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Development of Pavement Condition and Roughness Evaluation Models for Asphalt Concrete Pavements

by

Saurav Shrestha

A THESIS REPORT

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ABSTRACT

In order to maintain the functional and operational condition of the road, the deterioration in the pavement's condition must be properly evaluated and dealt with at the earliest. To suggest maintenance activities, DoR presently employs the SDI measure in general which is subjective and inadequate pavement performance measure. Due to the incorporation of all forms of distresses, their density, and their severity, PCI is thought to be one of the most comprehensive and widely recognized global method of pavement condition evaluation and is the focus of the study. The IRI, an indicator of perceived road roughness and ride quality is also in practice by DoR in some major national projects as evaluation measure. Therefore, an IRI model and its correlation to PCI is also a focus of this study.

The PCI and IRI pavement evaluation models is developed using regression analysis and ANN. The distress data is collected and quantified as per ASTM 6433 whereas, the IRI data is collected using RoadRoid application after validation. A total of 503 and 468 data is collected and used for the evaluation of PCI and IRI respectively based on the distresses. The regression models yielded a R^2 of 0.600 and 0.621 for PCI and 0.599 and 0.614 for IRI for grouping set 1 and 2 respectively showing moderate fit of the data. In order to further improve the results, ANN model is developed using python 3.9 for PCI and IRI evaluation. Based on the ANN output, R^2 of 0.857, 0.715 and 0.747 for training, validation and testing for grouping set 1 and 0.852, 0.810 and 0.670 for grouping set 2 is obtained which indicating improvement in result when comparing to the regression models for PCI whereas the R^2 value in training, validation and testing 0.559, 0.518 and 0.536 for grouping set 1 and 0.699, 0.597 and 0.575 for set 2 during ANN for IRI evaluation. Similarly from sensitivity analysis, high severity potholes are found to be most significant parameter of both PCI and IRI. Finally, the PCI-IRI relationship was established in excel showed negative correlation & yielded maximum R^2 of 0.7858 taking polynomial relationship.

Keywords: *Pavement Condition Index, International Roughness Index, Coefficient of Determination, Artificial Neural Network, Distress Density, Distress Severity.*

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVERATIONS

SDI	Surface Distress Index
IRI	International Roughness Index
PCI	Pavement Condition Index
PSD	Power Spectral Density
PSI	Present Serviceability Index
PSR	Present Serviceability Rating
ANN	Artificial Neural Network
ASTM	American Society for Testing Materials
BI	Bump Integrator
BP	Back Propagation
DoR	Department of Roads
GA	Genetic Algorithm
GEP	Gene Expression Programming
HDM	Highway Development and Management
HMIS	Highway Management Information System
MERLIN	Machine for Evaluating Roughness using Low-cost Instrumentation
MoPIT	Ministry of Physical Infrastructure and Transport
PURELIN	Purely Linear Transform function
RBN	Roads Board Nepal
RCI	Road Condition Index
RMSE	Root Mean Square Error
MSE	Mean square error
ReLU	Rectified Linear Unit

CHAPTER 1: INTRODUCTION

1.1 Background

The efficiencies of the road network plays an important role for social as well as economic development of a region and in turn the entire nation. For the construction of any road, a huge amount of capital investment is required. However, as time passes by, the constructed road deteriorates due to several factors such as the type and the materials used for the construction of the road, sub grade soil, traffic loading intensity and volume, drainage facilities, climatic conditions and so on. The deterioration seen in the surface of the pavement is to be timely assessed, maintained and taken care of before the cost of maintenance exceeds the desired limit forcing rehabilitation or reconstruction of the pavement. The governing agency for development as well as maintenance of National Highways in Nepal falls under the responsibility of Department of Roads (DoR). The jurisdiction as well as governance of maintenance activities along with maintenance funding falls under the responsibility of Roads Board Nepal under Ministry of Physical Infrastructure and Transport (MoPIT).

In order to determine which road section is to be prioritized, different computation measures have been developed which includes metric in terms of International Roughness Index (IRI), Pavement Serviceability Rating (PSR), Surface Distress Index (SDI), Pavement Condition Index (PCI) and so on. In order to prioritize the maintenance interventions in Nepal, Surface Distress Index (SDI) and International Roughness Index (IRI) are used. Among these measures, SDI is a pavement performance rating system ranging from 0-5 which is vastly subjective and depends on the judgment of the surveyor whereas PCI is considered to be the most comprehensive and widely acceptable internationally as it takes into account all types of distresses, the density of the distresses along with the severity of the distresses (Issa et.al, 2021). However in Nepal, it is not often used because of its cumbersome procedure and field tediousness. IRI is the most objective measure among the three as it is a measure of vehicle response which is caused as a result of interaction between the vehicle and the pavement due to the roughness of the road (Lusan, 2003).

The International Roughness Index; which is a measure of road roughness and ride quality perceived in the road is generally determined with the help of the mounted bump indicator/ Roughometer or calculated using a quarter car vehicle math model (Handwiki, 2021). The Android based roughness estimation methods have been getting wide acceptability in the recent as smartphones can be used (which uses the tri-axis accelerometer sensor present in the smartphone) for the evaluation of the road profile in terms of roughness. RoadRoid Pro 3 and RoadBump Pro are some of the widely used and validated smartphones applications commonly used to measure IRI (Hossain et al., 2019).

Artificial Neural Network (ANN) can be considered as an effective tool of soft computing which is used to develop, analyze or evaluate various computational problems. A system based on the functioning of biological neural networks, or an imitation of a biological brain system, is called an artificial neural network. The ability of an artificial neural network to think and learn through sensing, reasoning, and interpretation is modeled after that of the human brain. Artificial neurons, also known as processing elements, are used in place of real neurons in a neural network (PEs). The input, hidden, and output layers of an ANN are made up of at least three linked PE layers. The number of input variables utilized to forecast the intended output is equal to the number of PEs in the input layer (independent variables) (Shahnazri, et al., 2012). The variables to be predicted are represented by PEs in the output layer (dependent variables). One or more intermediate PE layers, also known as hidden layers, are used to connect the input and output layers (Issa, et al., 2021).

Depending on how complex the issue is, trial and error is used to determine how many hidden PEs there are inside these levels. Artificial Neural network uses pattern recognition system as its main component which develops and adapts the model by adapting from experience from various trends fed through trainings. There are different algorithms of ANN which can be used in order to train the problem and the selection of the ANN algorithm, the number of hidden layer, the learning rate and the number of iterations is carried out based on the accuracy requirement and type of data (Kumar, 2021).

1.2 Problem Statement

Roads are generally constructed with a motive of providing basic accessibility as well as serviceability to the people. The road deteriorates with time due to several factors including traffic, type of pavement, age and climate. So, it is necessary to identify the condition of the pavement in order to propose most effective maintenance strategy. Also, most of the roads of Nepal are low volume roads which are assigned with limited amount of funding, further requiring the most effective and efficient use of the available budget in proposing and prioritizing maintenance activities. In order to describe the condition of the existing pavement surface and to categorize the surface of the road an effective tool is desired. DoR currently uses metric of SDI so as to indicate the functional performance and state of the road in order to propose maintenance activities for the selected section. Despite SDI having a simple procedure and being relatively easy to use, the accuracy in estimating the road's functional condition using this technique is only subjective measure and is fairly unsatisfactory leaving a lot to be desired in terms of accuracy. In recent years, IRI based contracts have been also practiced in some major national projects in Nepal including the IRI based contract for improvement project of East-West highway for an extended maintenance period of four years. Despite IRI not being used in Nepal to that extent, it is collected on a yearly basis (IQL III). The use and implementation of IRI in maintenance planning in country like Nepal can possess significant challenges because of limited budget for road maintenance especially for low volume roads. Most of the roads of Nepal in present are of poor condition therefore specific set of maintenance activities would be required in order to uplift the pavement into fair/good condition. The use of IRI as metric in such cases can propose expensive treatment and maintenance options which is a major constraint in country like Nepal. However for road sections where ride quality and comfort are of paramount importance along with the roads structural condition (such as major National highways of economic significance), IRI can be the most effective and objective indicator of pavement performance. The analysis of pavement condition through numerical assessment of pavement condition in terms of PCI provides a reasonably accurate estimate based on the existing distresses in the pavement which can be used and adapted in various rehabilitation as well as pavement management programs with budget constraint (especially project level maintenance). The application of PCI can be advantageous over IRI for maintenance planning for roads with major distresses requiring localized repair due to maintenance budget constraint as the type of distress along with its severity can be identified which may help to propose specific set of maintenance activities under budget to keep the pavement in serviceable condition. For roads where both IRI and PCI or either of them can't be evaluated, the relation between the two indices can be helpful to generalize the change in the roughness of the pavement with the change in the pavement distresses. i.e the change in PCI with IRI and vice versa.

The determination of Pavement condition index using conventional methods is also however tedious and requires a lengthy and cumbersome process that requires large amount of time and technical expertise of the personnel. The use of Artificial Neural Network, which is a form of machine learning technique, can be used which helps to minimize the efforts as well as the time in the determination of PCI. The IRI data can be collected with the help of the tri-axis accelerometer of smartphone using software application such as RoadRoid. Also the IRI is directly related with various major distresses like rutting, potholes, cracking and so on so the estimation of these distresses can help to prepare the model of the roughness index for that section as well.

1.3 Objective of Study

The primary aim of the thesis is to develop Pavement Condition and Roughness Evaluation models suitable for asphalt concrete pavements in Nepal. The detailed objectives include:

1) To develop modified relationship of PCI with various distresses groups and their severities using regression and ANN model.
2) To develop relationship between Roughness Index with various distresses groups and their severities using regression and ANN model.

3) To develop relationship/correlation between pavement condition index and international roughness index.

1.4 Scope of the Study

The various scope incorporated in the study are:

1) Aid in Pavement Condition evaluation with substantial less effort in data computation through use of machine learning algorithm in the determination of PCI and IRI.
2) Determination of IRI with the help of collected distress data.
3) Assessment of relationship between the distresses and its severity with ride quality and roughness.
4) Use of common tri-axis accelerometer present in smartphone for the determination of roughness index-cost effective alternative for IRI determination.
5) Addressing the non-linearity of Pavement Condition Index and related parameters.
6) Comparison of PCI determined using conventional technique and machine learning technique.
7) Assessment of relationship between the distress and roughness indices.

1.5 Significance of the study

The major significance of the study are as follows:

1) Assessment of Maintenance and Rehabilitation needs based on the developed condition index model at project level.
2) Assessment of IRI, crucial for maintenance planning of road sections where ride quality and comfort are of paramount importance along with the roads structural using the distress data collected.
3) Development of PCI model based on the data already collected by the DoR for National Highways as well as Feeder Roads.
4) Reliable pavement condition evaluation with less effort and time in data computation using the developed model.

1.6 Limitations of the study

Some limitations of the study are:

- The PCI/IRI does not give direct estimate of structural capacity of the pavement.
- The study is only limited to asphalt concrete pavements and its distresses. Separate analysis should be carried out for rigid pavements.
- The direct evaluation of IRI using vehicle mounted bump integrator/roughometer is constrained by its availability and cost requiring use of RoadRoid application as an alternative
- The sections are assumed to have same material properties, same method of construction and composition throughout.
- All the individual distresses and the corresponding severities couldn't be used in their isolated form for the development of the model.

1.7 Organization of Report

The project report consists of seven chapters as follows:

Chapter 1: Introduction: This section generally describes the need of pavement condition identification in road, the application of Pavement Condition Index in condition Analysis, and its relation with distress types and severities, application of RoadRoid App in pavement roughness estimation. The relationship between condition index with roughness index and use of ANN in the determination of PCI.

Chapter 2: Literature Review: This chapter provides a review of the available literatures in the field of determination of PCI, relationship between distress, roughness, ride quality and condition indices, and application of conventional as well as various machine learning techniques in PCI and IRI evaluation and determination.

Chapter 3: Methodology: This chapter deals in detail, the steps and procedure followed in the selection of study area, data collection for the development of pavement condition and roughness evaluation models, the assessment of pavement condition and roughness in terms of distress type and severity.

Chapter 4: Condition and Roughness Evaluation Models: This chapter presents the models developed for modified PCI and IRI using both regression and ANN, and includes discussion of results of validation and sensitivity analysis.

Chapter 5: PCI vs IRI Relationship: The results of relationship between the Roughness Index and the Pavement Condition Index is presented in this chapter.

Chapter 6: Conclusion and Future Works: The chapter summarizes the results of various tests and concludes this thesis work based on the results. This section also includes the directions for future and remaining works.

Chapter 7: References: The references followed in the study are included in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Pavement Management System and Trend in Nepal

As per distress identification manual developed by Hawks and Teng (1993), pavement distresses can be defined as the visible damages which are generally seen on the surface of the pavement. Most of these evaluated damages can be used in order to provide with valuable information regarding the pavement's rehabilitation as well as maintenance needs in the future which is primarily based on their severity, extent, and type. Deterioration of pavement can be seen as a complex issue which involves both the functional as well as the structural form of distresses, which is generally caused due to a combination of factors including materials, traffic, climate, time, and roadways geometric parameters. To measure defects in flexible pavement, appearance and unit of measurements are used as primary parameters.

As per DoR report (2015), based on the amount of information needed for the purpose of analysis, different methods are used in order to collect data on the distress on the pavement. The increase in sophistication impacts the increase in complexity in evaluating the distress data. World Bank suggests the streamlined technique which has been updated so as to meet the country's unique circumstances.

As per DoR report (1995), the evaluation of pavement distress is carried out manually by the department of roads with the help of well qualified and trained highway engineers which consists of a team of 2 persons. The drive and walk method of survey is generally used for the evaluation of surface distress. The distress in the pavement surface comprises of cracking, texture deficiency, patching works, deformations, disintegration in form of potholes, edge break, and so on, the 10 % sampling procedure is used in order to assess these distresses and the cumulative index method is then used in order to record these distresses in form of surface distress index.

Large amount of government funding is currently being spent on the development and maintenance of the transport sector. The construction as well as maintenance of the roads before the 1990s were carried out as per the demand of the public. At the end of 1992, greater than half of the highways were in poor condition which required immediate interventions in form of reconstruction or rehabilitation. Therefore, the ninth five year plan was formulated in between 1992 and 1997 so as to ensure higher focus on road maintenance activities as well as assets protection. Road Fund Board Act was established in 1992 AD in order to increase the funding for the road maintenance activities. In order to provide sustainable funding and collect and use road revenues, Road Board Nepal was established.

The use of IRI as a performance measure has recently been adopted in recent years. IRI based contracts have been also practiced in some major national projects in Nepal including the IRI based contract for improvement project of East-West highway for an extended maintenance period of four years (Sigdel et al., 2021). Some IRI, PCI and correlation models were developed in the past but only at research level and no specific models have been adopted in specific to Nepal in project level either in terms of PCI or IRI.

2.2 Research Developments in Nepal

The Pavement Condition Index for Simara Airport of Nepal was presented as a case study in the research carried out by Kalika et al. (2021) The standard deduct values were determined and the PCI was determined to transform it to polynomial functions. The survey of distress was conducted for all 64 runway unit samples and 7 taxiway unit samples with each sample size ranging between 550 sqm and 700 sqm. It was found that the PCI of the runway was 76 and taxiway was 82. The sampling rate for the estimation of PCI was within the permissible limit.

The research was carried out by Ojha and Joshi (2020) in order to evaluate the condition of the flexible pavement with the help of a numeric rating system in Pokhara region of Nepal. Firstly, the visual inspection survey was carried out to identify the different failures seen in the section in consideration in order to identify the cause of the failures and subsequently propose various remedial practices for the distress encountered. The results showed substantial damage in all of three sections in consideration which was caused by fatigue, poor drainage system, inadequate thickness of the pavement layer and so on.

Shakya (2013) developed the relationship between the IRI measurement with the help of profilometric measure and MERLIN. The SDI model was initially developed in which the independent variable was considered to be time. The models were separated for hilly and plain area of Nepal. It was found that, the deterioration of the road was mainly caused by climatic factors in the hilly area whereas it was more dependent on the traffic factors in plain area. It was recommended that, traffic and climatic factor should be incorporated in time dependent IRI modelling.

