4.8.8 Overlay Thickness

In the final step the Evaluator calculates the thickness of the overlay required for the selected section. The same procedure is repeated for all the remaining sections which will give us the thickness required for the specific section. Input Parameters

- SN_{eff}
- a_{OL}
- Design Overlay

Figure 4.9: Design of Overlay

4.9 Summary

The AASHTO design procedure is based on the structural deficiency approach. The basic equation is $(SCOL)^n = (SCf)^{n} - (SCeff)^{n}$ in which SCoL is required structural capacity of the overlay, SCi = structural capacity of a new pavement to carry future ESALs during the overlay period ,SCeffis effective structural capacity of the existing pavement ,and n is an exponent with the value = 1 for all cases except for the unbounded PCC overlays on PCC pavements, where n = 2. If the overlay or the existing pavement has a rigid layer, the structural capacity is the thickness of PCC, D; if all layers are flexible, the structural capacity is the structural number, SN.

However, the only method applicable to all cases is the condition survey, and the only case to which all three methods can be applied is the AC overlay of existing AC pavement. When the overlay design is based on SN, the condition survey method involves the evaluation of layer and drainage coefficients in their existing condition s; The NOT method is recommended in all cases to determine the resilient mod-ulus, MR, or k-value of the sub grade, but its application to the evaluation of SCeff is limited to AC overlay of existing AC pavement.

Chapter 5

TREATMENT SPECIFIC EFFECTIVENESS AND COST ANALYSIS (PERFORMANCE / COST MODELS)

5.1 Introduction

The understanding of treatment specific performance models is helpful in M&R strategy optimization and in estimating the time when the next maintenance, rehabilitation or re-construction would be needed and therefore can facilitate the development of realistic, schedules. Pavement treatment performance models estimate the effectiveness of preservation treatments from a variety of viewpoints which are:-

- Asset/ treatment service life.
- The area bounded by performance curve.
- Increased average pavement performance over the treatment life (long term measures not monetized),
- Performance jump (a short term measure). These effectiveness measures are useful in comparative analysis for different asset treatment types.

This chapter first presents what is pavement performance, performance modelling, regression modelling. How models are formed, what is diagnostic test, selection of best functional form of model, parameter estimates, validation of models etc. Then it throws some light on general concepts of short term measure of effectiveness i.e performance jump and long term measure of effectiveness as described above. The effectiveness analysis for hypothetical treatment is then discussed on flexible pavement.

5.2 Pavement Performance

Performance describes how well the asset fulfils the functions for which it is designed. Thus Pavement performance is the term used to describe how well the pavement has served the users for the duration it was designed for.

5.3 Models and Their Classifications

A simple definition of model is “representation of part of reality”.

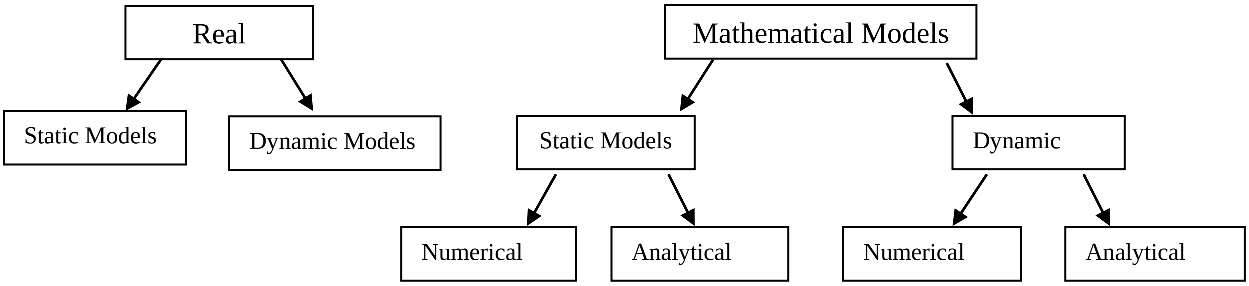


Figure 5.1 : Classifications of Models

Real Models are those which are physical, 3-D as well as objects which can be touched. These are further classified as Static Models for example Moment equationDynamic Models for example V= U+at (Newton’s second Law of Motion).

Static and dynamic models are further classified into Numerical & Analytical Models. Static models are the most common of these are simulation models that replicate the behavior or operation of the highway asset. Example is video games. Analytical Models are mostly models used today are of this type and they can be used as inputs for simulating modeling of asset condition. These models include Linear and Non Linear Regression Models etc. Pavement modeling is necessary because Pavement is a very sophisticated physical structure that responds in a complex manner to the external traffic loading and environmental conditions. This is mainly due to heterogeneous composition of the asphalt mixture, aggregate and sub grade soil and vast variation in traffic and environmental characteristics from one region to another. A key component in making design, construction, and maintenance and rehabilitation decisions for Pavement consists of evaluation like assessing and measuring surface distresses namely cracking, rutting and roughness or structural properties say deflection thus forecasting the effect of such conditions on future performances. Condition forecasts are generated with performance models, which are mathematical expressions that relate condition data to a set of explanatory variables such as material properties, pavement design characteristics. Traffic loading, environmental factors etc. Thus it can be said that a pavement performance models is an equation or relation that relates some extrinsic “Time factor” (age or number of load repetitions) to a combination of intrinsic factors (Structural response, material properties etc.) and performance indicators

5.4 Regression Models

Regression models are used to predict one variable from one or more variables. Regression models are a power tool, allowing predictions about past, present or future events to be made with information about past or present events. These models are used because either it is less expensive in terms of time or money to collect the information to make the predictions than to collect the information about the events itself, or more likely because the events to be predicted will occur in some future time.

In order to construct a regression model, both the information which are going to be used to make prediction and the information which is to be predicted must be obtained from the sample of objects or individual. The relationship between two pieces of information is then modeled with a linear transformation. Then in future, only the first information is necessary, and the regression model is used to transform this information into predicted.

5.4.1 Steps for Building Regression Model

5.4.1.1 Sampling/ Data Collection

The treatment specific modelling should be preceded by collection and collation of various types of data sets and preparation of input data for treatment specific performance and cost models. The data sets and data collection techniques are already described in proposed methodology chapter.

