INTERNATIONAL ROUGHNESS INDEX PREDICTION MODEL FOR FLEXIBLE PAVEMENTS IN SRI LANKA

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Abstract

Due to the significance as an indicator of the pavement condition, International Roughness Index (IRI) is using globally as a pavement performance parameter. It also provides an idea about the riding comfort of a particular road segment and the level of riding quality. Therefore, it is using as a quality assurance criteria of roads just after construction or rehabilitation.

But in Sri Lanka, there is no proper pavement performance models has been developed yet to suite our own conditions. Hence any simple planning level analysis cannot be perform due to lack of a proper performance model(s). In Road Development Authority, HDM 4 software is using for performance modelling and predictions. But, HDM 4 has developed basically taking into account of road conditions in countries all over the world. The aim of this paper is to develop an accurate IRI prediction model for Road pavements in Sri Lanka using linear regression analysis and compare it with the default HDM 4 Model.

The key parameters that the IRI value directly related on a particular pavement was decided based on the literature and the availability of data. The proposed regression model from this paper predict IRI as a function of Pavement Age from construction or last Rehabilitation (years), Average Daily Traffic (ADT), Percentage of Area of All cracks identified on pavement surface (%), Percentage of Raveling Area (%) and Number of potholes. After completing three trials by changing different variables the final IRI prediction model developed is,

$$IRI = 1.594 + 0.207\ Age + 0.1202\ e^{-\ln (ADT / 10^{4})} + 0.1343\ Ravel\ \% + 0.0295\ No.\ of\ potholes$$

A set of available data was used to calibrate the regression model and using other set of data, relationship between the measured and predicted IRI values for the proposed model was observed using the coefficient of correlation (R- value) as a statistical measure to determine how close the data are to the fitted regression line, as the validation process. The proposed model yielded an R-value of 0.75. Finally the developed model was compared with the default HDM 4 Model which is currently using in Sri Lanka.

Key words: IRI, regression analysis, age, AADT, initial IRI, cracks, R-value

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CHAPTER 1: INTRODUCTION

1.1 General Background

Due to the significance as an indicator of the pavement condition, International Roughness Index (IRI) is using globally as a pavement performance parameter. It also provides an idea about the riding comfort of a particular road segment and the level of riding quality. Therefore, it is using as a quality assurance criteria of roads just after construction or rehabilitation.

Prevailing IRI of a pavement can be used to predict required pavement maintenance actions or reconstruction needs. The identification of exact condition of the pavement is required for correct decision making to optimize the cost for the maintenance and management. Therefore, a proper pavement performance model is an essential requirement for a country or a region to perform analysis and for planning the road network.

1.2 Problem Identification and research background

Road Development Authority (RDA) is the main organization in Sri Lanka, which holds the responsibility of the development of the National Road network. Under RDA there is more than 12,000km of Trunk (A Class) and Main (B Class) roads. Also under its purview there is 271.67 km length of Expressways. But, as a developing country and under limited budgetary allowance for maintenance it is difficult to maintain each and every road segment up to the designed Level of Service. So the decision making with regard to maintenance and management become critical under these circumstances. If any proper pavement performance model is available it can be used for perform simple planning level analysis to prepare maintenance schedules and to decide on expenditure choices in long term.

But in Sri Lanka, there is no proper pavement performance models has been developed yet to suite our own conditions. Hence any simple planning level analysis cannot be perform due to lack of a proper performance model(s). In Road Development Authority, HDM 4 software is using for performance modelling and predictions. But, HDM 4 has developed basically taking into account of road conditions in countries all over the world. The available pavement condition prediction model(s) does not interpret the Sri Lankan conditions very well. Also in HDM 4, most of the outcomes (e.g.:

Vehicle Operating Cost, Speed calculations, Travel Time savings, Economic Analysis parameters) has a direct relationship with Roughness.

Therefore, it is essential to have a check on the suitability of this method to analyze the Sri Lankan road conditions considering our own **traffic characteristics, pavement structural parameters, pavement distresses and environmental conditions etc.** A pavement performance model developed for our own conditions can be used as the planning tool for the pavement management system (PMS) to predict the future condition of the road and to calibrate scientific PMS models such as HDM-4 to economize the maintenance process.

1.3 Objectives

Development of a Pavement Performance Prediction Model using Multiple Linear Regression Analysis based on available Pavement Loading, Structural and Environmental parameters to suit with Sri Lankan conditions and compare the results with already using Pavement Performance Prediction Model(s)

1.4 Scope

For the study following Roads were selected extending whole country and representing different climatic conditions.

- All "A" class Roads in Sri Lanka (35 Roads)
- All "B" class Roads of following provinces
    - Western Province
    - Central Province
    - Northern Province

1.5 Structure of the Dissertation

The structure of this report contains following Chapters in order to give organized and extensive understanding to the readers.

Chapter 01 - Introduction

This Chapter includes the introduction part to the study. General background of International Roughness Index (IRI), problem identification for the study, objectives and scope of the study were included.

Chapter 02 – Literature Review

This Chapter collects and analyses extensively the secondary information relates to Pavement Performance Prediction Modelling based on the international studies as well as local studies.

Chapter 03 – Research Methodology

This Chapter describe basic steps followed in this research and strategy to analyze and present data.

Chapter 04 – Data Analysis

This Chapter deeply analyses and presents the primary research evidences. The statistical data analysis was performed using Microsoft Excel and SPSS software and the findings are presented in statistical tables and charts.

Chapter 05 – Conclusions and Recommendations

In this last Chapter of the dissertation which provides the overall summary of the research together with the recommendations based on the analysis.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The concept of the International Roughness Index (IRI) was introduced by the World Bank in the 1980s and it is defined as ‘the accumulated suspension vertical motion divided by the distance travelled as obtained from a mathematical model of a simulated quarter-car traversing a measured profile at 80 km/h (ARA 2004). Around the world, many highway agencies consider the initial IRI value (IRI just after construction or rehabilitation) as a quality assurance criterion while the existing IRI value as an indicator of required pavement improvements needs (Perera and Kohn 2002,Robbins 2016).

Pavements with poor roughness leads to an increase in vehicle maintenance cost, fuel consumption, harmful emissions and decrease in vehicle efficiency. It may result in traffic safety issues and could lead to multi millions loss of money every year (Robbins 2016). For the Pavement Design, considers the current IRI value as one of the design criteria and while the initial IRI is the key input required to do the design (ARA 2004). In most countries the Present Serviceability Rating is using for pavement condition evaluation. It is concluded in many studies, a robust correlation between serviceability and IRI (ARA 2004). Thus, many agencies consider roughness as a pavement condition evaluating parameter over the time. Due to the importance of its usage many Research studies have done around the world related to International Roughness Index (IRI).

2.2 Independent variables used for the performance evaluation

Environment factors should be considered in the model analyzing such as Rainfall data, air temperature, solar radiation, wind speed caused for the alter moisture condition, pavement temperature, asphalt binder aging. (Salini, Pais, Pereira, & Santos, 2008)

Climate condition affect very much on the behaviour of asphalt concrete layers. Pavement temperature depends on the air temperature, wind velocity and solar radiation while solar radiation and UV radiation influence the bonding agent of the pavement. Fatigue life and modulus of elasticity affected by most of the environmental factors which are mentioned above. (Salini, Pais, Pereira, & Santos, 2008)

It is used built sections to get experimental data which are subjected to the accelerated action of traffic and environmental conditions. (J.A.Prozzi & S.M.Madanat, 2005)

Certain type of distresses caused for various type of condition measurement parameters. Rut depth gives measure of the ride quality and comfort. International roughness index (IRI) provide measurement of surface condition and skid resistance, water ponding gives measure of safety performance. (Huvstig, 2012)

Loading data also plays a main role when we design the performance model. Traffic capacity and how its affect to the surface are very important factors to considered. (Huvstig, 2012) Repetition of heavy vehicles, axle arrangement and tyre arrangement of the vehicles, Speed of the vehicle, time duration of the heavy traffic, tyre pavement stresses are the main sub factors should be evaluated separately to identify the their effects on the pavement condition. (Salini, Pais, Pereira, & Santos, 2008), (saba, 2007)

Structural data such as base, sub base, subgrade, asphalt layer thickness, material properties and construction quality also should check with developing the model. (saba, 2007)

There are lots of variables have been chosen to model the pavement performance evaluation. For each country there are identical factors affecting. Before the modelling first, it should be chosen the most suitable variables to represent the Sri Lankan conditions by reviewing the literature. The variables identified during the literature can be grouped into 3 main categories. They are, Environmental, Loading and Pavement structural data.

2.2.1 Environmental Data

Under this category following independent variables are identified during the Literature review.

- Rainfall or precipitation
- Temperature / Solar radiation
- Wind velocity
- Freezing Index

2.2.2 Pavement Loading Data

Under this category following independent variables are identified during the Literature review.

- Equivalent Single Axle Load (ESAL)
- Average Daily Traffic (ADT)

2.2.3 Pavement Structural Data

Under this category following independent variables are identified during the Literature review.

- Pavement Age
- Base, sub base, subgrade strength
- Plasticity Index of soil
- Structural number
- Cracks
- Rutting
- Raveling
- Potholes
- Any other pavement distresses

2.3 Previous IRI models developed

Around the world many researchers have proposed several roughness (in terms of IRI) prediction models. Some of these models were derived based on the Long-Term Pavement Performance (LTPP) database while others were developed by using respective countries' databases.

Some models mainly predict IRI as a function of traffic parameters and/or structural parameters. As an example, George (2000) developed two IRI predictive models using the Mississippi Pavement Management System (MPMS) database. The first model was for the original pavements and the second model was for the overlaid pavements. The first model yielded a coefficient of determination (R^2) of 0.35 based on 690 observations and it is described by Equations (2.1)–(2.4). The second model resulted in an R^2 of 0.48 based on 4109 observations.

$IRI = [2.4169 + Age^{0.2533} (1 + CESAL^{0.2572})] * MSN^{-0.7753}$ ……………Equation (2.1)

Where,

IRI = roughness, m/km

Age = age of pavement since construction, years

CESAL =cumulative 18-kip Equivalent Single Axle Load (ESAL) applied to the pavement (in the heavily trafficked lane) in millions

MSN =modified structural number

Where,

$MSN = SN + SN_{SG}$ …………………….. Equation (2.2)

$SN = a_1D_1+a_2D_2M_2+a_3D_3M_3$…………………….. Equation (2.3)

$SN_{SG} = 3.51*log10CBR- 0.85(log10CBR)-1.43$… Equation (2.4)

Where,

SN = structural number

ai = *i*th layer coefficient

mi = *i*th drainage coefficient

Di = *i*th layer depth

CBR = California bearing ratio

Al-Suleiman and Shiyab (2003) developed two IRI regression models for Dubai (one for the slow lanes and the other for the fast lanes) considering pavement age as the independent variable where an exponential relationship was deduced describing the relation between IRI and age.

$IRI (s) = 0.796 \exp^{(0.0539Age)}$ ……………….Equation (2.5)

IRI (f)= 0.824 $\exp^{(0.0359Age)}$ …………………Equation (2.6)

Where,

IRI(s) = International Roughness Index (mm/m or m/km) in the slow lane

IRI (f) = International Roughness Index (mm/m or m/km) in the fast lane

Age = Age of pavement since construction or last overlay, years

Based on 440 observations for each model, the first model yielded an R^2 of 0.80, while the second model resulted in an R^2 of 0.61.

Nader Abdelaziza et al. (2018) developed IRI models based mainly on pavement distresses conditions. The model yielded an R^2 of 0.57 based on 2439 observations will be described by Equations (2.9) below.

$IRI = IRI_o + 0.01479 * Age + 0.00382 * (F.C)_{all} + 0.00053 * (T.C)_{all} + 0.08941 * SDRUT$……………………………………………………………………………..Equation (2.9)

IRI_o = initial IRI, m/km

Age = age after construction or overlay for original and overlaid pavements respectively

$(F.C)_{all}$ = all severities fatigue cracking (per cent of wheel path area %)

$(T.C)_{all}$ = all severities transverse cracks length, m/km

SDRUT = standard deviation of rut depth, mm

Sadamal and Pasindu (2020) developed IRI model for Thirty-one different road sections in the Western Province National Road Network in Sri Lanka. The model yielded an R2 of 0.79 and standard error (SE) 0.63 for the sample size (N) of 221.

