THESIS

DETERIORATION MODEL FOR BITUMINOUS PAVEMENTS OF LOW-VOLUME ROADS IN NEPAL

SHYAM PRASAD KHAREL

GRADUATE SCHOOL, KASETSART UNIVERSITY

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NAME: Mr. Shyam Prasad Kharel

THIS THESIS HAS BEEN ACCEPTED BY

THESIS ADVISOR
(Mrs. Suneerat Kusalasai, Ph.D.)

COMMITTEE MEMBER
(Mr. Suphawut Malaikrisanachalee, Ph.D.)

COMMITTEE MEMBER
(Associate Professor Trakool Aramraks, Ph.D.)

DEPARTMENT HEAD
(Associate Professor Warakorn Mairaing, Ph.D.)

APPROVED BY THE GRADUATE SCHOOL ON 26 April 2006

DEAN
(Associate Professor Vinai Artkongharn, M.A.)

THESIS

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SHYAM PRASAD KHAREL

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Department of Roads (DoR), Nepal conducts the Surface Distress Index (SDI) survey of Strategic Road Network (SRN) each year. In the absence of the deterioration models, the future planning of works and budget allocation is based on the presently available SDI values. This may not provide effective and efficient solutions, since the rate of deteriorations for each road is different. Therefore, this study's objective is to formulate the pavement deterioration models from the available SDI and other information at the DoR. Model formulation is limited only to the low-volume flexible pavements prior to the resealing (cyclic maintenance).

Since the rate of pavement deterioration is affected by many factors, the pavement sections are grouped into eight pavement families depending on the topography, pavement types, and the traffic levels. This grouping is essential to capture the various pavement deteriorating factors for which there is no information available. For each pavement family, regression with four forms of the deterioration functions is performed. The model selection is based on the coefficient of determination (R^2), and the significance of the parameter estimates are ascertained through the t-statistic and the associated p-values. SDI as the function of previous year's SDI yields the best models for the pavement families with surface treated surfacing. Similarly, SDI as a function of pavement age yields the best models for the remaining pavement families that are asphaltic surfacing. The currently developed models seem to be fairly accurate and therefore, could be very useful in the management of the pavements of Nepal.

Student's signature	Thesis Advisor's signature	24 Apr. 06 Date

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Shyam Prasad Kharel

April 2006

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LIST OF ABBREVIATIONS

ADT	- Average Daily Traffic
BI	- Bump Integrator
DoR	- Department of Roads, Nepal
HMG/N	- His Majesty's Government of Nepal
HMIS	- Highway Management Information System
IRI	- International Roughness Index
Km	- Kilometer
NRB	- Nepal Roads Board
PMS	- Pavement Management System
R^2	- Coefficient of Determination
SDI	- Surface Distress Index
SRN	- Strategic Road Network
ST	- Surface Treatment
VMBI	- Vehicle Mounted Bump Integrator
VOC	- Vehicle Operating Cost
vpd	- Vehicle per Day

DETERIORATION MODEL FOR BITUMINOUS PAVEMENTS OF LOW-VOLUME ROADS IN NEPAL

INTRODUCTION

Background

Nepal is a mountainous country with 83% of the total area as mid-hills and mountains. The hills are geologically very young and active and have rugged topography. Any type of construction and the maintenance of the basic infrastructures are extremely challenging and at the same time costly too. But roads are still the vital mode of transport in the country and it always remains vital. Roads are the principal means for the mass transport system in Nepal and their contribution towards the economic and social development is enormous.

The roads development history in Nepal is not very long and the first motor able road was constructed in the capital in 1924. However, the first road link of 115 kilometers to Kathmandu from Terai was opened to traffic in 1956 under the Indian Government's Assistance and is a pioneering effort in the road development. Road development history is illustrated in Figure 1.

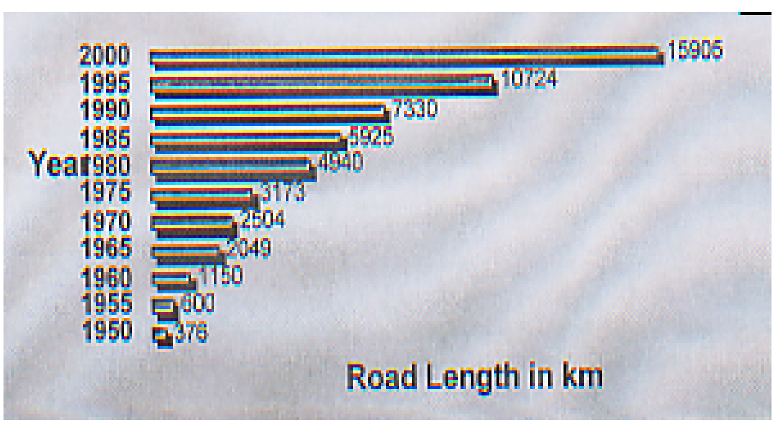

Figure 1 Road developments over the last 5 decades

Source: Nepal road statistics 2000

In Nepal, road classification is primarily based on functional and administrative requirements rather than on the flow of traffic and the application of a particular standard of construction or maintenance was not envisioned in it. In order to address the functional importance of the roads and to actualize the network planning concept, roads are now classified into four types of network as: National Highways, Feeder Roads, District Roads and Urban Roads. Now the development and maintenance of the Strategic Road Network (SRN) alone, comprising national highways and the feeder roads is the responsibility of the Department of Roads (DoR) and SRN data as of 2000 is illustrated in figure 2.

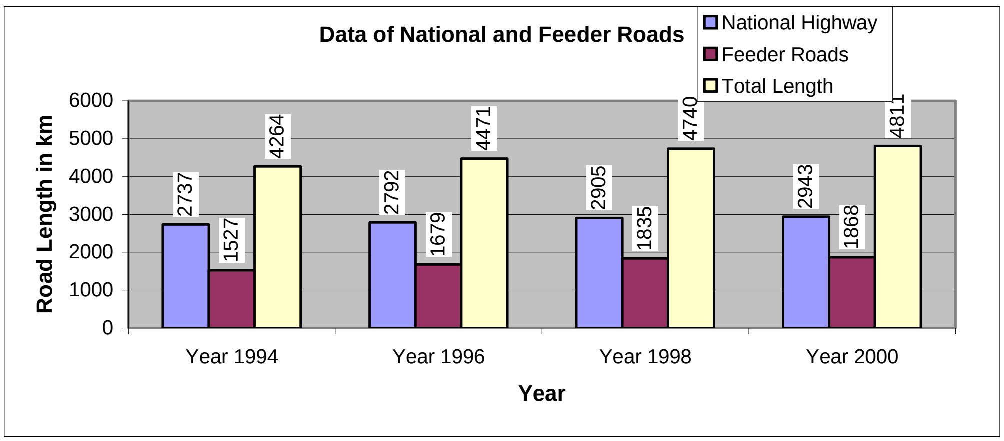

Figure 2 Data on Strategic Road Network

Source: PIP Report, Nepal Road Statistic (1998) and HMIS (2000)

According to the 2001 National Transport Policy, the principal objectives set are as "to develop a reliable, cost effective, safe facility oriented and sustainable transport system that promotes and sustains the economic, social, cultural and tourism development of the kingdom of Nepal as a whole."

The road sub-sector goal has been introduced in the eighth- five-year plan (1992~1997) and the concept of this goal is to reduce user cost by keeping the total transport cost to a minimum. Since the introduction of road sub-sector goal, an appropriate budget has been allocated for the development and maintenance of roads in Nepal as presented in the Table 1.

Table 1 Roads sub-sector budgets 1990/91 to 1999/00 (in million NRs.)

Budget Item	*1990/91*	*1991/92*	*1992/93*	*1993/94*	*1994/95*	*1995/96*	*1996/97*	*1997/98*	*1998/99*	*1999/00*
Total Roads Budget	***1,739***	***2,505***	***2,919***	***2,763***	***3,168***	***4,046***	***4,698***	***4,774***	***5,298***	***5,350***
% of National Budget	*9%*	*9%*	*9%*	*8%*	*8%*	*8%*	*9%*	*8%*	*8%*	*7%*
HMG/N contribution	*733*	*1,246*	*1,126*	*947*	*1,012*	*1,725*	*1,663*	*1,667*	*1,703*	*1,982*
% contribution	*42%*	*50%*	*39%*	*34%*	*32%*	*43%*	*35%*	*35%*	*32%*	*37%*
Development Budget	***1,613***	***2,400***	***2,812***	***2,657***	***3,065***	***3,887***	***4,547***	***4,618***	***5,137***	***5,188***
% of total roads budget	*93%*	*96%*	*96%*	*96%*	*97%*	*96%*	*97%*	*97%*	*97%*	*97%*
Road construction/reconstruction	*1,445*	*2,054*	*2,530*	*2,219*	*2,132*	*2,875*	*3,452*	*3,436*	*4,079*	*3,899*
% of total roads budget	*83%*	*82%*	*87%*	*80%*	*67%*	*71%*	*73%*	*72%*	*77%*	*73%*
Bridge and culvert works	*91*	*226*	*152*	*232*	*363*	*410*	*442*	*535*	*459*	*720*
% of total roads budget	*5%*	*9%*	*5%*	*8%*	*11%*	*10%*	*9%*	*11%*	*9%*	*13%*
Recurrent/periodic maintenance	*77*	*120*	*130*	*206*	*570*	*602*	*653*	*647*	*599*	*569*
% of total roads budget	*4%*	*5%*	*4%*	*7%*	*18%*	*15%*	*14%*	*14%*	*11%*	*11%*
Regular Budget	***126***	***105***	***107***	***107***	***103***	***159***	***151***	***156***	***161***	***162***
% of total roads budget	*7%*	*4%*	*4%*	*4%*	*3%*	*4%*	*3%*	*3%*	*3%*	*3%*
Routine maintenance	*50*	*50*	*30*	*30*	*40*	*39*	*40*	*40*	*40*	*30*
% of total roads budget	*3%*	*2%*	*1%*	*1%*	*1%*	*1%*	*1%*	*1%*	*1%*	*1%*
Overheads	*76*	*55*	*77*	*77*	*63*	*120*	*111*	*116*	*121*	*132*
% of total roads budget	*4%*	*2%*	*3%*	*3%*	*2%*	*3%*	*2%*	*2%*	*2%*	*2%*

* *Source: HMG/N Budget Statements*

With the increase in budget allocation, there have been the persistent efforts in the efficient and effective maintenance of road network; as a result, most of the road network is brought back into the maintainable condition by the end of fiscal year 2000/01 as presented in the Figure 3.

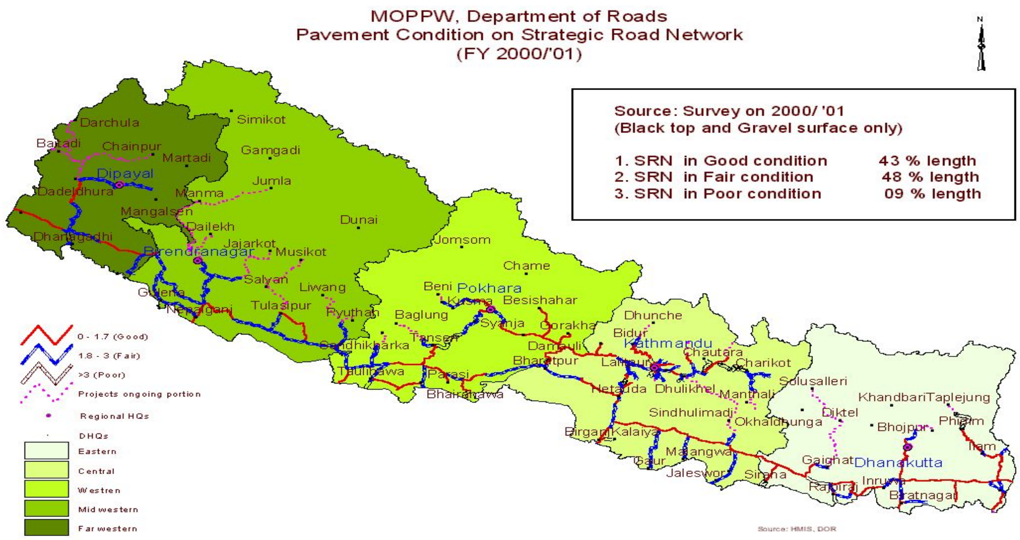

Figure 3 Strategic road network conditions

The performance of the existing pavement conditions and predictions of their future conditions are most essential for effective road maintenance management. Proper timing of the maintenance has a great effect towards pavement deterioration process. If maintenance and rehabilitation are performed during early stages of deterioration, over 50% of repair costs can be saved (Shahin, 1994). However, the specified maintenance activities that are required to be taken can not be identified by the prediction models (Haas et al., 1994). Selecting the most cost-effective maintenance actions requires the combination of network and project level management. Various models have been produced by many road authorities around the world that suit to their road conditions. It is strongly recommended that the models are developed based on the local data collection process and the local environment (Haas et al., 1994).

Statement of Problem

Until now the Department of Roads (DoR) has not developed a pavement deterioration models for its road pavement management. Therefore, in the absence of the pavement deterioration models, the available information on road roughness and distress are used to monitor road deterioration and, in particular, to indicate the need for periodic maintenance (resealing) of bituminous roads. Surface distress information can also be used to determine if a particular road section exceeds established distress levels (SDI equal to 3.0) for implementing planned maintenance actions or for rehabilitation or/reconstruction. Therefore, to determine the resealing and rehabilitation or/reconstruction needs, the distress survey need to be done every year in all the road sections, which is very time consuming and costly. Planning and budgeting future year's workload is based on the presently available SDI values, which is not very precise as one could obtain from the pavement deterioration models, because the accurate models allow for predicting the future evolution of pavement performance more correctly.

Objectives

As per the literature, the results from the pavement deterioration models can be useful in budget allocation of MR&R actions and in addition, the accurate models allow the road agencies to obtain significant budget savings through timely intervention and accurate planning in advance. Therefore, the objective in this study is:

To develop pavement deterioration models for low-volume roads in Nepal. The models account for different types of pavement, levels of traffic, and geographic characteristics.

Scope of the Study

This study mainly focuses on one aspect of the pavement management system (PMS), which is the pavement deterioration model. The pavement deterioration model will be developed for the bituminous and low-volume roads in Nepal. In this study the models are to be developed so that all bitumen road types, geography and the traffic levels are taken into account. The models will be developed from the available data that the DoR is maintaining at its database in Highway Management Information System (HMIS). The presently available distress data is the cumulative index called the Surface Distress Index (SDI). The available data limits the pavement deterioration model development on pavements prior to the resealing only.

LITERATURE REVIEW

This chapter outlines the pavement management system (PMS), classes and the uses of pavement management data, pavement conditions and performances, concepts on deterioration and deterioration models, factors affecting pavement deterioration, types of deterioration models, basic techniques in the model development, and existing pavement deterioration models.

Pavement Management System (PMS)

Pavement management system (PMS) is a broad-based system that consists of set of engineering tools for performing pavement condition surveys and condition prediction, and developing work plans with the objective of optimizing the spending (Ghassan Abu- Lebdeh et al., 2003). According to AASHTO, pavement management system is designed to provide objective information and useful data for analysis so that highway managers can make more consistent, cost – effective and defensible decisions related to the preservation of a pavement network. The Federal Highway Administration (FHWA) more clearly defines PMS as "a set of tools or methods that (can) assist decision makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in a serviceable conditions" (Shahin, 1994). In general, PMS is used for three W's;

1. What: Rehabilitation needs in terms of the amount of equivalent asphalt concrete overlay
2. Where: The selection of pavement segments for rehabilitation is based on pavement structural conditions
3. When: The determination of when to rehabilitate a specific pavement segments based on age performance curves or equations

Pavement Management is not at all a new concept within the road agencies in Nepal since management decisions are made as a part of everyday operations. However, good pavement management is not business as usual and it requires an organized and systematic approach to the way we think and in the way we do our business. The important ideas behind a Pavement Management System (PMS) are:

1. To improve the efficiency of decision making

2. To expand its scope

3. To provide feedback as to the consequences of decisions

4. To ensure the consistency of decisions made at different levels of the road agencies

A good PMS enables people to think and accordingly act to information and make rational decisions in a logical, effective and coordinated manner. Modern Pavement Management System has been introduced during the last two decades and its main focus is to provide systematic procedures to select Maintenance and Rehabilitation and Reconstruction (MR&R) needs, set priorities and determine the optimal maintenance time intervals. In the broader sense, PMS comprises all the activities involved in planning and programming, design, construction, maintenance and rehabilitation of the roads.

Pavement Management involves the identification of optimum strategies at various management levels as well as the implementation of these strategies. It is the process covering the activities involved in providing and maintaining the pavements at an adequate and acceptable level of service as defined by the concerned road agencies.

Figure 4 represents the major components of PMS (Haas et al., 1994). It is clear from the figure that data base is the most important issue regarding the PMS at network and project Level.

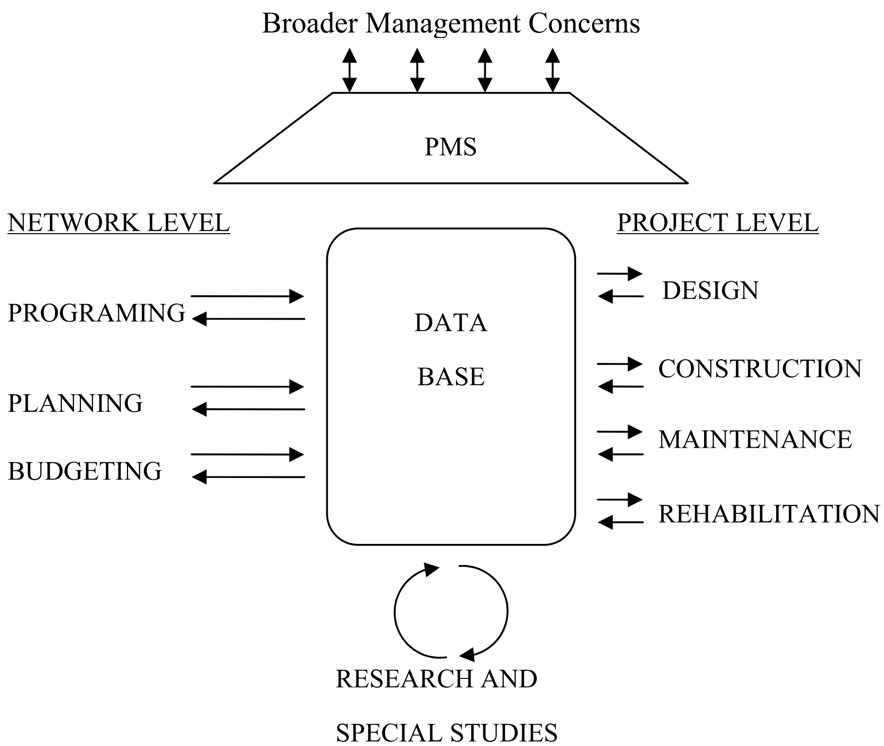

Figure 4 Major components of PM

The nature of the PMS is a broad–based process that includes preservation of the existing pavements through effective and efficient maintenance. The Maintenance procedure consists of the following four steps called the “building blocks” as illustrated in figure 5 (IRRD No. 292813).

1. data acquisition
2. models / analysis
3. criteria / optimization
4. consequences / implementation

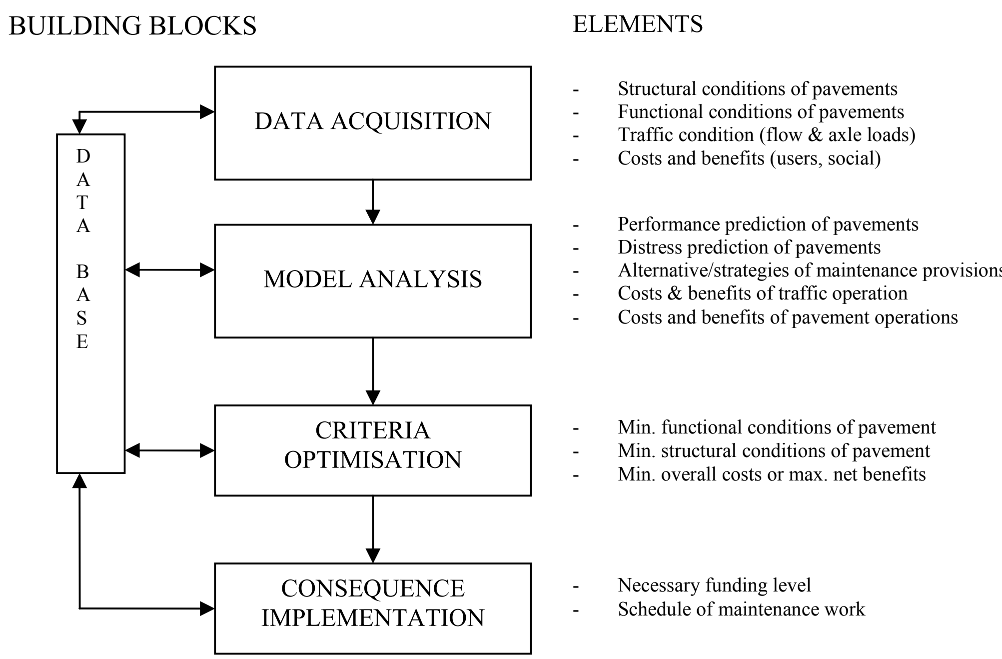

Figure 5 Basic building blocks in Pavement management process

The purpose and benefits of PMS could be economical, technical and/ or administrative. As per International Road Research Documentation (IRRD No. 292813); economically, an appropriate PMS should be able to work towards maximizing net benefits subject to constraints and includes:

1. Manage the budget by determining the most appropriate funding level;
2. Plan network improvements according to budget requests;
3. Determine the effects of deferring maintenance on owner's (highway authority) and road users' costs;
4. Determine the effects on users' cost of raising/lowering the quality standard of road pavement; and
5. Assure cost effectiveness through prioritization based as comparison of costs and benefits of alternatives.

Technically, an appropriate PMS should:

1. Constitute a comprehensive and efficient data base;

2. Learn from past and present facts and figures and improve construction and maintenance techniques;

3. Select the best maintenance methods;

4. Define problems (defects) and find objective answers to solve these problems;

5. Contain an appropriate performance prediction model of pavement to control future performance and evaluate costs / benefits of PMS; and

6. Generate meaningful decision criteria (desirable level, warning level, intervention level of pavement condition).

Administratively, an appropriate PMS should be able to:

1. Define the state of road network rationally;

2. Plan or program maintenance activities of present and future workloads;

3. Establish the most efficient monitoring method;

4. Determine consequences of different levels of funding on pavement conditions; and

5. Provide an objective base for political decisions.

Pavement evaluation is tied up to all phases of PMS and without this it is not possible to operate effectively. The degree of detail and frequency of measurement necessary for pavement evaluation depends upon the situation and the particular requirement of the individual road agency.

Classes and Uses of Pavement Management Data

As explained earlier the objective of the pavement management system is to coordinate all activities required for keeping the pavement structure in the most cost-effective order with the users' satisfaction of the facility. To support these activities, broad data base is essential and the data base should include pavement condition and performance, among the various items. The existing pavement management system (PMS) focuses on condition and performance of the pavement surface and the structure. However, a comprehensive PMS requires data from a variety of sources. The Figure 6 lists the classes of data and their uses (Haas, 1991).

Data	Use	Data	Use
Section Description	R	Geometry Related Data	
		- Section dimensions	R
Performance Related Data		- Curvature	R
- Roughness	R	- Cross slope	R
- Surface distress	R+M	- Grade	R
- Deflection	R	- Shoulder/curb	R+M
- Friction	R+M		
- Layer material property	R		
History Related Data		Environment Related Data	
- Maintenance history	R+M	- Drainage	R+M
- Construction history	R+M	- Climate	R
- Traffic	R+M	(Temperature, rainfall, freezing)	
- Accidents	R+M		
Policy Related Data		Cost Related Data	
- Budget	R+M	- Construction cost	R
- Available alternatives	R+M	- Maintenance cost	R+M
(Maintenance & rehabilitation)		- Rehabilitation cost	R
		- User cost	R

Figure 6 Major classes and component types of pavement data [Haas, 1991]

R: data primarily for rehabilitation R+M: data for both cases

M: data primarily for maintenance

Data are used at the network and project levels of the pavement management. The network level data is used in program prioritizing, budgeting and finance planning, whereas, the project level data is used for the engineering related aspects of the road sections or a project.

The measurement of pavement characteristics and evaluation of the data required has the following three objectives (Roads and Transportation Association of Canada, 1977).

1. To check whether the intended function and expected performance are being achieved;
2. To provide information for planning rehabilitation for existing pavement; and
3. To provide information for improving the technology of design, construction and maintenance.

The evaluation of pavement for the above listed objectives can involve one or more of the following (RTA Canada, 1977).

1. Structural capacity;
2. Physical deterioration or distress;
3. User-related factors such as riding comfort, safety and appearance; and
4. User-related costs and benefits associated with varying serviceability and with various rehabilitation measures.

Thus having the capability to perform a comprehensive pavement evaluation that considers condition rating, deterioration rate, structural capacity and previous maintenance allows rational determination of maintenance and rehabilitation requirements and avoids over- or under-maintenance of the pavement (Shahin, 1979).

Concepts of Deterioration

All road pavements deteriorate over time irrespective of their design and construction standards. Deterioration is progressive and is influenced by the various factors grouped hereunder into three main headings.

1. Environmental – terrain, climate and local parameters
2. Traffic – volume and axle load
3. Construction – design and construction standards and material and workmanship quality

The deterioration starts when the pavement is opened to the traffic and increases with the time. The deterioration is due to pavement components such as sub-base, base, wearing course being exposed to loads applied on them, and Mother Nature, such as rain, snow, freeze-thaw cycle, and so on. Factors responsible for deterioration are included in the subsequent section.

The condition and /or performance of the pavement are continually deteriorated by several factors. A deterioration curve shows relationship between the response (dependent) and the predictor (independent) variables. These factors which cause deterioration are used as independent variable in modeling deterioration curve. Hajek and Haas (1987) defined the important reasons for pavement damage in Ontario, Canada as a traffic loads, temperature changes, moisture effects and construction flaws due to materials and construction techniques.

Other researchers have described a variety of factors affecting deterioration. George et.al., (1989) described the factor that affect the rate of deterioration, which include traffic loads, pavement layer thickness, material, sub-grade strength, environmental factors and construction techniques.

Haas et al., (1994) defined the factors that affect pavement performance such as pavement type, pavement thickness, traffic volumes or loads, sub-grade type or strength, environmental and regional effects.

Pavement deterioration models play an important role in PMS. Shahin (1994) has described that, "an important feature of a pavement management system (PMS) is the ability both to determine the current condition of a pavement network and to predict its future condition". Projection of future condition requires the ability to measure condition on a repeatable scale. Not only the best MR&R alternative will be selected, but the optimal time of application is also determined (Haas et al., 1994).

It is mentioned that good materials evaluation and good mechanistic modeling of pavement structure are essential to pavement management (Shahin, 1994). Therefore, an effort has been directed toward developing prediction models in order to relate pavement serviceability, pavement age history and its performance (Haas et al., 1994).

The deterioration model always allows the road authorities to prioritize and plan the maintenance and rehabilitation of their pavements. It also provides the following useful information for rehabilitation and maintenance management.

1. Rate of Deterioration – provides a number of deterioration in the unit of time. If the rate is high, it is an alarming signal for immediate attention. If nothing is done at that moment, condition of a pavement rapidly deteriorates so the cost for repair becomes higher and the condition becomes below the minimum acceptable.

2. Future Condition – it is important in the pavement management system. Knowing the future condition will assist in planning the future maintenance or rehabilitation plan appropriately and this allows the cost-effective alternative selection so that the pavement conditions are normally superior.

Pavement Condition and Performance

Normally any infrastructure just after construction is in the perfectly excellent condition or has the excellent performance. The condition is the potential to reach failure or the state in which a facility no longer performs its functions; whereas, the performance is measured by the comfort of facility users or the potential of a facility to work potentially. For the different types of infrastructures, the parameter measures for condition and performance are also different. A road pavement normally starts to deteriorate continuously under the vehicular loading and the exposed environment. The performance of the road pavement is therefore the ability to satisfy the traffic demand and the environment over its entire design life. Pavement performance therefore, indicates the condition and serviceability level of the pavement. Performance is defined as its ability to meet the requirements for which it has been designed (Ramaswamy, 1989). Pavement performance can also be defined as the ability of pavement to carry the traffic with an acceptable level (Paisalwattana, 2000). Therefore, in a complete sense, a good pavement rides well, carries traffic satisfactory, provides a safe tire interface for both rolling and stopping, and looks pleasing to the “pavement manager” and the “user” (Haas and Hudson, 1978).

Pavement evaluation must precede the maintenance strategies. Many methods are in use to evaluate pavement such as individual distress characteristics and condition index. Evaluation of Performance involves the functional behavior of pavement (Haas et al., 1994). Roughness is an indicator of pavement riding quality. Various methods such as visual inspection/survey, condition rating based on distress severity, and non-destructive testing are available to evaluate the pavement performance and this is the first step towards modeling the pavement deterioration. Figure 7 illustrates a typical performance curve relating the pavement condition rating to the age of the pavement.

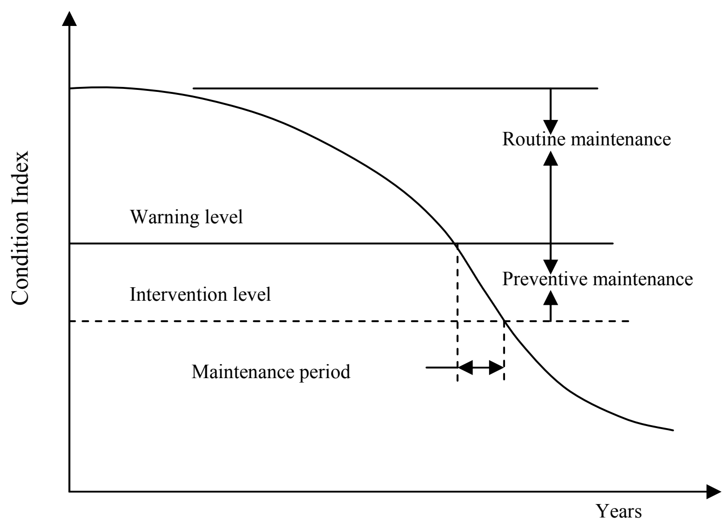

Figure 7 Performance curve

The most commonly applicable indicators of pavement performances are; cracking, rutting, riding quality and skid resistance. In general there are two types of performance indexes; one type of index (Type I) represents raw data for only one pavement condition parameters (examples are distress, roughness, deflection, skid resistance, etc.) and the other type of index (Type II) represents a combination of more than one pavement condition parameters. This method consists of combining all or some of the ratings so as to constitute a global (or serviceability) index representing the pavement conditions (IRRD No 292813). The Table 2 lists some of the unique indexes used by different highway administrations. Therefore, only some of the widely used pavement performance indexes are described below and these indexes are used in formulating the prediction model in general.

1. Distress Type – Distress is visible imperfection of the road pavement that directly represents the pavement performance. The general distress types are cracking and rutting and they are measured in terms of their density (percentage or area).

Cracking – Cracking includes alligator, block, longitudinal and transverse cracking. Pavement deterioration is measured by cracking area. HDM III involves the cracking model. In deterioration model, crack initiation and progression are forecasted [Haas et al., 1994

Rutting – Rutting is a depression normally in the wheel paths and it may be associated with shoving of the adjacent sides. Rutting begins with a permanent deformation of sub-grade. Significant rutting leads pavement to a major structural failure.

2. International Roughness Index (IRI) – roughness is an important aspect and it presents riding comfort and safety of the road users. According to the American Society for Testing and Materials (ASTM, specification E867-82A) road roughness is defined as "the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic pavement loads and pavement drainage". Roughness increases the wear on vehicle parts and rolling resistance and has appreciable impacts on VOC and the safety, comfort and speed of vehicle. Some agencies combine roughness condition index with other pavement condition index such as distress to formulate a composite index (Type II) in the management activities.

3. Present Serviceability Index (PSI) – PSI was developed in the early 1960s and constituted the first comprehensive effort to establish performance standards based upon considerations of riding quality (Carey and Irick, 1960; Highway Research Board, 1962).