Section_ID (Stretch and National Highway Nr.)	2001 Age	2001 Roughness	2002 Age	2002 Roughness	2003 Age	2003 Roughness	2004 Age	2004 Roughness	2005 Age	2005 Roughness	2006 Age	2006 Roughness
R-28095_N_55	1	63.16	2	71.34	3	79.45	4	86.41	5	97.32	6	101.55
R-24520_N_55	2	45.49	3	82.01	4	85.89	5	94.11	6	97.89	7	118.57
B-27892_N_45	3	75.55	4	97.99	5	101.87	6	110.09	7	113.87	8	134.55
R-28097_N_45	5	83.94	6	92.12	7	100.23	8	107.19	9	118.1	10	122.33
RS-28299_N_45	7	88.04	8	97.567	9	101.44	10	109.66	11	113.44	12	134.12
R-23988_N_40	9	103.59	10	113.11	11	116.99	12	125.21	13	128.99	14	149.67
R-26244_N_40	10	108.45	11	117.97	12	121.85	13	130.07	14	133.85	15	154.53
R-26459_N_40	8	98.8	9	108.32	10	112.2	11	120.42	12	124.2	13	144.88
R-24410_N_40	6	90.49	7	98.67	8	106.78	9	113.74	10	124.65	11	128.88
R-24942_N_5	11	106.25	12	115.77	13	119.65	14	127.87	15	131.65	16	152.33
R-28628_N_5	4	86.27	5	94.45	6	102.56	7	109.52	8	120.43	9	124.66

Figure 5.2: Roughness data in time series

5.4.1.2 Specify Dependent Variable (Response Variable)

They are also called as performance indicators and are mostly continuous variables, Manual or automated inspections (surveys) are carried out to measure the values. They actually represent the asset's functional state or structural integrity and serves as a key input in pavement performance modelling. For pavement assets, this performance is measured as an index. The serviceability indices include IRI, PSI, Rut etc. The indicator of skid resistance is friction number and structural condition is indicated by the deflection number. In context of maintenance and rehabilitation optimization, a key pre-requisite for developing treatment specific performance model is to select an appropriate performance indicator. In this thesis IRI which embodies the pavement surface condition and ride quality is used as a performance indicator. Nevertheless any other performance indicator can be selected.

5.4.1.3 Selection of Independent Variables

These variables are also called as explanatory variables. Some independent variables for pavement performance models are:-

5.4.1.3.1 Stress Factors

- Age
- Traffic loading (No of trucks, ESALs, Gross weight and vehicles etc)
- Climatic Effects (Climatic Zone, Freeze index, Freeze-thaw cycles etc)

5.4.1.4 Strength Factors

- Pavement Thickness
- Structural Number
- Sub grade Strength
- Maintenance History

5.4.1.5 Carryout Preliminary Analysis of Data

The main purpose of this step is to determine the interesting trends or relationships between dependent and independent variables. It can be done by various methods but we will restrict ourselves to scatter diagrams (A simple plot of X & Y).

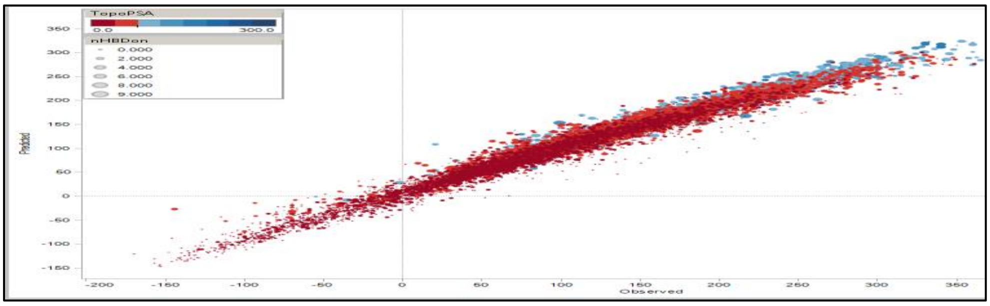


Figure 3.3: Scatter Plot

5.4.1.6 Specify the Model Form

This is also called as functional form or mathematical form. In order to determine the functional form to be used for a given data set, we have to plot the raw data and then determine which model form closely resembles the plot. Different functional forms can be:-

- Linear
- Polynomial
- Exponential
- Logarithmic
- Power

5.4.1.7 Final Selection of Independent Variables

In cases where there are several independent variables, it may be necessary to drop some of the variables to simplify the analysis. From the previous step it is found that some independent variables have absolutely no impact on the dependent variables so these may be dropped.

5.4.1.8 Separate the Dataset

Suggest 80% of your dataset for model calibration and rest 20% is left for model validation.

5.4.1.9 Model Calibration

"Calibration" simply means determining the best line passing through the points. Mathematically a "better line" could mean a line that passes through the points such that the sum of vertical deviations of various points from regression line is minimized

5.4.1.10 Model Evaluation

5.4.1.10.1 The Co-Efficient of Determination (R-Square)

R-Square in statistics is the measure of the extent to which the total variation of the dependent variable is explained by regression. The R-Square necessarily takes on a value between 0 & 1. A high value of this suggests that the regression model explains the variation in the dependent variable well and is obviously important if one wishes to use the model for predictive purposes.

5.4.1.10.2 Significance of Variables

In order to determine whether the variable is significant or not a hypothesis test is performed called as null hypothesis test. First of all we have to select the level of confidence level for our variables.

5.4.1.10.3 Select Level of Confidence

This is one sided test with the "regression region" in the upper tail. e.g for 95% level of confidence.

