DEVELOPMENT OF PAVEMENT DISTRESS MODELS FOR KHULNA JESSORE HIGHWAY IN BANGLADESH

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Development of Pavement Distress Models for Khulna – Jessore Highway in Bangladesh.

by

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Declaration

This is to certify that the thesis work entitled " Development of Pavement Distress Models for Khulna – Jessore Highway in Bangladesh." has been carried out by S.M. Moazzem Hossain in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Approval

This is to certify that the thesis work submitted by S.M. Moazzem Hossain entitled " Development of Pavement Distress Models for Khulna – Jessore Highway in Bangladesh " has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in July, 2016.

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Abstract

General function of a pavement is to provide a safe and comfortable riding surface to road users. Pavements represent an important infrastructure to all countries. However, pavement distress is major problems faced by road users. This pavement requires great care through conducting periodic evaluation and timely maintenance to keep the pavement operating under acceptable level of service. An adequate assessment of pavement distresses is necessary before carrying out maintenance and rehabilitation.

Since maintenance of pavement is a vital and continuous activity, maintenance shall be done effectively to avoid any reoccurrence and repeatedly works.Thus, in fulfill and meet pavement goals,the aim of this study is to determine pavement distress model for effective maintenance works in term of cost, quality and time at National Highway. These models allow pavement authorities to predict the deterioration of the pavements and consequently determine the maintenance needs and activities, predicting the timing of maintenance or rehabilitation, and estimating the long range funding requirements for preserving the performance of the network.In this study, data of pavement distresses on the Khulna - Jessore National Highway (N7) were collected.Visual distress assessment using measuring tape, ruler and camera were carried out on selected test sections of that highway in order to have better understanding of the pavement response.These data were categorized, processed, and analyzed. These data have been employed to generate pavement distress models by statistical software SPSS.

Throughout the study, the most common types of pavement distress on the national highway have been identified. The behavior of these distress types has been investigated.A S-curve regression equation was found to be an excellent representation of the data. Six for national highway pavement distress models (NHPDM) have been developed.The developed models provide a reasonable prediction of pavement condition. The models were assessed by regression analysis.The implementation of the models for maintenance work has also been proposed.

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Nomenclature

y	Dependent variable
x	Independent variable
$_0$, $_1$	Parameter to be calculated by regression analysis using statistical software, SPSS
TF	Traffic Factor
RF	Road Factor
MF	Maintenance Factor
CEF	Cost Effectiveness Factor
MP	Maintenance Priority
t	Expected life for a maintenance type,
C	Maintenance activity unit cost.
y_n	Dependent variable for narrow crack distress
X_n	Independent variable year for narrow crack distress
y_w	Dependent variable for wide crack distress
X_w	Independent variable year for wide crack distress
y_p	Dependent variable for potholes distress
X_p	Independent variable year for potholes distress
y_d	Dependent variable for depression distress
X_d	Independent variable year for depression distress
y_r	Dependent variable for rutting distress
X_r	Independent variable year for rutting distress
y_{rv}	Dependent variable for ravelling distress
X_{rv}	Independent variable year for ravelling distress

List of Abbreviations

GDP	Gross Domestic Product
C&B	Construction & Building
RHD	Roads and Highways Department
N	National Highway
PMS	Pavement Management System
MMS	Maintenance Management System
HMMS	Highway Maintenance Management System
AASHO	American Association of State Highway Officials
FHWA	Federal Highway Administration
PCI	Pavement Condition Index
MEPDG	Mechanistic-Empirical Pavement Design Guide
AADT	Annual Average Daily Traffic
RMMS	Road Management and Maintenance System
NHPDM	National Highway Pavement Distress Model
PDI	Pavement Distress Index
D	Distress
ADT	Average Daily Traffic
RRD	Representative Rebound Deflection
DCP	Dynamic Cone Penetration
EAL	Equivalent Axle Load
CBR	California Bearing Ratio

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CHAPTER I

Introduction

1.1 History of Road Construction in Bangladesh

Geologically Bangladesh is a delta formed from 230 rivers including the Padma (Ganges), Jamuna (Brahmaputra) and the Meghna. Eighty percent of the total population are settled in rural areas. Road and water transport are the main means of travel and there is a well developed air services. As a result of the many rivers and regular flooding in rural areas most roads are built on embankments with a large number of bridges, culverts and ferries. Bangladesh is one of the most densely populated countries in the world with a population of almost 160 million. Flexible pavements almost are being used at all networks of local roads, village roads, zilla roads, regional highways, national highways and others road in Bangladesh. It is important that of these flexible pavements meet the requirement of pavement performances goals. Once the construction of the pavement works is completed, it is most essential to implement pavement preventive maintenance that emphasizes keeping roads in good condition through early application of maintenance treatments.

Transportation systems include highway, railway, airway, waterway and pipelines. Only waterway and pipelines of these systems do not make the use of pavements. The major elements of the highway system are the pavements. For air travel, runways, taxiways, and parking aprons are pavements. The pavements represent one-half of total highway expenditure and moreover expenditure on pavements continues to grow as maintenance and rehabilitation are required (Haas *et al*. 1994). Transportation infrastructure plays a vital role in the economic, social, and state of all countries and this role cannot be neglected. The impact of growth and prosperity achieved in this sector extends to include other sectors, and therefore, there is a strong relation between growth in the transportation sector and the growth of a country's economy as a whole. All of this is reflected in the significant contribution made by this sector to Gross Domestic Product (GDP) and increasing financial returns to the country directly or indirectly. Some studies indicate that costs attributable to transportation are on average almost 20% of the final cost of a product; thus, reducing transportation cost will reduce product cost. For example, reduction of transport cost by 10% leads to lower cost of the final product by almost 2% (SAMA 2004). The contribution of the transportation sector to the GDP of the United States of America for example, represents almost 20% and in Germany, 4.17%, which means that the contribution of this sector in many industrialized countries has significant importance on estimated GDP of these countries. This means that it is necessary to allocate a significant proportion of the budget to the transportation sector, as the sector is considered an important source of government revenue and has a big role in the growth of the country's GDP (SAMA 2004).

A road construction work, just like any other social endeavor or undertaking, has vast and wonderful history of its own, since it evolved with the social development of mankind. Transportation Infrastructure (roads, rail, airports and seaports) represents important infrastructure to all countries' economies. The Roads and Highways Department (RHD),Bangladesh was created in 1962 when the old 'Construction & Building (C&B) organization was split into 2 separate bodies (the other being Public Works Department). RHD is responsible for construction and maintenance of the major road network of Bangladesh and "To Provide a safe, cost effective & well maintained road network". Since the department was established the size of the major road network in Bangladesh has grown from 2,500 Kilometers to the present network of 21,302.08 Kilometers.

Pavement maintenance and rehabilitation incorporates all activities undertaken to provide and maintain serviceable roadways. Huge amount of money or capital had already being invested in the construction of roads and highways. In this country, several national highways had been constructed to connect the several parts of the country to the capital city Dhaka. The few main highways among those are namely N1-Dhaka (Jatrabari)-Comilla (Mainamati)-Chittagong-Teknaf Road, length-455 Km. ; N2-Dhaka (Katchpur)-Bhairab-Jagadishpur-Shaistaganj-Sylhet-Tamabil-Jaflong Road, length-286 Km. ; N3-Dhaka (Banani)-Joydebpur-Mymensingh Road, length-112 Km. ; N4-Joydebpur-Tangail-Jamalpur Road, length-146 Km.; N5-Dhaka (Mirpur)-Utholi-Paturia- Natakhola-Kashinathpur- Bogra-Rangpur-Beldanga- Banglabandh Road, length-507 Km. ; N6-

Kashinathpur-Dasuria-Natore-Rajshahi Road, length-150 Km. ; N7-Dauladia-Faridpur (Goalchamot)-Magura-Jhenaidah-Jessore-Khulna-Mongla (Digraj) Road, length-252 Km. ; and N8-Dhaka (Jatrabari)-Mawa-Bhanga-Barisal-Patuakhali Road, length- 191 Km. Huge amount of money would also be invested on the continuous maintenance of highways which is vital to ensure road worthiness, safety and end user satisfaction.

The allocation of funding for road maintenance and rehabilitation requires a continuous evaluation of the state of the highway network. Periodic survey of the condition of the pavements reveals how necessary it is to intervene with a major rehabilitation as an overlay or with crack sealing as a maintenance routine. Traditional pavement surveys range from a thorough walking survey of 100% of the pavement surface in which all distress types, severities, and quantities are measured, recorded, and mapped to a windshield survey at normal traffic speed in which the rater assigns the pavement a general category or sufficiency rating without identifying individual distress types. In either case, the inspection of the pavement surface is direct and human cognition is used to categorize and determine the type of distress, severity and quantity of distress present on the pavement surface. Overall, manual surveys are considered labor intensive, slow, expensive, and sometimes unsafe. They also invariably involve a certain degree of human subjectivity.

The main objective of the study is to develop a maintenance management system for Bangladesh road network by developing model of distresses. This objective has been achieved through tasks including, detailed study of existing maintenance practices, development of a maintenance management system with model of distresses, and improvement of existing maintenance practices using simple and direct techniques which enable evolution of more efficient maintenance programs. After the completion of the above three tasks, the system has then been gradually improved using more complicated techniques and measures to enhance or direct maintenance decisions. The final form of the system will be produced taking into consideration the possibility of using the system of maintenance on the Khulna - Jessore National Highway (N7), length-61 Km. (Part of N7-Doulotdia-Faridpur-Magura-Jhinaidah-Jessore-Khulna-Mongla National Highways).

1.2 Bangladesh Road Network Condition

According to the reference system (or hierarchy) developed by the RHD Master plan, the Roads fall within the following classifications:

Table 1.1: Road classifications (www.rhd.gov.bd)

Road length by classification		
National Highway	:	3,812.78 Km
Regional Highway	:	4,246.97 Km
Zilla Road	:	13,242.33 Km
Total Length	:	21,302.08 Km
Bridges & Culvert		
Bridges	:	4507 Nos.
Culvert	:	13751 Nos.

The country of Bangladesh covers a total area of 143998 sq.kms out of which about 40% are built up areas. There are 21,302.08 kms of main road network. The road density is relatively low in this country when compared with the required density for similar country network, which mostly ranges from 15% to 25% and even some times more depending on the desired level of standards. In addition to the above shortcomings related with the network, the road construction and maintenance has the problems such as no proper pavement evaluation, no proper quality control during construction and maintenance, no coordination between different bodies involved in the road construction and maintenance and do not comply with the country master plan, appropriate design standards and construction practice.

The above construction and maintenance problems are aggravating deterioration of roads and consequently repeated maintenance and repair is being made. The pavement distress severity is more on major highways. Such severe pavement distresses summed up with low road density, lack of pedestrian walkways, inadequate road sign and markings are resulting traffic congestion and subsequent accidents on the highways. Since the department was founded the size of the major road network in Bangladesh has grown from approximately 2500 kms to the present network of about 21,302 kms. The Department is responsible for an annual budget of approximately Taka 4000 crore of which about Taka 3000 crore is from the Annual Development Budget and Taka about 1000 crore from the revenue budget in each financial year (www.rhd.gov.bd). On the other hand, the RHD Authority is making proper strategy for the identification of distresses or for the selection of treatment options. The Authority's position is now improving with the development of pavement management system (PMS), which, if properly implemented, can assist them to identify and quantify pavement distresses. Hence, this research will have some input in upgrading the Authority’s maintenance management by indicating causes of pavement distress and using the model of pavement distresses.

1.3 Comparison Between Urban and Rural Roads

Rural and urban roads are the same in terms of service function and land service. However, there are significant differences between urban and rural roads. Traffic volumes are higher on urban roads than on rural roads, design speeds on urban roads are lower than on rural roads, and vehicle types are different. Therefore, the design standards, design features, and operational needs are different.

On urban networks, several groups share the roads. City roads commonly have a number of utility lines running parallel to and cross the roads. Utility cuts in the cities include those for electricity, water, storm, sewage, and telephone. Constructing and maintaining these utility lines requires the road pavement be dug. Each utility line is associated with a unique method of construction in terms of backfill, utility protection, separation from adjacent utilities, and depth from the pavement surface. Achievement of an adequate backfill compaction and a smooth finished surface are essential with utility repairs (Al-Swailmi 1994). As a result of this situation, urban roads experience a significant deterioration rate. Patching results in a noticeable decline in both riding quality and structural integrity of these pavements. Therefore, there is a need for a framework for a maintenance management system (MMS) rather than a pavement management system

(PMS); the MMS focuses only on road maintenance to coordinate maintenance works. On the other hand, for the rural networks, it is necessary to consider road construction, tunnels, and bridges in their specific maintenance management needs and this is usually termed a Highway Maintenance management System (HMMS). Some studies suggest a subsystem technique to define and record the information from each subsystem such as water, electricity, and others (Al-Swailmi & Al-Abdl Wahab 2002). The purpose of this system is to help the engineers to deal with the urban network in general and to define the effect of each subsystem in order to coordinate effectively, define responsibilities, increase the efficiency of road works, and reduce the effect of trenches on the network. According to Al-Swailmi (1994), the subsystem technique is a comprehensive system for infrastructure management.

Furthermore, the pavement distress types are different between urban and rural roads. For instance, some studies recommend including all distress types in the PMS; other studies recommend reducing the number of distress types and merging some together. However, all studies agree on the importance of distress definition in a successful PMS. In general the nature of pavement distress types on rural roads is less varied than on urban roads, especially when the environmental factors, construction standards, and traffic volumes are the same; pavement distress types are mainly correlated to traffic volumes. On the other hand, pavement distress types on urban networks are highly varied and they are less correlated with traffic (Al-Swailmi & Al-Abdl Wahab 2002).

In addition, one of the differences is the network size. Rural networks are bigger compared to urban networks and consequently the costs to develop and to implement the PMS will be more. For instance, on rural roads, the sample unit length is generally long to reduce the data volume and consequently to reduce the cost of network evaluation, and according to Al-Swailmi & Al-Abdl Wahab (2002), experience shows that this methodology does not affect the efficiency of road assessment because the road performance relatively similar over significant lengths. On the other hand, urban network engineers use short length pavement sections to represent the urban network because of number of intersections, traffic signals, and trenches. To conclude, the characteristics of urban and rural networks are not the same. The differences can be grouped into; technical issues such as the types of maintenance work, administrative issues such as sharing of the network by different organizations, the nature of pavement distress types, and the size of the network.

1.4 Problem Statement

The width of Jessore-Khulna road was extended from 5.5 m. to 7.3 m. in the year 1985. The maintenance work was conducted in the year 1996. This maintenance work was overlay only. But from the year 2010 this portion of the national highway (N7) started to be distressed. Now a days the road is full of various types of distresses and day by day the distresses are increasing. Some routine maintenance works have been conducted but the condition is not being improved. That is the main problem of this highway. On the basis of that problem, this research has been carried out.

1.5 Research Objectives

The aim of this research is in general to make initial assessment on performance of asphalt pavements and maintenance alternatives for the Khulna - Jessore National Highway (N7). The main objectives are as follows:

1. To review the concept of pavement deterioration models and the factors associated with their performance at network level for National Highway.
2. To review and identify the main pavement distress indicators.
3. To investigate the major asphalt pavement distresses and their severity in the Khulna - Jessore National Highway (N7) and finally,
4. To develop the pavement distress model.

1.6 Scope of the Research

The research has been done on the Khulna-Jessore National Highway (N7), length-61 Km. (Part of N7 – Doulotdia – Faridpur – Magura – Jhinaidah – Jessore – Khulna - Mongla National Highway). Nobody has worked before on this highway to collect the data to develop the distress model for maintenance work properly. But it is important to develop the pavement distress model for maintenance work of this highway.

1.7 Thesis Organization

The activities of this research will be described in total 7 chapters. Chapter 1 contains history and main road network condition of Bangladesh. It shows the deference between urban and rural road. The problem statement is given here. The objectives of this research have been mentioned in this chapter. In Chapter 2 the elements and function of asphalt pavement, types of distress, pavement management system, prediction parameter and maintenance and rehabilitation are reviewed. The research methodology is addressed in Chapter 3**.** Distress assessment and dataset which includes study area, sampling, raw data of distress, common distress types, severities and density of distress are given in Chapter 4. Chapter 5 represents the maintenance and rehabilitation options. Results and discussion,which includes the determination of co-efficient of distress models, are represented in Chapter 6. Finally, Chapter 7 highlights conclusions, limitations and recommendations of this research.

CHAPTER II

Literature Review

2.1 General

It is very important to know the definition of pavement distresses and behavior of pavement for proper maintenance. This chapter describes performance and failure criteria of asphalt pavement, types and sources of pavement distresses with definition and solutions, pavement management system, pavement evaluation, the need to predict deterioration, predicted parameters, maintenance and rehabilitation, traffic loading effect.

2.2 Performance and Failure Criteria of Asphalt Pavement

Pavement performance evaluation is an important activity in the maintenance and rehabilitation works. It includes evaluation of existing distresses, road roughness, structural adequacy, traffic analysis, material testing and study of drainage condition. This section deals with types of bituminous surfaces, types and causes of distresses. All photographs of distresses are taken during visual survey for understanding the definition of distresses. A typical flexible or bituminous pavement structure consists of the following pavement courses: sub-base, base, and bituminous wearing surface. The wearing surface is the uppermost layer of the pavement structure. In a flexible pavement, it is a mixture of bituminous binder material and aggregate. The binder may be sprayed on the surface followed by application of aggregate and referred to as a bituminous surface treatment. The binder and aggregate may be mixed in a central plant or mixed in place on the road and referred to as hot or cold mixes. The wearing surface may range in thickness from 35 mm, as in the case of a surface treatment, to several millimeters of high-quality paving mixture such as hot-mix asphalt concrete. The wearing surface has four principal functions: to protect the base from abrasive effects of traffic, to distribute loads to the underlying layers of pavement structure, to prevent surface water from penetrating into the base and sub-grade and to provide a smooth riding surface for traffic.

The base and sub-base are made using different materials designated the upper and lower base or sub-base. Where the soil is considered to be very weak, a capping layer may also be introduced between the sub-base and the soil foundation. This may be of an inferior type of sub-base material, or it may be the upper part of the soil improved by some form of stabilization (e.g. with lime or cement). The soil immediately below the sub base (or capping layer) is generally referred to as the sub grade and the surface of the sub grade is termed the formation level. The elements of a flexible pavement as defined above are shown in Figure 2.1.

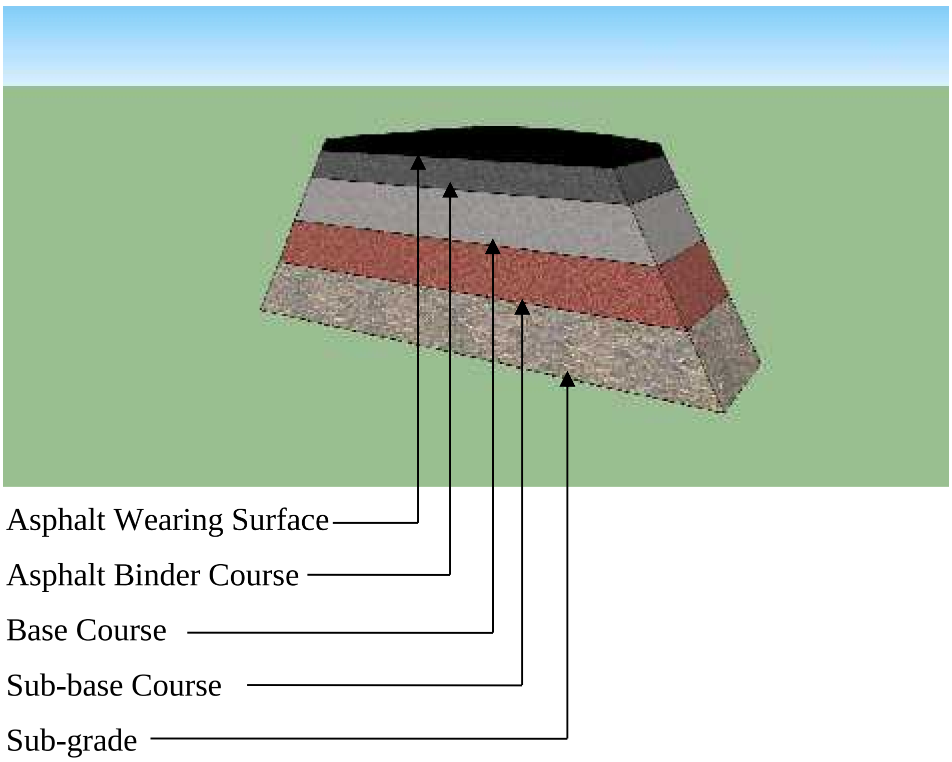

Figure 2.1: Elements of flexible pavement

Pavement deformation in the wheel path will start immediately following the passage of commercial vehicle over a flexible pavement. This permanent deformation in a well-designed pavement is fairly evenly distributed between the asphalted materials, the unbound base and sub-base, and the sub grade. In bituminous materials it may arise from additional compaction under traffic and from sideways displacement. A pavement layers are subject to vertical compressive stresses due to superimposed wheel loads. The wearing course, the binder course, and any bituminous base material will also be subject to tensile stress as the wheel load passes. Lower bituminous layers will be subject to smaller tensile stress. Unbound granular materials used in bases and sub-base cannot accept significant tensile stress, and the structure of such layers will relax under load, so reducing the effective elastic modulus of the materials.