A panel of highway users from different backgrounds evaluated 74 pavement sections and rated them on a five-point discrete scale (0 for poor; 5 for excellent). The rating was averaged for each section converting the discrete rating into a continuous rating referred to as the Present Serviceability Rating (PSR). The PSR was found to correlate highly with longitudinal profile variation in the wheel path (slope variance) and it was found to correlate to a lesser extend with rut depth, cracking, and patching. Ninety five percent of the change of the PSR could be explained by the variation of the slope variance (Haas et al., 1994). Therefore, an empirical equation was developed to determine serviceability as a function of surface slope variance, cracking, rutting and patching measured in the pavements. The serviceability value estimated with this equation was called the Present Serviceability Index (PSI) and it became the first objective measure of pavement performance based upon the consideration of riding quality. PSI ranges in integer scale from 0 (completely disintegrated) to 100 (newly constructed or resurfaced).

4. Pavement Condition Index (PCI) – It is developed by US Army Corps of Engineers for the PAVER maintenance management system (Shahin and Kohn, 1981). It measures in a scale of 0 to 100 (new pavement). It covers larger number of damage types than PSI. Nineteen damage types with three severity levels for each distress are used in calculating PCI.

5. Pavement Condition Rating (PCR) – It is the specific performance index that is developed by (George et al., 1989). It is similar to PCI since they both have indexes on a scale from 0 to 100. It is composite index derived from monitoring data pavement roughness or roughness rating (RR) and distress rating (DR) in accordance with the following equation.

$$PCR = RR^{0.6}\ DR^{0.4} \qquad (1)$$

Table 2 List of pavement performance indexes

Name of Index	Index Equation	Index Type	Condition parameters accounted for
Alaska			
Surface Condition Index	$SCI = 1.38R^2 + 0.01(A+P)$	I	Rutting (R), Alligator cracking (A), Full width patching (P)
Alberta			
Pavement Quality Index	PQI=(1.1607+0.0596*RCI*VCI + 0.5264*RCI log SAI)	II	Structural Adequacy Index (SAI), Riding Comfort Index (RCI), Visual Condition Index (VCI)
Denmark			
Present Serviceability Rating	PSR = 12.5 -4.25 lgt (BMT)	I	Bump integrator Measurement (BMI)

Table 2 Cont'd

Name of Index	Index Equation	Index Type	Condition parameters accounted for
Florida			
Ride Rating	RR = a + bx	I	Roughness from Mays Meter (x)
Defect Rating	DR = 100 - $\sum$ (defect points)	I	Distress (defect points) which includes cracking, rutting and patching
Basic Rating	BR = RR * DR	II	Roughness (RR), Distress (DR)
Adjusted Basic Rating	SR = f (ADT, BR)	II	Roughness and distress (BR), traffic (ADT)
Engineering Rating	ER = OR* SR	II	Roughness, distress, traffic (BR, ADT); ability of road to handle traffic (OR)
New South Wales			
Maintenance Index	MI = 0.25 (roughness rating)+ 0.25 (visual assessment rating) + 0.50 (deflection rating)	II	Self – explanatory
Safety Index	SI = 0.75 (scrim rating) + 0.25 (roughness rating)	II	Self - explanatory
New York State			
Present Readability Index	PRI = f (roughness meter data, subjective rating)	I	Roughness
Pavement Surface Rating	PSR = Subjective, 0-10	I	Distress
Base Rating	BR = Subjective, 0-10	I	Structural
Maintenance Index	MI = Subjective, 0-10	I	Indication of maintenance performed in the past years
Structural Rating	STR. R. = 3(PSR) + 4(BR) + 3(MI)	II	Distress, structural adequacy, maintenance performed during the past year
Ohio			
Present Serviceability Index	PSI = $4.18-0.007(RC)^{0.658}-0.01\ C + P-1.34(RD)^2$	II	Roughness (RC), Distress (C, P, RD): AASHO equation
Pavement Condition Rating	PCR = 100 - $\sum_{i-1}^{n} Deduct_i$	I	Distress, where $Deduct_i$ = (weight for distress) * (weight for severity) * (weight for extent)
Utah			
Distress Index	DI = $\frac{(2A+2M+L+T)}{36}$	I	Distress [Alligator (A), Map (M), Longitudinal (L) and Transverse cracking (T)]

Table 2 Cont'd

Name of Index	Index Equation	Index Type	Condition parameters accounted for
Washington State			
Pavement Rating	PAV'T RT. = 100 - $\sum$D	I	Distress (D = weighted deduct points)
Ride Rating	RIDE RT.=1.0 – 0.3 $\frac{(CPM)^2}{(5000)}$	I	Roughness (CPM)
Pavement Condition Rating	PCR = (PAV'T RT. * RIDE RT.)	II	Distress, roughness

Source: IRRD No. 292813

Types and Techniques of Deterioration Modeling

There are various types of deterioration model in practice. Haas et al., (1994) has classified the prediction models into four basic types, for operational purposes as follows:

1. Purely mechanistic – Mechanistic models are based on a physical representation of the pavement deterioration process. Purely mechanistic model is based on the structural behavior parameters such as stress, strain, or deflection. This approach at the present is considered to be less feasible due to the complexity of the road deterioration process. Those deterioration models rely on the use of material behavior and pavement response models, which are believed to represent the actual behavior of the pavement structure under the combined actions of traffic and the environment. These behavior and response models are used to estimate strains, stress and deflections at various pavement structure locations. The critical responses are then used to predict pavement performance in terms of surface deformation and crack propagation. Until today, a comprehensive and reliable model that is purely mechanistic is not developed. However, material behavior and pavement response models presently in usages are very simplistic and only represent material and structural responses under the restricted conditions.

2. Mechanical – Empirical – where a response parameter is related to measures structural or functional deterioration, such as distress or roughness, through regression equation. These models use material characterization (usually laboratory testing) and pavement response models (usually linear elastic or finite element type models) to determine pavement response. This part constitutes the mechanistic component. The calculated pavement response (critical strain, stress or deflection) is correlated with pavement performance and finally calibrated to an actual pavement structure. Pavement test sections are used for this purpose as well as in-service pavement sections. This part constitutes the empirical component.

3. Regression/Empirical – The dependent variables in the empirical models is pavement performance indicator of interest. Both aggregate indicators of performance (such as PSI, RCI and PCI), and the individual performance indicators (such as rutting, cracking, IRI, and skid resistance) have been used as dependent variable. These dependent variables are regressed to one or more explanatory variables representing pavement structural strength, traffic loading, and environment conditions. However, most of the specifications available in the literature are just linear association of the variables. The criterion typically used to select the best fit of the data is the coefficient of determination, R^2.

4. Subjective – where experience is captured in a formalized or structural way using transition process model to develop deterioration model such as Markov model

Empirical and mechanistic – empirical models are currently the most widely used deterioration models for the road pavements. Empirical models based on regression analysis have been used for many years and constitute some of the most widely used models. But during the past 20 years, there is more inclination towards developing the mechanistic-empirical models.

Pavement evaluation is a key part of PMS which is used to measuring and assessing the outputs of the pavement. Figure 8 is a schematic representation of the major types of pavement outputs versus time.

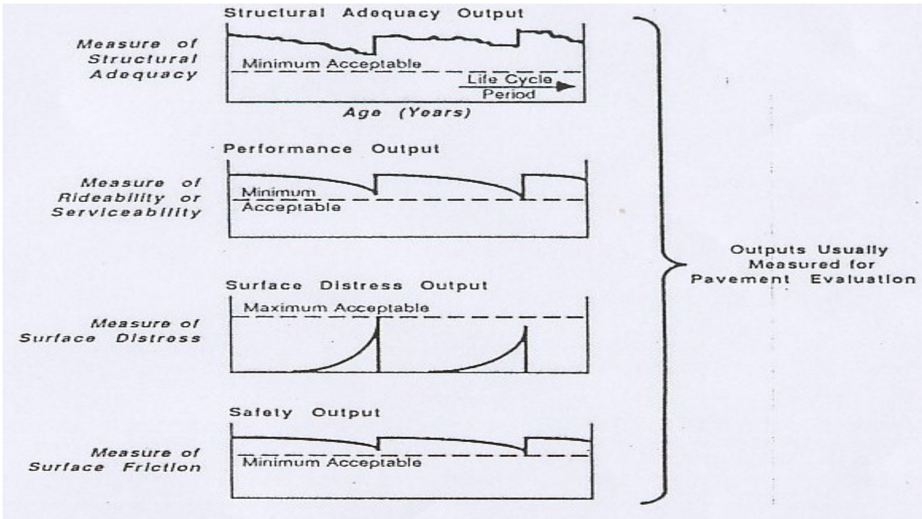

Figure 8 Major types of pavement models

The most satisfactory method for an appropriate optimal mix and timing of maintenance and rehabilitation could be the development of the Pavement Deterioration Model/Curve because it provides the rate of deterioration and the future conditions of the pavement.

The deterioration model developed must suit the local condition of a particular country and it should incorporate the inspection data being currently in use by them. Data collection is always the most vital issue for deterioration mode. Due to constrained resources, it is always important that the deterioration model must be an effective tool used in proposing the appropriate maintenance strategy. Figure 9 represents an example of the prediction models for pavement deterioration (Haas et al., 1994). This curve shows relationship between pavement condition, measured in PSI and time and axle loads.

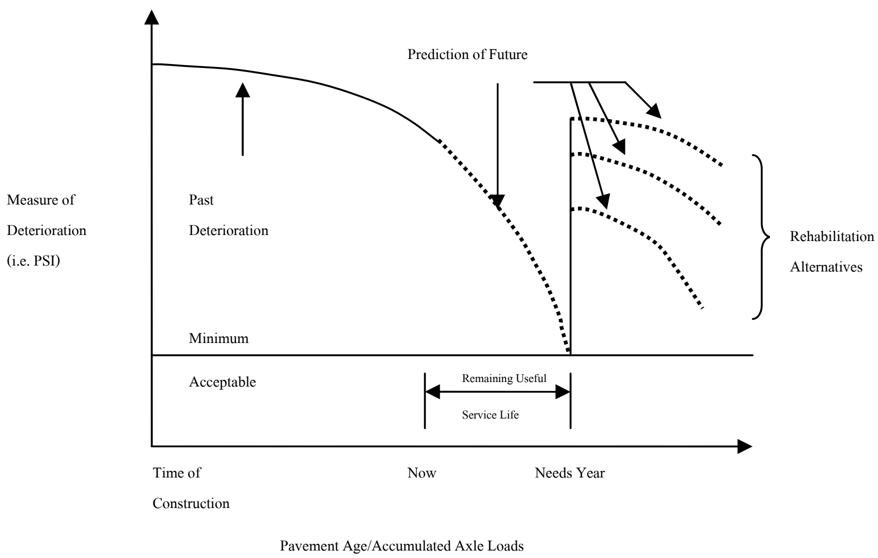

Figure 9 Prediction models for pavement deterioration

Source: (Haas et al., 1994)

Figure 9 is also a schematic illustration for how a deterioration model is used to predict future deterioration of an existing pavement, and rehabilitation alternative constructed in the needs year. The basic requirements for any prediction model have been described by (Darter 80) and they include the following:

1. An adequate data base
2. Inclusion of all significant variables affecting deterioration
3. Careful selection of the functional form of the model to represent the physical, real-world situation
4. Criteria to asses the precision of the model

Various forms of mathematical formulas are used in the model formulation. Many techniques are available for formulating the pavement deterioration models. Shahin, (1994) has described seven techniques straight-line extrapolation, regression (empirical), mechanistic-empirical, polynomial constrained least square, s-shaped curve, probability distribution, and Markovian. Some techniques are described in the following sub-headings.

Straight-line technique

Straight-line technique is the simplest technique and the main assumption of this technique is a deterioration rate has the straight-line relationship. This technique requires two points of data but the accuracy of prediction may be questionable. According to Shahin (1994), this technique can not be used to predict the rate of deterioration of a relatively new pavement or a pavement that has recently received major rehabilitation. This technique underestimates the pavement condition at the earlier stage and overestimates at the later stage.

Regression (Empirical) Techniques

Regression technique is used to generate an empirical relationship between two or more variables. Each variable is described in term of its mean and variance. Though there are various forms of regression analysis, two most common forms are linear regression and non-linear regression.

Linear Regression – is the simplest form of regression analysis. For predicting a model there are two variables, dependent and independent variables are associated in the model formulation.

Model is described as,

$$Y_i = a + bX_i + e_i \quad (2)$$

where

Y_i = dependent variable

X_i = independent variable

a ,b = regression parameters

e_i = prediction error

Non-linear Regression – when the two variables are not reasonably associated in linear regression form, non-linear regression is used as a model.

$$E(Y) = a + b\,f(x) \quad (3)$$

where

$f(x)$ = function of x, such as x^2 or ln x

One of the most widely used forms is hyperbolic curve based on a long-term infrastructure data base as;

$$C = C_0 - aT^b \quad (4)$$

where

C = Present condition index

C_0= initial condition index (100 assumed in PCR)

a = slope coefficient of the curve

b = constant which controls the shape

Mechanistic-Empirical Model

Mechanistic-empirical combines two approaches; a pure mechanistic approach and a regression (empirical) technique. Pure mechanistic approach is applicable to calculate pavement response (stress, strain, or deflection) and the response is caused by traffic, climate or a combination of the two. The calculated stress and strain from pure mechanistic approach can be used as a response variable to a regression prediction model. An example of mechanistic-empirical model is expressed below and the model is used to predict asphalt pavement fatigue life (N).

$$N = A*(1/e)^B \quad (5)$$

where

N = asphalt pavement fatigue life

A, B = coefficients of regression

e = strain from wheel loading (calculated by mechanistic approach)

Polynomial Constrained Least Square

Polynomial constrained least square is most efficient technique for predicting the change in dependent variable, Y (PCI, Roughness) as a function of another independent variable, X (Age or Traffic). This method consists of three steps:

1. Inspect the pavement condition for collecting data

$$(X_i , Y_i) \qquad i = 1, 2, …., n$$

where

X_i = age of sample i

Y_i = pavement condition of sample i

2. Establish the polynomial equation of degree n

$$Y(X) = a_0 + a_1X + a_2X^2 + …… +a_nX^n \qquad (6)$$

3. Ensure that the deterioration model corresponds to the two constrained need by minimizing the sum of $[Y_i – Y(X_i)]^2$. The constraints are;

a_0 = value equal to the excellent pavement condition value

$Y'(X) \leq 0$, to ensure a non-positive slope, condition of pavement from the prediction would not be better as the age or traffic increases.

S-shaped Curve

Similar to the polynomial constrained least square, the S-shaped curve fitting technique is useful when predicting the change in a variable, Y as a function of one variable, X (Shahin, 1994). The S-shaped curve equation developed by Smith, 1986 for predicting PCI to pavement age is given by;

$$PCI = 100 - \frac{\rho}{\left[\ln(\alpha) - \ln(Age)\right]^{1/\beta}} \qquad (7)$$

where

ρ, β and α are constant and which can be determined by regression analysis.

Existing Pavement Deterioration Models

After the development of the first pavement performance index, namely PSI in 1960s, the development of the pavement deterioration models initiated. The first of the models, which is the linear models based on experimental data, was developed based on data provided by the AASHO Road Test in Illinois (HRB, 1962). The AASHO equation estimates pavement deterioration based on the definition of dimensionless parameter g referred to as damage. The damage parameter was defined as the loss in the value of the PSI at any given time as:

$$g_t = \frac{P_0 - P_t}{P_0 - P_f} = \left[\frac{N_t}{\rho}\right]^w \qquad (8)$$

where

g_t = dimensionless damage parameter,

P_t = serviceability at time t (in PSI units),

P_0 = initial serviceability at time t = 0,

P_f = terminal serviceability,

N_t = cumulative number of equivalent 80 KN single axle loads applied until time t, and

ρ, w = regression parameters

The data from AASHO Road Test provided little information on long-term environmental effects and no direct information on pavement response and performance under actual highway traffic. The parameters ρ and w were obtained for each test section by applying equation (8) in a step-wise linear regression approach and when the values of ρ and w were estimated, the estimated values were expressed as a function of design and load variables, and two new linear regressions were carried out. The assumed relationship between w and these variables was (HRB, 1962):

$$w = w_0 + \frac{\beta_0 (L_1 + L_2)^{\beta_2}}{(a_1 D_1 + a_2 D_2 + a_3 D_3 + a_4)^{\beta_1} L_2 \beta^3} \qquad (9)$$

where

$L_{1=}$ axle load,

L_2=1 for single axle vehicles, 2 for tandem axle vehicles,

w_0 = a minimum value assigned to w,

β_0 to β_3 = regression parameters,

a_1 to a_4 = regression parameters that were obtained by performing analyses of variance, and

D_1 to D_3 = thickness of the surface, base, and sub base layers

The specification form for the relationship between ρ and the design and load variables was the following (HRB, 1962):

$$\rho = \frac{\beta_0 D^{\beta_1} L_2^{\beta_3}}{(L_1 + L_2)^{\beta_2}} \qquad (10)$$

where

D $= a_1 D_1 + a_2 D_2 + a_3 D_3 + a_4$, represents the structural number (SN), and

β_1 to β_3 = regression parameters (not necessarily the same as in Equation 2.10)

Equation 8 (or a modification of it) has been used as the basis for pavement design for approximately 50 years (AASHTO, 1981, 1993).

Linear models based on field data were developed from the study conducted by the Transportation Road Research Laboratory of the U.K. (TRRL) on in-service road pavement in Kenya. This provided the additional data needed to update the AASHO models to establish the relationship between pavement riding quality, pavement strengths and actual highway traffic (Hodges et al., 1975; Parsley and Robinson, 1980). This improved model incorporated mixed traffic loading, different pavement structures over different sub grades, and a variety of pavement ages. Actual measurements of roughness in terms of IRI were used instead of serviceability as a measure of riding quality in the models as:

$$R_t = R_0 + f(SN)N_t \qquad (11)$$

where

R_t = roughness at time t,

R_0 = initial roughness at time t = 0,

f(SN) = a function of structural number, SN,

SN = structural number developed during the AASHO Road Test (denoted by D in Equation 2.11 above) and,

N_t = cumulative number of equivalent 80 KN (18,000 lbs) single axle loads applied until time t.

A study of ten-year time series data by Way and Eisenberg (1980) failed to identify the effect of traffic loading or pavement strength and the developed model related roughness to time and pavement age only in the State of Arizona. The incremental model developed is in the form:

$$\Delta R_t = \beta_1 R_t \Delta_t - \beta_2 \qquad (12)$$

where

ΔR_t = change in roughness level at time t,

Δ_t = time increment, and

β_1, β_2 = regression parameters that depend on the environmental variables

The parameters β_1 and β_2 were estimated by grouping the data into categories according to environmental conditions such as rainfall, elevation, freeze-thaw cycles and temperature.

Karan (1983) developed a model in Alberta with the data available in their pavement management system (PMS) database. The data consisted observation of riding quality, surface distress and deflections for 25 years.

$$RCI_t = \beta_0 + \beta_1 \ln(RCI_0) + \beta_2 \ln(t^2 + 1) + \beta_3 t + \beta_4 t \ln(RCI_0) + \beta_5 \Delta t \quad (13)$$

where

RCI_t = riding comfort index (scale 0 to 10) at any age t,

RCI_0 = initial RCI at t = 0,

t = age in years,

Δt = years between observation, and

β_1 to β_5 = regression parameters

The Department of Transportation of the State of Washington has developed a set of regression equations based on their long-term pavement performance database (Kay et al., 1993). The model has the general form of:

$$\text{PCR} = 100 - \beta_1 t^{\beta_2} \quad (14)$$

where

PCR = Pavement Condition Rating (scale 0 to 100)

t = pavement age, and

β_1, β_2 = regression parameters

The regression parameter values are estimated for Western Washington and are dependent on the type of construction and the surface type of the pavements.

Queiroz (1983) developed linear model based on field data and empirical-mechanistic principles. Multi-layer linear-elastic theory has been adopted in formulating the model. The responses calculated are surface deflection, horizontal tensile stress, strain and strain energy at the bottom of the surface asphalt layer, and vertical compressive strain at the top of the sub-grade material. The specified equation for the prediction of roughness is as:

$$Log(QI_t) = \beta_0 + \beta_1 t + \beta_2 ST + \beta_3 D_1 + \beta_4 SEN \log N_t \quad (15)$$

where

QI_t = roughness at time t as measured by the quarter car index in counts/km,

t = pavement age in years,

ST = dummy variable (0 for original surface and 1 for overlaid surface),

D_1 = thickness of the asphalt layer,

SEN = strain energy at the bottom of the asphalt,

N_t = cumulative equivalent single axle loads up to time t, and

β_1 to β_4 = regression parameters

The above mentioned existing models are compiled from J. A. Prozzi (2001).

A. I. Al-Mansour and K. C. Sinha developed a empirical model for Indiana Department of Transportation (INDOT) in the form as given in equation:

$$\text{PSI} = a + b * Age \quad (16)$$

where

PSI = Present Serviceability Index (scale 0 to 100),

Age = pavement age in years, and

a, b = regression parameters

A. I. Al-Mansour (1999) developed a model for Riyadh street network in Saudi Arabia in the following form:

$$\text{UDI} = a + b * Age^{n} + c * ADT + d * DR \quad (17)$$

where

UDI = Urban Distress Index.

ADT= annual daily traffic (0 for low traffic and 1 for high), and

DR= Drainage (0 for without and 1 for with drainage)

A. I. Al-Mansour (2004) developed an empirical model for the city of Riyadh, Saudi Arabia in which non-linear transformation function was used to improve the fit and the ability to predict future performance. The model equation is in the form:

$$\text{DEN} = ae^{bT} \quad (18)$$

where

DEN = distress density in percentage,

T = time in years, and

a, b = regression coefficients

G. A. Lebdeh et al., (2003) developed an empirical model for the Michigan Department of Transportation (MDOT). In this modeling, the random variable is the Distress Index (DI) for a given project and the associated variable is the previous DI value (the previous DI is the DI value 2 years earlier – called the “first lag”). In the regression, DI is regressed on its first lag and the age that corresponds to the first lag.

$$\text{DI}(t+1) = f[\text{DI}(t), \text{Age}(t)] \quad (19)$$

However, MDOT is currently using the empirical model in the form of logistic function with the chronological age (time) as the independent variable and is given in the form:

$$\mathrm{DI}(t) = \frac{1}{[(1/u) + b_0 (b_1)^t]} \qquad (20)$$

Overview of Road Maintenance Practice in Nepal

This section gives the overview of the road maintenance practice in Nepal and includes background information on pavement maintenance, strategy used by Department of Roads (DoR), pavement distresses, maintenance types, SDI measurement procedures, and ranking and prioritization of the periodic maintenance candidates based on SDI data of the road sections.

Background Information and DoR's Strategy

Over the years, Nepal has added a greater length of roads into its network. As illustrated in Figure 1.1, the road length has grown from a meager 376 kilometers in the year 1950 to 15,905 kilometers in the year 2000. Nearly 30% of the total length is blacktopped roads. His Majesty's Government of Nepal (HMG/N) has accorded high priority to road transport development and accordingly the roads sub-sector is receiving a large chunk of public investment.

Before 1990s' more roads were built as per the aspiration and demand of the people and less priority was put towards up keeping of the existing roads. During that period the roads were depreciated at a loss rate of 5 kilometers for each 100 kilometers of roads. By the end of 1992 more than 50% of the major roads were in poor condition, urgently requiring the reconstruction. Therefore the government introduced a road sub-sector goal in the eighth- five- year plan (1992~1997) and since this time more focus has been made towards road maintenance and asset preservation. More and more emphasis was given in the planned maintenance practices in order to bring back the road network into the maintainable condition. Furthermore, in order to build reliability in financing the maintenance activities the HMG/N has enacted the Road Fund Board

Act 2002. Nepal Roads Board (NRB) has been established and is authorized to collect service charge as well as fuel levy independent of the government revenue basket.

DoR's Strategy - Periodic maintenance is an essential element of planned maintenance and comprises re-gravelling of gravel roads and cyclic resealing of bitumen roads. In particular, cyclic resealing is considered to be the single most cost effective operation to improve the serviceability of bitumen roads in Nepal. It involves applying a seal to all roads in a maintainable condition at a fixed interval of 5-8 years depending on environment and traffic. All resealing has a high economic rate of return; the principle of cyclic resealing is therefore to reseal 12 months early rather than one day late. With the present road network and traffic levels, the intervention approach using economic models such as HDM III is not appropriate for developing a resealing programme for Nepal and could be counter-productive. For the time being, prioritizing in the selection of the roads for resealing will be limited to the consideration of the four parameters namely road age, visual survey rating, traffic and strategic importance.

The aim of the DoR Strategy in adopting cyclic resealing is to build-up a programme of 400 km of resealing annually which can be undertaken as a straightforward management exercise and with predictable funding needs. Such a programme will, in addition, provide an on-going source of work for the local contracting industry. Resealing is not structural; it slows down the rate of deterioration by renewing the water proofing properties of the pavement. Types of resealing include double and single seal surface dressing, slurry seals and cape seals using straight-run bitumen or bitumen emulsion.

Pavement Distresses

Road pavement will deteriorate over time, no matter what the design and construction standards have been adopted. Deterioration is a continuous process and influenced by various factors that has been mentioned earlier.

But Nepal in particular, has a difficult environment for road construction and since the traffic levels are normally low outside the urban areas (maximum ADT 2,200), the environment is the main cause of pavement damage/deterioration. Surface distress is importance to the maintenance work since it provides the first visual indication of the damages. The following are the forms of deterioration that is recorded for the planned maintenance purposes.

Cracks – are in the form of narrow interconnected, longitudinal and transverse, sealed crack, and wide interconnected (major) and the causes could be one or more of the followings:

1. Fatigue damage of AC or stabilized base
2. AC being too stiff for the climate
3. AC mix subjected to low traffic volume may not be densified sufficiently and may become brittle
4. Brittle due to mixed too long, mixed too hot, or stored too long
5. Inadequate compaction at the edges of longitudinal paving lane, reflection, crack in stabilized base, application of heavy loads or high tire pressure in rutted wheel paths.

Potholes – various form of cracks progresses to the potholes first at the locations where the underlying base and sub-grade material are the weakest.

Texture defects – are in the form of stripping, bleeding and raveling and weathering. It may pose a safety hazard. The causes could be the following:
For AC raveling is due to loss of bond between aggregate and binder due to insufficient binder content, poor adhesion of binder with aggregate, hardening of asphalt cement or segregation or inadequate compaction.
For surface treated roads

1. Poor adhesion of the binder with aggregate
2. Aggregate applied on the cooled binder
3. Insufficient compaction
4. Dusty aggregate and breakage
5. Excess binder or inadequate binder

6. Road surface temperature low

Exposed base – considered as a major defect and is due to deterioration of the top pavement layer (pothole, loss of aggregate)

Edge break – considered major or minor depending on its magnitude. The causes are inadequate lateral support, inadequate compaction at the edge.

Depression and humps – form of corrugations and may be due to foundation movement (frost heave, swelling soil) or localized consolidation (example is bridge and culvert approaches). It imparts riding discomfort and safety hazard. Like wise, high or low shoulder is another defect of the shoulder and it posses the safety hazard due to drivers being unable to recover from them. It also accelerates the edge breakage of the pavement.

Repair Methods

Maintenance activities are carried out both on and off the carriageway.

1. On-road maintenance – activities designed to keep the road open and serviceable throughout the year. Planned maintenance decreases the rate of deterioration and thus defers the need for rehabilitation and reconstruction.

2. Road –side support maintenance – deals with protecting hill slopes against land-sliding and erosion

For the purpose of road management, DoR has classified maintenance activities in terms of their frequencies as follows:

1. Routine Maintenance – required continually on every road because of environmental degradation whatever its engineering characteristics or traffic volume. Main works include grass

cutting, drain cleaning and repairing, re-cutting ditches, bridge and culvert maintenance, road furniture maintenance etc.

2. Recurrent Maintenance – required at varying intervals during the year with a frequency that depends mostly on the volume of traffic using the road. Work activities included are repairing pot-holes, patching, repairing edges and shoulders, sealing cracks.

3. Periodic Maintenance – required only at intervals of several years. Work activities include resealing (surface dressing, slurry sealing, fog spray etc), re-gravelling shoulders, road surface marking, and painting of the steel structures.

4. Emergency Maintenance – needed to deal with emergencies and problems calling for immediate action when a road is threatened or close. Works include removal of debris and other obstacles, placement of warning signs and diversion works.

5. Preventative Maintenance – required adapting the road to the changing nature of the slopes and streams (i.e. to the geophysical environment). Works include slope netting, trimming, scale-off rock faces, masonry wall and revetments, cascade, gabion walls, prop walls, check dams, river training and bank protection and bio-engineering etc.

Measurement of Surface Distress Index (SDI)

The method adopted by the DoR is a simplified procedure suiting the particular conditions in Nepal and the need of DoR. The method in use is a "drive and walk" survey and is manual. Surface distress comprises cracking, disintegration (potholes), deformation, texture deficiency, pavement edge defaults and maintenance work (patchwork). The above distresses are visually assessed using a 10% sampling procedure and recorded using a cumulative index called a "Surface Distress Index (SDI)". The SDI is a six level rating index from 0 to 5. The rating 0 indicates a perfect pavement that is without any defects and rating 5 indicates a maximum possible deterioration. The distress elements are divided into two groups; major defects and minor defects. Among the different defect types, cracking, raveling and potholes are generally characterized by extent and severity while for rut depth, being continuous in nature, only severity of the deformation is noted.

The Tables 3 and 4 shows the scoring system for the various distresses and categories of defects and distress code and Figure 10 is the sample of SDI survey done in the DoR.

Table 3 Pavement Distress Score

Scores	Incidence of Minor Defects	Incidence of Major Defects
0	None	None
1	1 to 20 sq.m. per 100 m.	1 Occurrence
2	<50% of the area	2 to 4 occurrence
3	= 50%	< 30% of area
4		= 30% or potholes and base exposed < 20% of the area
5		Potholes and exposed base = 20% of the area

Table 4 Categories of Defects and Distress Code

Defects	Code	Minor	Code	Major
Cracking	CN	Narrow interconnected cracks (1-3 mm width)	CW	Wide interconnected cracks (> 3.0 mm)
	CL	Line cracks (Longitudinal or Transverse)		
	M	Sealed cracks		
Maintenance Patch	M	Patch		
Texture	RA	Shallow raveling or scabbing (< 20 mm)	V	Scabbing (> 20 mm)
	S	Slickness (Texture depth < 1 mm)		
		Bleeding		
	S			
Rutting			RL	Rut depth > 15 mm
Potholes			P	Potholes (> 30 mm depth, > 150 mm dia.)
Exposed base			G	Exposed base or sub-base or gravel
Edge break	ES	Short edge break (> 100 mm, < 5 m long)	EL	Long edge break (> 100 mm, > 5 m long)

PAVEMENT SURFACE DISTRESS INDEX (SDI) SURVEY

ad Link No : F2602 U   From : Pipalboat   To : Sankhu   Survey by : 1. Gopi C. Shrestha
2. Samuel Pradhan

rrain: ☐ Plain ☑ Rolling ☐ Hill   Surface Type: ☑ Ac ☑ ST ☐ GT   Weather Condition: ☑ Sunny ☐ Cloudy ☐ After rain   Date : 059/07/05

Location	Scores			Width (in meters)		Main Distress Type	Distress in %													Remarks
							MINOR						MAJOR							
	Surface	Shoulder Left	Shoulder Right	Pavement	Formation		CN	CL	M	RA	S	ES	CW	V	RL	P	G	EL	D	
0 + 900 - 1 + 000	3			6.90	10.50	P, RA, M			1	2						3				
1 + 900 - 2 + 000	2	3	3	7.10	8.50	P, RA, G			1	2	1	1				2	1	1		
2 + 900 - 3 + 000	4	3		5.50	6.70	EL, S, RA				1	2							4		
3 + 900 - 4 + 000	1			6.30	8.50	P, EL, RL	1	1	1	1	1	1	1		1	1		1		
4 + 900 - 5 + 000	2			5.20	6.50	S, ES, EL				1	2	2						1		
5 + 900 - 6 + 000	1			5.20	6.80	P, ES, RA				1		1	1			1				
6 + 900 - 7 + 000	1		2	4.70	6.70	RA				1										
7 + 900 - 8 + 000	1		3	9.80	6.00	EL, RA				1								1		
8 + 900 - 9 + 000	1			4.60	5.60	P, G, RA				1		1				1	1			
9 + 900 - 10 + 000	1			5.20	6.90	P, RA				1						1				
10 + 876 - 10 + 886	2	3	3	4.20	6.00	P, RA, ES				1		1				2				

SDI (Avg.) = 1.73
Pavement condition = Good

Minor Deffects

CN	NARROW INT. CON. CRACKS
CL	LINE CRACKS
M	SEALED CRACKS/PATCH
RA	RAVELLING/SCABBING (SHALLOW)
S	BLEEDING/SLICKNESS
ES	SHORT EDGE BREAK

Major Deffects

CW	WIDE CRACK
V	SCABING
RL	RUTING > 15 mm
P	POTHOLE
G	EXPOSED BASE/SUBASE
EL	LONG EDGE BREAK
D	CORRUGATION/SHOVING

Figure 10 SDI survey sample

SDI is averaged over each road link or section under consideration and can only be used to provide an objective assessment of pavement condition and to indicate the need for periodic maintenance, rehabilitation or reconstruction. To assess the pavement condition the terms "good", "fair" and "poor" are used based on averaged SDI for a particular road links.