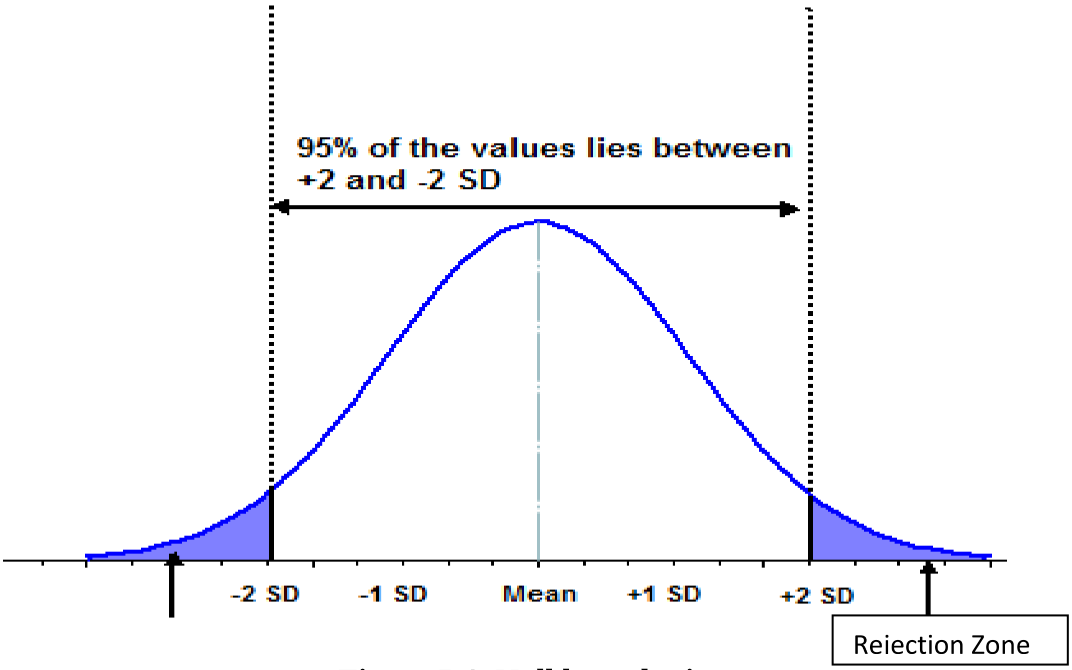


Figure 5.4: Null hypothesis test

If the value of t-stat test t= B/SE falls between -2 & +2 then we fail to reject the null-hypothesis, then it means that the variable is insignificant and vice versa.

5.4.1.11 Model Validation Procedure

- Plug the values of independent variables from the validation dataset into the calibrated model and determine the corresponding values of dependent variables. This gives Y^ (Predicted).
- Compare the values of Y^ with Yi (Observed) values i.e (The Y-values in the validation dataset).
- Calculate the deviation for each validation observation, square them, sum them up and divide by number of observation and find square root.
- The model validation plot thus obtained should be of this shape

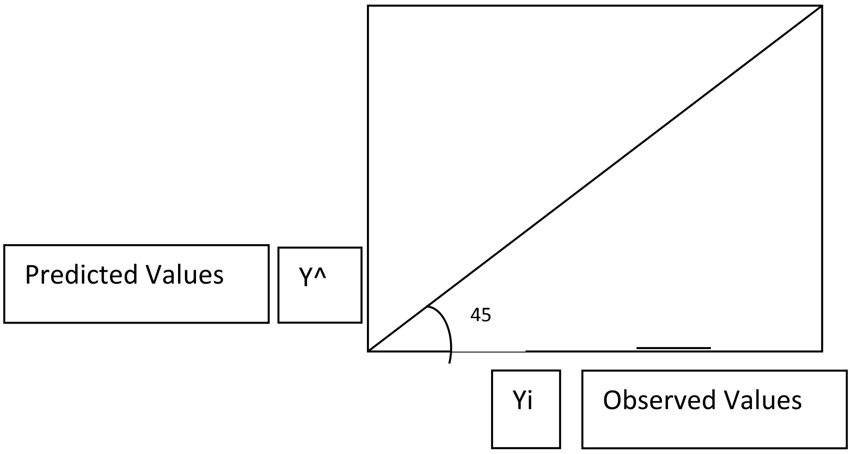


Figure 5.5 : Model Validation

5.5 Performance Indicators

The “Performance” or serviceability of an asset which is closely related to its condition is basically its efficiency to provide a certain minimum level of service. It actually represents he asset’s functional state or structural integrity and serves as a key input in pavement performance modelling. For pavement assets, this performance is measured as an index. The serviceability indices include IRI, PSI, Rut etc. The indicator of skid resistance is friction number and structural condition is indicated by the deflection number. In context of maintenance and rehabilitation optimization, a key pre-requisite for developing treatment specific performance model is to select an appropriate performance indicator. In this thesis IRI which embodies the pavement surface condition and ride quality is used as a performance indicator. Nevertheless any other performance indicator can be selected.

5.6 Treatment Specific Effective Analysis using Performance Models

Effectiveness of maintenance and rehabilitation strategy can be quantified using performance models. \which allows us to compare different treatments. In effectiveness analysis both monetized and non-monetized benefits are considered. Broadly MOEs are categorised as long term and short term.

5.7 Performance Jump as a Measure of Short Term Effectiveness (Non Monetized)

Figure below illustrates the concept of treatment performance jump (sudden elevation of pavement performance upon treatment) and post treatment performance

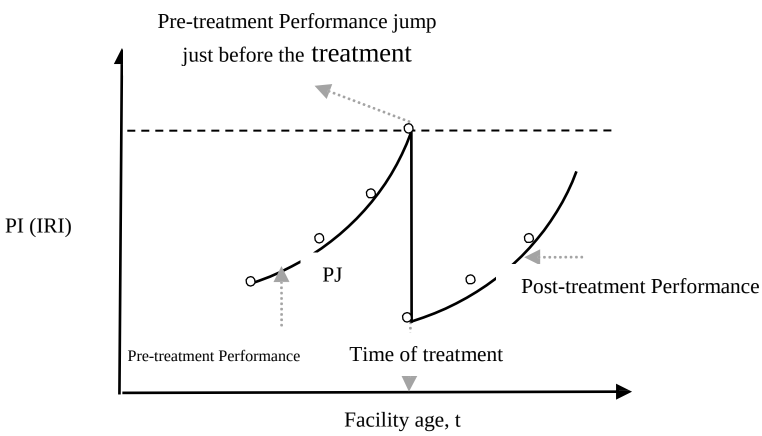


Figure 5.6 : Performance Jump and Post-Treatment Performance Trend

Thus the performance jump is defined as the instantaneous increase (reduction in IRI) in the performance of an asset upon the application of the treatment. As shown in figure graphically this can be represented as the vertical rise in asset performance or fall in deterioration. Performance jump is measured as simply the difference in the asset performance before and just after the treatment.

The general form of developed treatment specific performance jump is given in equation below:-

PJ= F(y)

Where PJ= Performance jump at the time of treatment application (in terms of performance indicator).