Structural failure will generally be initiated by fatigue cracking in the wearing course, followed by similar cracking in the binder course and any other bituminous layers. Pavements should be designed and constructed to provide, during the design life, a riding quality acceptable for both private and commercial vehicles. The assumption is often made that road pavements begin to deteriorate as soon as they are opened to traffic. However, there should be no visible premature deterioration at the early stage of the design life except due to faulty design. Deterioration of flexible pavements arises from deformation under traffic loading generally associated, in the later stages, with cracking. Such deformation is associated with heavy commercial vehicles; the contribution of private cars and light commercial vehicles is negligible. Once the permanent deformation exceeds 15mm there is an increasing probability of cracking in the wheel tracks. Water entering the cracks is likely to accelerate failure. In some countries, for flexible pavements, a maximum deformation of 25mm in the wheel tracks has been defined as the failure condition, and a maximum deformation of 15 to 20mm is regarded as the optimum condition for remedial work such as the provision of an overlay or replacement of the surfacing. In practice, measurements of rutting are more likely to be made with a 2-m straight edge (Croney,D.).

Flexible pavements which are called upon to carry much heavier traffic loads than their design would permit often crack as a result of the large elastic deflections. This condition can cause breakup of the surface and give rise to potholing, before appreciable permanent deformation has occurred. The American Association of State Highway Officials (AASHO) has carried out road test in the United States early in the sixties, and developed a rating system, known as the present serviceability index (PSI) to classify the condition of pavements. The failure condition for flexible roads, defined above, corresponds to a PSI value of between 2 and 2.5 depending on the desired level of standard of the road. The concept of pavement performance using Present Serviceability Index is as shown in Figure 2.2 (Garber N.J etal).

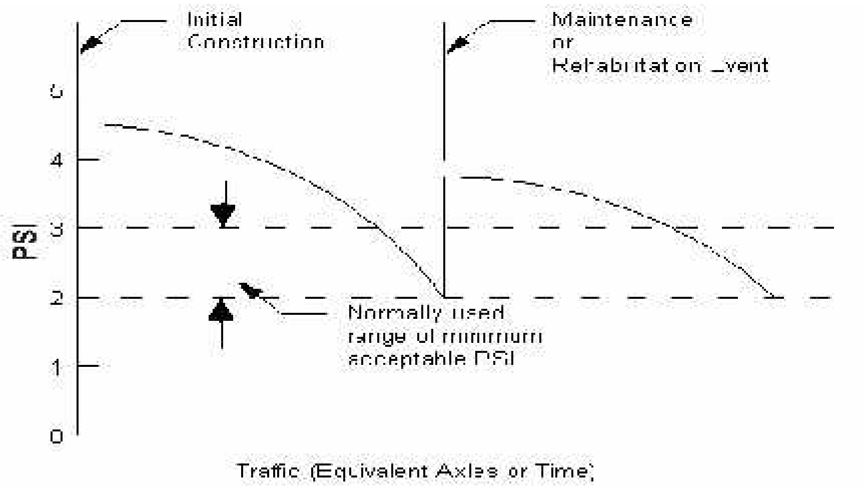

Figure 2.2: Concept of Pavement Performance Using Present Serviceability Index

2.3 Types And Sources of Pavement Distress

2.3.1 Crack.

Cracks are fissures resulting from partial or complete fractures of the pavement surface. Road pavement surface cracking can happen in a wide variety of patterns, ranging from isolated single crack to an interconnected pattern extending over the entire pavement surface. The detrimental effects associated with the presence of cracks are; loss of water proofing of the pavement layers, loss of load spreading ability of the cracked material, pumping and loss of fines from the base course, loss of riding quality through loss of surfacing and loss of appearance. The loss of spreading ability and water proofing, usually lead to accelerate deterioration of the pavement condition. The possible causes of crack include depression, fatigue life of the surfacing being exceeded, reflection of cracks in underlying layers, shrinkage and poor construction joints. There are few types of cracks, such as crocodile cracks, block cracks, longitudinal cracks, transverse cracks and crescent shaped cracks.

2.3.1.1 Alligator cracks

Crocodile cracks are also known as alligator, chicken wire, fish net, polygonal and fatigue cracks. Crocodile cracks is a interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading (Figure 2.3). The cracking initiates at the bottom of the asphalt surface (or stabilize base) where tensile stress and strain is highest under a wheel load. The cracks propagate to the surface initially as a series of parallel cracks. After repeated traffic loading the cracks connect, forming many-sided, sharp-angled pieces that developed that pattern. The block size can range from 100mm to about 300mm. Severity levels of crocodile cracks are:

Low	Interconnected or interlaced hairline cracks running parallel to each other, cracks not spilled.
Moderate	A pattern of articulated pieces formed by cracks that may be lightly spilled. Cracks may be sealed.
High	Pieces more severely spilled at edges and loosened; pieces rock under traffic; pumping may exist.

Measurements to be taken are area affected, predominant crack width and predominant cell width. The possible causes and probable treatments are as shown in Table 2.1.

Figure 2.3: Photograph of alligator cracks

Table 2.1: Possible causes and probable treatments of alligator cracks

Sl.No.	Possible Causes	Probable Treatments
1	Inadequate pavement thickness	Strengthen the pavement or reconstruction
2	Low modulus base	Strengthen the base or reconstruction
3	Brittle base	Base recycling or reconstruction
4	Poor base drainage	Improve the drainage and reconstruct
5	Brittle wearing course	Replace or treat wearing course

2.3.1.2 Block cracks

Block cracks are also known as ladder cracks. Block cracks are interconnected cracks forming a series of block, approximately rectangular in shape (Figure 2.4). Block sizes are usually greater than 300mm and can be exceed 3000mm. Severity Levels of block cracks are:

Low — Blocks defined by unspoiled cracks with a mean width of 3 mm or less, cracks with sealant in good condition.

Moderate — Blocks defined by moderately spilled cracks; cracks with a mean width greater than 3 mm.

High — Blocks well defined by severely spilled cracks.

Measurements to be taken are area affected, predominant crack width and predominant cell width. The possible causes and probable treatments are as shown in Table 2.2.

Figure 2.4: Photograph of block cracks

Table 2.2: Possible causes and probable treatments of block cracks

Sl.No.	Possible Causes	Probable Treatments
1	Joints in underlying layer	Crushed aggregate overlay
2	Shrinkage and fatigue of underlying cemented materials	Replace underlying cemented materials
3	Shrinkage cracks (due to bitumen hardening) in bituminous surfacing	Seal cracks or replace bituminous surfacing
4	Fatigue cracks in embrittled bituminous wearing course	Cut and patch or crushed aggregate overlay.

2.3.1.3 Longitudinal cracks

Longitudinal Cracks are also known as line cracks. Longitudinal cracks are crack which are usually straight and parallel to the centre line, situated at or near the middle of the lane (Figure 2.5). It can happen singly or as series of almost parallel cracks or with some limited branching. Severity levels of longitudinal cracks are:

Low	Cracks with low severity or no spalling; mean unsealed crack width of 3 mm or less
Moderate	Cracks with moderately severe spalling; mean unsealed crack width greater than 3 mm; sealant material in bad condition
High	Cracks with high severity spalling

Measurements to be taken are width of dominant crack, length of dominant crack, spacing and area affected. The possible causes and probable treatments are as shown in Table 2.3.

Figure 2.5: Photograph of longitudinal cracks

Table 2.3: Possible causes and probable treatments of longitudinal cracks

Sl.No.	Possible Causes	Probable Treatments
1	Reflection of shrinkage cracks	Cut and patch
2	Poorly Constructed paving lane in bituminous surfacing	Replace bituminous surfacing
3	Displacement of joints at pavement widening	Reconstruction of joints
4	Differential settlement between cut and fill	Reconstruction
5	Reflection of joints in the underlying base	Crushed aggregate overlay or reconstruction of joints.

2.3.1.4 Transverse cracks

Transverse cracks are unconnected cracks running transversely (relatively perpendicular to pavement centre line) across the pavement (Figure 2.6). Severity levels of transverse cracks are:

Low	Cracks with low severity or no spalling; mean unsealed crack width of 3 mm or less; sealant material in good condition.
Moderate	Cracks with moderate severity spalling; mean unseals crack width of greater than 3mm; sealant material in bad condition.
High	Cracks with high severity spalling.

Measurements to be taken are width of predominant crack, length of dominant crack, spacing and area affected. The possible causes and probable treatments are as shown in Table 2.4

Figure 2.6: Photograph of transverse cracks

Table 2.4: Possible causes and probable treatments of transverse cracks

Sl.No	Possible Causes	Probable Treatments
1	Reflection of shrinkage cracks	Cut and patch
2	Construction joint in bituminous surfacing	Crack sealant
3	Structural failure of Portland Cement	Reconstruction of base
4	Shrinkage crack bituminous surfacing	Seal cracks or replace bituminous surfacing
5	Reflection of joints in the underlying base	Crushed aggregate overlay or reconstruction of joints.

2.3.1.5 Crescent shaped cracks

Crescent shaped cracks also known as parabolic, slippage and shear cracks. These types of cracks are half moon or crescent shaped cracks, commonly associated with shoving, often occurring in closely spaced parallel group (Figure 2.7). It is mainly associated with bituminous layer only. Severity levels of edges cracks are:

Low Cracks with no breakup or shoving.

Moderate Cracks with some breakup or shoving.

High Cracks with considerable breakup or shoving

Measurements to be taken are width of predominant crack, length of dominant crack, and area affected. The possible causes and probable treatments are as shown in Table 2.5.

Figure 2.7: Photograph of crescent shaped cracks

Table 2.5: Possible causes and probable treatments of crescent shaped cracks

Sl.No	Possible Causes	Probable Treatments
1	Lack of bond between wearing course and the underlying layers	Cut and patch
2	Low modulus bases course	Reconstruction of base
3	Thin wearing course	Bituminous overlay
4	Dragging of pavers during laying when bituminous mix temperatures were low	Cut and patch
5	High stress due to braking and acceleration movements	Bituminous overlay with stiffer mix or use high compaction mix.

2.3.1.6 Edge cracks

Edge cracks are also crescent shaped or fairly continuous cracks, parallel to, and usually within 300mm to 600mm on the pavement edge (See Figure 2.8). They usually occur when paved shoulders do not exist. Severity levels of edges cracks are:

Low Cracks with no breakup or raveling

Moderate Cracks with some breakup or raveling

High Cracks with considerable breakup or raveling along edge

Measurements to be taken are width of predominant crack, length of dominant crack, and area affected. The possible causes and probable treatments are as shown in Table 2.6

Figure 2.8: Photograph of Edge Cracks

Table 2.6: Possible causes and probable treatments of edge cracks

Sl.No	Possible Causes	Probable Treatments
1	Excessive traffic loading at pavement edge	Widen the pavement or strengthen the pavement edge
2	Poor drainage at pavement edge and shoulder	Improve drainage and shoulder
3	Inadequate pavement width which forces traffic too close to pavement edge	Widen treatment
4	Insufficient bearing support	Reconstruction

2.3.1.7 Rutting

Rutting is longitudinal deformation or deformation or depression in the wheel paths which occur after repeated applications of axle loading (See Figure 2.10). It may occur in one or both wheel paths of a lane.

A part from that, degradation of asphalt due to diesel spills on roads also resulted in longitudinal cracking and rutting. There are two types of pavement degradation due to diesel; rapid degradation (0-2 weeks) and residual degradation (> 2 weeks) (Brian Balwin, Onuma Carmody and Terry Collins 2004). Severity levels of rutting are:

Low — Rut depths of less than 12mm (measured under a transverse 1.2m straight edge).

Moderate — Rut depths of between 12mm to 25mm (may include slight longitudinal cracks).

High — Rut depths of greater than 25mm (may include multiple longitudinal or crocodile cracks).

The possible causes and probable treatments are as shown in Table 2.7.

Figure 2.9: Photograph of rutting

Table 2.7 Possible causes and probable treatments of rutting

Sl.No	Possible Causes	Probable Treatments
1	Inadequate pavement thickness	Strengthening overlay or reconstruction
2	Inadequate compaction of structural layers	Reconstruction
3	Unstable bituminous mixes	Replace or recycle bituminous surfacing or use stiffer mix
4	Unstable shoulder material which do not provide adequate lateral support	Shoulder improvement and overlay rutted area with bituminous surfacing.
5	Overstressed subgrade which deforms permanently	Reconstruction
6	Unstable granular bases or sub-bases	Base or sub base strengthening

2.4 Pavement Management System

A pavement management system consists of a coordinated set of activities, all directed toward achieving the best value possible for the available funds. This is an all inclusive set of activities, which may be characterized in term of major components or subsystems. A pavement management system must serve different management needs or levels and it must interface with the broader highway, airport, and /or transportation management system involved. Figure 2.10 shows a PMS consists of mutually interacting components as planning, programming, design, construction, maintenance, and rehabilitation.

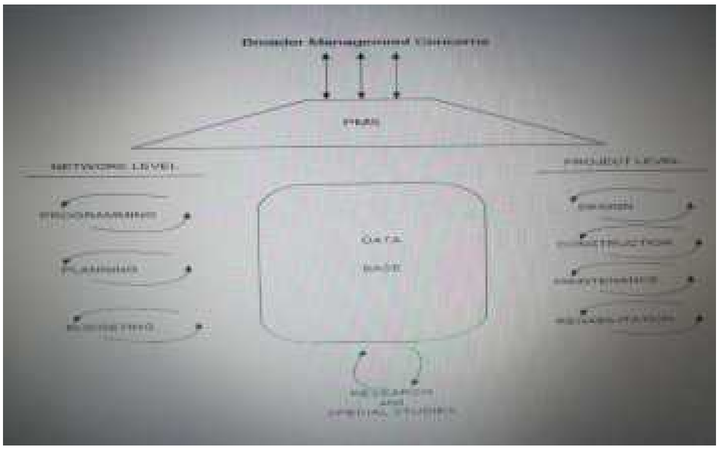

Figure 2.10: Major Component of a Pavement Management System (Hass *et al*. 1994).

However, the PMS components have important but changing impacts in terms of a level of influence. The concept shows that the effect on the total life cycle cost of a project decreases as the project evolves as shown in Figure 2.10. The lower portion of the Figure represents the length of time each major component acts over the life of a pavement. The upper portion shows increasing expenditures and decreasing influence over the pavement life. Expenditures during the planning phase are small compared with the total cost. Similarly, the capital costs for construction are a fraction of the operating and maintenance costs associated with a pavement life cycle. However, the decisions made during the early phases of a project have far greater relative influence on later required expenditures than some of the later activities.

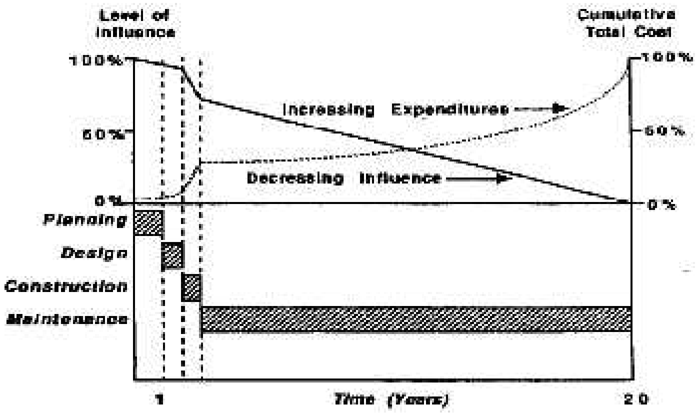

Figure 2.11: Influence Level of PMS Subsystems on the Total Costs (Hass *et al*. 1994).

Hass, one of the pioneers in PMS, said "Good pavement management is not business as usual, it requires an organized and systematic approach to the way we think and in the way we do day to day business. Pavement management, in its broadest sense, includes all activities involved in the planning and programming, design, construction, maintenance, and rehabilitation of the pavement portion of a public works program." (Hass *et al*.1994).

There is no solid agreement among most agencies and people who are working in the pavement field. However, there are definitions intended to provide a common and consistent basis for the use of certain fundamental terminology in the pavement field. Herein, some definitions have been stated by very well known agencies and people. According to the American Association of State Highway and Transportation Officials (AASHTO), "A 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" (AASHTO 2001). The Federal Highway Administration (FHWA) developed a clear definition of PMS "A set of tools or methods that can assist decision makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in serviceable conditions" (FHWA 1989). Haas, Hudson, and Zaniewski define a PMS as "a set of tools or methods that assist decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time" (Hass *et al.* 1994). To conclude, a PMS represents a strategy to manage a road network's needs to serve the users safely, comfortably and efficiently at least total cost and greatest benefit possible.

2.5 Pavement Evaluation

Evaluation is a key part of PMS because it provides the means for seeing how well the PMS components have been satisfied. The major types of pavement evaluation outputs versus time as shown in Figure 2.11 are measure of structural adequacy, measure of ride ability or serviceability, measure of surface distress, and measure of surface friction. In Figure 2.11, the surface distress output has reached a limit of acceptability before any of the other outputs. At this point, some rehabilitation measure has been implemented as shown by vertical discontinuity. The rehabilitation measure has been shown to affect the other outputs, such as improved surface friction, improved serviceability, and increased structural adequacy. The service life of the rehabilitation measures is ended by the serviceability reaching a minimum acceptable value. At this point, another rehabilitation measure has been applied and again the other outputs have been affected. Also, Figure 2.11 demonstrates that all the outputs of a pavement can reach a limit of acceptability one or more times during the life cycle or analysis period. Therefore, it can be concluded that the function of pavement evaluation in a PMS is measuring and assessing the mentioned four measurements in order to provide data for checking the design predictions and updating them if necessary, reschedule rehabilitation measures as indicated by these updated predictions, improve design models, improve maintenance practices, and update network programs (TAC 1997).

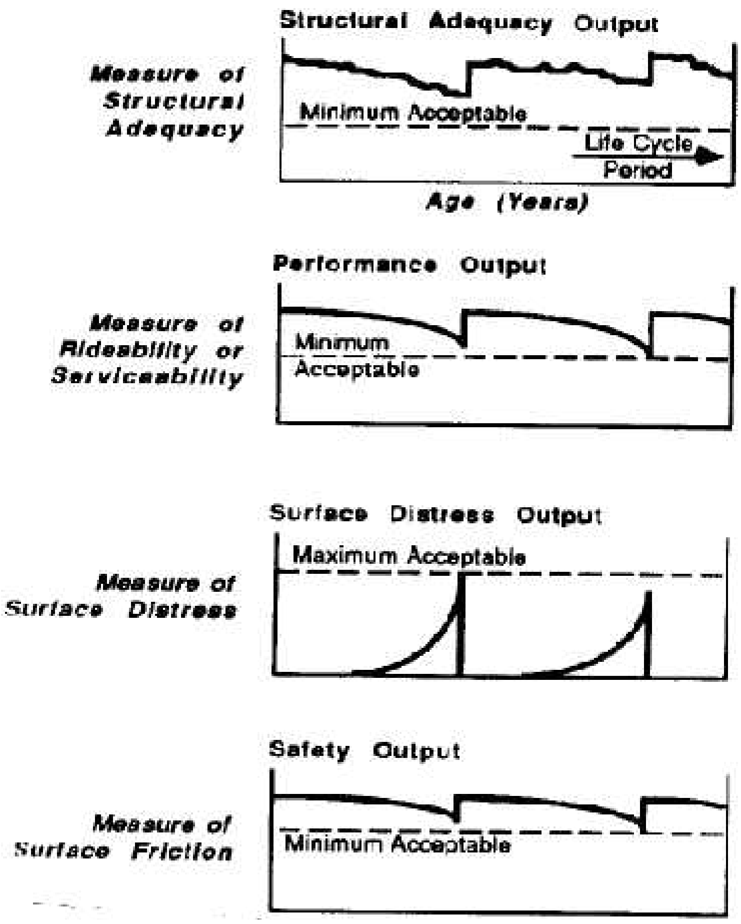

Figure 2.12: Major Types of Pavement Evaluation Outputs (Hass *et al.* 1994).

The uses of evaluation information are illustrated in Figure 2.12. The input variables include material and can be monitored by physical testing and sampling to provide direct information about layer thicknesses and material properties. Behavior can be defined as the immediate response of the pavement to load. Thus, deflection tests fall into this category. Distress can be defined as limiting response or damage in the pavement. Thus, the accumulated damage is monitored and evaluated. Performance can be defined as the serviceability history of the pavement, its evaluation accomplished by periodic measurements of the roughness which is directly related to user serviceability. Among the types of pavement evaluation, most agencies consider the following four as most important: serviceability, structural adequacy, surface distress, and safety. Safety is primarily in terms of surface distress and it is a user related measure. The other three considered in terms of functional behaviour using serviceability performance concept.

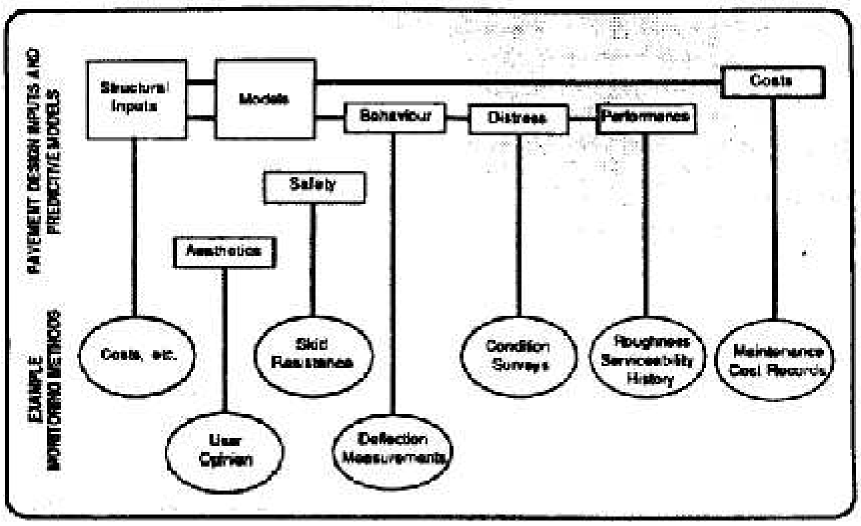

Figure 2.13: Simplified Prediction Portions of Pavement Design and Related Examples of Types of Periodic Evaluation Measurements (Hass et al. 1994).