IRI = 6.86 – 4.66exp - $0.0006Age^{3.46}$ ………………………………………… Equation (2.10)

As per the results it can be observed that it has a non-linear relationship between the pavement age and pavement roughness. Furthermore, as per the results, at the early stage (within the first 5 years) of pavement life, significant increase of roughness has not been observed (at 0.14m/km IRI per annum on average) and remains under the IRI value of 3m/km. After that roughness has shown a significant increase until 12th year and steadies at IRI of 7m/km (at 0.54m/km IRI per annum, on average). Further increase was not observed and that could be due to periodic maintenance works.

Furthermore, Sadamal and Pasindu (2020) have performed Multiple Regression Model for Roughness Progression. For that, it was taken Roughness and ADT as the independent variables.

The model yielded an R^2 of 0.83 and the sample size (N) of 79 is shown below in Equation 2.11

$IRI_t = 2.15 + 0.0003Age^{1.7343} (1 + ADT^{0.5075})$………………………………….. Equation (2.11)

In Road Development Authority, HDM 4 software is using for performance modelling and predictions. But, HDM 4 has developed basically taking into account of road conditions in countries all over the world. The available pavement condition prediction model(s) does not interpret the Sri Lankan conditions very well.

In HDM 4 Roughness model consists of several roughness components. They are cracking, disintegration, deformation and maintenance. The total incremental roughness is the sum of these components. The function is shown below in equation 2.12.

$\Delta RI = Kgp + \Delta RIs + \Delta RIc + \Delta RIr + \Delta RIt + \Delta RIe$...Equation (2.12)

Where,

ΔRI = gradual increase of pavement surface roughness

Kgp = calibration factor of general surface roughness development

ΔRIs = structural pavement deterioration

ΔRIc = deterioration due to cracking

ΔRIr = deterioration due to rutting

ΔRIt = deterioration due to potholes

ΔRIe = deterioration due to climate effects

The effect of distresses due to pothole, cracking and raveling, is established by using equations following equations.

$\Delta RIe = Kgm.\ m.\ RIa$.. Equation (2.13)

$\Delta RIc = Kgc.\ a0.\ \Delta ACRA$ .... Equation (2.14)

$\Delta RIp = Kgp.\ a0.\ (a1 - FM).\ (NPTbu)\ a2$ .... Equation (2.15)

m = temperature and precipitation adjustment factor (0.02 for Sri Lanka)

RIa = IRI at start of the analysis

$\Delta ACRA$ =incremental changing area percentage (%) during analysis year

FM =freedom to manuovre

NPTbu = number of potholes in a kilometer

a0, a1, a2 =constants

Kgm,, Kgc, Kgp are the calibration factors for environmental, cracking and potholes, respectively.

Summary of Models identified in the Literature Review is summarized in Table 2.1 below.

Table 2. 1 Summary of Models identified in the Literature Review

Model	**Age**	**Initial IRI**	**Distress**	**Climate**	**Soil**	**Traffic**	**Structural**	**Goodness of fit**
George (2000)	√	-	-	-	-	ESAL	SN	N=690 R^2=0.35
Al-Suleiman (2003)	√	-	-	-	-	-	-	N=440 R^2=0.6-0.8
Lin et al. (2003)	-	-	RUT, FC , BLEED, PATCH , POT, STRP, CORG	-	-	-	-	N=125 R^2=0.94
MEPDG (2004)	√	√	RUT, FC,TC, LC, BC	FREEZING	P_{200}	-	-	N=353 R^2=0.62
Pavement ME Design (2008)	√	√	RUT, FC,TC	PRECIPITATION, FREEZING	PI	-	-	N=1926 R^2=0.56
Khattak et al. (2014)	√	√	-	PRECIPITATION, TEMP.	-	ESAL	ASPHALT THICKNESS	N=623 R^2=0.87
Abdelaziz et al. (2018)	√	√	RUT, FC,TC	-	-	-	-	N=2439 R^2=0.57
Kelum and Pasindu (2020)	√	√	-	-	-	ADT	-	N=79 R^2=0.83

NOTE : BC- Block Cracks, CORG- Corrugation, ESAL- Equivalent Standard Axle Load, FC- Fatigue Cracks, LC- Longitudinal Cracks, PI- Plasticity Index, P_{200}- Passing through #200 sieve, PATCH-Patching, POT- Pot Holes, RUT- Rutting, SN- Structural Number, TC- Transverse Cracks, TEMP- Temperature Index, ADT-Average Daily Traffic

2.4 Testing Procedures

After choosing suitable variables, proper test procedure and data surveying of the selected variables should be done. To evaluate each variable separated test procedure should be used.

Test the pavement response, there should be conducted evaluation from the response variables such as skid resistance, roughness etc. Studying the pavement total elastic deformation Multi Depth Deflect meter (MDP) can be used under the control environment. By this value it can be obtained elastic behaviour of the entire layers of asphalt or concrete, base layer and subgrade. (Salini, Pais, Pereira, & Santos, 2008)

Pavement material which are used for the highway construction plays an important role. There are few types of basic materials such as only bituminous wearing courses, including asphalt, including surface dressing and concrete pavement. While considering that layer material respectively its performance model can be extended. (Technical committe 4.2 road pavements, 2016)

In the test procedure it can be used newly constructed pavement sections with different arrangement while controlling those variables. With same truck arrangement, same axle arrangement it can be modelled same truck traffic. Surface thickness (25mm-150mm), Base thickness(0mm-225mm),subgrade thickness(0mm-400mm) ranges used for the 284 test section with 32 duplicate sections to check the validity of the estimated model. (J.A.Prozzi & S.M.Madanat, 2005).To evaluates the roughness value of the pavement surface test procedures should be used with suitable scientific approach by using the bump integrator.

Introducing a threshold to evaluate the performance is must when building a performance model. Maintain threshold and intervention threshold (End of the service life) are the two-threshold used in the field. After choosing that threshold parameter should be considered in general, Technical and method with appropriate measuring devices and standards. (Technical committe 4.2 road pavements, 2016). From those thresholds, it can be get an idea about the data collecting procedure limitation.

2.5 Behavior of the variables

From evaluating the behavior of the variables some improvement technologies and relationship between the variables and pavement response can be obtained.

Initial serviceability (Perfect planer surface, 5PSI) can increase by increasing the asphalt layer thickness with better quality of finished surface. High strength material with higher strength pavement provides slower serviceability decreasing rate. (J.A.Prozzi & S.M.Madanat, 2005)

In environmental consideration, temperature and moisture variation affects lot to the stress-strain condition of the pavement sections. When moisture content decreases, the inter particle friction decrease, then it will be caused for reduction of material strength and stiffness. (Ghazi & Khalid, 2013)

In different level of significance there are some variables behave in very much important. In project level budget should be minimize with the suitable arrangement. In the state or province level surveys should done for effects on user costs and overweight fees. In addition to that monitoring data such as distresses in the pavement, traffic capacity and deflection of flexible pavement sections, surface friction and functional index should be evaluated regularly. (Lytton, 2011)

CHAPTER 3: METHODOLOGY

This research study started with comprehensive analysis of the relevant literature. Key independent variables were listed out from previous studies around the world and their relevant significance was critically analyzed. Special attention was given for studies that were conducted similar to our Geographic and Environmental conditions.

Then, the data were extracted for the study from the Road condition survey database maintaining by the Road Development Authority of Sri Lanka (RDA). They are maintaining this database for roughness measurements in the class A&B roads in Sri Lanka. The routine roughness survey data were collected using Multi-Functional Network Survey Vehicle (Hawkeye 2000) was available from 2013 onwards. Other parameters required to represent different environmental conditions were also collected.

Selection of independent variables used for the study was done by considering the availability of relevant data. Though a large number of variables were identified during the literature they have to reduce to a limited number due to this reason.

The database processing was accomplished in several steps. It was identified that the location where ADT data was collected as the decisive parameter that limits data points for analysis. Hence, after referring literature it was decided to do segmentation of 1km Road stretch (500m before and 500m after) of each ADT location and that segment was taken as one data point. Segments not having historical records or/and distress parameters was neglected. From raw data directly obtain from survey vehicle, Average IRI value (for both LHS & RHS) was calculated for every 100m intervals. Finally average IRI value for each segment was found separately. All the other selected variables were also processed to a format suitable with above segmentation.

Finally, the pavement performance model was developed using Multiple Linear Regression Analysis method (MLR). Then the developed model was statistically validated using some simple statistical tests. Then the developed model was compared with the HDM 4 model which is currently using in Sri Lanka as a pavement performance model.

CHAPTER 4: DATA ANALYSIS

4.1 Selection of Road Network

As described earlier in section 1.2, under the purview of RDA it is comprising more than 12000km of both A and B Class roads and 271.67 km length of Expressways. Developing a model covering entire road network is very difficult and will consume a long time. Therefore, a sample network has to be selected to represent the entire network and it was done based on following criteria.

- All "A" class Roads in Sri Lanka (35 Roads) selected because they extending through whole country and passes through different ADT categories and as well as different environmental conditions.
- All "B" class Roads of following provinces as they are representing different environmental and geographic conditions.
    - Western Province
    - Central Province
    - Northern Province

Average annual Temperature and Rainfall of those provinces are as follows.

Table 4. 1 Average annual Temperature and Rainfall of selected provinces

Province	**Average Annual Temp. / (·C)**	**Average Annual Rainfall/ (mm)**
Western	27.4	1840
Central	24.5	2420
Northern	28	1231

4.2 Data Collection

The variables identified during the literature review can be grouped under 3 main categories. They are,

- Pavement Structural data
- Loading data
- Environment data

During the Data collection it was tried to include at least one variable representing above 3 categories.

4.2.1 Pavement Structural data

Under pavement structural parameters category following data were collected from the Road Development Authority of Sri Lanka.

- International Roughness Index (IRI-m/km)
- Pavement Age from construction or last Rehabilitation (years)
- Percentage of Area of All cracks identified on pavement surface (%)
- Percentage of Raveling Area (%)
- Number of potholes

4.2.1.1 International Roughness Index (IRI-m/km)

Roughness data was collected from the Planning Division of the Road Development Authority. They are conducting Roughness measurements in class A&B roads in Sri Lanka using the Multi-Functional Network Survey Vehicle (MFNSV). The routine roughness survey data is available from year 2013 onwards. The data is in the form of each 100m intervals with relevant IRI values for both sides of a Road section (LHS and RHS separately). IRI value for each 100m section was obtained by averaging those two values as shown in the below table.

Table 4. 2 IRI measurements data sheet collected from MFNSV

Road Number	**From (km)**	**To (km)**	**LHS IRI Average (m/km)**	**RHS IRI Average (m/km)**	**Average IRI (m/km)**	**Survey Day**
A0000	216	292	4.51	3.90	3.77	2018-11-06
A0000	292	392	3.65	3.86	3.94	2018-11-06
A0000	392	492	3.25	4.50	4.50	2018-11-06
A0000	492	592	3.69	4.51	4.51	2018-11-06
A0000	592	692	4.01	3.88	3.88	2018-11-06
A0000	692	792	2.96	4.64	4.64	2018-11-06
A0000	792	892	3.25	4.16	4.16	2018-11-06
A0000	892	992	2.99	9.00	9.00	2018-11-06
A0000	992	1092	5.29	4.88	5.09	2018-11-06
A0000	1092	1192	3.97	4.57	4.27	2018-11-06
A0000	1192	1292	3.52	3.03	3.28	2018-11-06
A0000	1292	1392	3.91	4.20	4.06	2018-11-06
A0000	1392	1492	3.09	3.89	3.49	2018-11-06
A0000	1492	1592	3.41	3.15	3.28	2018-11-06
A0000	1592	1692	2.52	5.69	4.11	2018-11-06
A0000	1692	1792	2.52	4.15	3.34	2018-11-06
A0000	1792	1892	2.52	4.15	3.34	2018-11-06
A0000	1892	1992	4.14	6.38	5.26	2018-11-06

4.2.1.2 Pavement Age from construction or last Rehabilitation (years)

Pavement age is the time duration after construction or major rehabilitation work done on the road. Normally, pavement condition is excellent just after construction or rehabilitation completed. But, with the time it opens to the vehicle traffic, the permanent deformations are beginning to occur on pavement. Also for the development of the deterioration curve, age of the pavement is use as the independent variable.