F(y) = Function of pre-treatment performance (Initial Condition)

If the data in the time series is available then performance jump models can be developed using the above mentioned methodology. For the purpose of understanding, for this thesis data in time series of roughness of Indiana department of Transportation (INDOT) was taken and linear regression technique was followed using statistical analysis software (SAS 9.1.3) to develop performance jump model functional form which is

$PJ=\alpha+\beta \ln IRI_{trig}$

Where α= Constant, β= Treatment specific parameters estimates for the model explanatory variables. IRI_{trig} = IRI trigger value for treatments at the time of application t_S(trig). The estimated model statistics and respective performance jump values for each treatment are provided in table below

Treatment Type	Model Variable	Coefficient Value	Standard Error	t-statistic	Model Statistics	Pre-treatment Performance (in/ mi)	Performance Jump (in/ mi)
Thin HMA overlay	Constant	-267.88	18.552	-14.439	R^2 = 0.807 N = 38 SE= 2.342	117.285	67.22
	[1]PI_{trig}	70.332	3.900	18.034			
Micro-surfacing	Constant	-284.55	37.022	-7.686	R^2= 0.819 N = 31 SE = 4.841	114.840	58.81
	[1]PI_{trig}	72.386	7.817	9.260			
HMA overlay functional	Constant	-244.08	41.234	-5.919	R^2 = 0.802 N = 24 SE=3.424	129.440	77.42
	[1]PI_{trig}	66.109	8.485	7.791			
HMA overlay structural	Constant	-266.36	33.261	-8.009	R^2= 0.858 N = 21 SE = 3.998	137.868	81.99
	[1]PI_{trig}	70.713	6.779	10.431			
Resurfacing (partial 3R standards)	Constant	-272.86	32.104	-8.499	R^2= 0.857 N = 26 SE = 3.758	128.668	70.23
	[1]PI_{trig}	70.636	6.599	10.704			

[1]Pre-treatment pavement surface roughness (IRI in/mi)

Figure 5.7 : Performance Jump Models

The t-stat suggests that the selected variables are statistically significant at 95% confidence level. The co efficient of determination the coefficient of determination (R^2) values of all the developed models of various treatments indicated a good fit. The parameter estimate ofα is a constant and β measures the responsiveness of output performance jump to a change in pre-treatment performance. This observation also suggests that pavements with poor pre-treatment performance receive a greater performance jump up on treatment compared to pavements at a relatively good pre-treatment performance level.

Fig below shows the observed data points and the developed model that illustrates the relationship between the performance jump and the pre-treatment performance (PI at the treatment trigger) for thin HMA overlay.

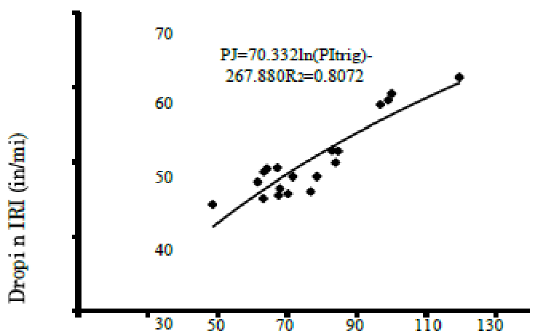
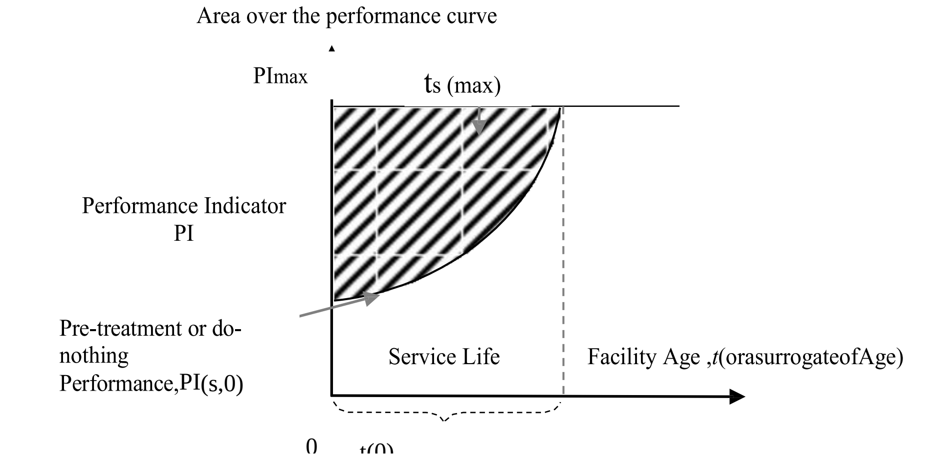


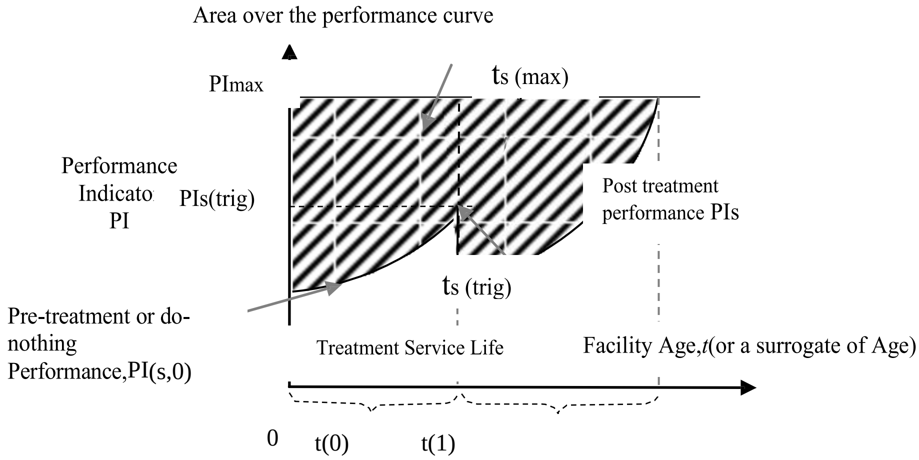
Figure5.8: Performance Jump due to Flexible Pavement M&R Treatments (Interstates) – Observed Points and Models:

5.8 Long Term Effectiveness (Non-Monetized)

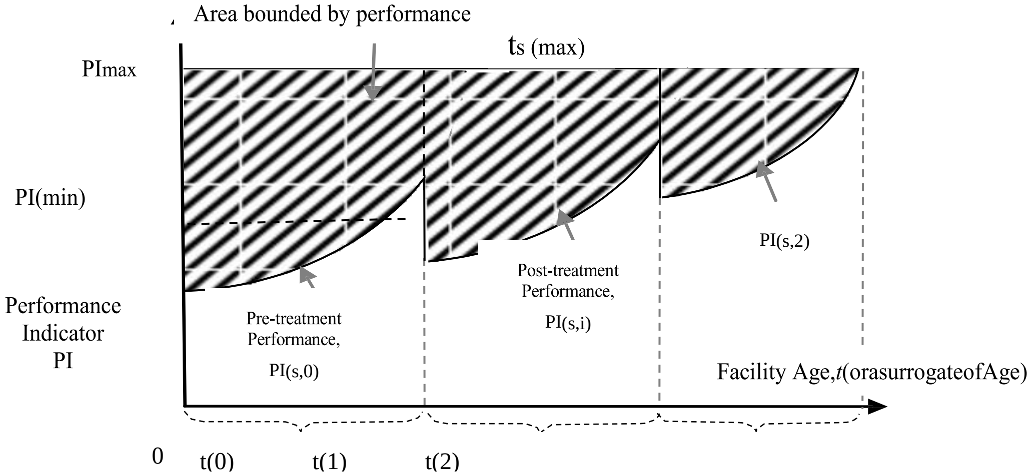
Effectiveness models quantify the benefits of M & R strategy and can be used to compare the desirability of alternative treatments that differ in material type, layer thickness procedure and other attributes. The most commonly used effectiveness measures are area bounded by performance curve, increase of an average pavement performance over the treatment life and treatment service life. Anyone of these measures of effectiveness (MOEs) can be determined in disaggregate approach or aggregate approach which are already discussed in previous chapter. The abscissa variable (X), against which the performance is being measured could be time (years). A M & R Strategy comprises different M & R treatments and each specific M & R treatment has its unique f(x) equation to describe its post treatment performance trend. Together with performance model and threshold performance the service life, the increase in pavement performance over the service life and area bounded by performance curve could be determined. Figures below present examples of single stage and multi-stage M & R strategies for non-decreasing performance indicator i.e PI (IRI, Rut). Each strategy yield different benefits in terms of three different MOEs which are discussed in the following paragraphs.



a. Effectiveness of strategy (Do-Nothing)



b. Effectiveness of a strategy (Single Treatment)



c. Effectiveness of a strategy (Multiple Treatments)

Figure 5.9: Graphical Representation of Pavement Life-Cycle Profiles – Increasing PIs

Where PI s,0 = Do nothing on new construction in terms of performance indicator.

PI s,i= post treatment performance model for ith stage treatment at any year t.

ts(trig) = time of triggering of subsequent treatment

tps(max)= Time or age, t at maximum acceptable performance of pre-treatment (Ps)

ts(max)= Time or age at maximum acceptable performance of triggered treatment(s)

The service life can be estimated by measuring how much time or accumulated traffic has passed between the time of treatment and next treatment similar or of high level. This is simply a difference in calendar dates. The determination of treatment service life in this manner is economical from the perspective of data requirements. However, a limitation is that preservation treatment contract records spanning a considerable length of time are typically not available at most agencies. Secondly, the treatment life values obtained in this manner may be reflective of funding availability rather than engineering need and therefore may be highly variable and thus may fail to reflect the true life of the treatment. Another method to determine the treatment life is to collect field data from several assets that received that treatment type, develop a performance trend curve for the treatment, and then project these curves (forward) to the point where the curve meets an established performance threshold, thus yielding the amount of time that is expected to pass between the time of treatment and the time that asset reverts to the predefined threshold performance level as shown in Figure below.

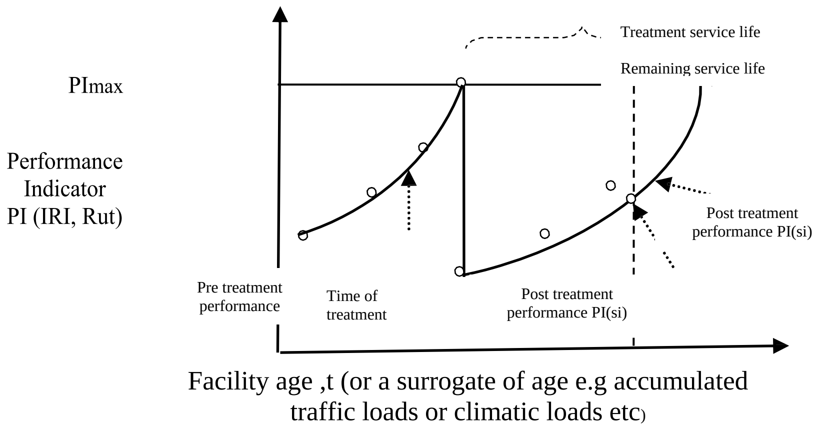


Figure 5.10: Illustration of Treatment Service Life and Remaining Service Life

This threshold or absolute performance level is normally defined as some maximum (or minimum) acceptable performance level above (or below) which the asset is considered to be unacceptable for its designated function. It could be any arbitrary level established or predefined by the agency and well suited to required performance level of the asset in question. Another associated measure of effectiveness is remaining service life: the time from any selected performance until the asset is projected to reach a designated threshold.

The increase in average performance due to the intervention can be determined as the change in average performance relative to the performance before intervention (do-nothing scenario). This is given in the Equation below

$$PIs(avg\ ) \frac{1}{ts(max)} = (\ (PIs(0) + PIs(1) + PIs(2), \dots \dots \dots , +PIs(max\ )\ )$$

Where, PIs(avg)=Average performance of the asset after receiving the intervention, s, over the Service life of the intervention.

PIs(max)=Predefined threshold performance level for intervention, s.

ts(max)=Time or age, tat which the asset reaches the end of treatment service life

PIs0,PIs1,…PIs(max) represent the asset performance values at intervening years, between treatment intervention and the end of the treatment service life, ts(max).

The concept of are abounded by post-treatment performance curve integrates the above two MOEs (service life and increase in average asset performance) and is consistent with the rationale that superior average performance over a longer period provides more benefits compared to inferior performance over as shorter period. For the non-increasing performance indicators, such as PCR and PSI, etc. This effectiveness is the area under the curve (AUC). For non-decreasing indicators such as IRI, rutting this is area over the curve (AOC). The mathematical form of the post treatment specific area bounded by the performance curve for increasing performance indicators is given as

$$AOCs,i = [PImax.\ (ts(max) - ts(trig) - \int_{t_{smax}}^{}\ \int_{ts(trig)}^{tpsm} PIs,idt] - [PImax.(tps(max) - ts(trig\ ) - \int_{ts(trig)}^{} PIs,0dt]$$

Where: AOCs = Additional are a over the performance curve yielded by treatment, s.

