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Development of Present Serviceability Index (PSI) for Flexible Pavements

by

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ABSTRACT

One of the most key challenge on road pavement is to determine the quality and condition of existing pavements. Irrespective of design and construction, road pavement deteriorate with time and most credential factors of determining pavement condition is its surface roughness and distress. Although, Department of Road, Nepal measures the roughness as International Roughness Index (IRI) and distress as Surface Distress Index (SDI) separately, but there is no any single composite index that can predict the pavement condition. This research work deals with condition surveys which aims is to develop the Present Serviceability Index (PSI) to evaluate the pavement condition in effective way which comprise the both roughness index IRI and distress index SDI, where roughness is measured through vehicle mounted bump integrator and distress is accessed through visual inspection and manual measurement.

And the model developed using regression analysis is $PSI = 10.0745 – 1.107 * SDI – 0.4645 * IRI$, where correlation coefficient value is found to be 0.9397. Performance curve of any flexible pavement section can be drawn out from this PSI value and also indicates the treatment measures needed for those sections.

Key Words: *Present Serviceability Index, Surface Distress Index, International Roughness Index, performance curve, PSI, SDI, IRI*

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LIST OF ABBREVIATIONS

AASHO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing Materials
BCMoT	British Columbia Ministry of Transportation
BI	Bump Integrator
DOR	Department of Roads
FHA	Federal Highway Administration
HMIS	Highway Management Information System
IRI	International Roughness Index
Mn/DOT	Minnesota Department of Transportation
MRCU	Maintenance and Rehabilitation Co-ordination Unit
MR&R	Maintenance and Rehabilitation and Reconstruction
NCHRP	National Co-operative Highway Research Program
NPS	National Park Service
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
PDI	Pavement Distress Index
PMS	Pavement Management System
PQI	Pavement Quality Index
PSI	Present Serviceability Index
PSR	Present Serviceability Rating
RCI	Roughness Condition Index
RD	Rut Depth
RQI	Ride Quality Index

SCR	Surface Condition Rating
SDI	Surface Distress Index
SR	Surface Rating
SRN	Strategic Road Network
SV	Slope Variance
TRL	Transport Research Laboratory
TWD	Total Weighted Distress
VMBI	Vehicle Mounted Bump Integrator
VOC	Vehicle Operating Cost

CHAPTER 1: INTRODUCTION

1.1 Background

Nepal is landlocked country with hills and mountains and principal mode of transport used in Nepal is road transport system, covering almost all parts of country. Road classification is primarily based on functional and administrative requirements, which are classified as National Highways, Feeder roads, District roads and urban roads. One of the most key challenges facing highway agencies today is the ability to maintain the quality of existing pavements. Due to insufficient maintenance and poor management system, road transport is unable to provide adequate facility and good serviceability to road users.

The success of pavement management and maintenance is based on selecting the right treatment for the right pavement at the right time. Pavement maintenance management is the process of coordinating and controlling a comprehensive set of activities in order to maintain pavements, so as to make the best possible use of resources available, i.e. maximize the benefit for society.

Since, the road pavement deteriorate with time. Factors that cause pavements to deteriorate are accumulated traffic, environmental conditions, climate, etc. Deterioration creates conditions that undermine the performance of pavements. So it is necessary to know the present condition of road network and also to predict its future condition. For this we need to evaluate the pavement condition which involves the certain parameters: surface roughness, surface distress, structural capacity and texture and skid resistance. Thus, rating of pavement helps to evaluate the pavement condition and its quality management. Pavement condition rating refers to a score that quantifies the performance of a pavement section or an entire network.

Of all the parameters for measuring the pavement condition, roughness has greatest concern to road users. As the pavement begins to deteriorate, surface becomes rougher and subsequently increases in vehicle operating costs. Although various systems and technology have been developed for measuring roughness, but vehicle mounted bump integrator has been used in Nepal. However, regardless of system been used, the International Roughness Index (IRI) in meters/km is used to provide a common scale for recording roughness measurements.

Surface distress has vital role for maintenance program as it provides the visual indication of pavement deterioration and should apply certain remedial measures. Although highly equipped systems have been developed for collecting distress but measured through visual and manual inspection in Nepal.

Development and maintenance of the strategic road network (SRN), comprising national highways and feeder roads which is the responsibility of Departments of Roads (DOR) and the DOR Planning Branch has been conducting annual roughness and distress surveys of the Strategic Network from fiscal year 1992/93 and the information is held on the HMIS central database. However DOR conducts the condition assessment of pavement through International Roughness Index (IRI) and Surface Distress Index (SDI) separately, there is no any single index that can evaluate the pavement condition. So, this research work develops the Present Serviceability Index (PSI) which comprise the both roughness and distress value for the condition assessment of pavement.

1.2 Problem Statement

In Nepal, Deterioration of pavements is very common. The maintenance of deteriorating or deteriorated pavements is a great challenge to the engineers because of the random features of deterioration process and complex relationship between different parameters. In order to carry out the effective pavement quality management, road condition assessment need to be done for both functional and structural conditions. Though we have IRI for roughness and SDI for distress condition assessments, which are measured separately. Combined form of index has not been yet developed in Nepal. So this research efforts for making Present Serviceability Index which comprise both these parameters.

1.3 Objective

The Main objective of this research is "to develop a composite index of pavement performance that incorporates Surface distress and roughness value named as Present Serviceability Index (PSI)".

And Specific objective of this study is to

1. To draw a Performance Curve for the flexible pavement section
2. Identify the current condition of existing pavement

3. Indicate the maintenance options

1.4 Scope and Limitations of Study

This research is limited to flexible pavements where it deals only with condition survey (i.e. surface roughness & distress). Since pavement gets deteriorated every year where performance also gets decline. Whenever pavement is maintained or improved, road condition gets better and performance increases leaving some part as unrecoverable damages. On every maintenance of certain duration, this unrecovered damages gets accumulated and a stage appears where further treatment of maintenance doesn't alter the pavement condition. At this stage, distress and roughness gets higher and for further treatment, analysis of structural behavior of pavement is needed either for the rehabilitation or reconstruction measures.

1.5 Report Organization

This report has been presented in six chapters. First chapter deals with Introduction and Objectives of study, Chapter two gives the Literature review regarding theories and research works whereas Chapter three presents the Methodology adopted for developing the model of present serviceability index (PSI). In Chapter four, validation for the developed PSI model and results has been included. Different Performance Curve of different sections along with its interpretation and maintenance measures are included in Chapter Five and the final Chapter Six includes Conclusion and Recommendation of this research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

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). 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 after 1980s 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.

The most useful feature of an effective PMS is the ability to both determine the current condition of a pavement network and predict pavement condition sometime into the future. To predict condition reliably, an objective, repeatable rating system for identifying the pavement's present condition must be used.

2.2 Pavement Survey

Pavement are surveyed in two types which are “condition” and “Evaluation” surveys.

2.2.1 Condition surveys[10]

These surveys are made for the purpose of determining the condition of a pavement at a given time. This type of survey is not concerned with evaluating the structural strength of pavements and generally no attempt is made to determine the reason for the pavement’s condition. The survey indicates pavement condition at a given time.

This type of survey is qualitative in nature in that subjective rating by individuals is made. Information obtained from condition surveys are used in setting up needs studies, priority ratings and maintenance programs. (EJ Yoder et al., 1975)

2.2.2 Evaluation surveys[10]

The purpose of the evaluation survey is to determine the structural adequacy of a pavement and to establish reasons why the pavement condition is as it is. Condition surveys generally form an integral part of this, but the evaluation survey considers many other factors, such as pavement type, pavement thickness, quality of paving materials, traffic, etc. (EJ Yoder et al., 1975)

2.3 Parameters

The parameters for evaluating the pavement condition are surface roughness, surface distress, structural capacity and pavement texture (friction). Here, we only deal with condition surveys i.e. surface roughness and distress.

2.3.1 Surface Roughness[1]

From the Road Pavement Management Discussion Paper (MRCU 1995), Road Roughness is defined as "the deviations of a pavement surface from a true planar surface with characteristics dimensions that affect vehicle dynamics, ride quality, dynamic pavement loads and pavement drainage". (ASTM E867 – 87)

The roughness of a road surface is an important measure of road condition when related to the type of pavement construction, and it is a key factor in determining vehicle operating costs (VOC). Roughness increases the wear on vehicle parts and rolling resistance and has an appreciate impact on VOC and safety, comfort and speed of travel.

Reliable measurement of road roughness is therefore an important activity in pavement management. For this purpose, a variety of roughness measuring devices have been developed and these can be grouped into three different class as given in the Transport Research Laboratory (TRL) Research Report 301.

- The simplest in concept are the static road profile measuring devices such as rod and level, which measure surface undulations at regular intervals.
- The second type of instrument is the dynamic profile measuring device such as TRL high speed profilometer.

- The third type of instrument is the response type road roughness measuring device. The standard device (fifth wheel towed Bump Integrator, BI) and non – standard device (vehicle mounted Bump Integrator). These instruments measure the cumulative vertical movements of a wheel or axle with respect to the chassis of a vehicle as it travels along the road.

The response measurement is used directly as a roughness index in a standard device. Whereas using a non – standard device, the response is converted to a standard roughness measure by calibration.

Two types of instrument are in use by DOR:

1. The MERLIN Roughness Machine
2. The Vehicle Mounted Bump Integrator (VMBI)

The MERLIN Roughness Machine is a Machine for Evaluating Roughness using Low Cost Instrumentation. The device was designed by the Transport Research Laboratory, UK, and can be used either for direct measurement or for calibrating non – standard response type instruments such as the vehicle mounted Bump Integrator. It can be locally manufactured, is relatively cheap to produce and is wheeled along the road to measure surface undulations at regular intervals.

The VMBI consists of essentially three components: a vehicle, a Bump Integrator (BI) unit and display counter which is connected electrically to the BI unit. The BI unit is fixed to the rear floor of the vehicle and is connected to the differential by means of a special cable and attached hook. The measurement obtained represents the response of the vehicle and all of the variables affecting its response (such as weight, tyre balance, shock absorbers, tyre pressure etc.). Therefore, the instrument has to be calibrated to a standard reference to ensure that the results obtained are consistent with the standardized values.

The VMBI reading is converted to a unit roughness value in terms of mm/km using the following relationship

$$Roughness\ Value\ \left(\frac{mm}{km}\right) = \frac{actual\ count * 25.4}{length\ of\ the\ section\ (km)}$$

The scale widely adopted for roughness measurements these days is the International Roughness Index (IRI). This scale is derived from the road profile data by a fairly complex mathematical procedure and represents the vertical movement of a wheel with respect to the chassis in an idealized suspension system. Roughness using the VMBI is measured in terms of units of vertical movement of the wheel per unit length of road, and is produced in BI (mm/km). BI is then converted to IRI (m/km) using the following relationship:

$$IRI = 0.0032\ (BI\ \ mm/km\ )^{0.89}$$

(Source: MRCU, 1995)

2.3.2 Surface Distress

These distress usually accessed by visual inspection and manual measurement which includes: alligator cracking, longitudinal cracking, transverse cracking, rutting, potholes, lane/shoulder drop-off, bock cracking, joint reflection cracking and edge cracking.