2.6 The Need to Predict Deterioration

Models of road deterioration help to improve management, planning techniques, and give economic justification of expenditure and standards in the highways sector. Without adequate data, the road needs can't be quantified or evaluated accurately, and planning decisions tend to become short-term. It is important, therefore, to identify which parameters are essential and relevant for predictive models. Four major applications of predictive models will greatly help in identifying the modeling process and the data needs (Paterson, 1987). They are: planning policy and standards; pavement management; pricing and taxation; and verification of design methodologies.

Planning deals with forecasting the needs of the road network to assess the current and future condition and the demands on the network. Such questions as “at what stage should the pavement be resurfaced or strengthened”, “what should be the design life”, and “which project has priority”. Pavement management systems are being applied at regional or national levels to improve the planning and effectiveness of maintenance works and expenditures. Two basic elements are: An information system, comprising a database of network inventory, current and historical data, data for traffic volume and loading, maintenance works, and regular monitoring of the network to update; and a decision – support system, which analyses the data, and identifies current and future needs.

The majority of systems use predictive models to forecast future road condition, the timing, and the consequence of deferring maintenance. Some agencies use extrapolation models based on the historical trend of condition established in past regular condition surveys. Some use basic correlative models from whatever local performance data are available. In either case, the reliability of such models is low until a considerable history of data has been established. Predictive models which have been derived from a broad empirical base, and which use the current condition and physical parameters to estimate deterioration, are extremely valuable because they are versatile and relatively little effort is required to adapt them to local conditions. Pricing and taxation amongst various classes of road user involves two primary issues. First, the effects of vehicles and environment on road damage and repair costs are must be investigated. Second, the basis of costs must be determined and allocated. Verification of design methodologies has different forms and types. Engineering methods for designing road pavement and analyzing the effects of vehicle loading and climate on pavement condition have developed considerably due to the results of major road tests.

2.7 Predicted Parameters

Pavement condition prediction models can be developed to forecast condition in terms of one of the several different measures of condition. Sometimes models are classified based on what types of parameters they predict. Four common groupings include primary response, structural performance, functional performance and damage (Lytton 1987). In addition, these types of models can predict the impact of treatments on the condition of sections. Damage models are derived from either the structural or functional models. Damage is a normalized measure of distress, roughness, surface friction, or other measure of condition. In damage analysis, a damage number of 0 indicates no damage while a damage number of 1 indicates the maximum possible damage. Using damage allows predict the maximum and minimum levels into a single function or formula. In this study, the damage is available in terms of historical condition data such as distress density and pavement condition data.

2.8 Maintenance and Rehabilitation

It should be emphasized that properly designed and constructed pavement should provide many years of maintenance free service. Anyhow pavements have finite life, as they are susceptible to wear for several reasons. Many pavement managers use the pavement condition index (PCI) to track pavement distress over time and apply maintenance treatments. Pavements are usually maintained and/or rehabilitated when the PCI drops to a level of 40-60.

Pavements are costly not only to build but also to maintain. These costs are born by the owner funding the facility. Road users also cost a lot when operating their vehicles on deteriorated and poorly maintained roads. Hence, it is advisable to develop a definite action plan in order to keep asphalt road pavements in a continuous serviceable condition. The pavement maintenance problem is not simple. Many factors are involved that affect the performance of a pavement. Hence the type of maintenance that will be required for any particular pavement will depend on a number of conditions: the traffic system to which the pavement is subjected; Climate; the structure of the pavement; the quality of construction; the frequency and extent of inspection performed, both during construction and during maintenance; engineering talent involved, maintenance practices; discipline; and money; not necessarily in that order. In general, it is necessary to have the following in order to have the best maintenance program:

1. Organize the maintenance crew with experienced engineering and maintenance personnel.
2. Keep records of all pavement structures that are as precise as possible. These should include records of sub grade soils, sub base and base course, wearing courses and drainage system.
3. Arrange a pavement condition survey program to check and record the pavement condition at regular intervals.
4. Reviews and analyze the condition survey reports systematically.
5. Review the current maintenance methods to make sure that they are being carried out effectively.
6. Prepare work orders for preventive maintenance and to correct distresses investigated during the condition surveys.
7. Establish suitable timetable by prioritizing the projects.
8. Prepare realistic budgets and carry out the maintenance under the most favorable weather and traffic condition

2.9 Traffic Loading Effect

Traffic loading is considered as the primary factor that affects both pavement design and performance. Traffic loading characteristics include traffic volume, axle load, axle configuration, repletion of axle load, tyre pressure, and vehicle speed. The traffic loading in pavement design is well formulated and investigated whereas the method of using axle loads in PMS as a pavement condition prediction variable is still not well understood (Wijk, A and Sodzik, E 1998).

Since loadings are one of the most important factors that affects damages of most pavement section, it is often used as an independent variable in developed condition prediction equations. It is sometimes combined with age as an independent variable. Since in most circumstances, agencies want to know when in years, the pavement will need work, in some models loads are used as a factor that affects the rate of condition change as a function of time which is considered the independent variable. Few studies have discussed the effect of loading on pavement performance and how it should be used in PMS in an effective manner. For example, a new understanding of the traffic effect was investigated in the light of shake down load limit. If the pavement is subjected to a repeated load greater than the shake down limit, then the pavement will fail as a result of a result of the excessive plastic deformation, this indicates that if the design load is made more than the shakedown load limit, the pavement may gradually fail by the accumulation of plastic strain, resulting in a form of rutting and surface cracking. Excessive stresses and strain in asphalt surfaced pavement due traffic loading will eventually result in deformation and cracking (Shaiu and Yh, 2000).

According to Huang (1993), the critical tensile and compressive strains under multiple axles are only slight different from those under single axle, for example, the damage caused by the standard 18-kip (80 KN) is almost equal to the damage caused by the 36kip (160 KN)tandem axles or that of 54-kip (240 KN) tridem axles. According to AASHTO (1993), pavement distress propagation is associated with continuous traffic growth. The formulation of distress types leads to a failure in one the pavement components. AASHTO pavement design procedure requires traffic evaluation for both design and rehabilitation. Therefore, the accuracy of traffic volumes and weight is very important.

For example - Six pavement structures were analyzed where three of them are representative of Portuguese pavements, and three are representative of Brazilian pavements. It was performed a linear-elastic mechanistic analysis to determine two structural responses: horizontal tensile strain at the bottom of the asphalt layer and vertical compressive strain at the top of sub grade, associated to the most important pavement distress types in Portugal and Brazil, respectively fatigue cracking and rutting (Fernandes *et al*. 2005)

Axle load spectra plays a critical role in the impact of traffic on pavement performance. Weigh-in-motion (WIM) systems are becoming widely used as an efficient means of collecting traffic load data for mechanistic pavement design. The results of this study not only support for maintenance but also advance the existing research in this area. The findings of this study can be used to estimate pavement life prediction. They can also serve as guidelines for highway agencies for the selection of Weigh-in-motion (WIM) equipment and the establishment of criteria for equipment calibration.

CHAPTER III

Methodology

3.1 General

A research methodology should be described specifically and clear understandable so that it is possible to achieve the objectives of the research written in chapter one. The proposed methodology describes objective and procedure, Visual Distress Survey, Database Development, Model Parameter Definition, Model Formulation, Design of Experiment and limitations in the data collection.

3.2 Objective and Procedure

This research aims to develop pavement distress models for Jessore-Khulna National Highway (N7). In order to achieve the targets, the following descriptions were made to clarify the proposed methodology for this research:

The study focuses on National Highway only. This research investigates Part of Doulotdia-Faridpur-Magura-Jhinaidah-Jessore-Khulna-MonglaNational Highways (N-7). In general there is one standard policy for constructing the National Highways. For others road, there is a different standard. The reason behind this is the different functions of the roads. The typical cross section for the National Highways sections is shown in Figure 3.1. Since the construction policy is similar across the country, the selected road data will be data for research pavement sections which have homogenous pavement characteristics in terms of structure.

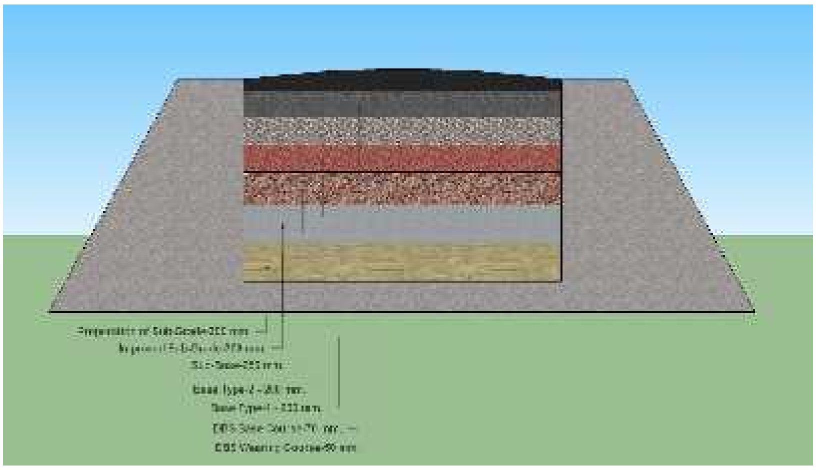

Figure 3.1: Typical cross section for the National Highway

This road was constructed by the Ministry of Road Transport and Bridges and Roads and Highways Department (RHD). Since RHD has constructed the road network across the country, the general procedure for construction is similar everywhere. A different design is used for severe conditions where necessary. These severe condition cases are very few and they represent a very small percentage of the network. Maintenance activities are almost the same across the country and usually the main activity is surfacing work. The pavement distress data was collected from the Road Management and Maintenance System (RMMS) unit of the RHD. Although the source of the data is RMMS, the objectives of the study are to develop deterioration models for the selected road. Therefore, to some extent the data can be generalized to develop pavement distress models. The distress data information contains; road name, road number, highway class, section number, sample number, survey date, maintenance data, Annual Average Daily Traffic (AADT), drainage, distress density, and distress severity. The distress types include Narrow Cracks, Wide Cracks, Patching, Potholes, Depressions, Rutting, Bleeding, Weathering & Raveling, Edge Breaking, Patching Depressions, Patching Potholes, Patching Weathering & Raveling. Only three types of maintenance have been applied on this road, namely deep patching, shallow patching, and thin overlay. However, most of the maintenance is overlay work. In this research, only data of overlaid surface were used. Overlay is considered since an overlay increases the pavement performance to its maximum. This ensures consistency with the assumption that the pavement condition is at its highest value of 100 immediately after the maintenance and before opening the road to the traffic. The pavement age is determined from the last major maintenance date, which is an overlay date. The factors considered in this study are common types of distress, percent of distress density, pavement age, traffic and drainage. The major types are pavement distress data. The pavement distress data are percent of distress density in the surveys for each distress, pavement age, traffic, and drainage. The pavement distress data sets are stored into a database. After building the required database, it will be subjected individually to two major steps. The first major step is that the database will be analyzed in terms of normality, and then a model factors significance test. The second major step is to build the distress models. Chapters 4, 5, and 6 deal with analyzing the data and modeling for the distress. Model determination and accuracy has been fixed by regression analysis. The developed models has been named as ”National Highway Pavement Distress Model (NHPDM)” .The developed model has been assessed against standard error. The coefficients of developed models has been analyzed in terms of regression analysis by SPSS. The flow chart in Figure 3.2 shows the activities of this research. The flow chart explains the major components of this study, namely developing the database after checking the data, developing the required models, and the validation process on the models, and finally the implementation of the models in the improvement of national highway network.

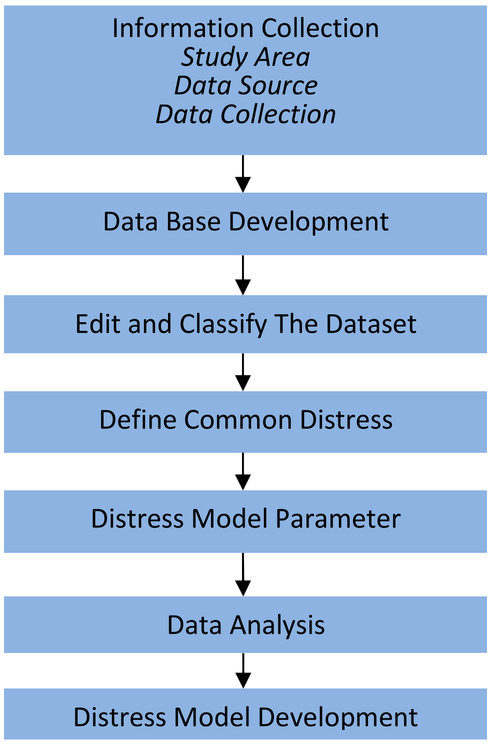

Figure 3.2: Flow Chart of the Research Methodology

3.3 Visual Distress Survey

The visual Distress survey was made in order to measure various types and degrees or severity of distress. The measured components were surface defects (such as cracks, potholes, raveling, rutting and edge cracking etc.), permanent deformation or distortion, fatigue cracking and patch deterioration. These evaluations were also necessary for defining, and subdividing sections of road in similar condition when the uniform sections were relatively short, the detailed condition survey can be best carried out over the entire length of the section. For time and resource limitation a maximum 5.0 km length of road was used for visual survey from the Jessore – Khulna (N7) highway . The condition survey procedure offers a method for identifying pavement distress types and defining the levels of severity and extent associated with each distress. The visual survey was made using commonly used recording formats and guidelines for determining pavement condition that involves observing and recording the presence of specific types and severities of defects or distresses on the pavement surface.

The procedure, followed for visual inspection of the road pavement, was recording distresses walking along the test road sections. Measurement of distresses using proper parameters such as cracking (sq.meter), bleeding (sq.meter), corrugation (sq.meter), depression (sq.meter), patch deterioration (sq.meter), potholes (number), raveling, weathering (sq.meter) and rutting (linear meter) was recorded on the data collection form.

Figure 3.3 shows the visual condition surveys on test road. The identified distress was quantified and recorded using the following estimators.

- Distress type - Identify types of physical distress existing in the pavement. The distress types are categorized according to their casual mechanisms (i.e. functional or structural).
- Distress severity - Estimating the distress items in three damage levels i.e. low (L), medium (M) and high (H) severity (as stated in AASHTO Guide). This assessment helps to estimate degree of deterioration.

• Distress extent - Denote relative area (percentage of the road section) affected by each combination of distress type and severity.

Figure 3.3: Visual Surveys on Test road

During the visual survey, the inspector walks over the road section, measure each data on the inspection sheet (Raw data is shown in Appendix B). The equipment used for this survey is measuring tape to measure distress lengths and areas, ruler to measure the depth of rutting or depressions and camera. One form was used for each sample unit (i.e. test section). Drainage condition surveys were also made as part of the visual condition surveys.

A five point assessment scale is used as follows:

1. Very good: where the shape and level of drains is as designed.
2. Good: where drainage functions can be easily fulfilled.
3. Average: where drainage condition is slightly impeded.
4. Poor: where drainage function is impeded due to sedimentation, vegetation or scour.
5. Very poor: drainage non-existent.

3.4 Database Development

To obtain generic models for selected road that can be utilized with a significant level of confidence, this study has covered all possible and accessible pavement sections that satisfy the research scope. The RMMS unit in the RHD is the only source for distress data. In this study, the obtained data from RHD have been checked for outlier cases. For this study, the dataset was developed through different steps are described as follows:

Some apparent outliers exist beyond the data range but all data was analyzed so that extreme values could be identified as part of modeling process. Only overlaid sections were included in the study to ensure that the initial pavement condition is close to 100. Section boundary modifications were as checked. Any section that had been merged with another due to any reason was removed to ensure accuracy for the selected sections used in building the research dataset. Maintenance ratio was also checked to ensure that most of the section had been maintained by overlay. Any section with less than 90 % was removed. The maintenance ratio is calculated based on maintenance area and the survey area for a given section. Any section was exposed to maintenance activities after the overlay date were removed. Any section satisfies the above four conditions was used to build the research work or the dataset for the research and can be considered as the original work in this study. Each section contains different number of sample unit depends on the geometry of the section. Each sample unit contains one or more than pavement distress type's record (type, severity, density).For the pavement distress index (PDI) dataset, the original work used the PDI of pavement section at given survey date by averaging the sample PDI values. This value has been used as one reading in the dataset. The other reading point for same pavement section was taken by same process but at different survey time. The dataset of the PDI models was built based on the above steps. This process is same for all sections of the road. For the pavement distress type's dataset, weighting values were used for each distress type and severity. These weighting values were developed for road maintenance and management system. The original work used the average for each distress types for severity level. The checked collected data have been summarized and tabulated to develop individual distress models for selected road. The collected data are detailed in chapter four. A brief description for database development in this research will be presented. However, the details will be given in chapter four. The number of pavement sections in the test road is more than 305. In this stage the data needs to be filtered and stored to remove irrelevant data. The data is then classified according to the mentioned parameters. The classification will be formatted to cover all possible cases. The possible cases depend on parameters that are under investigation in this study. In general, the parameters are; road class, traffic count, drainage condition, pavement condition values, distress types, and distress density of Bangladesh national roads network.

3.5 Model Parameter Definition

The model parameters depend on; the features of the study, the nature of the collected data, the requirements of the study, and the parameters that affect the behavior of the pavement. It was hypothesized that these parameters should include: distress type, distress severity, distress density, pavement condition, maintenance type, pavement age, highway class, traffic volume, drainage, and climate condition. However, not all parameters will be included in the process of modeling and chapter 4 and 5 covers this point thoroughly. The following is a brief discussion of these parameters:

Distress Type:

Development and implementation of a pavement distress survey procedure requires a clear definition of the distress type. During the research of the road, the research considers 13 distress types which are commonly observed on the Bangladesh road network and they are, Fatigue cracks, Block cracks, Longitudinal cracks, transverse cracks, Edge cracks, Patching, Potholes, Depression, Rutting, Shoving, Bleeding, Polishing and Weathering and Raveling. This study considered only the most common distress types on the Jessore – Khulna highway.

Distress Severity:

Distress types can take on a variety of severity conditions. Although these levels are subjective descriptions, they describe distinct categories of the progression of the distress type that relate well to rehabilitation needs. In general, the three levels of distress severity are; low, medium, and high. This study will consider these severity levels.

Distress Density:

The quantity of each type and severity level measured and expressed in convenient units. Density for distress types measured by the square meter is calculated as follows;

Density = (distress amount in square meters/sample unit area in square meters) * 100

Density for distress types measured by the linear meter is calculated as follows;

Density = (distress amount in linear meters /sample unit area in square meters) * 100

Density for distress types measured by number (potholes) is calculated as follows;

Density = (distress amount in square meters /sample unit area in square meters) * 100

Pavement Condition:

Any pavement condition assessment procedure establishes a standard critical threshold level below which the pavement is considered unacceptable and in need of major maintenance, and/or routine maintenance. In addition, a pavement condition assessment procedure permits ranking of roads according to their maintenance/rehabilitation needs. Pavement condition surveys collected over several years allows determination of the rate of deterioration of different pavement sections of the network. Furthermore, this helps the organization to modify or calibrate their prediction models.

Roads and Highways department uses Pavement Distress Index (PDI) to report the pavement condition. The PDI or other measures is based on visual distress data. The distress data basically consists of types, densities, and severities. The PDI is a composite distress measure derived from the 10 individual pavement distress types. Theoretically, the PDI ranges from 0 to 100 where 100 represent the highest performance point (Excellent). This index is calculated using the type, severity and quantity of each distress in a specific sample. The pavement section can be evaluated based on PDI using the following rating:

Table 3.1 : Rating of evaluation based on Pavement Distress Index

Score	**Rating**
0 - 39	Poor
40 - 69	Fair
70 - 89	Good
90 - 100	Excellent

Maintenance Types:

The options or the maintenance decisions which have been applied on the selected road in general and country road network in particular are; overlay, patching, crack sealing, potholes treatment and others. However, due to lack of information about the exact date of road network construction, the focus was only on overlaid road network as the overlay is a major maintenance and it will bring the pavement condition to the highest performance point. The researcher presumes that the pavement condition is 100 after applying the overlay and before opening the overlaid road to the traffic. Therefore, the pavement age can be defined.

Pavement Age (Last major maintenance date):

It is presumed that the overlay date is the starting point. Therefore, the pavement age, for pavements on road network start at the most recent overlay date.

Road Class:

In RMMS, three classes are defined: national highways, regional highways and zila roads. A national highway is 7.3 meters width in total of both directions with two lane. National highways represent about 17 % of the total network area in the country. On the other hand, others road represent about 82 % of the country network.

Traffic:

Pavement deterioration is highly affected by traffic volume and vehicle types. Average Annual Daily Traffic (AADT) data is available for highways. The traffic volume on zila roads is low. Traffic influences will not be included in this research.

Drainage:

This factor has been adopted on the grounds that the method of drainage could be important and have a significant impact on the pavement condition on the network. The availability of a drainage system can affect the condition of a pavement. Therefore, pavement sections are grouped into two groups: sections with a drainage system and sections without a drainage system. It is expected that pavement sections with a drainage system will have a better condition than pavement sections without a drainage system. Therefore, the study will consider the two conditions.

Climatic Condition:

The climate condition across Bangladesh is almost uniform in terms of temperature and rainfall.

Survey Date:

The inspector has to write the date of survey for each section surveyed to be recorded for future planning. The RHD surveys the network every year. This data is very important to study the progression of the deterioration.

Section Number:

A section is a division of the road; it has certain consistent characteristics throughout its area or length. The reference number is given by RHD to each section, starting from the beginning of the road under consideration. Section number depends on the district and region.

Sample Number:

A sample unit (number) is any identifiable area of the pavement section; it is the smallest component of the pavement network. Each pavement section is divided into sample units for pavement inspection.