PIs, 0= Do-nothing on new construction in terms of performance indicator

PIs, i=Post-treatment performance model for i stage treatment at any year, t

ts(trig)= time of triggering of subsequent treatment

tps(max)=Time or age, tat maximum acceptable performance of pre-treatment (ps)

ts(max)=Time or age, tat maximum acceptable performance of triggered-treatment(s)

5.9 Long Term Effectiveness (Monetized)

The benefits of highway improvements are sometimes based on the concept of reduction in an agency‘s maintenance costs, vehicle operating costs (VOC), travel time costs, accident costs, etc. When the facility is improved, the agency and user costs are decreased and the benefits of highway improvements thus can be quantified as a reduction in the agency and user costs, which translate into savings (benefits) from both the agency and user perspectives. Consumer surplus analysis can be used to evaluate the impacts of candidate M&R strategies on consumers. Strategies that offer better asset performance therefore provide positive incentives (e.g., benefits of VOC savings, safety, mobility and convenience, etc.), while strategies that use negative incentives (e.g., increased operating costs due to deteriorated road, crash cost, delay cost etc.) tend to cause direct reductions in consumer surplus (minus any social benefits and revenues). Maximizing the consumer surplus is the maximization of the economic utility of the consumer [Sinha and Labi, 2007]. The concept of consumer surplus is common in transportation systems evaluation. For example, VOC with and without improvement asset improvement intervention at a particular asset is VOC1 and VOC2 per million VMT. Using the concept of change in consumer surplus, monetary benefit of reduction in VOC can be determined due to an increased asset performance as shown in Figure

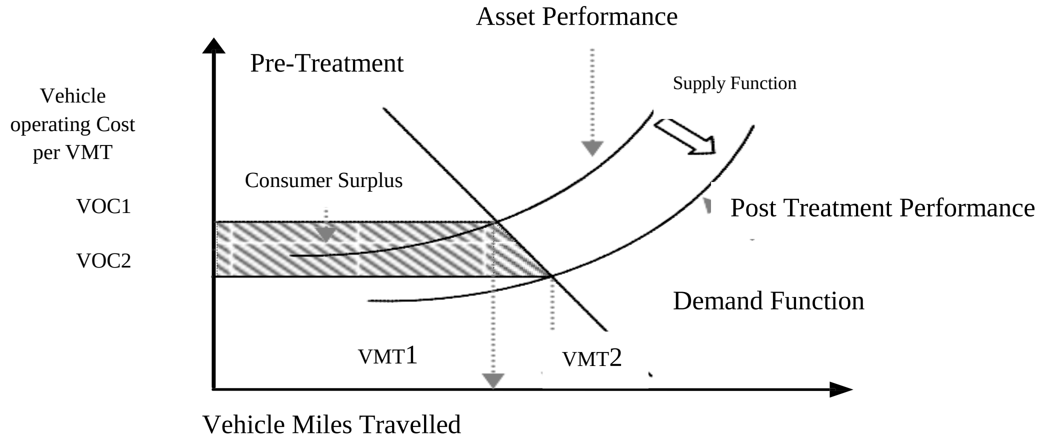


Figure 5.11: Illustration of Change in Consumer Surplus due to Increase in Asset Performance [Sinha and Labi, 2007]

5.10 Treatment Specific Cost Analysis

Agency costs and user costs incurred during an asset's life cycle can be placed into two categories: (a) generic costs, which largely remain the same across different M&R alternatives and include agency costs of advance planning, preliminary planning and engineering cost; and (b) alternative-specific costs which vary across the M&R alternatives and can influence the choice of alternative, and include construction cost, user costs during work zone and normal highway operations. Agency costs generally include direct costs that the highway agency incurs in building and maintaining the highway asset. Direct costs refer to the labor, material, equipment, and overhead costs of (re) construction, rehabilitation, or maintenance directly incurred by the highway agency in paying a contractor for work done or in spending force-account funds for work done in-house. Agency costs or user costs can be further categorized as initial (incurred at the time of intervention) construction costs or and future costs (during the normal operation and at maintenance and rehabilitation interventions during the life-cycle).of the various cost categories, this dissertation focuses on the initial agency costs and the user costs during the times of interventions, (i.e., work zones).In the aggregate approach, intervention cost is established as an average value, such as dollars per unit dimension or as a function that describes the total cost as a function of the asset dimension (length, width, area, etc.), and other factors such as pre-intervention performance, material type, functional class, etc. In this dissertation, the aggregate approach is used because M&R scheduling is a planning stage task of asset project development.

Work zone user costs typically include travel time delay costs, increased VOC, and crash cost. These costs area function of the work zone characteristics, the volume of affected traffic and the dollar cost rate of delay, VOC, and crashes. Also, these costs are inter-related with the work zone duration, contract and project type, size, and scope. This dissertation incorporates the travel delay and increased VOC while the crash costs are assumed to be in variant across various alternative M&R treatments. The estimated agency costs and user costs of each intervention M&R treatment were brought to their constant rupees value using the government of Pakistan construction price index (CPI).

A variety of functional forms were investigated for the cost models for standard preservation treatments under each of three highway functional classes. This dissertation also investigates the influence of the variables affecting agency costs and user costs. The objective is to show how the art of cost modeling could be enhanced further using data that currently exist in state agency databases. Specifically, the cost models can enhance the agency business processes of assessing monetary needs for preservation, long-term planning, programming, and budgeting, and also to quantify the monetary impacts of deferred preservation.

5.11 Procedure for Developing Agency Cost Models

The general form of a statistical cost model which is used in this research is as follows Agency Cost = f(x1,x2,x3,….)

Where agency cost is the total cost of treatment and f(x1,x2,x3,…)is the function of attributes such as physical, asset condition and material type.

5.11.1 Diagnostic Plots

The modeling process should be preceded by investigation of diagnostic plots for each of the treatment under consideration in order to observe any relationship between cost and explanatory variables.

If we have cost per lane mile we can plot the data to observe the scatter .A hypothetical treatment was plotted to observe the trends as shown in figures below. It is obvious from the figure that there is existence of economies of scale also non linearity between cost and explanatory variables.