2.3 Pavement Condition Index and Its Relation with Different Indices

Pavement Condition Index is a numerical rating ranging from 0 to 100 indicating the present condition of the pavement. The PCI was originally developed by United States Army Corps of Engineers for airfield pavement rating system. It was later revised for highways and parking by ASTM (ASTM, 2018). Lower value of PCI refers to high degree of deterioration of road whereas, higher value of PCI represents better roads with lower degree of road deterioration. The PCI is dependent on the distress density, distress severity and distress type so, it gives an idea of the degree of deterioration caused by the distresses.

Park. et al. (2007) developed the relationship between the international roughness index and the pavement condition index with the help of the data collected from a total of nine different states and provinces in United States of America. The DataPave program was used in order to extract the data set of PCI-IRI for states of New York, New Jersey, Virginia, Vermont, Maryland, Delaware, Quebec (Canada), Ontario and Prince Edward Island for a combined period of nine years ranging from 1991 AD to 2000 AD. The regression model was developed between the 2 variables with a R2 value of 59 %. The relation was in the form of Equation (2.1).

$$\log PCI = 2 - 0.436 \log(IRI) \tag{2.1}$$

Arhin et al. (2015) developed a model in order to evaluate the International Roughness index based on the Pavement condition index in California. The main aim of the model was to estimate the ratio of cost and benefit of the users in the pavement management system. The research used SPSS software as the primary tool for analysis and modelling and the regression analysis and its subsequent validations were carried out in order to come up with the equation consisting of PCI in relation to the IRI. The coefficient of correlation between the models was found to be 0.53, Graphical comparison was used in order to graphically compare the data dispersion seen in the model. The relationship between the IRI and PCI was as given in Equation (2.2).

$$IRI = 0.0171(153 - PCI) \tag{2.2}$$

The relationship between the SDI and IRI was developed by Suryoto and Siswoyp in 2016. They were able to present the relationship between the two in form of a linear fit equating in the relation of SDI= 32.684 + 3.3455 x IRI. The Pearson correlation analysis was used In order to define the value of coefficient of correlation between the two variables. The correlation coefficient was found to be 0.203 which could be deemed as poor correlation.

2.4 Relationship of IRI with Various Distresses

Prasad (2013) established a relationship that existed between the roughness of the pavement and various surface distresses found on PMGSY roads. To achieve this, a total of eight PMGSY roads that were located in Jhunjhunu district and Churu district of Rajasthan, India, were selected as the study sites. Distress data was systematically gathered at 50-meter intervals along these roads. The collection of the roughness data was done using a Bump Integrator after calibrating with MERLIN on selected stretches for the study. Additionally, unevenness data was obtained from a newly constructed road section, and this value was deducted from the unevenness values that were observed of the test stretches. This subtraction helped determine the net impact of distresses on the overall pavement condition. Based on the field-collected data, a regression equation was developed, considering the IRI value as the dependent variable and the visible distresses as the independent variables that were present on the roads.

The study by Abdullah and Shokri (2022) conducted a statistical correlation analysis to examine the connection between IRI and pavement distresses. The objective was to assess the extent of distress associated with the quality of the ride. By employing a statistical correlation test, the study determined the relationship between distress density and IRI values. The findings revealed a noteworthy correlation between IRI and cracking, patching, depression, and raveling for both main and secondary street categories, with a confidence level of 95%. However, no significant relationship was found between IRI values and potholes or rutting distress types in either the main or secondary streets. Consequently, the statistical investigation suggests that cracking, patching, depression, and raveling could potentially be classified as distress types related to ride quality.

Joni et al. (2022) assessed and evaluated 83 sections of flexible pavement with each section having width of 250 m and the distresses as well as the IRI data was collected for each section in consideration. The IRI data was collected with the help of Dynatest RSP test system and the relationship between the visible pavement distresses and the IRI was developed. The result of the SPSS regression indicated that the model was strong enough for the prediction of IRI with the help of visible pavement distresses.

Abdullah et al. (2022) conducted statistical correlation analysis was conducted to examine the connection between International Roughness Index (IRI) and pavement distresses. The objective was to assess the extent of distress associated with the quality of the ride. By employing a statistical correlation test, the study determined the relationship between distress density and IRI values. The findings revealed a noteworthy correlation between IRI and cracking, patching, depression, and raveling for both main and secondary street categories, with a confidence level of 95%. However, no significant relationship was found between IRI values and potholes or rutting distress types in either the main or secondary streets. Consequently, the statistical investigation suggests that cracking, patching, depression, and raveling could potentially be classified as distress types related to ride quality.

Mubaraki (2016) evaluated the highway connecting from Jadan to Jeddah in order to assess the IRI and its relationship with distresses including rutting, ravelling, cracking and so on. RST vehicle was used in order to assess the IRI and distresses were calculated manually. Two models were developed with cracking, rutting and raveling vs IRI and It was found that rutting didn’t contribute to IRI which concluded ravelling and cracking to the major Influencing factors for IRI.

2.4 Application of Smartphones-Based Evaluation of IRI (Recent Developments)

According to Forslöf and Jones (2015), the build-in vibration sensors of the smartphones could be used to collect the roughness of the road up to class II or class III in effective way. The roughness value changes significantly with time so frequent measurement were necessary. The cIRI value of the interface indicated the calculated IRI value using the sensor of the smartphone. The correlation was developed in terms of eIRI to further simulate the conditions of quarter car system. Hundreds of road link sections were compared between the smartphone measured IRI and class I IRI measurements for 20 m length intervals and 81 % correlation was found with the laser measurement systems which indicated that RoadRoid could be used as an alternative to conventional IRI measurement systems.

Donny and Mamok (2018) highlighted that the RoadRoid app could be used as a cost effective alternative for the estimation of IRI. A total of 5 road segments were analyzed in the Mageten District road. The PCI was initially evaluated and the road was found to be in good condition. The IRI using RoadRoid showed that the pavement was in medium condition in terms of roughness. The negative correlation with value -0.23 was found.

Arianto et al. (2018) used Android based application in form of RoadRoid in order to measure the roughness of the road with the help of smartphones vibration and accelerometer sensors. The IRI was the output of the application which was used to indicate the roughness condition of the pavement. The pavement condition evaluation was also evaluated in addition to the roughness measurement of Janderal Sudirman Kalianget road. The obtained IRI value was combined with SDI in order to propose suitable maintenance strategy for the road. The pavement condition of Jenderal Sudirman-Kalianget 4.2 kilometers (37.17%) was in good condition and 2.3 kilometers (20.35%) was in fair that needed routine maintenance. While 2.1 kilometers (18.58%) were bad and 2.7 kilometers (23.89%) were poor that need periodical maintenance and reconstruction.

2.5 Application of Artificial Neural Network (ANN) in the Evaluation of PCI and IRI

In order to estimate the relationship between the PCI and the IRI, a neural network model was developed by Vidya et al. (2013) based on the data obtained in the construction work zones. The IRI values which were obtained with the help of the analysis was compared with the actual IRI values with the help of MERLIN. In order to evaluate IRI from PCI, the neural network model was used after training and testing. The Levenberg Marquardt back propagation method was used during the course of training and analysis and the E2 value of 0.86 was found for training with MSE of 0.041. Satisfactory performance was concluded in order to predict PCI from IRI.

Optimization techniques in form of Artificial Neural Network and Genetic programming models were used by Shahnazri et al. (2012) in order to estimate the values of PCI with the help of pavement indices other than the IRI based on the distress types and the level of severity. The PCI data was gathered from the highways of Iran and the extent of survey was 1250 KM. In ANN, feed forward propagation method was used for training of the model whereas in GP algorithm, the root mean square fitness technique was validated and used. The results presented that, the correlation between the field measured PCI values and PCI values using these models was high.

10 different sections of the road in Nablus city of Palestine was taken for study by Issa et al. (2022) which consisted of a total of 348 directional sections so as to collect the data related to distresses in order to determine the PCI values. ASTM 6433 07 method was followed in the study and the correlation was determined among the PCI value and the distresses. The main aim of the project was to develop and model the PCI with the help of ANN in order to determine the present condition of the pavement so as to prioritize and suggest relevant repair and maintenance strategies. Along with distresses and their severities, the research also considered a new variable in terms of number of manholes in the section which affected the pavements condition. The PCI score was ranged from 0-100. First the qualitative analysis of the collected distress data was performed and proper classification system was formed. The feed forward back propagation method of ANN was used consisting of three layers and they were weighed accordingly before subjecting them to model training, validation and determination. The highest amount of distresses between the severity, type of distress and the PCI was found to be 0.38. ANN model was prepared in order to determine and predict the PCI value with high level of reliability with an R2 value of 0.9971, 0.9964 and 0.9975 for training, validation and testing datasets, respectively.

The main aim of the study carried out by Kumar (2021) was to assess the performance of three different algorithms of ANN which includes Lavenberg Margeret, Bayesian Regularization (BR) and scaled conjugate gradient (SCG) available in the NN toolbox of MATLAB-2015 version using the calculated value of the pavement condition index and the distress density. The minimum statistical approach and the correlation coefficient was used as a basis for comparison of the accuracy of these algorithms in this project. From the analysis, it was concluded that, among three of the algorithms selected in the research, the LM algorithm was better than the remaining algorithms as highest correlation of 89 % was found following this algorithm as opposed to 76 % for BR and 58 % for SCG respectively during training and validation of the data points considered in the research. The five-fold cross-validation has been performed to explain the accuracy of the ANN model which is higher compare to random forest and support vector machine (SVM). The ANN model has shown the highest model accuracy (73%) compared to the SVM model (72%) and RF model (61%).

Setiadjim et al. (2019) highlighted that the functional classification or assessment of the road is generally assessed in terms of international roughness index IRI and surface distress index SDI which is generally used by DGH. According to the study, the main reason of using this method is because of simple procedure and easy to use nature. An attempt was made in order to evaluate the surface distress index with the help of the damage in terms of crack, its dimension and its corresponding severity level. In this research, the most comprehensive and reliable measure for evaluating the roads functional classification was used as a reference. The estimation of PCI in the field is limited by untrained and unskilled personnel and their capabilities in the field.

Issa et al. (2021) developed a new model in order to define the condition of the pavement through visual details using machine learning technique. The proposed machine learning techniques are found to be much less cost as well as time efficient when compared to the conventional ASTM procedure in the determination of the pavement condition index. The determination of PCI includes six major parameters in terms of patching, longitudinal cracking, potholes, shoving, alligator cracking and transverse cracking. The developed optimized hybrid model of the PCI was based on the database of FHWA LTTP database. The cascade architecture was followed in the research with three models of machine learning and neural network is used in the second stage in order to model a nonlinear estimation curve so as to minimize the errors. Cross validation analysis was carried out in order to verify the model and the research was concluded on a note that PCI is determined with a high degree of accuracy.

2.6 Summary of Literature Review and Research Contribution

This section of the Literature Review chapter summarizes the findings of all the literature followed throughout the course of this thesis work. Pavement Management System (PMS) is a crucial concept in up keeping the existing pavements in operational state which requires careful understanding of all the distresses that deteriorates the pavement condition. This section includes previous works carried out in the field of determination of Pavement Condition Index (PCI) and International Roughness Index (IRI). The section also summarizes the pavement management trend which is currently being followed in Nepal. The relationship between these indices also helps to relate the condition of the pavement with the pavement roughness and in all of the literature, negative correlation between the PCI and IRI value is observed. The use of RoadRoid application for the determination of IRI is also validate with the help of numerous literature which indicated that, RoadRoid could be used in order to estimate IRI value with IQL III with acceptable accuracy. The difficulty in evaluation of Pavement Condition Index using manual method is also highlighted in most of the literature requiring alternative measure of evaluation of PCI. Application of ANN has been considered as one of the most effective tools for modelling the condition and roughness index as presented in this chapter. Most of the literature suggests that, ANN could be used in the evaluation of PCI and IRI based on existing distresses with moderate to high degree of accuracy. The literature also focuses on the advantages as well as disadvantages of using various regression and ANN models in model development which are crucial in my study. The major research gap being the lack of research which contributes to the development of pavement condition evaluation model in the context of Nepal. The significance of various distresses and their corresponding severities with the condition and roughness of the pavement is also an area which is yet to be explored to full extent. For example, so far to the knowledge of the authors, the pavement condition evaluation model is not developed in the context of Nepal and there have been IRI models which only considers some specific distresses like rutting, cracking, potholes, depressions and raveling. Therefore, this study contributes to this gap in literature by developing a model to assess the present condition and roughness of the pavement with the help of the distresses in the pavement.

CHAPTER 3: METHODOLOGY

3.1 General

The methodological process starts with the critical review of various sources of literatures mentioned in previous chapters. The evaluation of pavement condition and the pavement roughness is carried out on the basis of the distresses and the severity of the distress at present in order to give the concerned authority the idea about the condition of the existing pavement so as to make necessary pavement management decisions related to pavement maintenance and pavement rehabilitation. It is to be noted that the methodology followed in this study solely focuses on the evaluation of pavement condition and roughness in asphalt concrete pavements. The methodological steps are discussed in detail in the following sections.

3.2 Methodological Framework

The detailed methodological framework followed in this study is shown in Figure 3.1. It includes the selection of the study area, the data collection of IRI and distresses, the validation of the RoadRoid IRI data with Romdas z-250 reference profiler, analysis of the collected data, and the development of regression and ANN-based models for PCI and IRI along with their validation and testing. The collection of distress data for the evaluation of PCI is based on the specifications of ASTM 6433, which also provides in detail, the steps for the evaluation of the Pavement Condition Index through evaluation of deduct values and corrected deduct values. The RoadRoid IRI represents the roughness of the pavement section in consideration while also providing with idea about the ride quality in the same section. The presets used for IRI survey using RoadRoid, and the detailed process and steps of regression analysis and ANN model are discussed in respective sub sections of this chapter.

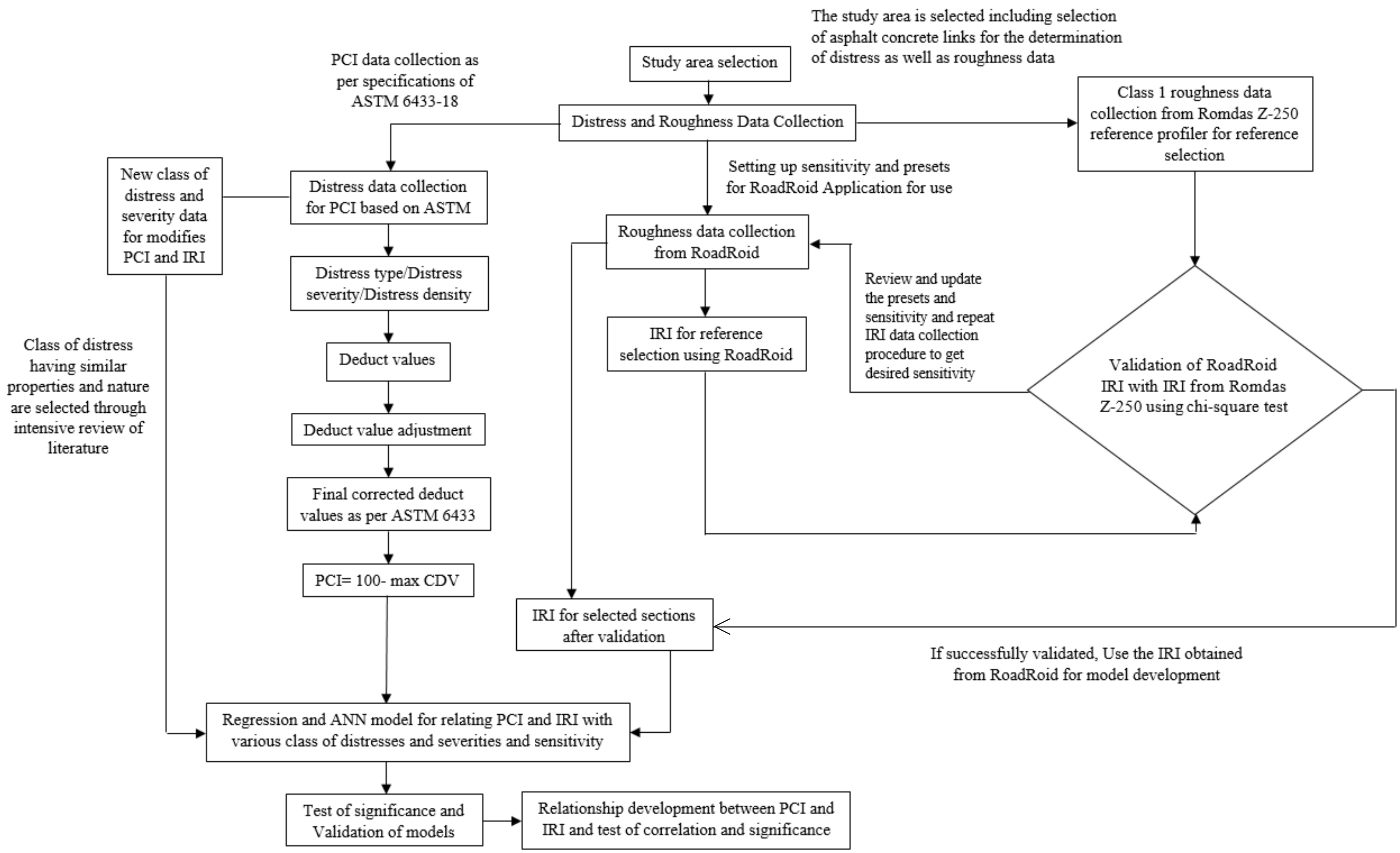

Figure 3.1: Methodological framework of the study

3.3 Study Area

The study area primarily for data collection is based on feeder roads of Kathmandu, Lalitpur and Bhaktapur District and National Highways near to Kathmandu valley. The sites from where the distress and roughness data are collected are included in Table 3.1.