3.6 Model Formulation

The main objective of distress models is to predict the distress density at any time and to determine the extrapolated quantities for a given pavement section. The developed models will help greatly in determining the effective timing of applying maintenance. There are different categories of modeling techniques. The mechanistic approach requires a huge detailed data base of structural, field, and laboratory testing, in addition to pavement characterization parameters, which generates difficult task. On the other hand, probabilistic modeling, such as the Markovian approach, depends primarily on very skilled and expert pavement engineers to develop transition probability matrices for different combinations of pavement condition. The empirical approach (regression modeling) is simple and easy compared to the previous techniques and does not require elaborate involvement of any mechanistic structural testing for the fundamental pavement responses, or engineering judgment, and it captures as many factors as available that affect the distress behavior.

3.7 Data screening

The purpose of conducting data screening is to identify data with errors and to examine how appropriate the data meet the assumptions of the intended analysis. In data screening, the first step taken is to find values outside the reasonable range for a variable and to determine whether they are real outliers or errors. Outliers are values that stand markedly apart from others in a batch (SPSS Inc., 1999).

According to Hair et al. (1998), outliers can be classified into one of four classes. The first class arises as a result of data entry error and should be eliminated or recorded as missing values. The second class of outlier is the observation that occurs as the result of an extraordinary event and a decision must be made as whether the event should be represented in the sample. If the event could be explained, then the outlier should be retained in the analysis and if not, it should be deleted. The third class of outlier comprises of extraordinary observations which have no explanation. These are the outliers most likely to be omitted. The final class of outlier consist of observations that fall within the ordinary range of values on each variable but are unique in their combination of values across the variables. In this situation, these observations should be retained in the analysis unless there is specific evidence that discounts the outlier as a valid data. Therefore, before further hypothesis testing is to be carried out, a decision must be made as whether to retain or eliminate an outlier judging not only from the characteristics of the outlier but also the objectives of the analysis.
For quantitative variable, stem-and-leaf diagrams can be used to identify outliers. It is useful to examine a stem-and-leaf diagram. In a stem-and-leaf diagram, gaps are exposed and the leading digits of each outlier are reported (SPSS Inc., 1999).

As for stem-and-leaf diagram, an example of the stem-and-leaf diagram generated for wide crack is shown in Figure 3.4.

```
Log Stem-and-Leaf Plot

 Frequency    Stem &  Leaf

     4.00      163 .  3333
      .00      163 .
     1.00      164 .  3
      .00      164 .
     1.00      165 .  3
      .00      165 .
     9.00      166 .  222222222
      .00      166 .
     2.00      167 .  22
      .00      167 .
     9.00      168 .  111111111
      .00      168 .
     4.00      169 .  0000
     7.00      169 .  8888888
      .00      170 .
     5.00      170 .  77777
      .00      171 .
     9.00      171 .  666666666
     3.00      172 .  444
      .00      172 .
     8.00      173 .  22222222
      .00      173 .
     2.00      174 .  00
     1.00      174 .  8
      .00      175 .
     7.00      175 .  5555555
      .00      176 .
      .00      176 .
      .00      177 .
     3.00      177 .  888

 Stem width:       .01
 Each leaf:       1 case(s)
```

Figure 3.4 : An example of stem-and-leaf diagram generated for wide crack.

As shown in Figure 3.4, a stem-and-leaf diagram is more informative about the digits of each number and show values that are identified as outliers. As seen in the stem-and-leaf diagram, the digits of each number are separated into stem and leaf and each part is listed under its respective head. In this case, the stem width is 0.01 and each leaf represents 1 case. In the end of the leaf column of the diagram, when the word *Extremes* is printed instead of a stem value, outliers are identified. They may be one or more outliers at either end of the distribution. A value is an outlier if it falls below the lower hinge minus 1.5 times the hspread or upper hinge plus 1.5 times the hspread.

After stem-and-leaf diagrams, histograms with normal curves overlaid are used to assess the distribution assumptions of individual variables. It is the simplest diagnostic test for normality. In hypothesis testing such as *F*–test and *t*–test, normality is required. Normally distributed variables are also important particularly in regression analysis because if it were used to predict one variable from another, it will yield poor results due to highly skewed variables. For larger data sets, the values of mean, 5% trimmed mean and mean are compared and if they differ significantly, then the distribution is skewed.

3.8 Assessing the distribution of data

Apart from assessing the distribution graphically, statistical measures such as skewness and kurtosis can be used to check for normality. Skewness measures the symmetry of the sample distribution while kurtosis measures its peakedness. These measures are centered at zero. However, even for samples from a normal distribution, these values fluctuate around zero (SPSS Inc., 1999).

Nevertheless, a large positive value of skewness indicates a long right tail and an extreme negative value of skewness indicates a long left tail. Similarly, a large positive value of kurtosis indicates that the tails of the distribution are longer than those of a normal distribution and a negative value indicates shorter tails. However, skewness and kurtosis are sensitive to inconsistencies in the distribution and therefore should be studied in combination with histogram, boxplot or stem-and-leaf diagram.

3.9 Model development

In SPSS, more than one curve estimation regression models can be tested. If the variables appear to be related linearly, then a simple linear regression model will be used. However, if the variables are not linearly related, then data transformation might be able to solve the problem. When a transformation does not help, a more complicated model may be needed. The models that are available in the Curve Estimation procedure are as shown in Table 3.2.

Table 3.2 : Models available in the Curve Estimation procedure

Model	Form of Equation	Alternate Form
Linear	$y = \ _0 + \ _1x$	-
Logarithm	$y = \ _0 + \ _1 \ln(x)$	-
Inverse	$y = \ _0 + \ _1 / x$	-
Quadratic	$y = \ _0 + \ _1x + \ _1x^2$	-
Cubic	$y = \ _0 + \ _1x + \ _1x^2 + \ _1x^3$	-
Power	$y = \ _0(x^{\ _1})$	$\ln(y) = \ln(\ _0) + \ _1 \ln(x)$
Compound	$y = \ _0(\ _1^x)$	$\ln(y) = \ln(\ _0) + x \ln(\ _1)$
S	$y = e^{(\ _0 + (\ _1 / x))}$	$\ln(y) = \ _0 + \ _1 / x$
Growth	$y = e^{(\ _0 + (\ _1 . x))}$	$\ln(y) = \ _0 + \ _1 . x$
Exponential	$y = \ _0 . e^{(\ _1 . x)}$	$\ln(y) = \ln(\ _0) + \ _1 . x$

3.10 Limitations in the Data Collection

The whole pavement evaluation data were collected in two years and six months time, i.e. from October, 2012 to March, 2015. As a result all collected pavement performance data could only give accurate information during that time. On the other hand, some portion of the analysis such as determining predominant distresses in the network, developing functional relationship between different pavement distresses, pavement response variables and material properties require long historical data and other details as noted below:

Total service time of each test toad, total load repetitions that the test sections sustained until the time of investigation, historical data of measured distresses categorized at different seasons of the year, design details of each pavement structure and the sub grade material, detail information regarding maintenance history of each test section and seasonal data about moisture fluctuation on each test road. Generally speaking, collection of the above relevant data would only be much easier on experimental test sections that are carefully made in such a way to reasonably model the road network under study. In view of such remarks, one can understand that the analysis and findings of this research couldonly be considered as an initial assessment that may serve as a springboard to further carry out detailed assessment within the Bangladesh road network.

CHAPTER IV

Distress Assessment and Dataset

4.1 General

This chapter describes the role of the database in a pavement management system (PMS). This chapter also contains study area, the network and the sampling, raw data of pavement condition surveys, pavement distress surveys, distress density and calculation and data analysis.

4.2 Study Area

The national highway N7 passes through several districts. The selected portion of this highway for the research is within two districts namely Jessore and Khulna under Khulna division. It is southern area of the country. The starting chainage of the research road is 154 Km and end chainage is 215 Km among the total length of the highway 251 Km.The most reliable and the comprehensive data set were found from RHD. Thus, it was decided to use RHD pavement distress data and visual data only for this research.

4.3 The Network and Sampling

The purpose for obtaining pavement distress models, for research road, that can be utilized with a significant level of confidence, the study covered all accessible pavement ranges of Bangladesh road network. The roads of Bangladesh are classified into three categories; National highway, Regional highway and Zilla road section. National highway section is defined as the roads with total width of 7.3 meter with two lanes both direction without Middle Island. The study road is divided into a number of sample units. A sample unit for the road is 200 meter length with full width of 7.3 meter. The data were collected based on pavement distress which were surveyed by RHD several times. The developed dataset includes information extracted from different surveys. Only information that are required or needed in this research were summarized and tabulated. The General directorate of operation and maintenance of road is subjected to RHD. It was the main source contacted to collect the data for Road Network. The data were collected through the RMMS unit. The RHD updates surveying the network from time to time. Several surveys were completed for roads of the country. The research included all accessible data regarding the distress survey rating for selected road. Therefore, information regarding the network and the sampling was presented before describing the collected data and developed dataset. The several important parts of the country are connected with capital city Dhaka by national highways and also the important places such as land port, sea port etc are connected by national highways and regional highways. Districts and others areas of the country are connected by the zilla road. The study included national highway from the entire network. The national highway on the network represents 16% of the total network and the others represent 84% of the total network. The total network makes up more than 3500 national highway sections and more than 17900 others section (www.rhd.gov.bd). However, the study covers sections that meet the study criteria to develop the required dataset. Figure 4.1 shows the percentage of the national highways and others sections.

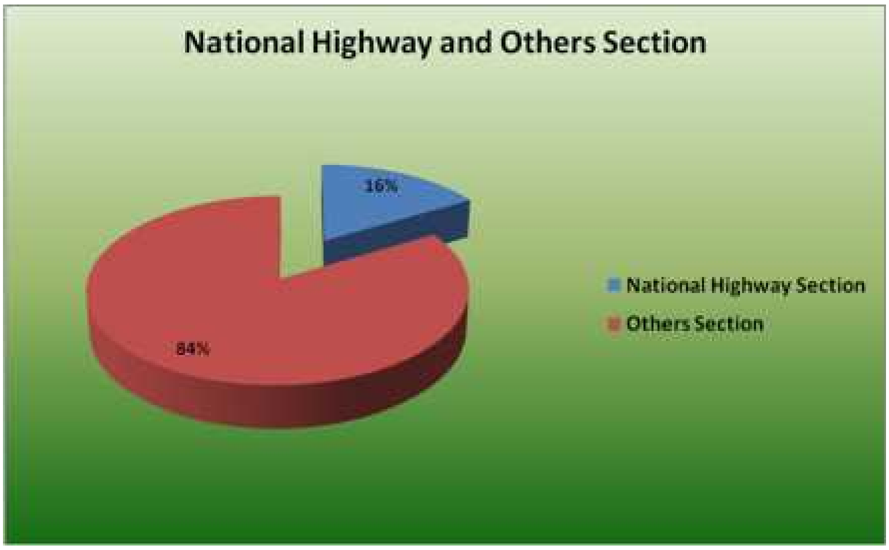

Figure 4.1: Percentage of the national highway and others sections.

4.4 Raw Data of Pavement condition Surveys

The raw data of obtained distress survey contain much information. The raw data information contains highway number, region name, sample number, road chainage, district name, sample date, sample length, sample width, sample area, number of lane, distress area, distress severity level and distress density,. There are many manuals identifying and describing the types of flexible pavement distress. For example, the federal highway administration (FHWA) identified 15 types (FHWA 2003), American Association of State Highway and Transportation Officials(AASHTO) identified 15 types (AASHTO 2007), the PAVER system identified 19 types (Shain 2002), and Washington department of transportation identified 17 types (WSDT 1998), Ontario Ministry of Transport identified 23 types (MTCO 1989), and British Columbia Ministry of Transport identified 12 types (BC 2009). However, in Bangladesh road network, According to RHD there are nine types were most frequent and they affect the performance of the network. Table 4.1 shows the classification groups of the distress, distress names, and the distress codes. Distress sample codes are from D1 to D9.

Table 4.1: Distress on Roads Network of The Country.

Groups Name	Distress Names	Code
Cracking	Narrow Crack	D1
	Wide Crack	D2
Potholes	Potholes	D3
Surface Deformation	Depression	D4
	Rutting	D5
Surface Defects	Weathering and Raveling	D6
	Bleeding	D7
Patching	Patching	D8
Edge Breaking	Edge Breaking	D9

Since the purpose of this study is developing pavement distress models, it is important to see which of the above distress types are more frequent on the highways. The most frequent distress types that have been detected in the study area for the selected road are shown in Table 4.2. They are Narrow Crack, Wide Crack, Potholes, depressions, Ravelling and Rutting out of the nine distress types.

4.5 Pavement Distress Surveys

The visual inspections of the N7 highway was conducted in this study. 13 nos. distress types were monitored and inspected. The degree of pavement deterioration is a function of distress type, distress severity, and distress density. The data collected for distress evaluation included the followings:

- Distress Type
- Distress Density, and
- Distress Severity

Table 4.2: Common Distress Types on Highways

Distress Names	Code
Narrow Crack	D1
Wide Crack	D2
Potholes	D3
Depression	D4
Rutting	D5
Raveling	D6

A special manual was developed for Road Distress Index methodology, procedure and calculations to enable collection of appropriate road distress data. Moreover, a team of inspectors from the RHD was given an extensive short course on this System. Each inspector was then sent to a particular region of the network to record the existing distress types, quantities, and severity for each sample unit within that region. Collection of this information was performed by the inspector walking through the selected road and recording the distress types, quantities and severity. A distress evaluation form was designed, through RMMS, for each sample unit in the road section. Since each calculated distress density corresponded to a certain distress severity level, a combined value was calculated based on a weight factor for each severity level. These weight factors are listed in Table 4.3 . These weight factors have been used based on the idea of deducting points used by RMMS and the PAVER system. Since patching has assigned only low severity level, the weight factor is 1.

Table 4.3: Weight Factors for Different Severity Levels on The Highways

Weight Factors for Different Severity Levels				
Distress Names	Code	Low severity	Medium Severity	High Severity
Narrow Crack	D1	3.0	4.0	4.5
Wide Crack	D2	2.0	3.0	4.0
Potholes	D3	4.0	4.5	5.0
Depression	D4	2.0	3.5	4.0
Rutting	D5	2.0	2.5	4.0
Raveling	D6	2.0	2.5	3.5

4.6 The Impact of Weighting Factors

The previous Table 4.3 suggests weighting factors for each severity level. Distress is one of the primary measurements of pavement condition. Thus, in a pavement evaluation program, distress type, severity, and extent should be properly identified. The pavement distress index (PDI) calculated mathematically combining the effects of distress types on pavement conditions. Before the calculation of PDI, each distress attribute must be assigned a weight factor and a severity factor. RHD used subjective rating values of distress attributes to a rational weighting scale that provides quantified measurements of the effects of each distress on pavement damage. These weighting factors were based on Micro Paver, and experience of engineers. Through the analysis and calculation of a PDI value, it was found that pothole has the largest weight factor (5) and patching has the lowest (1) for national highways. The severity factors vary from 1 to 5, depending on the distress type and severity level. For instance, a sample unit in a pavement section has one high severity of potholes could drop the quality of a pavement section 5 times a pavement section has distress of Raveling.

4.7 Distress Density and Calculation

The following example shows how the distress density and the PDI are calculated. A pavement section has the following information: asphalt concrete, National highway, area of 36500 square meters, 25 number of sample units in the study section, and a team surveyed 25 sample units as follows:

The distress density calculation was discussed in chapter three as follows (RRM 1998b):

Density for distress D1, D2, D3, D4, and D6 is measured by the following formula

Density = (distress amount in square meters/sample unit area in square meters) * 100

Density for distress D5 measured by the following formula

Density = (distress amount in linear meters /sample unit area in square meters) * 100

The density of common pavement distress is as shown in Appendix A

4.8 Data analysis

There is wide range of research design and methods are available. These methods are broadly classified into two categories : qualitative and quantitative. Qualitative methods are more committed to research in everyday setting, to allow access and to minimize reactivity among the subjects. Qualitative methods also enable explanation by understanding. Quantitative methods, on the other hand, involve the generation and use of data in form of numbers, figures and illustration, usually includes physical or statistical control to allow the testing of hypothesis and analyzing. For this study, qualitative and quantitative methods have been used so that the objectives will be achieved through the selecting and analyzing data from the several of sources and aspects. The summary of the study are then presented with the recommendations along with the conclusion for further studies in this area.

CHAPTER V

Maintenance and rehabilitation Alternatives

5.1 General

This chapter represents the options for maintenance and rehabilitation. It shows factors affecting pavement deterioration**,** priority of maintenance and methods of maintenance.

5.2 Significant Factors Affecting Pavement Deterioration

The selection of independent variables for the prediction equation is based on experience suggesting that the prediction of pavement condition depends on the following factors: pavement age, traffic volume, and availability of a drainage system. Therefore, in this study, pavement deterioration recognizes three factors in defining distress propagation. However, the three factors will be subjected to tests of significance to determine the significant factors for distress models. As a basic principle, the form of the model is selected based on the boundary conditions and/or other variables that govern the deterioration of the pavements
(Chen et al. 1995, Hajek and Hass 1987, Prozzi and Madanat 2004, and Vepa et al. 1996).

5.3 Priority Setting Procedure of Maintenance

The methodology of setting up a maintenance priority procedure depends on quantitative and qualitative factors. There are many priority programming methods ranging from simple subjective ranking to true optimization. One of the traditional practices of setting up maintenance priority is to list in a descending order all network roads that need maintenance. Priority is based on engineering and subjective judgment by help of pavement condition value. This approach might work for small network and sufficient budget. However, an approach insures the right treatment to the right pavement at the right time is not simple (Haas et al. 1994) because all possible combinations of the three points must be evaluated.

However, this study suggests a maintenance priority procedure. The idea of this suggestion is based on pavement condition models, traffic volumes, road classification, maintenance programs database, effectiveness of maintenance types, and cost of maintenance types. If a road agency has ability to have reliable information on all the five factors, the priority can be solved to a reasonable degree of acceptance. General speaking, the first and foremost important factor is pavement condition, a road needs high priority of maintenance if its condition poor. Therefore, pavement condition value is inversely proportional to maintenance. Using traffic volumes as Average Daily Traffic (ADT) in setting up the maintenance priority is vital and very practical especially those roads which have good condition because the ADT represents how busy the road is. Thus ADT range must be established. Table 5.1 gives a traffic factor for each ADT range. Road class has impact upon maintenance decision since main roads are more important than secondary roads. Table 5.2 gives a class factor.

Table 5.1: Traffic Factor (Modified from Al-Swailmi and Al-Abadwhab 2001)

Traffic Factor (TF)	
ADT Range	Value
0-100	10
101-500	20
501-1000	30
1001-2000	40
2001-5000	50
>5000	100

Table 5.2: Road Classification Factor (Modified from Al-Swailmi and Al-Abad Whab 2001)

Road Factor (RF)	
Class Road	Value
Main	1.2
Secondary	1.1

As discussed previously, maintenance programs contain certain types of maintenance. Each has expected life on the pavement condition and has cost as well. Availability of precise database on maintenance leads to increased maintenance efficiency and better utilization of resources. On the other hand, in the absence of proper database on maintenance, maintenance depends on existence surface condition of pavement. Therefore, Table 5.3 gives factor value for this issue to account for the amount of past maintenance that have been taken place The effectiveness of maintenance is very important factor in proper priority setting since it is more feasible to implement the most effective maintenance activity than activities otherwise. Also the cost is important factor. Cost effectiveness factor has been assigned for each. Table 5.4 shows the suggested values for cost effectiveness factor.

Table 5.3: Maintenance Record Factor (Modified from Al-Swailmi and Al-Abad Whab 2001)

Maintenance Factor (MF)	
Past Maintenance	Value
No	1.0
Poor	1.1
Fair	1.2
Moderate	1.3
High	1.4
Very High	1.5

Table 5.4 Cost Effectiveness Factor

Cost Effectiveness Factor (CEF)	
Maintenance Programs	value (Effectiveness)
Corrective	1
Preventive	2
Structural Overlay	3
Reconstruction	4

Or alternatively the cost effectiveness factor can be calculated as follows:

CEF= (Pavement Condition x t)/ C

This equation has been modified from Transportation Association of Canada (TAC 1997),

where

Pavement Condition = Difference between pavement condition after and before activity application,

t= Expected life for a maintenance type,

C= Maintenance activity unit cost.

Pavement condition and t can be obtained from performance curve if the road agency has theses curves (this study does not cover these curves due to lack of data), or can be estimated from the developed prediction curves UMPCM and USPCM, or can be estimated from experience. However, for time being, the cost effectiveness will be excluded from maintenance priority procedure till a good database can gives the anticipated effect of a maintenance type, and the expected life for a maintenance type.

Based on that, maintenance priority can be calculated as follows:

Maintenance Priority (MP) = (TF x RF x MF)/ Pavement Condition

The TF, RF, and MF can be obtained from the suggested Tables and the pavement condition value can be obtained from the developed models. Higher values of MP indicate higher priority, means the maintenance budget is first allocated to pavement sections according to MP list. When the allocated budget is not sufficient for all sections, the remaining sections are deferred to the next year.

5.4 Methods of Maintenance

Major maintenance methods to be applied for non-load associated distresses comprises the following: crack sealing, skin patches, partial and full depth patches, pothole patching, surface sanding, surface treatments, fuel resistant seals or overlays, or porous friction course.

5.4.1 Maintenance of Cracking Type Distress

Maintenance methods for cracking type distresses vary depending on the type of crack, which in turn is an indicator of the cause.

(i) Alligator cracks maintenance

The maintenance should include removing the wet material and installing appropriate drainage. Full depth asphalt patching is necessary for having a strong and dependable repair. When necessary, temporary repairs can also be made by applying skin patches or aggregate seal coats to the affected areas to avoid any further damage to the pavement.

(ii) Edge Cracks

Poor drainage will aggravate edge cracking by causing settlement or yielding of the material underlying the cracked area. Hence improving drainage by installing under drain is necessary, in those areas where drainage facilities don't exist, before repairing the cracked surface.