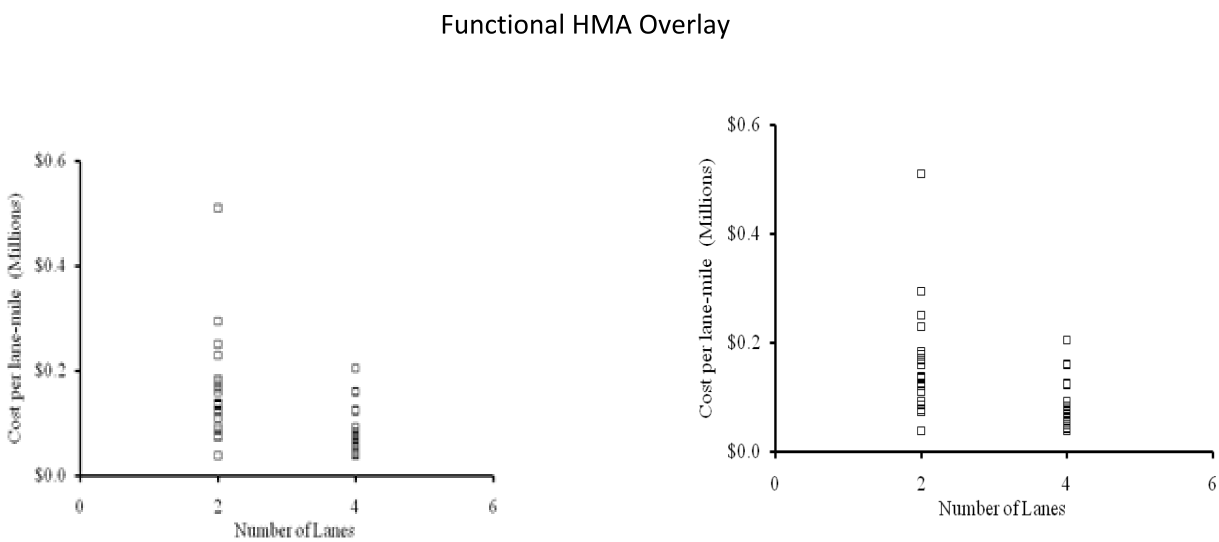


Figure 5.12 : Cost/lane-mile vs. Length, NHS Non Interstate.

5.11.2 Functional Forms

The various functional forms for each preservation cost model should be investigated; for example Functional Forms with length, Nr. of lanes and Pre-treatment Performance as Predictor Variables

Functional Form(1)[Cobb–DouglasI]

Agency Cost=α.lengthβ.Nγ.[ln(PItrig)]δ

Functional Form (2):

Agency Cost=$\alpha + \beta$. length + γ.N + δ. ln(PI_{trig})

Functional Forms with length, and Nr. of lanes as Predictor Variables

Functional Form(3) [Cobb Douglas]

Agency Cost=α.lengthβ.Nγ

Functional Form (4):

Agency Cost=$\alpha + \beta$.length + γ.N

Where, Cost = Total Agency Cost of pavement preservation in millions (2007 Constant Dollars), length= Total length of construction (miles);N=Number of lanes.

PI_{trig}=—Pre-treatment performance of the asset (i.e., condition just before the application of preservation treatment (in this case, surface roughness in IRIin/mi).

α, β, γ, δ are the parameter for explanatory variables.

The software packages including PASW or Microsoft excel can be used for this purpose.

5.11.3 Parameter Estimates for Developed Models

The parameter estimates of various functional forms developed above can done via nonlinear regression modeling technique in the same way as explained earlier in this chapter. The t-statistics of all the selected variables should be significant at the desired confidence level normally 95% and coefficient of determination (R^2) values should indicate good fit.

5.12 Cost Model Validation

The overall methodology presented in this research for agency cost model is general and can be adopted across regions. However the cost estimates using the developed statistical models could be different across the regions/years owing to variability in agency and contract prices/practices, inflation therefore the underlying technique present a solution to this problem by explaining how the costs can be adjusted for various regions/years. The cost estimates can be adjusted spatially and temporally by applying the factors given in equation below;

$C_{YQ}=C_{PY}.CPI_{PY}/CPI_{BY}$

Where

C_{YQ}=cost of activity in the years in question

C_{PY}=cost of activity in present years

CPI_{PY}=construction price index in present year

CPI_{BY}= construction price index in base year

To elaborate this concept considers the cost of following example;

For the year 2013for which the model was developed for functional overlay 30mm thick for 10 mile 2 lane highway costs Rs $6.92* 10^6$ per 7.3m wide road per kilometer. It is sought to estimate the construction cost of similar preservation technique for the year 2014.

With the appropriate indices from the price trends, the cost of functional overlay 30mm thick in 2014 can be calculated as;

$C_{PY}=6.92*10^6/7.3$m wide /km

$CPI_{PY}=2.02$, $CPI_{BY}=1.80$ so,

$CP_{YQ}=6.92*10^6*2.02/1.8 = 7.058*10^6$

The cost of 10 mile 2 lane highways is taken from NHA financial plan 2014 attached as appendix B. Similarly if the cost across various regions is shown and their construction price indices, spatial adjustments can be done.

5.12.1 Procedure for Determining User Cost

User cost during the period of intervention activities are only considered, which includes travel delay cost and vehicle operating cost (VOC) due to speed reduction in the work zone.

5.12.2 Steps for Calculating Work Zone User Costs

The following steps are involved in quantifying and costing the individual work zone user cost components:

Estimate the project agency cost (a function of length, number of lanes, and pre-treatment performance and project type.

5.12.2.1 Establish Work Zone Characteristics and Inputs as follows:

- Determine the length and number of lane closures.
- Estimate the work zone duration (a function of total cost (computed in step I), the project type, and the contract type).
- Calculate the work zone hourly demand and directional distribution.
- Determine the work zone posted speed.

5.12.2.2 Establish the Traffic Characteristics and Inputs by Determining the Following:

- AADT
- Traffic growth/ projected future years traffic
- Traffic according to various vehicle classes
- Traffic volume affected in the work zone

5.12.2.3 Compute Individual User Cost Components:

- Identify the user cost components (i.e., travel time delay, work zone VOC, etc.)
- Compute the additional reduced speed delay and assign the travel time delay cost as per the selected rates by vehicle class.

5.12.2.4 Compute the Additional Fuel Consumption Due to Delay in the Work Zone and Assign the VOC Cost as per Selected Rates by Vehicle Class.

5.12.2.5 Calculate the Total Work Zone User Costs.

The computational details for the work zone user cost specifically, time delay cost and additional Vehicle Operating Cost due to work zone are discussed below:

5.12.3 Work Zone Travel Delay Cost

Work zone User Cost (WZUC) is a function of work zone (WZ) characteristics such as duration, lane closure and speed limit etc.; delay costs; and traffic volume.

The user cost due to delay is given in equation below [AASHTO,2003; Irfan et al;2009]

User cost(travel time delay)= $D_{W2} \sum_j^1 (NV_j.AT_j.DC_j)$

Where: DWZ =delay (hours) due to work zone; NVj = number of vehicles (traffic) delayed by the speed changes due to work zone for vehicle class j, in hours; DC j=delay cost rate (Rs/hour)for vehicle class j.

ATj = travel time difference for the speed changes due to work zone for vehicle class j,in hrs

DCj = delay cost rate for vehicle class j,inRs/mile,

J = vehicle class (auto or truck).