Table 3.1: Study area for data collection

Link	Designation	Distance Surveyed
Jadibuti-Manohara-Sanothimi	F086	2.4 km
Samakhusi-Grande-Tokha	F082	4.4 km
Lubhu to Lakuri Bhanjyang road	H15	5.0 km
Lainchaur-Maharajgunj-Bansbari-Budhanilkantha	F021	9.3 km
Hattiban-Harisiddhi-Thaiba-Godawari	F024	6.6 km
Imadol-Sanagau-Mahalaxmi-Biruwa-Lamatar	F072	7.6 km
Tripureswor-Kalimati-Kalanki-Satungal-Thankot	H18	9.5 km
Chabail-Jorpati-Gokarna	F088	5.5 km
Total length surveyed		50.3 km

3.4 Data Collection

3.4.1 Distress Data Collection

Collection of data is carried out on the selected sections to assess the current condition of the pavement, including visual inspections and measurements of various pavement distresses, such as cracking, rutting, alligator cracking, roughness and so on.

- For the collection of data, each link is divided into sections of 100 m length and the distresses and roughness are evaluated for each of the sections.

- A total of 20 distresses along with their corresponding severities (low, medium, high) are included as per ASTM 6433-18 for evaluation of PCI for each of the divided sections. The quantification of the distresses as per ASTM 6433 is presented in Table 3.2 and Table 3.3 below:

Table 3.2: Distress quantification based on ASTM 6433-18

<table>
<tr><th>Distress</th><th>Severity</th><th colspan="3">Specification</th></tr>
<tr><td rowspan="3">Rutting</td><td>Low</td><td colspan="3">Average rut depth- 6 to 13 mm (1⁄4 to 1⁄2 in.)</td></tr>
<tr><td>Medium</td><td colspan="3">Average rut depth- 13 to 25 mm (>1⁄2 to 1 in.)</td></tr>
<tr><td>High</td><td colspan="3">Average rut depth->25 mm (>1 in.)</td></tr>
<tr><td rowspan="3">Longitudinal and Transverse Cracking</td><td>Low</td><td colspan="3">Average width of crack < 10 mm (3/8 in)</td></tr>
<tr><td>Medium</td><td colspan="3">Average width of crack – 10 mm to 75 mm (3/8 in to 3 in)</td></tr>
<tr><td>High</td><td colspan="3">Average width of crack > 75 mm (3 in)</td></tr>
<tr><td rowspan="4">Potholes</td><td>Maximum depth</td><td>Diameter 100 mm – 200 mm (4 in -8 in)</td><td>Diameter 200 mm – 450 mm (8 in -18 in)</td><td>Diameter 450 mm – 750 mm (18 in -30 in)</td></tr>
<tr><td>13 to 25 mm (0.5 to 1 in)</td><td>Low severity</td><td>Low severity</td><td>Medium severity</td></tr>
<tr><td>25 to 50 mm (1 to 2 in)</td><td>Low severity</td><td>Medium severity</td><td>High severity</td></tr>
<tr><td>> 50 mm (2 in)</td><td>Medium severity</td><td>Medium severity</td><td>High Severity</td></tr>
<tr><td rowspan="3">Slippage Cracking</td><td>Low</td><td colspan="3">Average width of crack < 10 mm (3/8 in)</td></tr>
<tr><td>Medium</td><td colspan="3">Average width of crack – 10 mm to 40 mm (3/8 in to 1.5 in)</td></tr>
<tr><td>High</td><td colspan="3">Average width of crack > 40 mm (1.5 in)</td></tr>
</table>

Table 3.3: Remaining distress quantification based on ASTM 6433-18

Depression	Low	Depth of depression- 13 mm to 25 mm (0.5 in-1 in)
	Medium	Depth of depression- 25 mm to 50 mm (1 in-2 in)
	High	Depth of depression > 50 mm(> 2 in)
Lane/Shoulder Drop off	Low	Difference in elevation between pavement edge and shoulder- 25 mm – 50 mm (1 in to 2 in)
	Medium	Difference in elevation between pavement edge and shoulder- 50 mm – 100 mm (2 in to 4 in)
	High	Difference in elevation between pavement edge and shoulder > 100 mm(> 4 in)
Patching	Low	Patch is in good condition and not worn out. (Qualitative Identification)
	Medium	Patch is moderately deteriorated
	High	Patch is badly deteriorated and spalling off.
Weathering/ Ravelling	Low	Aggregate or binder is starting to wear away.
	Medium	Aggregate or binder has worn away moderately.
	High	Aggregate or binder has worn away considerably
Swell/Corrugations/ Shoving (Ride quality distresses)	Low	Qualitative measure causing noticeable vehicle vibration not requiring speed reduction.
	Medium	Qualitative measure causing significant vehicle vibration requiring speed reduction.
	High	Qualitative measure causing excessive vehicle vibration requiring significant speed reduction.

- During the collection of data, only asphalt concrete pavements are considered and rigid pavements are omitted/neglected.
- Some sample distresses encountered during the course of the survey are presented in Table 3.4.

Table 3.4a: Pictures and description related to distress evaluation survey

Photo	Interpretation/Distress information
	Section measurement at Pepsicola Chowk-Manohara section
	High severity pothole @ Pepsicola-Manohara section Pothole depth- 35 mm Pothole diameter- 460 mm

Table 3.4b: Pictures and description related to distress evaluation survey

	Low severity pothole @ Gwarko-Lubhu section Diameter- 125 mm Depth - 15 mm
	High Severity Alligator Cracking @ Chakrapath - Bansbari section
	Low severity alligator cracking and linear cracking @ Chakrapath-Bansbari section

Table 3.4c: Pictures and Description related to distress evaluation survey

	Medium severity slippage cracking @ Gwarko Imadol section
	Medium severity alligator cracking and medium severity patching @ Lainchaur to Chakrapath section

Table 3.4d: Pictures and Description related to distress evaluation survey

	High Severity Potholes, Depressions, alligator cracking at same section @Lainchaur-Chakrapath link
	Medium severity rutting, potholes, depressions at same section @Chakrapath-Budhanilkantha link

3.4.2 PCI Estimation Procedure

Analysis of the collected data is carried out to determine the PCI value using ASTM 6433-18, which provides a numerical rating of the overall condition of the pavement and distress rating of pavement respectively. The standard PCI scale is as shown in Figure 3.2

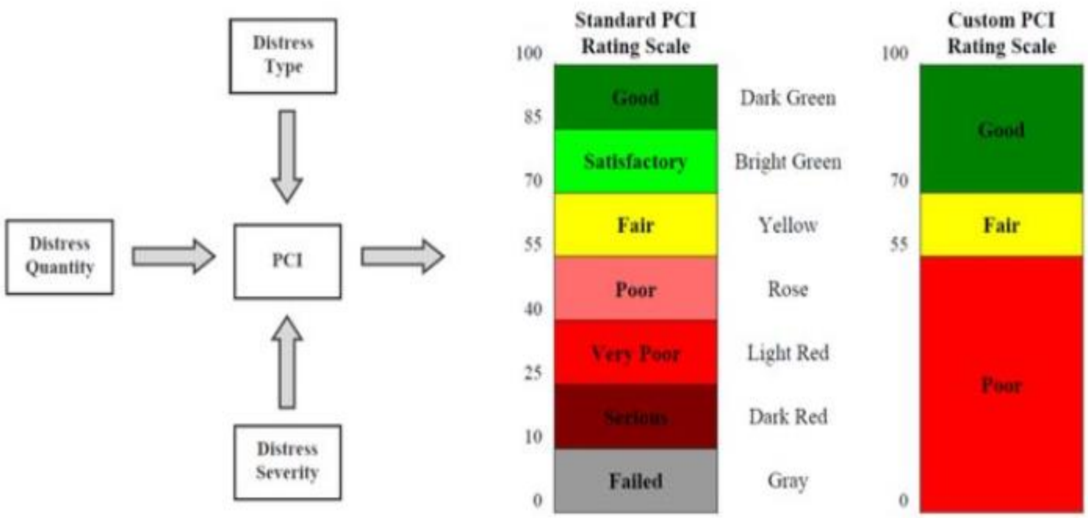

Figure 3.2: Standard PCI scale (Source: ASTM 6433)

The section of 100 m length is first measured and marked before collection of data. The visual inspection survey of distress along with the severities is then carried out as per ASTM 6433 instructions.

The manual PCI calculation procedure based on ASTM 6433 is summarized as:

1) The selected road sections are divided into equal sub sections of 100 m length and the corresponding average width of the section are noted.

2) Then the distress are noted and quantified with the help of visual field inspection survey and are the corresponding distress density is determined as percentage of total area of the section by dividing the area of distress with the area of the pavement section. The distress to be evaluated as per ASTM 6433 as presented in Table 3.5.

Table 3.5: List of distresses to be collected for PCI

(A) Different Cracking	(B) Potholes and Patching	(C) Deformation related distresses	(D) Surface Defects	Group (E) Other distresses
Edge Cracking	Potholes	Swelling	Raveling	Rail-Road Crossing
Reflection Cracks	Utility patching	Shoving	weathering	Lane Shoulder Drop
Block Cracking	Patching	Corrugation	Polished Aggregate	
Slippage Cracks		Rutting	Bleeding	
Longitudinal and Transverse Cracks		Depressions		
Alligator Cracking				

3) The deduct values are then determined for each type of distresses and the corresponding severity levels for the particular distress.

4) The PCI is estimated by applying the deduct value for each distress type along with any required correction factors (Corrected Deduct Values, CDVs) to account for multiple distress types. The PCI is obtained by reducing the maximum CDV from 100. Figure 3.3 shows sample deduct value curves for bleeding and potholes respectively.

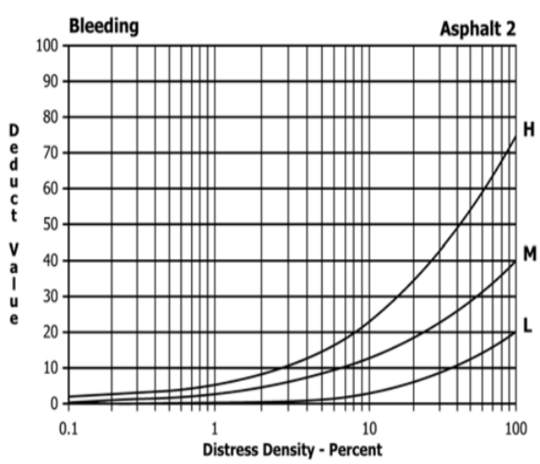

FIG. X3.2 Bleeding

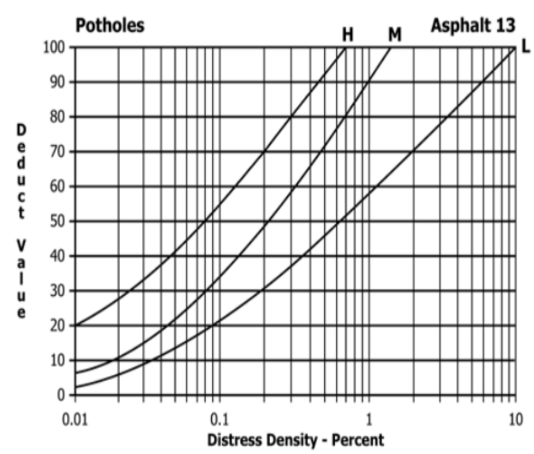

FIG. X3.18 Potholes

Figure 3.3 Sample deduct value graph for bleeding and potholes (Source: ASTM 6433)

5) If none or only one individual deduct value is greater than two, the total value is used in place of the maximum CDV in determining the PCI; otherwise, maximum CDV is determined using following procedures.

6) The individual deduct values are listed in descending order and the allowable number of deducts are determined with the help of the Equation (3.1):

$$m = 1 + (9/98)\ (100 - \mathrm{H}DV) \leq 10 \qquad (3.1)$$

(Where, HDV = highest individual DV. The number of individual deduct values then is reduced to the m largest DVs, including the fractional part. If less than m DVs are available, all of the DVs are used.

7) The maximum CDV is determined using iterations following the given procedure:

a) The total deduct values are initially determined by adding up individual deduct values,
b) Determine total deduct value (TDV) by summing individual DVs.
c) q as the number of DVs whose value greater than 2.0 is then determined.
d) The CDV is then determined for the value of q and total deduct value from appropriate curve of correction as in Figure 3.4.
e) The value of smallest individual DV greater than 2 is reduced to 2 and the process is repeated until q=1 is obtained;

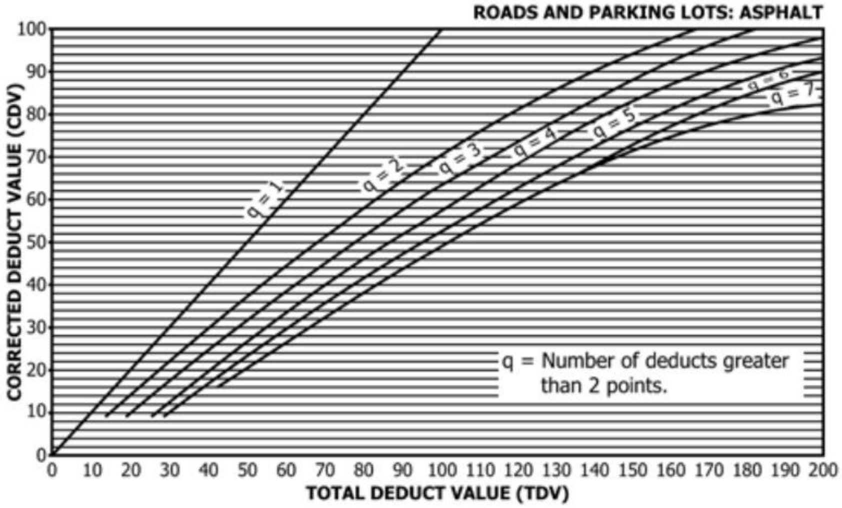

Figure 3.4: Corrected Deduct Value vs Total Deduct Value graph (Source: ASTM 6433)

8) The maximum of corrected deduct values is found and the PCI is determined with the help of the Equation (3.2):

$$PCI = 100 - maxCDV \tag{3.2}$$

The sample calculation of PCI is presented as follows:

Jadibuti-Manohara Section (chainage 0+200-0+300)

Table 3.6.1: Distress quantity, density and deduct values estimation

Distress-type	***Distress quantity***								***total distress quantity***	***Density (%)***	***Deduct values/weight***
1M	8.2	0.56							8.76	0.80	**20**
2L	4.6	3.6							8.2	0.75	**4.4**
2M	2.4	2.06	2.1	3.3	3.14	2.6	6.24	10.2	32.04	2.91	**5**
11H	2	1.6							3.6	0.33	**12.5**
17M	0.5	0.9							1.4	0.13	**4**
15H	0.6	0.5	0.6	1.2					2.9	0.26	**16.2**
13H	1	2	3						6	0.55	**44**
5L	2.5	2.5	3.1						8.1	0.74	**8**
19M	3.84	2.06	2.1						8	0.73	**7**

For 1 M – Medium severity Alligator cracking

Distress quantity= 8.76 m^2

Distress density = 8.76/11000*100=0.8 %

The corresponding deduct value/ weight curve for alligator cracking is given by

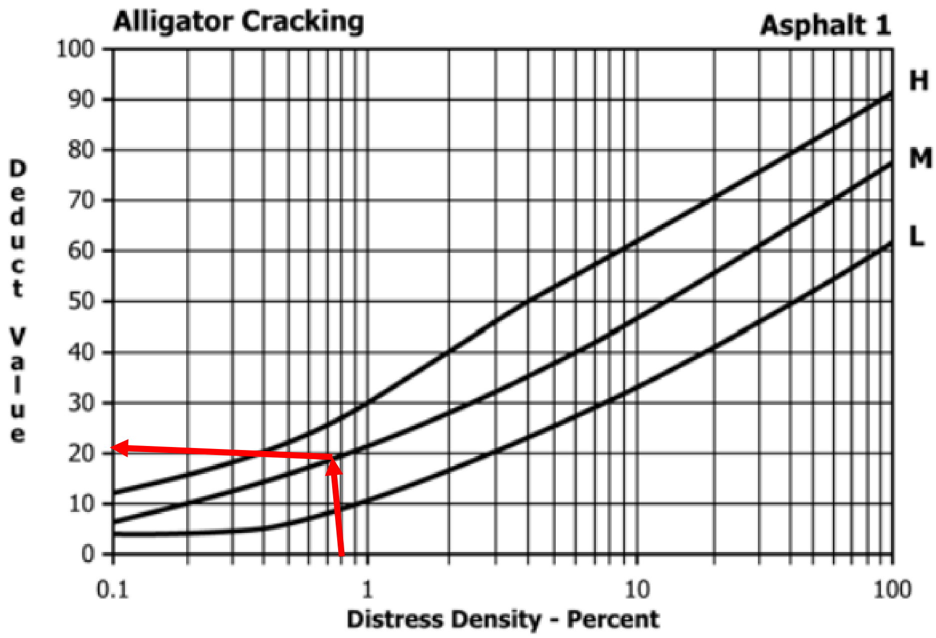

FIG. X3.1 Alligator Cracking

The corresponding deduct value is 20 for medium severity alligator cracking for distress density of 0.8 % of total area. Similarly deduct values for all distress mentioned are also computed.