It is required to get the latest rehabilitation date to calculate the pavement age. This data was collected from two different divisions of the Road Development Authority. From Foreign Funded Projects Division details of latest rehabilitation projects were obtained. From the Maintenance & Management Division details of latest rectification works were obtained.

When collecting rehabilitation data major difficulty was to find out the exact completion date of the entire road section/stretch. When constructing or rehabilitating a road it is normally done in segments. Length of a segment differ from each another. Each segment has different completion date and different date of opening for traffic. But this record is not available in any project. Completion and Handing over date for entire project was available and therefore that date was considered as the completion date of the entire road section/stretch. Roads segments not having historical records or unrealistic records was neglected using engineering judgment.

4.2.1.3 Area of All cracks identified on pavement surface

There are many types of cracks available on pavement surfaces. In some literature it was found that certain types of cracks area were included individually when developing models (eg : Block cracks, Fatigue cracks, Longitudinal cracks). In some models all cracks area identified was used as a block area in developing models. Since in the RDA pavement performance database includes only the total cracks area, it was decided to use all cracks identified on pavement surface as an independent variable using for developing the model.

4.2.1.4 Area of Raveling

Though, Raveling is not frequently identified distress pattern in Sri Lankan pavements it was included as an independent variable for developing the model. Area of Raveling can be directly obtained from RDA pavement performance database.

4.2.1.5 Number of potholes

Potholes are frequently identified distress pattern in Sri Lankan pavements. The criteria for calculating Number of potholes will be described in section 4.4.5.

A raw data sheet obtained including above 3 parameters is shown in Table 4.3 below.

Table 4. 3 Pavement distresses data sheet collected from MFNSV

Road No.	**From (m)**	**To (m)**	**All Crack Area (m2)**	**Raveling (m2)**	**Number of Potholes**	**Survey Date**
B034	0	93	0	62.23	0	2018-02-09
B034	93	193	0	0	0	2018-02-09
B034	193	293	0	28.56	0	2018-02-09
B034	293	394	0	0	0	2018-02-09
B034	394	494	7.03	0	0	2018-02-09
B034	494	594	0	11.05	0	2018-02-09
B034	594	694	0	0	0	2018-02-09
B034	694	794	0	27.32	0	2018-02-09
B034	794	895	21.59	18.75	0	2018-02-09
B034	895	995	2.33	0	0	2018-02-09
B034	995	1095	0	4.63	0	2018-02-09

4.2.2 Pavement Loading data

Under pavement loading parameters following two independent variables was frequently used in literature.

- Equivalent Single Axle Load (ESAL)
- Average Daily Traffic (ADT)

Depending on the data availability it was decided to use ADT as the independent variable to include as a pavement loading parameter. A raw data sheet obtained including ADT data is shown below in Table 4.4.

Table 4. 4 ADT data sheet collected from RDA

ROUTE NO	NAME OF ROAD	LOCATION	LATEST	
		KM	ADT	YEAR
AA000	Kollupitiya - Sri Jayewardenepura	3.0	74811	2017
AA000	Kollupitiya - Sri Jayewardenepura	5.0	72101	2010
AA000	Kollupitiya - Sri Jayewardenepura	7.0	138825	2018
AA001	Colombo - Kandy	6.0	90548	2010
AA001	Colombo - Kandy	10.0	60173	2011
AA001	Colombo - Kandy	24.0	27451	2015
AA001	Colombo - Kandy	27.0	27361	2003
AA001	Colombo - Kandy	31.0	23549	2004
AA001	Colombo - Kandy	36.0	39026	2016
AA001	Colombo - Kandy	41.0	36290	2016
AA001	Colombo - Kandy	44.0	16107	2003
AA001	Colombo - Kandy	52.0	25006	2013
AA001	Colombo - Kandy	55.0	29703	2017
AA001	Colombo - Kandy	59 (58)	40231	2018
AA001	Colombo - Kandy	68.0	21070	2016
AA001	Colombo - Kandy	78.0	12573	2000
AA001	Colombo - Kandy	81.0	15838	2005
AA001	Colombo - Kandy	91.0	33347	2016
AA001	Colombo - Kandy	95.0	24155	2017
AA001	Colombo - Kandy	100.0	23033	2017

4.2.3 Environment data

No parameter is included representing Environmental category due to non-availability of data.

4.3 Factors consider before Data Processing

4.3.1 Identify significant variables

When collecting data it was identified that IRI measurements, pavement age and other distress parameters are available continuously in a selected road segment. But, ADT data are available only at particular locations in a selected road segment as shown in above figure 4.3. ADT data vary from place to place even on the same road hence it directly depends on the vehicle accumulation from connecting roads. Therefore, ADT data of a particular location cannot be taken as an average value to represent whole road segment selected. Considering these factors it was identified that ADT data is the decisive parameter that limits data points available for analysis.

4.3.2 Selection of Segmentation

As per Austroads – Research Report AP-R566-18A, lane segment length of 100 m was preferred for processing convenience although other lengths were considered. Further it described that the most important to note that the first step of lane segment selection was to identify segments with available maintenance history within the datasets supplied by the contributing road agencies.

Considering the facts from above report and as well as from the literature it was decided to select 1000m segments considering 500m before and after each ADT Location. It was assumed that the ADT value was not significantly change within 500m distance before and after each ADT Location.

4.3.3 Selection of Data range

Segments not having historical records or/and distress parameters were neglected. Also, in segments which having historical records it was observed that some records were not practically acceptable. For an example a road segment having longer life span of more than 30 years, practically cannot have a small IRI value (eg:1 or 2). There is not any proper database maintaining in RDA to obtain maintenance records and therefore they were collected from respective regional offices of RDA. Most of these records are manually entered and not properly maintained also. Therefore reliability of data was very low. Hence it was decided to eliminate data points having pavement age more than 20 years and to remove unacceptable data by using Engineering judgment. Then the data set was reduced to 484 data points.

4.4 Data Process

4.4.1 ADT Data

ADT data is identified as the decisive parameter for analysis and hence it was arranged for analysis at first. When examine ADT data it was noted that the data collected year was different from point to point even on the same road. They had to predict for the year of other parameters collected such as IRI and other distress parameters. In all selected roads for this analysis IRI and other distress parameters were available in the year 2018 only. Hence, it was decided to convert all ADT data as a predicted value for year 2018.

To predict ADT data following simple equation was used.

$ADT\ (predict) = ADT\ (current) x\ (1 + growth\ rate)$^ (No. of years) ……..Equation 4.1

Vehicle growth rates are preparing annually by the Planning division of the Road Development Authority and for year 2015-2018 period average annual growth in Sri Lanka was calculated as 3.5%. For ADT data collected before 2015, same growth rate was assumed.

Specimen calculations

ADT Data on A000 (Kollupitiya- Sri Jayawardenapura) at 3^{rd} km is 74811 in year 2017.

$ADT\ (2018)$ $= 74811 *$ (1+.035) ^ (2018-2017)

= 77429

Sample of processed ADT sheet is shown below in Table 4.5 below.

Table 4. 5 Sample of Processed ADT sheet for analysis

ROUTE NO	NAME OF ROAD	PROV.	LOCATION	LATEST		Prediction 2018
			KM	ADT	YEAR	
AA000	Kollupitiya - Sri Jayewardenepura	West	3.0	74811	2017	77429
AA000	Kollupitiya - Sri Jayewardenepura	West	5.0	72101	2010	94943
AA000	Kollupitiya - Sri Jayewardenepura	West	7.0	138825	2018	138825
AA001	Colombo - Kandy	West	6.0	90548	2010	119234
AA001	Colombo - Kandy	West	10.0	60173	2011	76557
AA001	Colombo - Kandy	West	24.0	27451	2015	30435
AA001	Colombo - Kandy	West	27.0	27361	2003	45839
AA001	Colombo - Kandy	West	31.0	23549	2004	38119
AA001	Colombo - Kandy	West	36.0	39026	2016	41806
AA001	Colombo - Kandy	West	41.0	36290	2016	38875
AA001	Colombo - Kandy	West	44.0	16107	2003	26985
AA001	Colombo - Kandy	West	52.0	25006	2013	29699
AA001	Colombo - Kandy	West	55.0	29703	2017	30743
AA001	Colombo - Kandy	Sab	59.0	40231	2018	40231
AA001	Colombo - Kandy	Sab	68.0	21070	2016	22571
AA001	Colombo - Kandy	Sab	78.0	12573	2000	23354
AA001	Colombo - Kandy	Sab	81.0	15838	2005	24770
AA001	Colombo - Kandy	Sab	91.0	33347	2016	35722
AA001	Colombo - Kandy	Sab	95.0	24155	2017	25000
AA001	Colombo - Kandy	Cent	100.0	23033	2017	23839
AA001	Colombo - Kandy	Cent	107 .0	13520	2000	25113
AA001	Colombo - Kandy	Cent	111.0	36064	2010	47489
AA001	Colombo - Kandy	Cent	112.0	23242	2014	26671

4.4.2 Pavement Age

Even on the same road rehabilitation or improvement was completed in different segments and hence Pavement age from after construction or major rehabilitation/improvement work was different from segment to segment. For different segment age was calculated in year 2018 since ADT data also predicted for year 2018.

Sample of processed Pavement age sheet is shown in Table 4.6 below.

Table 4. 6 Processed Pavement age sheet for analysis

Route	From (m)	To (m)	Last Rehabilitation Year	Latest IRI Year	AGE / (years)	IRI
A000	0.000	0.949	2010	2017	7	4.09
A000	0.949	3.564	2013	2017	4	4.33
A000	3.500	5.000	2011	2017	6	3.52
A000	5.000	7.000	2011	2017	6	3.51
A001	6.800	8.800	2014	2017	3	2.95
A001	8.800	10.800	2014	2017	3	1.84
A001	10.800	12.800	2014	2017	3	1.52
A001	12.781	16.000	2011	2017	6	2.75
A001	39.236	42.000	2009	2017	8	3.68
A002	42.000	44.000	2009	2017	8	2.53
A001	44.000	46.000	2009	2017	8	2.78
A001	46.000	48.000	2009	2017	8	2.67
A001	48.000	50.000	2009	2017	8	2.87
A001	50.000	52.000	2009	2017	8	2.85
A001	52.000	54.000	2009	2017	8	2.90
A001	54.000	56.000	2009	2017	8	2.96
A001	56.000	58.000	2009	2017	8	3.26
A001	58.000	60.000	2009	2017	8	2.91
A001	60.000	62.000	2009	2017	8	2.57
A001	62.000	64.000	2009	2017	8	2.32
A001	64.000	66.000	2009	2017	8	2.61
A001	66.000	68.000	2009	2017	8	2.59
A001	68.000	70.000	2009	2017	8	2.38
A001	70.000	72.000	2009	2017	8	2.34
A001	72.000	74.000	2009	2017	8	3.09
A001	74.000	76.000	2009	2017	8	2.64
A001	76.000	78.000	2009	2017	8	3.42

4.4.3 IRI Measurements

Processing IRI data for analysis was completely depends on ADT data. Depending on the ADT location IRI data was extracted as segments as per the procedure described in above section 4.2.2.

Average IRI value for each 100m section (For both LHS & RHS) was averaged for each selected 1000m segments as per ADT location.

<u>Specimen calculations</u>

<u>ADT data point on A000 (Kollupitiya- Sri Jayawardenapura) at 3+000 km</u>

Road	From	To	LHS	RHS	Avg.	Date
A0000	2592	2692	4.24	5.05	4.65	2018-11-06
A0000	2692	2792	3.74	4.64	4.19	2018-11-06
A0000	2792	2892	4.41	4.20	4.31	2018-11-06
A0000	2892	2992	2.92	5.22	4.07	2018-11-06
A0000	2992	3092	2.92	8.95	5.94	2018-11-06
A0000	3092	3192	2.68	3.72	3.20	2018-11-06
A0000	3192	3292	2.68	3.21	2.95	2018-11-06
A0000	3292	3392	4.98	5.42	5.20	2018-11-06
A0000	3392	3492	3.63	3.80	3.72	2018-11-06
A0000	3492	3592	7.35	2.13	4.74	2018-11-06

Since the ADT location is 3+000 segment from 2+592 to 3+592 was selected.

Average IRI value for 2+592 to 3+592 = (4.65+4.19+4.31+4.07+5.94+3.2+2.95+5.2+3.72+4.74) / 10

= 4.29

Sample of processed IRI measurements sheet is shown below in Table 4.7 below.