Alligator Cracking[3]

Alligator cracking may be considered a combination of fatigue and block cracking. It is a series of interconnected cracks of various stages of development. Alligator cracking develops into a many-sided pattern that resembles chicken wire or alligator skin. It can occur anywhere in the road lane. Alligator cracking must have a quantifiable area.

Longitudinal Cracking

Longitudinal cracking occurs predominantly parallel to the pavement centerline. It can occur anywhere within the lane. Longitudinal cracks occurring in the wheel path may be noteworthy.

Transverse Cracking`

Transverse cracking occurs predominantly perpendicular to the pavement centerline. It can occur anywhere within the lane.

Rutting

Rutting is a longitudinal surface depression in the wheel path.

Potholes[2]

Potholes are small usually less than 3 ft (0.9 m) in diameter bowl shaped depressions in the pavement surface. They generally have sharp edges and vertical sides near the top of the hole. Their growth is accelerated by free moisture collection inside the hole. Potholes are produced when traffic abrades small pieces of the pavement surface. The pavement then continues to disintegrate because of poor surface mixture, weak spots in the base or subgrade, or because it has reached a condition of high severity alligator cracking. Potholes most often are structurally related distress and should not be confused with raveling and weathering. When holes are created by high severity alligator cracking, they should be identified as potholes, not as weathering.

Measured by counting the number that are low, medium and high severity.

Lane/shoulder Drop-off

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

Block Cracking[4]

A pattern of cracks that divides the pavement into approximately rectangular pieces. Rectangular blocks range in size from approximately 0.1 sq. m to 10 sq.m (1 sq. ft to 100 sq. ft).

Joint Reflection Cracking

Cracks in asphalt concrete overlay surfaces that occur over joints in concrete pavements. Note: Knowing the slab dimensions beneath the asphalt concrete surface helps to identify reflection cracks at joints.

Edge Cracking[12]

Edge cracking is crack in the side which is parallel to the edge of the pavement and away from a distance ranging between 0.3-0.5 meters from the edge, and extends these cracks longitudinal and transverse direction and branching towards the shoulders.

Surface distress measurements are useful for providing intervention levels for maintenance activities, in particular, for indicating the timely need for resealing. Used independently or in conjunction with an objective assessment of the condition of the strategic network.

Surface distress is an important visual indictor of pavement deterioration. Surface distress includes all types of defects affecting the integrity of the surface which, if they are left untreated, will seriously reduce the serviceability of the road and the life of the pavement.

The information obtained is used to monitor road deterioration and, in particular, to indicate the need for periodic maintenance (resealing) of bitumen surfaced roads. Surface distress information can also be used by the department to

- determine if a particular road section exceeds established distress levels for implementing planned maintenance activities or for carrying out rehabilitation;
- provide a consistent and objective assessment of overall pavement condition (good, fair, poor);
- Monitor the performance of the pavement and the effectiveness of maintenance activities. (MRCU, 1995)

Methods of Measuring SDI[1]

There are various methods for collecting surface distress data and these increase in complexity and sophistication according to the quality of information required. The method adopted by the Department is a simplified procedure recommended by the World Bank which has been modified to suit the particular conditions in Nepal and the needs of DOR.

Pavement distress surveys are carried out manually in the Department by trained Highway Engineers working as a two person team; the method in use is a “drive and walk” survey. Surface distress comprises cracking, disintegration (potholes), deformation, texture deficiency, pavement edge defaults and maintenance works (patching). The faults 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 pavement surface without any defects, whereas a rating of 5 indicates the maximum possible deterioration. A 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 the severity of the deformation in noted.

The 10% sampling procedure comprises a walk – over survey generally covering the last 100 meter section in each kilometer of the road on which the SDI is to be determined. The full width of the pavement is examined for the 100 meter sample length. To start the survey, the team drives at 10 – 20 km/hour from the starting point of the section. As in the case of roughness measurements, each section will commence and finish at a defined road link node point in the Network referencing system. When the 900 meter point in each kilometer is reached, the team stops and undertake a walk – over survey of the final 100 meters.

While walking, it is necessary to first identify the major and minor defects and then calculate the percentage of the total defective area for both major and minor defects individually. The shoulder condition is also noted. The results are recorded on a standard form which shows the degree and extent of damage on the road surface rated on a scale of 0 to 5 and the main distress type. The process is then repeated for another 100m sample section in the next km. About 50-60 km of visual distress survey is achievable in one day by a single team. (MRCU, 1995)

Data Use:

The SDI is averaged over each road link or section under consideration. The results can be used to provide an objective assessment of pavement condition and to indicate the need for periodic maintenance, rehabilitation or reconstruction. For assessing pavement condition, the terms “good”, “fair” and “poor” are used based on the following averaged values of SDI for a particular section of road.

Table 2.1 SDI Value and Condition

SDI Value	**Condition**
0 – 1.7	Good
1.8 – 3.0	Fair
3.1 – 5.0	Poor

(Source: MRCU, 1995)

The above values are based on conditions in Nepal. Planned maintenance can be carried out on roads in good/fair condition and rehabilitation or reconstruction is generally needed for roads in poor condition to bring them to a maintainable state.

Similarly, an indication of the type of pavement remedial action is given by the percentage of the number of sampling sections with the given SDI value of a particular link as shown in the following table.

Table 2.2 Pavement remedial action

Percentage	**SDI Values**	**Action**
20%	SDI - 5	Reconstruction
10 – 30%	SDI - 4	Rehabilitation
20 – 30 %	SDI - 3	Resealing with local patching
20 – 30%	SDI – 2	Resealing only

(Source: MRCU, 1995)

The rate of deterioration of the road pavement is important for determining the timing of remedial action. However, in order to produce pavement deterioration curves for Nepal conditions, pavement data, including SDI measurements, must be collected and processed for a period of at least 5 years in order to determine historical trends.

Pavement Condition Survey – Surface Distress Index

Table 2.3 Pavement Distress Score for Black Topped Pavements

Score	**Incidence of Minor Defects**	**Incidence of Major Defects**
0	None	None
1	1 to 20 m^2 per 100 meters	1 occurrence
2	<50% of the area	2 to 4 occurrence
3	>= 50% of the area	<30 % of the area
4	…..	>= 30% or potholes and base exposed < 20% of the area
5	……	Potholes and exposed base >= 20 % of the area

(Source: MRCU, 1995)

Table 2.4 Categories of Defect and Distress Type Codes

Defect	Code	Minor	Code	Major
Cracking	CN CL M	Narrow interconnected cracks (1-3 mm width) Line Cracks (Longitudinal or transverse) Sealed crack	CW	Wide interconnected cracks (>3mm)
Maint. Patches	M	Patches		
Texture	RA S S	Shallow raveling or scabbing (<20mm) Slickness (texture depth < 1mm) Bleeding	V	Scabbing (>20 mm depth)
Rutting			RL	Rut depth > 15 mm
Pothole			P	Pothole (>30 mm depth, >150 mm Φ)
Exposed Base			G	Exposed base or sub base or gravel
Edge Break	ES	Short edge break (>100 mm, < 5 m L)	EL	Long edge break (>100 mm, >5 m L)
Depression/Humps			D	Corrugations

Note: Width applicable to line cracking: 0.5 meter. (Source: MRCU, 1995)

2.4 Present Serviceability Index[10]

Present Serviceability Index (PSI) is based upon the concept of correlating user opinions with measurements of road roughness (as measured by the roughometer or profilometer), cracking, patching and rutting. This concept was first presented by Carey and Irick.

The PSI is formulated by rating a series of pavements by a group of individuals. The panel members drive over selected pavements and rate the pavements. It will be noted that the scale runs from 0 to 5 and that qualitative descriptions of pavement performance is indicated on the scale. The raters make a mark on the scale, which indicates the opinion they have of the condition of the pavement at the time that it is rated. A rating of 5 indicates a perfect pavement whereas a rating of 0 is an exceedingly poor pavement. Also on the rating card, the raters are asked to give their opinions relative to the objective feature of the pavement that influenced their rating and are asked to determine whether the road is acceptable for the intended traffic (EJ Yoder et al., 1975).

The average of the rating numbers, designated the Present Serviceability Rating (PSR), was correlated on the AASHO Road Test with measurements of roughness, patching and cracking. The regression analysis equations developed on the Road Test took the general form as given in following equation

$$PSI = A_0 + A_1 (R) + A_2 (F_1) + A_3 (F_2)$$

Where,

PSI = Present Serviceability Index

A = regression analysis constants

R = measure of roughness

F = physical measurements of cracking, etc.

It is to be noted that the PSR refers to the rating assigned by a panel of individuals, whereas the PSI refers to the calculated value obtained from the regression analysis.

It should be emphasized at this point that the rating given by this method is a condition rating at the time that the rater travels over the pavement surface. No indication is given as to the structural adequacy of the pavement nor to the probable behavior of the pavement in the future.

The key word in the definition Present Serviceability Index is “present”. In fact, the raters are asked to look at nothing but the pavement, and in addition are asked to rate the pavements as it is *now*, without being influenced by such factors as potential behavior, pavement width, shoulder width, condition of shoulder, grade, alignment, structural adequacy, traffic and climate. Thus, it can be seen that in order to relate serviceability index with pavement life, it becomes necessary to rate the pavements over a period of time in order to get a rating history. It is important, therefore, for the engineer to recognize that the serviceability rating is, as the name implies, the condition of the pavement at an instant of time. The PSI is not meant to imply potential suitability of the pavement nor is there anything in the rating concerned with the history of the pavement itself. The concept of PSI was used in the evaluation of the AASHO Road Test by relating PSI with number of load applications.

2.4.1 Factors affecting and uses of PSI[10]

The present serviceability index has many uses. First, it permits rating of pavements on a common basis. For example, a serviceability index of 2.5, has specific meaning to engineers regardless of the pavement's location. Second, it permits the formulation of priority and maintenance programs in a logical manner, and third, the present serviceability index establishes relationships between objective pavement measurements and subjective ratings of the road user. The engineer can formulate in his mind some measure of the degree of rutting and cracking and patching through these ideas. Still another point is that the method permits obtaining measurements at various times and the establishment of a parameter that defines pavement condition in design equations. Histories of pavement performance can be related to change in serviceability with time.

There is widespread agreement among engineers that the present serviceability concept makes available a tool which has been needed for a long time. There are, however, some limitations to the method and to make the method most useful, it must be recognized that it is based upon a statistical approach.