Allowable number of deducts is then calculated with the help of formula as below. (This step ensures the maximum cumulative sum of deduct values of all distresses does exceed 100 yielding –ve PCI)

$m = 1 + (9/98)\,(100 - \mathrm{H}DV) \leq 10$

m=1+(9/98)*(100-44)=6.14

So we use the highest 6 deducts and 0.14 x 7^{th} deduct for computation of corrected deduct values.

Table 3.7.2: Calculation of total and corrected deducted values

#	*DV*							*Total*	*q*	*CDV*
1	44	20	16.2	12.5	8	7	0.7	108.4	6	54
2	44	20	16.2	12.5	8	2	0.7	103.4	5	53
3	44	20	16.2	12.5	2	2	0.7	97.4	4	52
4	44	20	16.2	2	2	2	0.7	86.9	3	51
5	44	20	2	2	2	2	0.7	72.7	2	50
6	44	2	2	2	2	2	0.7	54.7	1	54

PCI = 100- maximum CDV

=100-54

=46

3.4.3 IRI Data Collection

IRI value is determined for all the selected sections of the road with the help of licensed version of RoadRoid Pro 3.

3.4.3.1 Specifications and Presets

The following device and presets shown in Table 3.6 and Table 3.7, and Figure 3.5 and Figure 3.6 are used after validation for the estimation of IRI value.

Smartphone used- Samsung Galaxy S9

Vehicle used throughout the survey: Nissan Magnite (SUV)

Car mount used- Logitech Car Mount (Most stable within the budget)

Table 3.8: Accelerometer sensitivity set for different speeds

Speed	Accelerometer Sensitivity Set
20 Km/hr	0.28
40 Km/hr	0.42
60 Km/hr	0.52
80 Km/hr	0.56
100 Km/hr	0.57
120 Km/hr	0.52

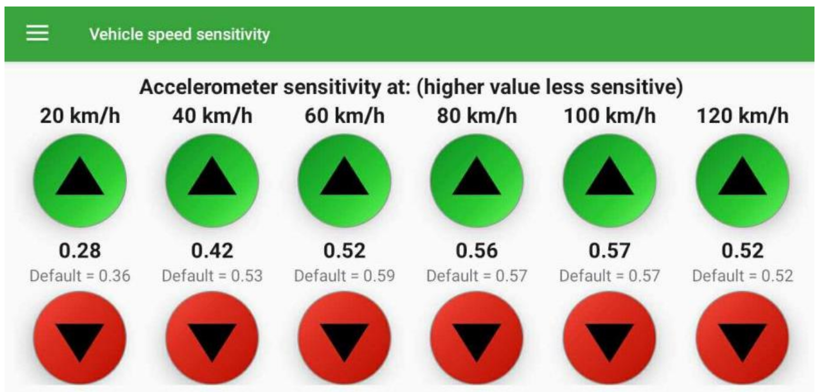

Figure 3.5: Accelerometer sensitivity set for different speeds

Table 3.9: Parameter Sensitivity set for testing

Parameter	Sensitivity
eIRI (texture)	1.0
cIRI (Roughness)	1.3

Figure 3.6: Parameter Sensitivity set for testing

RoadRoid calculates roughness in the form of cIRI which is calibrated as per the IRI using advanced laser sensing equipment and also calibrated for various operational speeds. The aggregate IRI values are then generated for 100 m section from RoadRoid application itself and the sections are validated with the help of video of the section taken from camera in the survey. The sample view of instantaneous eIRI, cIRI and Speed can be shown through graph as in the example given below in Figure 3.7.

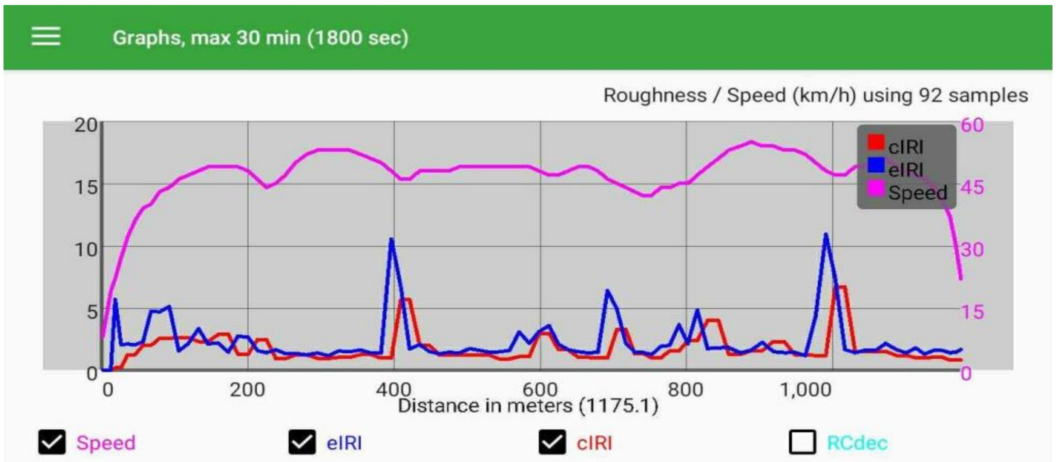

Figure 3.7: Sample instantaneous eIRI, cIRI and speed

3.4.3.2 RoadRoid IRI Data Collection Procedure

Following lists out the RoadRoid IRI data collection steps:

I. After setting the presets and sensitivity for the device after validation, the stable car mount, Logitec+ is fixed in the windshield.

II. The mount is connected with the windshield of the vehicle with a suction cup and oriented in direction such that the phone is oriented in landscape mode.

III. The phone is placed in the mount and the Road Roid application is opened. The fitting button is pressed in order to adjust the 3D sensor of the phone. This is done in order to ensure that the accelerometer only picks vertical acceleration (Y direction) and excludes turning (Z direction) and breaking (X direction).

IV. The camera is oriented towards the road to take video to set up and identify reference points in order to compare data with distresses obtained in the next phase of the survey.

V. The start survey button is then pressed in order to commence the road quality/roughness estimation survey.

VI. The application collects date in form of latitude and longitude of the path, eIRI, cIRI, distance covered, free space remaining and temperature of the phone.

3.4.3.3 RoadRoid IRI Validation

The IRI obtained from RoadRoid is tested against the roughness data collected for same stretch of road for validation of IRI obtained from RoadRoid. For this, the ROMDAS Z-250 Reference Profiler is used in order to obtain highly accurate data of ride quality in terms of IRI. The Reference profiler is used inside the periphery of Pulchowk Campus and a total length of 100 m is surveyed for IRI. The data is then converted for 5 m intervals using ProVAL 3.1 software because the least interval that could be analyzed from RoadRoid is 5m. The IRI value is again estimated for the same section of the road with the help of RoadRoid application. A total of 4 passes on the same section is carried out and the average of the four values is termed as RoadRoid average IRI. Table 3.8 shows the RoadRoid IRI in each pass of the section along with the IRI measured for the same section with the help of ROMDAS Z-250 reference profiler. The Chi-square test of goodness of fit is then carried out in order to test the goodness of fit of the observed data (data obtained from RoadRoid) with the estimated data (Data obtained from ROMDAS Z-250 Reference Profiler). The test of goodness of fit is presented in the following along with hypothesis testing. The various parameters and speed is then changed in order to provide better fit of IRI with Romdas Profilometer IRI. In order to carry out chi-square test, the expected and the observed frequencies are determined as shown in Table 3.9.

Table 3.10: Measured ROMDAS reference profiler IRI and RoadRoid IRI

Section(m) a	The ROMDAS Z-250 Reference Profiler IRI	RoadRoid IRI 4 passes same section				RoadRoid average IRI
0-5	1.251	1.5	1.45	1.32	1.36	1.408
5-10	1.631	1.85	2.05	2.12	1.9	1.980
10-15	2.777	2.85	2.98	3.01	2.94	2.945
15-20	10.502	5.88	6.18	6.45	5.98	6.123
20-25	7.253	6.45	6.78	6.12	6.23	6.395
25-30	5.123	4.23	4.12	4.57	4.23	4.288
30-35	1.941	2.05	2.33	2.08	2.06	2.130
35-40	2.530	2.8	2.6	2.56	2.48	2.610
40-45	3.794	3.8	3.98	3.77	3.23	3.695
45-50	6.424	5.21	5.23	5.98	5.15	5.393
50-55	7.156	6.15	6.35	6.66	6.39	6.388
55-60	6.471	6.12	6.32	6.89	6.44	6.443
60-65	3.859	3.5	3.26	3.55	3.68	3.498
65-70	3.491	3.5	3.66	3.45	3.54	3.538
70-75	3.318	3.12	3.28	3.18	3.5	3.270
75-80	3.151	3.05	3.5	3.22	3.32	3.273
80-85	3.246	3.44	3.08	3.2	3.22	3.235
85-90	2.748	2.89	2.85	2.98	2.74	2.865
90-95	2.606	2.4	2.56	2.14	2.71	2.453
95-100	2.484	2.56	2.55	2.87	2.49	2.618

Before the development of the IRI model, the RoadRoid IRI is validated for goodness of fit between the observed IRI values and expected IRI values with the help of Chi-Squared test. Since the data for 5 m internal is not enough to generate adequate number of frequencies, the IRI from Romdas profiler is determined for 2.5 m section intervals to generate 40 data of IRI. The data of 2.5 m interval Romdas IRI is presented in ANNEX section. Hypothesis testing is carried out to perform this test in which the null hypothesis and the alternative hypothesis are defined.

Null hypothesis (H_0): There is no significant difference between the expected frequencies and the observed frequencies.

Alternative Hypothesis (H_1): There is significant difference between the expected frequencies and the observed frequencies.

The level of significance is set as 0.05.

Table 3.11: Chi square test table

IRI interval	Observed frequency	Expected frequency	O-E	(O-E)^2/E
0-1.5	4	5	-1	0.2
1.5-3	12	14	-2	0.285714286
3-4.5	12	9	3	1
4.5-6	4	5	-1	0.2
6-7.5	8	7	1	0.142857143
Sum	40	40		1.828571429

Chi Square = 1.8285

Degree of freedom = 5-1 =4

The P value corresponding to Chi square value of 1.8285 and DOF 4 is 0.7672 >>> 0.05, therefore there is no significant difference between the observed values and the expected values and the null hypothesis is accepted. Therefore, we can say that, the IRI obtained from RoadRoid can be used for IRI evaluation in this thesis.

3.5 Data Processing

The collected raw data for the estimation of IRI is processed in order to match it with the corresponding sections for which the PCI value is to be estimated or for which the distress data is to be calculated. The IRI value is initially acquired for entire section length on either side of the road. The average IRI of the two passes is then evaluated by coordinate matching and validated using video taken during IRI determination. There are some cases where the asphalt concrete pavements are infiltrated by certain section of rigid concrete. In such cases, the start and end locations are marked during the IRI data collection phase and the IRI for corresponding sections are filtered out for accurate estimation of IRI of the section.

3.6 Grouping of Distress for Model Development

Individual distresses along with their corresponding severities could not be directly used in our case due to the limitation of data availability and lack of availability of time to collect the data. Therefore, grouping of distresses is necessary. The grouping of 20 number of distresses and their corresponding severities is carried out based on the nature of the distresses after extensive review of literature. Distresses with similar nature are placed in same group. Potholes and rutting which are not related to any other distresses and had major contribution are assigned as isolated distresses. Railroad crossing is not considered in the study. In the second model, Alligator cracking and bleeding are separated into isolated distresses as it is found that they contributed to significant proportion among all the distresses after data collection. Two groupings of data are taken as input for model development of PCI and IRI as shown in Table 3.10 and Table 3.11 respectively.

Table 3.12: Grouping Set 1

Designation	Distress Designation as per ASTM 6433	Distress Type	Nature
AC	1+3+7+9+10+17	Alligator Cracking + Block Cracking+ Edge cracking + Long and Trans cracking+ Lane shoulder drop off+ Joint reflection cracking+ Slippage cracking	Cracking
D	4+5+6+16+18	Bumps + corrugation+ Swell+ Shoving +Depression	Visco Elastic Deformations
BE	2+12+19+20	Bleeding+ Polished aggregate+ Raveling + Weathering	Surface Wear
F	13	Potholes	Potholes
G	15	Rutting	Rutting
H	11+14	Patch +Utility cut patch	Patching and Others

Table 3.13: Grouping Set 2

Designation	Distress Designation as per ASTM 6433	Distress Type
A	1	Alligator Cracking
B	2	Bleeding
C	3+7+9+10+17	Block Cracking+ Edge cracking + Long and Trans cracking+ Lane shoulder drop off+ Joint reflection cracking+ Slippage cracking
D	4+5+6+16+18	Bumps + corrugation+ Swell+ Shoving +Depression
E	12+19+20	Polished aggregate+ Raveling + Weathering
F	13	Potholes
G	15	Rutting
H	11+14	Patch +Utility cut patch

The numerals 1, 2 and 3 represents low, medium and high severity of the corresponding distress grouping. The nomenclature of all forms of distresses on the basis of their nature and corresponding severity are incorporated in Table 3.12.

Table 3.14: Nomenclature of variables

Designation	Nomenclature
AC1	Low Severity Cracking
AC2	Medium Severity Cracking
AC3	High Severity Cracking
BE1	Low Severity Surface Wear
BE2	Medium Severity Surface Wear
BE3	High Severity Surface Wear
A1	Low Severity Alligator Cracking
A2	Medium Severity Alligator Cracking
A3	High Severity Alligator Cracking
B1	Low Severity Bleeding
B2	Medium Severity Bleeding
B3	High Severity Bleeding
C1	Low Severity Cracking (except Alligator Cracking)
C2	Medium Severity Cracking(except Alligator Cracking)
C3	High Severity Cracking(except Alligator Cracking)
D1	Low Severity Visco-Elastic Deformations
D2	Medium Severity Visco-Elastic Deformations
D3	High Severity Visco-Elastic Deformations
E1	Low Severity Surface Wear (except Bleeding)
E2	Medium Severity Surface Wear(except Bleeding)
E3	High Severity Surface Wear(except Bleeding)
F1	Low Severity Potholes
F2	Medium Severity Potholes
F3	High Severity Potholes
G1	Low Severity Rutting
G2	Medium Severity Rutting
G3	High Severity Rutting
H1	Low Severity Patching
H2	Medium Severity Patching
H3	High Severity Patching

3.7 PCI and IRI Evaluation Models

Using the collected and grouped distress values, calculated PCI values as per ASTM 6433, and determined IRI values using RoadRoid applications in different sections of the road, models are developed using various techniques in order to develop the relationship of corresponding distress and their severities with PCI and IRI. Both the regression and ANN-based models are developed and then compared to select the best fit model among the two.