Table 4. 7 Processed IRI measurements sheet for analysis

Road Number	From(km)	To(km)	LHS IRI Avg (m/km)	RHS IRI Avg (m/km)	Average IRI (m/km)	Survey Day	Average for Segment
A000	2592	2692	4.24	5.05	4.65	2018-11-06	4.29
A000	2692	2792	3.74	4.64	4.19	2018-11-06	
A000	2792	2892	4.41	4.20	4.31	2018-11-06	
A000	2892	2992	2.92	5.22	4.07	2018-11-06	
A000	2992	3092	2.92	8.95	5.94	2018-11-06	
A000	3092	3192	2.68	3.72	3.20	2018-11-06	
A000	3192	3292	2.68	3.21	2.95	2018-11-06	
A000	3292	3392	4.98	5.42	5.20	2018-11-06	
A000	3392	3492	3.63	3.80	3.72	2018-11-06	
A000	3492	3592	7.35	2.13	4.74	2018-11-06	
A000	4592	4692	2.76	2.10	2.43	2018-11-06	2.85
A000	4692	4792	3.35	2.47	2.91	2018-11-06	
A000	4792	4892	2.66	2.52	2.59	2018-11-06	
A000	4892	4992	3.26	4.23	3.75	2018-11-06	
A000	4992	5092	3.54	3.79	3.67	2018-11-06	
A000	5092	5192	3.39	1.92	2.66	2018-11-06	
A000	5192	5292	1.94	1.86	1.90	2018-11-06	
A000	5292	5392	1.98	2.03	2.01	2018-11-06	
A000	5392	5492	2.67	3.62	3.15	2018-11-06	
A000	5492	5592	3.56	3.41	3.49	2018-11-06	

4.4.4 Area of All cracks and Area of Raveling identified on pavement surface

Cracks and Raveling area identified on a particular segment has been calculated for Total area of the pavement section considered. Depending on the ADT location Cracks and Raveling data was extracted as segments as per the procedure described in above section 4.2.2.

Average Cracks and Raveling area for each 100m section was averaged for each selected 1000m segments as per ADT location. But, this value has been calculated for Total area of the pavement section considered. But pavement width is different from place to place even along same road. Therefore this has to be converted to a percentage area in order to do a comparative analysis. So this value was has to be divided from road width of that section.

Specimen calculations

Data point on A001 (Colombo - Kandy) at 41+000 km

Road No.	From (m)	To (m)	All Crack Area (m2)	Raveling (m2)
A0001	40598	40698	164.78	0
A0001	40698	40798	179.7	36.83
A0001	40798	40898	31.21	11.96
A0001	40898	40998	35.13	31.73
A0001	40998	41098	83.22	12
A0001	41098	41198	67.6	8.82
A0001	41198	41298	58.47	0
A0001	41298	41398	58.66	18.97
A0001	41398	41498	95.97	58.18

Average crack area for 40+598 -41+598 =

(164.78+179.7+31.21+35.13+83.22+67.6+58.47+58.66+95.97)/ 9

= 88.30

Average width of the section = 7.4 m

Since, measurements are taken in 100m intervals,

Area of the section considered = 7.4 x 100 = 740 m^2

% of Average crack area = (88.3 / 740) x 100

= 11.93 %

Average crack area for 40+598 -41+598 = (0+36.83+11.96+31.73+12+8.82+0+18.97+58.18)/9

= 19.83

= (19.83/7.4) x 100

= 2.68 %

Sample of processed Average Cracks and Raveling area is shown below in Table 4.8 below.

Table 4. 8 Processed Cracks and Raveling areas for analysis

ROUTE	km	IRI	ADT	Age	Crack%	Ravel %
AA000	3.0	4.2945	77429	4	0.00	0.00
AA000	5.0	2.853	94943	6	0.00	2.80
AA000	7.0	3.792	138825	6	1.24	0.74
AA001	41.0	3.09	38875	8	11.93	2.68
AA001	44.0	3.142	26985	8	13.59	10.75
AA001	52.0	2.892	29699	8	5.18	0.72
AA001	55.0	3.006	30743	8	5.66	4.05
AA001	59.0	3.3345	40231	8	2.32	2.00
AA001	68.0	2.5675	22571	8	11.16	1.55
AA001	78.0	2.6215	23354	8	0.02	0.00
AA001	81.0	2.524	24770	8	0.29	0.26
AA001	91.0	4.1525	35722	8	4.73	18.98
AA001	95.0	4.286	25000	8	0.58	1.83
AA001	100.0	3.6985	23839	8	0.29	0.16
AA001	107.0	2.9715	25113	8	0.68	2.69
AA001	111.0	3.7175	47489	8	10.73	1.58

4.4.5 Number of potholes

According to the HDM4 software definition, a pothole is defined as a circular area of radius 0.1m regardless of its depth. As per this definition Number of potholes were calculated and averaged in to required segment length.

As per the data processing methods described above from section 4.3.1 to 4.3.5 final spreadsheet was prepared for analysis and a section of that spreadsheet is shown below in Table 4.9.

Table 4. 9: Sample of final spreadsheet prepared for analysis

ROUTE	km	IRI	ADT	Age	Crack%	Ravel %	Pot holes (Nos.)
AA000	3.0	4.2945	77429	4	0.00	0.00	0.00
AA000	5.0	2.853	94943	6	0.00	2.80	0.00
AA000	7.0	3.792	138825	6	1.24	0.74	0.00
AA001	41.0	3.09	38875	8	11.93	2.68	6.54
AA001	44.0	3.142	26985	8	13.59	10.75	0.00
AA001	52.0	2.892	29699	8	5.18	0.72	9.96
AA001	55.0	3.006	30743	8	5.66	4.05	4.10
AA001	59.0	3.3345	40231	8	2.32	2.00	0.00
AA001	68.0	2.5675	22571	8	11.16	1.55	0.00
AA001	78.0	2.6215	23354	8	0.02	0.00	0.00
AA001	81.0	2.524	24770	8	0.29	0.26	9.74
AA001	91.0	4.1525	35722	8	4.73	18.98	20.75
AA001	95.0	4.286	25000	8	0.58	1.83	0.00
AA001	100.0	3.6985	23839	8	0.29	0.16	0.00
AA001	107.0	2.9715	25113	8	0.68	2.69	0.00

CHAPTER 5: DATA ANALYSIS

In the final spreadsheet prepared for the analysis contains 484 data points. For the calibration of the model it was decided to use 360 data points (around 75% of total) and 124 data points (around 25% of total) for the validation. Collected data was analyzed with the Microsoft Excel spreadsheets and SPSS data analysis software. During initial modelling, simple regression analysis between IRI and selected independent variables were developed. Then the model was redone with variables which shows higher correlation with IRI.

5.1 Trail 1

Results obtained during initial modelling for Regression coefficients is as follows:

Table 5. 1 Test Results obtained from Trial1

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.9305204	0.159519449	12.1021	1.94E-28	1.616792	2.244248
ADT x 10^4	-1.113E-05	4.96828E-06	-2.2399	0.025719	-2.1E-05	-1.4E-06
Age	0.2192511	0.014471256	15.1508	2.69E-40	0.19079	0.247712
crack%	-0.016663	0.026049095	-0.63968	0.522798	-0.06789	0.034568
Ravel %	0.1514803	0.016443446	9.212197	2.92E-18	0.119141	0.18382
No. of Pot holes	0.0297955	0.011073675	2.690664	0.00747	0.008017	0.051574

Hypothesis Test was developed to examine the relationship between Independent variables with Roughness. The developed hypothesis was,

H_0 = IRI is not related to Age, ADT, Cracks%, Ravel%, No. of potholes

H_1 = IRI is related to Age, ADT, Cracks%, Ravel%, No. of potholes

Cracks% doesn't reflect adequately the impact on roughness since it has relatively higher p-value and coefficient of less than zero. Then the null hypothesis can be accepted. Thus, it can be concluded that a relation does not exists between the IRI with cracks % . Though, the *p*-value of the regression coefficient of ADT are lower than the significance level (α = 5%), it has a coefficient of less than zero. But due to its significant impact to the IRI identified in the literature and it has a lower p-value than the significance level (α = 5%), it was decided not to remove ADT as an independent variable.

5.2 Trail 2

Depending on the above results model was rerun without cracks %. Test results can be summarized as in the below table.

Table 5. 2: Test Results obtained from Trial2

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.926854934	0.159283	12.09702	1.97E-28	1.613594172	2.240116
Age	0.218527552	0.014415	15.1598	2.34E-40	0.190177864	0.246877
ADTx10^4	-0.1129231	0.049575	-2.27781	0.023333	-0.21042	-0.01542
Ravel %	0.149231604	0.01605	9.297986	1.51E-18	0.11766649	0.180797
No. of Pot holes	0.028980754	0.010991	2.636773	0.008739	0.007364904	0.050597

For this trial also a Hypothesis Test was developed to evaluate the adequacy of the proposed model. This analysis was conducted with,

H_0 = IRI is not related to Age, ADT, Ravel%, No. of potholes

H_1 = IRI is related to Age, ADT, Ravel%, No. of potholes

The null hypothesis in both tests is rejected as the *p*-values of the independent variables are lower than the significance level (α = 0.05). Therefore, it can be concluded that a relation exists between independent variables with IRI.

Analysis of Variance (ANOVA) test was conducted for further validation of the obtained results. This test was conducted with the same null hypothesis and alternate hypothesis developed above. ANOVA test results can be summarized below as in Table 5.3.

Table 5. 3: ANOVA Test Results obtained from Trial2

	df	SS	MS	F	Significance F
Regression	4	1418.148	354.537	146.152	1.23071E-73
Residual	354	858.7371	2.425811		
Total	358	2276.885			

Further, each independent variables was evaluated by evaluating each regression coefficient by developing another hypothesis test that the null hypothesis is coefficient equals zero. Since the *p*-value of ANOVA test also lower than the risk level (α = 5%), the null hypothesis is rejected. Therefore, it can be concluded that a relation exists between the independent variables with IRI.

After completing two trials by changing different variables the final IRI prediction model developed is, described by Equation 5.1 as follows:

IRI = 1.927 + 0.219Age – 0.1129 ADT + 0.1509 Ravel % + 0.0265 No. of potholes (Equation 5.1)

Regression statistics of the developed model can be summarized as in Table 5.4 below. The Model yielded fairly good results compared to Models identified in the Literature Review.

Table 5. 4: Regression statistics of the developed model Trial 2

Multiple R	0.789
R Square	0.622
Adjusted R Square	0.619
Standard Error	1.557
Observations	360

5.3 Trial 3

In the previous model obtained in Trial 2, ADT has a coefficient of less than zero. Hence the model was redeveloped by using exponential values of ADT. Test results can be summarized as in the below table.

Table 5. 5: Test Results obtained from Trial3

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.59473531	0.133702967	11.92745	8.47E-28	1.331783	1.857687
Age	0.20733762	0.014099416	14.70541	1.53E-38	0.179608	0.235067
Ravel %	0.13433896	0.015771865	8.517633	4.73E-16	0.103321	0.165357
No. of Pot holes	0.0295162	0.010579482	2.789947	0.005557	0.00871	0.050323
$e^{-\ln(ADT/10^4)}$	0.120268	0.02162154	5.562452	5.25E-08	0.777454	0.162790

For this trial also a Hypothesis Test was developed to evaluate the adequacy of the proposed model. This analysis was conducted with,

H_0 = IRI is not related to Age, ADT, Ravel%, No. of potholes

H_1 = IRI is related to Age, ADT, Ravel%, No. of potholes

The null hypothesis in both tests is rejected as the *p*-values of the independent variables are lower than the significance level ($\alpha = 0.05$). Therefore, it can be concluded that a relation exists between independent variables with IRI.

Analysis of Variance (ANOVA) test was conducted for further validation of the obtained results. This test was conducted with the same null hypothesis and alternate hypothesis developed above. ANOVA test results can be summarized below as in Table 5.6.

Table 5. 6: ANOVA Test Results obtained from Trial3

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	1475.597	368.899	162.98	6.0892E-79
Residual	354	801.2878	2.26352		
Total	358	2276.885			

Further, each independent variables was evaluated by evaluating each regression coefficient by developing another hypothesis test that the null hypothesis is coefficient equals zero. Since the *p*-value of ANOVA test also lower than the risk level (α = 5%), the null hypothesis is rejected. Therefore, it can be concluded that a relation exists between the independent variables with IRI.