A hypothetical maintenance and rehabilitation strategy is used to illustrate the user cost calculations. Consider a road section having two lanes with posted speed of 65mph.if one of the lanes has to be closed during work zone operations and speed limit was reduced to 45mph, than the reduction in speed yields travel time difference of (1/45 - 1/65) hr/mile = 0.0068 hr/mile and delay cost rate for passenger car or auto truck can be found by following procedure;

- Find annual household income of the area
- Find hourly time value of a person (50% of income / 2080)
- Find average vehicle occupancy of travel (AVO)
- Multiply average vehicle occupancy with hourly time value of a person.

Using above analogy if the annual income of a person is Rs52,000/- then hourly time value would be (0.5*52,000/2080) = Rs 12.5/hr, multiplying this with average vehicle occupancy factor of 2 gives us Rs 25/veh-hr for passenger car and 12.5*4 = Rs 50/veh-hr for truck.

Now if work zone for this maintenance and rehabilitation strategy is assumed to be 50 days, than

User Cost (travel time delay) = 50*{(1*0.0068*25) + (1*0.0068*50)} = 25.5 Rs/veh-mile

5.12.4 Work Zone Vehicle Operating Cost Due to Additional Fuel Consumption

Work zone VOC Due to Additional Fuel Consumption:

Fuel consumption (in gals/minute of delay) by vehicle type was estimated using AASHTO methodology [AASHTO, 2003, Sinha and Labi, 2007]. The change in the fuel VOC is estimated using Equation (3.25):

User Cost VOC=$D_{WZ\,.\,j}(NV_j.AT_j.g_j.p_j)$

Where: gj= fuel consumption in gallon/hr. of delay, pj= Average fuel price$/ gallon

Other symbols and subscripts have usual meanings.

According to AASHTO fuel consumption tables , the auto average fuel consumption is 2.04 gal/veh-hr and for truck it is 20.73 gal/veh-hr. The fuel price to be used should be current fuel priceof that time(i.eRs 250/gal)

For all vehicle classes. Thus the Vehicle Operating Cost is estimated as;

User Cost (VOC) = 50*{(1*0.0068*2.04*250) + (1*0.0068*20.73*250)} = Rs 1935.45

5.12.5 Cost –Effectiveness Calculation

As we know the main objective of any asset prevention technique is to maximize effectiveness (i.e to prolong the service life while maintaining the same service level and keep the related costs to minimum), thus cost effectiveness evaluation is a technique for comparing that what is the benefit (effectiveness) to that of cost for the purpose of evaluating different alternatives. By knowing the cost effectiveness of a maintenance and rehabilitation strategy, asset managers can compare different alternatives and can select the one which gives the best results. The cost should refer to long-term cost of an asset treatment over the given evaluation period, where alternatives have different levels of costs service lives or monetized benefits they should be converted to equivalent uniform annual costs(EUAC) consistent with principles of economic analysis. Since benefits of a well maintained pavement are numerous and may be difficult to quantify in monetary terms, non-monetized benefits (e.g., the asset treatment service life, the are abounded by the performance curve, and the increased average performance over the treatment life) may be used as a surrogate for the monetized benefits. In an effort to avoid the issues associated with monetization of benefits, a number of past studies resorted to using non-monetized benefits such as the are abounded by the curve, the service life.

The cost-effectiveness (CE) Index of each Maintenance and Rehabilitation strategy can be calculated using Equation given below:

Cost Effectiveness CE Index= Benefits (non monetized)/ Cost

Where benefit =non-monetized effectiveness, cost= cost is sum of agency and user cost .

As stated above the present worth of the agency costs and the user cost should be annualized using EUAC formula to account for differences in the lengths of service life for different strategies.

Cost= $[CRF .PWF . \{(AC)+(WZUC_{TT}+WZUC_{VOC})\}]$

Where;

AC=agency cost for treatment selected

$WZUC_{TT}$=work zone user costs due to travel time delay

$WZUC_{VOC}$=work zone user cost due to increased VOC.

Capital Recovery factor (CRF)=$i.(1+i)^T/(1+i)^T-1$

T= analysis period, i=interest rate for the analysis

Present Worth factor (PWF)= $1/(1+i)^N$

N= time elapsed between start of analysis period and intervention.

5.13 Summary

In this chapter endeavour is made to explain what is modelling, how regression modelling is done, how to calibrate and validate a model . Then generic concepts of Shot term effectiveness i.e, performance jump and long term effectiveness in the form of treatment service life, average in increase in pavement performance and areas bounded by curve is explained. The concept of cost modelling is also explained a hypothetical treatment application is also explained.

Chapter 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The study demonstrated that road networks are one of the important assets in our country which need to be sustained and maintained up to a desired level. Pavement Management System serves as a milestone for all echelon of decision makers in order to find out the most desirable M & R strategy so as to maintain the pavements in a serviceable and safe condition in a cost effective way. The objective of the research study was to develop Pavement Management System for flexible pavements pertinent to conditions and criteria's in our country. Various Management Systems of various countries were studied which are given in the literature review of this research. They helped in shaping and finally developing a best possible method that should be adopted. The management system guides in detecting the possible distresses and selecting the most cost effective intervention technique. The cost effectiveness relies on cost and performance models. The effectiveness (benefits) on a constituent treatment are categorized as monetized and non-monetized and termed as long term and short term. Thus this system would help the managers in better managing the road assets, deciding when most optimum treatment would be applied and finally allocate sufficient resources for it beforehand.

6.2 Recommendations

- The usefulness of Pavement Management System is highly dependent on the availability of quality data, skilled manpower, adequate training, therefore a pertinent follow up plan be created as part of Pavement Management System implementation process. This plan should outline the steps needed to improve and maintain the quality of data collected, adequate training of concerned staff to collect and handle the data carefully. The accuracy of data and expertise of the staff will directly affect the precision of the decision being made through

Pavement Management System.

- Another area of enhancement could be to refine the performance and cost models by incorporating more explanatory variables that have the capability to increase the predictive capability of such models. This would call for greater refinement and range of data collection such as pavement material properties etc.

- Future research should investigate the results of using different performance indicators, as roughness was used as performance indicator for our research. A non-increasing performance indicator such as PCR could be used to analyze the result in selecting the most optimum activity profile.

- Sufficient funds as well as manpower for the Pavement Management System should be allocated to implement and sustain it in long run.

- The framework developed in this research should be applied to determine optimum life cycle treatment profiles for other highway assets such as bridges etc.

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APPENDICES