3.7.1 Regression Based Models

One of the most widely used analytical tool to develop the relationship between the dependent variable with one or a number of independent variables is the multiple regression model. The main reason of popularity of the model is because of the fact that, regression models are easier to interpret and construct. The regression models may take linear form known as linear regression models whereas, the degree of the independent variable may be increased in order to best fit the model with the data in concern and such regression models are known as polynomial regression models. The multiple linear regression in which 'y' represents the dependent variable modelled with 'x' as independent variable, β as regression coefficient and Ɛ as residual error can be expressed with the help of the Equation (3.3) as follows.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \varepsilon \tag{3.3}$$

Where,

y: Dependent variable

$x_1, x_2, \ldots x_n$: Independent variables

$\beta_0, \beta_1, \beta_2 \ldots \beta_n$: Regression coefficients

Ɛ: Residual error

If the degree of x in the relation is increased, it takes the form of polynomial regression equation. The relationship takes a very complex form when the number of independent variables are used in the equation.

The equation form with only one independent variable is as presented through Equation (3.4):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_1^2 + \ldots + \beta_n x_1^n + \varepsilon \tag{3.4}$$

In the first trial, the first set of distress data with 18 independent variables is used in order to develop the model. Linear relationships of different distresses which are taken as independent variables with PCI which is taken as dependent variable is modelled out. In the second trial, the degree of variable is increased in iterations to check for the MSE for each degree of polynomial and the degree of variable for which the MSE is minimum is taken as the best fit regression model for PCI. This process is repeated for second set of input distress data with 24 variables. In order to develop the model, it is a prerequisite that, the independent variables show minimum amount of correlation with each other. If the degree of correlation between the independent variables is high, such independent variables can be merged or adjusted before using it for the analysis. High degree of correlation between the variables also affects the true relationship of the dependent variable with the independent variables. Therefore, for both sets of data, the study of correlation is carried out before using them for model development. The correlation matrix is therefore developed for both sets of data for both PCI and IRI.

3.7.2 Artificial Neural Network (ANN)-Based Models

The regression models hold true for majority of the cases with satisfactory performance but the accuracy and reliability of the model can further be improved with the help of several machine learning algorithms one of which is Artificial Neural Network (ANN). Artificial neurons, also known as processing elements, are used in place of real neurons in a neural network (PEs). The input, hidden, and output layers of an ANN are made up of at least three linked PE layers. The number of input variables utilized to forecast the intended output is equal to the number of PEs in the input layer (independent variables) (Shahnazri, et al. 2012).

3.7.3 Network Architecture of ANN

For the development of the model, Python 3.9 is used. The collected data is formatted in excel and it is later saved in .csv (comma separated variables) format in order to import it in Python. The data is loaded in Python with the help of the library known as Pandas. The data cleaning process is then performed which includes process like correcting typos and handling the missing data. The predictors are scaled with the help of standard scalars. After that, a model is build which consists of input neurons equal to the number of independent variable i.e. 18 for first grouping set and 24 for the second grouping set of input data. A single hidden layer is used and the optimum number of neurons in the hidden layer is determined with the help of hit and trial method. In order to predict the value of PCI or IRI as dependent variable a single output neuron is used in each trial. MSE is used as a loss function and as a metric to estimate how well the model is performing in the trial. 'Adam' is used as an optimizer which tries to minimize the loss function by adjusting the weights between the neurons in each iteration. Rectified Linear Unit 'ReLU' is used as an activation function in both the hidden as well as output layers in ANN model. The learning rate for the ANN model is set as 0.01. For the purpose of training and testing the model, the data set is split into train_set and test_set in the ratio 90:10 using train_test_split function in the model selection module of the scikit-learn library. The train_set is used to fit the ANN model using the validation split to be 0.1. i.e. data used for training and validation of the model is in the ratio of 90:10. The sample Neural Network using Rectified Linear Unit (ReLU) activation function is as shown in Figure 3.8.

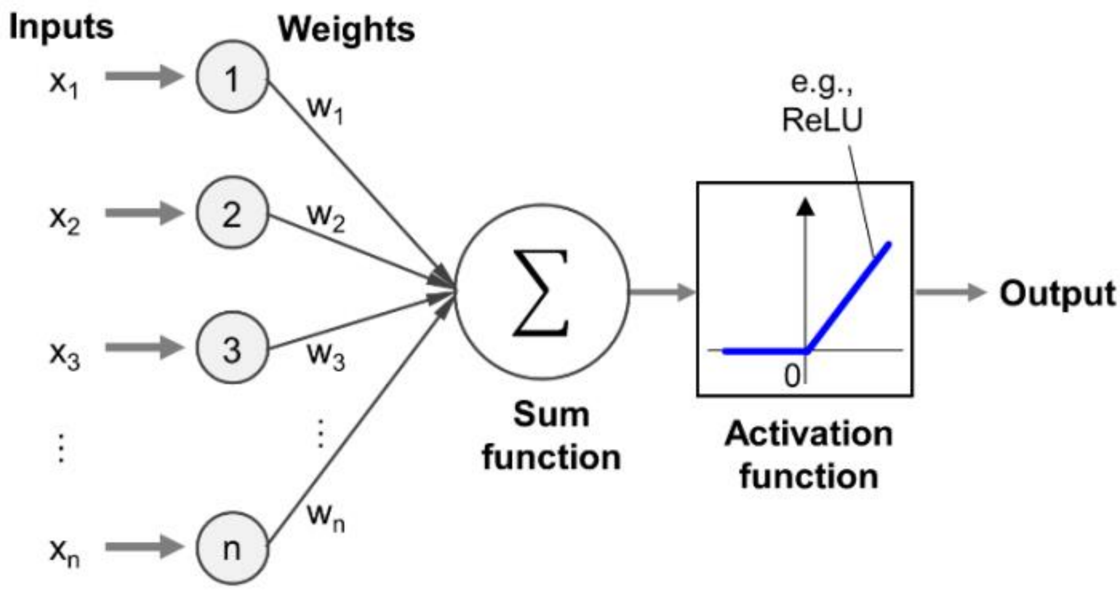

Figure 3.8: Sample Neural Network using ReLU activation function (Mitsgu et,al, 2021)

For 1st set of data with 18 number of input variables, the optimum number of neurons in the hidden layers is found to be 12 after several trials and iterations as it offered least RMSE and maximum value of R^2 in the iterative trials, whereas for 2nd set of data with 24 input variables, the optimum number of neurons in the hidden layers is found to be 18. Therefore, the network structure of the ANN model for evaluation of PCI is proposed as 18-12-1 for 18 input variables and 24-18-1 for 24 input variables. A sample ANN architecture with 18 input variables, 12 neurons in 1 hidden layer and 1 output layer is shown in Figure 3.9.

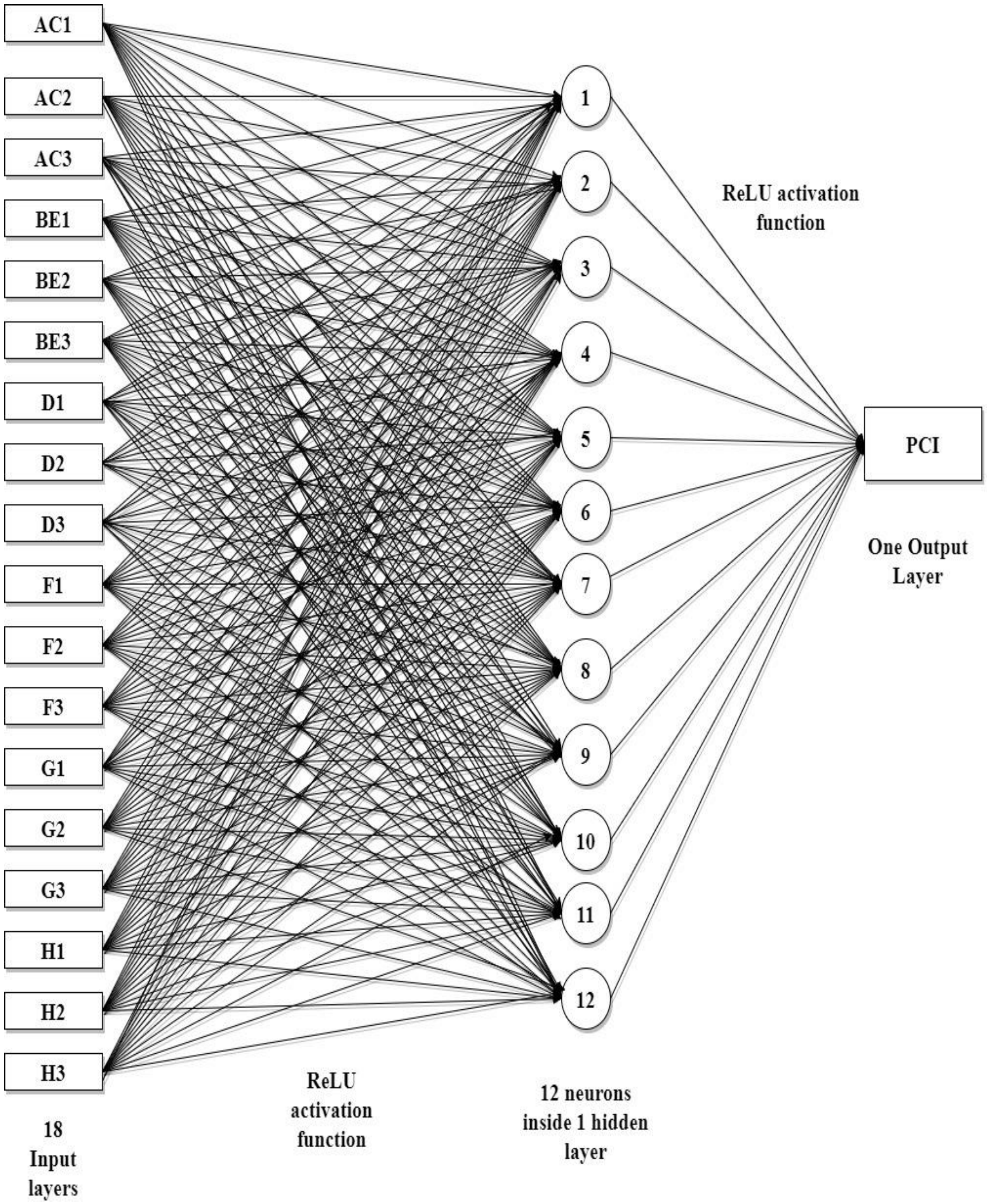

Figure 3.9: ANN architecture for data set 1 (18-12-1)

CHAPTER 4: PCI AND IRI EVALUATION MODELS

4.1 General

This chapter presents the PCI and IRI models developed in this study and discusses their performances. The model for PCI and IRI evaluation is developed with the help of both multiple linear regression along with machine learning technique in the form of Artificial Neural Network (ANN) which is discussed in the previous chapter. The details related to the development of the model followed by the results of testing as well as validations are discussed in the following subsections. A total of 503 sample units with each unit of length 100 m are used for the development of the PCI model whereas 468 sample units are used for the development of IRI estimation model and for the development of relationship between PCI and IRI. The comparisons are made between the multiple regression models and ANN models in order to select the best model for the estimation of the dependent variables. To compare the performance of the models, Mean Square Error (MSE), Root Mean Square Error (RMSE) and coefficient of determination (R^2) are used.

4.2 PCI Evaluation Models

4.2.1 Performance of Regression-Based PCI Model

To initiate the development of regression model, it is necessary to derive and estimate the relationship between the independent variables (distresses) which can be checked by developing the correlation matrix. The correlation between each of the independent variables for PCI determination is checked with the help of Python 3.9 as well as excel 2016 with the help of solver add ins. The correlation matrices are derived for each of the data set of independent variables with 18 input variables and 24 input variables as shown in Figure 4.1 and Figure 4.2, respectively.

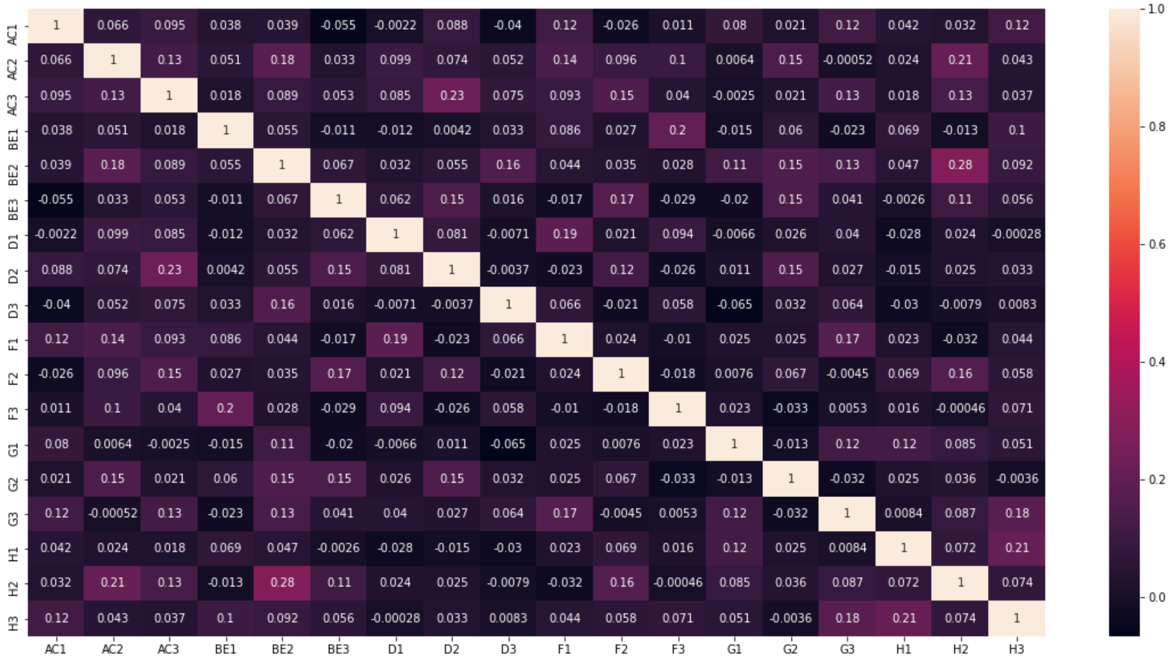

Figure 4.1: Pearson correlation coefficient matrix for PCI grouping set 1

Figure 4.2: Pearson correlation coefficient matrix for PCI grouping set 2

As per the correlation matrices for both set of input data, it can be seen that, the coefficient of correlation for the individual variables is weak indicating that there is no multicolinearity between the selected numbers of independent variables in the respective cases. Therefore, all the input variables could be used for the development of regression models for both the PCI as well as IRI. For the development of PCI evaluation model using regression analysis, the collected input data is split into 90:10 for the purpose of training and testing respectively. Only 90 % of the total data is considered for the development of the regression models.

Initially, multiple linear regression model is carried out in Python 3.9 with the help of the linear regression function imported from sk.learn_linearmodel library. After that, the degree of variable is increased one by one to check for the Mean Square Error (MSE) for each degree of polynomial and the degree of variable for which the MSE is minimum is taken as the best fit regression model for PCI. Based on the comparison of the validation MSE, it can be seen that the MSE is minimum for the regression set with degree one and MSE increases significantly with the increase in degree of the variable as shown in Figure 4.3. Therefore, it can be said that the regression model with degree one i.e. multiple linear regression model is to be considered the best regression model among regression models of all degrees.