(iii) Wide Cracks Maintenance

Cracks bigger than 3mm in width can be filled with asphalt mixed with fine sand.

(iv) Slippage Cracks

The proper method of repairing a slippage crack is by removing the damaged surface layer and patching the area with plant mixed asphalt material after applying a light tack coat.

5.4.2 Maintenance of distortion type distresses

Distortion types distresses are characterized by a change of the pavement surface form its original shape. Lack of proper compaction, excessive fines in the mix, too much asphalt, swelling of underlying courses, or settlements are major causes of distortion. Distortion takes a number of different forms: grooves or ruts, showing corrugations, depression and upheaval. The type of distortion and its cause must be determined before the correct remedy can be applied.

i. Ruts

It is necessary to repair such distresses by applying light tack coat and spreading asphalt concrete in the channel since rutting can be aggravated and lead to major structural failures and hydroplaning.

ii. Corrugations and shoving

Corrugations in a thick asphalt surface can be repaired using a pavement planning machine and shoved areas can be repaired using deep patch like for the alligator cracking.

iii. Depressions

Two or more layers of asphalt are required in the repair of deep depression. Filling the area by following the contour of depression is mostly mistakenly done. The correct way to repair a deep depression is to begin in the deepest part of the depression and place a thin layer, the surface of which, when compacted, will be parallel to the original pavement surface. Successive layers can be placed in the same manner. Figure 5.1 shows the correct and incorrect way to place asphalt backfill in a deep depression.

Correct way **incorrect way**

Figure 5.1: Back fill in deep depression

iv. Swell

Swelling can be repaired using deep patch as alligator cracks.

v. Utility cut depressions

The repair method is the same as for depressions.

5.4.3 Maintenance of disintegrating type distresses

Disintegration type distresses are characterized by the breaking up of a pavement into small loose fragments. This includes the dislodging of aggregate particles. If not repaired at its early stage, it can progress until the pavement requires complete reconstruction. The two common types of early stage disintegration are potholing and raveling. Repair ranges from simple seals to deep patches.

i. Potholes

For best results, all materials for filling potholes must meet appropriate and approved standards. Proper preparation and backfilling are very important. This can be done using asphalt cutter, jack hammer, chisel and other hand tools. The sides of cut surface have to be vertical and base. The base materials should be replaced with equal or better material than that removed or with bituminous material. The hole should be primed before placing and compaction of the bituminous material. It is advisable to overfill the bituminous material by around 40% of the pavement thickness to allow for compaction. Figure 5.2 shows the steps to be followed for permanent repair of potholes .

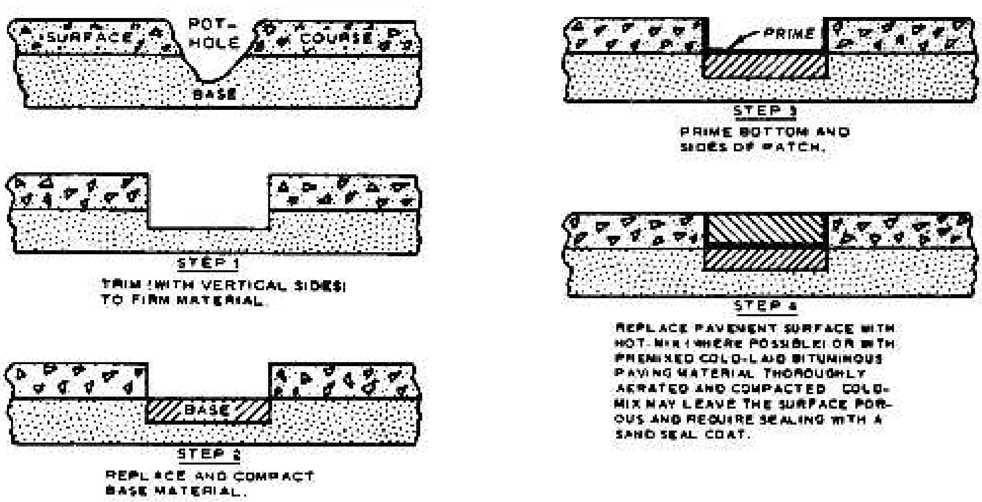

Figure 5.2: Steps to be followed for permanent repair of potholes

ii. Raveling

Raveling surfaces usually require a surface treatment that can be looked upon as corrective or preventive maintenance. The type of surface treatment can be selected depending on the extent of damage and nature of traffic.

5.4.4 Summary of maintenance & repair alternatives

The pavement maintenance in general consists of all the routine repair tasks necessary to keep the pavement, under normal conditions of traffic and normal forces of nature, as nearly as possible in its as-constructed condition. All distress types and their corresponding method of maintenance and repair is as shown in Chapter-2 .

5.5 Major Rehabilitation Methods

As already discussed in Chapter-2, that type of distress is the result of one or more causes, which when properly identified, provide good indication about the type of rehabilitation work that is required. Several factors such as level of surface distress, structural condition, and functional condition of the existing pavement must be considered when proposing rehabilitation methods of both overlay and non-overlay types. Only structurally adequate pavements or pavements restored to structurally adequate condition are candidates for maintenance and rehabilitation without overlay. On the other hand, pavements having distresses of load associated type surely require overlay type rehabilitation or otherwise complete reconstruction. Hence, more attention has to be given for the structural evaluation (i.e. the deflection and DCP tests) results before deciding the most feasible and effective rehabilitation method. Rehabilitation may range from complete pavement reconstruction to the improvement of provision of some elements such as drainage facilities. Many rehabilitation methods often provide only for the design of asphalt overlays which, in some cases are not the most suitable options. Hence, identifying the cause of distress should be made before selecting rehabilitation option . The detail techniques for rehabilitation without overlay are more or less similar to methods of maintenance as discussed in Section 5.2 above. Hence, rehabilitation methods with overlay are only discussed in this Section. Preliminary pavement thickness requirement for test road showing severe structural inadequacy is also checked to propose rehabilitation alternatives for the same.

5.5.1 Rehabilitation Method with Asphalt Overlays (structural)

One of the following two approaches can be employed in order to check the rehabilitation requirement on the test roads:

a. Deflection Approach

This approach applies the remaining pavement life concepts. It considers the magnitude of distress within the existing pavement versus the terminal serviceability level within overlaid pavement. Non-destructive deflection tests are used for estimating the in-situ pavement structural condition. The differences in structural capacity between what is needed for the future overlay period and what is effectively available in-situ at the time of the overlay represents the additional structural capacity required. The following steps can be followed for determining the overlay thickness and structural adequacy evaluation :

1. Determine the representative rebound deflection (RRD) by the Benkelman deflection test.
2. Estimate the EAL (equivalent axle load) that the pavement will be required to support in the future after overlay. The traffic volume estimate can be done using actual counts, existing data or by estimating using traffic classifications.
3. Enter the overlay thickness chart at the RRD determined in step 1 and EAL determined in step 2 to get the overlay thickness required.

b. Effective Thickness Approach

This approach applies the concepts that pavement reduces life upon exposure to traffic for extended periods of time. By the time distress conditions appear on the surface of the pavement, a certain amount of the useful life of the pavement has been utilized and this must be accounted for in the design process. This approach considers that as a pavement uses part of its total life, its effective thickness becomes less and less. The effective thickness of an existing pavement can be determined considering composition of each pavement layer, their thickness and the nature of the sub grade. The following steps can be followed for calculating overlay thickness on an existing asphalt concrete surface on unbound base:

1. Collect soil specimen to determine the strength values using the resilient modulus or socked CBR.

2. Estimate the design EAL.

3. Calculate effective thickness of the existing pavement layers using conversion factors for each pavement layer. The conversion factor can directly convert each layer thickness to equivalent thickness of asphalt concrete. The total effective thickness for the existing pavement structure is the sum of the effective thickness of all layers.

4. Estimate the full depth Asphalt concrete using design charts by entering the data's obtained in steps (1) & (2) above.

5. Get the overlay thickness by deducting the effective thickness (step 3) from the full depth asphalt (Step 4)

5.6 Summary of Maintenance & Rehabilitation Options on Test Road

As already discussed earlier, there are numerous pavement maintenance and rehabilitation alternatives to make good defects identified through different stages of condition surveys. It should be noted that maintenance options for localized surface defects can be directly done as prescribed earlier in section 5.2 provided that the pavement is structurally adequate to withstand the loading, environmental and other effects it has encountered. On the other hand, it is nothing but wastage of resource to maintain those pavements, without strengthening the structure and provision of necessary drainage facilities, where structural failures are observed during condition surveys. The maintenance options already discussed but for rehabilitation options it needs to collect more data related pavement present condition from field. Those have not been collected in this research, so providing rehabilitation option was avoided.

CHAPTER VI

Results and Discussion

6.1 General

In this study, the statistical analysis programme, SPSS Base 16.0 was used. It is a comprehensive system for analysing data and can take data from almost any type of file, edit them and use them to generate tabulated reports, charts, plots of distributions, trends and descriptive statistics, and carried out complex statistical analyses (SPSS Inc., 1999). It is relatively easy to use and no computer programming expertise is required. This chapter includes distress prediction equations and determination of co-efficient for narrow crack, wide crack, potholes, depression, rutting and ravelling distress model.

6.2 Distress Prediction Equations

Linear and Nonlinear regression models were tested and evaluated. These were linear models, Logarithmic models, Inverse models, Quadratic models, Cubic models, compound models, Power models, S-curve models, Growth modes, Exponential models and Logistic models. Among those the S curve model has been chosen for this research, because it is the one which can suit the research methodology. The S curve model represents the evolution of technology performance clearly. Its capacity to analyze technological performance potential makes the model a useful tool for designing technological strategies. This model, initially conceived by Foster (1986), director of the consulting firm McKinsey, has received widespread acclaim in the field of technology management. There is a great deal of empirical evidence that the S curve reveals the general evolution process of the performance of technologies and that finding systematically repeats itself in various sectors. In addition to the original works of Foster (1982, 1986) other authors have developed theories with effective data. Lee and Nakicenovic (1988) have analyzed substitution phenomena among different technologies as they are employed in the transportation sector. Therefore, if the performance parameter is defined adequately, the S curve model would provide reliable analysis from which significant recommendations for the design of technological strategies could be derived.

For comparison, regression analysis was performed using data of six distresses in this study and the values of R-square of different models were evaluated which are as shown in Table 6.1.

Table 6.1 : Evaluation of the values of R square among different models after regression analysis.

	Narrow Crack (R square)	Wide Crack (R square)	Potholes (R square)	Depression (R square)	Rutting (R square)	Raveling (R square)
Linear	0.541	0.483	0.403	0.734	0.555	0.615
Logarithmic	0.554	0.463	0.419	0.701	0.551	0.608
Inverse	0.546	0.429	0.417	0.647	0.528	0.578
Quadratic	0.554	0.485	0.420	0.738	0.557	0.616
Cubic	0.554	0.485	0.420	0.738	0.557	0.616
Compound	0.543	0.484	0.406	0.725	0.552	0.612
Power	0.561	0.468	0.425	0.704	0.558	0.613
S	0.556	0.437	0.427	0.661	0.543	0.591
Growth	0.543	0.484	0.406	0.725	0.552	0.612
Exponential	0.543	0.484	0.406	0.725	0.552	0.612
Logistic	0.543	0.484	0.406	0.725	0.552	0.612

This evaluation indicates the suitability of S curves in modelling to represent distress predictions. In this study S curve for each distress model was selected for uniformity though the R-square value for depression, rutting and revelling was lower than the other linear and non-linear model.

6.3 Determination of co-efficient for narrow crack distress model

The general form of regression equation (S-curve equation) for narrow crack distress model is as shown in Equation 6.1 .

$$y_n = e^{(\beta_0+(\beta_1/x_n))} \qquad (6.1)$$

Where,

y_n = Narrow Crack Distress (sq.meter)

β_0, β_1 = Parameter to be estimated by regression analysis using the statistical software,SPSS.

X_n = Year

The use of statistical software is needed for determination of co-efficient for narrow crack distress model. The raw data is shown in appendix has been used as the input data in SPSS. The data was used for outliers. Stem-and-leaf diagram for the dependent variable, y_n (the narrow crack distress) has been generated to check for outliers. The stem-and-leaf diagram for y prior to data regression is as shown in Figure 6.1. Upon checking outliers, histogram was generated to check normality. The histograms plotted after data generating are as shown in Figure 6.2. The histogram generated prior to data regression shows symmetrical and indicate a normal distribution.

```
NarrowCrack Stem-and-Leaf Plot

 Frequency    Stem &  Leaf
     4.00       39 .  0000
     1.00       40 .  0
     1.00       41 .  0
     8.00       42 .  00000000
     2.00       43 .  00
      .00       44 .
     4.00       45 .  0000
    11.00       46 .  00000000000
     4.00       47 .  0000
     8.00       48 .  00000000
     5.00       49 .  00000
     5.00       50 .  00000
     8.00       51 .  00000000
     2.00       52 .  00
     1.00       53 .  0
     7.00       54 .  0000000
     1.00       55 .  0
      .00       56 .
     3.00       57 .  000

 Stem width:       1.00
 Each leaf:        1 case(s)
```

Figure 6.1: Stem-and-leaf plot of y_n (the narrow crack distress) prior to data regression

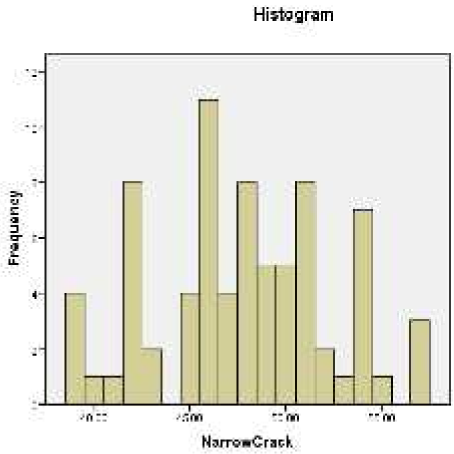

Figure 6.2: Histogram for y_n (the narrow crack distress) before data regression.

Hence, the raw data are used in the S-curve regression. The value of coefficient of determination, R^2 and adjusted R^2 obtained from regression are as shown in Table 6.2. The values of the coefficient of determination, R^2 and adjusted R^2 is 0.556 and 0.550 respectively. The results indicate that the correlation between the dependent and independent variables is well when passing through origin. Here, the correlation coefficient is 0.556. It means that 55.6% of the variation of dependent (y_n) is explained by the independent variable (X_n). The analysis of variance is as shown in Table 6.3.

Table 6.2: Model summary for S-curve regression of narrow crack

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.745	0.556	0.550	0.065

The independent variable is Year.

Based on ANOVA Table 6.3, the value of the observed significance level for the *F*-statistic is less than 0.0005 indicating that the simultaneous test of each coefficient of zero is rejected. The estimation results obtained from the S-curve regression are as shown in Table 6.4.

Table 6.3: Analysis of variance for narrow crack

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.386	1	0.386	91.299	0.000
Residual	0.309	73	0.004		
Total	0.695	74			

The independent variable is Year.

Based on Table 6.4, all of the *t*-values are well above 2. This shows that the independent variable meet the guideline. The independent variable, the value of narrow crack distress with the *t*-statistic value of -9.555 and 224.878 is clearly the stronger predictor. The residual plots are as shown in Figure 6.3.

Table 6.4 : Estimation results for co-efficient of narrow crack distress model by regression analysis

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Year	-0.507	0.053	-0.745	-9.555	0.000
(Constant)	4.016	0.018		224.878	0.000

The dependent variable is ln(NarrowCrack).

The data points in the normal probability plot in Figure 6.3 are distributed closely around the 45° straight line, indicating that the normality assumption is satisfied. As for the subject of homogeneity of variance, the residuals in Figure 6.3 appeared to be randomly scattered around the horizontal axis and thus variance is constant.

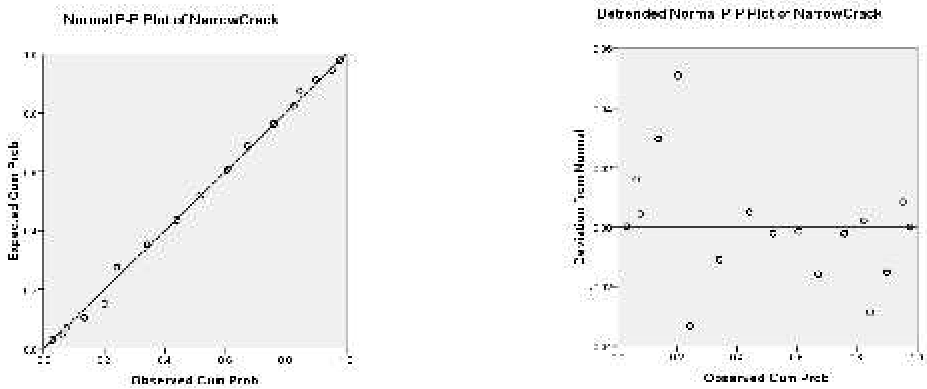

Figure 6.3: Normal probability plot and residual plot of narrow crack

The results of the Kolmogorov-Smirnov and Shapiro-Wilk tests are shown in Table 6.5 . Based on Table 6.5, the p-value of the Kolmogorov-Smirnov and Shapiro-Wilk test is 0.200 and 0.108, respectively, which are more than 0.05. Thus, the null hypothesis for normal distribution is not rejected. This indicates that the residuals are normally distributed.

Table 6.5 : Results of the test of normality on the residuals for y_n (the narrow crack distress)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
NarrowCrack	0.085	75	0.200*	0.973	75	0.108

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Hence, the coefficients of regression equation of narrow crack distress derived in this study based on the values in Table 6.4 is as shown in Equation 6.2 .

$$y_n = e^{(4.016+(-0.507/x_n))} \qquad (6.2)$$

6.4 Determination of co-efficient for wide crack distress model

The same procedures as described in the previous section will be applied in this analysis. The general form of regression equation (S-curve equation) for wide crack distress model is as shown in Equation 6.3 .

$$y_w = e^{(\ _0+(\ _1/x_w))} \qquad (6.3)$$

Where,

y_w = Wide Crack Distress (sq.meter)

β_0, β_1 = Parameter to be estimated by regression analysis using the statistical software,SPSS.

X_w = Year

The raw data of wide crack is shown in appendix has been used as the input data in SPSS. The data was used for outliers. Stem-and-leaf diagram for the dependent variable, y_w (the wide crack distress) has been generated to check for outliers. The stem-and-leaf diagram for y_w prior to data regression is as shown in Figure 6.4. Upon checking outliers, histogram was generated to check normality. The histograms plotted after data generating are as shown in Figure 6.5. The histogram shows symmetrical and indicate a normal distribution.

```
WideCrack Stem-and-Leaf Plot

 Frequency    Stem &  Leaf

     4.00       43 .  0000
     1.00       44 .  0
     1.00       45 .  0
     9.00       46 .  000000000
     2.00       47 .  00
     9.00       48 .  000000000
     4.00       49 .  0000
     7.00       50 .  0000000
     5.00       51 .  00000
     9.00       52 .  000000000
     3.00       53 .  000
     8.00       54 .  00000000
     2.00       55 .  00
     1.00       56 .  0
     7.00       57 .  0000000
      .00       58 .
      .00       59 .
     3.00       60 .  000

 Stem width:      1.00
 Each leaf:       1 case(s)
```

Figure 6.4: Stem-and-leaf plot of y_w (the wide crack distress) prior to data regression

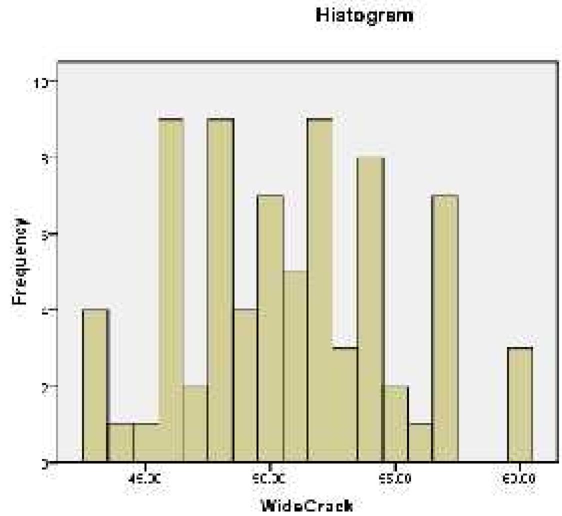

Figure 6.5 : Histogram for y_w (the wide crack distress) before data regression.

Hence, the raw data are used in the S-curve regression. The value of coefficient of determination, R^2 and adjusted R^2 obtained from regression are as shown in Table 6.6. The values of the coefficient of determination, R^2 and adjusted R^2 is 0.437 and 0.429 respectively. The results indicate that the correlation between the dependent and independent variables is well when passing through origin. Here, the correlation coefficient is 0.437. It means that 43.7% of the variation of dependent (y_w) is explained by the independent variable (X_w). The analysis of variance is as shown in Table 6.7.

Table 6.6: Model summary for S-curve regression of wide crack

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.661	0.437	0.429	0.063

The independent variable is Year.

Based on Table 6.7, the value of the observed significance level for the *F*-statistic is less than 0.0005 indicating that the simultaneous test of each coefficient of zero is rejected. The estimation results obtained from the S-curve regression are as shown in Table 6.8.

Table 6.7: Analysis of variance for wide crack

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.227	1	0.227	56.610	0.000
Residual	0.293	73	0.004		
Total	0.520	74			

The independent variable is Year.

Based on Table 6.8, all of the *t*-values are well above 2. This shows that the independent variable meet the guideline. The independent variable, the value of wide crack distress with the *t*-statistic value of -7.524 and 232.444 is clearly the stronger predictor. The residual plots are as shown in Figure 6.6.