2.4.2 Present Serviceability Index Equations[10]

The present serviceability index is determined by correlating objective measurements of roughness as described in previous paragraphs and other measurements of pavement cracking, and so on, with the present serviceability rating. The correlation takes the general form shown in following equation

For flexible pavements

$$PSI = 5.03 - 1.9 \log (1 + SV) - 0.01 \sqrt{(C + P)} - 1.38\, RD^2$$

Where,

PSI = Present Serviceability Index

SV = Slope Variance

C = linear feet of major cracking per 1000 sq ft area

P = bituminous patching in sq ft per 1000 sq ft area

RD = rut depth in inches (both wheel tracks) measured with a 4 foot straightedge

(Source: EJ Yoder et al., 1975)

2.5 Some Foreign Indexes

2.5.1 Pavement Quality Index of Minnesota[5]

According to Mn/DOT's, 2006, they uses three indices to report and quantify pavement condition. One index represents pavement roughness, second represents pavement distress and third indicates overall condition of the pavement. These indices, listed in Table 2.5, are used to quantify the present condition of the pavement and predict future condition, both of which are needed for project planning and programming. For each index, a higher value means better pavement condition. The indices are reported to the tenths place.

Table 2.5 Mn/DOT Pavement Condition Indices

Index Name	Pavement Attribute Measured by Index	Rating Scale
Ride Quality Index (RQI)	Pavement Roughness	0.0 – 5.0
Surface Rating (SR)	Pavement Distress	0.0 – 4.0
Pavement Quality Index (PQI)	Overall Pavement Quality	0.0 – 4.5

(Source: Mn/DOT, 2006)

The first step in determining the RQI is to calculate the International Roughness Index (IRI), from the pavement profile measured by the front lasers on the van. This international standard simulates a standard vehicle traveling down the roadway and is equal to the total anticipated vertical movement of this vehicle accumulated over the length of the section. The IRI is typically reported in units of inches/mile (vertical inches of movement per mile traveled). If a pavement were perfectly smooth, the IRI would be zero (i.e. no vertical movement of the vehicle). In the real world, however, roughness in the form of dips and bumps exist and vertical movement of vehicles occurs. As a result, the IRI is always greater than zero. The higher the IRI is, the rougher the roadway.

To convert IRI to RQI, a correlation has been developed. This was done using a rating panel. A rating panel involves driving people over sections of pavement and getting their opinion as to how well it rides. 32 citizens were asked to rate over 120 test sections. The sections included all pavement types, a wide variety of roughness conditions and were 0.25 miles long. Panelists were instructed to disregard grade, alignment, pavement surface condition, right-of way, shoulders, ditch conditions and all other factors not directly related to the ride of the pavement.

Each rater assigned a numerical value between zero and five to each segment based on the following scale:

Table 2.6 RQI Categories and Ranges

Numerical Rating	**Verbal Rating**
4.1 – 5.0	Very Good
3.1 – 4.0	Good
2.1 – 3.0	Fair
1.1 – 2.0	Poor
0.0 – 1.0	Very Poor

(Source: Mn/DOT, 2006)

The raters ask themselves, “How would I like to ride on a road just like this section all day long?” First they decide what qualitative rating to give the ride, ranging from Very Good to Very Poor. Then they refine the corresponding numerical range by rating to one-tenth of a point. For example, a roadway considered Good and approaching Very Good might be given a rating of 3.8 or 3.9.

The results of all the ratings for each test section are compiled, a mean and standard deviation are calculated and then a search for outliers is made and if necessary, an adjusted mean is calculated. The mean or adjusted mean for each section is the panel’s RQI for that section.

Using regression analysis, the panels RQI is correlated to the measured IRI.

Bituminous Pavements:

$RQI = 5.697 - 2.104 * \sqrt{IRI}$, where IRI is in m/km

$RQI = 5.697 - 0.264 * \sqrt{IRI}$, where IRI is in inches / mile

(Source: Mn/DOT, 2006)

Pavement Distress

Pavement distresses are those defects visible on the pavement surface. They are symptoms, indicating some problem or phenomenon of pavement deterioration such as cracks, patches and ruts. The type and severity of distress on pavement can provide great insight into what its future maintenance and/or rehabilitation needs will be.

Mn/DOT uses the Surface Rating (SR), to quantify pavement distress. The SR was formerly based on the type and amount of distress measured by two raters driving along the shoulder of the road at 5 – 10 mph. The percentage of each distress in the 500-foot sample is determined and multiplied by a weighting factor to give a weighted percentage. The weighting factors are higher for higher severity levels of the same distress and higher for distress types that indicate more serious problems exist in the roadway such as alligator cracking and broken panels.

Once all of the weighted percentages are calculated, they are summed to give the Total Weighted Distress or TWD. The SR is calculated from the TWD using the following equation

$$SR = e^{(1.386 - 0.045 * TWD)}$$

So, the final PQI which is calculated from the RQI and SR as:

$$\boldsymbol{PQI = \sqrt{RQI * SR}}$$

(Source: Mn/DOT, 2006)

2.5.2 Pavement Condition Rating of National Park Service, **prepared by FHA[3]**

From the NPS Road Inventory Program, 2006, Pavement Condition Rating has been developed from the combination of distress and roughness index.

Surface distresses are measured in the primary lane only through digital video images which are transverse cracks, longitudinal cracks, alligator cracks patching/potholes and rutting. In the classification and measurement of all surface condition data, results will be reported in the database in record intervals of 0.02 miles (105.6 feet) along the route.

Each distress is computed as their distress index namely, transverse crack index, longitudinal crack index, alligator crack index, patching/pothole index and rutting index which are measured as:

Alligator Crack Index

AC Index = 100 – 40 * [(%LOW / 70) + (%MED / 30) + (%HI / 10)]

Where,
the values *%LOW*, *%MED* and *%HI* report the percentage of the observed pavement (0.02 mile, primary lane) that contains alligator cracking within the respective severities.

Longitudinal Crack Index

LC Index = 100 – 40 * [(%LOW / 350) + (%MED / 200) + (%HI / 75)]

Where,
The values *%LOW*, *%MED*, and *%HI* report the length of longitudinal cracking within each severity as a percent of the section length (0.02 mile, primary lane).

Transverse Crack Index

TC Index = 100 – {[20 * ((LOW / 15.1) + (MED / 7.5))] + [40 * (HI / 1.9)]}

Where,
The values *LOW*, *MED* and *HI* report a count of the total number of transverse cracks (reported to three decimals) within each severity level, where one transverse crack is equal to the lane width.

Patching Index

Patch Index = 100 – 40 * (%PATCHING / 80)
Where,
The value *%PATCHING* reports the percentage of the observed pavement (0.02 mile, primary lane) that contains patching/potholes.

Rutting Index

Rut Index = 100 – 40 * [(%LOW / 160) + (%MED / 80) + (%HI / 40)]

Where,

Rut depth measurements are taken per 0.02 interval for each of 2 wheel paths (left and right), resulting in a total of 20 measurements taken for both wheel paths. The values *%LOW*, *%MED* and *%HI* report the percentage of the 20 measurements within that severity.

All these distress index value ranges from 0 to 100.

Surface Condition Rating Index is measured as:

$$SCR = 100 - [\,(100 - AC\ Index) + (100 - LC\ Index) + (100 - TC\ Index) + (100 - Patch\ Index) + (100 - Rut\ Index)$$

The threshold for failure for this index is SCR = 60.

Roughness is the measurement of the unevenness of the pavement in the direction of travel. It is measured in units of IRI (International Roughness Index), inches per mile, and is indicative of ride comfort.

Table 2.7 IRI Range Description

Rating Category	**IRI Value Range (inches/mile)**	**RCI Value Range**
Excellent	<= 127	95 – 100
Good	128 – 154	85 – 94
Fair	155 – 240	61 – 84
Poor	>240	<=60

(Source: NPS Road Inventory Program, 2006)

IRI is then converted to RCI as:

$$RCI = 32 * (\ 5 * 2.718282^{-0.0041 * avg\ IRI})$$

Where,

avg *IRI* is the average value of the Left IRI and Right

So, pavement condition rating index developed is

$$\mathbf{PCR = 0.6 * SCR + 0.4 * RCI}$$

2.5.3 British Columbia Ministry of Transportation (BCMoT) [6]

The British Columbia Ministry of Transportation (BCMoT) has developed their own pavement distress condition rating survey manual for flexible pavements. For each distress type there are three severity levels (low, moderate and high) and five density levels (few, intermittent, frequent, extensive and throughout). The severity and density level is assigned subjectively by an evaluator for every 50m segment according to the pavement condition rating manual (BCMoT, 2009).

The BCMoT uses an overall pavement performance index called Pavement Condition Ratio (PCR). This index is a function Pavement Distress Index (PDI) and Ride Comfort Index (RCI). The PDI is a modified version of PCI, which was developed by the U.S. Army Corps of Engineers (Shahin 2005). The PDI is scaled from 0 to 10, with 10 representing a newest pavement condition and 0 represents a poorest pavement condition. The PDI is determined by calculating “deduct values” for each distress type that is present from the perfect score which is 10. And the RCI is used to determine the pavement roughness.

The PCR is calculated by the following equation:

$$PCR = PDI^{0.5} * RCI^{0.5}$$

Where,

PCR = Pavement Condition Rating (0-10)

PDI = Pavement Distress Index (0-10)

RCI = Ride Comfort Index (0-10)

(Source: BCMoT, 2009)

Table 2.8 Other Foreign Indexes

State/Agency	Survey/Score Name	Rating Computation
Alberta	Surface Condition Rating (SCR) converted to Surface Distress Index (SDI) Pavement Quality Index (PQI) combination of SCR and SDI	$PQI = \left(100 * e^{(-0.2221*IRI)^{0.7}}\right) * SDI^{0.3}$
Indiana	Pavement Quality Index (PQI)	$PQI = PCR * a\ IRI^{b}$
Tennessee	Pavement Quality Index (PQI) Pavement Serviceability Index (PSI)(Based on Roughness) Pavement Distress Index (PDI)(Based on Distress)	$PQI = PDI^{0.7} * PSI^{0.3}$
Ohio	Pavement Condition Rating (PCR)	PCR = 100 – Deduct Deduct = weight of distress * weight for severity * weight for extent

(Source: NCHRP 2004)

2.6 Ranges of SDI, IRI and PSI

Table 2.9 SDI Value

Value	Condition
0 - 1.7	Good
1.8 - 3.0	Fair
3.0 - 5.0	Poor

(Source: MRCU, 1995)

Table 2.10 IRI Value

Value	Condition
<2	Excellent
2 – 4	Good
4 – 6	Fair
6 – 8	Poor
>8	Bad

(Source: HMIS)

Table 2.11 Present Serviceability Index (PSI) value

Value	0 – 2	2 – 4	4 – 6	6 – 8	8 – 10
Condition	V. Poor	Poor	Fair	Good	v. Good

(Source: Ping and Yunxia, 1998)

2.7 Performance Curve

The two key elements of a pavement management system are performance prediction and distress prediction. Current formulations for pavement management systems require some type of prediction model for both performance and distress. A typical performance curve relating the pavement condition rating to the age of the pavement, is shown in following figure.