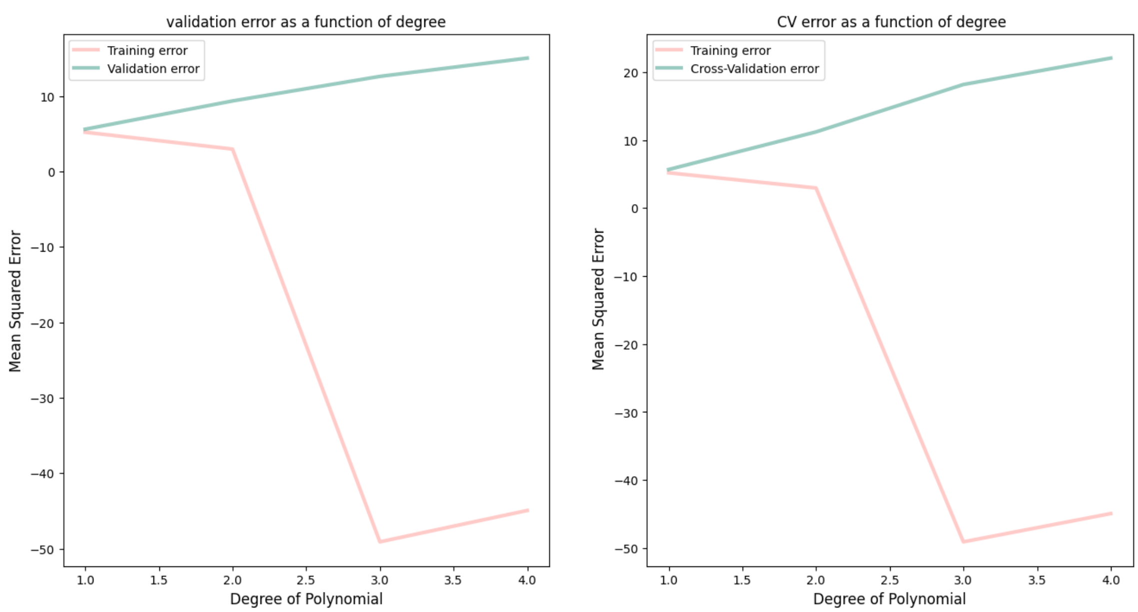

Figure 4.3: MSE vs degree of polynomial for training and validation

Based on the regression model, the ANOVA test is performed to evaluate the P value for each coefficient of regression equation. In data set 1 the P value of coefficients of D1, G2 and H1 are found to be greater than 0.05. This indicates that, there is no significance of change in the predicted PCI with the change in these independent variables therefore can be omitted from the equation. The reasons behind these can be infrequent occurrence of these distresses in the collected set of data and the low deduct value associated with these variables, resulting in their low impact on the PCI (for example: low/medium severity alligator cracking). Therefore, the regression model is prepared using the remaining coefficients. The R^2 value for multiple linear regression models for data set 1 is found to be 0.600 and 0.603 for training and testing, respectively. The summary of regression results and test statistics for grouping set 1 are shown in Table 4.1 and Table 4.2, respectively.

Table 4.1: Summary of Regression Results for PCI regression set 1

Dependent Variable:	PCI
R-squared:	0.600
Adj. R-squared:	0.583
F-statistic:	35.94
P value	3.32×10^{-74}
Degree of Freedom	18

Table 4.2: Test statistics and regression coefficients for PCI regression set 1

	Coefficient	Standard Error	t-statistics	P-value	Remarks
constant	76.6235	1.19	64.371	0	
AC1	-3.7493	1.238	-3.028	0.003	
AC2	-1.2415	0.715	-1.735	0.0083	
AC3	-4.4961	0.695	-6.467	0	
BE1	3.5914	1.714	2.095	0.037	
BE2	-2.01	1.003	-2.003	0.046	
BE3	-3.0152	0.988	-3.052	0.002	
D1	-4.4415	2.205	-2.014	0.45	P>0.05
D2	-0.3849	1.722	-0.224	0.023	
D3	-13.693	1.738	-7.88	0	
F1	-22.214	3.953	-5.62	0	
F2	-67.384	7.92	-8.508	0	
F3	-82.208	6.177	-13.308	0	
G1	-6.7471	4.718	-1.43	0.0153	
G2	-4.3134	3.623	-1.191	0.234	P>0.05
G3	-7.6866	3.06	-2.512	0.012	
H1	1.2442	2.854	0.436	0.663	P>0.05
H2	-1.9881	1.439	-1.382	0.016	
H3	-9.8945	2.607	-3.795	0	

The regression model for grouping set 1 with 18 variables is presented in Equation (4.1):

$$PCI = 76.62 – 3.74 * AC1 -1.24 * AC2- 4.49 * AC3 -2.00 * BE2 – 3.01 * BE3- 0.38*D2– 13.69 * D3- 22.21 * F1 – 67.38 * F2 – 82.20 * F3 -6.74* G1- 7.68 * G3 - 1.98 * H2- 9.89 * H3 \tag{4.1}$$

$R^2_{train} = 0.600$

$R^2_{test} = 0.606$

Equations (4.2) and (4.3) shows the relationship between predicted PCI with the target PCI based on regressions for training and testing set 1. The corresponding plots are shown in Figure 4.4 and Figure 4.5, respectively.

$$PCI_{predicted\_train} = 0.604 * PCI_{target\_train} + 23.498 \tag{4.2}$$

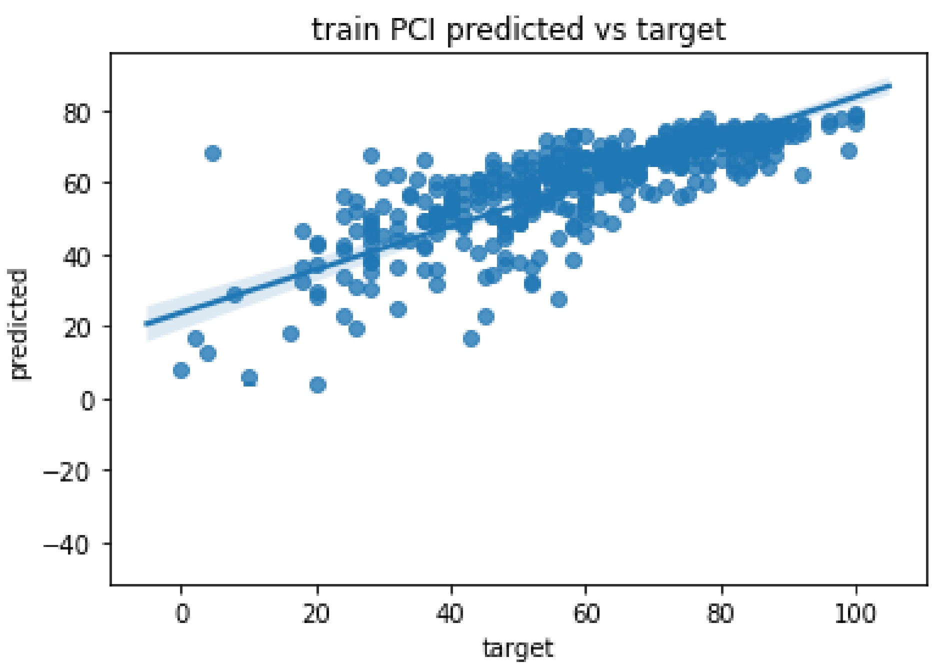

Figure 4.4: Predicted PCI vs target PCI (regression training set 1)

$$PCI_{predicted\_test} = 0.621* PCI_{target\_test} + 22.889 \tag{4.3}$$

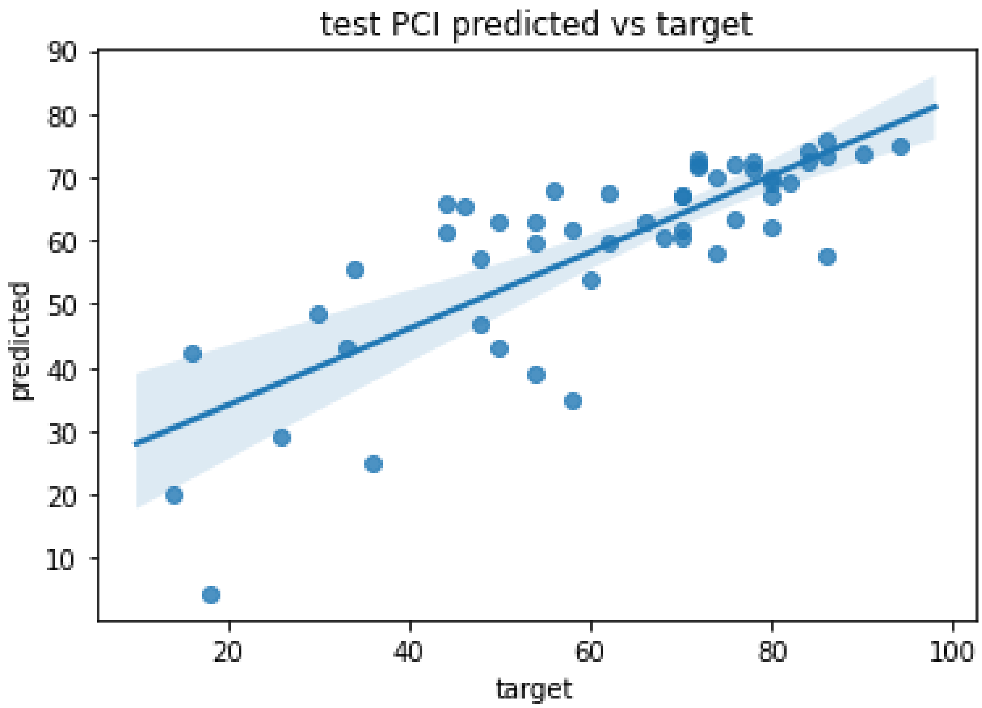

Figure 4.5: Predicted PCI vs target PCI (regression test set 1)

The summary of regression results and test statistics for grouping set 2 are shown in Table 4.3 and Table 4.4, respectively.

Table 4.3: Summary of Regression Results for PCI regression set 2

Dependent variable	PCI
R-squared:	0.622
Adj. R-squared:	0.601
F-statistic:	29.26
P value:	5.41×10^{-75}
Df Model:	24

Table 4.4: Test statistics and regression coefficients for PCI regression set 2

	Coefficient	Standard Error	t-statistics	P- value	Remarks
constant	77.4037	1.194	64.836	0	
A1	-3.4576	2.094	-1.651	0.009	
A2	-2.3877	1.18	-2.024	0.044	
A3	-10.912	1.867	-5.845	0	
B1	4.8451	2.256	2.147	0.587	P>0.05
B2	-1.9705	1.295	-1.522	0.129	P>0.05
B3	-0.6977	1.283	-0.544	0.032	
C1	-4.2781	1.435	-2.982	0.003	
C2	-1.0461	1.121	-0.933	0.035	
C3	-3.2472	0.766	-4.24	0	
D1	-3.2063	2.305	-1.391	0.165	P>0.05
D2	-1.2009	1.722	-0.697	0.048	
D3	-13.4344	1.744	-7.701	0	
E1	0.8103	2.982	0.272	0.786	P>0.05
E2	-2.2808	1.556	-1.466	0.0143	
E3	-5.24	1.33	-3.94	0	
F1	-22.3395	3.997	-5.589	0	
F2	-67.6581	8.305	-8.147	0	
F3	-84.8696	6.005	-14.133	0	
G1	-6.7377	4.788	-1.407	0.016	
G2	-2.9572	3.701	-0.799	0.425	P>0.05
G3	-6.2897	3.11	-2.022	0.044	
H1	2.7123	2.851	0.951	0.342	P>0.05
H2	-1.1102	1.482	-0.749	0.045	
H3	-9.7197	2.674	-3.635	0	

In grouping set 2, the P value of coefficients of B1, B2, D1, E1, G2 and H1 are found to be greater than 0.05. This indicates that, there is no significant effect of these variables to bring significant change in the predicted PCI therefore can be omitted from the equation. This may be because distress like low severity bleeding and medium severity bleeding contribute to very less reduction in PCI therefore resulting little effect during modeling after separation. Therefore, the regression model is prepared using the remaining coefficients. The coefficient of determination i.e R^2 value from multilinear regression models for grouping set 2 is found to be 0.622 and 0.603 for training and testing respectively. The regression model for grouping 2 with 24 variables is presented in Equation (4.4).

$$PCI = 77.40 - 3.45 * A1 - 2.38 * A2 - 10.91 * A3 - 0.69 * B3 - 4.27 * C1 - 1.04 * C2 - 3.24 * C3 - 1.2 * D2 - 13.43 * D3 - 2.28 * E2 - 5.24 * E3 - 22.33 * F1 - 67.65 * F2 - 84.86 * F3 - 6.73 * G1 - 6.28 * G3 - 1.11 * H2 - 9.71 * H3 \quad (4.4)$$

$R^2_{train} = 0.622$
$R^2_{test} = 0.603$

Equation (4.5) and (4.6) shows the relationship between predicted PCI with the target PCI based on regression for training and testing set 2. The corresponding plots are shown in the Figure 4.6 and Figure 4.7 respectively.

$$PCI_{predicted\_train} = 0.621 * PCI_{target\_train} + 22.354 \quad (4.5)$$

$$PCI_{predicted\_test} = 0.653 * PCI_{target\_test} + 20.171 \quad (4.6)$$

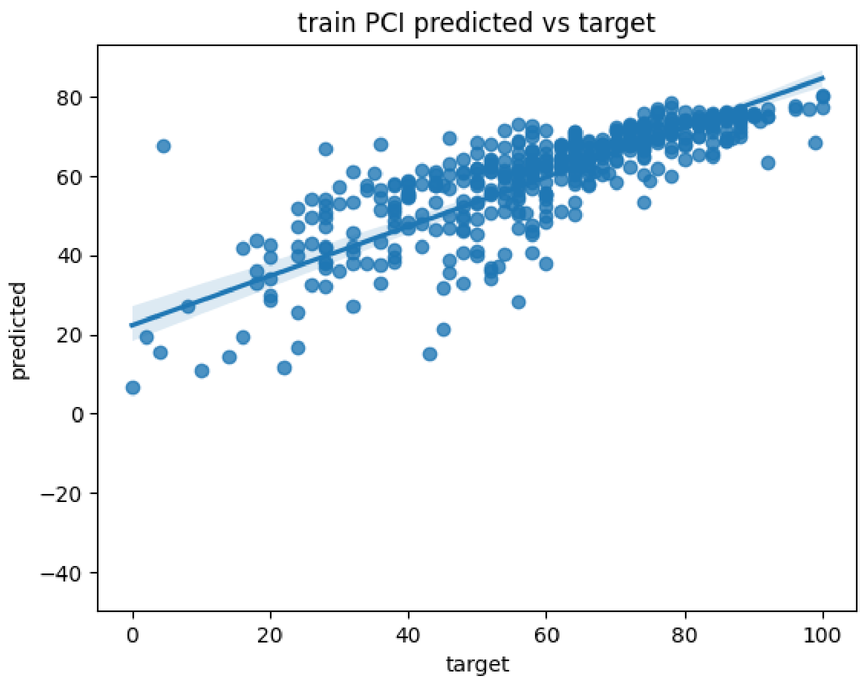

Figure 4.6: Predicted PCI vs target PCI (regression training set 2)