Table 6.8: Estimation results for co-efficient of wide crack distress model by regression analysis

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Year	-0.388	0.052	-0.661	-7.524	0.000
(Constant)	4.042	0.017		232.444	0.000

The dependent variable is ln(WideCrack).

The data points in the normal probability plot in Figure 6.6 are distributed closely around the 45° straight line, indicating that the normality assumption is satisfied. As for the subject of homogeneity of variance, the residuals in Figure 6.6 appeared to be randomly scattered around the horizontal axis and thus variance is constant.

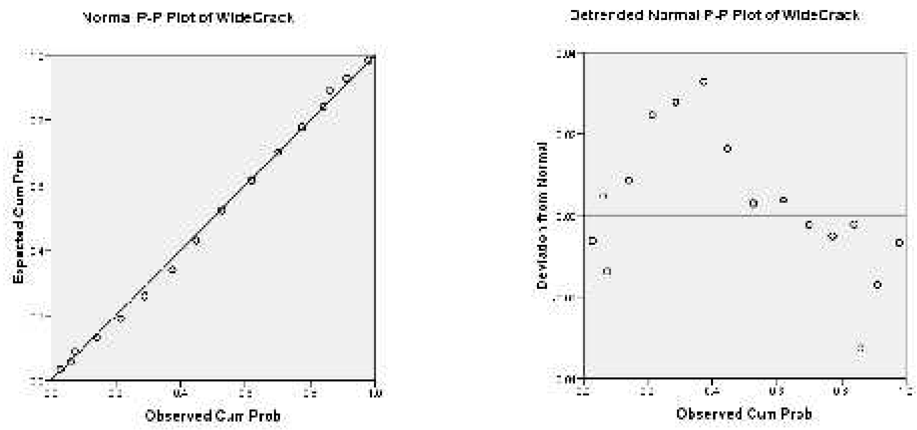

Figure 6.6: Normal probability plot and residual plot of wide crack

The results of the Kolmogorov-Smirnov and Shapiro-Wilk tests are shown in Table 6.9 . Based on Table 6.9, the p-value of the Kolmogorov-Smirnov and Shapiro-Wilk test is 0.200 and 0.108, respectively, which are more than 0.05. Thus, the null hypothesis for normal distribution is not rejected. This indicates that the residuals are normally distributed.

Table 6.9 : Results of the test of normality on the residuals for y_w (the wide crack distress)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
WideCrack	0.087	75	0.200*	0.973	75	0.108

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Hence, the coefficients of regression equation of wide crack distress derived in this study based on the values in Table 6.8 is as shown in Equation (6.4).

$$y_w = e^{(4.042 + (-0.388 / x_w))} \qquad (6.4)$$

6.5 Determination of co-efficient for potholes distress model

The same procedures as described in the previous section will be applied in this analysis. The general form of regression equation (S-curve equation) for potholes distress model is as shown in Equation 6.5 .

$$y_p = e^{(\beta_0+(\beta_1/x_p))} \qquad (6.5)$$

Where,

y_p = Potholes Distress (number)

β_0, β_1 = Parameter to be estimated by regression analysis using the statistical software,SPSS.

X_p = Year

The raw data of potholes is shown in appendix has been used as the input data in SPSS. The data was used for outliers. Stem-and-leaf diagram for the dependent variable, y_p (the potholes distress) has been generated to check for outliers. The stem-and-leaf diagram for y_p prior to data regression is as shown in Figure 6.7. Upon checking outliers, histogram was generated to check normality. The histograms plotted after data generating are as shown in Figure 6.8. The histogram shows symmetrical and indicate a normal distribution.

```
Potholes Stem-and-Leaf Plot

 Frequency    Stem &  Leaf

     4.00       32 .  0000
     1.00       33 .  0
     2.00       34 .  00
     8.00       35 .  00000000
     1.00       36 .  0
     2.00       37 .  00
    12.00       38 .  000000000000
     2.00       39 .  00
    14.00       40 .  00000000000000
     2.00       41 .  00
    12.00       42 .  000000000000
     2.00       43 .  00
     1.00       44 .  0
     7.00       45 .  0000000
     1.00       46 .  0
     1.00       47 .  0
     3.00       48 .  000

 Stem width:      1.00
 Each leaf:       1 case(s)
```

Figure 6.7: Stem-and-leaf plot of y_p (the potholes distress) prior to data regression

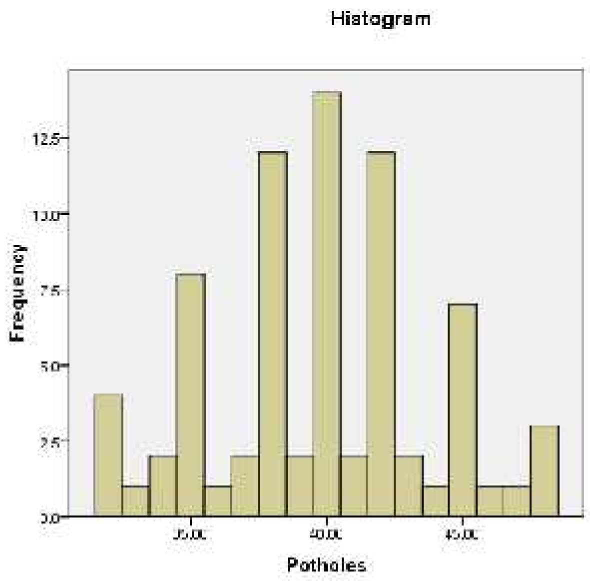

Figure 6.8 : Histogram for y_p (the potholes distress) before data regression.

Hence, the raw data are used in the S-curve regression. The value of coefficient of determination, R^2 and adjusted R^2 obtained from regression are as shown in Table 6.10 . The values of the coefficient of determination, R^2 and adjusted R^2 is 0.427 and 0.419 respectively. The results indicate that the correlation between the dependent and independent variables is well when passing through origin. Here, the correlation coefficient is 0.427. It means that 42.7% of the variation of dependent (y_p) is explained by the independent variable (X_p). The analysis of variance is as shown in Table 6.11.

Table 6.10 : Model summary for S-curve regression of potholes

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.653	0.427	0.419	0.078

The independent variable is Year.

Based on Table 6.11, the value of the observed significance level for the F-statistic is less than 0.0005 indicating that the simultaneous test of each coefficient of zero is rejected. The estimation results obtained from the S-curve regression are as shown in Table 6.12 .

Table 6.11: Analysis of variance for potholes

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.328	1	0.328	54.315	0.000
Residual	0.441	73	0.006		
Total	0.770	74			

The independent variable is Year.

Based on Table 6.12, all of the *t*-values are well above 2. This shows that the independent variable meet the guideline. The independent variable, the value of potholes distress with the *t*-statistic value of -7.370 and 178.953 is clearly the stronger predictor. The residual plots are as shown in Figure 6.9.

Table 6.12: Estimation results for co-efficient of potholes distress model by regression analysis

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Year	-0.467	0.063	-0.653	-7.370	0.000
(Constant)	3.820	0.021		178.953	0.000

The dependent variable is ln(Potholes).

The data points in the normal probability plot in Figure 6.9 are distributed closely around the 45° straight line, indicating that the normality assumption is satisfied. As for the subject of homogeneity of variance, the residuals in Figure 6.9 appeared to be randomly scattered around the horizontal axis and thus variance is constant.

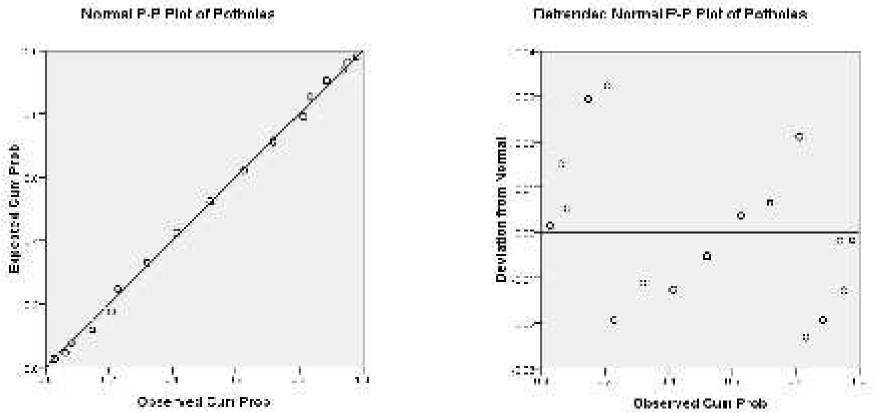

Figure 6.9: Normal probability plot and residual plot of potholes

The results of the Kolmogorov-Smirnov and Shapiro-Wilk tests are shown in Table 6.13 . Based on Table 6.13, the p-value of the Kolmogorov-Smirnov and Shapiro-Wilk test is 0.069 and 0.075, respectively, which are more than 0.05. Thus, the null hypothesis for normal distribution is not rejected. This indicates that the residuals are normally distributed.

Table 6.13: Results of the test of normality on the residuals for y_p (the potholes distress)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Potholes	0.098	75	0.069	0.970	75	0.075

a. Lilliefors Significance Correction

Hence, the coefficients of regression equation of potholes distress derived in this study based on the values in Table 6.12 is as shown in Equation 6.6 .

$$y_p = e^{(3.820+(-0.467\ /\ x_p))} \qquad (6.6)$$

6.6 Determination of co-efficient for depression distress model

The same procedures as described in the previous section has been applied in this analysis. The general form of regression equation (S-curve equation) for depression distress model is as shown in Equation 6.7 .

$$y_d = e^{(\ _0+(\ _1/x_d))} \qquad (6.7)$$

Where,

y_d = Depression Distress (sq.meter)

β_0, β_1 = Parameter to be estimated by regression analysis using the statistical software,SPSS.

X_d = Year

The raw data of depression is shown in appendix has been used as the input data in SPSS. The data was used for outliers. Stem-and-leaf diagram for the dependent variable, y_d (the depression distress) has been generated to check for outliers. The stem-and-leaf diagram for y_d prior to data regression is as shown in Figure 6.10. Upon checking outliers, histogram was generated to check normality. The histograms plotted after data generating are as shown in Figure 6.11. The histogram shows symmetrical and indicate a normal distribution

```
Depression Stem-and-Leaf Plot

 Frequency    Stem &  Leaf

     4.00       23 .  0000
     1.00       24 .  0
     1.00       25 .  0
     5.00       26 .  00000
     1.00       27 .  0
     1.00       28 .  0
     2.00       29 .  00
     6.00       30 .  000000
     4.00       31 .  0000
     5.00       32 .  00000
     1.00       33 .  0
     5.00       34 .  00000
     1.00       35 .  0
     6.00       36 .  000000
     1.00       37 .  0
     1.00       38 .  0
     4.00       39 .  0000
     1.00       40 .  0
     1.00       41 .  0
     3.00       42 .  000

 Stem width:      1.00
 Each leaf:       1 case(s)
```

Figure 6.10: Stem-and-leaf plot of y_d (the depression distress) prior to data regression

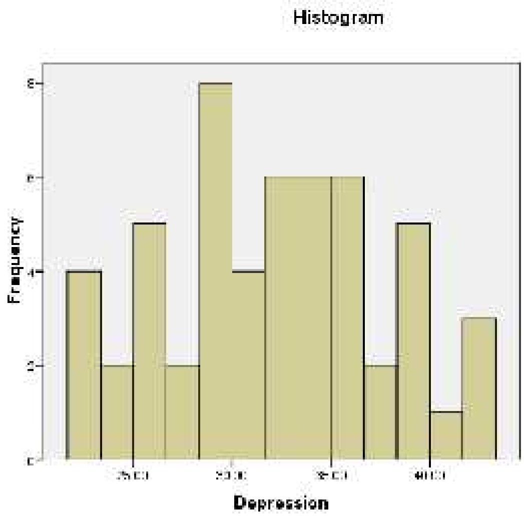

Figure 6.11: Histogram for y_d (the depression distress) before data regression.

Hence, the raw data are used in the S-curve regression. The value of coefficient of determination, R^2 and adjusted R^2 obtained from regression are as shown in Table 6.14. The values of the coefficient of determination, R^2 and adjusted R^2 is 0.661 and 0.655 respectively. The results indicate that the correlation between the dependent and independent variables is well when passing through origin. Here, the correlation coefficient is 0.661. It means that 66.1% of the variation of dependent (y_d) is explained by the independent variable (X_d). The analysis of variance is as shown in Table 6.15.

Table 6.14: Model summary for S-curve regression of depression

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.813	0.661	0.655	0.100

The independent variable is Year.

Based on Table 6.15, the value of the observed significance level for the *F*-statistic is less than 0.0005 indicating that the simultaneous test of each coefficient of zero is rejected. The estimation results obtained from the S-curve regression are as shown in Table 6.16.

Table 6.15: Analysis of variance for depression

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.017	1	1.017	101.450	0.000
Residual	0.521	52	0.010		
Total	1.539	53			

The independent variable is Year.

Based on Table 6.16, all of the *t*-values are well above 2. This shows that the independent variable meet the guideline. The independent variable, the value of depression distress with the *t*-statistic value of -10.072 and 115.881 is clearly the stronger predictor. The residual plots are as shown in Figure 6.12.

Table 6.16: Estimation results for co-efficient of depression distress model by regression analysis

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Year	-0.969	0.096	-0.813	-10.072	0.000
(Constant)	3.755	0.032		115.881	0.000

The dependent variable is ln(Depression).

The data points in the normal probability plot in Figure 6.12 are distributed closely around the 45° straight line, indicating that the normality assumption is satisfied. As for the subject of homogeneity of variance, the residuals in Figure 6.12 appeared to be randomly scattered around the horizontal axis and thus variance is constant.

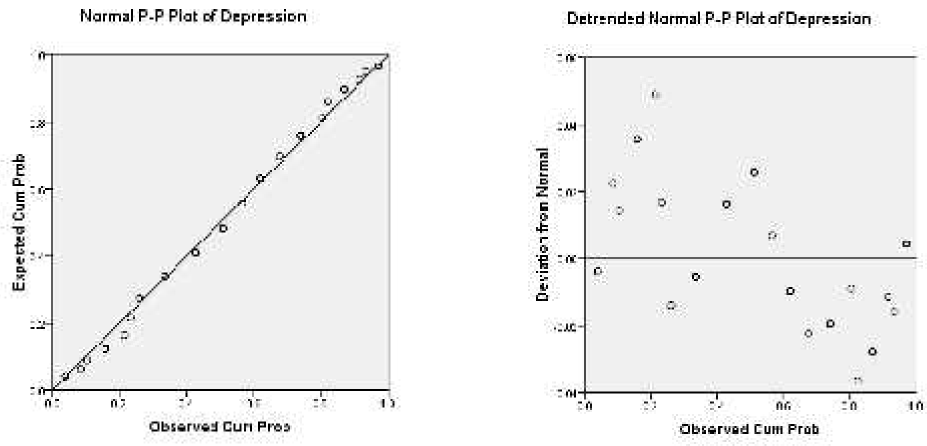

Figure 6.12: Normal probability plot and residual plot of depression

The results of the Kolmogorov-Smirnov and Shapiro-Wilk tests are shown in Table 6.17 . Based on Table 6.17, the p-value of the Kolmogorov-Smirnov and Shapiro-Wilk test is 0.200 and 0.132, respectively, which are more than 0.05. Thus, the null hypothesis for normal distribution is not rejected. This indicates that the residuals are normally distributed.

Table 6.17: Results of the test of normality on the residuals for y_d (the depression distress)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Depression	0.080	54	0.200*	0.966	54	0.132

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Hence, the coefficients of regression equation of depression distress derived in this study based on the values in Table 6.16 is as shown in Equation 6.8 .

$$y_d = e^{(3.755+(-0.969/x_d))} \quad (6.8)$$

6.7 Determination of co-efficient for rutting distress model

The same procedures as described in the previous section has been applied in this analysis. The general form of regression equation (S-curve equation) for rutting distress model is as shown in Equation 6.9 .

$$y_r = e^{(\beta_0+(\beta_1/x_r))} \qquad (6.9)$$

Where,

y_r = Rutting Distress (millimeter)

β_0, β_1 = Parameter to be estimated by regression analysis using the statistical software,SPSS.

X_r = Year

The raw data of depression is shown in appendix has been used as the input data in SPSS. The data was used for outliers. Stem-and-leaf diagram for the dependent variable, y_r (the rutting distress) has been generated to check for outliers. The stem-and-leaf diagram for y_r prior to data regression is as shown in Figure 6.13. Upon checking outliers, histogram was generated to check normality. The histograms plotted after data generating are as shown in Figure 6.14. The histogram shows symmetrical and indicate a normal distribution.

```
Rutting Stem-and-Leaf Plot

 Frequency    Stem &  Leaf

     3.00       13 .  000
      .00       13 .
      .00       14 .
     3.00       15 .  000
      .00       15 .
      .00       17 .
     6.00       18 .  000000
      .00       18 .
      .00       19 .
     7.00       20 .  0000000
      .00       20 .
      .00       21 .
     6.00       22 .  000000
      .00       22 .
      .00       24 .
     4.00       25 .  0000
      .00       26 .
      .00       26 .
     1.00       27 .  0

 Stem width:      1.00
 Each leaf:       1 case(s)
```

Figure 6.13: Stem-and-leaf plot of y_r (the rutting distress) prior to data regression

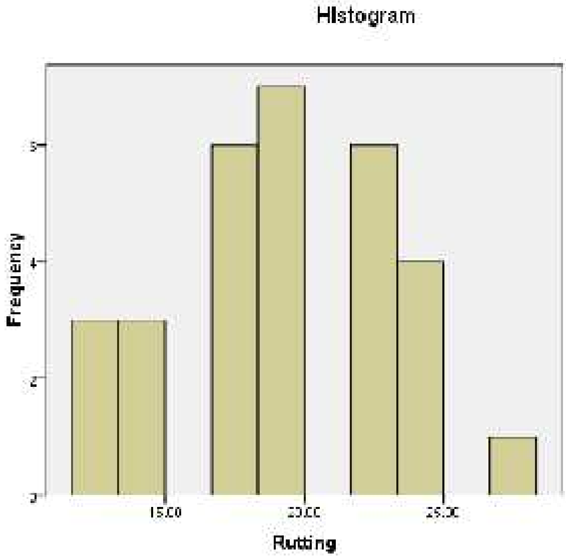

Figure 6.14: Histogram for y_r (the rutting distress) before data regression.

Hence, the raw data are used in the S-curve regression. The value of coefficient of determination, R^2 and adjusted R^2 obtained from regression are as shown in Table 6.18. The values of the coefficient of determination, R^2 and adjusted R^2 is 0.543 and 0.526 respectively. The results indicate that the correlation between the dependent and independent variables is well when passing through origin. Here, the correlation coefficient is 0.543. It means that 54.3% of the variation of dependent (y_r) is explained by the independent variable (X_r). The analysis of variance is as shown in Table 6.19.

Table 6.18 : Model summary for S-curve regression of rutting

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.737	0.543	0.526	0.139

The independent variable is Year.

Based on Table 6.19, the value of the observed significance level for the *F*-statistic is less than 0.0005 indicating that the simultaneous test of each coefficient of zero is rejected. The estimation results obtained from the S-curve regression are as shown in Table 6.20.

Table 6.19: Analysis of variance for rutting

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.641	1	0.641	33.224	0.000
Residual	0.540	28	0.019		
Total	1.180	29			

The independent variable is Year.

Based on Table 6.20, all of the *t*-values are well above 2. This shows that the independent variable meet the guideline. The independent variable, the value of depression distress with the *t*-statistic value of -5.764 and 54.360 is clearly the stronger predictor. The residual plots are as shown in Figure 6.15.

Table 6.20 : Estimation results for co-efficient of rutting distress model by regression analysis

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Year	-1.032	0.179	-0.737	-5.764	0.000
(Constant)	3.277	0.060		54.360	0.000

The dependent variable is ln(Rutting).

The data points in the normal probability plot in Figure 6.15 are distributed closely around the 45° straight line, indicating that the normality assumption is satisfied. As for the subject of homogeneity of variance, the residuals in Figure 6.15 appeared to be randomly scattered around the horizontal axis and thus variance is constant.

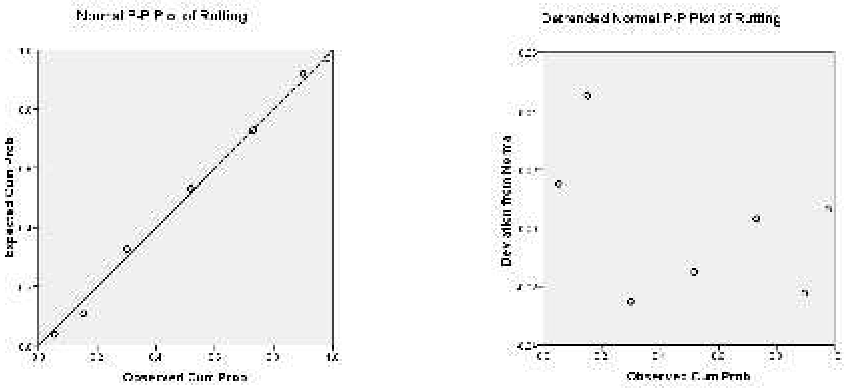

Figure 6.15: Normal probability plot and residual plot of rutting

The results of the Kolmogorov-Smirnov and Shapiro-Wilk tests are shown in Table 6.21 . Based on Table 6.21, the p-value of the Kolmogorov-Smirnov and Shapiro-Wilk test is 0.196 and 0.148, respectively, which are more than 0.05. Thus, the null hypothesis for normal distribution is not rejected. This indicates that the residuals are normally distributed.