Table 5 Categories of pavement conditions

Surface Distress Index (SDI) Value	Pavement Condition
0 – 1.7	Good
1.8 – 3.0	Fair
3.1 – 5.0	Poor

Planned maintenance can be carried out on the roads which are in the good to fair conditions only. Rehabilitation or reconstruction is needed for the road section with poor conditions.

Ranking and Prioritization of Resealing Candidates

Periodic maintenance within the context of planned maintenance procedure refers to a planned cyclic maintenance strategy for resealing bituminous surfaced roads, and takes into account their present condition (SDI), age, geographic location, traffic and their strategic importance. But presently, prioritizing in the selection of the roads for resealing will be limited to the consideration of the four parameters; road age, visual survey ratings, traffic, and strategic importance. Current DoR policy states that all roads in a maintainable condition are to be resealed every 5 – 8 years depending on environment and traffic.

The following procedures and guidelines on periodic maintenance planning have been developed by the Strengthened Maintenance Divisions Programme (SMDP).

Step 1**:** Determine T in years from Table 6 – Nominate which roads (links or sections) are to be resurfaced every 5, 6, 7 and 8 years based upon traffic volume and terrain.

Table 6 Nominated Maintenance Cycle

	Traffic volume – vehicles per day		
	Low < 250 vpd	Moderate 250 – 1500 vpd	High >1500 vpd
Terrain			
Plains	8	7	6
Rolling	7	7	6
Hills	6	6	5

Step 2**:** Determine Age of the surfacing A in years – first determine the date when each road link or sections was surfaced, or last resurface. This will lead to the age of the surfacing. The age may be corrected depending upon the present surface condition (SDI), using the values in Table 7.

Table 7 Age Correction Information

	Road Condition – Surface Distress Index (SDI)		
	0 – 1.7	1.8 – 3.0	3.1 – 5.0
	Good	Fair	Poor
Age correction factor	Plus 2	zero	Minus 2

Step 3: The time/year for each road to be resealed is calculated by deducting the corrected age of the road from the Table 7 (T minus A corrected). If the time for resealing calculated is negative, then the road is due for resealing now – year 0. If the corrected time is greater than 8 years, then use 8 years as a maximum to comply with the DoR Policy.

Step 4: Prepare budget costs for roads that require resealing now; these are determined using DoR Norms for resealing work.

Surface life can only be extended by periodic maintenance if the underlying pavement is sound. There are three ways of screening to test this;

1. Visual Screening: If the road section is free of rutting, extensive deformation and/or dense cracking, it may be deemed to be a suitable candidate for resealing.

2. Estimated Remaining Pavement Life: If the pavement design axle loading and traffic history is known or can be reasonably be inferred, a residual pavement life can be obtained. This may be modified by a visual pavement condition assessment.

3. Pavement Deflection Survey: Benkelman Beam survey is used to measure the pavement deflection of the road section for the screening test.

Once the unsuitable roads sections for resealing have been screened out using the above guidelines, the remaining road links or the sections are periodic maintenance candidates for the year under consideration that is for this year.

Resealing Project Selection

Normally the initial screening, ranking and prioritization are carried out at the regional level. As mentioned in the preceding sections, resealing will be limited to the consideration of four parameters. However, the age of the road had already been taken into account in determining which year the road is due for resealing. So for the remaining 3 parameters; namely visual survey ratings, traffic and strategic importance, index values (between zero and one) can be developed for different situations.

Table 8 Traffic Group Index (TG)

	Traffic Group – vehicles per day		
	< 250 vpd	250 – 1500 vpd	> 1500 vpd
Index Value (TG)	0.15	0.50	0.90

Traffic Index – traffic groups based upon the same grouping as before. A measure of traffic volume relates to optimized economic efficiency. So maintaining the roads with high traffic levels will have greater economic benefits

Table 9 Road Condition Index

	Road Condition – Surface Distress Index (SDI)		
	0 – 1.7	1.8 – 3.0	3.1 – 5.0
	Good	Fair	Poor
Index Value (RC)	0.02	0.30	1.00

Improvement to road condition by resealing relates to asset preservation. The Table 9 is used to find the Road Condition Index value (RC).

Table 10 Strategic Importance Indices

	Strategic Importance		
	Low Importance	Medium Importance	High Importance
Index Value (SI)	0	0.30	0.60

Indices have been developed for strategic importance as given in Table 10 above. If the same weighting is given to all three indices, then a ranking index can be obtained by the addition of the three indices; Traffic Group (TG) plus Road Condition (RC) plus Strategic Importance (SI). For example: A road with traffic > 1500 vpd, in poor condition and of high strategic importance will have the highest score possible. That is the Ranking Index = 0.9+1.0+0.6 = 2.50

Finally the road links or sections in each yearly – cyclic groups (year 0, year 1, …) can now be ranked according to their Ranking Index. The highest RI value being at the top of the priority in order to ranking and prioritizing the road candidate for resealing now. Until now this method is found to be popular and manageable within the department of roads and its staff.

MATERIALS AND METHODS

In this chapter, methods of data collection, pavement data composition, data manipulation and filtration, observation and discussion on data, various forms of regression-based modeling, and model validation are provided in the following sub-headings.

Data Collection

Data collection is the first step for the analysis and the pavement deterioration model development. The source of data is the extensive database on pavement SDI that the Department of Roads (DoR) maintains within its Highway Management and Information System (HMIS) unit. The data available in HMIS are SDI and Annual Average Daily Traffic (AADT) for each road links. As discussed in the previous chapter, the distresses are visually assessed using the 10% sampling procedure and are recorded using a cumulative index called SDI. In this study the SDI data available for use are from the year 1995-96 to 2004-05. But within this period, there were no SDI measurement done for the years 2001-02 and 2003-04, which could be due to delay in the administrative and procurement procedures since those surveys are conducted by the private consultants. There are also no SDI data available for many of the road links in the said period which were either due to the security reasons or due to some of the road links undergoing reconstruction or rehabilitations.

The important data required for this study is the pavement construction history, and this could not be readily available in HMIS. Therefore this information is collected through the project completion reports and from the inputs from the 25 divisional road offices around the country. The pavement history is required to figure out the pavement's age corresponding to the each years SDI value. The Table 11 illustrates the road lengths and links in each road category consisting of the SDI data required for the deterioration model.

Table 11 Road Length and Link under Study

Category	Roads (Nos.)	Total Road Length (km)	Study Roads (Nos.)	Study Road Lengths (km)	Study Road Links (Nos.)
National Highways (NH)	15	3,594	15	2,301	165
Feeder Roads (FR)	51	1,909	38	732	71
Total	66	5,503	53	3,033	236

According to Table 11, the length of the National Highways (NH) under this study is 2,301 km as compared to total length of 3,594 km; this is due to some of the road lengths are still gravel surfaced and some are still under construction. Similarly only 38 feeder roads out of 51 have bituminous surfacing and that also partly only. Most of the road length under FR are either earthen or gravel. Like wise the bituminous road links within the municipal boundaries are excluded from the analysis and model development. This is necessitated due to these roads having the deteriorating phenomena different from other road sections under the study. The other information collected from the Department of Roads (DoR), Nepal includes traffic volume, terrain types, and surfacing type of each of the road links, and they are presented in the Appendix A.

Deterioration model development requires a considerable amount of effort in data observation, manipulation and filtration and the modeling technique, model analysis, and model validation. Figure 11 illustrates the working structure of this study.

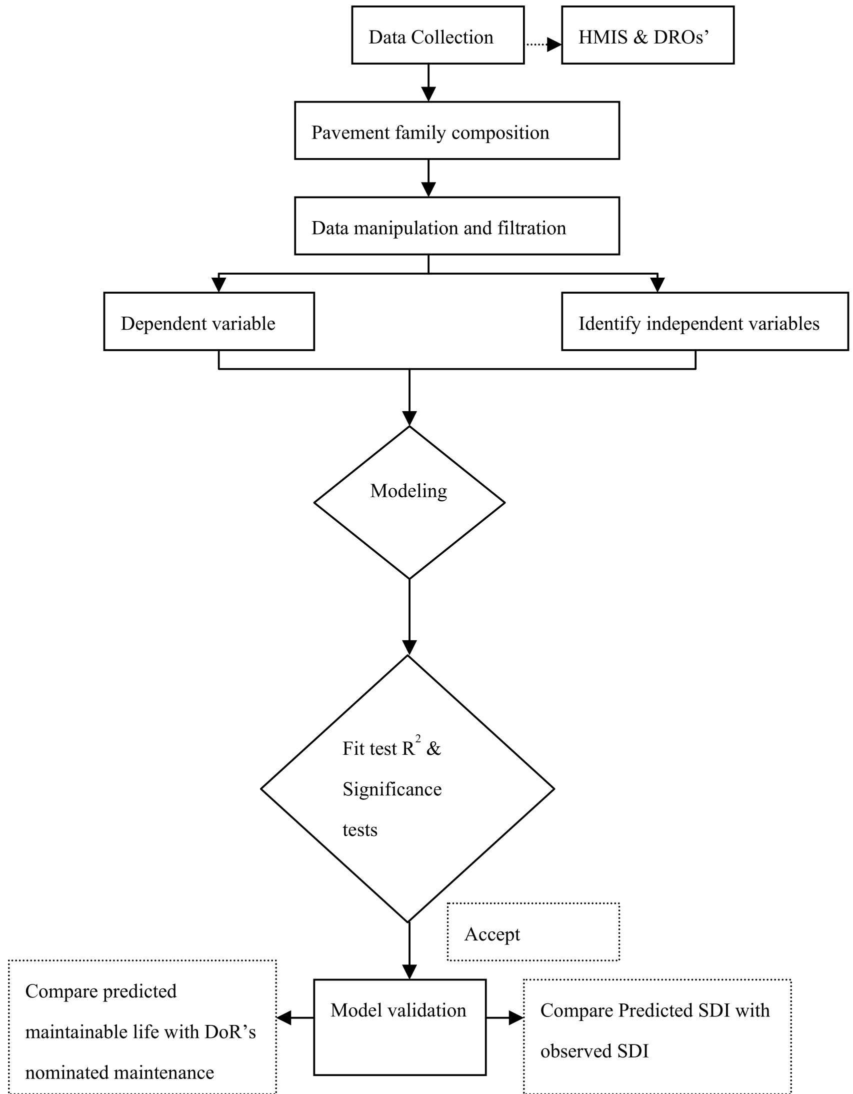

Figure 11 Working structure of the study

Data Preparation

The data collected from HMIS must be observed prior to analysis and this observation is necessary to identify the unreliable data before analysis. Not all the road links or sections for which SDI data is available are used in the analysis and model development. The presence of the unusual data may cause errors and mislead the model development. Therefore, the road links or sections with unexplained decline in the SDI value need to be eliminated from the analysis. But there are cases where pavement may have actually shown a decline in SDI over time even without resealing or rehabilitation. This would be the case if the first SDI reading was taken during cold weather and the later reading was taken during the relatively higher temperature time. However, no information is available to discern this type of phenomenon, all roads with a decline in SDI but no rehabilitation or resealing was not used in the model development.

Therefore, there are large numbers of road links that are eliminated for analysis due to non availability of the respective pavement construction/rehabilitation history. Also many of the SDI values within the road links are also eliminated due to their declining nature without any justification of the pavement history. The road link list and the SDI values and other relevant information that are acquired from HMIS and the data used in analysis and model development are included in the Tables A1 through A8 and Tables A9 through A16 in the Appendix A.

Data outliers are the values in a data set which appear to deviate markedly from other members of the same sample in which it occurs, and has low statistical probability of belonging to the same population were also randomly checked. Outliers indicate mistakes, blunders, or malfunctions of the measurement process, and may indicate that corrective actions need to be taken to improve the system. Many procedures are used to identify outliers. The Rule of Huge Error, the Dixon Test, and the Grubbs Test are available for this purpose. However, the rule of huge error alone is considered for the rejection or retention of a suspected outlier in this study.
The Rule of Huge Error – If one has a reasonable idea (even an informed guess) as to what the standard deviation might be, then if the suspected point deviates from the mean by some predetermined multiple of it, it may be considered to be an outlier.

$$\mathrm{M} = \frac{|Suspect - mean|}{Std.deviation} \tag{21}$$

If M is greater than 4, then the suspect may be considered to be an outlier. The suspect is excluded and sample mean is calculated. The difference of a suspect from the mean is compared with the sample mean to calculate the value of M. The decision to reject depends on a value of M > 4

Classification of Pavement Family

The pavement SDI for the purpose of analysis and model development is first divided into two large groups; pavement in hills and pavement in plains. Each of these two groups is further divided into categories according to the types of the pavement surfacing; asphaltic pavement surface and the surface treated surface. Furthermore each pavement surfacing types are grouped according to the traffic level on them; low traffic (< 250 vpd), moderate (250- 1500 vpd) and high (> 1500 vpd). SDI data is thus organized as shown in the Figure 12.

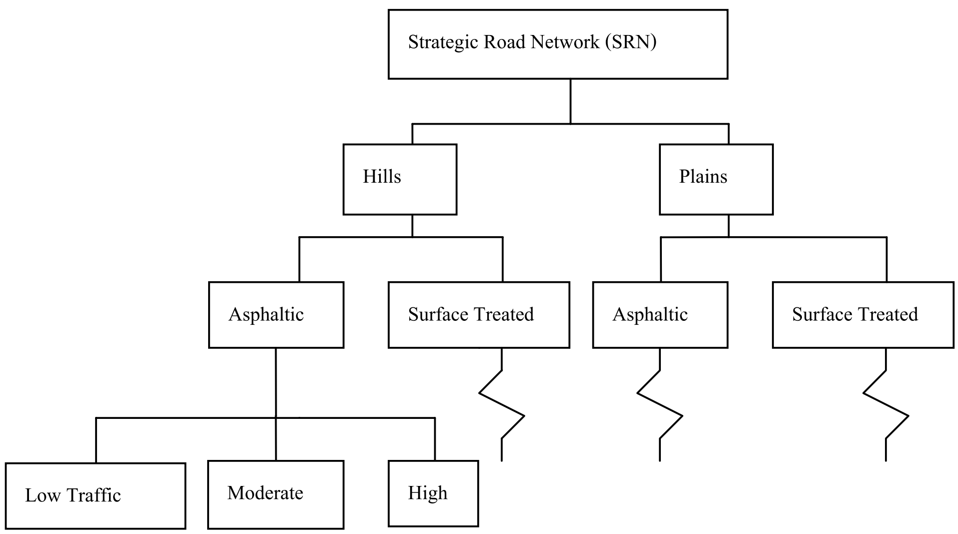

Figure 12 Pavement Family Definitions

The SDI data is thus grouped into twelve families. A "Family" is a group of road links or sections that exhibit a similar surface distress index trend. The idea of grouping the roads into the above mentioned families is to isolate projects with similar SDI behavior and thereby, reducing or eliminating the unexplained variability within the SDI data. The various pavement deteriorating factors such as construction methodology, road gradient, road geometry, vehicle speed, rainfall and temperature variation and land use pattern; all are not the same for the roads in different regions. Therefore grouping of the pavements into different families is an indirect way to account/control for variables that impact the SDI and when their specific information is not available. Now 12 pavement families are identified as shown in the Figure 12 and further details of the each family is presented in the Table 12 below.

Table 12 Length and Link Details of Pavement Families

Family	Description	Road Length (km)	Road Links (Nos.)	Remarks
1	Low traffic asphalted road in hills	0	0	No modeling
2	Moderate traffic asphalted road in hills	11.11	3	No modeling
3	High traffic asphalted road in hills	114.42	9	Modeled
4	Low traffic ST road in hills	239.38	13	Modeled
5	Moderate traffic ST road in hills	1,029.11	66	Modeled
6	High traffic ST road in hills	77.886	9	Modeled
7	Low traffic asphalted road in plains	0	0	No modeling
8	Moderate traffic asphalted road in plains	107.97	8	Modeled
9	High traffic asphalted road in plains	95.77	11	Modeled
10	Low traffic ST road in plains	0	0	No modeling
11	Moderate traffic ST road in plains	1,052.52	92	Modeled
12	High traffic ST road in plains	305.45	25	Modeled
Total		3,033.68	236	

Observation and Discussion of Data

Initial screening and diagnostics of SDI data revealed some trends and characteristics that are significant for the model development. Initial examination of the SDI for the individual road links or sections within the pavement family has revealed significant variation in the SDI among the different links for the same age. This variability is illustrated in the Figure 13 for pavement family 5: Surface treated pavement in hills with moderate traffic.

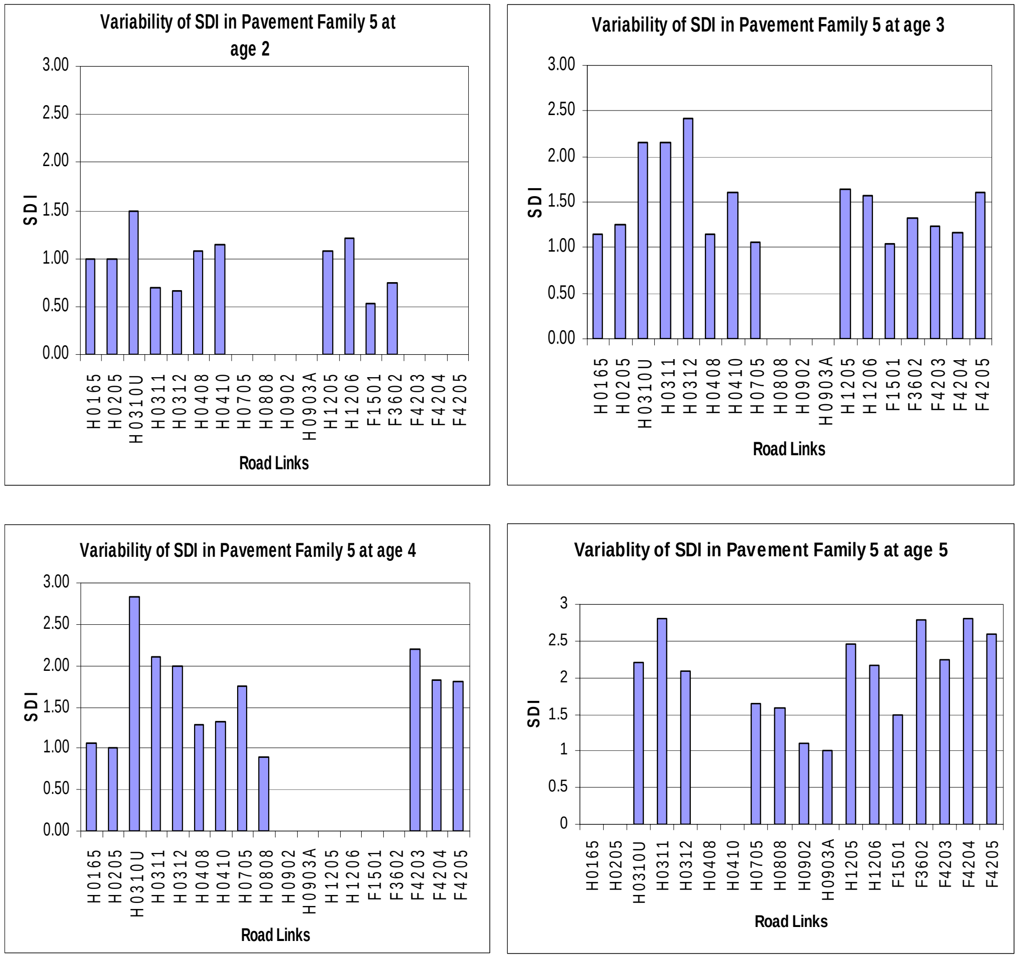

Figure 13 Variability of SDI data

The Figure 13 above clearly suggests, among other things, that pavement chronological age alone is unable to determine the SDI value even after controlling for pavement through different families. A "Family" is a group of road links or sections that exhibit similar SDI trend. The main idea to grouping of road sections is to isolate road sections with similar SDI behavior and thereby, reducing the unexplained variability. However, there is still a large variability in the SDI values indicating the deterioration rate of road links within the families is still significantly different. It indicated that the other important factors are missing to account for the deterioration process.

Those “other” factors should be considered in projecting SDI values for the future years. There are two possible ways to account for the other factors that influence the SDI; direct, and indirect. The direct way is to simply determine which factors are important and inventory information on those factors could be used in the model development directly. Since, we do not have those information available to model the deterioration, the indirect way involving the use of appropriate “surrogate” measures could work well (provided those surrogate measures could be identified). The surrogate measure should capture the after effects of the “other” factors without having to deal with those factors explicitly. Therefore, this indirect way could be used in the regression-based modeling.

Identifying Independent Variables

Independent variables are basically the factors that cause deterioration of the pavement and are used in modeling the pavement deterioration models. As explained earlier, the important factors that influence the deterioration are grouped under the three broad headings; namely environment, traffic and construction. The terrain, climate and local parameters under the environment, traffic volume and axle load under the traffic and design and construction standards, materials and workmanship quality under the construction are the most widely applicable independent variables used in the model development. In general, the deterioration functions indicate the impacts of different independent variables and could be represented as:

$$D = f[C_0, C, A, L, W, T, e] \tag{22}$$

where

D = deterioration function

C_0 = initial condition

C = present condition

A = rehabilitation performed in the past

L = load applied on the pavement

W = climate and environment factors (or locations)

T = time since construction of last rehabilitation

E = errors

However, in our study pavement chronological age is an independent variable available from the HMIS. But as discussed earlier, the previous year's SDI is equally an important independent variable to be considered in the model development. Since the information relating to traffic and environment for model development is not available, selecting the previous year's SDI as an independent variable is an indirect way in developing the model and this variable should capture the various pavement deteriorating factors without having to deal with those factors explicitly. Therefore, in our study there are two independent variables identified: namely pavement age and the previous year's SDI that could be used to formulate the pavement deterioration models.

Modeling Deterioration Function

The data are first collected for the initiation of the model formulation as mentioned earlier. The data are then carefully observed and filtered so that the reliable data values are only incorporated into the analysis and model development. Also, the data values are randomly checked for the outliers. The road pavements were also grouped into different families in order to isolate the road links or sections with similar deterioration rate and thereby to reduce the unexplained variability. The trend and the characteristics of data within each family are valuable for the model development and this revealed that there is significant variation in the SDI of different road sections for the same age within each families. Four forms of regression –based modeling are performed to develop an appropriate and correct model for the pavement deterioration.

SDI as a Function of Previous Year's SDI and Pavement Age (Form 1 Function)

The first form of the regression-based modeling is the multiple variable regressions. In this form, the present SDI is regressed against its previous year's SDI value and the corresponding pavement age. As mentioned in the preceding sections, there are important factors missing to address the pavement deterioration process and the chronological pavement age alone is unable to determine the SDI value even after controlling for pavement through different families. So as an indirect way to capture those missing factors, SDI value of the earlier year is considered to be one of the independent variables for multiple variable regressions and the function for this regression is given as follows:

$$SDI\ (t+1) = f[SDI\ (t)\ ,\ Age\ (t)] \tag{23}$$

where

SDI (t) is the SDI value at age t.

In this method, the value of a dependent variable is estimated given that the value of an associated variable is known. The dependent variable is the SDI for a given pavement family and the associated variable is the previous year's SDI value. The summarized results of multiple variable regressions for all pavement families under form 1 function will be presented in the Table B1 of the Appendix B.

SDI as a Function of Previous Year's SDI (Form 2 Function)

For the enhancement of the model's predicting ability, form 2 function (Equation 24) is considered in the regression-based modeling with the following five methods/formulas (Equations 25 through 29) for each pavement families.

$$SDI\ (t+1) = f[SDI\ (t)] \tag{24}$$

Linear $$SDI\ (t+1) = b_0 + b_1 * SDI\ (t) \tag{25}$$

S $$SDI\ (t+1) = e\text{^}[b_0 + [b_1/SDI(t)]] \tag{26}$$

Exponent $$SDI\ (t+1) = b_0 * [e\text{^}[b_1 * SDI(t)]] \tag{27}$$

Power $$SDI\ (t+1) = b_0 * [SDI\ (t)\text{^}b_1] \tag{28}$$

Logistic $SDI(t+1) = 1/[1/u+[b_0*[b_1\^SDI(t)]]]$ (29)

The dependent variable, SDI for given pavement family and the associated variable, the previous SDI value (the previous SDI value is SDI value 1 year earlier) are regressed. Like in the first form, SDI (1 year earlier) is only the independent variable that takes account of the missing important "other" factors into the regression. The summarized results of this form 2 function will be presented in the Table B2 through B9 in the Appendix B.

SDI as a Function of Pavement Age (Form 3 Function)

In general, the pavement deterioration increases as the age of the pavement increases. Therefore, form 3 functions as shown in Equation 30 and the different methods (formulas) as shown in Equations 31 through 41 are performed in the regression-based modeling for each pavement families. The dependent variable, observed SDI is regressed with the pavement's chronological age, independent variable. The methods also incorporate the non – linear transformation functions such as power and exponent methods. The transformed functions could enhance the regression results.

$SDI(t) = f[Age(t)]$ (30)

Linear $SDI(t) = b_0 + b_1*Age(t)$ (31)

Quadratic $SDI(t) = b_0 + b_1*Age(t) + b_2*Age(t)\^2$ (32)

Compound $SDI(t) = b_0*b_1\^Age(t)$ (33)

Growth $SDI(t) = e\^[b_0 + [b_1*Age(t)]]$ (34)

Log $SDI(t) = b_0 + [b_1*\ln[Age(t)]]$ (35)

Cubic $SDI(t) = b_0 + [b_1*Age(t)] + [b_2*[Age(t)\^2] + [b_3*Age(t)\^3]$ (36)

S $SDI(t) = e\^[b_0 + [b_1/Age(t)]]$ (37)

Exponent $SDI(t) = b_0*[e\^[b_1*Age(t)]]$ (38)

Inverse $SDI(t) = b_0 + [b_1/Age(t)]$ (39)

Power $SDI(t) = b_0*[Age\^b_1]$ (40)

Logistic $SDI(t) = 1/[1/u + [b_0 * [b_1 \text{^} Age(t)]]]$ (41)

The summarized results of this form 3 function will be presented in the Tables B10 through B17 in the Appendix B.

SDI as a Function of Previous Year's SDI and this Year's Pavement Age (Form 4 Function)

The form 4 function shown in Equation 42 is the multiple variable regressions. In this form, the present SDI is regressed against its previous year's SDI value and the present pavement age as independent variables. This functional form is considered into regression analysis to check whether or not this form could deliver better regression outputs.

$$SDI(t+1) = f[SDI(t), Age(t+1)] \quad (42)$$

The results from the form 4 function will be presented in the Table B18 in the Appendix B. Therefore, the process of building the pavement deterioration model that is the SDI prediction model from the collected data included running the regression analysis for each of the pavement families. The best functional equation or the deterioration models from each deterioration function forms discussed above will then be considered in selecting the best prediction model of each pavement family and that will be discussed in the next chapter.

Model Selection Criteria

Model accuracy is the most important aspect of the prediction model development and it is essential to ensure that:

1. The developed deterioration models fit well with the information that were used to produce the models

All the models that are formulated are analyzed statistically to ensure their accuracy towards their predicting ability. The criterion typically used to select the best fit of the data is the coefficient of determination, R^2. In addition to the accuracy of models, the significance of independent variables is determined using the t statistical test.

We want to know how powerful an explanation (or prediction) our regression model provides. A preliminary judgment could be done by a visual inspection of the scatter plot, the closer the regression line to the data points, the better the equation fits the data. Though such a 'eyeballing' is an essential first step, we further need a formal measure to determine the "goodness of fit" and the coefficient of determination or coefficient of multiple determination R^2 gives this to us. One of the best ways of interpreting a correlation coefficient (R) is to look at the square of the coefficient (R –squared). R-squared can be interpreted as the proportion of variance in one of the variables that can be explained by variation in the other variable.

For a particular value of $X_{1,}$ the regression line predicts the dependent (response) variable equal to $\hat{Y}_1$. The regression line manages to account for some of the deviation of this observation from the mean; specifically, it explains the proportion $\hat{Y}_1 - \overline{Y}$. However our prediction line is not perfect, but rather off by the quantity, $Y_1 - \hat{Y}_1$; this deviation is left unexplained by the regression equation. So the deviation of Y_1 from the mean can be grouped into the following components;

$(Y_1 - \overline{Y})$ = Total deviation of Y_1 from the mean, $\overline{Y}$

$(\hat{Y}_1 - \overline{Y})$ = Explained deviation of Y_1 from $\overline{Y}$

$(Y_1 - \hat{Y}_1)$ = Unexplained deviation of Y_1 from $\overline{Y}$

If we now square the deviations for each observation in our study and then sum, we obtain the complete components of variation for the response variable.

$\sum(Y_i - \overline{Y})^2$ = Total Sum of Squared deviations (TSS)

$\sum(\hat{Y}_1 - \overline{Y})^2$ = Regression (explained) Sum of Squared deviations (RSS) or model Sum of Squares

$\sum(Y_i - \hat{Y}_1)^2$ = Error (unexplained) Sum of Squared deviation (ESS)

Therefore,

$$TSS = RSS + ESS \tag{43}$$

TSS indicates the total variation in the response variable that we want to explain. This total variation can be divided into two parts; the part accounted for by the regression equation (RSS) and the part the regression equation can not account for, ESS. It is important to note that the Least Squares procedures guarantees that this error component is at the minimum. It is now clear that larger RSS relative to TSS the better the fit of the model. This forms the basis of the R^2 measure.

$$R^2 = RSS / TSS \tag{44}$$

So, larger RSS means smaller the ESS, the unexplained error sum of squared deviations. When ESS is equal to zero, R^2 is equal to its maximum value of 1, all the data points pass through the regression/model line. When R^2 is equal to zero, independent variables account for no variation in the dependent variable and the slope of the line equals to zero. Another thing to be noted is that when the data points are clustered more tightly around the regression line, the model fits much better.

In the case of multiple regressions, R^2 is referred to as the coefficient of multiple determinations.

$$R^2 = \frac{\sum (\hat{Y}_i - \overline{Y})^2}{\sum (Y_i - \overline{Y})^2} \tag{45}$$

R^2 in the multiple regression equation indicates the proportion of variation in Y explained by all the independent variables used in modeling.

Normally the deviation about the regression line (error mean square) is compared to the deviation between the predicted values and the mean (model mean square) to see the goodness of the regression line.

To compare Mean Squares (MS), the ratio is formed,

$$F = \text{Mean Square Model} / \text{Mean Square Error} \tag{46}$$

The larger the ratio, the better is the fit for the given number of data values. Significance F is the probability of obtaining F value this large or larger by chance alone. If this probability is large (> 0.05) then our linear model is not doing good job in describing the relationship or association between the variables.

T values and the associated probabilities Prob > |T| tests the Hypothesis that the parameter is actually zero i.e. if the true slope and the intercept were zero, what would be the probability be of obtaining by chance alone, a value as large as or larger than the one actually obtained.

Formally we have two basic hypotheses:

Null Hypothesis: It states that X is not associated with Y; therefore the slope is zero in the population.

An Alternative Hypothesis: It states that X is associated with Y; therefore, the slope is not zero in the population.

H_0: $\beta = 0$ (null hypothesis)

H_1: $\beta \neq 0$ (alternative hypothesis)

Smaller p-value indicates that the parameter estimates are significantly different from zero. Generally, if a p-value is less than 0.05 it is thought that the chance of the null hypothesis holding true is so unlikely that the null hypothesis is rejected in favor of the alternative hypothesis.

Maintainable Pavement Age Prediction

The road pavements are maintainable until certain deterioration levels only and in Nepal, roads are considered to be in the maintainable condition when the SDI value is equal to or less than 3.0. Therefore, an approach by which the maintainable pavement age is predicted using the pavement deterioration model may be termed as maintainable pavement age prediction. The maintainable age prediction will depend on the form of functions of pavement deterioration that will be selected in the pavement deterioration models. The four forms of the pavement deterioration have been already presented in the previous section. There could be two possible cases for this age prediction; one is when the deterioration is the function of previous year's observed SDI; and another is when the deterioration is the function of the pavement age alone.