After completing three trials by changing different variables the final IRI prediction model developed is, described by Equation 5.2 as follows:

IRI = 1.594 + 0.207 Age + 0.1202 $e^{-\ln(ADT/10^{4})}$ + 0.1343 Ravel % + 0.0295 No. of potholes……………. (Equation 5.2)

Regression statistics of the developed model can be summarized as in Table 5.7 below. **The Model yielded very good results compared to Models identified in the Literature Review.**

Table 5. 7: Regression statistics of the developed model Trial 3

Multiple R	0.805
R Square	0.648
Adjusted R Square	0.644
Standard Error	1.504
Observations	360

5.4 Validation of the Model

For the validation of the model a separate set of data points were used (124 points). Using the above developed model in Equation 5.2, IRI value was predicted for each data point and that was plotted with the actual measured IRI value. A sample of prepared spreadsheet for the validation process can be shown as below.

Table 5. 8: Sample of final spreadsheet prepared for validation process

ROUTE	km	IRI	Age	Ravel%	No. of potholes	ADT	e^{-ln} (ADT/10^4)	IRI Measured	IRI Predicted
AA001	10	2.06	3	0.00	0	76557	0.13	2.06	2.23
AA001	52	2.89	8	0.72	9.96	29699	0.34	2.89	3.66
AA001	68	2.57	8	1.55	0	22571	0.44	2.57	3.54
AA001	91	4.15	8	18.98	20.75	35722	0.28	4.15	6.70
AA001	111	3.72	8	1.58	3.05	47489	0.21	3.72	3.59
AA002	24	1.95	3	0.00	0	20795	0.48	1.95	2.27
AA002	50	3.18	10	1.44	5.57	30901	0.32	3.18	4.07
AA002	130	2.51	10	0.00	7.19	14966	0.67	2.51	3.94
AA002	141	2.73	10	5.57	0	15158	0.66	2.73	4.58
AA002	225	2.73	8	0.04	0	18263	0.55	2.73	3.32
AA002	307	2.74	8	0.17	0	7731	1.29	2.74	3.43
AA003	27	2.96	12	0.37	0	49890	0.20	2.96	4.16
AA003	30	3.48	12	0.27	0	18922	0.53	3.48	4.18
AA003	80	3.16	18	0.16	0	14088	0.71	3.16	5.43
AA004	22	2.16	2	0.00	0	45442	0.22	2.16	2.03
AA004	63	3.47	22	0.00	0	18482	0.54	3.47	6.21
AA004	90	3.19	17	0.11	0	23190	0.43	3.19	5.18
AA004	117	2.69	13	0.00	0	12376	0.81	2.69	4.38
AA004	300	4.54	7	0.00	0	1077	9.29	4.54	4.16
AA004	304	4.49	7	0.00	0	993	10.07	4.49	4.25
AA004	396	3.12	7	0.00	0	12357	0.81	3.12	3.14
AA005	13	3.7805	10	0.00	0	15147	0.66	3.78	3.74

<u>Specimen Calculations</u>

Consider A001 data point at CH 52+000

Measured IRI = 2.89

Age = 8 years

% Raveling = 0.719 %

No. of potholes = 9.96

ADT = 29699

e^ (-ln (ADT/10^4)) = 0.130622

IRI Predicted = 1.594 + 0.207 * 8 + 0.1202 * 0.3367 + 0.1343 * 0.720 + 0.0295*9.96 (as per Equation 5.2)

= 3.66

To validate the accuracy of the predicted model a graph has been drawn between actuals with predicted Roughness values is shown in Figure 5.1 below with relevant statistics.

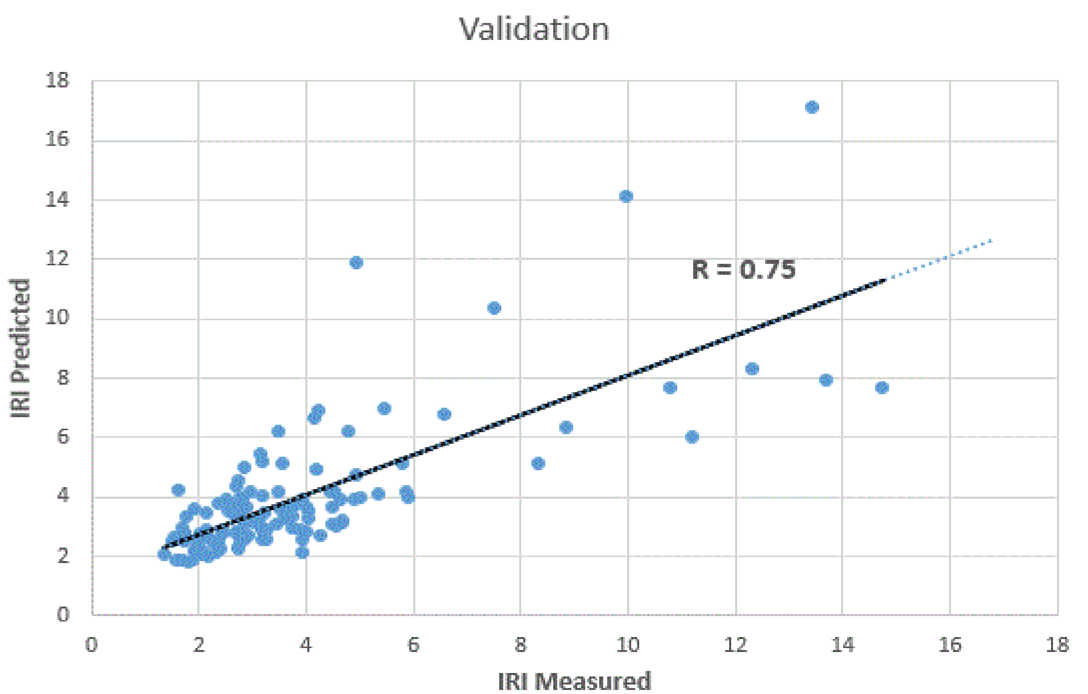

Figure 5. 1 Relationship between the measured and predicted IRI values

The proposed model yielded a Correlation coefficient (R-value) of 0.75**. This implies statistically significant relationship between two variables analyzed. Also, compared to Models identified in the Literature Review this model yielded a very good result.**

There are several improvements can be proposed to increase the accuracy of the developed model and those will be discussed under chapter 6.

5.5 Comparison with default HDM 4 Model

In Road Development Authority, HDM 4 software is using for performance modelling and predictions. But, HDM 4 has developed basically taking into account of road conditions in countries all over the world. The available pavement condition prediction model(s) does not interpret the Sri Lankan conditions very well. Also in HDM 4, most of the outcomes (eg: Vehicle Operating Cost, Speed calculations, Travel Time savings, Economic Analysis parameters) has a direct relationship with Roughness.

In order to achieve the objective, two prediction models were developed. One was developed using default HDM 4 values and the other one was developed using the above developed model. For the development of the two models, same data points that were used to validate the model in above section 5.4 were used (124 points). Therefore, totally 124 Road segments were used for the comparison. Developed graphs are shown in below Figure 5.2.

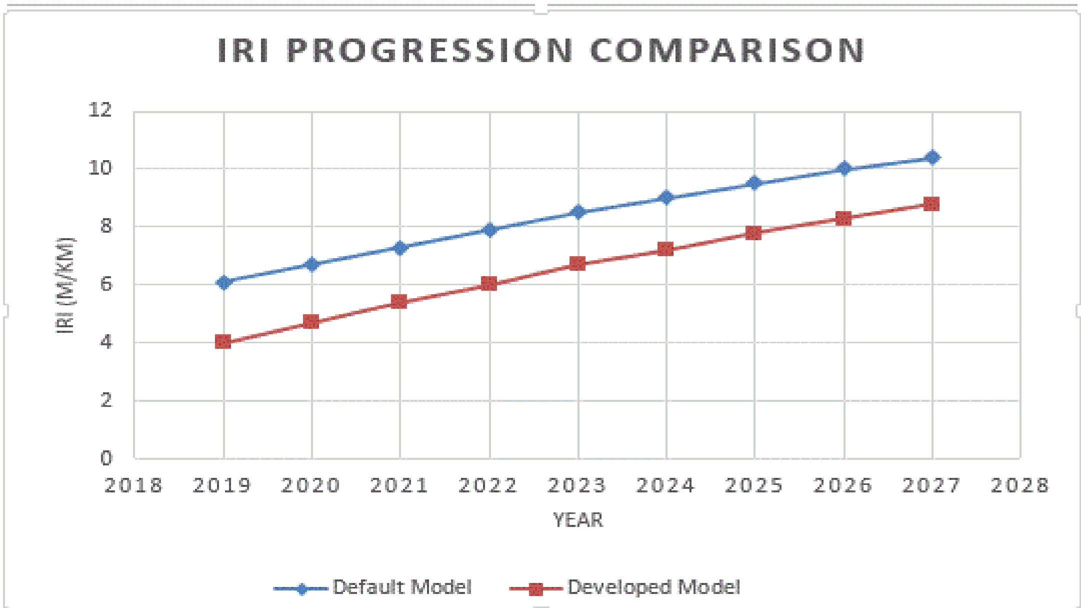

Figure 5. 2 IRI Progression comparison

As per the above results it can clearly observe that the Default model predicts greater values than the actuals. Therefore, it should not be used for decision making purposes hence it will not be economically viable since it predicts greater values than the actuals. Hence, it can be concluded that the Default HDM 4 Roughness model should be calibrated to represent actual Sri Lankan road conditions considering our own traffic characteristics, pavement structural parameters, pavement distresses and environmental conditions etc.

CHAPTER 6: CONCLUSION

6.1 Results

After completing three trials by changing different variables the final IRI prediction model developed is,

IRI = 1.594 + 0.207 Age + 0.1202 $e^{-\ln (ADT / 10^4)}$ + 0.1343 Ravel % + 0.0295 No. of potholes

This model can be used for perform simple planning level analysis to prepare maintenance schedules and to decide on expenditure choices in long term. IRI can be easily predicted with available data on site and records with minimum cost and saving of time.

The proposed model yielded an R-value of 0.75 as shown in the figure and that guarantees a good result when using the model for predictions.

To improve the accuracy of the model several proposals can be made and those are described in following section 6.2

6.2 Suggestions for Improvement

6.2.1 Use of accurate historical data

To improve the accuracy of model for that can be used in network level and specific road wise modelling it is very important to use accurate historical data. Due to unacceptability or unrealistic values, significant amount of data points were neglected. Therefore maintaining a comprehensive pavement history database is a timely need.

When rehabilitating or constructing a new road it is known that entire stretch will not be completing on the same day. Finished segments will be open for traffic in different days. Some segments may delayed for years to complete. Due to this age gap of different segments on the same road might be years. But in all records obtained, Road completion date was considered as the date of it was handed over to RDA. This could leads to inaccurate feeding of data to the model. Therefore maintaining one pavement history database for all Roads in RDA is highly recommended and there should be provision to enter each and every finished segment to the database.

To improve the accuracy of the model further it can be proposed to calculate pavement age in months instead of years. For an example if a road segment completed in month of January of a particular year and another segment on the same road completed in month of December on same year could have same age if we enter pavement age in years.

6.2.2 Allocation of budgets for collecting data and maintain database

Data directly obtained from Road survey vehicle cannot be directly use for analysis purposes and had to process into suitable formats and it consumes lot of time and money. Therefore allocation of budgets for collecting & maintaining such database is essential. Planning Division of RDA is currently facing this challenge with limited staff and resources available. Also there is a great possibility of making mistakes when entering data manually by the same person over days and days. Hence, allocation of required budget for collecting and maintaining databases is highly recommended.

6.2.3 Selection of ADT location

ADT data vary from place to place even on the same road hence it directly depends on the vehicle accumulation from connecting roads. When the segmentation done in 1000m, it is important not to vary ADT value considerably within the segment. Therefore, Selection of ADT location should done carefully in a way that it should not considerably change within the segment. This requirement has not been fulfilled during this research due to limited time period available.

6.2.4 Use of diversify pavement distress parameters

During Literature review it was identified in most models it was used diversify pavement crack patterns (e.g. Fatigue Cracks, Longitudinal Cracks, Transverse cracks). In this study it was used all crack patterns together as it was difficult to RDA to segregate and analyse different crack patterns due to the reason described in section 6.2.2 above. So, to improve the accuracy of results further, it can be proposed to use different cracks patterns separately.