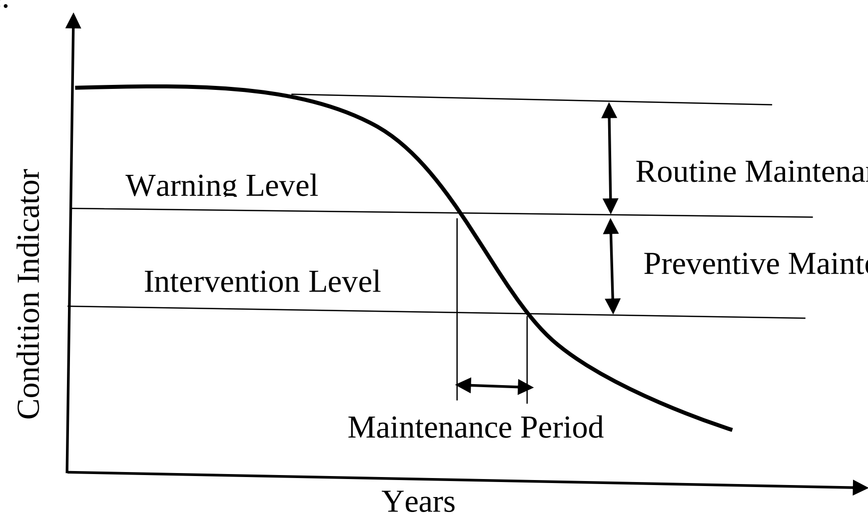

Figure 2.1 Performance Curve

(Source: Transport Road Research, 1987)

As a pavement ages its condition deteriorates to a point where some type of maintenance work should be applied. This is a state of deterioration at which distress is becoming apparent, but might not yet be severe enough to call for immediate action.

There are several basic consideration when relating distress to performance prediction. The model has to be able to predict both the type and the degree of distress that will occur as the pavement ages, related to traffic, climate and time. It must be able to predict the interaction of any particular distress with some other distress effect. It is also necessary to know what the effect will be of various maintenance strategies on the pavement's lifetime.

There is considerable controversy among experts as to the ability to predict reliably performance and distress. Until now each country or state has developed its own program and its own model, solving the problems to some extent.

CHAPTER 3: METHODOLOGY

3.1 Flow Chart of Methodology

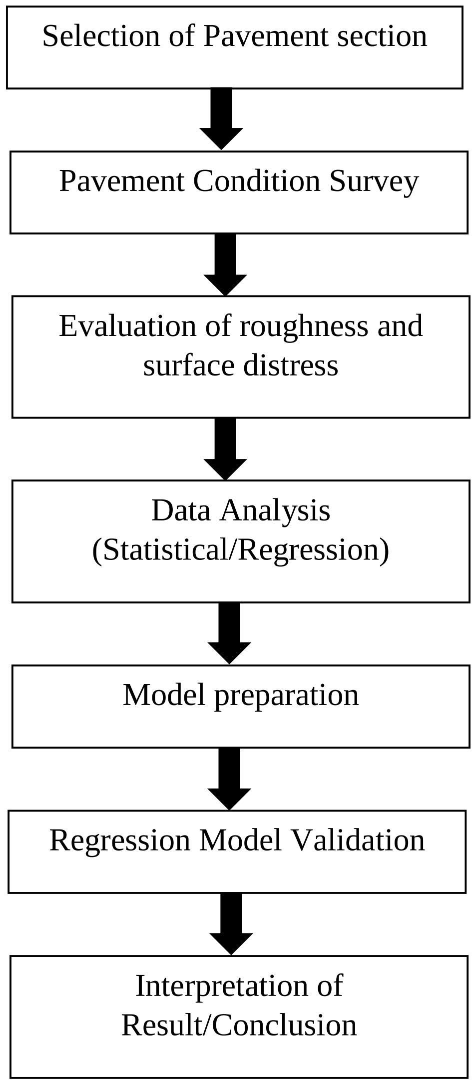

Figure 3.1 Flow chart of Methodology

3.2 Study Area

The study is focused on bituminous road network of Nepal. The Road Network selected for analysis are National Highways, Feeder Road and Ring Road of Kathmandu Valley.

3.3 Data Evaluation

International Roughness Index (IRI) and Surface Distress Index (SDI) values are taken from Department of Road.

Here, PSI is the factor of SDI and IRI which can be calculated by statistically modelling and regression. i.e.

PSI = *f* (SDI, IRI)

And for the modeling, PSI values are kept by concerning the ranges of SDI, IRI and PSI values.

3.4 Data Processing/Statistical Analysis

The regression method will be employed in the development of the PSI model. The statistical significance of the regression coefficients of the resulting model will be tested at 5% level of significance using the F-test (ANOVA). For the data analysis, SDI and IRI values of Mahendra Highway of 2012 has been taken for the modelling

Table 3.1 Data analysis for prediction of PSI

Sn	Link code	Link name	SDI	IRI	PSI
1	H0101	Kakarbhitta-Charali	1.14	4.65	6.5
2	H0102	Charali-Birtamod	1.08	4.57	7
3	H0103	Birtamod-Padajogi (Damak)	1.1	4.47	7
4	H0105	Ratuwa-Mawa	1.23	4.61	6
5	H0106	Mawa-Harichamod	1.63	4.48	6
6	H0107	Harichamod-Budhi Khola	1	3.54	7.5
7	H0108	Budhi Khola-Itahari	1	4.54	7
8	H0109	Itahari-Sakhawa Gachhi	1	3.41	*7.5*
9	H0110	Sakhawa Gachhi-Sunsari bridge	1	3.27	7.5
10	H0111	Sunsari bridge-Koshi Barrage	1.02	3.84	7

Sn	Link code	Link name	SDI	IRI	PSI
11	H0112	Koshi Barrage-Bharadaha	1.38	4.29	6.5
12	H0113	Bharadaha-Rupni	1.16	3.82	7
13	H0114	Rupni-Kadmaha	1.46	3.6	*7*
14	H0115	Kadmaha-Balan	1	3.36	7.5
15	H0116	Balan-Padariyachok	1.2	3.69	7
16	H0117	Padariyachok-Chauharwa	1	3.7	7
17	H0118	Chauharwa-Mirchaiya	1.4	8.69	4.5
18	H0119	Mirchaiya-Kamala	1.07	6.38	6
19	H0120	Kamala-Dhalkebar	1.15	5.53	6.5
20	H0121	Dhalkebar-Ratu	1	4.53	7
21	H0122	Ratu-Bardibas	1	5.63	6.5
22	H0123	Bardibas-Banke	1.16	5.2	6.5
23	H0124	Banke-Nawalpur	1.15	6.05	6
24	H0125	Nawalpur-Bagmati	1.26	6.34	6
25	H0126	Bagmati-Chandranigahapur	1.07	5.67	6.5
26	H0127	Chandranigahapur-Dhansar	1.16	5.17	6.5
27	H0128	Dhansar-Pathlaiya	1.18	4.9	6.5
28	H0129	Pathlaiya-Chure	1.38	5.32	6
29	H0130	Chure-Ratmate	1.75	6.29	*5*
30	H0131	Ratmate-Hetauda	1.82	0	8
31	H0132	Hetauda-Sarashwati Khola	1.67	4.75	6
32	H0133	Sarashwati Khola-Lothar	1.5	5.19	6
33	H0134	Lothar-Tikauli	1.92	4.51	6

Sn	Link code	Link name	SDI	IRI	PSI
34	H0135	Tikauli-Hakimchok	1.5	4.29	*6.5*
35	H0136	Hakimchok-Narayanghat	1.86	5.43	6
36	H0137	Narayanghat-Narayani bridge	2	6.79	4.5
37	H0138	Narayani bridge-Junction (Tiger Mountain)	1.13	4.51	7
38	H0140	Arun Khola-Bardaghat	1.1	5.3	6.5
39	H0141	Bardaghat-Sunwal	1.14	4.48	6.5
40	H0142	Sunwal-Maha Khola	1	4.09	7
41	H0143	Maha Khola-Sukoura	1	4.4	6.5
42	H0144	Sukoura-Butwal (Milanchok)	1	4.25	7
43	H0145	Butwal (Milanchok)-Butwal(Mahendrachok)	0.67	5.63	7
44	H0146	Butwal-Bamaha Khola	1.06	6.52	6
45	H0147	Bamaha Khola-Kothi River	1	6.66	6
46	H0148	Kothi River-Jitpur	0.89	7.14	6
47	H0149	Jitpur-Gorusinge	1.23	6.68	5.5
48	H0150	Gorusinge-Chanauta	1.79	7.15	4.5
49	H0151	Chanauta-Dhan Khola	1.32	7.38	5
50	H0152	Dhan Khola-Ram Singh Khola	1.67	8.07	4.5

Sn	Link code	Link name	SDI	IRI	PSI
51	H0153	Ramsimgh Khola-Rapti River	1	9.1	5
52	H0154	Rapti River-Bhalubang	1	7.3	5.5
53	H0155	Bhalubang-Lamahi	1.22	8.11	5
54	H0156	Lamahi-Ameliya	1.26	7.25	5
55	H0157	Ameliya-Shiva Khola	1	7.23	5.5
56	H0158	Shiva Khola-Khairi Khola	1.03	6.98	5.5
57	H0159	Khairi Khola-Kohalpur	1.27	6.31	5.5
58	H0160	Kohalpur-Man River	2.21	4.64	5.5
59	H0161	Man River-Bhuregaon	1.24	4.66	7
60	H0162	Bhuregaon-Karnali	0	5.01	7.5
61	H0163	Karnali-Junga	1.69	5.9	5.5
62	H0164	Junga-Sukhad Choraha	1.74	5.11	5.5
63	H0165	Sukhad Choraha-Atariya	2.42	5.37	5
64	H0166	Atariya-Mohana River	0.88	5.54	6.5
65	H0167	Mohana River-Daiji	0.96	4.57	6.5
66	H0168	Daiji-Sukhanala	1	4.96	6.5
67	H0169	Sukhanala-Gadda Chauki	1.05	4.88	6.5

After regression analysis done in MS Excel Software, results obtained is:

PSI = 10.0745 – 1.107 * SDI – 0.4645 * IRI

R^2 value = 0.9397

3.5 Regression Model Validation Tests[12]

The following test have been employed to confirm the validity of the developed model. R^2 indicates the goodness of fit of the model and provides the proportion of total variance that is explained by the model.

$$R^2 = 1 - \frac{SSres}{SStot} \qquad SS_{res} + SS_{reg} = SS_{tot}$$

$$Stot = \sum_i^n (yi - \bar{y})^2 \quad SSreg = \sum_i^n (fi - \bar{y})^2 \quad SSres = \sum_i^n (yi - fi)^2$$

3.5.1 F-test[12]

The F-test evaluates the null hypothesis that all regression coefficients are equal to zero versus the alternative that at least one does not. An equivalent null hypothesis is that R^2 equals zero. A significant F-test indicates that the observed R^2 is reliable, and is not a spurious result of oddities in the data set. Thus, the F-test determines whether the proposed relationship between the response variable and the set of predictors is statistically reliable.

$$F = \frac{\text{Estimate of } \sigma^2 \text{ from means}}{\text{Estimate of} \sigma^2 \text{ from individuals}}$$

3.5.2 T Test[12]

The test statistic in the t-test is known as the t-statistic. The t-test looks at the t-statistic, t-distribution and degrees of freedom to determine a ‘p value’ (probability) that can be used to determine whether the population means differ. The t-test is one of a number of hypothesis tests. To compare three or more variables, statisticians use an analysis of variance (ANOVA).

$$t = \frac{\overline{x_1} - \overline{x_2}}{s_{\overline{x_1} - \overline{x_2}}} \qquad s_{\overline{x_1} - \overline{x_2}} = \sqrt{\frac{{s_1}^2}{n_1} + \frac{{s_2}^2}{n_2}}$$

$$t = \frac{\text{difference between sample means}}{\text{estimated standard error of difference between means}}$$

R^2, F Test, T test done for the model formed at 5% significance level done in MS Excel is shown here:

Table 3.2 Validity of Regression Analysis of PSI

Multiple R	0.969391323
R Square	0.9397195
Adjusted R Square	0.9378357
Standard Error	0.2096477
Observations	67

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	2	43.85124	21.92562	498.8519	9.23955E-40
Residual	64	2.812938	0.043952		
Total	66	46.66418			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	10.074493	0.1270249	79.3111	1.26E-65	9.8207323	10.328255
SDI	-1.1070215	0.0685355	-16.152	2.92E-24	-1.2439370	-0.9701060
IRI	-0.4644587	0.0171927	-27.014	1.05E-36	-0.4988052	-0.4301122

The above tables, summary of regression analysis using data of PSI, SDI and IRI shows the R^2 values as 0.9397, which indicates the model has good fitting. Also, the p-value (T test) for the F-statistic for regression determined to be less than 0.05, indicating that the regression model is adequate.