In the first case, the maintainable pavement age prediction is a step-wise process and could be easily programmed in a spreadsheet. In this case the previous year's SDI is an associated variable (independent) so model equation will calculate this year's SDI value using the previous year's observed SDI value and similarly the next year's value is calculated from the calculated SDI value for this year and so on. This step-wise process is continued until we get our predefined SDI threshold (SDI = 3.0).

Whereas, in the second case when the deterioration function is the pavement age alone; we simply need to plug the pavement age values in the model equation to get the predefined SDI threshold. The results and discussion regarding the maintainable pavement age prediction will be included in the next chapter.

RESULTS AND DISCUSSION

Four forms of regression-based modeling are initially evaluated and their corresponding results are summarized in the Tables B1 through B18 in the Appendix B. Two forms of modeling approaches are based on multivariable regressions and the remaining two forms are based on bi-variable regressions. In the multivariable regressions, the Equations 23 and 42 are used as the general form of deterioration for analysis, whereas, in bi-variable regressions, Equations 24 and 30 are the general form of deterioration for regression analysis. Results from the above four form of deterioration in the analysis are discussed in the following sub-headings.

SDI as a Function of Previous Year's SDI and Pavement Age (Form 1 Function)

In the first forms of the regression – based modeling, the present SDI is regressed against its previous year's SDI and the corresponding pavement age. The general equation for this form of regression is as:

$$\text{SDI}(t+1) = f[\text{SDI}(t), \text{Age}(t)] \tag{47}$$

The summarized results for each pavement groups (families) with general form of deterioration as in Equation 47 is presented in the Table 13 and the table shows R^2 value, Standard error, F value, Significance F, T Statistics and Significance T (P value). The R^2 values ranges from 0.5740 to 0.9526, which is considerably satisfactory. Standard errors are in the range of 0.2332 to 0.4959 and the Significance F is less than 0.05 levels for all pavements. If this Significance F value is greater than 0.05, the model is considered not to describe the relationships of the variables quite well. However, the P-value for SDI parameter estimates are 0.4905 (pavement family 4), 0.8325 (pavement family 8), 0.0633 (pavement family 12); all P values are higher than the maximum allowable limit of 0.05. Likewise, P –values for age parameter estimates are 0.3838 (pavement family 3), 0.1169 (pavement family 5), 0.6047 (pavement family 6), and 0.1985 (pavement family 11); all values are greater than 0.05. But for pavement family 9, P-values for SDI and age parameter estimates are 0.0892 and 0.0606 both being higher than 0.05. Those higher P –values indicate that the parameter estimates are significantly not different from zero and there is always a high chance of the Null Hypothesis being true. The pavement deterioration model equations under this form of deterioration are presented in the Table 14.

Table 13 Regression model results – all pavement families (form 1 as per Equation 47)

Family	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T (P value)
3	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.6773	0.4914	5.0684	0.2415	20.9856	0.0000	SDI (1yr before)	0.6239	0.2728	3.1768	0.0047
									Age (1yr before)	0.1136	0.1964	0.8904	0.3838
									Intercept	0.8128	0.1276	2.9796	0.0074
4	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.9526	0.2332	7.1055	0.0544	130.6275	0.0000	SDI (1 yr before)	0.1527	0.2151	0.7096	0.4905
									Age (1 yr before)	0.4339	0.1303	3.3313	0.0054
									Intercept	0.3118	0.2180	1.4304	0.1762
5	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.6493	0.3646	3.8175	0.1329	28.7035	0.0000	SDI (1 yr before)	0.5930	0.1423	4.1652	0.0002
									Age (1 yr before)	0.0917	0.0568	1.6128	0.1169
									Intercept	0.8263	0.1713	4.8227	0.0000
6	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.6975	0.4959	2.2684	0.2459	9.2221	0.0084	SDI (1yr before)	0.8299	0.2419	3.4300	0.0089
									Age (1yr before)	-0.0916	0.1701	-0.5387	0.6047
									Intercept	0.9685	0.3589	2.6986	0.0271
8	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.5740	0.3585	1.3863	0.1285	10.7811	0.0010	SDI (1 yr before)	0.0809	0.3767	0.2148	0.8325
									Age (1 yr before)	0.3891	0.1643	2.3669	0.0309
									Intercept	0.6379	0.3187	2.0017	0.0625
9	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.7314	0.2889	2.0400	0.0834	24.5036	0.0000	SDI (1yr before)	0.4427	0.2464	1.7963	0.0892
									Age (1 yr before)	0.2302	0.1150	2.0015	0.0606
									Intercept	0.3681	0.2237	1.6447	0.1173
11	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.7974	0.2516	7.0978	0.0632	112.1501	0.0000	SDI(1 yr before)	0.7003	0.1076	6.5043	0.0000
									Age (1 yr before)	0.0603	0.0463	1.3006	0.1985
									Intercept	0.6299	0.0901	6.9868	0.0000
12	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.6653	0.3226	2.0697	0.1041	19.8823	0.0000	SDI (1 yr before)	0.4612	0.2346	1.9657	0.0633
									Age (1 yr before)	0.2096	0.0902	2.3226	0.0309
									Intercept	0.1691	0.2772	0.6099	0.5487

Table 14 Pavement deterioration models

Pavement Family	Pavement Deterioration Model
3	SDI(t+1) = 0.8128 + 0.6239*SDI(t) +0.1136*Age(t)
4	SDI(t+1) = 0.3118 + 0.1527*SDI(t) +0.4339*Age(t)
5	SDI(t+1) = 0.8263 + 0.5930*SDI(t) +0.0917*Age(t)
6	SDI(t+1) = 0.9685 + 0.8299*SDI(t) +0.0916*Age(t)
8	SDI(t+1) = 0.6379 + 0.0809*SDI(t) +0.3891*Age(t)
9	SDI(t+1) = 0.3681 + 0.4427*SDI(t) +0.2302*Age(t)
11	SDI(t+1) = 0.6299 + 0.7003*SDI(t) +0.0603*Age(t)
12	SDI(t+1) = 0.1691 + 0.4612*SDI(t) +0.2096*Age(t)

SDI as a Function of Previous Year's SDI (Form 2 Function)

In the second form of regression–based modeling, present SDI is regressed against its previous year's SDI. Equation 48 is the general form of deterioration function for analysis. Five methods (formulas) are used under for regression analysis and they are presented in the Equations 49 through 53. The summarized regression results from Equations 49 through 53 for each pavement groups (families) are presented in Tables B2 through B9 in the Appendix B.

	SDI (t+1) = f[SDI (t)]	(48)
Linear	SDI (t+1) = b_0 + b_1*SDI (t)	(49)
S	SDI (t+1) = e^[b_0 +[b_1/SDI(t)]]	(50)
Exponent	SDI (t+1) = b_0*[e^[b_1*SDI(t)]]	(51)
Power	SDI (t+1) = b_0*[SDI (t)^b_1]	(52)
Logistic	SDI (t+1) = 1/[1/u+[b_0*[b_1^SDI (t)]]]	(53)

The selection criteria are based on the value of coefficient of determination, R^2. Therefore, only the best results from the above five formulas of each pavement families are considered in discussion and are presented in Table 15. According to Table 15, R^2 of all pavement families range from 0.4718 to 0.9121 and Standard errors from 0.2038 to 0.6257. Similarly Significance F and P – values for SDI parameter estimates are nearly equal to zero for all the pavement families. The selected pavement deterioration model equations under this form of deterioration are presented in the Table 16.

<u>Table 15</u> Regression model results – all pavement families (form 2 as per Equation 48)

Family	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables				Sig. T (P value)
									Parameters	Values	Std. Error	T Stat	
3	LGSTIC	$y = 1/[1/u + [b_0*[b_1\hat{}SDI]]]$	0.6669	0.6257	16.4629	0.3915	42.0485	0.0000	SDI	0.3747	0.0567	6.6050	0.0000
		u = +ve & larger than Dep. Var.(4)							Constant	0.9306	0.2543	3.6600	0.0015
4	LINEAR	$y = b_0 + b_1*SDI$	0.9121	0.3060	13.6074	0.0936	145.3334	0.0000	SDI	0.8468	0.0702	12.0550	0.0000
									Constant	0.9109	0.1617	5.6320	0.0001
5	LGSTIC	$y = 1/[1/u + [b_0*[b_1\hat{}SDI]]]$	0.6208	0.3757	7.3952	0.1412	52.3911	0.0000	SDI	0.4681	0.0491	9.5360	0.0000
		u = +ve & larger than Dep. Var.(4.2)							Constant	0.7895	0.1323	5.9680	0.0000
6	LGSTIC	$y = 1/[1/u + [b_0*[b_1\hat{}SDI]]]$	0.7042	0.5051	5.4647	0.2551	21.4213	0.0012	SDI	0.4413	0.0780	5.6580	0.0003
		u = +ve & larger than Dep. Var.(4)							Constant	0.8736	0.2704	3.2310	0.0103
8	POWER	$y = b_0 *[SDI\hat{}b_1]$	0.4718	0.2038	0.6305	0.0415	15.1845	0.0012	SDI	0.6482	0.1663	3.8970	0.0012
									Constant	1.5164	0.1127	13.4530	0.0000
9	LINEAR	$y = b_0 + b_1*SDI$	0.6716	0.3110	3.7576	0.0967	38.8541	0.0000	SDI	0.8634	0.1385	6.2330	0.0000
									Constant	0.5765	0.2132	2.7040	0.0141
11	LINEAR	$y = b_0 + b_1*SDI$	0.7914	0.2531	14.0886	0.0640	219.9846	0.0000	SDI	0.8207	0.0553	14.8320	0.0000
									Constant	0.6827	0.0810	8.4270	0.0000
12	LGSTIC	$y = 1/[1/u + [b_0*[b_1\hat{}SDI]]]$	0.5852	0.3701	4.0574	0.1369	29.6296	0.0000	SDI	0.3918	0.0674	5.8090	0.0000
		u = +ve & larger than Dep. Var.(4)							Constant	1.1722	0.3024	3.8760	0.0009

Table 16 Pavement deterioration models

Pavement Family	Formula	Pavement Deterioration Model
3	Logistic	SDI(t+1) = 1/[1/4+[0.9306*[0.3747^SDI(t)]]]
4	Linear	SDI(t+1) = 0.9109 + 0.8468*SDI(t)
5	Logistic	SDI(t+1) = 1/[1/4.2+[0.7985*[0.4681^SDI(t)]]]
6	Logistic	SDI(t+1) = 1/[1/4+[0.8736*[0.4413^SDI(t)]]]
8	Power	SDI(t+1) = 1.5164*[SDI(t)^0.6482]
9	Linear	SDI(t+1) = 0.5765 + 0.8634*SDI(t)
11	Linear	SDI(t+1) = 0.6827 + 0.8207*SDI(t)
12	Logistic	SDI(t+1) = 1/[1/4+[0.1.1722*[0.3918^SDI(t)]]]

SDI as a Function of Pavement Age (Form 3 Function)

In the third form of regression-based modeling, observed SDI as a dependent variable is regressed against the pavement chronological age as an independent variable. The general deterioration function for the regression analysis is presented in the Equation 54. Various forms of mathematical equations (methods) as given in Equations 55 through 65 are used under the regression in this deterioration form. The summarized regression results for each pavement families are presented in the Tables B10 through B17 in the Appendix B

	$SDI(t) = f[Age(t)]$	(54)
Linear	$SDI(t) = b_0 + b_1 * Age(t)$	(55)
Quadratic	$SDI(t) = b_0 + b_1 * Age(t) + b_2 * Age(t)^2$	(56)
Compound	$SDI(t) = b_0 * b_1 ^{Age(t)}$	(57)
Growth	$SDI(t) = e^{[b_0 + [b_1 * Age(t)]]}$	(58)
Log	$SDI(t) = b_0 + [b_1 * \ln[Age(t)]]$	(59)
Cubic	$SDI(t) = b_0 + [b_1 * Age(t)] + [b_2 * [Age(t)^2] + [b_3 * Age(t)^3]$	(60)
S	$SDI(t) = e^{[b_0 + [b_1 / Age(t)]]}$	(61)
Exponent	$SDI(t) = b_0 * [e^{[b_1 * Age(t)]}]$	(62)
Inverse	$SDI(t) = b_0 + [b_1 / Age(t)]$	(63)
Power	$SDI(t) = b_0 * [Age^{b_1}]$	(64)
Logistic	$SDI(t) = 1/[1/u + [b_0 * [b_1 ^{Age(t)}]]]$	(65)

Since 11 equations are used to formulate the deterioration model under the deterioration function in Equation 54 for each pavement families, only the best results amongst above formulas are considered for discussion. The best results are selected based on the R^2 values. The regression results thus obtained for each pavement families are presented in the Table 17. According to the Table 17, the R^2 values range from 0.5676 to 0.8858 and the Standard errors range from 0.1598 to 0.3882. The F significance and the P – values for parameter estimates are all zero indicating the suitability of the models for future pavement performance predictions. The selected pavement deterioration model equations under this form of deterioration are presented in the Table 18.

Table 17 Regression model results – all pavement families (form 3 as per Equation 54)

Family	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables Parameters	Values	Std. Error	T Stat	Sig. T (P value)
3	S	$y = e^{\wedge}[b_0 + [b_1/age]]$	0.8847	0.3383	27.2232	0.1144	237.8933	0.0000	AGE	-4.4608	0.2892	-15.4240	0.0000
									Constant	1.8794	0.1134	16.5710	0.0000
4	LINEAR	$y = b_0 + b_1 * age$	0.8858	0.3421	29.9462	0.1170	255.9190	0.0000	AGE	0.5066	0.0317	15.9970	0.0000
									Constant	-0.2831	0.1550	-1.8260	0.0769
5	POWER	$y = b_0 * [age^{\wedge}b_1]$	0.5676	0.2799	7.199	0.0784	91.87676	0.0000	AGE	0.7184	0.0749	9.5850	0.0000
									Constant	0.6119	0.0662	9.2460	0.0000
6	S	$y = e^{\wedge}[b_0 + [b_1/age]]$	0.6349	0.3882	5.5040	0.1507	36.5250	0.0000	AGE	-2.1442	0.3548	-6.0440	0.0000
									Constant	1.2778	0.1558	8.1990	0.0000
8	POWER	$y = b_0 * [age^{\wedge}b_1]$	0.8146	0.1598	2.5804	0.0255	101.0224	0.0000	AGE	0.9041	0.0900	10.0510	0.0000
									Constant	0.5411	0.0619	8.7440	0.0000
9	EXPONENT	$y = b_0 * [e^{\wedge}[b_1 * age]]$	0.8148	0.1581	2.7468	0.0250	109.9555	0.0000	AGE	0.2396	0.0228	10.4860	0.0000
									Constant	0.5824	0.0570	10.2110	0.0000
11	S	$y = e^{\wedge}[b_0 + [b_1/age]]$	0.7756	0.2544	22.3788	0.0647	345.6840	0.0000	AGE	-4.0848	0.2197	-18.5930	0.0000
									Constant	1.5267	0.0660	23.1240	0.0000
12	EXPONENT	$y = b_0 * [e^{\wedge}[b_1 * age]]$	0.7025	0.1943	2.4954	0.0378	66.1030	0.0000	AGE	0.2048	0.0252	8.1300	0.0000
									Constant	0.5353	0.0718	7.4560	0.0000

Table 18 Pavement deterioration models

Pavement Family	Formula	Pavement Deterioration Model
3	S	SDI(t) = e^[1.8794 +[-4.4608/Age(t)]
4	Linear	SDI(t) = -0.2831 + 0.5066*Age(t)
5	Power	SDI(t) = 0.6119*[Age(t)^0.7184]
6	S	SDI(t) = e^[1.2778 +[-2.1442/Age(t)]
8	Power	SDI(t) = 0.5411*[Age(t)^0.9041]
9	Exponent	SDI(t) = 0.5824*[e^[0.2396*Age(t)]]
11	S	SDI(t) = e^[1.5267 +[-4.0848/Age(t)]
12	Exponent	SDI(t) = 0.5353*[e^[0.2048*Age(t)]]

<u>SDI as a Function of Previous Year's SDI and this Year's Pavement Age (Form 4 Function)</u>

In the fourth form of the regression – based modeling, the present SDI is regressed against its previous year's SDI and the present pavement age. The general deterioration functional equation for this form of regression is as:

$$SDI\ (t+1) = f[SDI\ (t),\ Age\ (t+1)] \quad (66)$$

The summarized results for each pavement groups (families) with general form of deterioration as in Equation 66 is presented in the Table 19 and the table shows R^2 value, Standard error, F value, Significance F, T Statistics and Significance T (P value). According the Table 19, R^2 values for all pavement families ranges from 0.5740 to 0.9526; the values being same as that obtained from the Equation 47, and is considerably satisfactory. Standard errors are in the range of 0.2332 to 0.4960 and the Significance F is less than 0.05 levels for all pavements. However, the P-value for SDI parameter estimates are 0.4905 (pavement family 4), 0.8326 (pavement family 8), 0.0634 (pavement family 12); all P values are higher than the maximum allowable limit of 0.05. Likewise, P –values for age parameter estimates are 0.3839 (pavement family 3), 0.1169 (pavement family 5), 0.6047 (pavement family 6), and 0.1986 (pavement family 11); all values are greater than 0.05. But for pavement family 9, P-values for SDI and age parameter estimates are 0.0892 and 0.0606 both being higher than 0.05. The results from this form of deterioration function are virtually unchanged to that from the deterioration function in Equation 47. Those higher P –values indicate that the parameter estimates are significantly not different from zero and there is always a high chance of the Null Hypothesis being true. The selected pavement deterioration model equations under this form of deterioration are presented in the Table 20.

Table 19 Regression model results – all pavement families (form 4 as per Equation 66)

Family	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T (P value)
3	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t+1)	0.6773	0.4914	5.0684	0.2415	20.9856	0.0000	SDI (t)	0.6239	0.1964	3.1768	0.0047
									Age (t+1)	0.1136	0.1276	0.8904	0.3839
									Constant	0.6991	0.3656	1.9121	0.0703
4	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t+1)	0.9526	0.2332	7.1055	0.0544	130.6275	0.0000	SDI (t)	0.1527	0.2151	0.7096	0.4905
									Age (t+1)	0.4340	0.1303	3.3313	0.0054
									Constant	-0.1221	0.3337	-0.3660	0.7202
5	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t+1)	0.6493	0.3647	3.8175	0.1330	28.7035	0.0000	SDI (t)	0.5930	0.1424	4.1653	0.0002
									Age (t+1)	0.0917	0.0569	1.6129	0.1169
									Constant	0.7346	0.1968	3.7335	0.0008
6	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t+1)	0.6975	0.4960	2.2684	0.2460	9.2221	0.0084	SDI (t)	0.8299	0.2420	3.4300	0.0090
									Age (t+1)	-0.0916	0.1701	-0.5387	0.6047
									Constant	1.0602	0.4721	2.2457	0.0549
8	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t+1)	0.5740	0.3586	1.3863	0.1286	10.7812	0.0011	SDI (t)	0.0810	0.3768	0.2149	0.8326
									Age (t+1)	0.3891	0.1644	2.3669	0.0309
									Constant	0.2489	0.3796	0.6557	0.5214
9	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t+1)	0.7314	0.2890	2.0460	0.0835	24.5036	0.0000	SDI (t)	0.4427	0.2464	1.7963	0.0892
									Age (t+1)	0.2302	0.1150	2.0015	0.0606
									Constant	0.1379	0.2954	0.4667	0.6463
11	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t+1)	0.7974	0.2516	7.0978	0.0633	112.1501	0.0000	SDI (t)	0.7003	0.1077	6.5043	0.0000
									Age (t+1)	0.0603	0.0464	1.3007	0.1986
									Constant	0.5697	0.1185	4.8083	0.0000
12	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t+1)	0.6654	0.3226	2.0698	0.1041	19.8823	0.0000	SDI (t)	0.4612	0.2346	1.9657	0.0634
									Age (t+1)	0.2096	0.0903	2.3227	0.0309
									Constant	-0.0405	0.3380	-0.1199	0.9058

Table 20 Pavement deterioration models

Pavement Family	Pavement Deterioration Model
3	SDI(t+1) = 0.6991 + 0.6239*SDI(t) +0.1136*Age(t+1)
4	SDI(t+1) = -0.1221 + 0.1527*SDI(t) +0.4340*Age(t+1)
5	SDI(t+1) = 0.7346 + 0.5930*SDI(t) +0.0917*Age(t+1)
6	SDI(t+1) = 1.0602 + 0.8299*SDI(t) - 0.0916*Age(t+1)
8	SDI(t+1) = 0.24879 + 0.0810*SDI(t) +0.3891*Age(t+1)
9	SDI(t+1) = 0.1379 + 0.4427*SDI(t) +0.2302*Age(t+1)
11	SDI(t+1) = 0.5697 + 0.7003*SDI(t) +0.0603*Age(t+1)
12	SDI(t+1) = - 0.0405 + 0.4612*SDI(t) +0.2096*Age(t+1)

Selected Pavement Deterioration Models

As explained earlier, four forms of the deterioration functions were selected in the formulation of pavement deterioration models. The summarized results for four forms were presented in Tables 13, 15, 17, and 19 and accordingly discussed in the previous sections. The accuracy of the models is determined based on the value of R^2 and the significance in the relationships is determined by the p-values. So based on the R^2 and p-values the pavement deterioration models are selected for each of the pavement families. In the pavement deterioration functions presented in Equations 47 and 66 (form 1 and 4 functions), the p-values for parameter estimates are greater than 0.05. Those higher p-values indicate that the parameter estimates are significantly not different from zero and there is always a high chance of the Null Hypothesis becoming true. Therefore, the pavement deterioration models are not selected from those two forms of the deterioration functions as summarized in the Tables 13 and 19.

The final selection of pavement deterioration models are limited to the deterioration functional Equations 48 and 54 only and the pavement deterioration model equations are presented in the Table 22. The complete summarized results for eight pavement families are presented in the Table 21 and the discussion regarding them are presented in the following paragraphs.

The curve fit plots are presented in the Figures 14 through 21; it also includes the values of R^2 and standard error and the deterioration model equation. The curve fit plots have the dependent variable in y-axis and the independent variable in x-axis with the best fit curves of different mathematical functions. The Statistical Package for Social Science (SPSS) has been used in the regression analysis and in the curve plots.

Table 21 Best Selected Regression Models for All Pavement Families

Family	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Variables: Values	Variables: Std. Error	T Stat	Sig. T (P value)	Maintainable pavement life in yrs.
3	S	SDI (t) =e^[b_0 +[b_1/age(t)]]	0.8847	0.3383	27.2232	0.1144	237.8933	0.0000	AGE	-4.4608	0.2892	-15.4240	0.0000	**Approximately 6**
									Constant	1.8794	0.1134	16.5710	0.0000	
4	LINEAR	SDI (t+1) = b_0+b_1*SDI(t)	0.9121	0.3060	13.6074	0.0936	145.3334	0.0000	SDI	0.8468	0.0702	12.0550	0.0000	**6 ~ 7**
									Constant	0.9109	0.1617	5.6320	0.0001	
5	LGSTIC	SDI (t+1) = 1/[1/u+[b_0*[b_1^SDI(t)]]] u = +ve & larger than Dep. Var.(4.2)	0.6208	0.3757	7.3952	0.1412	52.3911	0.0000	SDI	0.4681	0.0491	9.5360	0.0000	**6 ~ 9**
									Constant	0.7895	0.1323	5.9680	0.0000	
6	LGSTIC	SDI (t+1) = 1/[1/u+[b_0*[b_1^SDI(t)]]]	0.7042	0.5051	5.4647	0.2551	21.4213	0.0012	SDI	0.4413	0.0780	5.6580	0.0003	**7 ~ 9**
		u = +ve & larger than Dep. Var.(4)							Constant	0.8736	0.2704	3.2310	0.0103	
8	POWER	SDI (t) = b_0 * [age(t)^b_1]	0.8146	0.1598	2.5804	0.0255	101.0224	0.0000	AGE	0.9041	0.0900	10.0510	0.0000	**6 ~ 7**
									Constant	0.5411	0.0619	8.7440	0.0000	
9	EXPONENT	SDI (t) = b_0 *[e^[b_1*age(t)]]	0.8148	0.1581	2.7468	0.0250	109.9555	0.0000	AGE	0.2396	0.0228	10.4860	0.0000	**6 ~ 7**
									Constant	0.5824	0.0570	10.2110	0.0000	
11	LINEAR	SDI (t+1) = b_0+b_1*SDI(t)	0.7914	0.2531	14.0886	0.0640	219.9846	0.0000	SDI	0.8207	0.0553	14.8320	0.0000	**8 ~ 10**
									Constant	0.6827	0.0810	8.4270	0.0000	
12	EXPONENT	SDI (t) = b_0 *[e^[b_1*age(t)]]	0.7025	0.1943	2.4954	0.0378	66.1030	0.0000	AGE	0.2048	0.0252	8.1300	0.0000	**Approximately 8**
									Constant	0.5353	0.0718	7.4560	0.0000	

Table 22 Selected pavement deterioration models

Pavement Family	Formula	Pavement Deterioration Model	Independent Variable
Asphaltic roads in hills with high traffic (Family 3)	S	SDI(t) = e^[1.8794 + [-4.4608/Age(t)]	Age
Surface treated roads in hills with low traffic (Family 4)	Linear	SDI(t+1) = 0.9109 + 0.8468*SDI(t)	Previous year's SDI
Surface treated roads in hills with moderate traffic (Family 5)	Logistic	SDI(t+1) = 1/[1/4.2+[0.7985*[0.4681^SDI(t)]]]	Previous year's SDI
Surface treated roads in hills with high traffic (Family 6)	Logistic	SDI(t+1) = 1/[1/4+[0.8736*[0.4413^SDI(t)]]]	Previous year's SDI
Asphaltic roads in plains with moderate traffic (Family 8)	Power	SDI(t) = 0.5411*[Age(t)^0.9041]	Age
Asphaltic roads in plains with high traffic (Family 9)	Exponent	SDI(t) = 0.5824*[e^[0.2396*Age(t)]]	Age
Surface treated roads in plains with moderate traffic (Family 11)	Linear	SDI(t+1) = 0.6827 + 0.8207*SDI(t)	Previous year's SDI
Surface treated roads in plains with high traffic (Family 12)	Exponent	SDI(t) = 0.5353*[e^[0.2048*Age(t)]]	Age

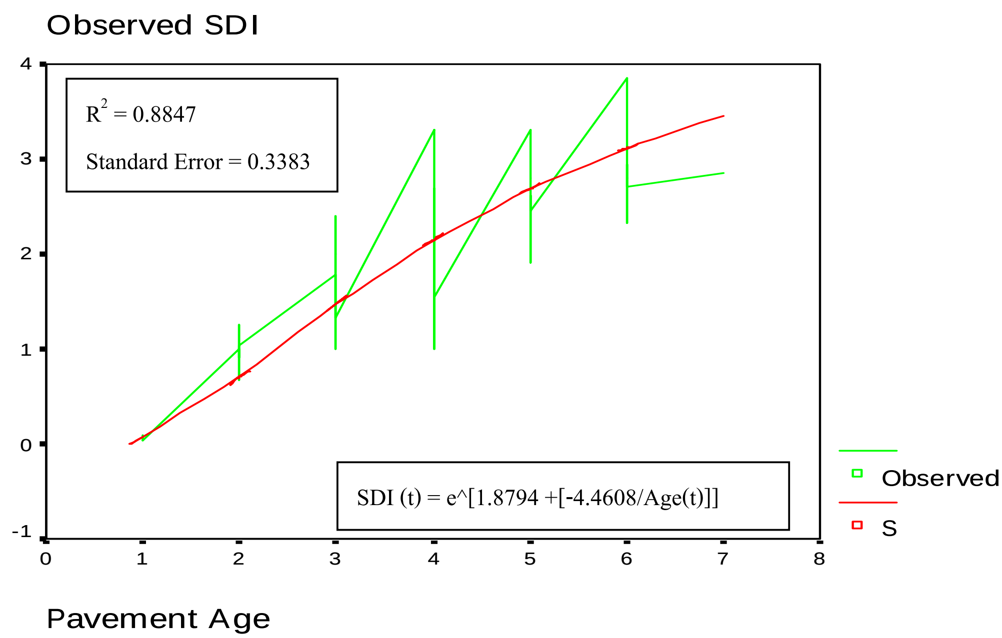

Figure 14 Curve fit plot for Family 3- Asphalted pavement in hills with high traffic

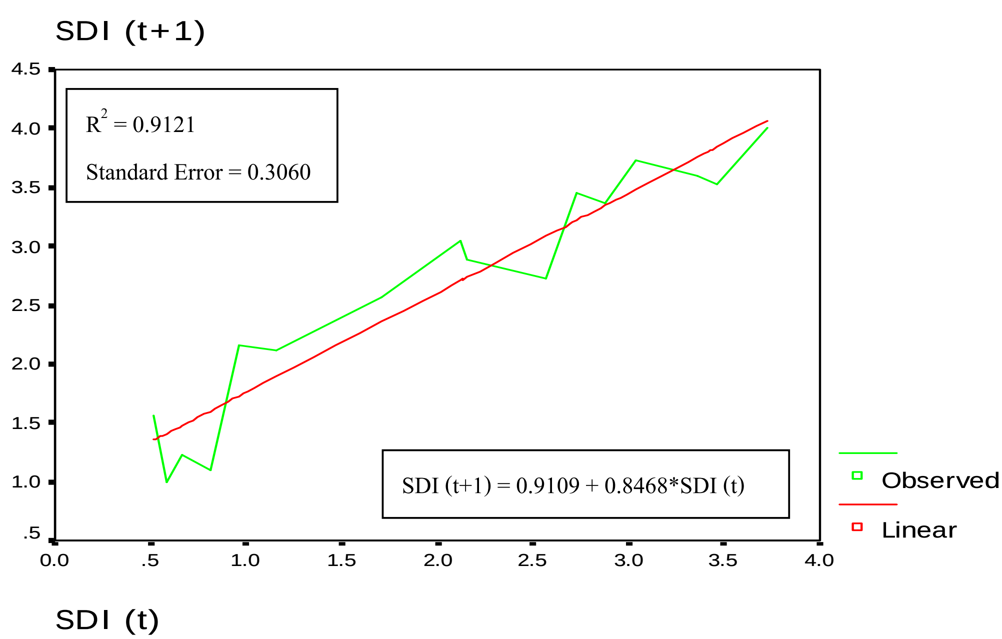

Figure 15 Curve fit plot for Family 4- Surface treated pavement in hills with low traffic

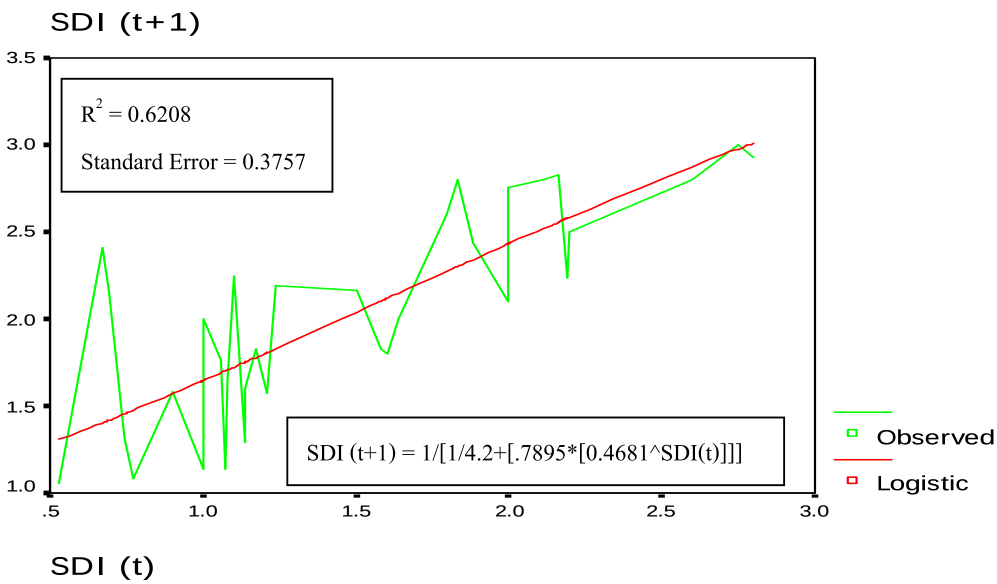

Figure 16 Curve fit plot for Family 5- Surface treated pavement in hills with Moderate traffic