Table 6.21: Results of the test of normality on the residuals for y_r (the rutting distress)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Rutting	0.132	30	0.196	0.948	30	0.148

a. Lilliefors Significance Correction

Hence, the coefficients of regression equation of rutting distress derived in this study based on the values in Table 6.20 is as shown in Equation 6.10 .

$$y_r = e^{(3.277+(-1.032/x_r))} \qquad (6.10)$$

6.8 Determination of co-efficient for ravelling distress model

The same procedures as described in the previous section has been applied in this analysis. The general form of regression equation (S-curve equation) for ravelling distress model is as shown in Equation 6.11 .

$$y_{rv} = e^{(\ _0+(\ _1/x_{rv}))} \qquad (6.11)$$

Where,

y_{rv} = Ravelling Distress (sq.meter)

β_0, β_1 = Parameter to be estimated by regression analysis using the statistical software,SPSS.

X_{rv} = Year

The raw data of ravelling is shown in appendix has been used as the input data in SPSS. The data was used for outliers. Stem-and-leaf diagram for the dependent variable, y_{rv} (the ravelling distress) has been generated to check for outliers. The stem-and-leaf diagram for y_{rv} prior to data regression is as shown in Figure 6.16. Upon checking outliers, histogram was generated to check normality. The histograms plotted after data generating are as shown in Figure 6.17. The histogram shows symmetrical and indicate a normal distribution.

```
Ravelling Stem-and-Leaf Plot

 Frequency    Stem &  Leaf

     3.00       18 .  000
      .00       18 .
     1.00       19 .  0
      .00       19 .
     3.00       20 .  000
      .00       20 .
     2.00       21 .  00
      .00       21 .
     1.00       22 .  0
      .00       22 .
     6.00       23 .  000000
      .00       23 .
     1.00       24 .  0
      .00       24 .
     7.00       25 .  0000000
      .00       25 .
     1.00       26 .  0
      .00       26 .
     6.00       27 .  000000
      .00       27 .
     3.00       28 .  000
      .00       28 .
     2.00       29 .  00
      .00       29 .
     4.00       30 .  0000
      .00       30 .
     2.00       31 .  00
      .00       31 .
     1.00       32 .  0

 Stem width:      1.00
 Each leaf:       1 case(s)
```

Figure 6.16: Stem-and-leaf plot of y_{rv} (the ravelling distress) prior to data regression

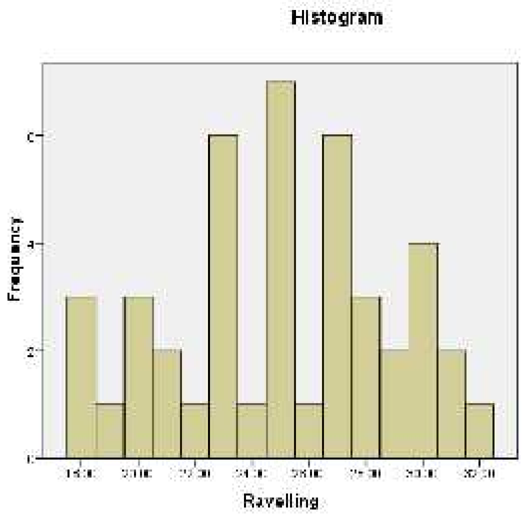

Figure 6.17: Histogram for y_{rv} (the raveling distress) before data regression.

Hence, the raw data are used in the S-curve regression. The value of coefficient of determination, R^2 and adjusted R^2 obtained from regression are as shown in Table 6.22. The values of the coefficient of determination, R^2 and adjusted R^2 is 0.591 and 0.581 respectively. The results indicate that the correlation between the dependent and independent variables is well when passing through origin. Here, the correlation coefficient is 0.591. It means that 59.1% of the variation of dependent (y_{rv}) is explained by the independent variable (X_{rv}). The analysis of variance is as shown in Table 6.23.

Table 6.22: Model summary for S-curve regression of ravelling

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.768	0.591	0.581	0.103

The independent variable is Year.

Based on Table 6.23, the value of the observed significance level for the *F*-statistic is less than 0.0005 indicating that the simultaneous test of each coefficient of zero is rejected. The estimation results obtained from the S-curve regression are as shown in Table 6.24.

Table 6.23: Analysis of variance for ravelling

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.633	1	0.633	59.125	0.000
Residual	0.439	41	0.011		
Total	1.071	42			

The independent variable is Year.

Based on Table 6.24, all of the *t*-values are well above 2. This shows that the independent variable meet the guideline. The independent variable, the value of depression distress with the *t*-statistic value of -7.689 and 93.024 is clearly the stronger predictor. The residual plots are as shown in Figure 6.18.

Table 6.24: Estimation results for co-efficient of ravelling distress model by regression analysis

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Year	-0.876	0.114	-0.768	-7.689	0.000
(Constant)	3.469	0.037		93.024	0.000

The dependent variable is ln(Ravelling).

The data points in the normal probability plot in Figure 6.18 are distributed closely around the 45° straight line, indicating that the normality assumption is satisfied. As for the subject of homogeneity of variance, the residuals in Figure 6.18 appeared to be randomly scattered around the horizontal axis and thus variance is constant.

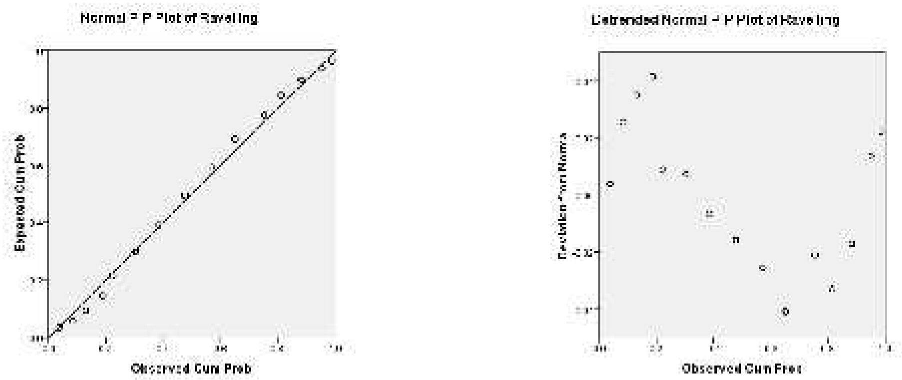

Figure 6.18: Normal probability plot and residual plot of raveling

The results of the Kolmogorov-Smirnov and Shapiro-Wilk tests are shown in Table 6.25 . Based on Table 6.25, the p-value of the Kolmogorov-Smirnov and Shapiro-Wilk test is 0.200 and 0.179, respectively, which are more than 0.05. Thus, the null hypothesis for normal distribution is not rejected. This indicates that the residuals are normally distributed.

Table 6.25: Results of the test of normality on the residuals for y_{rv} (the ravelling distress)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Ravelling	0.110	43	0.200*	0.963	43	0.179

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Hence, the coefficients of regression equation of ravelling distress derived in this study based on the values in Table 6.24 is as shown in Equation 6.12 .

$$y_{rv} = e^{(3.469+(-0.876/x_{rv}))} \qquad (6.12)$$

6.9 Model Validation

One of the significant consideration of this research is to validate the developed models against a set of data of the distresses. It is considered that comparing and testing against an dependent set of data should be undertaken so as to ensure the models goodness -of-fit to further verify the models. In this research dependent set of data has been collected from the Khulna – Jessore highway at different location. Then drawn a graph by using the observed data from the field and data obtained from the equation of the prediction model. The best-fitting line from the data closely follows a 45-degree slope as expected.

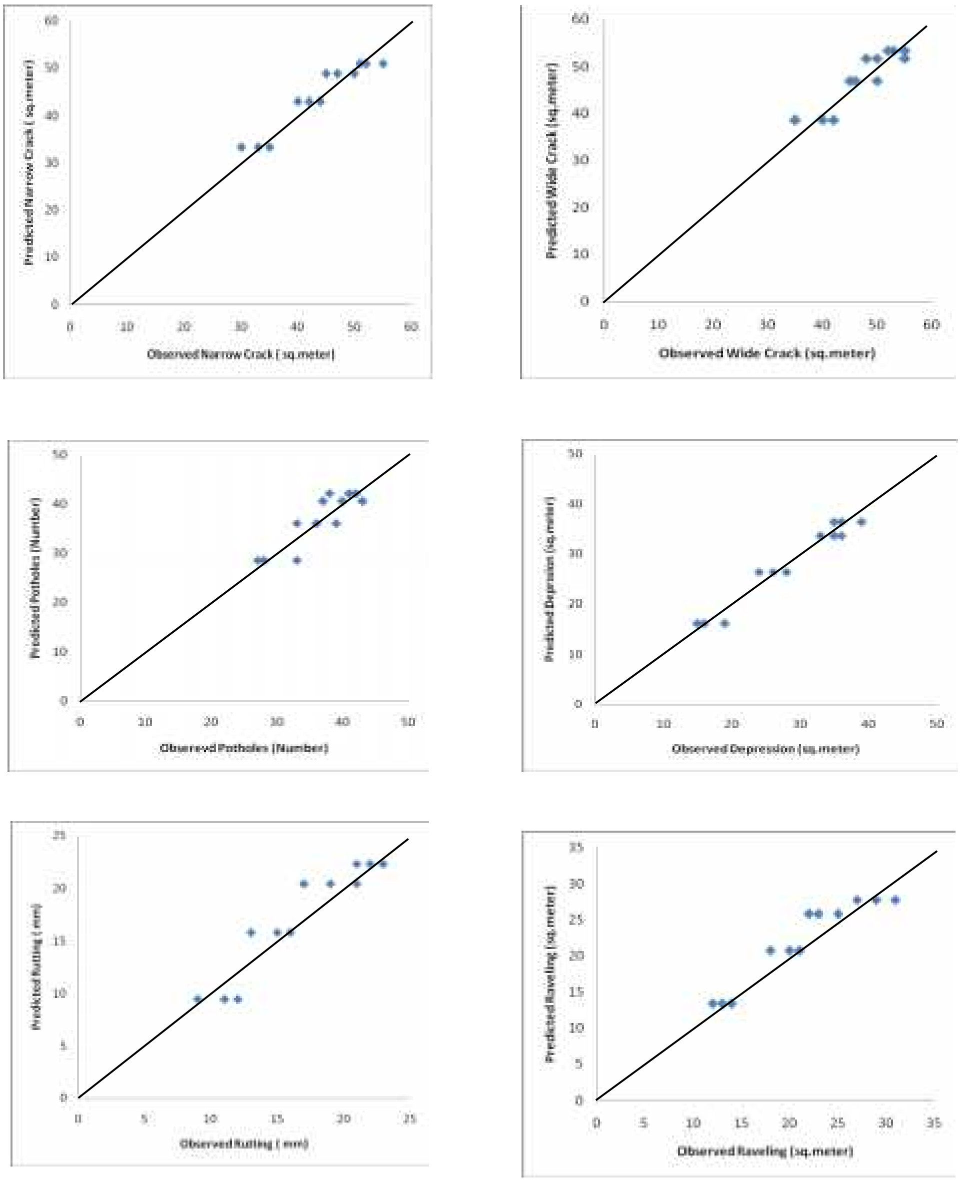

Figure 6.19: Relationship between the observed and The predicted data for the validation of developed models.

6.10 T-test

In this research, the *t*-test was involved for the validation of observed and predicted data based on regression analysis using SPSS. The *t*-test procedure compares the deviation for two independent groups of cases of six distresses-Narrow Crack, Wide Crack, Potholes, Depression, Rutting and Raveling. The t-test results for the validation data are found significant. The values of t-statistics in all cases are 224.878, -9.555, 232.444, -7.524, 178.953, -7.370, 115.881, -10.072, 54.360, -5.764, 93.024 and -7.689 . Thus it can be concluded that the null hypothesis that the deviation of observed and predicted data of six distresses are equal to zero is not rejected at 95% confidence interval.

Table 6.26 : T-test relationship developed between the observed and predicted data

Coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	t-test value	Sig.
	B	Std. Error	Beta		
Constant	4.016	0.018		224.878	0.000
Observed Narrow Crack	-0.507	0.053	-0.745	-9.555	0.000
Constant	4.042	0.017		232.444	0.000
Observed Wide Crack	-0.388	0.052	-0.661	-7.524	0.000
Constant	3.820	0.021		178.953	0.000
Observed Potholes	-0.467	0.063	-0.653	-7.370	0.000
Constant	3.755	0.032		115.881	0.000
Observed Depression	-0.969	0.096	-0.813	-10.072	0.000
Constant	3.277	0.060		54.360	0.000
Observed Rutting	-1.032	0.179	-0.737	-5.764	0.000
Constant	3.469	0.037		93.024	0.000
Observed Raveling	-0.876	0.114	-0.768	-7.689	0.000

Based on Table 6.26, it is seen that the t-test values are significant for the observed and predicted value of six distresses.

6.11 Project Summary

- Pavement distress information is one of the best methods to evaluate the pavement condition as well as selecting the appropriate treatments.
- Basically there are four techniques in modeling pavement deterioration. They are; purely mechanistic technique, regression technique, mechanistic empirical technique, and probabilistic technique. Regression technique has been used in this study.
- Nonlinear regression technique was used due to type of data available.
- For obtaining generic models for National highway that can be utilized with a significant level of confidence, the study covered all accessible and reliable data. This study included National highway data only.
- The datasets were developed for pavement distress types on national highway.
- These datasets were used in pavement distress analysis, pavement distress models and the implementation.
- Data for six common distress types on national highway were used in the analysis of distress behavior as well modeling these distresses. These common distress types are Narrow Crack, Wide Crack, Potholes, Depressions, Rutting and Ravelling.
- The factors in the study are the ones commonly available and reliable. They are; distress frequency, percent of distress density, pavement age and drainage.
- 25 units with 12 reading locations over about 2 years and 7 months the data are collected for the study.
- In this study, only overlays are considered since an overlay increases the pavement condition to its maximum.
- The propagation of the pavement distress types were presented as combined sum of distress density at different severity levels using weight for each severity.
- The data was large and the variation on data was noticed. Normality was checked and then nonparametric tests were performed to check significance of the factors.
- Inferences from normality tests and nonparametric tests showed that the data are normally distributed and the pavement age factor shows high significance.

- The empirical technique (nonlinear regression) was the best technique to be used in modeling behavior distress due to first and foremost nature of the data, its practicality, simplicity, and ease in developing provided that adequate data is available.

- The data has been collected taking in consideration the engineering principles.

- Analysis of residuals showed the models were of acceptable accuracy and could therefore be applied in a PMS.

- Critical pavement condition levels have been proposed for Highways with rehabilitation at both network and project levels.

- The drop in pavement quality and the damage quantity and probability are understandable and measurable with the pavement distress model.

CHAPTER VII

Conclusions and Recommendations

7.1 General

This chapter contains the main elements of the thesis. It addresses the objectives of the research. A summary, conclusions, limitations, and recommendations of the research are presented in this chapter.

7.2 Remarks on the road maintenance practice of Bangladesh.

In past, the maintenance and rehabilitation works in Bangladesh followed more of a traditional practice. No proper pavement evaluation was done in advance or during maintenance and rehabilitation. As already discussed in section 1.2, many roads were constructed without proper design and construction supervision. Later on the same roads were simply overlaid and widened without strengthening the bottom weak layers. Such defective works are affecting the pavement performance until now since no appropriate remedial action is taken. The current maintenance and rehabilitation practice also depends more on visual observation and functional evaluations such as surface roughness and visual survey at network level rather than detail pavement evaluation at project level. In general, the following major remarks can be noted regarding the road maintenance and rehabilitation practices in Bangladesh:-

1. The road maintenance and rehabilitation works for Bangladesh, particularly until the establishment of PMS, was being carried out without formal policy and standards. Roads were constructed and maintained by RHD without proper policy. This has resulted in sub standard works which are causes of subsequent damages.
2. There is still no proper material and construction quality control for the road maintenance and rehabilitation works. As a result, repeated and premature failures are observed.

3. The maintenance and rehabilitation work force is not properly organized with adequate resource such as finance, equipment and skilled staff. This has resulted in the maintenance operation not to be efficient and effective.

4. The whole of the existing road network in Bangladesh have poor side drainage line and pedestrian walk ways. This lack of drainage system and side walks is causing damage on the asphalt pavement and affecting the proper functioning of the road respectively.

5. Different utility organizations (like water works, electric and telecommunication) are not carrying out their duties on the basis of long term plan and with coordination of one another. As a result, it is not uncommon to observe repetitive destruction on the asphalt pavements, some times even in the same year of construction. The method of patching utility trenches also lacks proper workmanship and control.

7.3 Conclusions

- Pavement age is most significant in the predicting pavement deterioration. Age is significant because it is a common factor in the estimation of both traffic and effect of drainage over the life cycle period. Age can be a surrogate for the effect of traffic and drainage in prediction model. So it can be concluded that age plays a pivotal role in predicting pavement condition. The maintenance work was conducted in the year 1996. This maintenance work was overlay only.
- Traffic and drainage factors play a statistically important role in predicting pavement deterioration in this study. The AADT of this road is 11451 and the drainage condition is poor as stated in section 3.3 .
- Pavement age factor is the only factor in the prediction equation form for pavement distress models.
- Six for National Highway Pavement Distress Model (NHPDM) :
- Narrow Cracking Model, $y_n = e^{(4.016+(-0.507/x_n))}$
- Wide Cracking Model, $y_w = e^{(4.042+(-0.388/x_w))}$
- Potholes Model, $y_p = e^{(3.820+(-0.467/x_p))}$
- Depression Model, $y_d = e^{(3.755+(-0.969/x_d))}$
- Rutting Model, $y_r = e^{(3.277+(-1.032/x_r))}$
- Raveling Model, $y_{rv} = e^{(3.469+(-0.876/x_{rv}))}$

- Developed models by using site data or historical data involve the use of an iterative non linear regression analysis to determine the model coefficients. The advantage of this modeling approach over other models is that the site models more closely match the reality on every section in the network.
- The developed models can be used by several departments across the country due to, first, construction and maintenance specifications are same, second, the environmental factors are almost same like temperature and rainfall.
- Distress types are dependent of each other for national highways except depressions are significantly less dependent on other distress types.
- Distress types on highways are high correlated to the pavement condition by about 70% except depression by about 50%.
- Critical pavement distress levels and minimum distress levels have been proposed based on deterioration behavior as guidance for road agencies officials and engineers in pavement management.
- Three critical levels for pavement deterioration over time on national highways to trigger corrective, preventive and major maintenance.
- Four maintenance programs with eight maintenance activities are defined as follows; corrective program (Crack sealing, Shallow and Deep patching), Preventive program (slurry sealing, thin overlay, Mill and Repave), Structural Overlay, and Reconstruction.
- Pavement distress behavior on national highways varies from distress to other distress.
- The deterioration rate for weathering and raveling was observed to be the fastest in propagation.
- The deterioration rate for depression was observed to be the slowest in propagation.
- Block cracking and cracking (due to patching) have similar propagation compared to others.
- Potholes propagation has moderate deterioration.
- Pavement distress behavior on national highways almost have same trend except patching has higher progression compared to others.

- Maintenance Priority (MP) can be found through some factors for traffic level, road classification (RC), maintenance record (MR), and cost effectiveness (CEF), and pavement condition.
- The following formulas was suggested Maintenance Priority (MP)= (TF x RF x MF)/ Pavement Condition.

7.4 Limitations

There was some limitations to study the pavement condition on the test road. Due to limitations it was not possible to collect all kinds of data of the test road pavement. Limitations are :

1. There was shortage of facilities to collect all data from the whole length of the highway.
2. There was unavailability of instrument to collect pavement condition details data. Such as Benkelmen beam deflection test machine, DCP etc.
3. The highway is very busy with heavy traffic. It was risk to collect data with destructive or non-destructive way with long time on this highway.
4. Skilled manpower team to collect data accurately.

7.5 Recommendations

1. The distress density models developed in this research should be utilized to evaluate the pavement condition.
2. Collection of accurate data for determining dominant distresses in a road network, identifying primary causes of distress and developing functional relationship among different pavement evaluation variables would only be easier on experimental test sections which are carefully designated in such a way to reasonably model the road network under study. To this effect one can understand that the analysis and findings of this research could only be considered as a preliminary assessment that may serve as a spring board to further carry out detailed assessment within the country road network. Hence, it is advisable to develop a continuous system of data collection for distresses, classified traffic counts, pavement evaluation results, and maintenance and construction records on

representative test sections for a longer period of time. Such strategic data collection and analysis could certainly enable to develop clear functional relationship among different pavement evaluation parameters.

3. No detail material test of the existing pavement structure is carried out under this research. Hence, it is also advisable to perform some destructive tests such as coring and component analysis techniques to further check the structural capacity of the pavement.

4. As observed from the visual survey, nearly 90% the test road was constructed without side drain of any kind. This can easily indicate that the road design and construction traditionally adopted by the government department has fully ignored the effect of excess water in the pavement layer. According to the survey made for this thesis purpose, even some of the existing surface drains are not properly functioning. On the other hand, The Roads Authority's traditional maintenance practice until now, to repair damaged pavements, is patching or providing additional thickness of asphalt without an attempt to improve the drainage conditions. Therefore, the pavement design and construction practice must be modified in such a way to have structural pavement layers capable of draining free water rapidly after its entry. Such rapid drainage can be achieved by providing highly permeable layers of open graded material with collector pipes to ensure constant gravity drainage. The design and construction practice should be improved and practical way in the roads networks. Such kinds of surface and sub-surface drainages not only protect pavements from large surface inflow, but also from inflows of high ground water in wet periods or any unexpected inflows.