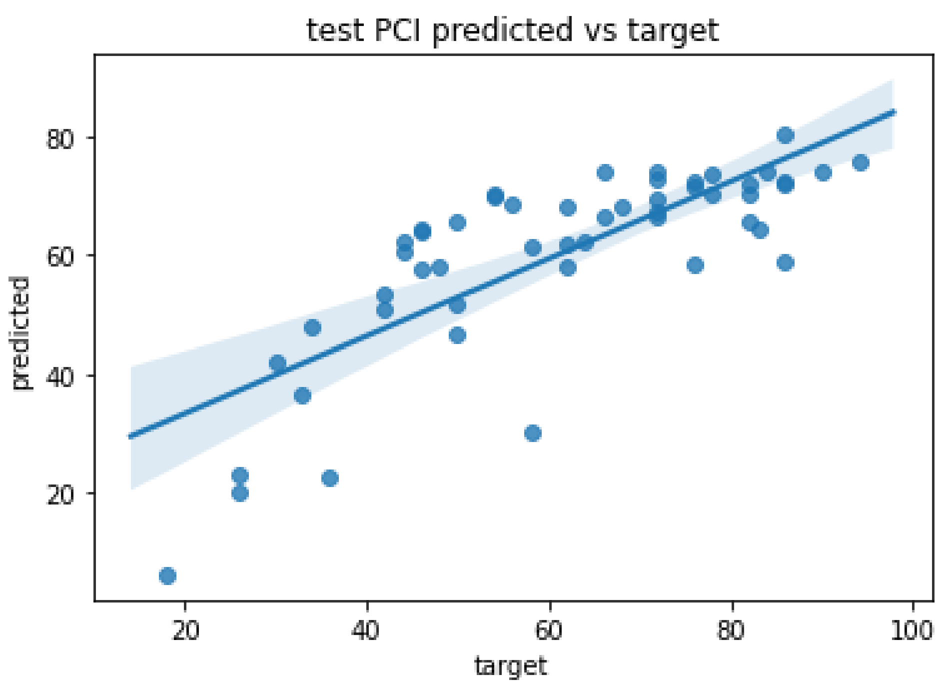

Figure 4.7: Predicted PCI vs target PCI (regression testing set 2

4.2.2 Performance of ANN Based PCI Models

The model of PCI is developed using data sets containing 18 and 24 features as independent variables in Python 3.9. For the development of PCI model, 503 data records collected from a road length of 50.3 km, segmented into 503 sections of 100 m length are used. Out of 503 records, 90 % of data set (453 records) is used for training the models and 10 % of data set (50 records) are used for testing of the model. Among the 453 records used for training, 10 % is used for validating the model. For the evaluation of the model, the metrices in terms of Mean Square Error (MSE) and R^2 are used. The decision on the network architecture of the ANN is made based on literature and by conducting several trial runs as discussed in section 3.7.3. During the training phase of ANN, the learning rate is set as 0.01 and the number of epochs required to deliver the best model is found out by comparing the MSE for each number of iterations performed on the same data. For the training of the model, the number of epochs is set as 200 for grouping 1 and 60 for grouping 2. For the training and testing of the data set using the ANN model, the coefficient of determination of the training and testing models are found to be 0.857, 0.715 and 0.747 for grouping set 1 (18 independent variables) similarly it is found to be 0.852, 0.810 and 0.670 for grouping set 2 (24 independent variables). In both cases, the model represents good fit with the actual values during testing. The plot of predicted PCI with the target PCI for training based on ANN is as shown in the Figure 4.8 for grouping set 1. The corresponding relationship is shown in Equation (4.7).

$$PCI_{predicted\_train} = 0.853 * PCI_{target\_train} + 8.589 \tag{4.7}$$

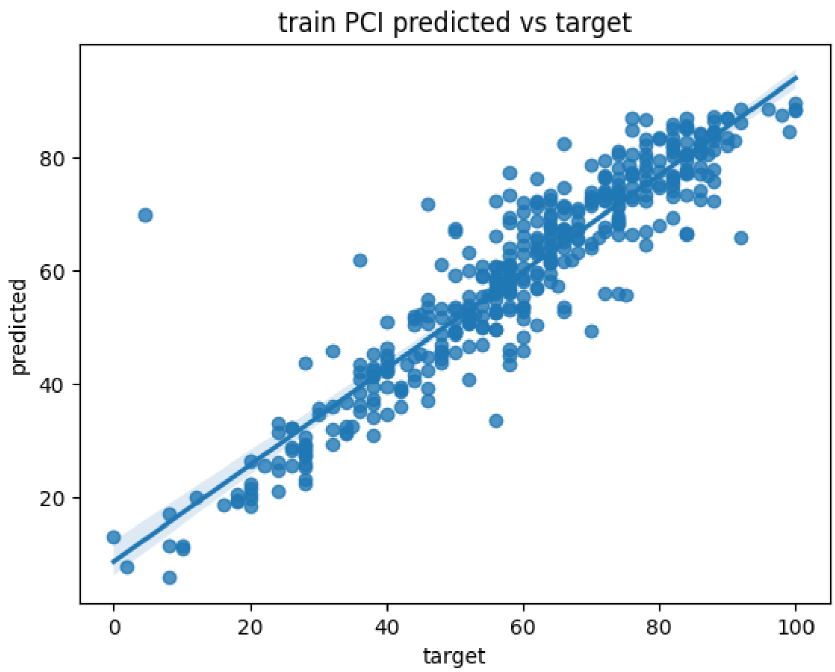

Figure 4.8: Predicted PCI vs target PCI (ANN training set 1)

The plot of predicted PCI with the target PCI for validation set on ANN is as shown in Figure 4.9. The corresponding relationship is shown in Equation (4.8).

$$PCI_{predicted\_val} = 0.864 * PCI_{target\_val} + 7.114 \quad (4.8)$$

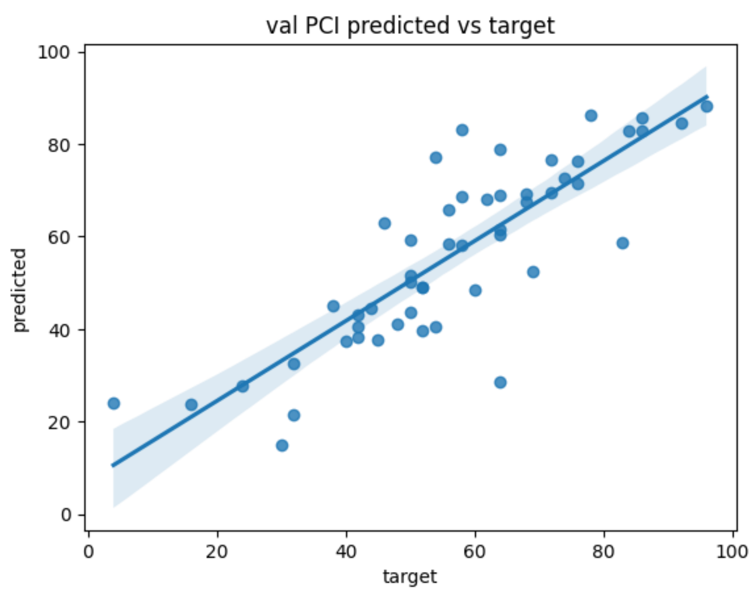

Figure 4.9: Predicted PCI vs target PCI (ANN validation set 1)

The plot of predicted PCI with the target PCI for testing based on ANN is as shown in the plot in Figure 4.10 for grouping set 1 and is presented in form of Equation (4.9)

$$PCI_{predicted\_test} = 0.856 * PCI_{target\_test} + 6.612 \tag{4.9}$$

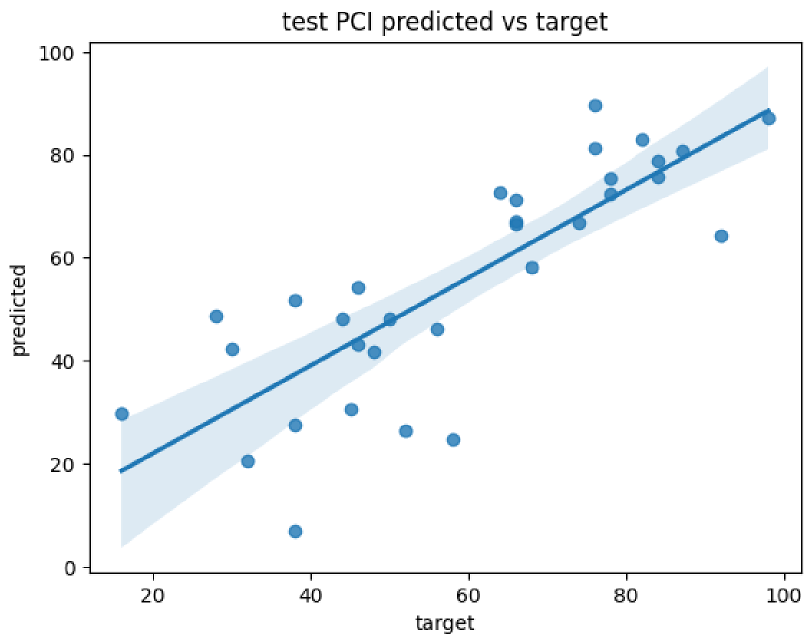

Figure 4.10: Predicted PCI vs target PCI (ANN testing set 1)

The plot of predicted PCI with the target PCI for training based on ANN for grouping set 2 is presented in Figure 4.11 and in form of Equation (4.10)

$$PCI_{predicted\_train} = 0.863 * PCI_{target\_train} + 8.154 \tag{4.10}$$

Figure 4.11: Predicted PCI vs target PCI (ANN training set 2)

The plot of predicted PCI with the target PCI for validation based on ANN for grouping set 2 is presented in Figure 4.12. The corresponding relationship is shown in Equation (4.11).

$$PCI_{predicted\_val} = 0.943 * PCI_{target\_val} + 2.465 \tag{4.11}$$

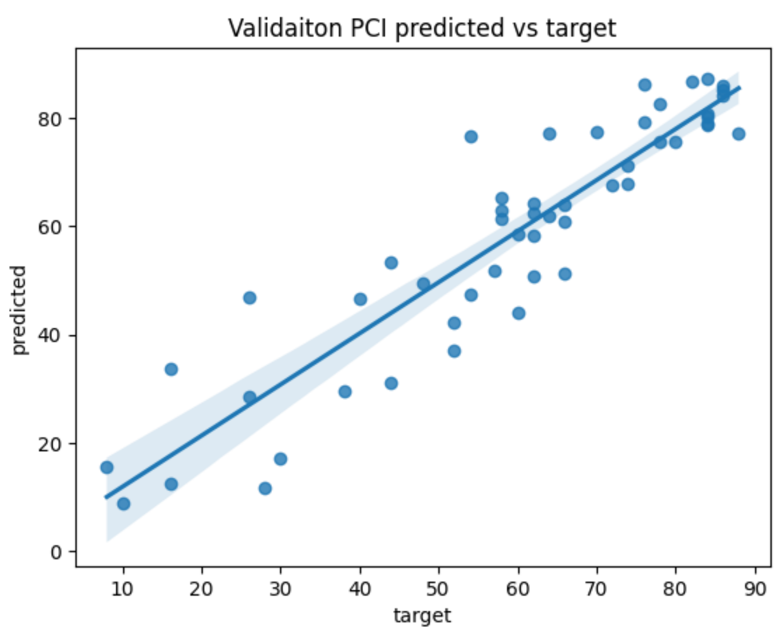

Figure 4.12 Predicted PCI vs target PCI (ANN validation set 2)

The plot of predicted PCI with the target PCI for testing based on ANN for data set 2 is presented in Figure 4.13 below. The corresponding relationship is shown in Equation (4.12).

$$PCI_{predicted\_test} = 0.756 * PCI_{predicted\_test} + 14.955 \tag{4.12}$$

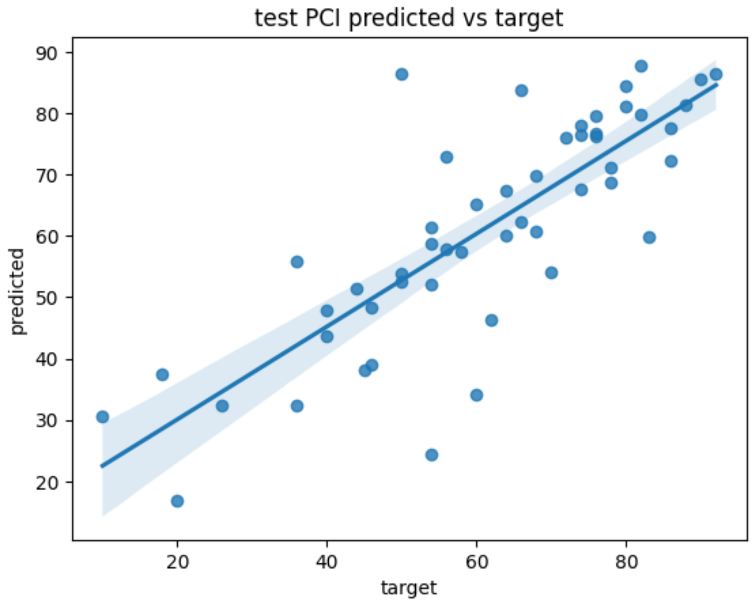

Figure 4.13: Predicted PCI vs target PCI (ANN testing set 2)

4.3 IRI Evaluation Models

4.3.1 Performance of Regression-Based IRI Evaluation Models

The regression model for the evaluation of IRI based on the distress types as well as severities is developed in same way as that for the PCI. However, only 468 data records is used in this case due to constraints in collection of IRI data in the same area where the distress data is collected. Out of this data, 80 % is used for the regression model development and 20 % of the data is used for testing purpose. Before the initiation of the model development, the correlation between each of the independent variables for IRI determination using regression is checked with the help of Python 3.9. The correlation matrices derived for the grouping sets with 18 input variables and 24 input variables are shown in Figure 4.14 and Figure 4.15, respectively.

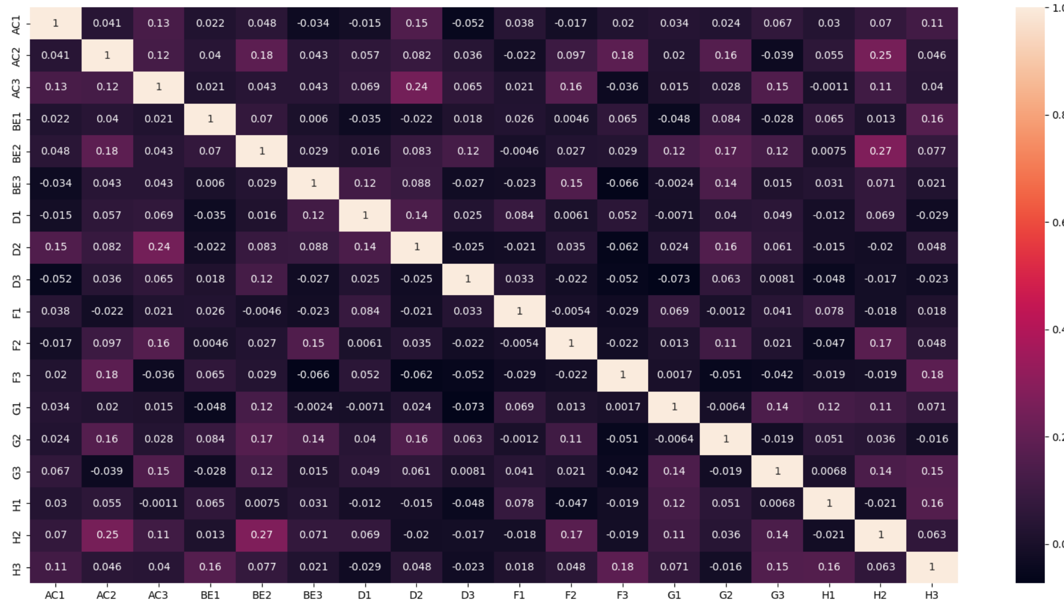

Figure 4.14: Pearson correlation coefficient matrix for IRI input set 1(18 input variable)

Figure 4.15: Pearson correlation coefficient matrix for IRI input set 2(24 input variable).

Multiple linear regression is carried out in Python 3.9 with 18 and 24 input variables to establish the relationship between IRI and the distresses. The collected input data is split into 80:20 for the purpose of training and testing respectively. For the data set using the regression model, R^2 is found to be 0.599 and 0.543 for training and testing for grouping 1 (18 independent variables) similarly it is found to be 0.614 and 0.616 for training and testing for set 2 (24 independent variables). In both cases, the model represents moderate fit with the actual values. The test statistics and summary of regression results for data set 1 of IRI are as shown in Table 4.5 and Table 4.6, respectively.