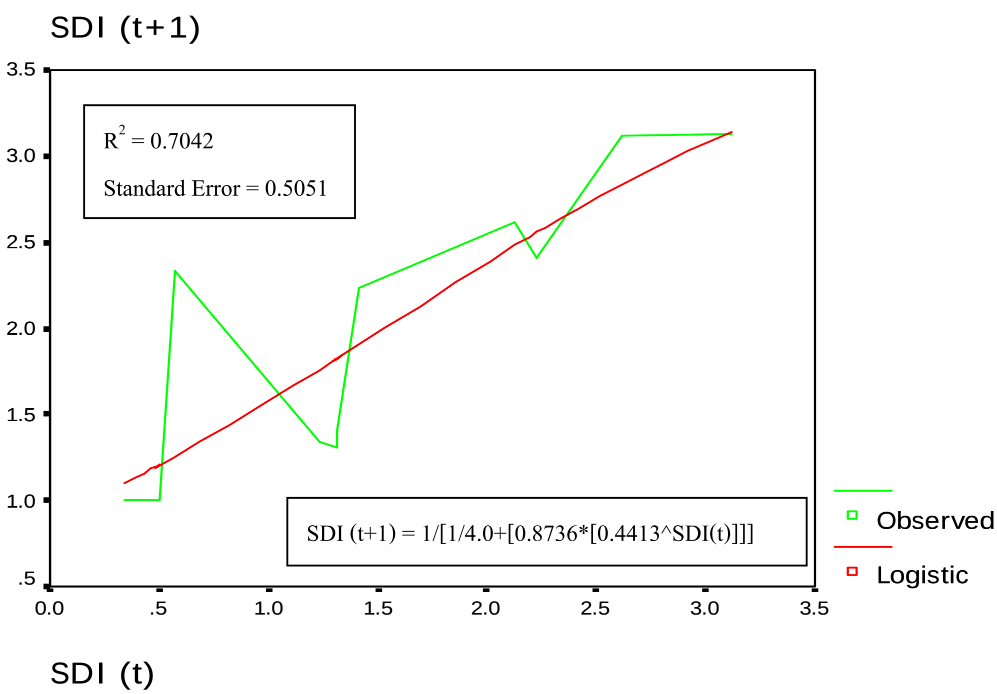

Figure 17 Curve fit plot for Family 6- Surface treated pavement in hills with High traffic

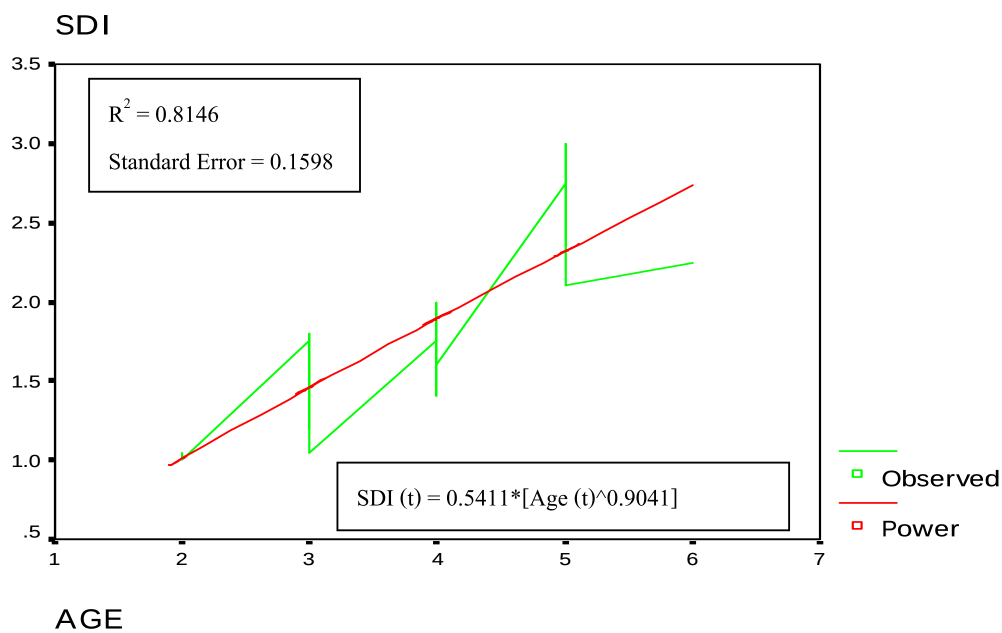

Figure 18 Curve fit plot for Family 8- Asphalted pavement in plains with moderate traffic

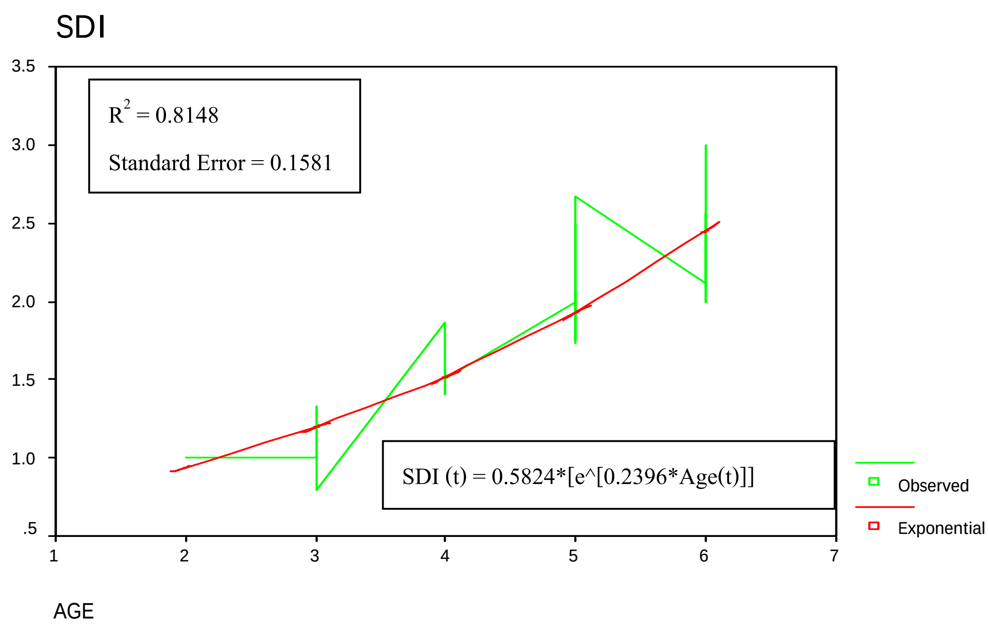

Figure 19 Curve fit plot for Family 9- Asphalted pavement in plains with high traffic

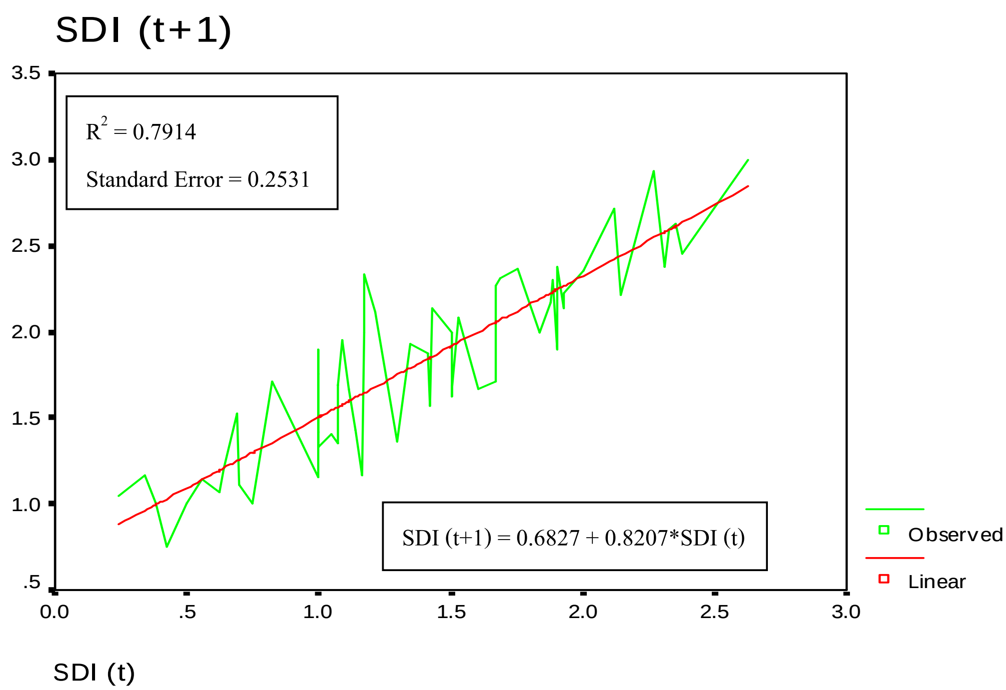

Figure 20 Curve fit plot for Family 11- Surface treated pavement in plains with moderate traffic

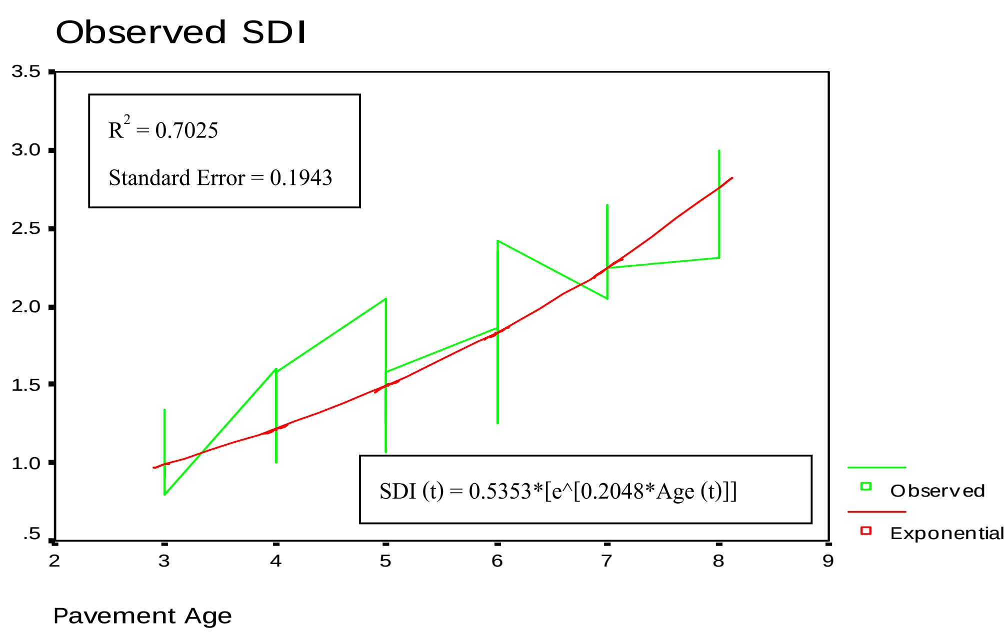

Figure 21 Curve fit plot for Family 12- Surface treated pavement in plains with high traffic

Discussion on Selected Models

1. The pavements are grouped broadly into hill and plain pavements and they are each further divided into two depending on the pavement surfacing; asphaltic and surface treated. Each group formed above is further divided into three groups depending on the traffic volume on them; they are low, moderate and high traffic levels. Therefore there is a formation of 12 pavement families under this study and out of which only 8 families are considered into modeling. From the summarized results in Table 22, it is clear that all the pavement families with asphaltic surfacing exhibit the best model equations when present SDI is regressed against the chronological pavement age alone. Pavement families namely; asphalted pavement in hills with high traffic (family 3), asphalted pavement in plains with moderate traffic (family 8) and asphalted pavement in plains with high traffic (family 9) have the significant relationship with the pavement age as an independent variable.. How ever, the methods (formulas) presenting the best results on those families are S – method, Power method and the Exponent method respectively; all methods are the non – linear transformation.

2. The pavement families with surface treated surfacing namely; surface treated pavement in hills with low traffic (family 4), surface treated pavement in hills with moderate traffic (family 5), surface treated pavement in hills with high traffic (family 6) and surface treated pavement in plains with moderate traffic (family 11) exhibit the best regression – based models when present SDI is regressed against the associated variable, SDI (1 year earlier) as an independent variable.

3. It has been seen in the previous chapters that the chronological age alone is not sufficient to determine the SDI values, even after controlling pavement through the grouping into different families. Figure 13 illustrates that there is a high variability in the SDI values in different road sections within the families having the surface treated surfacing. So it could be concluded that there are some important "other" factors missing for the model development and therefore, regression of the dependent variable, SDI with the associated variable, the SDI (1 year earlier) could well capture the most important "other" factors that has considerable influence in the

deterioration. The results of the surface treated pavements justify the assumptions of missing "other" important factors.

4. However, the surface treated pavement in plains with high traffic (family 12) exhibits the exceptional results, where the selected model is obtained when the present SDI is regressed against the chronological age of the pavement as an independent variable. But the results obtained in the first form of regression – based modeling; where the present SDI is regressed against the associated SDI (1 year earlier) and the corresponding pavement age is equally good. Only the difference is that the R^2 obtained for the selected model is 0.7025 as against R^2 of 0.6653 for the regression under form one. Also the P–value for SDI parameter estimate is 0.06, which is slightly higher than the maximum acceptable value of 0.05.

5. There may be some limitations in the regression models for family 4, 5, 6, and 11 where the present SDI is regressed against the associated SDI variable 1 year earlier: it is less used for forecasting beyond its range of experience. Though we can plug any values for its independent variables and produce a prediction for Y, however the worth of the forecast diminishes as this independent variable values depart from the actual range of variable values in the data used for modeling. The maintainable pavement age prediction using these forms of models is presented in the next section.

6. The pavement's maintainable life is presented in the last column of Table 21. The pavement's maintainable life for the asphalted pavement in hills with high traffic (family 3) is approximately 6 years which is comparatively less than the maintainable life of asphalted pavement in plains with high traffic (family 9). This is due to family 3 pavements are subjected to the very high level of traffic (> 3000 vpd); mostly heavily loaded and the road sections have higher geometric radius and gradients.

7. Similarly, the pavement's maintainable life for the surface treated pavements in hills with low traffic (family 4,< 250 vpd) is 6 to 7 years only whereas, the surface treated pavements in plains with high traffic (> 1500 vpd, family 12) has this life of about 8 years. The low

trafficked surface treated roads in hills are mainly in the harsh topographic area and at the higher altitudes where the climatic variation is very high and the geology is very fragile; all this justifying its shorter maintainable pavement life as compared with other surface treated roads with high or moderate traffic.

8. The entire asphaltic surfaced pavement in plains have the similar pavement maintainable life; this justifying that the pavement's deterioration is more dependent in the environment rather than in the level of traffic because the level of traffic is not that high to cause pavements to deteriorate. The pavement age is believed to capture the various "other" missing important deteriorating factors in the model equation.

Maintainable Pavement Age Prediction

The methodology for predicting the maintainable pavement age has been described in the previous chapter. The maintainable pavement age for all road pavement families is included in the last column of the Table 21 as per the selected pavement deterioration model equations. However, only four pavement families 4, 5, 6, and 11 have their model equations selected from the general deterioration functional Equation 48 and their maintainable pavement age prediction is presented in the tabular form in Tables 23 through 26. For other pavement families 3, 8, 9, and 12, the model equations have been selected from the general deterioration functional Equation 54 where the associated variable (independent) is pavement age. Maintainable pavement age prediction based on the associated variable (independent) as previous year's SDI could be equally useful for those pavement families even though their selected model equation is based on the functional Equation 5.8.

Therefore, the maintainable pavement age prediction for pavement families3, 8, 9, and 12 are presented in Tables 27 through 30. The tables are arranged to be used as follows: For the given pavement family, the present age and present SDI values, the cells show the age at which the SDI will reach 3.0 (SDI of 3.0 is threshold when rehabilitation or reconstruction becomes necessary). For example, in Table 24 if the present age of the pavement is 3 years and the present

SDI is 1.5 then that pavement will reach a SDI of 2.99 at age 7 years. In other words, that pavement in example has about 4 more years of useful life in terms of maintainable condition.

Table 23 Predicted pavement age when SDI = 3.0, given the present SDI

Family 4: Surface treated pavement in hills with low traffic SDI(t+1) = 0.9109 + 0.8468*SDI(t)												
P-SDI	P-Age 1		P-Age 2		P-Age 3		P-Age 4		P-Age 5		P-Age 6	
	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE
0.10	2.91	5										
0.25	3.02	5	3.02	6								
0.50	3.15	5	3.15	6	3.15	7	3.15	8	3.15	9		
0.75	3.27	5	3.27	6	3.27	7	3.27	8	3.27	9		
1.00	2.94	4	2.94	5	2.94	6	2.94	7	2.94	8	2.94	9
1.25	3.09	4	3.09	5	3.09	6	3.09	7	3.09	8	3.09	9
1.50			3.25	5	3.25	6	3.25	7	3.25	8	2.76	8
1.75					2.94	5	2.94	6	2.94	7	2.94	8
2.00					3.12	5	3.12	6	3.12	7	3.12	8
2.25									2.82	6	2.82	7
2.50									3.03	6	3.03	7
2.75												
3.00												

Table 24 Predicted pavement age when SDI = 3.0, given the present SDI

Family 5: Surface treated pavement in hills with moderate traffic SDI(t+1) = 1/[1/4.2+[0.7985*[0.4681^SDI(t)]]]												
P-SDI	P-Age 1		P-Age 2		P-Age 3		P-Age 4		P-Age 5		P-Age 6	
	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE
0.10	3.04	7										
0.25	3.06	7	3.06	8								
0.50	3.09	7	2.93	7	2.93	8	2.93	9	2.93	10		
0.75	2.98	6	2.98	7	2.98	8	2.98	9	2.98	10		
1.00	3.04	6	3.04	7	3.04	8	3.04	9	3.04	10	3.04	11
1.25	3.08	6	3.08	7	3.08	8	3.08	9	3.08	10	3.08	11
1.50			2.99	6	2.99	7	2.99	8	2.99	9	2.99	10
1.75					3.06	7	3.06	8	3.06	9	3.06	10
2.00					2.98	6	2.98	7	2.98	8	2.98	9
2.25							3.07	7	3.07	8	3.07	9
2.50									3.01	7	3.01	8
2.75											2.98	7
3.00												

Table 25 Predicted pavement age when SDI = 3.0, given the present SDI

Family 6: Surface treated pavement in hills with high traffic
SDI(t+1) = 1/[1/4+[0.8736*[0.4413^SDI(t)]]]

P-SDI	P-Age 1		P-Age 2		P-Age 3		P-Age 4		P-Age 5		P-Age 6	
	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE
0.10	3.00	8										
0.25	3.01	8	3.01	9								
0.50	3.04	8	3.04	9	3.04	10	3.04	11	3.04	12		
0.75	2.97	7	2.97	8	2.97	9	2.97	10	2.97	11		
1.00	3.01	7	3.01	8	3.01	9	3.01	10	3.01	11	3.01	12
1.25	3.04	7	3.04	8	3.04	9	3.04	10	3.04	11	3.04	12
1.50			2.99	7	2.99	8	2.99	9	2.99	10	2.99	11
1.75					3.04	8	3.04	9	3.04	10	3.04	11
2.00					3.00	7	3.00	8	3.00	9	3.00	10
2.25							2.96	7	2.96	8	2.96	9
2.50									3.03	8	3.03	9
2.75											3.03	8
3.00												

Table 26 Predicted pavement age when SDI = 3.0, given the present SDI

Family 11: Surface treated pavement in plains with moderate traffic
SDI(t+1) = 0.6827 + 0.8207*SDI(t)

P-SDI	P-Age 1		P-Age 2		P-Age 3		P-Age 4		P-Age 5		P-Age 6	
	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE
0.10	3.04	9										
0.25	3.08	9	3.08	10								
0.50	2.98	8	2.98	9	2.98	10	2.98	11	2.98	12		
0.75	3.04	8	3.04	9	3.04	10	3.04	11	3.04	12		
1.00	2.95	7	2.95	8	2.95	9	2.95	10	2.95	11	2.95	12
1.25	3.03	7	3.03	8	3.03	9	3.03	10	3.03	11	3.03	12
1.50	2.95	6	2.95	7	2.95	8	2.95	9	2.95	10	2.95	11
1.75					3.04	8	3.04	9	3.04	10	3.04	11
2.00					2.99	7	2.99	8	2.99	9	2.99	10
2.25							2.95	7	2.95	8	2.95	9
2.50									3.08	8	2.93	8
2.75											2.94	7
3.00												

Table 27 Predicted pavement age when SDI = 3.0, given the present SDI

Family 3: Asphaltic pavement in hills with high traffic SDI(t+1) = 1/[1/4+[0.9306*[0.3747^SDI(t)]]]												
P-SDI	P-Age 1		P-Age 2		P-Age 3		P-Age 4		P-Age 5		P-Age 6	
	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE
0.10	3.02	5										
0.25	3.11	5										
0.50	3.26	5	3.26	6								
0.75	2.87	4	2.87	5								
1.00	3.08	4	3.08	5	3.08	6	3.08	7				
1.25			3.27	5	3.27	6	3.27	7				
1.50			2.91	4	2.91	5	2.91	6	2.91	7	2.91	8
1.75					3.12	5	3.12	6	3.12	7	3.12	8
2.00					3.30	5	3.30	6	3.30	7	3.30	8
2.25							2.94	5	2.94	6	2.94	7
2.50									3.14	6	3.14	7
2.75												
3.00												

Table 28 Predicted pavement age when SDI = 3.0, given the present SDI

Family 8: Asphaltic pavement in plains with moderate traffic SDI(t+1) = 1.5164*[SDI(t)^0.6482]												
P-SDI	P-Age 1		P-Age 2		P-Age 3		P-Age 4		P-Age 5		P-Age 6	
	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE
0.10												
0.25	3.01	9										
0.50	2.98	8	2.98	9								
0.75	3.04	8	3.04	9								
1.00	2.99	7	2.99	8	2.99	9						
1.25			3.04	8	3.04	9	3.04	10				
1.50					2.99	8	2.99	9	2.99	10		
1.75					3.04	8	3.04	9	3.04	10	3.04	11
2.00							2.99	8	2.99	9	2.99	10
2.25									2.95	8	2.95	9
2.50									3.04	8	3.04	9
2.75											3.04	8
3.00												

Table 29 Predicted pavement age when SDI = 3.0, given the present SDI

Family 9: Asphaltic pavement in plains with high traffic SDI(t+1) = 0.5765 + 0.8634*SDI(t)												
P-SDI	P-Age 1		P-Age 2		P-Age 3		P-Age 4		P-Age 5		P-Age 6	
	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE
0.10												
0.25	2.99	9										
0.50	3.07	9	3.07	10								
0.75	2.98	8	2.98	9	2.98	10						
1.00	3.07	8	3.07	9	3.07	10	3.07	11				
1.25	2.99	7	2.99	8	2.99	9	2.99	10				
1.50			3.09	8	3.09	9	3.09	10	2.92	10		
1.75					3.04	8	3.04	9	3.04	10	3.04	11
2.00					2.99	7	2.99	8	2.99	9	2.99	10
2.25									2.95	8	2.95	9
2.50									2.94	7	2.94	8
2.75											2.95	7
3.00												

Table 30 Predicted pavement age when SDI = 3.0, given the present SDI

Family 12: Surface Treated pavement in plains with high traffic SDI(t+1) = 1/[1/4+[0.1.1722*[0.3918^SDI(t)]]]												
P-SDI	P-Age 1		P-Age 2		P-Age 3		P-Age 4		P-Age 5		P-Age 6	
	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE	SDI	AGE
0.10												
0.25	3.02	9										
0.50	3.07	9	3.07	10								
0.75	2.99	8	2.99	8	2.99	10						
1.00	3.06	8	3.06	9	3.06	10	3.06	11	3.06	12		
1.25			3.01	8	3.01	9	3.01	10	3.01	11	3.01	12
1.50					2.96	8	2.96	9	2.96	10	2.96	11
1.75					3.06	8	3.06	9	3.06	10	3.06	11
2.00									3.02	9	3.02	10
2.25											2.98	9
2.50												
2.75												
3.00												

P-SDI: Present SDI

P-Age: Present Age

Model Accuracy Discussion

The selected deterioration prediction models must be validated and verified to ensure their predicting ability and accuracy. The validation is carried out by determining the coefficient of determination, R^2 as mentioned earlier. Similarly the significance of the relationship is determined by the P-value for the parameter estimate in the model. The R^2 values of the selected models are in the range from 0.6208 to 0.9121; this indicating the strong associations in between the variables considered in modeling. Similarly, the P-value of the parameter estimates are all zero indicating that the parameter estimates are significantly different from zero and therefore the chance of Null Hypothesis holding true in all models are totally unlikely and the relationships are significant.

As an alternative, the comparison of predicted maintainable pavement age could be compared with the DoR's nominated maintenance cycle of resealing presented in the Table 6. Maintainable pavement life is the pavement's life within which the pavement could be maintained by resealing the surface. The DoR has considered the pavement whose SDI value is less or equal to 3.0 as the maintainable pavement. Therefore, for the comparison, the threshold SDI value equal to 3.0 is first calculated by the model equation and comparison made with the existing resealing cycle. This approach to some extent can ensure the model's age predicting ability. The predicted maintainable pavement age is presented in the Table 21. The comparison is made between those two ages in the Table 31.

Table 31 DoR's nominate maintenance cycle and predicted maintainable pavement age

	Low traffic < 250 vpd		Moderate traffic 250 to 1500 vpd		High traffic > 1500 vpd	
	Maintenance cycle	Predicted age	Maintenance cycle	Predicted age	Maintenance cycle	Predicted age
Terrain						
Plains	8	NA	7	6~10	6	6~8
Hills	6	6~7	6	6~9	5	6

According to the Table 31, there is not much variation between the DoR' nominate maintenance cycle and the predicted maintainable pavement age from the selected pavement deterioration models.

In addition to the above mentioned validation approaches, predicted SDI values are compared with the measured values of SDI in the different pavement sections under each pavement families. However, part of the collected data could not be reserved for model validation, which is due to very limited data available for modeling. Therefore, the data of the pavement sections that have been used into model formulation are used to make this comparison. The percent difference between predicted values and observed values should be reasonable in order to accept the models' predicting ability. Families 4, 5, 6 and 11 (mainly surface treated pavements) have the best results when present SDI is regressed against the associated SDI 1 year earlier and they show the percent difference of 2 – 25% between predicted and observed SDI values. Similarly other remaining pavement families (asphaltic surfacing) have this percent difference of 1 - 30%. In both pavement types the percent difference between the predicted and observed SDI values are in the reasonable range. To visualize these, graphical plots in Figures C1 through C8 are presented in the Appendix C.

CONCLUSIONS AND RECOMMENDATIONS

It is evident that the pavement performance and the maintenance affect the total transportation cost significantly. This is particularly more relevant in Nepal where the geographical and climatic environments, construction methods and technologies and traffic characteristics are more diverse. Therefore, the pavement performance guided by the pavement deterioration models are of greater use in planning of maintenance and budgets for the road pavements. Database is the key in any kind of pavement management system (PMS), including the formulation of model, hence accuracy and reliability in data should be the foremost requisite for the road agencies.

<u>Conclusions</u>

Based on the analysis and the regression – based modeling results presented in the previous chapter, the following conclusions may be drawn.

1. The presently developed models are the first of this kind in Nepal for the pavements and they represent only for the bituminous pavements which are newly constructed, rehabilitated, or reconstructed. The model is unable to predict the performances for the pavements which have received the resealing on them; this is due to insufficient data available for formulating the models on such cases.

2. Based on the value of R^2, developed prediction models can predict the future performances under the eight pavement groups (families) with reasonable accuracy. So those models are useful to plan and budget the maintenance actions for future.

3. Pavement chronological age by itself does not seem sufficient to predict the changes in SDI values, particularly for the surface treated pavements. This is evidenced by a very wide variation in SDI values that correspond to the same age in each pavement under surface treated families. It clearly indicates that the other factors need to be identified for the modeling. Since we

do not have those factors conveniently available at present, the use of the associated SDI, 1 year earlier as an independent variable captures the other missing important factors. So the best models obtained for the surface treated pavements have been found when the present SDI variable is regressed against the associated SDI value of 1 year earlier.

4. The most accurate models for the asphalted pavements are found from the regression – based modeling when the observed SDI is regressed against the pavement chronological age. The non-linear transformation function such as exponent and power enhanced the model's predicting accuracy. Since the traffic level in the asphalted pavements are small as it should be, except the asphalted pavement in hills with high traffic, where traffic is larger than 3,000 vpd. This indicates that traffic is not the main factor for the deterioration process in asphalted roads. The other casual factors are believed to be well captured by the chronological age alone for asphalted roads.

5. The projections of SDI values obtained from the models will have to be compared to actual future SDI values when those become available. This will further aid in determining the accuracy of the models. This, however, is true for any modeling process.

Recommendations

The following recommendations seem to be an appropriate for the future modeling works since the modeling process is always a dynamic in nature.

1. The model developing technique is the dynamic one, so they need to be further refined as more SDI values become available in the years to come

2. To enhance the predicting ability of the model in the future, it might be a worthwhile effort to start acquiring the other casual factors that affect the deterioration process. Other factors may include: environment (temperature, precipitation), truck volumes, and pavement cross-sections.

3. It is recommended that DoR puts more efforts in maintaining the reliable and accurate database. For instance, in the large road projects with long project durations, different road links or sections in the project are completed and opened to the traffic in different times. However, the reports available normally mention the date on which the entire project is completed; this makes it difficult or virtually impossible for the analyst to find the chronological pavement age for the different road sections within the project when they are completed and handed over to the concerned road agencies.

4. It is also recommended that the on-going road projects maintain the types of pavement works that have been done in each road links. For example, there are many instances when some of the road links are just repaired and resealed under the rehabilitation or reconstruction road projects and are not reported. This gives the impression that the entire road length has been rehabilitated or reconstructed.

5. It is recommended to have the consistency in SDI measurements. The present records in database shows that there are many road sections that have the declining SDI values without any resealing or rehabilitation on them.

6. The SDI survey needs to be conducted always within one particular period of the year only. Otherwise there is tendency of declining SDI values, when first survey is done in the winter and the subsequent survey in the hot climates.

7. It is also recommended that the DoR initiates to acquire the pavement construction history (dates) of each road links that are first blacktopped followed by the subsequent resealing, rehabilitation and reconstruction. This information could be included in the "Road Statistics" that is periodically published by the department.

8. It is further recommended that the models need to be developed for the pavements after resealing. This is possible when more information is available in the future. The information should comprise of pavement conditions at the time of resealing and the subsequent pavement

conditions after resealing for some years. The model thus developed could be useful to verify the extended pavement life by resealing.