CHAPTER 4: VALIDATION AND RESULT

4.1 Model Validation

In addition to the previously discussed validation approaches, observed PSI values are compared with the expected PSI values predicted from the regression analysis.

The percent difference between predicted values and observed values should be reasonable in order to accept the models' predicting ability.

4.2 Validation Tests: χ^2 Tests

$$\chi^2 = \sum \frac{(\text{Observed} - \text{Expected})^2}{\text{Expected}}$$

The fitted regression model is selected as the PSI forecast model for the roads under study and are checked for its validity. For this model, test of hypothesis (chi-square goodness of fit test) is applied, in which χ^2- value for the test is compared with critical χ^2- value at 5% level of significance.

For this test, SDI and IRI values of Ring Road of Kathmandu valley of 2012 has been selected.

Null Hypothesis

Ho: Model has good fit on prediction of PSI

Alternative Hypothesis

Ha: Model hasn't good fit on prediction of PSI

Table 4.1 Validation Test using data's of Ring Road of Kathmandu Valley

Sn	Link code	Link name	SDI	IRI	Observed PSI (O)	Expected PSI (E)	O - E	$(O - E)^2$ /E	% of chi square
1	H1601	Manohara River - Koteswor (H03)	1.00	4.92	6.50	6.6822	-0.1822	0.0050	6.7959
2	H1602	Tinkune - Sinamangal - Gaushala)	1.75	4.57	6.00	6.0145	-0.0145	0.0000	0.0477
3	H1603	Gaushala - Mitrapark	2.00	6.57	5.00	4.8087	0.1913	0.0076	10.4111
4	H1604	Mitrapark - Chabahil	3.00	5.27	4.50	4.3056	0.1944	0.0088	12.0139
5	H1605	Chabahil - Sankhapark	1.50	4.61	6.50	6.2727	0.2273	0.0082	11.2766
6	H1606	Sankhapark - Maharajganj	2.00	4.81	5.50	5.6263	-0.1263	0.0028	3.8773
7	H1607	Maharajganj - Balaju Bypass Junction	2.00	4.81	5.50	5.6263	-0.1263	0.0028	3.8773

Sn	Link code	Link name	SDI	IRI	Observed PSI (O)	Expected PSI (E)	O - E	$(O - E)^2$ /E	% of chi square
8	H1608	Balaju Junction - Banasthali - Swoyambhu	2.25	3.90	6.00	5.7722	0.2278	0.0090	12.3033
9	H1609	Swoyambhu - Kalanki	1.83	4.01	6.50	6.1860	0.3140	0.0159	21.8061
10	H1610	Kalanki - Balkhu	2.00	4.99	5.50	5.5426	-0.0426	0.0003	0.4490
11	H1611	Balkhu - Ekantakuna	1.25	3.75	7.00	6.9489	0.0511	0.0004	0.5148
12	H1612	Ekantakuna-Kusanti - Satdobato	1.50	4.70	6.50	6.2309	0.2691	0.0116	15.9110
13	H1613	Satdobato - Gwarko	1.67	3.79	6.50	6.4654	0.0346	0.0002	0.2541
14	H1614	Gwarko-Manohara River(Balkumari)	1.00	4.34	7.00	6.9516	0.0484	0.0003	0.4617
								0.0731	**100.0**

Here,

Calculated $\chi 2$- value = 0.0731 with degree of freedom 13 and Critical $\chi 2$- value for 5 % level of significant for 13 degree of freedom is 22.36 which is greater than calculated value which shows null hypothesis is accepted.

Hence, model is accepted for the determination of PSI.

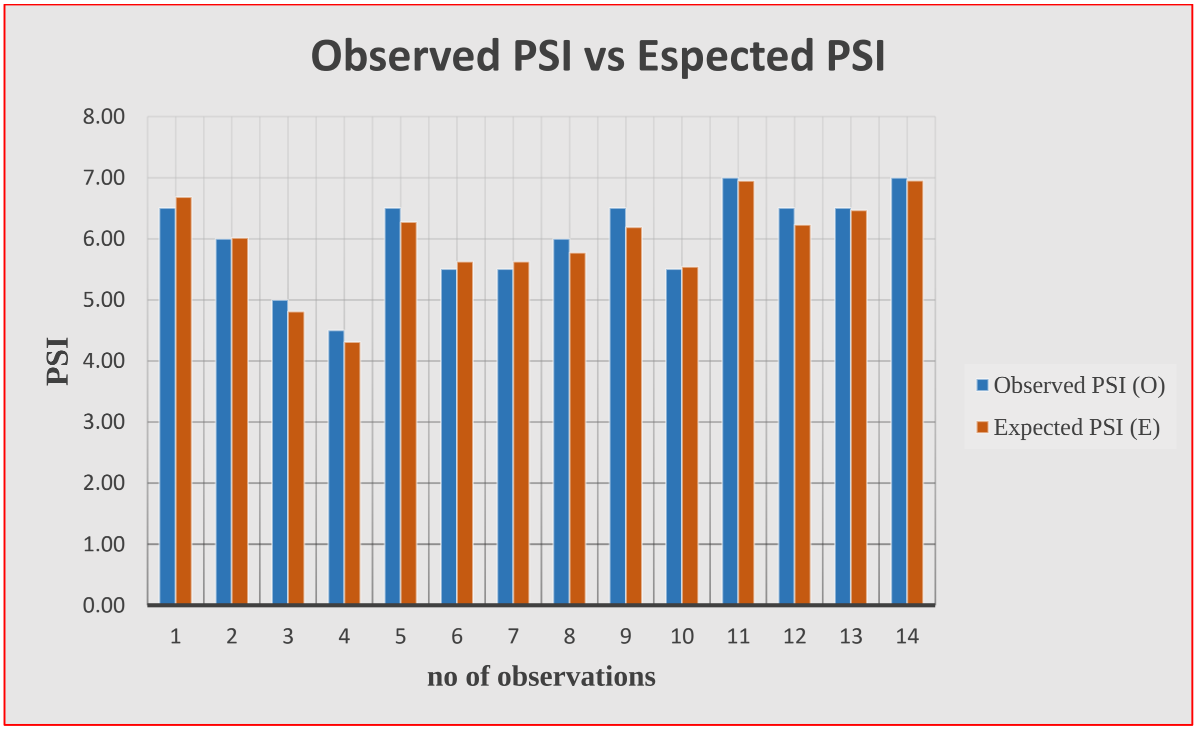

Figure 4.1 Observed PSI vs Expected PSI

Here, above graph shows the observed and expected values are quite similar.

CHAPTER 5: PERFORMANCE CURVE AND MAINTENANCE OPTIONS

5.1 Data Collection

The performance curve shows the condition of pavement, which is being deteriorated with age. For the performance curve, SDI and IRI values of different years are collected and PSI value is calculated. The graph is plotted between PSI values and time period. As the time period of pavement increases, distress and roughness values increases which consequently shows the PSI value degrading with pavement duration. For the perfect and accurate performance curve, SDI and IRI values before the maintenance period should be taken because once the maintenance is provided, distress and roughness value decreases i.e. PSI value increases and perfect performance curve can't be plotted.

Different SDI and IRI values of different sections of different years before the maintenance period has been collected from the department of road.

5.2 Calculation of PSI

PSI of different road sections are calculated as:

Table 5.1 PSI of different road sections

SN	Link Code	Link Name	Year	SDI	IRI	PSI
1	H0101	Kakarbhitta-Charali	2010	0.95	5.15	6.63
			2012	1.14	4.65	6.65
			2014	1.83	4.41	6.00
			2015	2	5.45	5.33
2	H0102	Charali-Birtamod	2010	1.08	5.11	6.51
			2012	1.08	4.57	6.76
			2014	1.71	4.07	6.29
			2015	2	4.93	5.57
3	H0103	Birtamod-Padajogi (Damak)	2010	0.98	5.59	6.39
			2012	1.1	4.47	6.78
			2014	1.9	3.8	6.21
			2015	2	5.56	5.28

SN	Link Code	Link Name	Year	SDI	IRI	PSI
4	H0104	Padajogi (Damak) - Ratuwa	2010	0.98	5.59	6.39
			2012	1.1	4.47	6.78
			2014	2	4.3	5.86
			2015	3	5	4.43
5	H0105	Ratuwa-Mawa	2010	1.08	5.5	6.32
			2012	1.23	4.61	6.57
			2014	1.71	4.31	6.18
			2015	2	5.24	5.43
6	H0120	Kamala-Dhalkebar	2010	0.95	6.02	6.23
			2012	1.15	5.53	6.23
			2014	3	5.3	4.29
			2015	2	7.6	4.33
7	H0121	Dhalkebar-Ratu	2010	0.94	6.05	6.22
			2012	1	4.53	6.86
			2014	2.56	5.69	4.60
			2015	2.25	7.28	4.20
8	H0122	Ratu-Bardibas	2010	2	6.73	4.73
			2012	1	5.63	6.35
			2014	2	5.35	5.38
			2015	2	9.1	3.63
9	H0123	Bardibas-Banke	2010	1	6.7	5.86
			2012	1.16	5.2	6.37
			2014	2.31	6.8	4.36
			2015	2.13	8.69	3.68
10	H0124	Banke-Nawalpur	2010	1	8.01	5.25
			2012	1.15	6.05	5.99
			2014	2.39	8.2	3.62
			2015	2	10.74	2.87
11	H0125	Nawalpur-Bagmati	2010	1	8.06	5.22
			2012	1.26	6.34	5.73
			2014	2.43	8.43	3.47
			2015	2.64	11.11	1.99

5.3 Performance Curve

Performance Curve of respective road sections are plotted below:

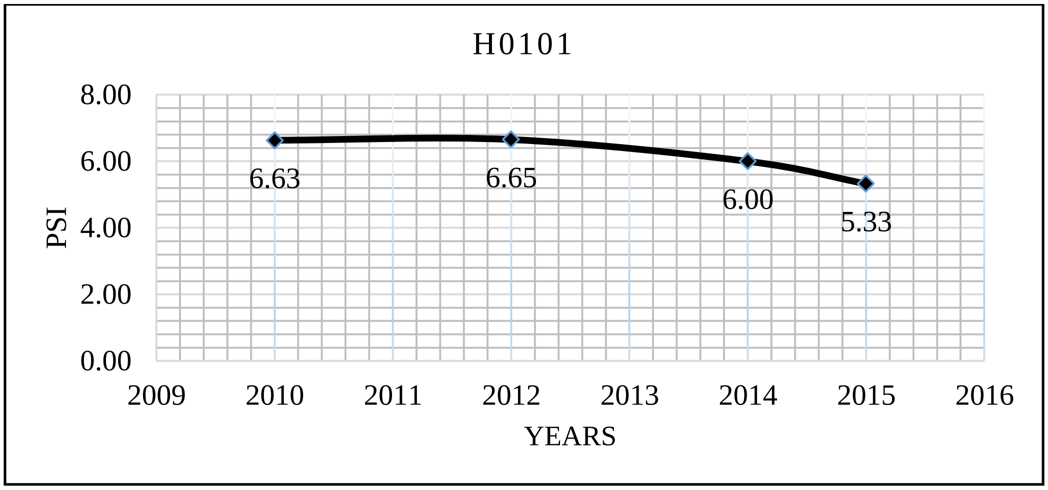

Figure 5.1 Performance Curve of Kakarbhitta-Charali section

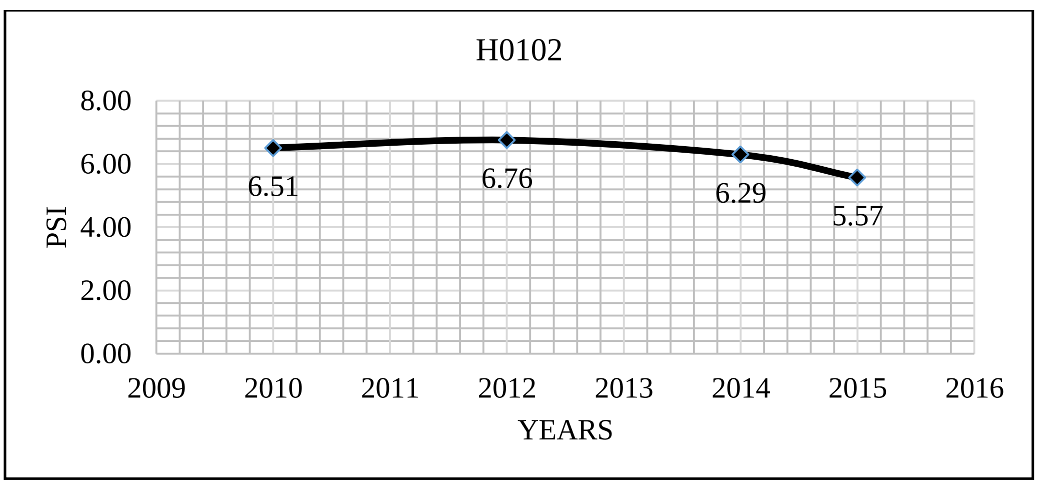

Figure 5.2 Performance Curve of Charali-Birtamod section

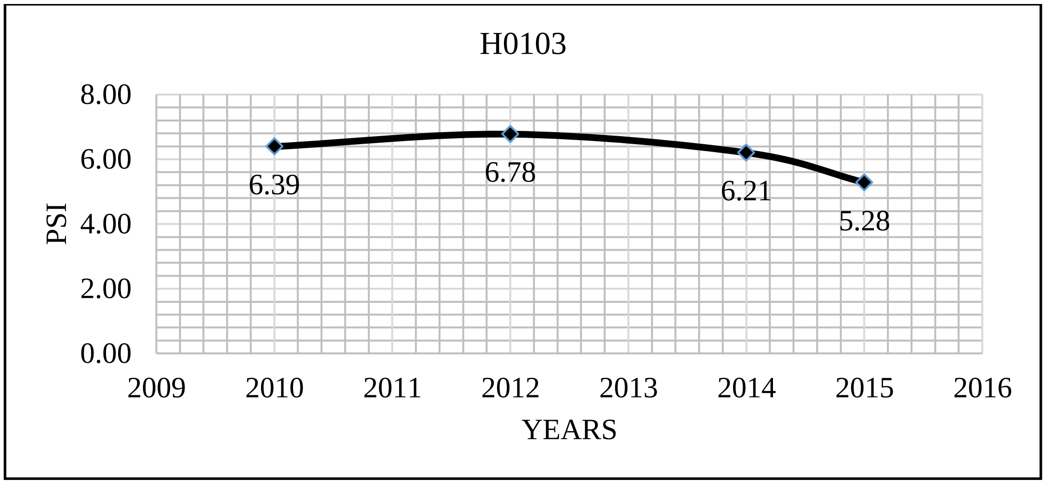

Figure 5.3 Performance Curve of Birtamod-Padajogi (Damak) section

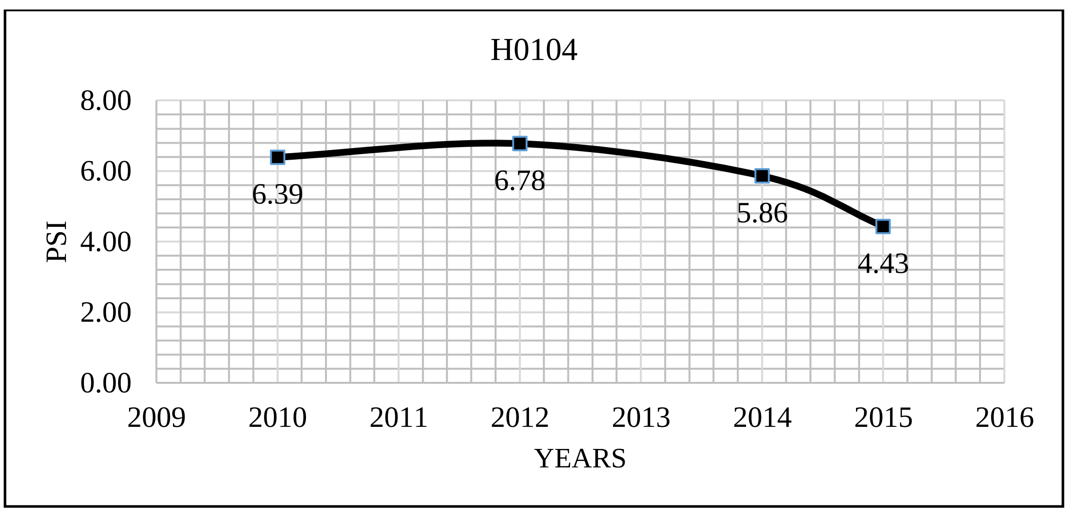

Figure 5.4 Performance Curve of Padajogi (Damak)-Ratuwa section

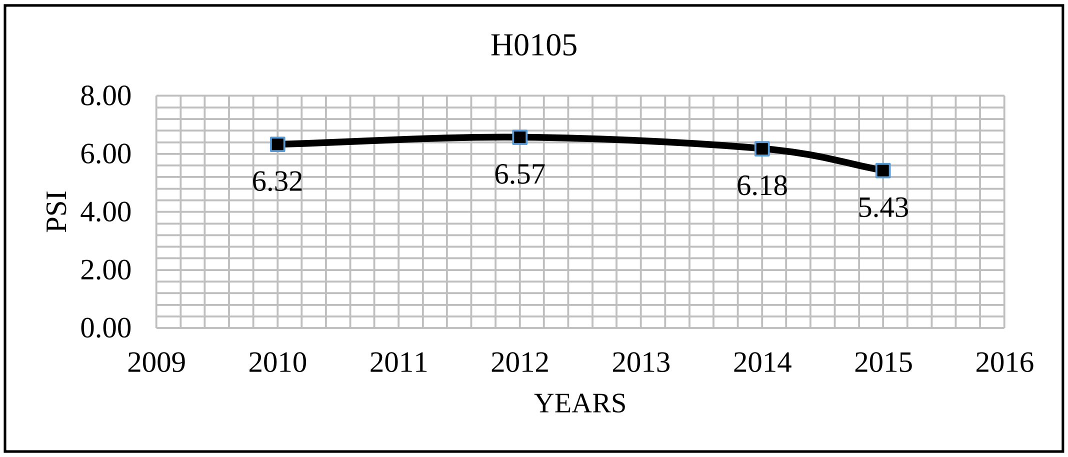

Figure 5.5 Performance Curve of Ratuwa-Mawa section

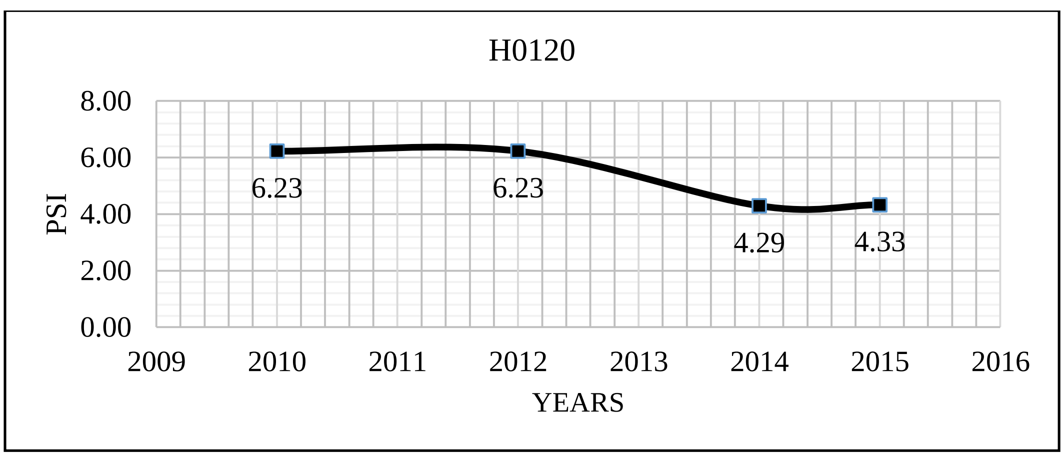

Figure 5.6 Performance Curve of Kamala-Dhalkebar section

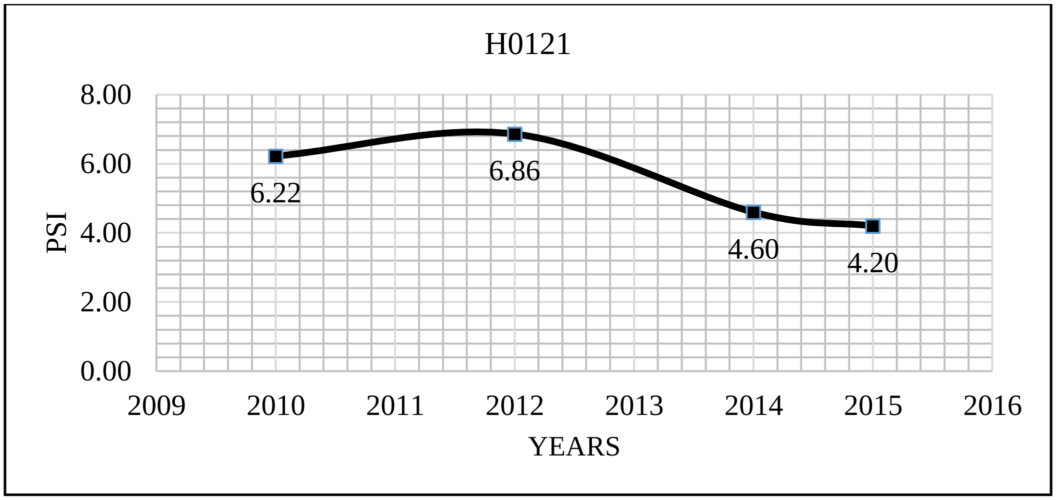

Figure 5.7 Performance Curve of Dhalkebar-Ratu section

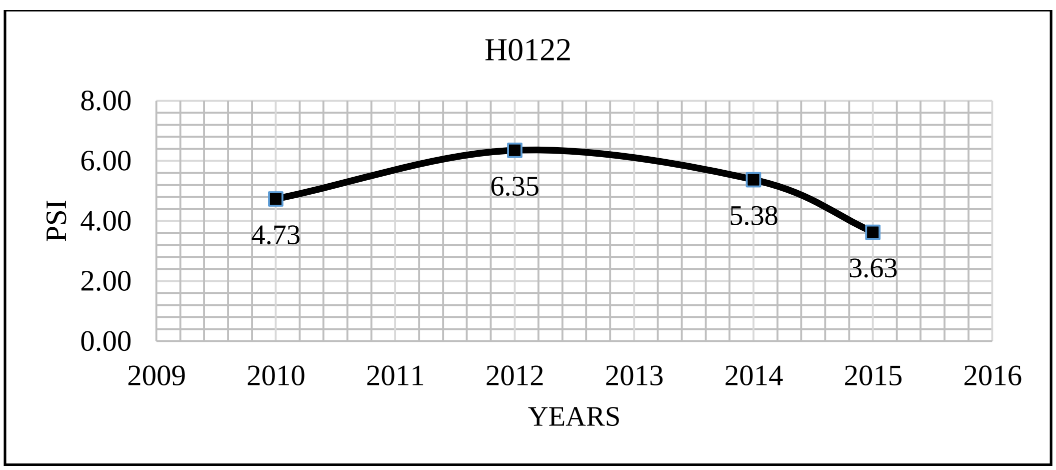

Figure 5.8 Performance Curve of Ratu-Bardibas section

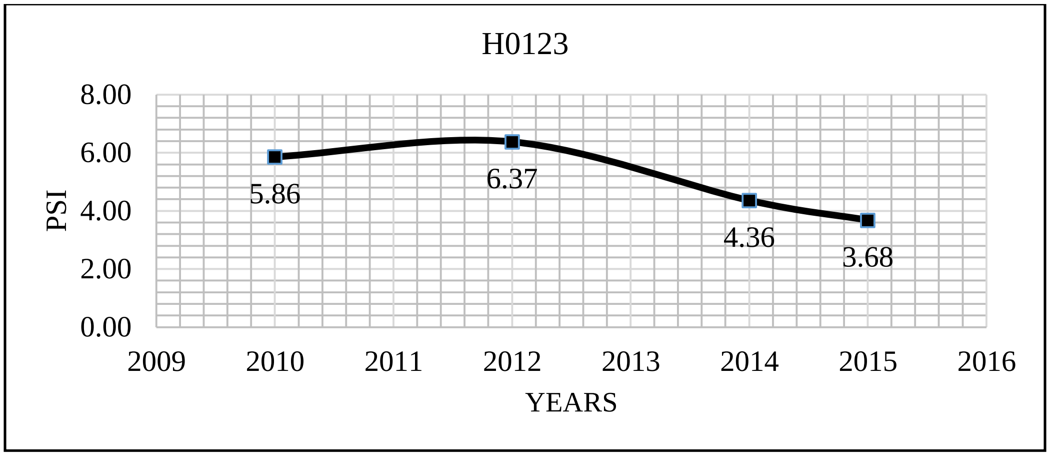

Figure 5.9 Performance Curve of Bardibas-Banke section

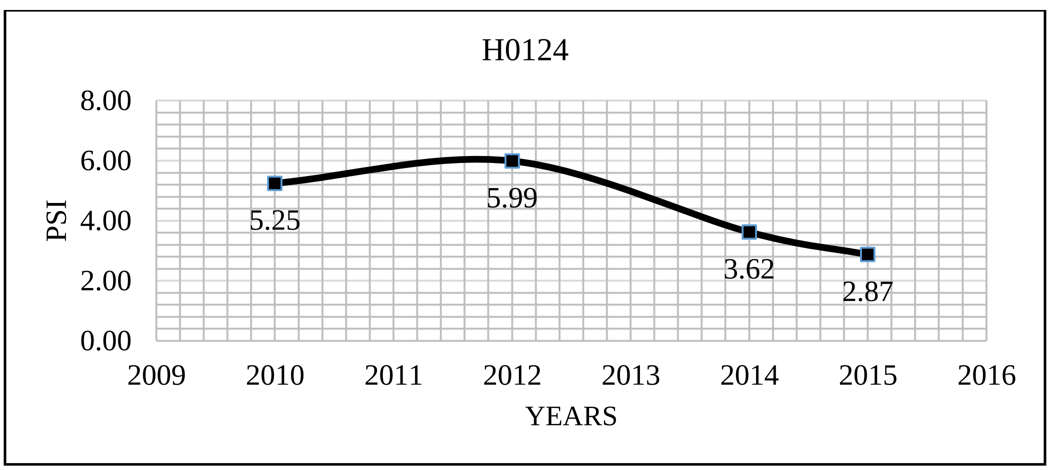

Figure 5.10 Performance Curve of Banke-Nawalpur section

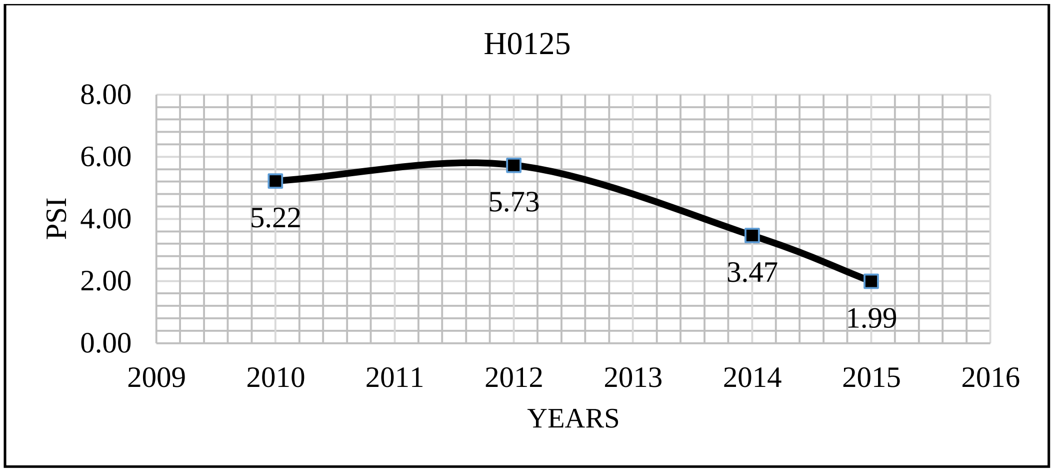

Figure 5.11 Performance Curve of Nawalpur-Bagmati section

5.4 Maintenance Options