6.3 Discussion

Due to the significance as an indicator of the pavement condition, International Roughness Index (IRI) is using globally as an important pavement performance parameter. Before this research there were very limited studies carried out to analyze the Sri Lankan road conditions considering its own traffic characteristics, pavement structural parameters, pavement distresses and environmental conditions etc. Hence, this study lays a great platform for future research studies regarding pavement performance modelling in Sri Lanka with the improvements suggested above.

In Road Development Authority, HDM 4 software is using for performance modelling and predictions. But, HDM 4 has developed basically taking into account of road conditions in countries all over the world. In this research it was proved that the Default HDM 4 model predicts greater values than the actual Sri Lankan conditions. Therefore in a future study it is highly recommended to calibrate the default HDM 4 to represent actual Sri Lankan conditions it in order to ensure more accurate results.

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HDM 4 Manual – Analytical Framework and Model Descriptions – Part C (Version 2.0)

Appendix A– Data set used for Model Calibration

Point No.	ROUTE	km	ADT	IRI	Age	e^ -ln (ADT/10^4)	Ravel %	No. of Pot holes
1	AA000	3	77429	4.295	4	0.13	0.00	0.00
2	AA000	5	94943	2.853	6	0.11	2.80	0.00
3	AA000	7	138825	3.792	6	0.07	0.74	0.00
4	AA001	41	38875	3.090	8	0.26	2.68	6.54
5	AA001	44	26985	3.142	8	0.37	10.75	0.00
6	AA001	55	30743	3.006	8	0.33	4.05	4.10
7	AA001	59	40231	3.335	8	0.25	2.00	0.00
8	AA001	78	23354	2.622	8	0.43	0.00	0.00
9	AA001	81	24770	2.524	8	0.40	0.26	9.74
10	AA001	95	25000	4.286	8	0.40	1.83	0.00
11	AA001	100	23839	3.699	8	0.42	0.16	0.00
12	AA001	107	25113	2.972	8	0.40	2.69	0.00
13	AA001	112	26671	3.979	8	0.37	0.24	8.50
14	AA002	10	90057	5.721	5	0.11	1.90	4.83
15	AA002	15	95206	2.441	3	0.11	0.00	0.00
16	AA002	17	74060	2.104	3	0.14	0.00	0.00
17	AA002	29	47071	1.985	3	0.21	0.00	0.00
18	AA002	32 (31)	37773	3.034	12	0.26	14.11	9.00
19	AA002	39 (35)	34771	2.327	3	0.29	0.00	0.00
20	AA002	46	30793	2.206	10	0.32	0.00	0.00
21	AA002	74	13721	2.482	10	0.73	0.04	0.00
22	AA002	109	19082	2.084	10	0.52	0.00	0.00
23	AA002	111	19284	3.012	10	0.52	0.12	2.49
24	AA002	120	31788	3.058	10	0.31	0.29	2.61
25	AA002	166	21515	2.690	8	0.46	0.27	0.00
26	AA002	177	12218	2.453	8	0.82	0.23	3.53
27	AA002	180	17639	2.933	8	0.57	0.37	3.34
28	AA002	203	8129	2.485	8	1.23	0.00	0.00
29	AA002	256	8995	2.386	8	1.11	0.00	0.00
30	AA002	265	4500	2.120	8	2.22	0.00	0.00
31	AA002	284	5880	2.601	8	1.70	0.08	0.00
32	AA002	287	5199	2.790	8	1.92	0.08	0.00
33	AA003	7	70316	1.989	2	0.14	0.00	0.00
34	AA003	14	71052	2.798	2	0.14	0.00	0.00
35	AA003	18	46092	2.488	2	0.22	0.00	0.00

36	AA003	22	39586	2.547	12	0.25	0.00	0.00
37	AA003	36	47159	3.041	12	0.21	0.00	0.00
38	AA003	52	27062	3.645	18	0.37	0.00	0.00
39	AA003	58	23628	2.901	18	0.42	0.00	0.00
40	AA003	66	18572	3.099	18	0.54	1.03	0.00
41	AA003	105	9436	2.357	17	1.06	0.00	0.00
42	AA003	120	14170	2.271	17	0.71	0.68	0.00
43	AA003	126	15348	2.074	17	0.65	0.00	0.00
44	AA004	33 (29)	26456	3.071	22	0.38	0.00	0.00
45	AA004	41	35104	3.760	22	0.28	0.16	0.00
46	AA004	42	31591	5.111	22	0.32	1.83	0.00
47	AA004	47	25345	4.697	22	0.39	0.82	0.00
48	AA004	101	30136	5.084	13	0.33	2.15	0.00
49	AA004	104	20613	2.929	13	0.49	0.00	0.00
50	AA004	108	20464	2.755	13	0.49	0.00	0.00
51	AA004	109	21401	3.292	13	0.47	0.00	0.00
52	AA004	128	10636	2.228	13	0.94	0.00	0.00
53	AA004	146	7534	2.526	9	1.33	0.00	0.00
54	AA004	175	3729	2.725	9	2.68	0.00	0.00
55	AA004	180	5087	2.768	9	1.97	0.00	0.00
56	AA004	225	8142	2.762	8	1.23	0.00	0.00
57	AA004	240	9560	3.033	8	1.05	0.00	0.00
58	AA004	270	5609	3.041	8	1.78	0.00	0.00
59	AA004	328	1269	3.801	7	7.88	0.00	0.00
60	AA004	350	2906	3.728	7	3.44	0.00	0.00
61	AA004	370	8940	2.825	7	1.12	0.00	0.00
62	AA004	384	22568	4.655	7	0.44	0.00	0.00
63	AA004	420	18784	3.315	7	0.53	0.00	0.00
64	AA005	1	28152	10.317	25	0.36	28.00	0.00
65	AA005	4	21289	2.066	2	0.47	0.00	0.00
66	AA005	7	19551	2.074	2	0.51	0.00	0.00
67	AA005	7	14474	3.797	10	0.69	0.00	0.00
68	AA005	15	13788	3.115	10	0.73	0.00	0.00
69	AA005	28	6810	3.159	10	1.47	0.57	0.00
70	AA005	40	3643	4.499	10	2.75	0.00	0.00
71	AA005	75	3191	2.849	5	3.13	0.00	0.00
72	AA005	76	6374	3.139	5	1.57	0.00	0.00
73	AA005	90	4294	2.971	5	2.33	0.00	0.00
74	AA005	107	2640	2.979	5	3.79	0.00	0.00
75	AA006	4	19283	1.597	1	0.52	0.00	0.00

76	AA006	10	13533	1.345	1	0.74	0.00	0.00
77	AA006	20	19742	1.540	1	0.51	0.00	0.00
78	AA006	36	31175	2.479	1	0.32	0.00	0.00
79	AA006	53	15694	1.712	1	0.64	0.14	0.00
80	AA006	57	19541	1.346	1	0.51	0.00	0.00
81	AA006	66	11432	1.333	1	0.87	0.00	0.00
82	AA006	67	14354	1.609	1	0.70	0.00	0.00
83	AA006	116	3409	2.173	7	2.93	0.00	0.00
84	AA006	150	3674	1.553	7	2.72	0.00	0.00
85	AA006	154	3464	1.602	7	2.89	0.00	0.00
86	AA006	160	4400	2.094	5	2.27	0.00	0.00
87	AA006	198	43792	3.044	5	0.23	0.00	0.00
88	AA007	2	15838	4.718	25	0.63	0.00	0.00
89	AA007	4	14415	4.721	25	0.69	0.00	0.00
90	AA007	13	18320	3.324	25	0.55	0.00	0.00
91	AA007	55	5129	8.322	25	1.95	0.00	0.00
92	AA007	69	6591	6.397	25	1.52	0.00	0.00
93	AA007	75	3921	2.311	2	2.55	0.00	0.00
94	AA007	86 (91)	5600	2.061	2	1.79	0.00	0.00
95	AA007	107	970	3.093	2	10.31	1.03	9.22
96	AA007	110	3593	2.962	2	2.78	0.00	0.00
97	AA008	5	33436	2.049	9	0.30	0.00	0.00
98	AA008	11	18076	2.243	9	0.55	0.00	0.00
99	AA008	31 (22)	15471	2.677	9	0.65	0.00	0.00
100	AA008	52	9181	4.076	8	1.09	0.00	0.00
101	AA008	65	5884	3.971	8	1.70	0.00	0.00
102	AA009	3	63658	1.611	3	0.16	0.00	0.00
103	AA009	18	16550	2.899	2	0.60	0.00	0.00
104	AA009	29	22229	2.443	2	0.45	0.00	0.00
105	AA009	50	10879	1.920	2	0.92	0.00	0.00
106	AA009	71	8652	6.724	20	1.16	5.23	0.00
107	AA009	95	7133	2.135	5	1.40	0.00	0.00
108	AA009	106	6630	1.327	4	1.51	0.00	0.00
109	AA009	110	9069	1.555	4	1.10	0.00	0.00
110	AA009	120	7005	1.545	4	1.43	0.00	0.00
111	AA009	145	9912	5.341	4	1.01	2.59	0.00
112	AA009	150	11903	4.909	8	0.84	0.00	0.00
113	AA009	160	7830	2.102	7	1.28	0.00	0.00
114	AA009	168	6257	3.238	7	1.60	0.00	0.00
115	AA009	191	5640	1.810	4	1.77	0.00	0.00

116	AA009	220	3983	1.524	4	2.51	0.00	0.00
117	AA009	240	5422	1.539	4	1.84	0.00	0.00
118	AA009	269	5284	1.810	4	1.89	0.00	0.00
119	AA010	2	12123	3.867	9	0.82	0.95	0.00
120	AA010	7 (6)	21108	5.510	9	0.47	31.57	0.00
121	AA010	18	12223	3.025	9	0.82	0.00	0.00
122	AA010	30	17303	3.376	9	0.58	0.00	0.00
123	AA010	84 (70)	6751	1.830	8	1.48	0.00	0.00
124	AA010	110	5069	1.751	8	1.97	0.00	0.00
125	AA011	15	5227	3.045	8	1.91	0.00	0.00
126	AA011	28	7643	2.569	8	1.31	0.00	0.00
127	AA011	52	9761	2.951	8	1.02	0.00	0.00
128	AA011	76	13673	3.592	8	0.73	0.00	0.00
129	AA011	77	11998	3.700	8	0.83	0.00	0.00
130	AA011	90	7535	3.081	8	1.33	0.00	0.00
131	AA012	15	4576	1.536	5	2.19	0.00	0.00
132	AA012	38	7510	1.582	5	1.33	0.00	0.00
133	AA012	55	10360	1.438	5	0.97	0.00	0.00
134	AA012	75	8198	2.764	5	1.22	0.00	0.00
135	AA012	82	16680	2.801	5	0.60	0.00	0.00
136	AA012	91	5487	1.476	3	1.82	0.00	0.00
137	AA012	100	4473	1.340	3	2.24	0.00	0.00
138	AA012	126	3143	1.275	3	3.18	0.00	0.00
139	AA012	168	1212	1.285	3	8.25	0.00	0.00
140	AA012	170	2815	1.245	3	3.55	0.00	0.00
141	AA012	177	5616	1.325	3	1.78	0.00	0.00
142	AA013	3	6748	2.623	3	1.48	0.00	0.00
143	AA014	30	2580	3.749	7	3.88	0.00	0.00
144	AA014	35	1611	2.211	7	6.21	0.00	0.00
145	AA014	58	4176	1.472	2	2.39	0.00	0.00
146	AA014	70	2648	2.123	2	3.78	0.00	0.00
147	AA014	95	4182	5.413	7	2.39	6.29	0.00
148	AA014	103	1100	6.121	7	9.09	6.18	6.78
149	AA015	2	26728	2.562	6	0.37	0.00	0.00
150	AA015	4	18147	2.850	6	0.55	0.00	0.00
151	AA015	25	10373	2.512	6	0.96	0.00	0.00
152	AA015	47	2520	4.549	6	3.97	0.00	0.00
153	AA015	67	2041	3.316	6	4.90	0.00	0.00
154	AA015	80	3028	6.310	6	3.30	0.00	0.00
155	AA015	119	7854	5.737	6	1.27	0.00	0.00