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Appendix Table A1 Family 3 Data – Asphalted pavements in hills with high traffic

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
H0129	Pathlaiya-Chure	19.000	H	AC	High		1.00	1.78	3.30	3.30	3.85	
H0130	Chure-Ratmate	4.368	H	AC	High		1.25	1.00	1.00	2.80	2.80	
H0213	Naubise-Pipalamod	10.423	H	AC	High	0.09	0.91	1.36	1.91			
H0214	Pipalamod-Nagdhunga	1.836	H	AC	High	0.00	1.00	2.00	2.00			
H0215	Nagdhunga-Ring Road(Kalanki)	9.068	H	AC	High	0.03	0.67	2.40	2.70			
H0216U	Ring Road (Kalanki)-Tripureswor	3.431	H	AC	High			1.50	1.91	1.91	2.32	2.86
H0401	Naubise-Galchhi	22.060	H	AC	High			1.75	1.40	1.33	2.62	2.95
H0402	Galchhi-Junction Trisuli Bridge	20.500	H	AC	High		1.75	1.40	1.33	2.62	2.95	
H0403	Junction Trisuli Bridge-Mawa Khola	23.735	H	AC	High		1.04	1.33	1.54	2.46	2.71	

Appendix Table A2 Family 4 Data – Surface treated pavements in hills with low traffic

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0709	Chureghati-Ranke	30.663	H	ST	Low			1.35		2.16		1.97			
H0710/A	Ranke-Phidim	7.000	H	ST	Low			1.29		2.00		2.00			
H1208	Chhinchu-Newari Khola	24.946	H	ST	Low		0.52	1.56		2.28		1.81			
H1209U/A	Newari Khola-Bangesimal	6.000	H	ST	Low		1.57	1.00		3.00		1.43			
H1405	Faltunde-Budar	10.989	H	ST	Low		0.58	1.00		1.73		1.17			
H1406	Budar-Gairha	21.815	H	ST	Low		0.81	1.09		1.86		1.52			
H1407	Gairha-Syaule	29.274	H	ST	Low		0.67	1.23		1.93		1.33			
H1408	Syaule-Anarkholi	14.000	H	ST	Low				1.64						
H1501	Syaule Bazar-Korayal	24.96	H	ST	Low				1.16	2.12	3.04	3.73	4.00	2.20	
H1502	Korayal-Samuha Gad	24.73	H	ST	Low				0.96	2.16	2.88	3.36	3.60	2.12	
H1503U	Samuha Gad-Junction Sanfe Road	16.27	H	ST	Low				1.71	2.57	2.73	3.46	3.53	2.57	

Appendix Table A2 Cont'd

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
F1901	Bhainse-Bhimphedi	11.466	H	ST	Low			1.10	2.25	1.42	2.25	1.75	1.17		1.67
F3401A	Malekhu-Dhading	17.267	H	ST	Low		1.00		2.00		1.83				

Appendix Table A3 Family 5 Data – Surface treated pavements in hills with moderate traffic

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0165	Mohana Bridge-Daiji	27.976	H	ST	Moderate		1.00	1.14	1.07		2.04				
H0205	Hetauda-Samari	3.156	H	ST	Moderate		1.00	1.25	1.00		2.00		2.75		
H0206	Samari-Bhainse	7.900	H	ST	Moderate		1.00	1.88	1.87		2.38		3.00		
H0207	Bhainse-Lamidanda	18.063	H	ST	Moderate										
H0208	Lamidanda-Simbhanjyang	22.282	H	ST	Moderate										
H0209	Simbhanjyang-Palung	14.661	H	ST	Moderate										
H0210	Palung-Tistung	4.794	H	ST	Moderate										
H0211	Tistung-Dist. Border	17.185	H	ST	Moderate										
H0212	Dist. Border-Naubise	17.185	H	ST	Moderate										
H0310U	Chalnedhunga-Khawa	5.747	H	ST	Moderate		1.50	2.16	2.83	2.2	2.50	2.00		2.67	
H0311	Khawa-Lamidanda	13.817	H	ST	Moderate		0.69	2.15	2.11	2.8	2.93	2.23		2.79	
H0312	Lamidanda-Dolalghat	12.120	H	ST	Moderate		0.67	2.41	2.00	2.1	2.10	1.50		2.85	
H0313	Dolalghat-Lamosangu	19.050	H	ST	Moderate		0.6	0.80	1.00		1.11		1.75		
H0314	Lamosangu-Barabise	10.325	H	ST	Moderate		0.6	1.09	1.00		1.09		2.45		
H0315/A	Barabise-Kodari	11.000	H	ST	Moderate		1.27		2.79						
H0405	Mugling-Mugling Bridge	0.388	H	ST	Moderate		1.31	1.31	1.00	2.00	2.00				
H0406	Mugling Bridge-Anbukhaireni	7.230	H	ST	Moderate		1.13	1.00	1.12	1.25	1.50				
H0407	Anbukhaireni-Dumre	16.562	H	ST	Moderate	0.60	1.23	1.87	1.19						
H0408	Dumre-Muse Khola	13.852	H	ST	Moderate		1.07	1.14	1.29		2.00				
H0409	Muse Khola-Byas Munc_Border	5.255	H	ST	Moderate		2.00	2.00	1.40		2.33				

Appendix Table A3 Cont'd

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0410	Byas Munc_Border-Kotre	27.473	H	ST	Moderate		1.14	1.60	1.32		2.50				
H0411	Kotre-Bijayapur Khola	13.900	H	ST	Moderate										
H0705	Charali-Chihandanda	16.785	H	ST	Moderate			1.06	1.76	1.64	2.00	2.00			
H0706	Chihandanda-Fikkal	22.835	H	ST	Moderate			1.57	3.00	1.86		2.86			
H0707	Fikkal-Mai Khola	24.467	H	ST	Moderate			1.46	3.08	2.32		3.08			
H0708U	Mai Khola-Chureghati	13.943	H	ST	Moderate		1.92	1.93	1.64		2.43				
H0806	Base camp-Bhendetar	12.160	H	ST	Moderate				0.80	2.00	2.46	2.54	2.54		
H0807	Bhendetar-Mulghat	18.290	H	ST	Moderate				1.00	2.00	1.36	1.63	1.84		
H0808	Mulghat-Patle Khola	11.416	H	ST	Moderate				0.90	1.58	1.83	1.67	1.83		
H0809	Patle Khola-Hile	18.160	H	ST	Moderate				0.90	2.61	2.68	1.32	1.78		
H0901	Kadmaha Chowk-Siswari Bridge	12.000	H	ST	Moderate					1.00	1.83	1.81	1.58	1.66	
H0902	Siswari Bridge-Cement factory	8.509	H	ST	Moderate					1.10	2.25	1.88	2.44	2.44	
H0903A	Cement Factory-Gaighat	8.000	H	ST	Moderate					1.00	2.00	2.75	3.00	3.00	
H1005	Chidiya Khola-Banstari	26.850	H	ST	Moderate		0.59	1.89	2.03	1.37		2.56		2.68	
H1006U	Banstari-Bartung	5.290	H	ST	Moderate		1.00	1.00	1.00	1.00		2.00		3.17	
H1007U	Bartung-Tansen Municipal Border	2.210	H	ST	Moderate		1.33		2.00						
H1008	Tansen Municipal Boredr-Kaligandaki	23.721	H	ST	Moderate		1.67		2.00						
H1009	Kaligandaki Bridge-Waling	30.092	H	ST	Moderate		1.39		2.10						
H1010	Waling-Syangja	27.538	H	ST	Moderate		1.61		1.25						
H1011	Syangja-Kubinde	19.899	H	ST	Moderate										
H1012	Kubinde-Pokhara Municipal Border	11.917	H	ST	Moderate										
H1205	Kohalpur-Deurali	23.104	H	ST	Moderate	0.77	1.08	1.65		2.46		2.35			
H1206	Deurali-Harre	23.280	H	ST	Moderate		1.21	1.57		2.17		2.67			
H1207	Harre-Chhinchu	11.996	H	ST	Moderate		0.33	1.58		2.17		1.92			
H1404	Godavari Bridge-Faltunde	44.245	H	ST	Moderate			1.80	2.09	2.49		2.93			
F1501	Lamahi-Tribhuvannagar Munc_Bdr	19.149	H	ST	Moderate		0.53	1.05		1.50		2.20			
F2104	Nagarjun-Thulo Khola	10.142	H	ST	Moderate		2.80	3.00	3.10	3.10	3.80		3.82		
F2105	Thulo Khola-Kakani	7.663	H	ST	Moderate		2.75	2.37	3.00	3.10			3.50		
F2106	Kakani-Tadi Khola	34.357	H	ST	Moderate		0.80	0.80		3.23					

Appendix Table A3 Cont'd

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
F2107	Tadi Khola-Batar	7.489	H	ST	Moderate		1.00	1.00		4.00					
F2108U/A	Batar-Gerkha Khola	3.000	H	ST	Moderate		2.00	1.00		3.67					
F2802	Army Camp-Nagarkot	15.518	H	ST	Moderate										
F3201	Lamosangu-Nighaledanda	28.239	H	ST	Moderate										
F3202	Nigaledanda-Charikot	26.000	H	ST	Moderate										
F3203	Charikot-Tamakoshi, jn. Jiri Road	17.970	H	ST	Moderate										
F3501	Anbukhaireni-Marshyangdi River	0.896	H	ST	Moderate		1.28	1.57	1.00		4.00				
F3502	Marshyangdi River-Gorkha	23.600	H	ST	Moderate		1.00	1.32	1.33		2.16				
F3601	Dumre-District Border	24.000	H	ST	Moderate		0.56	1.33		2.21		1.68			
F3602	District Border-Besisahar	18.500	H	ST	Moderate		0.74	1.32		2.79		2.68			
F38	Fikkal-Pashupatinagar	10.630	H	ST	Moderate			1.18	2.91	1.45	2.18	1.90			
F4101	Pokhara-Sarangkot	4.864	H	ST	Moderate			1.40	2.00	2.20	2.20	1.80			
F4203	Yamdi Bridge-Fedi	9.177	H	ST	Moderate			1.24	2.19	2.24	1.67	2.16			
F4203	Fedi-Sandh Bridge	27.860	H	ST	Moderate			1.24	2.19	2.24	1.67	2.16			
F4204	Sandh Bridge-Kaligandaki Bridge	24.110	H	ST	Moderate			1.17	1.83	2.80	2.58	2.25			
F4205	Kaligandaki bridge-Baglung	4.710	H	ST	Moderate			1.60	1.80	2.60	2.80	2.20			
F4301	Bartung - Batase Danda	4.61	H	ST	Moderate		1.25	1.25			1.00		2.75		3.00

Appendix Table A4 Family 6 Data – Surface treated pavements in hills with high traffic

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0404	Mawa Khola-Mugling	16.170	H	ST	High		1.31	1.31	1.41	2.23	2.41				
H051U	Narayanghat-Anptari	2.441	H	ST	High		1.67	1.00		1.67					
H0502U	Anptari-Ramnagar	3.350	H	ST	High		0.50	1.00		2.50					
H0503	Ramnagar-Mugling	30.160	H	ST	High		1.23	1.34		3.10					

Appendix Table A4 Cont'd

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
F2301U	Satdovato-Sunakothi	2.420	H	ST	High	0.34	1.00		1.33		2.33				
F2302A	Sunakothi-Junction to Lele	7.000	H	ST	High	0.57	2.33		2.43		3.44				
F2401U	Satdovato-Karmanas Bridge	1.700	H	ST	High		1.00	1.00	1.00	1.00	1.00	3.00			
F2402	Karmanas Bridge-Godavari	7.600	H	ST	High		2.13	2.62	3.12	3.13	2.25		3.13		3.13
F2701	Jorpati-Sundarijal	7.045	H	ST	High			2.30	1.85	1.37	3.14	3.14	3.13		

Appendix Table A5 Family 8 Data – Asphalted pavements in plains with moderate traffic

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0111	Sunsari Brdg-Koshi Barrage	23.464	P	AC	Moderate		1.05	1.75	1.75	2.75	2.58				
H0112	Koshi Barrage-Bhardaha	6.024	P	AC	Moderate		1.00	1.20	1.40	3.00	2.52				
H0113	Bhardaha-Rupni	30.442	P	AC	Moderate		1.00	1.74	1.97	2.35	2.26				
H0114	Rupni-Kadmaha	21.000	P	AC	Moderate		1.00	1.71	2.00	2.76	2.42				
H0115	Kadmaha-Balan	1.735	P	AC	Moderate		1.00	1.50	2.00	2.00	2.00				
H0116U	Balan-Padariya Chowk	4.888	P	AC	Moderate		1.00	1.80	1.83	2.33	2.33				
H0117	Padariya Chowk-Chauharwa	19.467	P	AC	Moderate		1.00	1.05	1.60	2.10	2.25				
H0308U	Punyamati Bridge-Banepa	0.950	P	AC	Moderate	0.00	0.00		1.00						

Appendix Table A6 Family 9 Data – Asphalted pavements in plains with high traffic

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0105U	Ratuwa-Mawa	6.782	P	AC	High		1.00	1.00	1.86	2.00			2.00		
H0106	Mawa-Harichamod	25.843	P	AC	High		1.25	1.04	1.41	2.07	2.11				
H0107	Harichamod-Budikhola	10.218	P	AC	High		1.00	1.20	1.45	1.73	2.09				
H0108	Budikhola-Itahari	1.244	P	AC	High		1.00	2.00	2.00	2.00	2.00				
H0109	Itahari-Sakhuwa Gachhi	15.083	P	AC	High		1.00	1.27	1.56	2.50	2.56				
H0110U	Sakh.Gachhi-Sunsari Bridge	3.439	P	AC	High		1.00	1.33	1.50	1.75	2.00				
H0131	Ratmate-Hetauda	5.340	P	AC	High		1.40	0.80	1.50	2.67	3.00				
H0201U	Sirsia Border-Junction Old Alignmt.	1.330	P	AC	High										
H0202U	Jn.Old Alignment-Gandak Canal	7.300	P	AC	High										
H0203	Gandak Canal-Jitpur	12.323	P	AC	High										
H0204	Jitpur-Pathlaiya	6.869	P	AC	High										

Appendix Table A7 Family 11 Data – Surface treated pavements in plains with moderate traffic

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0101	Charali-Kakarbhitta	11.298	P	ST	Moderate		0.42	0.75	1.00		2.00				
H0102	Charali-Birtamod	6.212	P	ST	Moderate			1.14	1.14	1.00		1.71			
H0118	Chauharwa-Mirchaiya	5.099	P	ST	Moderate		1.00	1.16	1.17	2.00					
H0119	Mirchaiya-Kamala	13.443	P	ST	Moderate		1.00	1.42	1.57	1.50					
H0120	Kamal-Dhalkebar	20.200	P	ST	Moderate		0.70	1.11	1.67	1.71					
H0121	Dhalkebar-Ratu	8.000	P	ST	Moderate		1.00	1.75	2.25	2.25					
H0122	Ratu-Bardibas	1.769	P	ST	Moderate		0.50	1.00	1.50	2.00	2.00				
H0123	Bardibas-Banke	15.528	P	ST	Moderate		0.38	1.00	1.75	2.37	2.37				

Appendix Table A7 Cont'd

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0124	Banke-Nawalpur	16.670	P	ST	Moderate		0.24	1.05	1.41	1.88	2.17				
H0125	Nawalpur-Bagmati	13.437	P	ST	Moderate		0.62	1.07	1.35	1.93	2.14				
H0126	Bagmati-Chandranigahapur	13.374	P	ST	Moderate		0.56	1.14	1.43	2.14	2.21				
H0127	Chandranigahapur-Dhansar	12.664	P	ST	Moderate		0.62	1.07	1.69	2.31	2.38				
H0128	Dhansar-Pathlaiya	27.336	P	ST	Moderate		0.64	1.21	2.12	2.71	2.42				
H0149	Jitpur-Gorusinge	14.500	P	ST	Moderate				1.87	1.60	1.67	2.27	2.93		
H0150	Gorusinge-Chanauta	19.203	P	ST	Moderate				1.84	2.00	2.35	2.63	3.00		
H0151	Chanauta-Dhana Khola	21.944	P	ST	Moderate				2.05	1.90	2.13	2.81	2.50		
H0152	Dhana Khola-Bhalubang	12.240	P	ST	Moderate			2.17	1.75	2.15	2.31	2.65			
H0153	Bhalubang-Lamahi	26.874	P	ST	Moderate			1.89	2.07	1.59	2.48	2.33			
H0154	Lamahi-Ameliya	35.18	P	ST	Moderate			1.86	1.62	1.69	1.78	2.34			
H0155	Ameliya-Shiva Khola	2.66	P	ST	Moderate										
H0156	Shiva Khola-Khairi Khola	35.62	P	ST	Moderate			1.30	1.36	1.33	1.89	2.30			
H0157	Khairi Khola-Kohalpur	35.27	P	ST	Moderate			1.50	1.62	1.44	1.93	2.22			
H0158	Kohalpur-Man River	12.101	P	ST	Moderate							1.50	2.25		
H0159	Man River-Bhuregaun	41.343	P	ST	Moderate										
H0160	Bhuregaun-Karnali	22.793	P	ST	Moderate					0.90	0.52	1.39	1.68		
H0161	Karnali-Junga	14.188	P	ST	Moderate					1.70	1.55				
H0162	Junga-Bhadaipur Chouraha	34.448	P	ST	Moderate		1.26	1.32		2.60					
H0163	Bhadaipur Chouraha-Atariya	29.850	P	ST	Moderate		0.96	1.57		3.03					
H0164	Atariya-Mohana Bridge	4.250	P	ST	Moderate		1.00	1.00	1.50		3.00				
H0166	Daiji-Sukhanala	6.900	P	ST	Moderate		2.43	1.85	1.29		2.43				
H0167U	Sukhanala-Gaddachauki	9.426	P	ST	Moderate		1.00	2.00	1.22		2.50				
H0412U	Bijayapur Khola-Prithvi Chowk	4.662	P	ST	Moderate										
H0601U	Bhittamod-Jaleswor Munc_Border	5.555	P	ST	Moderate		1.17	2.33	2.60		3.50		3.00		
H0602	Jaleswor Munc_Border-Dudhmati	12.095	P	ST	Moderate		0.69	1.53	2.08		3.00		2.00		
H0603	Dudhmati-Janakpur Munc.Border	5.910	P	ST	Moderate		0.83	2.00	2.17		3.17		2.00		
H0604	Janakpur Munc.Border-Dhalkebar	18.872	P	ST	Moderate		1.21	1.47	2.21		3.84		3.15		
H0703U/A	Jhapa Chowk-Bhaire Chowk	4.000	P	ST	Moderate										

Appendix Table A7 Cont'd

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0704A	Bhaire Chowk-Charali	10.230	P	ST	Moderate		0.64	1.27	2.00		3.55		2.36		
H0804	Itahari-Seuti Bridge	10.970	P	ST	Moderate			0.70	1.72	1.55	2.18	2.27			
H0805U	Seuti Bridge-Base Camp	10.094	P	ST	Moderate			1.00	1.90	1.90	2.38	2.45			
H1004U	Butwal(Mahendra ch.)-Chidiya Khola	2.721	P	ST	Moderate										
H1013U	Pokhara Munc.Border-Prithvi Chowk	4.487	P	ST	Moderate										
H1201	Jamuniya-Campus	2.020	P	ST	Moderate										
H1202U	Campus-Dhamboji	4.000	P	ST	Moderate										
H1203U	Dhamboji-Nepalgunj Munc_Border	1.285	P	ST	Moderate										
H1204	Nepalgunj Munc_Border-Kohalpur	14.911	P	ST	Moderate	0.60	0.86	1.47		3.00					
H1401U	Mohana Bridge-Boradandi	6.23	P	ST	Moderate										
H1402	Boradandi-Atariya	8.32	P	ST	Moderate										
H1403	Atariya-Godavari Bridge	9.000	P	ST	Moderate										
F0101	Birtamod-Chandragadi	12.52	P	ST	Moderate		1.00	1.92		3.08		2.13			
F0201A	Damak-Gauradaha	6.000	P	ST	Moderate		1.00	0.75	1.45	1.86	1.57	1.17		3.00	
F0301	Bhardaha-Inaruwa	6.830	P	ST	Moderate		1.00	1.57		2.86		2.29			
F0302	Inaruwa-Rajbiraj Municipal Border	9.049	P	ST	Moderate		1.00	2.44		2.30		2.00			
F0401	Rupni-Rajbiraj Municipal Border	9.300	P	ST	Moderate										
F0404	Rajbiraj Munc. Bdr-Malhaniya Chowk	11.175	P	ST	Moderate										
F0501	Nawalpur-Malangawa Munc. Border	21.881	P	ST	Moderate		0.52	1.10		2.11		2.00			
F0502	Malangawa Munc.Border-Malangawa	4.536	P	ST	Moderate		0.52	4.80		4.56		4.25			
F0601	Nawalpur-Malangawa Munc. Border	21.881	P	ST	Moderate		0.95	2.50		2.77		2.22			
F0602	Malangawa Munc.Border-Malangawa	4.536	P	ST	Moderate		2.00	3.20		3.00		3.20			
F0701	Chandranigapur-Gaur Munc_Border	38.070	P	ST	Moderate			0.82	1.71		3.38		3.28		
F0702	Gaur Munc_border-Gaur	5.697	P	ST	Moderate			1.50	1.67		3.00		3.33		
F0801A	Bardaghat-Pratappur	8.000	P	ST	Moderate										
F0802	Pratappur-Surajpura	4.536	P	ST	Moderate										
F0803	Surajpura-Harpur Border	2.600	P	ST	Moderate										

Appendix Table A7 Cont'd

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
F0901	Sunwal-Parasi	8.935	P	ST	Moderate										
F1001	Jitpur-Taulihawa Municipal Border	7.996	P	ST	Moderate		1.00		2.13		1.91				
F1002	Taulihawa Munc. Bdr.-Bank Chouraha	4.347	P	ST	Moderate				2.20		2.40		2.60		
F1003	Bank Chouraha-Taulihawa Munc. Bdr.	3.000	P	ST	Moderate										
F1004	Taulihawa Munc_Border-Khunuwa	7.786	P	ST	Moderate										
F1201	Chanauta-Bahadurgunj	11.969	P	ST	Moderate										
F1202	Bahadurgunj-Krishnanagar	8.021	P	ST	Moderate										
F1502U	Tribhuvan Munc_Bdr-Tribhuvannagar	3.599	P	ST	Moderate		0.75	1.00		1.75					
F1503U	Tribhuvan -Tribhuvannagar Munc_Bdr	6.100	P	ST	Moderate		0.34	1.17		1.57					
F1504	Tri'nagar Munc_Bdr-Tulsipur Munc_Bdr	14.900	P	ST	Moderate		0.34	0.93		1.07					
F1505U	Tulsipur Munc_Bdr-Tulsipur	2.591	P	ST	Moderate		1.00	1.00		2.33					
F1801	Birgunj-Bara District Border	2.752	P	ST	Moderate			1.00	1.33		3.67				
F1802	Bara District Bdr-Kalaiya Munc.Bdr.	6.782	P	ST	Moderate			1.42	4.14		4.00				
F1803	Kalaiya Municipal Border-Kalaiya	2.018	P	ST	Moderate			1.50	4.50		3.50				
F2901U	Banepa-Punyamati Bridge	0.590	P	ST	Moderate										
F2902	Punyamati Bridge-Panauti	5.400	P	ST	Moderate										
F3902	Singiya Bridge-Rangeli	21.251	P	ST	Moderate		1.22	1.09	1.95	1.73		3.32		3.00	
F4201U	Pokhara-Bindebasini	3.924	P	ST	Moderate			1.25	3.00	2.50	1.50	2.50			
F4202U	Bindebasini-Yamdi Bridge	2.752	P	ST	Moderate			0.67	2.30	2.67	4.00	3.00			
F4401U	Bhairahawa-Bhairahawa Munc.Border	4.400	P	ST	Moderate										
F4402	Bhairahawa Munc.Border-Lumbini	13.510	P	ST	Moderate										
F4403	Lumbini Junction-Padariya Chouraha	4.700	P	ST	Moderate										
F4501	Lumbini jn. to Taulihawa-Kothi Bridge	5.741	P	ST	Moderate			1.00		2.17		2.67			
F4502	Kothi Bridge-Taulihawa Munc. Border	16.827	P	ST	Moderate		1.06		1.71		2.78				

<u>Appendix Table A7</u> Cont'd

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
F4503U	Taulihawa Munc. Border-Taulihawa	1.779	P	ST	Moderate			1.50		3.50		2.50			
F4601U	Nepalgunj-Nepalgunj Munc. Border	1.890	P	ST	Moderate		1.00	2.00		3.00		2.00			
F4602	Nepalgunj Munc. Bdr.-Man Bridge	13.477	P	ST	Moderate		1.10	2.00		3.14		2.00			
F4603	Man bridge-Gulariya	19.686	P	ST	Moderate		0.85	1.85		2.30		2.00			

<u>Appendix Table A8</u> Family 12 Data – Surface treated pavements in plains with high traffic

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0103	Birtamod-Damak, Padajogi	29.307	P	ST	High		0.7	1.00	1.00		1.50				
H0104	Padajogi-Ratuwa	0.960	P	ST	High			1.00	2.00	1.00	1.00		2.00		
H0132	Hetauda-Saraswoti Khola	5.380	P	ST	High										
H0133	Saraswoti Khola-Lothar	35.237	P	ST	High										
H0134	Lothar-Tikauli	30.000	P	ST	High										
H0135	Tikauli-Hakim Chowk	2.000	P	ST	High										
H0136U	Hakim Chowk-Narayanghat	3.598	P	ST	High										
H0137U	Narayanghat-Narayani Bridge	0.148	P	ST	High										
H0138	Narayani Brdg-Jn.Tiger Mount	35.016	P	ST	High			1.34	1.60	2.05	1.86	2.05	2.31		
H0139	Jn.Tiger Mountain-Arung Khola	14.930	P	ST	High			1.73	1.00	1.07	2.13	2.65	3.00		
H0140	Arung Khola-Bardaghat	24.543	P	ST	High			1.84	1.24	1.40	2.36				
H0141	Bardaghat-Sunwal	17.320	P	ST	High			1.88	1.35	1.70	1.53	1.11	1.82		1.94
H0142	Sunwal-Maha(Khaireni) Khola	5.780	P	ST	High			1.83	0.83	1.00	1.00	1.66	1.17		1.83
H0143	Maha(Khaireni) Khola-Sukoura	11.871	P	ST	High			2.00	1.16	1.33	1.67	2.00			
H0144U	Sukoura-Butwal(Milan Chowk)	3.327	P	ST	High				1.00	1.25	1.25	2.25			
H0145U	Butwal-Butwal(Mahendra Chowk)	1.395	P	ST	High										

Appendix Table A8 Cont'd

Road Link	Road Name	Length km	Terrain	Surface	Traffic	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
H0146U	Butwal(M. Chowk)-Bamaha Khola	9.447	P	ST	High										
H0147	Bamaha Khola-Kothi River	16.918	P	ST	High										
H0148	Kothi River-Jitpur	5.000	P	ST	High										
H0801U	Rani-Kanchanbari	12.274	P	ST	High			0.90	1.15	1.46	1.54				
H0802	Kanchanbari-Duhabi	5.666	P	ST	High			1.00	1.20	1.33	2.00				
H0803	Duhabi-Itahari	11.451	P	ST	High			0.80	1.58	1.58	2.42				
H1001U	Belhiya(Sunauli)-S.Nagar Munc.Bdr.	6.153	P	ST	High	1.50		3.14		2.00					
H1002	S.Nagar Munc.Bdr.-Butwal Munc.Bdr.	15.736	P	ST	High	1.81		3.00		2.50					
H1003	Butwal Munc.Bdr.-Butwal(Milan Ch.)	1.990	P	ST	High	1.00	3.00	3.00			3.00		2.50		

<u>Appendix Table A9</u> Family 3 - Asphalted pavement in hills with high traffic

SDI (t+1)	SDI (t)	AGE (t)	AGE (t+1)	SDI	AGE
1.78	1.00	2	3	1.00	2
3.30	1.78	3	4	1.78	3
3.30	3.30	4	5	3.30	4
3.85	3.30	5	6	3.30	5
1.00	1.00	3	4	3.85	6
2.80	1.00	4	5	1.25	2
0.91	0.09	1	2	1.00	3
1.36	0.91	2	3	1.00	4
1.91	1.36	3	4	2.80	5
2.00	1.00	2	3	2.80	6
2.00	2.00	3	4	0.09	1
0.67	0.03	1	2	0.91	2
2.40	0.67	2	3	1.36	3
2.70	2.40	3	4	1.91	4
1.91	1.50	3	4	1.00	2
1.91	1.91	4	5	2.00	3
2.32	1.91	5	6	2.00	4
2.86	2.32	6	7	0.03	1
2.95	2.62	5	6	0.67	2
1.33	1.04	2	3	2.40	3
1.54	1.33	3	4	2.70	4
2.46	1.54	4	5	1.50	3
2.71	2.46	5	6	1.91	4
				1.91	5
				2.32	6
				2.86	7
				2.62	5
				2.95	6
				1.04	2
				1.33	3
				1.54	4
				2.46	5
				2.71	6

<u>Appendix Table A10</u> Family 4 - ST pavement in hills with low traffic

SDI (t+1)	SDI (t)	AGE (t)	AGE (t+1)	SDI	AGE
1.56	0.52	2	3	1.35	3
1.00	0.58	2	3	2.16	5
1.09	0.81	2	3	1.29	3
1.23	0.67	2	3	2.00	5
2.12	1.16	4	5	0.52	2
3.04	2.12	5	6	1.56	3
3.73	3.04	6	7	2.28	5
4.00	3.73	7	8	1.57	2
2.16	0.96	4	5	3.00	5
2.88	2.16	5	6	0.58	2
3.36	2.88	6	7	1.00	3
3.60	3.36	7	8	1.73	5
2.57	1.71	4	5	0.81	2
2.73	2.57	5	6	1.09	3
3.46	2.73	6	7	1.86	5
3.53	3.46	7	8	0.67	2
				1.23	3
				1.93	5
				1.16	4
				2.12	5
				3.04	6
				3.73	7
				4.00	8
				0.96	4
				2.16	5
				2.88	6
				3.36	7
				3.60	8
				1.71	4
				2.57	5
				2.73	6
				3.46	7
				3.53	8
				1.00	2
				2.00	4

<u>Appendix Table A11</u> Family 5 - Pavement in Hills, Surface Treated with Moderate Traffic

SDI (t+1)	SDI (t)	AGE (t)	Age (t+1)	SDI	AGE
1.14	1.00	2	3	1.00	2
1.25	1.00	2	3	1.14	3
2.16	1.50	2	3	1.07	4
2.83	2.16	3	4	2.04	6
2.50	2.20	5	6	1.00	2
2.15	0.69	2	3	1.25	3
2.80	2.11	4	5	1.00	4
2.93	2.80	5	6	2.00	6
2.41	0.67	2	3	2.75	8
2.10	2.00	4	5	1.50	2
1.14	1.07	2	3	2.16	3
1.29	1.14	3	4	2.83	4
1.60	1.14	2	3	2.20	5
1.76	1.06	3	4	2.50	6
2.00	1.64	5	6	0.69	2
1.58	0.90	4	5	2.15	3
1.83	1.58	5	6	2.11	4
2.25	1.10	5	6	2.80	5
2.44	1.88	7	8	2.93	6
2.00	1.00	5	6	0.67	2
2.75	2.00	6	7	2.41	3
3.00	2.75	7	8	2.00	4
1.08	0.77	1	2	2.10	5
1.65	1.08	2	3	1.07	2
1.57	1.21	2	3	1.14	3
1.05	0.53	2	3	1.29	4
1.32	0.74	2	3	2.00	6
2.19	1.24	3	4	1.14	2
2.24	2.19	4	5	1.60	3
1.83	1.17	3	4	1.32	4
2.80	1.83	4	5	2.50	6
1.80	1.60	3	4	1.06	3
2.60	1.80	4	5	1.76	4
2.80	2.60	5	6	1.64	5
				2.00	6
				0.90	4
				1.58	5
				1.83	6
				1.10	5
				2.25	6
				1.88	7
				2.44	8
				1.00	5
				2.00	6
				2.75	7
				3.00	8

<u>Appendix Table A12</u> Family 6 Data -Surface Treated Pavement in Hills with High Traffic

SDI (t+1)	SDI (t)	AGE (t)	AGE (t+1)	SDI	AGE
1.31	1.31	2	3	1.31	2
1.41	1.31	3	4	1.31	3
2.23	1.41	4	5	1.41	4
2.41	2.23	5	6	2.23	5
1.00	0.50	2	3	2.41	6
1.34	1.21	2	3	0.50	2
1.00	0.34	1	2	1.00	3
2.33	0.57	1	2	2.50	5
2.62	2.13	2	3	1.21	2
3.12	2.62	3	4	1.34	3
3.13	3.12	4	5	3.10	5
				0.34	1
				1.00	2
				1.33	4
				2.33	6
				0.57	1
				2.33	2
				2.43	4
				3.44	6
				2.13	2
				2.62	3
				3.12	4
				3.13	5

Appendix Table A11 Cont'd

SDI (t+1)	SDI (t)	AGE (t)	Age (t+1)	SDI	AGE
				0.77	1
				1.08	2
				1.65	3
				2.46	5
				1.21	2
				1.57	3
				2.17	5
				2.67	7
				0.53	2
				1.05	3
				1.50	5
				2.20	7
				0.74	2
				1.32	3
				2.79	5
				2.68	7
				1.24	3
				2.19	4
				2.24	5
				1.17	3
				1.83	4
				2.80	5
				1.60	3
				1.80	4
				2.60	5
				2.80	6

Appendix Table A13 Family 8 Data - Asphaltic Pavement in Plains with Moderate Traffic

SDI (t+1)	SDI (t)	AGE (t)	AGE (t+1)	SDI	AGE
1.75	1.05	2	3	1.05	2
1.75	1.75	3	4	1.75	3
2.75	1.75	4	5	1.75	4
1.20	1.00	2	3	2.75	5
1.40	1.20	3	4	1.00	2
3.00	1.40	4	5	1.20	3
1.74	1.00	2	3	1.40	4
1.97	1.74	3	4	3.00	5
2.35	1.97	4	5	1.00	2
1.71	1.00	2	3	1.74	3
2.00	1.71	3	4	1.97	4
2.76	2.00	4	5	2.35	5
1.80	1.00	2	3	1.00	2
1.83	1.80	3	4	1.71	3
2.33	1.83	4	5	2.00	4
1.05	1.00	2	3	2.76	5
1.60	1.05	3	4	1.00	2
2.10	1.60	4	5	1.80	3
2.25	2.10	5	6	1.83	4
				2.33	5
				1.00	2
				1.05	3
				1.60	4
				2.10	5
				2.25	6