Prime objective of pavement maintenance is to provide adequate and effective serviceability for the road users. It is ongoing process which starts from the day of completion of road. The road once constructed or improved must be looked after on a regular basis. Inadequate road maintenance is due to several factors such as insufficient funds, lack of qualified staff, lack of materials and resources, deficient institutional arrangements, poor maintenance management system, etc.

In Nepal, for bituminous roads, non-structural seal coat is provide at intervals of about 5 to 6 years for hills and 6 to 7 years in terai (MRCU, 1995).

Pavement remedial action as given by the SDI values are:

Percentage	**SDI Values**	**Action**
20%	SDI - 5	Reconstruction
10 – 30%	SDI - 4	Rehabilitation
20 – 30 %	SDI - 3	Resealing with local patching
20 – 30%	SDI – 2	Resealing only

(Source: MRCU, 1995)

In case of roughness, deterioration is mainly considered in three phases. In phase 1, pavement is in good serviceability and marginal increase in roughness with limited minor cracking, whereas in phase 2, roughness increases from reasonable to poor and in phase 3, roughness reaches to unacceptable levels with total loss of serviceability, shown in figure below:

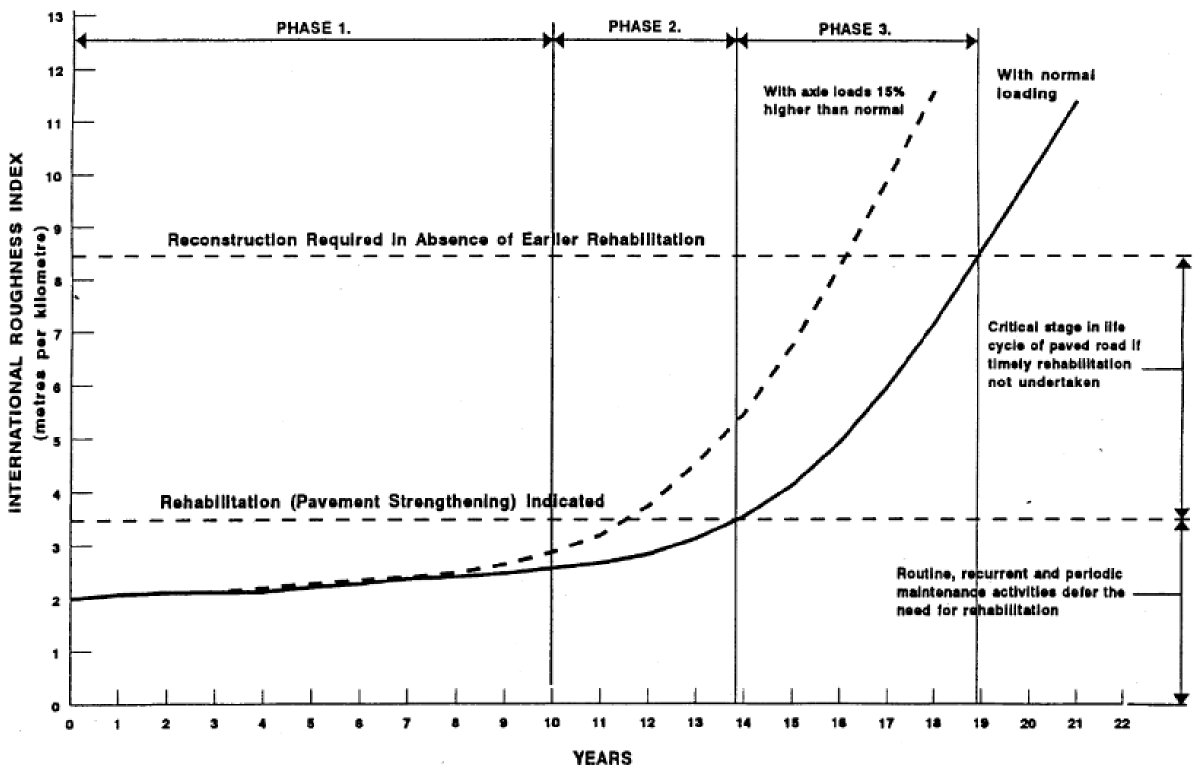

Figure 5.12 Deterioration of paved roads over time

(Source: MRCU, 1995)