156	AA015	128	11971	2.925	6	0.84	0.00	0.00
157	AA016	7	6642	3.365	9	1.51	0.00	0.00
158	AA016	8	5316	3.718	9	1.88	0.00	0.00
159	AA016	35	5333	4.006	9	1.88	0.00	0.00
160	AA017	5	9032	3.385	7	1.11	0.00	0.00
161	AA017	22	7286	3.663	7	1.37	0.00	0.00
162	AA017	42	5249	3.333	7	1.91	0.09	0.00
163	AA017	87	952	14.068	25	10.50	42.40	0.00
164	AA017	90	876	13.267	25	11.41	31.10	0.00
165	AA017	120	402	10.041	25	24.88	50.75	0.00
166	AA017	140	3001	1.916	2	3.33	0.00	0.00
167	AA018	30	6889	5.176	11	1.45	0.17	0.00
168	AA018	64	4352	4.890	11	2.30	0.00	0.00
169	AA018	67	7843	1.501	2	1.27	0.00	0.00
170	AA018	70	6506	1.848	2	1.54	0.00	0.00
171	AA018	82	3855	1.981	2	2.59	0.39	0.00
172	AA020	8	10834	1.912	6	0.92	0.00	0.00
173	AA021	35	1470	4.601	20	6.80	12.43	0.00
174	AA021	38	14623	2.390	2	0.68	0.00	0.00
175	AA024	2	14341	1.957	3	0.70	0.00	0.00
176	AA024	5	13445	2.286	3	0.74	0.00	0.00
177	AA024	12	10714	4.169	10	0.93	0.15	0.00
178	AA025	5	2742	3.376	7	3.65	0.00	0.00
179	AA025	27	932	2.821	7	10.73	0.00	0.00
180	AA025	40	1223	3.427	7	8.17	0.48	0.00
181	AA026	4	34426	4.470	9	0.29	0.00	0.00
182	AA026	14	12900	5.086	6	0.78	0.00	0.00
183	AA026	38	4557	2.395	5	2.19	0.00	0.00
184	AA026	71	6380	2.019	5	1.57	0.00	0.00
185	AA026	73	16528	2.234	4	0.61	0.00	0.00
186	AA026	75	2448	1.797	4	4.08	0.00	0.00
187	AA027	5	10393	3.025	3	0.96	0.00	0.00
188	AA027	8	11012	2.450	2	0.91	0.00	0.00
189	AA027	45	1833	7.906	5	5.46	0.09	0.86
190	AA027	55	2389	8.068	5	4.19	1.52	9.41
191	AA028	19	13225	1.923	5	0.76	0.00	0.00
192	AA028	35 (32)	15270	1.521	5	0.65	0.00	0.00
193	AA028	55	10809	1.682	5	0.93	0.00	0.00
194	AA028	72	16257	1.583	5	0.62	0.00	0.00
195	AA029	10	1702	1.491	1	5.88	0.00	0.00

196	AA029	23	3012	2.290	2	3.32	0.00	0.00
197	AA029	45	1679	2.904	7	5.96	0.00	0.00
198	AA030	4	11544	6.820	7	0.87	36.65	0.00
199	AA031	2	15399	3.365	7	0.65	0.00	0.00
200	AA031	18	6301	3.055	7	1.59	0.00	0.00
201	AA032	5	3011	2.346	4	3.32	0.00	0.00
202	AA032	62 (80)	941	2.157	3	10.63	0.00	0.00
203	AA033	5	19943	3.495	6	0.50	0.09	0.00
204	AA033	12	8835	2.926	6	1.13	0.00	0.00
205	AA033	15	30619	2.122	3	0.33	0.00	0.00
206	AA034	3	1090	2.468	5	9.17	0.00	0.00
207	AA034	24	2056	2.685	5	4.86	0.00	0.00
208	AA035	5	4496	1.890	3	2.22	0.00	0.00
209	B005	7	2300	13.298	25	4.35	22.53	70.63
210	B032	1.5	19061	5.599	15	0.52	2.45	2.10
211	B038	10	1703	6.529	20	5.87	1.76	0.00
212	B039	3	2652	8.381	10	3.77	0.30	0.00
213	B047	3	30923	2.041	1	0.32	0.00	0.00
214	B058	1	21003	3.887	18	0.48	0.00	17.31
215	B058	7	28303	2.904	18	0.35	0.00	0.00
216	B063	4	3158	5.695	6	3.17	0.00	0.00
217	B065	3	3139	11.683	23	3.19	0.00	0.00
218	B068	3	4166	2.859	5	2.40	0.00	0.00
219	B074	3	1682	7.789	15	5.95	1.05	0.00
220	B075	6	1366	12.211	25	7.32	5.67	0.00
221	B075	15	1290	12.393	25	7.75	13.03	0.00
222	B084	11	48588	4.944	5	0.21	0.07	0.00
223	B084	13	37523	6.050	5	0.27	0.00	0.00
224	B090	1	2199	3.307	3	4.55	0.00	0.00
225	B093	8	768	3.022	2	13.02	0.71	0.00
226	B096	1	35118	3.387	1	0.28	0.75	0.00
227	B108	5	9247	3.234	4	1.08	0.15	0.00
228	B110	10	910	2.654	1	10.99	0.00	0.00
229	B111	8	27955	3.406	6	0.36	0.14	0.00
230	B111	12	33659	4.608	6	0.30	0.00	0.00
231	B115	8	3790	3.698	7	2.64	0.15	0.00
232	B115	25	2576	11.733	25	3.88	4.16	0.00
233	B120	4	40369	2.559	2	0.25	0.00	0.00
234	B120	5	51093	3.198	2	0.20	0.21	0.00
235	B127	10	7436	2.863	2	1.34	0.00	0.00

236	B146	4	12531	2.169	3	0.80	0.00	0.00
237	B146	18	13376	3.774	6	0.75	0.05	0.00
238	B146	19	6595	4.872	6	1.52	0.00	0.00
239	B150	5	1309	4.790	17	7.64	0.00	0.00
240	B157	21	2132	1.986	3	4.69	0.00	0.00
241	B157	35	10228	8.076	14	0.98	15.15	0.00
242	B157	46	7966	2.345	2	1.26	0.00	0.00
243	B157	50	7305	1.894	2	1.37	0.00	0.00
244	B160	1	2125	6.016	15	4.70	2.48	0.00
245	B160	4	2068	5.919	17	4.84	0.12	0.00
246	B161	1	5988	9.533	17	1.67	0.00	0.00
247	B162	1	5700	4.018	7	1.75	0.00	0.00
248	B168	2	34583	4.320	7	0.29	0.00	0.00
249	B168	7	17523	3.075	7	0.57	0.00	0.00
250	B183	5	3078	2.621	3	3.25	0.00	0.00
251	B191	3	13862	4.239	5	0.72	0.00	0.00
252	B205	4	16903	6.196	16	0.59	11.72	10.60
253	B208	5	30490	2.657	3	0.33	0.00	0.00
254	B208	8	18532	2.433	3	0.54	0.00	0.00
255	B208	12	10544	2.794	3	0.95	0.00	0.00
256	B214	11	11993	3.168	4	0.83	0.00	0.00
257	B214	14	37246	3.000	4	0.27	0.00	0.00
258	B214	18	32550	2.747	6	0.31	0.00	0.00
259	B214	26	12111	3.707	6	0.83	0.00	0.00
260	B216	3	29604	2.308	1	0.34	0.00	0.00
261	B216	8	19016	2.461	1	0.53	0.00	0.00
262	B220	2	13715	3.491	5	0.73	0.14	0.00
263	B221	2	34043	2.981	5	0.29	0.00	0.00
264	B223	1	3115	7.289	18	3.21	0.15	0.00
265	B224	10	4710	6.337	8	2.12	4.13	0.00
266	B224	12	7236	4.995	8	1.38	2.88	0.00
267	B226	2	14911	4.935	4	0.67	0.19	0.00
268	B232	2	26428	2.001	2	0.38	0.00	0.00
269	B235	4	3186	4.377	8	3.14	0.25	1.78
270	B237	4	2631	4.199	5	3.80	0.00	0.00
271	B240	5	59264	3.525	5	0.17	1.44	111.36
272	B241	2	3578	3.902	17	2.79	1.19	0.00
273	B262	1	18621	3.700	6	0.54	1.98	0.00
274	B263	3	47851	3.549	8	0.21	0.36	0.00
275	B268	5	9915	2.139	5	1.01	0.00	0.00

276	B285	10	10530	2.162	1	0.95	0.00	0.00
277	B285	13	6693	1.638	1	1.49	0.00	0.00
278	B288	5	17901	2.655	7	0.56	0.00	0.00
279	B288	13	30262	3.774	7	0.33	2.56	0.00
280	B289	2	8185	3.695	6	1.22	0.00	0.00
281	B289	5	1822	3.034	6	5.49	0.00	0.00
282	B290	4	2222	3.999	4	4.50	0.00	0.00
283	B296	5	1701	2.905	6	5.88	0.00	0.00
284	B297	4	3576	1.859	4	2.80	0.00	0.00
285	B299	8	2199	4.435	7	4.55	2.20	0.00
286	B302	1	3678	5.592	22	2.72	0.49	0.00
287	B304	28	4685	2.828	5	2.13	0.00	0.00
288	B304	37	4146	2.499	3	2.41	0.00	0.00
289	B304	40	9681	2.331	3	1.03	0.00	0.00
290	B307	1	43340	5.967	20	0.23	0.30	0.00
291	B311	1	3176	11.803	20	3.15	2.30	0.00
292	B312	14	3603	2.460	15	2.78	0.00	0.00
293	B316	1	6470	6.432	8	1.55	3.01	7.73
294	B317	9	1194	11.982	21	8.38	9.35	0.00
295	B322	4	29176	2.451	3	0.34	0.00	0.00
296	B322	20	7805	3.031	6	1.28	0.00	0.00
297	B324	7	11343	2.235	5	0.88	0.00	0.00
298	B324	15	17269	2.587	5	0.58	0.00	0.00
299	B339	4	2761	4.278	15	3.62	0.00	0.00
300	B345	1	36468	6.174	21	0.27	0.00	0.00
301	B346	15	2010	10.243	19	4.98	7.45	0.00
302	B351	4	1697	10.096	21	5.89	1.14	0.00
303	B354	3	8055	4.321	4	1.24	0.33	0.00
304	B357	10	1223	2.454	4	8.17	0.10	0.00
305	B361	2	9482	2.690	5	1.05	0.00	0.00
306	B361	3	7975	2.492	5	1.25	0.00	0.00
307	B365	3	38251	4.335	8	0.26	3.68	1.40
308	B365	4	17788	4.962	8	0.56	4.12	0.00
309	B365	8	8770	6.764	8	1.14	14.66	22.40
310	B367	2	12782	5.099	15	0.78	0.00	0.00
311	B369	1	8460	6.796	20	1.18	8.45	20.42
312	B377	3	1161	12.488	18	8.61	13.10	39.10
313	B378	1	1433	3.255	9	6.98	0.98	0.00
314	B380	5	4582	14.072	23	2.18	28.34	0.00
315	B384	4	3845	2.309	1	2.60	0.00	0.00