Appendix Table A14 Family 9 Data - Asphaltic Pavement in Plains with High Traffic

SDI (t+1)	SDI (t)	AGE (t)	AGE (t+1)	SDI	AGE
1.00	1.00	2	3	1.00	2
1.86	1.00	3	4	1.00	3
2.00	1.86	4	5	1.86	4
1.41	1.04	3	4	2.00	5
2.07	1.41	4	5	1.04	3
2.11	2.07	5	6	1.41	4
1.20	1.00	2	3	2.07	5
1.45	1.20	3	4	2.11	6
1.73	1.45	4	5	1.00	2
2.09	1.73	5	6	1.20	3
1.27	1.00	2	3	1.45	4
1.56	1.27	3	4	1.73	5
2.50	1.56	4	5	2.09	6
2.56	2.50	5	6	1.00	2
1.33	1.00	2	3	1.27	3
1.50	1.33	3	4	1.56	4
1.75	1.50	4	5	2.50	5
2.00	1.75	5	6	2.56	6
1.50	0.80	3	4	1.00	2
2.67	1.50	4	5	1.33	3
3.00	2.67	5	6	1.50	4
				1.75	5
				2.00	6
				0.80	3
				1.50	4
				2.67	5
				3.00	6

<u>Appendix Table A15</u> Family 11 Data - Surface Treated Pavement in Plains with Moderate Traffic

SDI (t+1)	SDI (t)	AGE (t)	AGE (t+1)	SDI	AGE
0.75	0.42	2	3	0.42	2
1.00	0.75	3	4	0.75	3
1.16	1.00	2	3	1.00	4
1.17	1.16	3	4	2.00	6
2.00	1.17	4	5	1.00	2
1.42	1.00	2	3	1.16	3
1.57	1.42	3	4	1.17	4
1.11	0.70	2	3	2.00	5
1.67	1.11	3	4	1.00	2
1.71	1.67	4	5	1.42	3
1.00	0.50	2	3	1.57	4
1.50	1.00	3	4	0.70	2
2.00	1.50	4	5	1.11	3
1.00	0.38	2	3	1.67	4
1.75	1.00	3	4	1.71	5
2.37	1.75	4	5	0.50	2
1.05	0.24	2	3	1.00	3
1.41	1.05	3	4	1.50	4
1.88	1.41	4	5	2.00	5
2.17	1.88	5	6	0.38	2
1.07	0.62	2	3	1.00	3
1.35	1.07	3	4	1.75	4
1.93	1.35	4	5	2.37	5
2.14	1.93	5	6	0.24	2
1.14	0.56	2	3	1.05	3
1.43	1.14	3	4	1.41	4
2.14	1.43	4	5	1.88	5
2.21	2.14	5	6	2.17	6
1.07	0.62	2	3	0.62	2
1.69	1.07	3	4	1.07	3
2.31	1.69	4	5	1.35	4
2.38	2.31	5	6	1.93	5
1.21	0.64	2	3	2.14	6
2.12	1.21	3	4	0.56	2
2.71	2.12	4	5	1.14	3
1.67	1.60	5	6	1.43	4
2.27	1.67	6	7	2.14	5
2.93	2.27	7	8	2.21	6
2.00	1.84	4	5	0.62	2
2.35	2.00	5	6	1.07	3
2.63	2.35	6	7	1.69	4
3.00	2.63	7	8	2.31	5
1.36	1.30	3	4	2.38	6
2.30	1.89	6	7	0.64	2
1.62	1.50	3	4	1.21	3
2.22	1.93	6	7	2.12	4

<u>Appendix Table A16</u> Family 12 Data - Surface Treated Pavement in Plains with High Traffic

SDI (t+1)	SDI (t)	AGE (t)	AGE (t+1)	SDI	AGE
1.60	1.34	3	4	1.34	3
2.05	1.60	4	5	1.60	4
1.86	2.05	5	6	2.05	5
2.05	1.86	6	7	1.86	6
2.31	2.05	7	8	2.05	7
1.07	1.00	4	5	2.31	8
2.13	1.07	5	6	1.00	4
2.65	2.13	6	7	1.07	5
3.00	2.65	7	8	2.13	6
1.40	1.24	4	5	2.65	7
2.36	1.40	5	6	3.00	8
1.25	1.00	4	5	1.24	4
1.25	1.25	5	6	1.40	5
2.25	1.25	6	7	2.36	6
1.15	0.90	3	4	1.00	4
1.46	1.15	4	5	1.25	5
1.54	1.46	5	6	1.25	6
1.20	1.00	3	4	2.25	7
1.33	1.20	4	5	0.90	3
2.00	1.33	5	6	1.15	4
1.58	0.80	3	4	1.46	5
1.58	1.58	4	5	1.54	6
2.42	1.58	5	6	1.00	3
				1.20	4
				1.33	5
				2.00	6
				0.80	3
				1.58	4
				1.58	5
				2.42	6

Appendix Table A15 Cont'd

SDI (t+1)	SDI (t)	AGE (t)	AGE (t+1)	SDI	AGE
2.33	1.17	2	3	2.71	5
2.60	2.33	3	4	1.87	4
1.53	0.69	2	3	1.60	5
2.08	1.53	3	4	1.67	6
1.90	1.00	3	4	2.27	7
1.90	1.90	4	5	2.93	8
2.38	1.90	5	6	1.84	4
2.45	2.38	6	7	2.00	5
1.71	0.82	3	4	2.35	6
1.67	1.50	3	4	2.63	7
1.00	0.75	2	3	3.00	8
1.17	0.34	2	3	1.30	3
1.33	1.00	3	4	1.36	4
1.95	1.09	3	4	1.89	6
				2.30	7
				1.50	3
				1.62	4
				1.93	6
				2.22	7
				1.17	2
				2.33	3
				2.60	4
				3.50	6
				0.69	2
				1.53	3
				2.08	4
				3.00	6
				1.00	3
				1.90	4
				1.90	5
				2.38	6
				2.45	7
				0.82	3
				1.71	4
				3.38	6
				1.50	3
				1.67	4
				3.00	6
				0.75	2
				1.00	3
				1.75	5
				0.34	2
				1.17	3
				1.57	5
				1.00	3
				1.33	4
				3.67	6
				1.09	3
				1.95	4

Appendix Table A15 Cont'd

SDI (t+1)	SDI (t)	AGE (t)	AGE (t+1)	SDI	AGE
				3.32	7
				1.00	3
				2.17	5
				2.67	7
				1.06	2
				1.71	4
				2.78	6

<u>Appendix Table B1</u> Regression – based modeling in the form; SDI (t+1) = f[SDI (t), Age (t)] for all pavement families

Family	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T (P value)
3	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.6773	0.4914	5.0684	0.2415	20.9856	0.0000	SDI (1yr before)	0.6239	0.2728	3.1768	0.0047
									Age (1yr before)	0.1136	0.1964	0.8904	0.3838
									Intercept	0.8128	0.1276	2.9796	0.0074
4	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.9526	0.2332	7.1055	0.0544	130.6275	0.0000	SDI (1 yr before)	0.1527	0.2151	0.7096	0.4905
									Age (1 yr before)	0.4339	0.1303	3.3313	0.0054
									Intercept	0.3118	0.2180	1.4304	0.1762
5	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.6493	0.3646	3.8175	0.1329	28.7035	0.0000	SDI (1 yr before)	0.5930	0.1423	4.1652	0.0002
									Age (1 yr before)	0.0917	0.0568	1.6128	0.1169
									Intercept	0.8263	0.1713	4.8227	0.0000
6	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.6975	0.4959	2.2684	0.2459	9.2221	0.0084	SDI (1yr before)	0.8299	0.2419	3.4300	0.0089
									Age (1yr before)	-0.0916	0.1701	-0.5387	0.6047
									Intercept	0.9685	0.3589	2.6986	0.0271
8	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.5740	0.3585	1.3863	0.1285	10.7811	0.0010	SDI (1 yr before)	0.0809	0.3767	0.2148	0.8325
									Age (1 yr before)	0.3891	0.1643	2.3669	0.0309
									Intercept	0.6379	0.3187	2.0017	0.0625
9	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.7314	0.2889	2.0400	0.0834	24.5036	0.0000	SDI (1yr before)	0.4427	0.2464	1.7963	0.0892
									Age (1 yr before)	0.2302	0.1150	2.0015	0.0606
									Intercept	0.3681	0.2237	1.6447	0.1173
11	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.7974	0.2516	7.0978	0.0632	112.1501	0.0000	SDI(1 yr before)	0.7003	0.1076	6.5043	0.0000
									Age (1 yr before)	0.0603	0.0463	1.3006	0.1985
									Intercept	0.6299	0.0901	6.9868	0.0000
12	Mulitple Regression	SDI (t+1) = b_0 +b_1*SDI (t)+b_2*Age (t)	0.6653	0.3226	2.0697	0.1041	19.8823	0.0000	SDI (1 yr before)	0.4612	0.2346	1.9657	0.0633
									Age (1 yr before)	0.2096	0.0902	2.3226	0.0309
									Intercept	0.1691	0.2772	0.6099	0.5487

Appendix Table B2 Regression – based modeling in the form; SDI (t+1) = f[SDI (t)] for family 3,

Asphalted pavement in hills with high traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables				
									Parameters	Values	Std. Error	T Stat	Sig. T (P value)
1	LINEAR	$y = b_0 + b_1$*SDI	0.6645	0.4890	9.9454	0.2391	41.5888	0.0000	SDI	0.7630	0.1183	6.4490	0.0000
									Constant	0.9627	0.2135	4.5090	0.0002
2	S	y =e^[b_0 +[$b_{1/SDI}$]]	0.4318	0.3412	1.8583	0.1164	15.9617	0.0007	SDI	-0.0412	0.0103	-3.9950	0.0007
									Constant	0.7990	0.0759	10.5230	0.0000
3	EXPONENT	y = b_0 *[e^[b_1*SDI]]	0.6347	0.2736	2.7314	0.0748	36.4936	0.0000	SDI	0.3999	0.0662	6.0410	0.0000
									Constant	1.0607	0.1267	8.3710	0.0000
4	POWER	y = b_0 * [SDI^b_1]	0.6636	0.2626	2.8555	0.0689	41.4216	0.0000	SDI	0.3318	0.0515	6.4360	0.0000
									Constant	1.8988	0.1051	18.0710	0.0000
5	LGSTIC	y = 1/[1/u +[b_0*[b_1^SDI]]] u = +ve & larger than dep. Var.(4.2)	0.6669	0.6257	16.4629	0.3915	42.0485	0.0000	SDI	0.3747	0.0567	6.6050	0.0000
									Constant	0.9306	0.2543	3.6600	0.0015

Appendix Table B3 Regression – based modeling in the form; SDI (t+1) = f[SDI (t)] for family 4,

ST pavement in hills with low traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables				
									Parameters	Values	Std. Error	T Stat	Sig. T (P value)
1	LINEAR	$y = b_0 + b_1$*SDI	0.9121	0.3060	13.6074	0.0936	145.3334	0.0000	SDI	0.8468	0.0702	12.0550	0.0000
									Constant	0.9109	0.1617	5.6320	0.0001
2	S	y =e^[b_0 +[$b_{1/SDI}$]]	0.8406	0.1901	2.6682	0.0361	73.8400	0.0000	SDI	-0.7565	0.0880	-8.5930	0.0000
									Constant	1.4511	0.0817	17.7550	0.0000
3	EXPONENT	y = b_0 *[e^[b_1*SDI]]	0.8256	0.1988	2.6206	0.0395	66.2831	0.0000	SDI	0.3716	0.0456	8.1410	0.0000
									Constant	1.1341	0.1192	9.5150	0.0000
4	POWER	y = b_0 * [SDI^b_1]	0.8830	0.1629	2.8028	0.0265	105.6919	0.0000	SDI	0.6262	0.0609	10.2810	0.0000
									Constant	1.7456	0.0897	19.4550	0.0000
5	LGSTIC	y = 1/[1/u +[b_0*[b_1^SDI]]] u = +ve & larger than dep. Var.(4.2)	0.9088	0.3784	19.9825	0.1432	139.5754	0.0000	SDI	0.3584	0.0311	11.5130	0.0000
									Constant	0.9767	0.1953	5.0000	0.0002

Appendix Table B4 Regression – based modeling in the form; SDI (t+1) = f[SDI (t)] for family 5,

ST pavement in hills with moderate traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T (P value)
1	LINEAR	$y = b_0 + b_1 * SDI$	0.6199	0.3737	7.2890	0.1397	52.1937	0.0000	SDI	0.7536	0.1043	7.2250	0.0000
									Constant	0.9132	0.1667	5.4790	0.0000
2	S	$y = e\hat{}[\ b_0 + [b_{1/SDI}]]$	0.4615	0.2368	1.5369	0.0560	27.4209	0.0000	SDI	-0.5889	0.1125	-5.2360	0.0000
									Constant	1.1382	0.1001	11.3700	0.0000
3	EXPONENT	$y = b_0 * [e\hat{}[b_1 * SDI]]$	0.5674	0.2122	1.8897	0.0450	41.9692	0.0000	SDI	0.3837	0.0592	6.4780	0.0000
									Constant	1.0975	0.1039	10.5670	0.0000
4	POWER	$y = b_0 * [SDI\hat{}b_1]$	0.5445	0.2177	1.8135	0.0474	38.2537	0.0000	SDI	0.5372	0.0868	6.1850	0.0000
									Constant	1.6460	0.0749	21.9820	0.0000
5	LGSTIC	$y = 1/[1/u + [b_0 * [b_1 \hat{} SDI]]]$ u = +ve & larger than dep. Var.(4.2)	0.6208	0.3757	7.3952	0.1412	52.3911	0.0000	SDI	0.4681	0.0491	9.5360	0.0000
									Constant	0.7895	0.1323	5.9680	0.0000

Appendix Table B5 Regression – based modeling in the form; SDI (t+1) = f[SDI (t)] for family 6,

ST pavement in hills with high traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T (P value)
1	LINEAR	$y = b_0 + b_1 * SDI$	0.6849	0.4773	4.4546	0.2278	19.5579	0.0017	SDI	0.7386	0.1670	4.4220	0.0017
									Constant	0.8649	0.2925	2.9570	0.0160
2	S	$y = e\hat{}[\ b_0 + [b_{1/SDI}]]$	0.4721	0.3322	0.8884	0.1104	8.0481	0.0195	SDI	-0.3566	0.1257	-2.8370	0.0195
									Constant	0.9753	0.1640	5.9470	0.0002
3	EXPONENT	$y = b_0 * [e\hat{}[b_1 * SDI]]$	0.6471	0.2716	1.2178	0.0738	16.5052	0.0028	SDI	0.3862	0.0951	4.0630	0.0028
									Constant	1.0183	0.1695	6.0070	0.0002
4	POWER	$y = b_0 * [SDI\hat{}b_1]$	0.5858	0.2943	1.1024	0.0866	12.7295	0.0060	SDI	0.4616	0.1294	3.5680	0.0060
									Constant	1.6578	0.1545	10.7330	0.0000
5	LGSTIC	$y = 1/[1/u + [b_0 * [b_1 \hat{} SDI]]]$ u = +ve & larger than dep. Var.(4)	0.7042	0.5051	5.4647	0.2551	21.4213	0.0012	SDI	0.4413	0.0780	5.6580	0.0003
									Constant	0.8736	0.2704	3.2310	0.0103

Appendix Table B6 modeling in the form; SDI (t+1) = f[SDI (t)] for family 8, Asphalted pavement in plains with moderate traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T (P value)
1	LINEAR	$y = b_0 + b_1 * SDI$	0.4249	0.4042	2.0523	0.1634	12.5597	0.0025	SDI	0.8263	0.2332	3.5440	0.0025
									Constant	0.7497	0.3553	2.1100	0.0500
2	S	$y = e^\wedge[b_0 + [b_{1/SDI}]]$	0.4812	0.2020	0.6431	0.0408	15.7695	0.0010	SDI	-0.8904	0.2242	-3.9710	0.0010
									Constant	1.2960	0.1712	7.5700	0.0000
3	EXPONENT	$y = b_0 *[e^\wedge[b_1 * SDI]]$	0.4574	0.2065	0.6114	0.0427	14.3329	0.0015	SDI	0.4510	0.1191	3.7860	0.0015
									Constant	0.9783	0.1776	5.5090	0.0000
4	POWER	$y = b_0 * [SDI^\wedge b_1]$	0.4718	0.2038	0.6305	0.0415	15.1845	0.0012	SDI	0.6482	0.1663	3.8970	0.0012
									Constant	1.5164	0.1127	13.4530	0.0000
5	LGSTIC	$y = 1/[1/u + [b_0 * [b_1 ^\wedge SDI]]]$ u = +ve & larger than dep. Var.(4)	0.4082	0.4352	2.2201	0.1894	11.7235	0.0032	SDI	0.4234	0.1063	3.9840	0.0010
									Constant	0.9153	0.3501	2.6140	0.0181

Appendix Table B7 modeling in the form; SDI (t+1) = f[SDI (t)] for family 9, Asphalted pavement in plains with high traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T (P value)
1	LINEAR	$y = b_0 + b_1 * SDI$	0.6716	0.3110	3.7576	0.0967	38.8541	0.0000	SDI	0.8634	0.1385	6.2330	0.0000
									Constant	0.5765	0.2132	2.7040	0.0141
2	S	$y = e^\wedge[b_0 + [b_{1/SDI}]]$	0.6273	0.1799	1.0349	0.0324	31.9759	0.0000	SDI	-0.9758	0.1726	-5.6550	0.0000
									Constant	1.3075	0.1364	9.5830	0.0000
3	EXPONENT	$y = b_0 *[e^\wedge[b_1 * SDI]]$	0.6396	0.1769	1.0551	0.0313	33.7118	0.0000	SDI	0.4575	0.0788	5.8060	0.0000
									Constant	0.9058	0.1099	8.2460	0.0000
4	POWER	$y = b_0 * [SDI^\wedge b_1]$	0.6574	0.1725	1.0847	0.0297	36.4648	0.0000	SDI	0.7178	0.1189	6.0390	0.0000
									Constant	1.3973	0.0755	18.5090	0.0000
5	LGSTIC	$y = 1/[1/u + [b_0 * [b_1 ^\wedge SDI]]]$ u = +ve & larger than dep. Var.(4)	0.6715	0.3292	4.2099	0.1084	38.8446	0.0000	SDI	0.4010	0.0588	6.8200	0.0000
									Constant	1.1237	0.2536	4.4310	0.0003

Appendix Table B8 Regression – based modeling in the form; SDI (t+1) = f[SDI (t)] for family

11, ST pavement in plains with moderate traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T (P value)
1	LINEAR	$y = b_0 + b_1 * SDI$	0.7914	0.2531	14.0886	0.0640	219.9846	0.0000	SDI	0.8207	0.0553	14.8320	0.0000
									Constant	0.6827	0.0810	8.4270	0.0000
2	S	$y = e\^[b_0 + [b_{1/SDI}]]$	0.5528	0.2210	3.4998	0.0488	71.6886	0.0000	SDI	-0.3544	0.0419	-8.4670	0.0000
									Constant	0.8778	0.0502	17.4710	0.0000
3	EXPONENT	$y = b_0 * [e\^[b_1 * SDI]]$	0.7674	0.1594	4.8583	0.0254	191.3020	0.0000	SDI	0.4819	0.0348	13.8310	0.0000
									Constant	0.8886	0.0453	19.6010	0.0000
4	POWER	$y = b_0 * [SDI\^b_1]$	0.7481	0.1658	4.7362	0.0275	172.2196	0.0000	SDI	0.5320	0.0405	13.1230	0.0000
									Constant	1.5462	0.0348	44.4000	0.0000
5	LGSTIC	$y = 1/[1/u + [b_0 * [b_1\^SDI]]]$	0.7905	0.2719	16.1749	0.0739	218.8180	0.0000	SDI	0.4150	0.0247	16.8220	0.0000
		u = +ve & larger than dep. Var.(4)							Constant	1.0278	0.0895	11.4890	0.0000

Appendix Table B9 Regression – based modeling in the form; SDI (t+1) = f[SDI (t)] for family

12, ST pavement in plains with high traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T (P value)
1	LINEAR	$y = b_0 + b_1 * SDI$	0.5751	0.3548	3.5779	0.1259	28.4218	0.0000	SDI	0.8800	0.1651	5.3310	0.0000
									Constant	0.5455	0.2474	2.2050	0.0387
2	S	$y = e\^[b_0 + [b_{1/SDI}]]$	0.5033	0.2117	0.9539	0.0448	21.2785	0.0002	SDI	-0.9415	0.2041	-4.6130	0.0002
									Constant	1.2673	0.1619	7.8280	0.0000
3	EXPONENT	$y = b_0 * [e\^[b_1 * SDI]]$	0.5399	0.2038	1.0232	0.0415	24.6422	0.0001	SDI	0.4706	0.0948	4.9640	0.0001
									Constant	0.8832	0.1255	7.0390	0.0000
4	POWER	$y = b_0 * [SDI\^b_1]$	0.5392	0.2039	1.0219	0.0416	24.5712	0.0001	SDI	0.7116	0.1436	4.9570	0.0001
									Constant	1.3860	0.0857	16.1790	0.0000
5	LGSTIC	$y = 1/[1/u + [b_0 * [b_1\^SDI]]]$	0.5852	0.3701	4.0574	0.1369	29.6296	0.0000	SDI	0.3918	0.0674	5.8090	0.0000
		u = +ve & larger than dep. Var.(4)							Constant	1.1722	0.3024	3.8760	0.0009

Appendix Table B10 Regression – based modeling in the form; SDI (t) = f[Age (t)] for family 3,

Asphalted pavement in hills with high traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Errors	F Value	Sig. F	Variables: Parameters	Variables: Values	Variables: Std. Error	T Stat	Sig. T
1	LINEAR	$y = b_0 + b_1 * age$	0.7115	0.5152	20.2964	0.2654	76.4628	0.0000	AGE	0.4990	0.0571	8.7440	0.0000
									Constant	-0.0022	0.2340	-0.0100	0.9925
2	QUADRATI	$y = b_0 + b_1 * age + b_2 * age^2$	0.7419	0.4954	10.5817	0.2454	43.1224	0.0000	AGE	0.9889	0.2664	3.7130	0.0008
									AGE**2	-0.0631	0.0336	-1.8800	0.0699
									Constant	-0.7965	0.4787	-1.6640	0.1066
3	COMPOUND	$y = b_0 * b_1$^age	0.5236	0.6877	16.1101	0.4729	34.0650	0.0000	AGE	1.5598	0.1188	13.1290	0.0000
									Constant	0.2727	0.0852	3.2010	0.0032
4	GROWTH	y =e^[b_0 +[b_1*age]]	0.5236	0.6877	16.1101	0.4729	34.0650	0.0000	AGE	0.4446	0.0762	5.8370	0.0000
									Constant	-1.2995	0.3124	-4.1600	0.0002
5	LOGARITH	y = b_0 +[b_1*Ln[age]]	0.7362	0.4927	20.9988	0.2428	86.4910	0.0000	AGE	1.6348	0.1758	9.3000	0.0000
									Constant	-0.1187	0.2322	-0.5110	0.6127
6	CUBIC	y = b_0 +[b_1*age] +[b_2*[age^2]+[b3*age^3]	0.7420	0.5038	7.0548	0.2538	27.7948	0.0000	AGE	0.9403	0.8425	1.1160	0.2735
									AGE**2	-0.0490	0.2351	-0.2080	0.8365
									AGE**3	-0.0012	0.0200	-0.0610	0.9519
									Constant	-0.7497	0.9101	-0.8240	0.4168
7	S	y =e^[b_0 +[b_1/age]]	0.8847	0.3383	27.2232	0.1144	237.8933	0.0000	AGE	-4.4608	0.2892	- 15.4240	0.0000
									Constant	1.8794	0.1134	16.5710	0.0000
8	EXPONENT	y = b_0 *[e^[b_1*age]]	0.5236	0.6877	16.1101	0.4729	34.0650	0.0000	AGE	0.4446	0.0762	5.8370	0.0000
									Constant	0.2727	0.0852	3.2010	0.0032
9	INVERSE	y = b_0 +[b_1/age]	0.6353	0.5793	18.1211	0.3356	53.9937	0.0000	AGE	-3.6394	0.4953	-7.3480	0.0000
									Constant	3.1076	0.1942	16.0000	0.0000
10	POWER	y = b_0 * [age^b_1]	0.7277	0.5199	22.3919	0.2703	82.8460	0.0000	AGE	1.6882	0.1855	9.1020	0.0000
									Constant	0.1849	0.0453	4.0820	0.0003
11	LGSTIC	y = 1/[1/u +[b_0*[b_1^age]]] u = +ve & larger than dep. Var.(4.0)	0.6269	0.9131	43.4208	0.8337	52.0842	0.0000	AGE	0.4820	0.0487	9.8880	0.0000
									Constant	4.9411	2.0492	2.4110	0.0220

Appendix Table B11 Regression – based modeling in the form; SDI (t) = f[Age (t)] for family 4,

ST pavement in hills with low traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables				
									Parameters	Values	Std. Error	T Stat	Sig. T (P value)
1	LINEAR	y = b_0 +b_1*age	0.8858	0.3421	29.9462	0.1170	255.9190	0.0000	AGE	0.5066	0.0317	15.9970	0.0000
									Constant	-0.2831	0.1550	-1.8260	0.0769
2	QUADRATI	y = b_0 +b_1*age +b_2*age^2	0.8903	0.3405	15.0492	0.1159	129.8317	0.0000	AGE	0.3242	0.1622	1.9990	0.0542
									AGE**2	0.0190	0.0166	1.1460	0.2603
									Constant	0.0889	0.3594	0.2470	0.8062
3	COMPOUND	y = b_0 *b_1^age	0.8218	0.2380	8.6193	0.0566	152.1529	0.0000	AGE	1.3123	0.0289	45.3850	0.0000
									Constant	0.5125	0.0553	9.2700	0.0000
4	GROWTH	y =e^[b_0 +[b_1*age]]	0.8218	0.2380	8.6193	0.0566	152.1529	0.0000	AGE	0.2718	0.0220	12.3350	0.0000
									Constant	-0.6684	0.1079	-6.1960	0.0000
5	LOGARITH	y = b_0 +[b_1*Ln[age]]	0.8156	0.4347	27.5725	0.1889	145.9275	0.0000	AGE	2.0284	0.1679	12.0800	0.0000
									Constant	-0.8702	0.2502	-3.4790	0.0014
6	CUBIC	y = b_0 +[b_1*age] +[b_2*[age^2]+[b3*age^3]	0.9000	0.3303	10.1419	0.1091	92.9666	0.0000	AGE	-0.9458	0.7499	-1.2610	0.2166
									AGE**2	0.3048	0.1658	1.8390	0.0755
									AGE**3	-0.0194	0.0112	-1.7320	0.0932
									Constant	1.7340	1.0117	1.7140	0.0965
7	S	y =e^[b_0 +[b_1/age]]	0.7775	0.2660	8.1544	0.0707	115.2791	0.0000	AGE	-3.9039	0.3636	-10.7370	0.0000
									Constant	1.6040	0.1066	15.0480	0.0000
8	EXPONENT	y = b_0 *[e^b_1*age]]	0.8218	0.2380	8.6193	0.0566	152.1529	0.0000	AGE	0.2718	0.0220	12.3350	0.0000
									Constant	0.5125	0.0553	9.2700	0.0000
9	INVERSE	y = b_0 +[b_1/age]	0.6912	0.5624	23.3686	0.3163	73.8728	0.0000	AGE	-6.6087	0.7689	-8.5950	0.0000
									Constant	3.7750	0.2254	16.7470	0.0000
10	POWER	y = b_0 * [age^b_1]	0.8336	0.2300	8.7432	0.0529	165.2925	0.0000	AGE	1.1422	0.0888	12.8570	0.0000
									Constant	0.3464	0.0458	7.5550	0.0000
11	LGSTIC	y = 1/[1/u +[b_0*[b_1^age]]]	0.8729	0.4280	41.5202	0.1832	226.6370	0.0000	AGE	0.5507	0.0218	25.2370	0.0000
		u = +ve & larger than dep. Var.(4.2)							Constant	3.7610	0.7296	5.1550	0.0000

Appendix Table B12 Regression – based modeling in the form; SDI (t) = f[Age (t)] for family 5,

ST pavement in hills with moderate traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T or P value
1	LINEAR	$y = b_0 + b_1 * age$	0.54373	0.4587	17.5484	0.2104	83.4174	0.0000	AGE	0.2879	0.0315	9.1330	0.0000
									Constant	0.5369	0.1465	3.6650	0.0005
2	QUADRATI	$y = b_0 + b_1 * age + b_2 * age^2$	0.5533	0.45710	8.92865	0.20894	42.7328	0.0000	AGE	0.4759	0.1578	3.0170	0.0036
									AGE**2	-0.0207	0.0170	-1.2160	0.2282
									Constant	0.1720	0.3338	0.5150	0.6080
3	COMPOUND	$y = b_0 * b_1$^age	0.53467	0.29037	6.78173	0.08432	80.4313	0.0000	AGE	1.1960	0.0239	50.1020	0.0000
									Constant	0.7579	0.0703	10.7810	0.0000
4	GROWTH	y =e^[b_0 +[b_1*age]]	0.53467	0.29037	6.78173	0.08432	80.4313	0.0000	AGE	0.1790	0.0200	8.9680	0.0000
									Constant	-0.2772	0.0928	-2.9880	0.0039
5	LOGARITH	y = b_0 +[b_1*Ln[age]]	0.54492	0.45806	17.587	0.20982	83.8198	0.0000	AGE	1.1228	0.1226	9.1550	0.0000
									Constant	0.2377	0.1770	1.3430	0.1837
6	CUBIC		0.5539	0.46015	5.95876	0.21174	28.1425	0.0000	AGE	0.6337	0.5505	1.1510	0.2537
		y = b_0 +[b_1*age] +[b_2*[age^2]+[b3*age^3]							AGE**2	-0.0581	0.1261	-0.4610	0.6464
									AGE**3	0.0027	0.0089	0.2990	0.7655
									Constant	-0.0216	0.7285	-0.0300	0.9765
7	S	y =e^[b_0 +[$b_{1/}$age]]	0.50579	0.29925	6.41546	0.08955	71.6416	0.0000	AGE	-2.0672	0.2442	-8.4640	0.0000
									Constant	1.0766	0.0771	13.9580	0.0000
8	EXPONENT	y = b_0 *[e^[b_1*age]]	0.53467	0.29037	6.78173	0.08432	80.4313	0.0000	AGE	0.1790	0.0200	8.9680	0.0000
									Constant	0.7579	0.0703	10.7810	0.0000
9	INVERSE	y = b_0 +[$b_{1/}$age]	0.45507	0.50125	14.6869	0.25125	58.4559	0.0000	AGE	-3.1278	0.4091	-7.6460	0.0000
									Constant	2.6592	0.1292	20.5820	0.0000
10	POWER	y = b_0 * [age^b_1]	0.5676	0.27992	7.19905	0.07836	91.8768	0.0000	AGE	0.7184	0.0749	9.5850	0.0000
									Constant	0.6119	0.0662	9.2460	0.0000
11	LGSTIC	y = 1/[1/u +[b_0*[b_1^age]]]	0.54406	0.50482	21.2868	0.25484	83.5286	0.0000	AGE	0.7282	0.0253	28.8190	0.0000
		u = +ve & larger than dep. Var.(4.2)							Constant	1.2637	0.2038	6.2010	0.0000

Appendix Table B13 Regression – based modeling in the form; SDI (t) = f[Age (t)] for family 6,