As from above diagram, minimum and maximum roughness value for the routine, recurrent and periodic maintenance is 2.0 and 3.5

So, the PSI for the respective SDI and IRI values are calculated as:

SDI	IRI	PSI
2	2	6.93
3	3.5	5.12

Here, the PSI value are categorized in five different conditions, listed below:

Table 5.2 PSI Value and Condition

PSI Value	**Condition**
0 – 2	Very Poor
2 – 4	Poor
4 – 6	Fair
6 – 8	Good
8 – 10	Very Good

And the remedial action provided for the pavement with respect to PSI values is:

Table 5.3 Pavement Remedial Action with respect to PSI

Percentage	**PSI Value**	**Remedial Action**
20% - 30%	6.93	Resealing Only
20% - 30%	5.12	Resealing with local patching

Since, this research only deals with surface condition, if there is more distress and roughness then analysis of structural behavior of pavement is needed for the rehabilitation and reconstruction measures.

5.5 Analysis and Interpretation of Performance Curve

Even with the proper maintenance, roads deteriorate with time. The rate of this deterioration depends on the climate, the type and strength of pavement, strength of underlying soil, volume of traffic using the road and axle load of vehicles. For all roads, there will eventually come a time when they reach the end of their design life and they will need strengthening or improving. Strengthening, rehabilitation and reconstruction are all high cost activities and it is important to postpone them as long as possible.

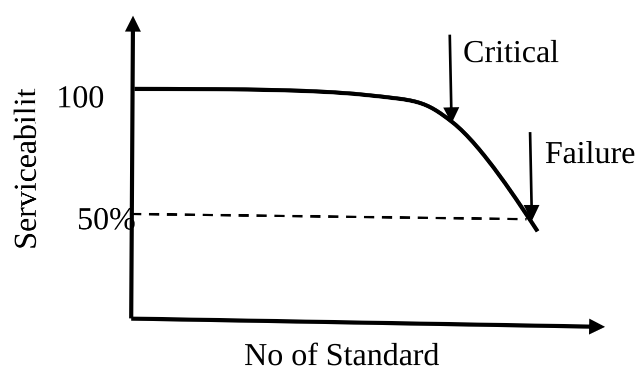

Figure 5.13 Pavement Serviceability

(Source: S.F. Brown, 1990)

As the pavement deteriorate, shown in above Figure 5.13, a stage comes (say critical), where routine and recurrent maintenance alone may not be sufficent, it might need periodic resealing or thin overlay. If critical condition is not addressed, deterioration will be faster and due to defer action, failure condition reaches and performance of pavement gets deteriorated where structural anlaysis might be needed for further treatment intervention, which might be very costly, however a condition will reach, which is discussed below:

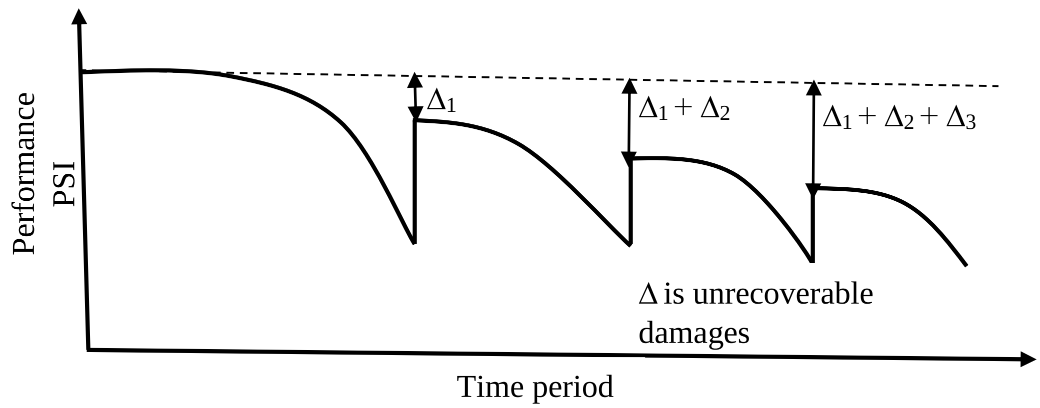

Figure 5.14 Performance Curve after maintenance

Even with cyclic routine, recurrent and periodic maintenance, pavement condition (i.e. PSI) deteriorates, leaving unrecoverable damage (say Δ) as shown in Figure 5.14, which can't be treated. A stage comes in life of a pavement in a road section where accumulation of unrecoverable damages gets higher which consequently increases the VOC causing discomfort to users. At this condition, structural analysis might be needed to determine further treatment of pavement. The treatment intervention could be pavement strengthening or rehabilitation or if condition has been further worsened, it may be reconstruction.

Table 5.4 Interpretation of performance curve

Figure No/Link Code	Road Name	Remarks
Figure 5.1 / H0101	Kakarbhitta-Charali	Pavement is in *Fair* condition Time for resealing Increase the no of intervention for recurrent maintenance
Figure 5.2 / H0102	Charali-Birtamod	Pavement is in *Fair* condition Time for resealing Increase the no of intervention for recurrent maintenance
Figure 5.3 / H0103	Birtamod-Padajogi (Damak)	Pavement is in *Fair* condition Time for resealing Increase the no of intervention for recurrent maintenance
Figure 5.4 / H0104	Padajogi (Damak) - Ratuwa	Pavement is in *Fair-Poor* condition Deterioration is high Resealing with local patching or Structural analysis is needed for strengthening intervention
Figure 5.5 / H0105	Ratuwa-Mawa	Pavement is in *Fair* condition Time for resealing Increase the no of intervention for recurrent maintenance
Figure 5.6 / H0120	Kamala-Dhalkebar	Pavement is in *Fair-Poor* condition Deterioration is high Resealing with local patching or Structural analysis is needed for possible structural strengthening intervention
Figure 5.7 / H0121	Dhalkebar-Ratu	Pavement is in *Fair-Poor* condition Deterioration is high Resealing with local patching or

Figure No/Link Code	Road Name	Remarks
		Structural analysis is needed for possible structural strengthening intervention
Figure 5.8 / H0122	Ratu-Bardibas	Pavement is in *Poor* condition Deterioration is very high Structural analysis is needed for possible structural strengthening intervention
Figure 5.9 / H0123	Bardibas-Banke	Pavement is in *Poor* condition Deterioration is very high Structural analysis is needed for possible structural strengthening intervention
Figure 5.10 / H0124	Banke-Nawalpur	Pavement is in *Poor* condition Deterioration is very high Structural analysis is needed for possible structural strengthening intervention
Figure 5.11 / H0125	Nawalpur-Bagmati	Pavement is in *Very Poor* condition Deterioration is very much high Structural analysis is needed for possible structural strengthening intervention

Limitations of Data:

Field visit could be more justifiable for the verification of data's.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

The main aim of this study is to develop the Present Serviceability Index for flexible pavements by comprising Surface Distress Index and International Roughness Index and the model formed is **PSI = 10.0745 – 1.107 SDI – 0.4645 IRI.** This predicted model is statically validated and accepted. From the study, following conclusions are drawn:

- From now on, PSI will evaluate the existing condition of pavement instead of SDI and IRI alone
- Performance curve of any pavement section can be drawn out with the help of PSI, where SDI and IRI alone can't draw it
- Maintenance measures can be provided with respect to PSI values

From the study, following recommendation are suggested:

- Pavement evaluation must be done yearly
- Road maintenance must be carried out at right time in a regular basis, where delay may lead to rehabilitation and reconstruction which is expensive
- Priority Investment Plan for the road maintenance should be carried out on the basis of PSI values
- PSI only evaluate the condition surveys i.e. surface distress and roughness only, which doesn't consider the structural behavior of pavement. So further research can be done by comprising structural behavior to get the complete index and performance curve.

REFERENCES

1. MRCU, 1995, *Road pavement management, discussion paper*, DOR Nepal
2. M.Y. Shahin, J.A. Walther, *Pavement Maintenance Management for Roads and Streets Using the PAVER System*, by US Army Corps of Engineer
3. *Pavement Distress Identification Manual*, prepared by Federal Highway Administration, FHWA, US DOT
4. Strategic Highway Research Program (SHRP), 1993, *Distress Identification Manual for the Long- Term Pavement Performance Project*,
5. *An Overview of Mn/DOT's Pavement Condition Rating Procedures and Indices*, 2006
6. Mehran Kafi Farashah, *Development Practices for Municipal Pavement Management Systems Application*
7. Stella O. Obazee-Igbinedion, Manoj K. Jha, Oludare Owolabi, *Building a sustainability index for highway infrastructures: case study of flexible pavements*
8. *Pavement Management System Report*, City of Bowling Green
9. Reza, Boriboonsomsin, and Bazlamit, 2006, *Development of a Pavement Quality Index for the State of Ohio*
10. *E. J. Yoder, M. W. Witczak,1975, Principles of Pavement Design, Second Edition, A Wiley-Interscience Publication, New York, ISBN O-471-97780-2*
11. Carol W. Blair, et al., *Pavement Management for Low-volume Roads*, Transportation Research Record 1106
12. Sanjay Panthi, 2016, *Applicability of the International Roughness Index (IRI) as a predictor of Pavement Condition Index (PCI)*, M.Sc. Thesis, Department of Civil Engineering, Tribhuvan University
13. *Final Report on traffic, surface distress and road roughness surveys on Strategic Road Network (SRN)*, 2012, HMIS
14. *Final Report on traffic, surface distress and road roughness surveys on Strategic Road Network (SRN)*, 2014, HMIS
15. *Final Report on traffic, surface distress and road roughness surveys on Strategic Road Network (SRN)*, 2015, HMIS

16. Phil Hunt et al., 2001, *Analysis of Unbound Granular Pavement Deterioration for use in Asset Management Modelling*
17. Bishnu Babu Pandey*, 2016, Probabilistic Model to develop a decision support system for planning of bituminous pavement*, M.Sc. Thesis, Department of Civil Engineering, Tribhuvan University
18. S.F. Brown, 1990, *Lecture Notes*, *Post Graduate Course in Flexible Pavement Engineering, Introduction to Pavement Design*, Department of Civil Engineering, University of Strathclyde.