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Table A1: Density of Common Pavement Distress

Unit Chainage (KM).	Narrow Crack D1 %			Wide Crack D2 %			Ravelling D6%			Potholes D3 %			Depression D4 %			Rutting D5 %		
	2009	2011	2013	2009	2011	2013	2009	2011	2013	2009	2011	2013	2009	2011	2013	2009	2011	2013
Unit-1 160+00-160+200	3.082192	3.424658	3.69863	3.356164	3.561644	3.90411	-	-	-	0.234247	0.258904	0.277397	1.9863014	2.3287671	2.6712329	0.001233	0.001507	0.001712
Unit-2 161+200-161+400	2.876712	3.287671	3.90411	3.150685	3.424658	4.109589	1.575342	1.849315	2.054795	0.215753	0.246575	0.29589	1.7808219	2.1917808	2.8767123	0.001027	0.00137	0.001849
Unit-3 162+100-162+300	2.671233	3.150685	3.493151	2.945205	3.287671	3.69863	1.369863	1.712329	2.191781	0.19726	0.234247	0.258904	1.5753425	2.0547945	2.4657534	0.00089	0.001233	0.001507
Unit-4 163+00-163+200	3.219178	3.424658	3.69863	3.493151	3.561644	3.90411	1.232877	1.575342	1.849315	0.246575	0.258904	0.277397	2.1232877	2.3287671	2.6712329	-	-	-
Unit-5 163+900-164+100	2.876712	3.150685	3.493151	3.150685	3.287671	3.69863	1.712329	1.849315	2.054795	0.215753	0.234247	0.258904	1.7808219	2.0547945	2.4657534	-	-	-
Unit-6 164+500-164+700	2.876712	3.150685	3.356164	3.150685	3.287671	3.561644	-	-	-	0.215753	0.234247	0.246575	1.7808219	2.0547945	2.3287671	-	-	-
Unit-7 165+300-165+500	3.219178	3.150685	3.493151	3.493151	3.287671	3.69863	1.369863	1.575342	1.849315	0.246575	0.234247	0.258904	2.1232877	2.0547945	2.4657534	-	-	-
Unit-8 166+00-166+200	2.671233	3.287671	3.69863	2.945205	3.424658	3.90411	1.369863	1.575342	1.712329	0.19726	0.246575	0.277397	1.5753425	2.1917808	2.6712329	-	-	-
Unit-9 166+400-166+600	2.671233	3.150685	3.493151	2.945205	3.287671	3.69863	1.712329	1.575342	1.849315	0.19726	0.234247	0.258904	1.5753425	2.0547945	2.4657534	-	-	-
Unit-10 167+200-167+400	3.219178	3.630137	3.356164	3.493151	3.767123	3.561644	1.232877	1.712329	2.054795	0.246575	0.277397	0.246575	-	-	-	-	-	-
Unit-11 168+300-168+500	3.356164	3.287671	3.90411	3.630137	3.424658	4.109589	-	-	-	0.258904	0.246575	0.29589	-	-	-	0.00137	0.001507	0.001712
Unit-12 169+00-169+200	2.876712	3.150685	3.493151	3.150685	3.287671	3.69863	-	-	-	0.215753	0.234247	0.258904	-	-	-	0.001027	0.001233	0.001507
Unit-13 169+300-169+500	2.671233	3.287671	3.493151	2.945205	3.424658	3.69863	-	-	-	0.19726	0.246575	0.258904	2.1232877	2.5342466	2.3287671	0.001027	0.001233	0.00137
Unit-14 170+200-170+400	3.219178	3.424658	3.69863	3.493151	3.561644	3.90411	-	-	-	0.246575	0.258904	0.277397	2.260274	2.1917808	2.8767123	-	-	-
Unit-15	2.876712	3.287671	3.90411	3.150685	3.424658	4.109589	-	-	-	0.215753	0.246575	0.29589	1.7808219	2.0547945	2.4657534	0.00137	0.001233	0.001507

Unit Chainage (KM).	Narrow Crack D1 %			Wide Crack D2 %			Ravelling D6%			Potholes D3 %			Depression D4 %			Rutting D5 %		
	2009	2011	2013	2009	2011	2013	2009	2011	2013	2009	2011	2013	2009	2011	2013	2009	2011	2013
172+600-172+800																		
Unit-16 173+500-173+700	3.082192	3.424658	3.69863	3.356164	3.561644	3.90411	-	-	-	0.234247	0.258904	0.277397	1.5753425	2.1917808	2.4657534	0.00089	0.00137	0.001712
Unit-17 178+300-178+500	2.876712	3.150685	3.356164	3.150685	3.287671	3.561644	-	-	-	0.215753	0.234247	0.246575	2.1232877	2.3287671	2.6712329	0.00089	0.001233	0.001507
Unit-18 178+700-178+900	2.876712	3.150685	3.493151	3.150685	3.287671	3.69863	-	-	-	0.215753	0.234247	0.258904	-	-	-	0.00137	0.001712	0.00137
Unit-19 179+700-179+900	3.082192	3.287671	3.69863	3.356164	3.424658	3.90411	-	1.575342	1.849315	0.234247	0.246575	0.277397	-	-	-	-	-	-
Unit-20 189+200-189+400	2.876712	3.150685	3.356164	3.150685	3.287671	3.561644	-	2.054795	1.712329	0.215753	0.234247	0.246575	1.7808219	2.1917808	2.8767123	-	-	-
Unit-21 189+600-189+800	2.739726	3.082192	3.287671	3.013699	3.219178	3.493151	1.232877	1.643836	1.986301	0.203425	0.228082	0.240411	1.6438356	1.9178082	2.6027397	-	-	-
Unit-22 195+100-195+300	2.808219	3.493151	3.424658	3.082192	3.630137	3.630137	1.712329	1.780822	2.123288	0.209589	0.265068	0.25274	1.7123288	1.9863014	2.739726	-	-	-
Unit-23 195+800-196+00	3.150685	3.561644	3.150685	3.424658	3.69863	3.356164	1.30137	1.917808	2.123288	0.240411	0.271233	0.228082	1.8493151	2.3972603	2.8082192	-	-	-
Unit-24 198+200-198+400	3.287671	3.69863	2.945205	3.561644	3.835616	3.150685	1.438356	1.438356	1.986301	0.25274	0.283562	0.209589	-	-	-	-	-	-
Unit-25 203+300-203+500	2.945205	3.767123	3.561644	3.219178	3.90411	3.767123	1.506849	1.917808	1.917808	0.221918	0.289726	0.265068	-	-	-	-	-	-

Raw Data of Narrow Crack Distress			
Unit Chainage (KM).	After Year	Narrow Crack (sq.m)	Density
160+00-160+200	2	45	3.08219178
161+200-161+400	2	42	2.87671233
162+100-162+300	2	39	2.67123288
163+00-163+200	2	47	3.21917808
163+900-164+100	2	42	2.87671233
164+500-164+700	2	42	2.87671233
165+300-165+500	2	47	3.21917808
166+00-166+200	2	39	2.67123288
166+400-166+600	2	39	2.67123288
167+200-167+400	2	47	3.21917808
168+300-168+500	2	49	3.35616438
169+00-169+200	2	42	2.87671233
169+300-169+500	2	39	2.67123288
170+200-170+400	2	47	3.21917808
172+600-172+800	2	42	2.87671233
173+500-173+700	2	45	3.08219178
178+300-178+500	2	42	2.87671233
178+700-178+900	2	42	2.87671233
179+700-179+900	2	45	3.08219178
189+200-189+400	2	42	2.87671233
189+600-189+800	2	40	2.73972603
195+100-195+300	2	41	2.80821918
195+800-196+00	2	46	3.15068493
198+200-198+400	2	48	3.28767123
203+300-203+500	2	43	2.94520548
160+00-160+200	4	50	3.42465753
161+200-161+400	4	48	3.28767123
162+100-162+300	4	46	3.15068493
163+00-163+200	4	50	3.42465753
163+900-164+100	4	46	3.15068493
164+500-164+700	4	46	3.15068493
165+300-165+500	4	46	3.15068493
166+00-166+200	4	48	3.28767123
166+400-166+600	4	46	3.15068493
167+200-167+400	4	53	3.63013699
168+300-168+500	4	48	3.28767123
169+00-169+200	4	46	3.15068493

Raw Data of Narrow Crack Distress			
Unit Chainage (KM).	After Year	Narrow Crack (sq.m)	Density
169+300-169+500	4	48	3.28767123
170+200-170+400	4	50	3.42465753
172+600-172+800	4	48	3.28767123
173+500-173+700	4	50	3.42465753
178+300-178+500	4	46	3.15068493
178+700-178+900	4	46	3.15068493
179+700-179+900	4	48	3.28767123
189+200-189+400	4	46	3.15068493
189+600-189+800	4	45	3.08219178
195+100-195+300	4	51	3.49315068
195+800-196+00	4	52	3.56164384
198+200-198+400	4	54	3.69863014
203+300-203+500	4	55	3.76712329
160+00-160+200	6	54	3.69863014
161+200-161+400	6	57	3.90410959
162+100-162+300	6	51	3.49315068
163+00-163+200	6	54	3.69863014
163+900-164+100	6	51	3.49315068
164+500-164+700	6	49	3.35616438
165+300-165+500	6	51	3.49315068
166+00-166+200	6	54	3.69863014
166+400-166+600	6	51	3.49315068
167+200-167+400	6	49	3.35616438
168+300-168+500	6	57	3.90410959
169+00-169+200	6	51	3.49315068
169+300-169+500	6	51	3.49315068
170+200-170+400	6	54	3.69863014
172+600-172+800	6	57	3.90410959
173+500-173+700	6	54	3.69863014
178+300-178+500	6	49	3.35616438
178+700-178+900	6	51	3.49315068
179+700-179+900	6	54	3.69863014
189+200-189+400	6	49	3.35616438
189+600-189+800	6	48	3.28767123
195+100-195+300	6	50	3.42465753
195+800-196+00	6	46	3.15068493
198+200-198+400	6	43	2.94520548
203+300-203+500	6	52	3.56164384

Raw Data of Wide Crack Distress			
Unit Chainage (KM).	Year	Wide Crack (sq.m)	Density
160+00-160+200	2	49	3.35616
161+200-161+400	2	46	3.15068
162+100-162+300	2	43	2.94521
163+00-163+200	2	51	3.49315
163+900-164+100	2	46	3.15068
164+500-164+700	2	46	3.15068
165+300-165+500	2	51	3.49315
166+00-166+200	2	43	2.94521
166+400-166+600	2	43	2.94521
167+200-167+400	2	51	3.49315
168+300-168+500	2	53	3.63014
169+00-169+200	2	46	3.15068
169+300-169+500	2	43	2.94521
170+200-170+400	2	51	3.49315
172+600-172+800	2	46	3.15068
173+500-173+700	2	49	3.35616
178+300-178+500	2	46	3.15068
178+700-178+900	2	46	3.15068
179+700-179+900	2	49	3.35616
189+200-189+400	2	46	3.15068
189+600-189+800	2	44	3.0137
195+100-195+300	2	45	3.08219
195+800-196+00	2	50	3.42466
198+200-198+400	2	52	3.56164
203+300-203+500	2	47	3.21918
160+00-160+200	4	52	3.56164
161+200-161+400	4	50	3.42466
162+100-162+300	4	48	3.28767
163+00-163+200	4	52	3.56164
163+900-164+100	4	48	3.28767
164+500-164+700	4	48	3.28767
165+300-165+500	4	48	3.28767
166+00-166+200	4	50	3.42466
166+400-166+600	4	48	3.28767
167+200-167+400	4	55	3.76712
168+300-168+500	4	50	3.42466
169+00-169+200	4	48	3.28767

Raw Data of Wide Crack Distress			
Unit Chainage (KM).	Year	Wide Crack (sq.m)	Density
169+300-169+500	4	50	3.42466
170+200-170+400	4	52	3.56164
172+600-172+800	4	50	3.42466
173+500-173+700	4	52	3.56164
178+300-178+500	4	48	3.28767
178+700-178+900	4	48	3.28767
179+700-179+900	4	50	3.42466
189+200-189+400	4	48	3.28767
189+600-189+800	4	47	3.21918
195+100-195+300	4	53	3.63014
195+800-196+00	4	54	3.69863
198+200-198+400	4	56	3.83562
203+300-203+500	4	57	3.90411
160+00-160+200	6	57	3.90411
161+200-161+400	6	60	4.10959
162+100-162+300	6	54	3.69863
163+00-163+200	6	57	3.90411
163+900-164+100	6	54	3.69863
164+500-164+700	6	52	3.56164
165+300-165+500	6	54	3.69863
166+00-166+200	6	57	3.90411
166+400-166+600	6	54	3.69863
167+200-167+400	6	52	3.56164
168+300-168+500	6	60	4.10959
169+00-169+200	6	54	3.69863
169+300-169+500	6	54	3.69863
170+200-170+400	6	57	3.90411
172+600-172+800	6	60	4.10959
173+500-173+700	6	57	3.90411
178+300-178+500	6	52	3.56164
178+700-178+900	6	54	3.69863
179+700-179+900	6	57	3.90411
189+200-189+400	6	52	3.56164
189+600-189+800	6	51	3.49315
195+100-195+300	6	53	3.63014
195+800-196+00	6	49	3.35616
198+200-198+400	6	46	3.15068
203+300-203+500	6	55	3.76712

Raw Data of Potholes Distress			
Unit Chainage (KM).	Year	Potholes (Nos)	Density
160+00-160+200	2	38	0.234247
161+200-161+400	2	35	0.215753
162+100-162+300	2	32	0.19726
163+00-163+200	2	40	0.246575
163+900-164+100	2	35	0.215753
164+500-164+700	2	35	0.215753
165+300-165+500	2	40	0.246575
166+00-166+200	2	32	0.19726
166+400-166+600	2	32	0.19726
167+200-167+400	2	40	0.246575
168+300-168+500	2	42	0.258904
169+00-169+200	2	35	0.215753
169+300-169+500	2	32	0.19726
170+200-170+400	2	40	0.246575
172+600-172+800	2	35	0.215753
173+500-173+700	2	38	0.234247
178+300-178+500	2	35	0.215753
178+700-178+900	2	35	0.215753
179+700-179+900	2	38	0.234247
189+200-189+400	2	35	0.215753
189+600-189+800	2	33	0.203425
195+100-195+300	2	34	0.209589
195+800-196+00	2	39	0.240411
198+200-198+400	2	41	0.25274
203+300-203+500	2	36	0.221918
160+00-160+200	4	42	0.258904
161+200-161+400	4	40	0.246575
162+100-162+300	4	38	0.234247
163+00-163+200	4	42	0.258904
163+900-164+100	4	38	0.234247
164+500-164+700	4	38	0.234247
165+300-165+500	4	38	0.234247
166+00-166+200	4	40	0.246575
166+400-166+600	4	38	0.234247
167+200-167+400	4	45	0.277397
168+300-168+500	4	40	0.246575
169+00-169+200	4	38	0.234247

Raw Data of Potholes Distress			
Unit Chainage (KM).	Year	Potholes (Nos)	Density
169+300-169+500	4	40	0.246575
170+200-170+400	4	42	0.258904
172+600-172+800	4	40	0.246575
173+500-173+700	4	42	0.258904
178+300-178+500	4	38	0.234247
178+700-178+900	4	38	0.234247
179+700-179+900	4	40	0.246575
189+200-189+400	4	38	0.234247
189+600-189+800	4	37	0.228082
195+100-195+300	4	43	0.265068
195+800-196+00	4	44	0.271233
198+200-198+400	4	46	0.283562
203+300-203+500	4	47	0.289726
160+00-160+200	6	45	0.277397
161+200-161+400	6	48	0.29589
162+100-162+300	6	42	0.258904
163+00-163+200	6	45	0.277397
163+900-164+100	6	42	0.258904
164+500-164+700	6	40	0.246575
165+300-165+500	6	42	0.258904
166+00-166+200	6	45	0.277397
166+400-166+600	6	42	0.258904
167+200-167+400	6	40	0.246575
168+300-168+500	6	48	0.29589
169+00-169+200	6	42	0.258904
169+300-169+500	6	42	0.258904
170+200-170+400	6	45	0.277397
172+600-172+800	6	48	0.29589
173+500-173+700	6	45	0.277397
178+300-178+500	6	40	0.246575
178+700-178+900	6	42	0.258904
179+700-179+900	6	45	0.277397
189+200-189+400	6	40	0.246575
189+600-189+800	6	39	0.240411
195+100-195+300	6	41	0.25274
195+800-196+00	6	37	0.228082
198+200-198+400	6	34	0.209589
203+300-203+500	6	43	0.265068

Raw Data of Depression Distress			
Unit Chainage (KM).	Year	Depression (sq.m)	Density
160+00-160+200	2	29	1.986301
161+200-161+400	2	26	1.780822
162+100-162+300	2	23	1.575342
163+00-163+200	2	31	2.123288
163+900-164+100	2	26	1.780822
164+500-164+700	2	26	1.780822
165+300-165+500	2	31	2.123288
166+00-166+200	2	23	1.575342
166+400-166+600	2	23	1.575342
169+300-169+500	2	31	2.123288
170+200-170+400	2	33	2.260274
172+600-172+800	2	26	1.780822
173+500-173+700	2	23	1.575342
178+300-178+500	2	31	2.123288
189+200-189+400	2	26	1.780822
189+600-189+800	2	24	1.643836
195+100-195+300	2	25	1.712329
195+800-196+00	2	27	1.849315
160+00-160+200	4	34	2.328767
161+200-161+400	4	32	2.191781
162+100-162+300	4	30	2.054795
163+00-163+200	4	34	2.328767
163+900-164+100	4	30	2.054795
164+500-164+700	4	30	2.054795
165+300-165+500	4	30	2.054795
166+00-166+200	4	32	2.191781
166+400-166+600	4	30	2.054795
169+300-169+500	4	37	2.534247
170+200-170+400	4	32	2.191781
172+600-172+800	4	30	2.054795
173+500-173+700	4	32	2.191781
178+300-178+500	4	34	2.328767
189+200-189+400	4	32	2.191781
189+600-189+800	4	28	1.917808
195+100-195+300	4	29	1.986301
195+800-196+00	4	35	2.39726
160+00-160+200	6	39	2.671233

Raw Data of Depression Distress			
Unit Chainage (KM).	Year	Depression (sq.m)	Density
161+200-161+400	6	42	2.876712
162+100-162+300	6	36	2.465753
163+00-163+200	6	39	2.671233
163+900-164+100	6	36	2.465753
164+500-164+700	6	34	2.328767
165+300-165+500	6	36	2.465753
166+00-166+200	6	39	2.671233
166+400-166+600	6	36	2.465753
169+300-169+500	6	34	2.328767
170+200-170+400	6	42	2.876712
172+600-172+800	6	36	2.465753
173+500-173+700	6	36	2.465753
178+300-178+500	6	39	2.671233
189+200-189+400	6	42	2.876712
189+600-189+800	6	38	2.60274
195+100-195+300	6	40	2.739726
195+800-196+00	6	41	2.808219

Raw Data of Rutting Distress			
Unit Chainage (KM).	Year	Rutting (mm)	Density
160+00-160+200	2	18	0.00123
161+200-161+400	2	15	0.00103
162+100-162+300	2	13	0.00089
168+300-168+500	2	20	0.00137
169+00-169+200	2	15	0.00103
169+300-169+500	2	15	0.00103
172+600-172+800	2	20	0.00137
173+500-173+700	2	13	0.00089
178+300-178+500	2	13	0.00089
178+700-178+900	2	20	0.00137
160+00-160+200	4	22	0.00151
161+200-161+400	4	20	0.00137
162+100-162+300	4	18	0.00123
168+300-168+500	4	22	0.00151
169+00-169+200	4	18	0.00123
169+300-169+500	4	18	0.00123
172+600-172+800	4	18	0.00123
173+500-173+700	4	20	0.00137
178+300-178+500	4	18	0.00123
178+700-178+900	4	25	0.00171
160+00-160+200	6	25	0.00171
161+200-161+400	6	27	0.00185
162+100-162+300	6	22	0.00151
168+300-168+500	6	25	0.00171
169+00-169+200	6	22	0.00151
169+300-169+500	6	20	0.00137
172+600-172+800	6	22	0.00151
173+500-173+700	6	25	0.00171
178+300-178+500	6	22	0.00151
178+700-178+900	6	20	0.00137

Raw Data of Raveling Distress			
Unit Chainage (KM).	Year	Ravelling (sq.m)	Density
161+200-161+400	2	23	1.57534
162+100-162+300	2	20	1.36986
163+00-163+200	2	18	1.23288
163+900-164+100	2	25	1.71233
165+300-165+500	2	20	1.36986
166+00-166+200	2	20	1.36986
166+400-166+600	2	25	1.71233
167+200-167+400	2	18	1.23288
189+600-189+800	2	18	1.23288
195+100-195+300	2	25	1.71233
195+800-196+00	2	19	1.30137
198+200-198+400	2	21	1.43836
203+300-203+500	2	22	1.50685
179+700-179+900	4	27	1.84932
189+200-189+400	4	25	1.71233
161+200-161+400	4	23	1.57534
162+100-162+300	4	27	1.84932
163+00-163+200	4	23	1.57534
163+900-164+100	4	23	1.57534
165+300-165+500	4	23	1.57534
166+00-166+200	4	25	1.71233
166+400-166+600	4	23	1.57534
167+200-167+400	4	30	2.05479
189+600-189+800	4	24	1.64384
195+100-195+300	4	26	1.78082
195+800-196+00	4	28	1.91781
198+200-198+400	4	21	1.43836
203+300-203+500	4	28	1.91781
179+700-179+900	6	30	2.05479
189+200-189+400	6	32	2.19178
161+200-161+400	6	27	1.84932
162+100-162+300	6	30	2.05479
163+00-163+200	6	27	1.84932
163+900-164+100	6	25	1.71233
165+300-165+500	6	27	1.84932

Raw Data of Raveling Distress			
Unit Chainage (KM).	Year	Ravelling (sq.m)	Density
166+00-166+200	6	30	2.05479
166+400-166+600	6	27	1.84932
167+200-167+400	6	25	1.71233
189+600-189+800	6	29	1.9863
195+100-195+300	6	31	2.12329
195+800-196+00	6	31	2.12329
198+200-198+400	6	29	1.9863
203+300-203+500	6	28	1.91781