ST pavement in hills with high traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Errors	F Value	Sig. F	Variables: Parameters	Variables: Values	Variables: Std. Error	T Stat	Sig. T
1	LINEAR	$y = b_0 + b_1 * age$	0.5483	0.6318	10.1727	0.3992	25.4858	0.0001	AGE	0.4272	0.0846	5.0480	0.0001
									Constant	0.3884	0.3225	1.2040	0.2418
2	QUADRATI	$y = b_0 + b_1 * age + b_2 * age\char`^2$	0.5585	0.6400	5.1816	0.4096	12.6508	0.0003	AGE	0.7267	0.4475	1.6240	0.1200
									AGE**2	-0.0417	0.0612	-0.6820	0.5031
									Constant	-0.0477	0.7181	-0.0660	0.9477
3	COMPOUND	$y = b_0 * b_1$^age	0.5440	0.4339	4.7158	0.1882	25.0542	0.0001	AGE	1.3376	0.0777	17.2090	0.0000
									Constant	0.5834	0.1292	4.5160	0.0002
4	GROWTH	y =e^[b_0 +[b_1*age]]	0.5440	0.4339	4.7158	0.1882	25.0542	0.0001	AGE	0.2909	0.0581	5.0050	0.0001
									Constant	-0.5388	0.2214	-2.4330	0.0240
5	LOGARITH	y = b_0 +[b_1*Ln[age]]	0.5566	0.6259	10.3283	0.3917	26.3646	0.0000	AGE	1.291	0.2514	5.1350	0.0000
									Constant	0.4201	0.3118	1.3470	0.1923
6	CUBIC	y = b_0 +[b_1*age] +[b_2*[age^2]+[b3*age^3]	0.5587	0.6565	3.4554	0.4310	8.0173	0.0012	AGE	0.8438	1.4946	0.5650	0.5790
									AGE**2	-0.0790	0.4579	-0.1730	0.8648
									AGE**3	0.0035	0.0426	0.0820	0.9353
									Constant	-.150826 1	1.4538	-0.1040	0.9185
7	S	y =e^[b_0 +[b_1/age]]	0.6349	0.3882	5.5040	0.1507	36.5250	0.0000	AGE	-2.1442	0.3548	-6.0440	0.0000
									Constant	1.2778	0.1558	8.1990	0.0000
8	EXPONENT	y = b_0 *[e^[b_1*age]]	0.5440	0.4339	4.7158	0.1882	25.0542	0.0001	AGE	0.2909	0.0581	5.0050	0.0001
									Constant	0.5834	0.1292	4.5160	0.0002
9	INVERSE	y = b_0 +[b_1/age]	0.4915	0.6703	9.1189	0.4493	20.2940	0.0002	AGE	-2.7599	0.6127	-4.5050	0.0002
									Constant	2.9103	0.2691	10.8150	0.0000
10	POWER	y = b_0 * [age**b_1]	0.6242	0.3939	5.4105	0.1551	34.8750	0.0000	AGE	0.9343	0.1582	5.9060	0.0000
									Constant	0.5601	0.1099	5.0960	0.0000
11	LGSTIC	y = 1/[1/u +[b_0*[b_1^age]]] u = +ve & larger than dep. Var.(4.0)	0.5604	0.7492	15.0258	0.5612	26.7726	0.0000	AGE	0.5950	0.0597	9.9660	0.0000
									Constant	1.8046	0.6900	2.6150	0.0162

<u>Appendix Table B14</u> modeling in the form; SDI (t) = f[Age (t)] for family 8, Asphalted pavement in plains with moderate traffic

S.Nos	Method	Formula	R2	Std. Error	F Value	Sig. F	Variables Parameters	Values	Std. Error	T Stat	Sig. T
1	LINEAR	y = b0 +b1*age	0.76944	0.3005	76.75518	0.000	AGE	0.438778	0.050083	8.761	0.0000
							Constant	0.156	0.190052	0.821	0.4202
2	QUADRATI	$y = b_0 + b_1$*age $+ b_2$*age^2	0.77279	0.30501	37.41372	0.0000	AGE	0.631	0.341009	1.85	0.0777
							AGE**2	-0.026212	0.045982	-0.570	0.5744
							Constant	-0.158545	0.584527	-0.271	0.7887
3	COMPOUND	$y = b_0$ *b_1^age	0.79439	0.16828	88.86304	0.000	AGE	1.302642	0.036536	35.654	0.0000
							Constant	0.62983	0.067034	9.396	0.0000
4	GROWTH	y =e^[b_0 +[b_1*age]]	0.79439	0.16828	88.86304	0.000	AGE	0.264394	0.028047	9.427	0.0000
							Constant	-0.462305	0.106432	-4.344	0.0002
5	LOGARITH	$y = b_0$ +[b_1*Ln[age]]	0.76242	0.30504	73.80942	0.000	AGE	1.475007	0.171687	8.591	0.0000
							Constant	-0.064894	0.218272	-0.297	0.7689
6	CUBIC	$y = b_0$ +[b_1*age] +[b_2*[age^2]+[b3*age^3]	0.78923	0.30068	26.21092	0.000	AGE	-1.424315	1.641009	-0.868	0.3952
							AGE**2	0.548	0.451024	1.215	0.2378
							AGE**3	-0.05013	0.039176	-1.28	0.2146
							Constant	2.100022	1.856728	1.131	0.2708
7	S	y =e^[b_0 +[$b_{1/}$age]]	0.79874	0.16649	91.28199	0.000	AGE	-2.752158	0.288059	-9.554	0.0000
							Constant	1.355527	0.096565	14.037	0.0000
8	EXPONENT	$y = b_0$ *[e^[b_1*age]]	0.79439	0.16828	88.86304	0.000	AGE	0.264394	0.028047	9.427	0.0000
							Constant	0.62983	0.067034	9.396	0.0000
9	INVERSE	$y = b_0$ +[$b_{1/}$age]	0.72255	0.32964	59.89803	0.000	AGE	-4.413949	0.570323	-7.739	0.0000
							Constant	3.124523	0.191188	16.343	0.0000
10	POWER	$y = b_0$ * [age^b_1]	0.8146	0.15982	101.02241	0.000	AGE	0.904133	0.089955	10.051	0.0000
							Constant	0.541111	0.061883	8.744	0.0000
11	LGSTIC	y = 1/[1/u +[b_0*[b_1^age]]]	0.76824	0.32543	76.24133	0.000	AGE	0.622759	0.033778	18.437	0.0000
		u = +ve & larger than dep. Var.(4.0)					Constant	1.831551	0.376975	4.859	0.0001

Appendix Table B15 Regression – based modeling in the form; SDI (t) = f[Age (t)] for family 9,

Asphalted pavement in plains with high traffic

S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Values	Std. Error	T Stat	Sig. T or P value
1	QUADRATI	$y = b_0 + b_1 * age + b_2 * age$^2	0.7743	0.2926	3.5257	0.0856	41.1650	0.0000	AGE	0.1792	0.2857	0.6270	0.5364
									AGE**2	0.0251	0.0349	0.7200	0.4785
									Constant	0.4525	0.5411	0.8360	0.4113
2	COMPOUND	$y = b_0 * b_1$^age	0.8148	0.1581	2.7468	0.0250	109.9555	0.0000	AGE	1.2707	0.0290	43.7670	0.0000
									Constant	0.5824	0.0570	10.2110	0.0000
3	GROWTH	y =e^[b_0 +[b_1*age]]	0.8148	0.1581	2.7468	0.0250	109.9555	0.0000	AGE	0.2396	0.0228	10.4860	0.0000
									Constant	-0.5407	0.0979	-5.5210	0.0000
4	CUBIC	y = b_0 +[b_1*age] +[b_2*[age^2]+[b3*age^3]	0.8024	0.2797	2.4358	0.0782	31.1359	0.0000	AGE	-2.3629	1.4312	-1.6510	0.1123
									AGE**2	0.7036	0.3765	-1.8090	0.0744
									AGE**3	-0.0563	0.0311	-1.8090	0.0835
									Constant	3.3675	1.6920	1.9900	0.0586
5	EXPONENT	y = b_0 *[e^[b_1*age]]	0.8148	0.1581	2.7468	0.0250	109.9555	0.0000	AGE	0.2396	0.0228	10.4860	0.0000
									Constant	0.5824	0.0570	10.2110	0.0000
6	INVERSE	y = b_0 +[$b_{1/}$age]	0.6288	0.3677	5.7261	0.1352	42.3437	0.0000	AGE	-4.2390	0.6514	-6.5070	0.0000
									Constant	2.8272	0.1951	14.4950	0.0000
7	POWER	y = b_0 * [age^b_1]	0.7850	0.1703	2.6465	0.0290	91.2959	0.0000	AGE	0.8706	0.0911	9.5550	0.0000
									Constant	0.4795	0.0608	7.8860	0.0000
8	LGSTIC	y = 1/[1/u +[b_0*[b_1^age]]]	0.7721	0.3126	8.2772	0.0977	84.7050	0.0000	AGE	0.6597	0.0298	22.1290	0.0000
		u = +ve & larger than dep. Var.							Constant	1.9994	0.3873	5.1630	0.0000
9	LINEAR	y = b_0 + b_1*age	0.7694	0.2898	7.0070	0.0840	83.4207	0.0000	AGE	0.3827	0.0419	9.1330	0.0000
									Constant	0.0854	0.1796	0.4760	0.6383
10	LOGARITH	y = b_0 +[b_1*ln[age]]	0.7204	0.3191	6.5607	0.1018	64.4165	0.0000	AGE	1.3708	0.1708	8.0260	0.0000
									Constant	-0.1983	0.2377	-0.8340	0.4119
11	S	y =e^[b_0 +[$b_{1/}$age]]	0.7048	0.1995	2.3762	0.0398	59.6977	0.0000	AGE	-2.7307	0.3534	-7.7260	0.0000
									Constant	1.1973	0.1058	11.3150	0.0000

Appendix Table B16 Regression – based modeling in the form; SDI (t) = f[Age (t)] for family 11, ST pavement in plains with moderate traffic

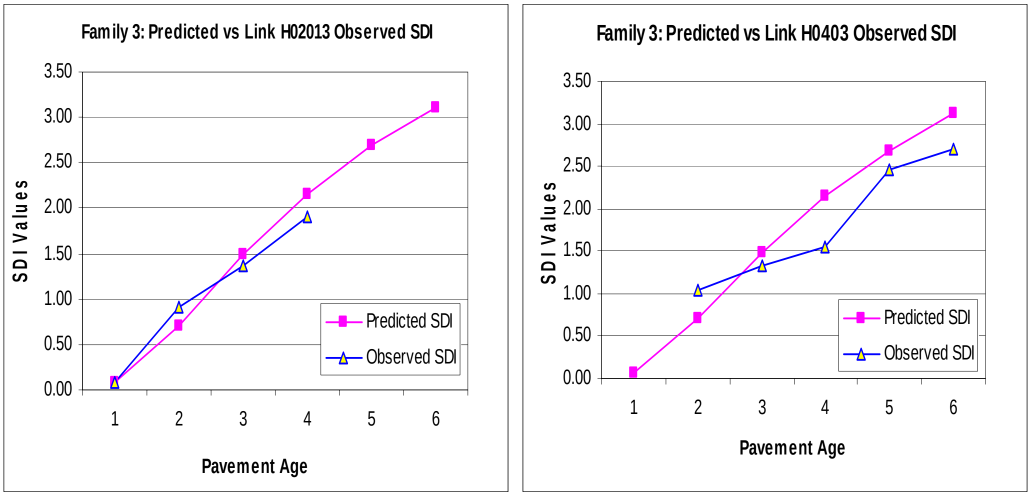
S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Variables: Values	Std. Error	T Stat	Sig. T or P value
1	LINEAR	y = b_0 +b_1*age	0.7383	0.3885	42.5767	0.1509	282.1399	0.0000	AGE	0.4073	0.0242	16.7970	0.0000
									Constant	-0.0415	0.1090	-0.3810	0.7042
2	QUADRATI	y = b_0 +b_1*age +b_2*age^2	0.7510	0.3808	21.6551	0.1450	149.3242	0.0000	AGE	0.6969	0.1310	5.3210	0.0000
									AGE**2	-0.0322	0.0143	-2.2490	0.0267
									Constant	-0.6091	0.2740	-2.2230	0.0285
3	COMPOUND	y = b_0 *b_1^age	0.6893	0.2994	19.8865	0.0897	221.7982	0.0000	AGE	1.3209	0.0247	53.5050	0.0000
									Constant	0.4590	0.0386	11.9030	0.0000
4	GROWTH	y =e^[b_0 +[b_1*age]]	0.6893	0.2994	19.8865	0.0897	221.7982	0.0000	AGE	0.2783	0.0187	14.8930	0.0000
									Constant	-0.7787	0.0840	-9.2680	0.0000
5	LOGARITH	y = b_0 +[b_1*Ln[age]]	0.7449	0.3836	42.9564	0.1471	292.0052	0.0000	AGE	1.6356	0.0957	17.0880	0.0000
									Constant	-0.5548	0.1357	-4.0880	0.0001
6	CUBIC	y = b_0 +[b_1*age] +[b_2*[age^2]+[b3*age^3]	0.7514	0.3825	14.4433	0.1463	98.7243	0.0000	AGE	0.5165	0.5088	1.0150	0.3126
									AGE**2	0.0101	0.1161	0.0870	0.9310
									AGE**3	-0.0030	0.0082	-0.3670	0.7144
									Constant	-0.3788	0.6851	-0.5530	0.5816
7	S	y =e^[b_0 +[b_1/age]]	0.7756	0.2544	22.3788	0.0647	345.6840	0.0000	AGE	-4.0848	0.2197	-18.5930	0.0000
									Constant	1.5267	0.0660	23.1240	0.0000
8	EXPONENT	y = b_0 *[e^[b_1*age]]	0.6893	0.2994	19.8865	0.0897	221.7982	0.0000	AGE	0.2783	0.0187	14.8930	0.0000
									Constant	0.4590	0.0386	11.9030	0.0000
9	INVERSE	y = b_0 +[b_1/age]	0.6933	0.4206	39.9790	0.1769	226.0193	0.0000	AGE	-5.4596	0.3632	-15.0340	0.0000
									Constant	3.1880	0.1091	29.2120	0.0000
10	POWER	y = b_0 * [age^b_1]	0.7608	0.2627	21.9519	0.0690	318.1121	0.0000	AGE	1.1693	0.0656	17.8360	0.0000
									Constant	0.3014	0.0280	10.7590	0.0000
11	LGSTIC	y = 1/[1/u +[b_0*[b_1^age]]]	0.7013	0.5049	59.8369	0.2549	234.7392	0.0000	AGE	0.6170	0.0194	31.7320	0.0000
		u = +ve & larger than dep. Var.(4.0)							Constant	2.7885	0.3950	7.0590	0.0000

Appendix Table B17 Regression – based modeling in the form; SDI (t) = f[Age (t)] for family 12, ST pavement in plains with high traffic

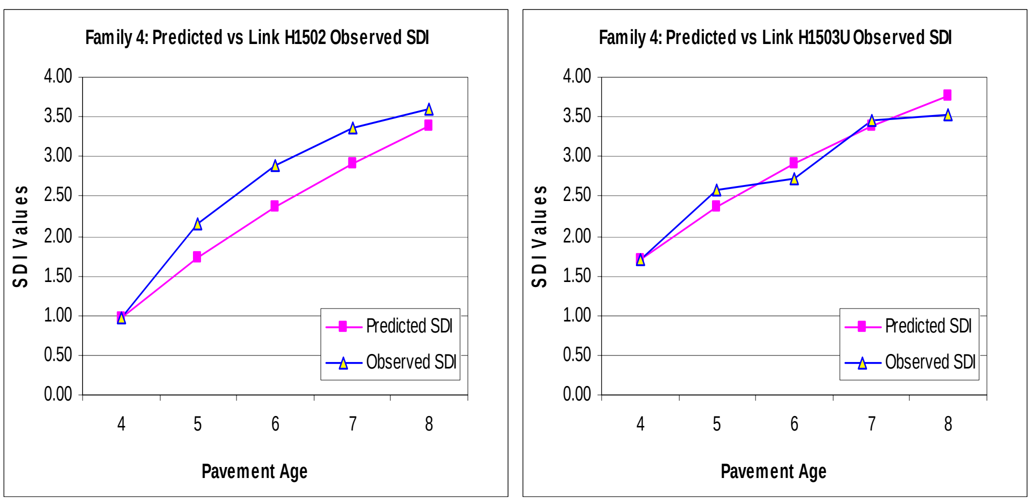
S. Nos	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Variables: Values	Variables: Std. Error	T Stat	Sig. T or P value
1	LINEAR	$y = b_0 + b_1 * age$	0.7058	0.3170	6.7516	0.1005	67.1862	0.0000	AGE	0.3370	0.0411	8.1970	0.0000
									Constant	-0.1040	0.2188	-0.4750	0.6382
2	QUADRATI	$y = b_0 + b_1 * age + b_2 * age^2$	0.7160	0.3172	3.4244	0.1006	34.0339	0.0000	AGE	0.0604	0.2845	0.2120	0.8335
									AGE**2	0.0260	0.0265	0.9820	0.3346
									Constant	0.5791	0.7290	0.7940	0.4339
3	COMPOUND	$y = b_0 * b_1$^age	0.7025	0.1943	2.4954	0.0378	66.1030	0.0000	AGE	1.2273	0.0309	39.6900	0.0000
									Constant	0.5353	0.0718	7.4560	0.0000
4	GROWTH	y =e^[b_0 +[b_1*age]]	0.7025	0.1943	2.4954	0.0378	66.1030	0.0000	AGE	0.2048	0.0252	8.1300	0.0000
									Constant	-0.6248	0.1341	-4.6590	0.0001
5	LOGARITH	y = b_0 +[b_1*Ln[age]]	0.6631	0.3393	6.3427	0.1151	55.1079	0.0000	AGE	1.6251	0.2189	7.4230	0.0000
									Constant	-0.9693	0.3550	-2.7300	0.0108
6	CUBIC	y = b_0 +[b_1*age] +[b_2*[age^2]+[b3*age^3]	0.7194	0.3213	2.2938	0.1032	22.2208	0.0000	AGE	-0.8393	1.6241	-0.5170	0.6097
									AGE**2	0.2008	0.3117	0.6440	0.5251
									AGE**3	-0.0107	0.0191	-0.5630	0.5783
									Constant	2.0348	2.6893	0.7570	0.4561
7	S	y =e^[b_0 +[b_1/age]]	0.6404	0.2136	2.2750	0.0456	49.8660	0.0000	AGE	-4.4704	0.6331	-7.0620	0.0000
									Constant	1.3698	0.1391	9.8460	0.0000
8	EXPONENT	y = b_0 *[e^[b_1*age]]	0.7025	0.1943	2.4954	0.0378	66.1030	0.0000	AGE	0.2048	0.0252	8.1300	0.0000
									Constant	0.5353	0.0718	7.4560	0.0000
9	INVERSE	y = b_0 +[b_1/age]	0.5942	0.3723	5.6838	0.1386	41.0001	0.0000	AGE	-7.0661	1.1035	-6.4030	0.0000
									Constant	3.1163	0.2425	12.8500	0.0000
10	POWER	y = b_0 * [age^b_1]	0.6865	0.1994	2.4387	0.0398	61.3132	0.0000	AGE	1.0077	0.1287	7.8300	0.0000
									Constant	0.3066	0.0640	4.7920	0.0000
11	LGSTIC	y = 1/[1/u +[b_0*[b_1^age]]] u = +ve & larger than dep. Var.(4.0)	0.7095	0.3407	7.9356	0.1160	68.3867	0.0000	AGE	0.6940	0.0307	22.6380	0.0000
									Constant	2.4425	0.5743	4.2530	0.0002

Appendix Table B18 Regression – based modeling in the form; SDI (t+1) = f[SDI (t), Age (t+1)] for all pavement families

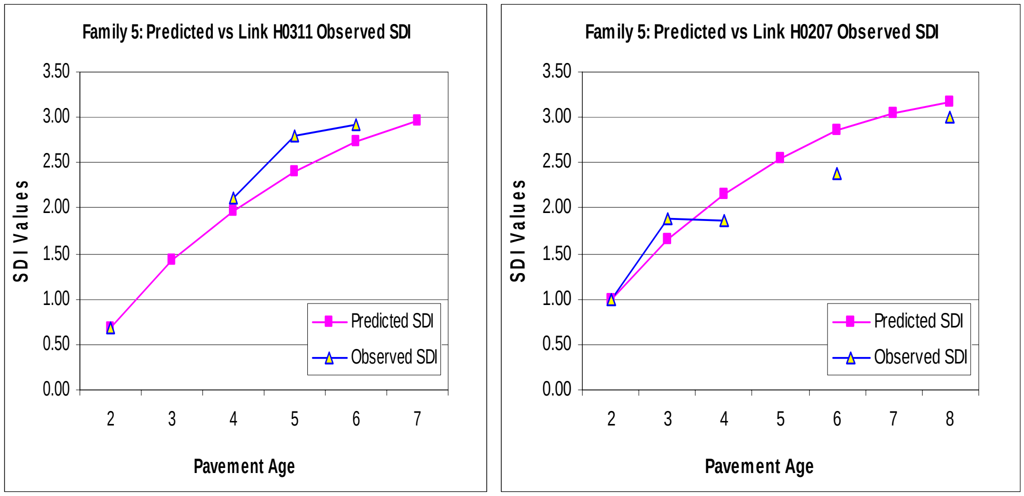
Family	Method	Formula	R2	Std. Error	MS Model	MS Error	F Value	Sig. F	Variables: Parameters	Variables: Values	Variables: Std. Error	Variables: T Stat	Variables: Sig. T (P value)
3	Multi Linear	$SDI(t+1) = b_0 + b_1*SDI(t) + b_2*Age(t+1)$	0.6773	0.4914	5.0684	0.2415	20.9856	0.0000	SDI (t)	0.6239	0.1964	3.1768	0.0047
									Age (t+1)	0.1136	0.1276	0.8904	0.3839
									Constant	0.6991	0.3656	1.9121	0.0703
4	Multi Linear	$SDI(t+1) = b_0 + b_1*SDI(t) + b_2*Age(t+1)$	0.9526	0.2332	7.1055	0.0544	130.6275	0.0000	SDI (t)	0.1527	0.2151	0.7096	0.4905
									Age (t+1)	0.4340	0.1303	3.3313	0.0054
									Constant	-0.1221	0.3337	-0.3660	0.7202
5	Multi Linear	$SDI(t+1) = b_0 + b_1*SDI(t) + b_2*Age(t+1)$	0.6493	0.3647	3.8175	0.1330	28.7035	0.0000	SDI (t)	0.5930	0.1424	4.1653	0.0002
									Age (t+1)	0.0917	0.0569	1.6129	0.1169
									Constant	0.7346	0.1968	3.7335	0.0008
6	Multi Linear	$SDI(t+1) = b_0 + b_1*SDI(t) + b_2*Age(t+1)$	0.6975	0.4960	2.2684	0.2460	9.2221	0.0084	SDI (t)	0.8299	0.2420	3.4300	0.0090
									Age (t+1)	-0.0916	0.1701	-0.5387	0.6047
									Constant	1.0602	0.4721	2.2457	0.0549
8	Multi Linear	$SDI(t+1) = b_0 + b_1*SDI(t) + b_2*Age(t+1)$	0.5740	0.3586	1.3863	0.1286	10.7812	0.0011	SDI (t)	0.0810	0.3768	0.2149	0.8326
									Age (t+1)	0.3891	0.1644	2.3669	0.0309
									Constant	0.2489	0.3796	0.6557	0.5214
9	Multi Linear	$SDI(t+1) = b_0 + b_1*SDI(t) + b_2*Age(t+1)$	0.7314	0.2890	2.0460	0.0835	24.5036	0.0000	SDI (t)	0.4427	0.2464	1.7963	0.0892
									Age (t+1)	0.2302	0.1150	2.0015	0.0606
									Constant	0.1379	0.2954	0.4667	0.6463
11	Multi Linear	$SDI(t+1) = b_0 + b_1*SDI(t) + b_2*Age(t+1)$	0.7974	0.2516	7.0978	0.0633	112.1501	0.0000	SDI (t)	0.7003	0.1077	6.5043	0.0000
									Age (t+1)	0.0603	0.0464	1.3007	0.1986
									Constant	0.5697	0.1185	4.8083	0.0000
12	Multi Linear	$SDI(t+1) = b_0 + b_1*SDI(t) + b_2*Age(t+1)$	0.6654	0.3226	2.0698	0.1041	19.8823	0.0000	SDI (t)	0.4612	0.2346	1.9657	0.0634
									Age (t+1)	0.2096	0.0903	2.3227	0.0309
									Constant	-0.0405	0.3380	-0.1199	0.9058



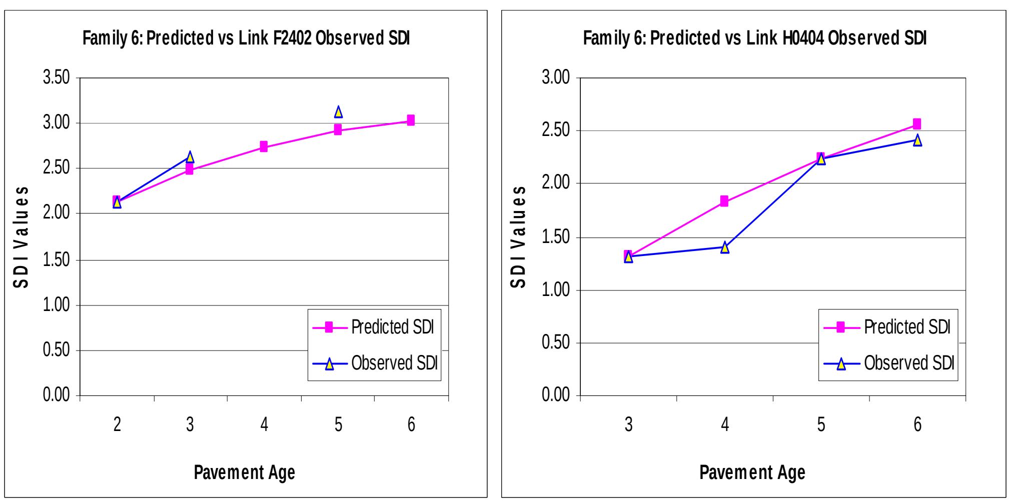
Appendix Figure C1 Comparison of predicted with observed values for family 3 pavements



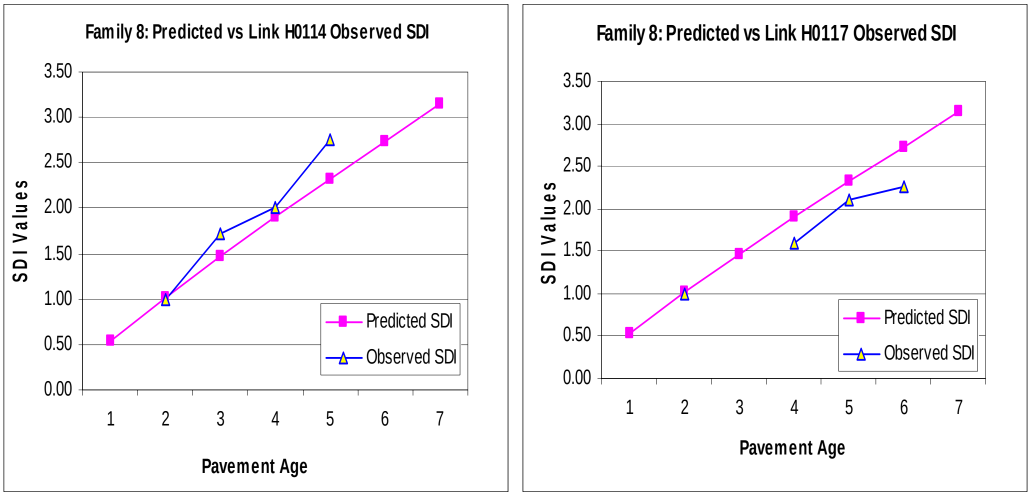
Appendix Figure C2 Comparison of predicted with observed values for family 4 pavements



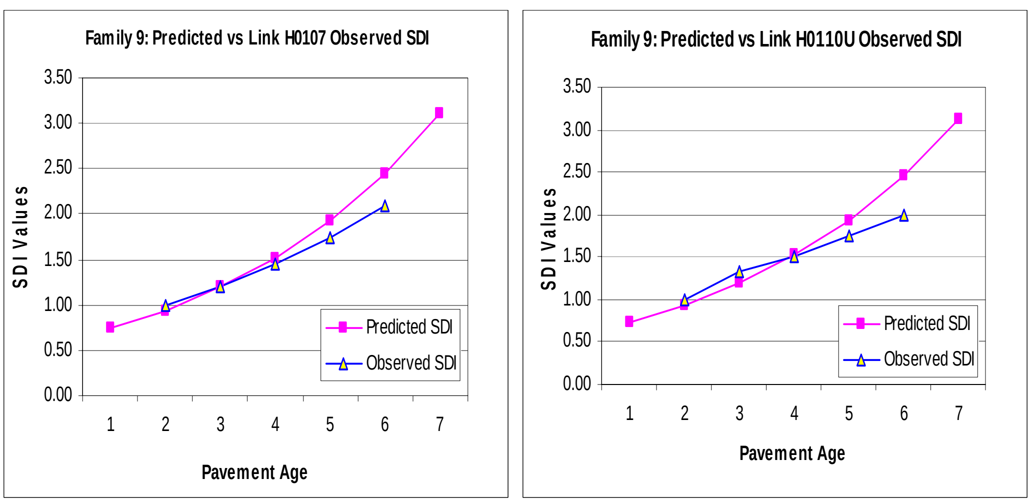
Appendix Figure C3 Comparison of predicted with observed values for family 5 pavements



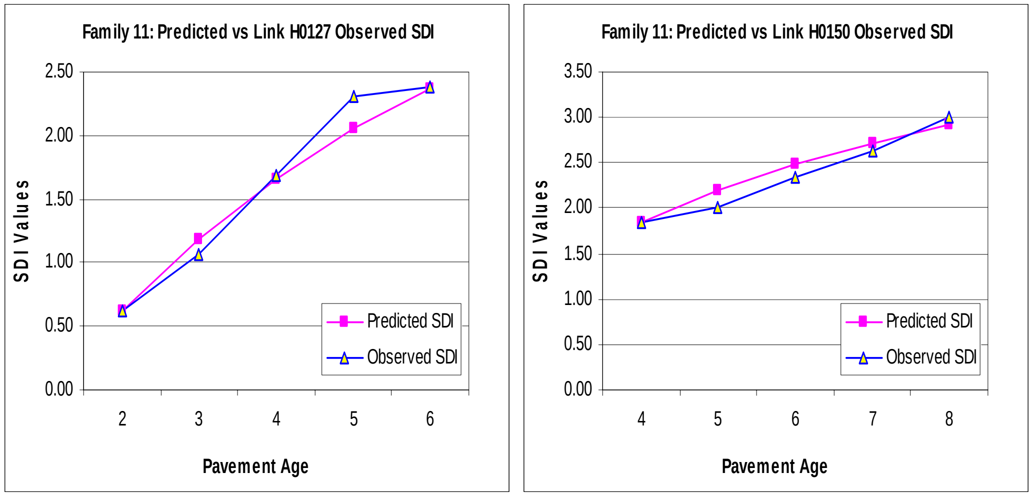
Appendix Figure C4 Comparison of predicted with observed values for family 6 pavements



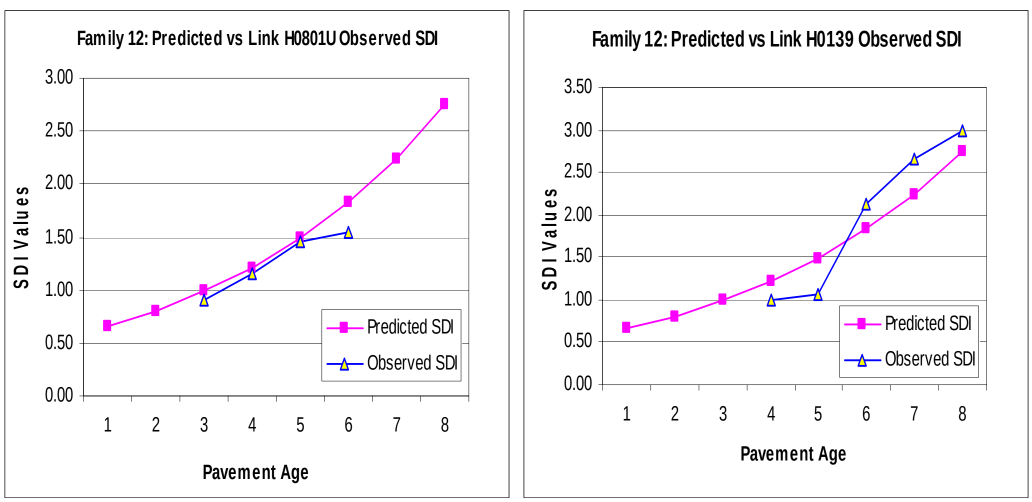
Appendix Figure C5 Comparison of predicted with observed values for family 8 pavements



Appendix Figure C6 Comparison of predicted with observed values for family 9 pavements



Appendix Figure C7 Comparison of predicted with observed values for family 11 pavements



Appendix Figure C8 Comparison of predicted with observed values for family 12 pavements