316	B388	2	24113	4.991	18	0.41	1.20	0.00
317	B389	4	34797	4.329	10	0.29	0.08	0.00
318	B389	5	36323	4.300	10	0.28	0.00	0.00
319	B389	7	27168	2.647	8	0.37	0.00	0.00
320	B392	4	1059	11.338	24	9.44	10.92	0.00
321	B400	2	30729	2.628	2	0.33	0.00	0.00
322	B400	6	9746	3.422	3	1.03	0.00	0.00
323	B413	2	8867	2.095	2	1.13	0.00	0.00
324	B413	4	13334	2.326	2	0.75	0.00	0.00
325	B416	2	2560	6.319	5	3.91	0.22	0.00
326	B417	3	886	9.847	16	11.29	13.76	0.00
327	B421	4	5506	2.821	4	1.82	0.00	0.00
328	B421	13	4872	2.773	4	2.05	0.00	0.00
329	B421	52	3797	2.269	4	2.63	0.00	0.00
330	B421	57	6195	2.400	4	1.61	0.00	0.00
331	B430	7	18369	4.200	13	0.54	0.85	0.00
332	B434	3	2073	2.730	5	4.82	0.00	0.00
333	B445	2	17273	2.720	3	0.58	0.00	0.00
334	B445	3	29719	2.479	3	0.34	0.00	0.00
335	B445	7	27351	4.920	10	0.37	0.79	0.00
336	B445	25	3414	2.574	3	2.93	0.00	0.00
337	B458	1	17211	2.076	1	0.58	0.00	0.00
338	B458	6	13003	2.091	1	0.77	0.00	0.00
339	B459	1	28899	8.024	7	0.35	16.55	0.00
340	B460	1	19899	2.671	2	0.50	0.00	0.00
341	B462	7	5438	2.323	2	1.84	0.00	0.00
342	B470	1	45500	2.849	7	0.22	0.00	0.00
343	B470	2	49390	2.836	7	0.20	0.10	0.00
344	B472	2	10606	2.720	2	0.94	0.00	0.00
345	B476	1	1552	3.833	5	6.44	0.00	0.00
346	B476	4	1513	4.345	5	6.61	0.00	0.00
347	B477	4	243	16.100	24	41.21	0.19	0.00
348	B479	7	5403	2.943	6	1.85	0.00	0.00
349	B486	7	5054	3.536	6	1.98	0.00	0.00
350	B490	3	1190	7.928	19	8.40	10.61	0.00
351	B492	7	2170	5.485	21	4.61	5.44	0.00
352	B492	27	2142	6.621	21	4.67	4.05	8.24
353	B493	3	263	5.075	21	38.06	1.56	0.00
354	B504	2	22235	5.102	20	0.45	0.00	0.00
355	B506	2	3141	11.615	21	3.18	15.02	18.01

356	B512	10	1120	6.635	5	8.93	0.08	0.00
357	B530	2	9399	5.548	9	1.06	0.05	0.00
358	B539	1	1078	4.254	2	9.27	4.97	2.37
359	B539	6	2860	12.895	24	3.50	5.68	15.72
360	B540	6	2860	12.895	24	3.50	5.68	15.72

Appendix B– Data set used for Model Validation

Point No.	ROUTE	km	IRI	Age	Ravel%	No. of potholes	ADT	$e^{-\ln(ADT/10^4)}$	IRI Measure	IRI Predict
1	AA001	10	2.061	3	0.00	0	76557	0.13	2.06	2.23
2	AA001	52	2.892	8	0.72	9.96	29699	0.34	2.89	3.66
3	AA001	68	2.568	8	1.55	0	22571	0.44	2.57	3.54
4	AA001	91	4.153	8	18.98	20.75	35722	0.28	4.15	6.70
5	AA001	111	3.718	8	1.58	3.05	47489	0.21	3.72	3.59
6	AA002	24	1.947	3	0.00	0	20795	0.48	1.95	2.27
7	AA002	50	3.179	10	1.44	5.57	30901	0.32	3.18	4.07
8	AA002	130	2.512	10	0.00	7.19	14966	0.67	2.51	3.94
9	AA002	141	2.735	10	5.57	0	15158	0.66	2.73	4.58
10	AA002	225	2.730	8	0.04	0	18263	0.55	2.73	3.32
11	AA002	307	2.737	8	0.17	0	7731	1.29	2.74	3.43
12	AA003	27	2.961	12	0.37	0	49890	0.20	2.96	4.16
13	AA003	30	3.480	12	0.27	0	18922	0.53	3.48	4.18
14	AA003	80	3.157	18	0.16	0	14088	0.71	3.16	5.43
15	AA004	22	2.160	2	0.00	0	45442	0.22	2.16	2.03
16	AA004	63	3.468	22	0.00	0	18482	0.54	3.47	6.21
17	AA004	90	3.190	17	0.11	0	23190	0.43	3.19	5.18
18	AA004	117	2.691	13	0.00	0	12376	0.81	2.69	4.38
19	AA004	300	4.537	7	0.00	0	1077	9.29	4.54	4.16
20	AA004	304	4.492	7	0.00	0	993	10.07	4.49	4.25
21	AA004	396	3.120	7	0.00	0	12357	0.81	3.12	3.14
22	AA005	13	3.781	10	0.00	0	15147	0.66	3.78	3.74
23	AA005	49	4.458	10	0	6.65	3759	2.66	4.458	4.16
24	AA005	64	4.654	10	0.396	0	6119	1.63	4.654	3.92
25	AA006	2	1.572	1	0	0	16576	0.60	1.572	1.87
26	AA006	40	1.633	1	0	0	22576	0.44	1.633	1.85

27	AA006	81	1.698	1	0	0	14176	0.71	1.698	1.89
28	AA006	105	1.522	4	0	0	11589	0.86	1.522	2.53
29	AA006	193	2.692	5	0	0	9486	1.05	2.692	2.76
30	AA007	40	5.472	25	0	0	4842	2.07	5.4715	7.02
31	AA007	99	2.158	2	2.338	0	2795	3.58	2.1575	2.79
32	AA007	102	2.703	2	0.468	0	819	12.21	2.703	3.55
33	AA008	21	2.622	9	0	0	27176	0.37	2.6215	3.50
34	AA009	7	2.383	3	0	0	27785	0.36	2.3825	2.26
35	AA009	75	1.688	5	1.454	0	9361	1.07	1.6875	2.98
36	AA009	86	2.014	5	0	0	9181	1.09	2.0135	2.76
37	AA009	127	2.033	4	0	0	3739	2.67	2.033	2.74
38	AA009	182	2.360	4	0	0	10528	0.95	2.36	2.54
39	AA009	292	1.546	4	0	0	6031	1.66	1.5455	2.62
40	AA009	311	1.726	4	0	0	9753	1.03	1.726	2.55
41	AA010	50	1.355	2	0	0	17591	0.57	1.355	2.08
42	AA011	34	3.142	8	0	0	9994	1.00	3.142	3.37
43	AA011	125	2.671	8	0	0	2918	3.43	2.6705	3.66
44	AA011	127	3.220	8	0	0	4962	2.02	3.2195	3.49
45	AA012	79	4.266	5	0	0	14433	0.69	4.266	2.71
46	AA012	134	1.993	3	0	0	4241	2.36	1.993	2.50
47	AA013	14	2.718	3	0	0	21159	0.47	2.7175	2.27
48	AA014	5	2.122	7	1.365	0	4895	2.04	2.1215	3.49
49	AA014	80	2.862	7	12.04	0	6891	1.45	2.8615	5.03
50	AA015	5	2.428	6	0	0	17091	0.59	2.4275	2.91
51	AA015	91	4.891	6	0	0	1133	8.82	4.891	3.90
52	AA015	100	4.481	6	0	0	5167	1.94	4.481	3.07
53	AA016	20	4.035	9	0	0	16126	0.62	4.0345	3.53
54	AA017	62	4.675	7	0	0	6796	1.47	4.6745	3.22
55	AA018	4	4.995	11	0	0	14018	0.71	4.995	3.96
56	AA018	18	5.908	11	0	0	11525	0.87	5.9075	3.98
57	AA018	72	1.906	2	0	0	6824	1.47	1.9055	2.18
58	AA022	21	2.367	9	0	0	3572	2.80	2.367	3.79
59	AA023	21	4.019	8	0	0	3053	3.28	4.019	3.64
60	AA025	24	2.859	7	0.516	0	2255	4.43	2.859	3.65
61	AA026	17	2.047	2	0	0	15496	0.65	2.047	2.09
62	AA026	80	1.731	4	0	0	3365	2.97	1.731	2.78
63	AA026	98	1.756	5	0	0	1683	5.94	1.756	3.34
64	AA028	13	1.746	5	0	0	9913	1.01	1.746	2.75
65	AA029	2	3.575	7	0.448	0	7265	1.38	3.575	3.28
66	AA030	12	4.921	15	44.53	6.68	3637	2.75	4.921	11.93

67	AA030	28	7.513	20	21.87	0	915	10.93	7.513	10.35
68	AA032	90	4.001	3	0	0	1894	5.28	4.001	2.85
69	AA034	9	1.909	5	0	0	1263	7.92	1.909	3.58
70	B015	4	3.936	3	0	0	3172	3.15	3.936	2.59
71	B015	7	4.663	3	2.367	0	2108	4.74	4.663	3.14
72	B047	5	2.707	6	0	0	45378	0.22	2.7065	2.86
73	B067	12	13.442	25	21.06	150.11	377	26.55	13.442	17.12
74	B084	2	4.183	16	0.18	0	48683	0.21	4.1825	4.96
75	B084	8	1.822	1	0	0	74379	0.13	1.8215	1.82
76	B093	13	2.849	2	1.127	0	3200	3.13	2.849	2.55
77	B108	2	3.275	4	0	0	6869	1.46	3.275	2.60
78	B111	12	3.173	6	0	0	23233	0.43	3.173	2.89
79	B111	18	3.257	6	0	0	22902	0.44	3.2565	2.89
80	B123	10	1.885	1	0	0	11759	0.85	1.8845	1.90
81	B146	6	2.275	3	0	0	5577	1.79	2.275	2.43
82	B157	12	2.722	3	0	0	9361	1.07	2.722	2.34
83	B157	20	2.186	3	0	0	2929	3.41	2.186	2.63
84	B157	53	2.329	2	0	0	12064	0.83	2.329	2.11
85	B161	2	8.848	18	0.156	25.71	3895	2.57	8.848	6.33
86	B168	8	3.454	7	0	0	33198	0.30	3.454	3.08
87	B169	1	3.172	4	0	0	7881	1.27	3.172	2.57
88	B199	5	5.879	6	7.577	1.05	6105	1.64	5.879	4.20
89	B214	10	3.734	4	0.323	30.07	22244	0.45	3.7335	3.32
90	B214	28	3.893	6	0	0	18092	0.55	3.8925	2.90
91	B215	2	4.572	6	0.588	0	13314	0.75	4.5715	3.02
92	B222	7	1.633	1	0	0	493	20.30	1.6325	4.24
93	B228	4	3.742	6	0	0	11114	0.90	3.7415	2.94
94	B240	7	3.525	5	2.278	22.75	39699	0.25	3.525	3.61
95	B240	16	4.235	12	5.805	72.8	25191	0.40	4.2345	6.93
96	B269	6	2.152	3	0.422	0	1899	5.27	2.152	2.91
97	B288	14	4.035	7	1.271	0	24293	0.41	4.035	3.28
98	B291	1	5.798	17	0	0	33720	0.30	5.798	5.15
99	B304	1	2.765	11	0	0	14141	0.71	2.765	3.96
100	B304	3	2.807	11	0	0	15317	0.65	2.807	3.95
101	B307	2	3.563	17	0	0	68853	0.15	3.5625	5.13
102	B319	6	3.929	10	0	0	5118	1.95	3.9285	3.90
103	B324	22	2.804	5	0	0	10918	0.92	2.804	2.74
104	B334	4	3.048	4	0	0	1699	5.88	3.0475	3.13
105	B351	6	11.192	19	0	0	2465	4.06	11.192	6.01
106	B365	2	2.913	5	0	2.04	32580	0.31	2.913	2.72

107	B367	3	4.952	15	0	0	14758	0.68	4.952	4.78
108	B368	3	5.346	12	0	0	43218	0.23	5.346	4.11
109	B383	0.5	4.775	20	0.389	0	2956	3.38	4.7745	6.20
110	B389	6	2.860	7	0	0	32731	0.31	2.8595	3.08
111	B403	15	3.129	3	0	0	1429	7.00	3.1285	3.06
112	B408	2	3.925	2	0	0	9191	1.09	3.925	2.14
113	B421	3	2.761	4	0	0	8532	1.17	2.7605	2.56
114	B426	4	13.694	20	10.49	0	1881	5.32	13.694	7.96
115	B438	3	9.952	22	47.67	0	1463	6.83	9.952	14.17
116	B457	11	2.288	2	0	0	2835	3.53	2.288	2.43
117	B461	26	10.797	22	1.875	0	940	10.64	10.797	7.71
118	B472	7	4.478	6	4.689	0	7902	1.27	4.478	3.70
119	B474	7	12.326	25	4.616	6.91	1749	5.72	12.326	8.34
120	B484	3	2.441	2	0	0	1507	6.64	2.4405	2.81
121	B492	50	6.574	19	0.578	0	1031	9.70	6.5735	6.78
122	B510	1	8.320	16	0.527	0	8336	1.20	8.32	5.13
123	B540	6	14.744	25	1.346	0	1739	5.75	14.744	7.66
124	B541	6	14.744	25	1.346	0	1739	5.75	15.744	7.66