Table 4.5: Test statistics and regression coefficients for IRI regression set 1

	Coefficient	Standard Error	t-statistics	P-value	Remarks
constant	2.6026	0.15	17.326	0	
AC1	0.5388	0.155	3.484	0.001	
AC2	0.1824	0.089	2.039	0.042	
AC3	0.576	0.092	6.269	0	
BE1	0.3058	0.24	1.276	0.203	P>0.05
BE2	0.1179	0.129	0.914	0.361	P>0.05
BE3	0.5054	0.132	3.82	0	
D1	0.3682	0.308	1.195	0.233	P>0.05
D2	0.2106	0.238	0.885	0.037	
D3	1.7121	0.225	7.593	0	
F1	4.1747	0.701	5.954	0	
F2	8.6833	1.2	7.233	0	
F3	12.5523	0.93	13.504	0	
G1	0.2278	0.603	0.378	0.706	P>0.05
G2	0.3434	0.462	0.743	0.458	P>0.05
G3	1.8824	0.417	4.519	0	
H1	0.2795	0.398	0.702	0.483	P>0.05
H2	0.3078	0.204	1.512	0.013	
H3	0.5715	0.36	1.587	0.0113	

Table 4.6: Summary of Regression Results for IRI regression set 1

Dependent variable	IRI
R-squared:	0.599
Adj. R-squared:	0.580
F-statistic:	31.40
P- value	7.28×10^{-64}
Degree of freedom	18

The ANOVA test is performed to evaluate the P value for each coefficient of regression equation. In data set 1 the P value of coefficients of BE1, BE2, D1, G1, G2 and H1 are found to be greater than 0.05. This indicates that, there is little to no effect of these variables in the predicted IRI therefore can be omitted from the equation, therefore the regression model is prepared using the remaining coefficients.

The IRI regression model for set 1 is given in Equation (4.13):

$$IRI = 2.60 + 0.53 * AC1 + 0.182 * AC2 + 0.576 * AC3 + 0.505 * BE3 + 0.21 * D2 + 1.71 * D3 + 4.17 * F1 + 8.68 * F2 + 12.55 * F3 + 1.88 * G3 + 0.307 * H2 + 0.571 * H3 \quad (4.13)$$

$R^2_{train} = 0.599$

$R^2_{test} = 0.543$

The summary of regression results and test statistics for data set 2 of IRI are shown in Table 4.7 and Table 4.8 respectively.

Table 4.7: Summary of Regression Results for IRI regression set 2

Dependent variable	IRI
R-squared:	0.615
Adj. R-squared:	0.588
F-statistic:	23.20
P value:	4.21×10^{-58}
Degree of freedom	24

Table 4.8: Test statistics and regression coefficients for IRI regression set 2

	Coefficient	Standard	t-statistics	P-	Remarks
const	2.5749	0.157	16.373	0	
A1	0.5701	0.279	2.047	0.041	
A2	0.4377	0.153	2.87	0.004	
A3	1.3785	0.271	5.082	0	
B1	0.4461	0.311	1.433	0.153	P>0.05
B2	0.0095	0.179	0.053	0.958	P>0.05
B3	0.3191	0.177	1.8	0.043	
C1	0.5376	0.196	2.745	0.006	
C2	0.0285	0.148	0.193	0.047	
C3	0.4723	0.103	4.606	0	
D1	0.2785	0.32	0.871	0.384	P>0.05
D2	0.3073	0.254	1.209	0.022	
D3	1.6624	0.232	7.156	0	
E1	-0.0305	0.442	-0.069	0.945	P>0.05
E2	0.1423	0.203	0.7	0.484	P>0.05
E3	0.614	0.197	3.124	0.002	
F1	4.3428	0.718	6.052	0	
F2	8.1075	1.242	6.526	0	
F3	12.7765	0.95	13.452	0	
G1	0.3373	0.63	0.535	0.593	P>0.05
G2	0.5206	0.502	1.037	0.301	P>0.05
G3	1.6754	0.428	3.916	0	
H1	0.4742	0.517	0.918	0.359	P>0.05
H2	0.198	0.215	0.921	0.035	
H3	0.4435	0.381	1.165	0.024	

The ANOVA test is performed to evaluate the P value for each coefficient of regression equation. In grouping set 2 the P value of coefficients of B1, B2,D1, E1, E2, G1, G2 and H1 are found to be greater than 0.05. This may be due to the fact that low severity distresses in form of rutting, surface wear, patching and bleeding have very less effect on the ride quality. Low severity rutting also contributes minimally to the roughness which is not perceived through this relation due to inadequacy of collected data containing that distress. Therefore the regression model is prepared using the remaining coefficients.

The IRI regression equation for set 2 is as shown through Equation (4.14):

$$IRI = 2.57 + 0.57 * A1 + 0.43 * A2 + 1.37 * A3 + 0.31 * B3 + 0.53 * C1 + 0.02 * C2 + 0.47 * C3 + 0.30 * D2 + 1.66 * D3 + 0.61 * E3 + 4.34 * F1 + 8.10 * F2 + 12.77 * F3 + 1.67 * G3 + 0.19 * H2 + 0.44 * H3 \tag{4.14}$$

$R_{train}^2 = 0.615$

$R_{test}^2 = 0.616$

The plot of predicted IRI with the target IRI for training based on regression model for grouping set 1 is shown in Figure 4.16 and their relationship is presented in Equation (4.15).

$$IRI_{predicted\_train} = 0.599 * IRI_{target\_train} + 1.913 \tag{4.15}$$

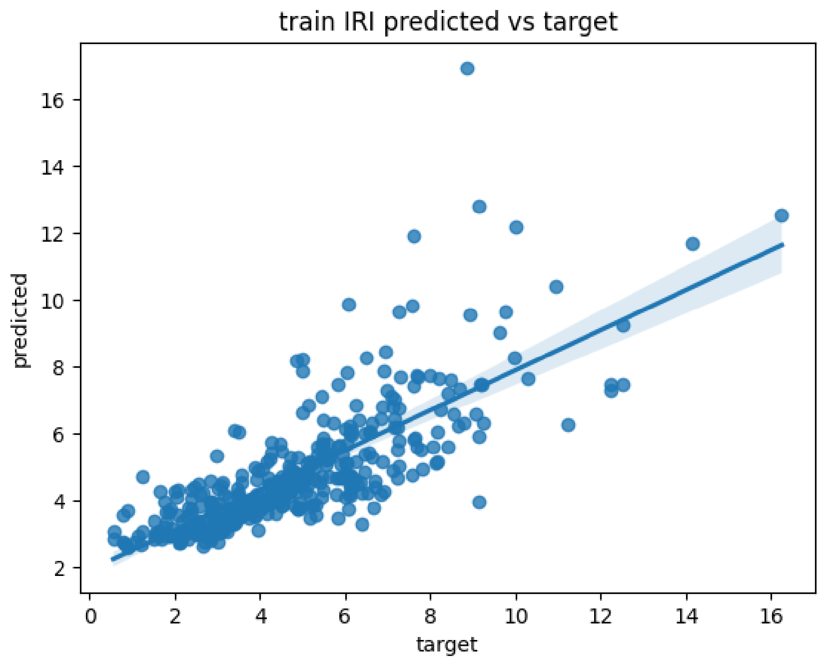

Figure 4.16: Predicted IRI vs target IRI (regression training set 1)

The plot of predicted IRI with the target IRI for testing based on regression model for data set 1 is shown in Figure 4.17 and their relationship is presented in equation (4.16).

$$IRI_{predicted\_test} = 0.521 * IRI_{target\_test} + 2.248 \tag{4.16}$$

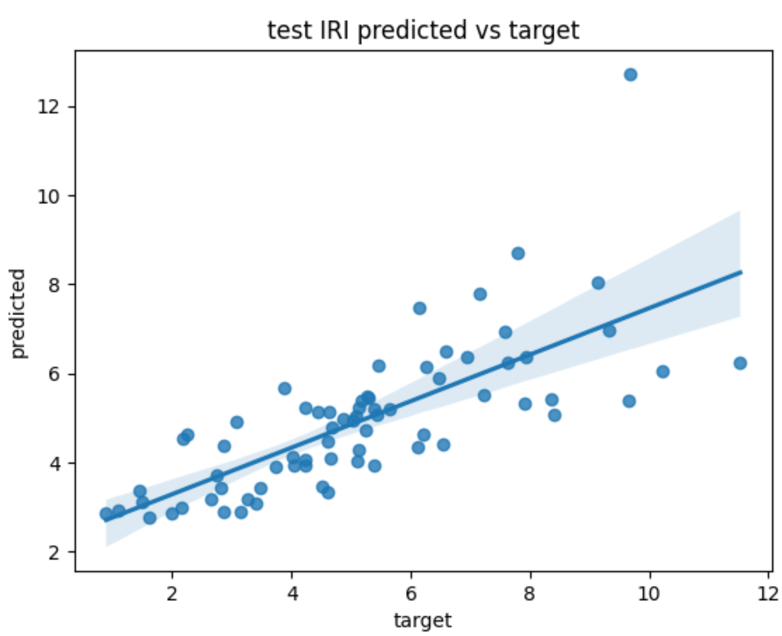

Figure 4.17: Predicted IRI vs target IRI (regression testing set 1)

The plot of predicted IRI with the target IRI for training based on regression model for grouping set 2 is shown in Figure 4.18 and their relationship is presented in Equation (4.17).

$$IRI_{predicted\_train} = 0.614 * IRI_{target\_train} + 1.851 \quad (4.17)$$

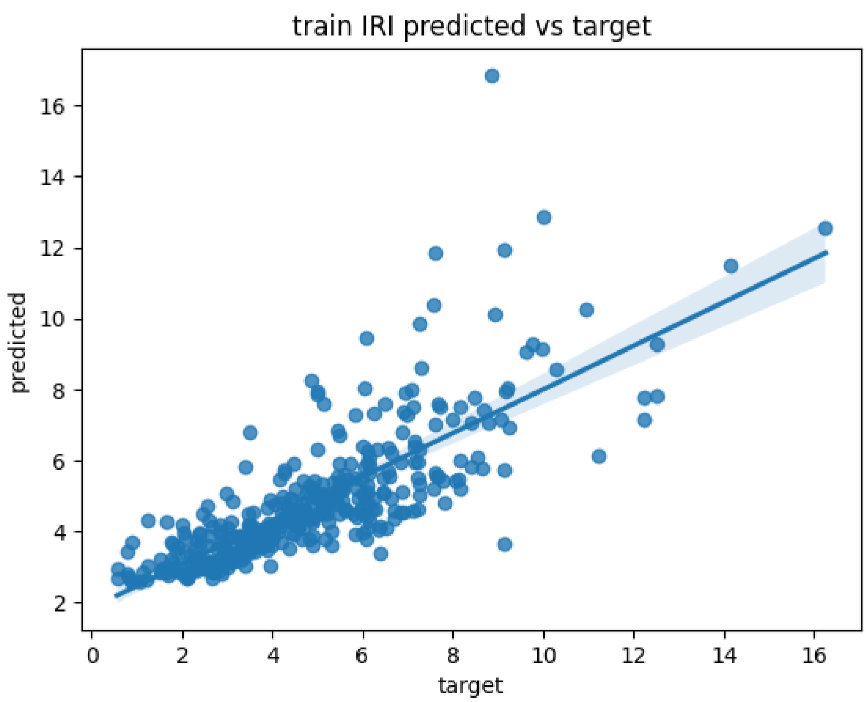

Figure 4.18: Predicted IRI vs target IRI (regression training set 2)

The plot of predicted IRI with the target IRI for testing based on regression model for data set 2 is shown in Figure 4.19 and their relationship is presented in Equation (4.18).

$$IRI_{predicted\_test} = 0.546 * IRI_{target\_test} + 2.044 \quad (4.18)$$

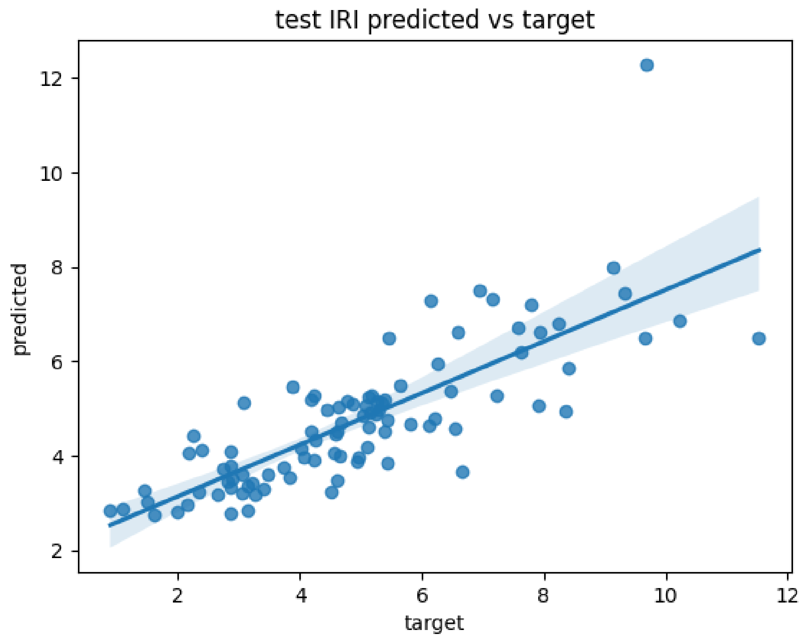

Figure 4.19: Predicted IRI vs target IRI (regression testing set 2)

4.3.2 Performance of ANN based IRI models

The model of IRI is also developed using data sets containing 18 and 24 features as independent variables in Python 3.9. For the development of IRI model, 468 data records collected from 468 road sections of 100 m length are used. Out of 468 records, 90 % of data set (421 records) is used for training the model in both cases and 10 % of data set (47 records) are used for testing of the model. Among the separated 421 records, 10 % is used for validating the model. For the evaluation of the model, the metrices in terms of Mean Square Error (MSE) and R^2 is used. During the training phase of ANN, the learning rate is set as 0.01 and the number of epochs is set as 20 grouping set 1 and 30 epochs for grouping set 2. The number of epochs is determined based on the point where both the MSE and validation MSE stabilize without further decrease. Figure 4.20 shows a sample decline in MSE and validation MSE over the epochs for grouping set 1. For the training and testing of the data set using the ANN model, the coefficient of determination of the training, validation and testing models are found to 0.559, 0.518 and 0.536, respectively for grouping set 1 (18 independent variables) and 0.699, 0.597 and 0.575, respectively for set

2 (24 independent variables). In both cases, the model represents moderate to good fit with the actual values during testing.

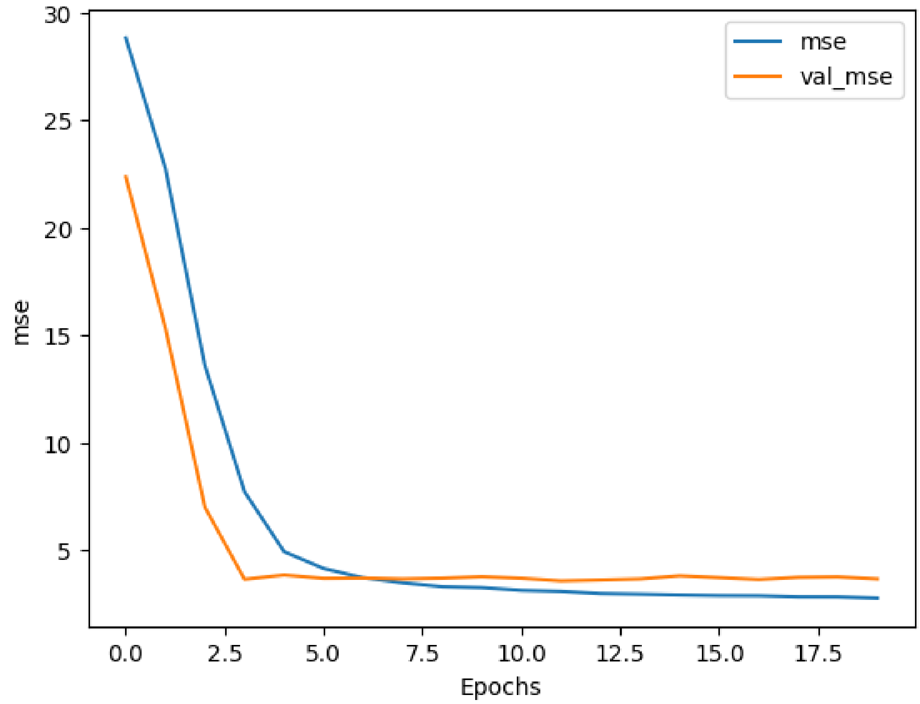

Figure 4.20: No of epoch for IRI training set 1

The plot of predicted IRI with the target IRI for training based on ANN model for data set 1 is as shown in Figure 4.21 and their relationship is presented in Equation (4.15).

$$IRI_{predicted\_train} = 0.540 * IRI_{target\_train} + 2.189 \quad (4.15)$$

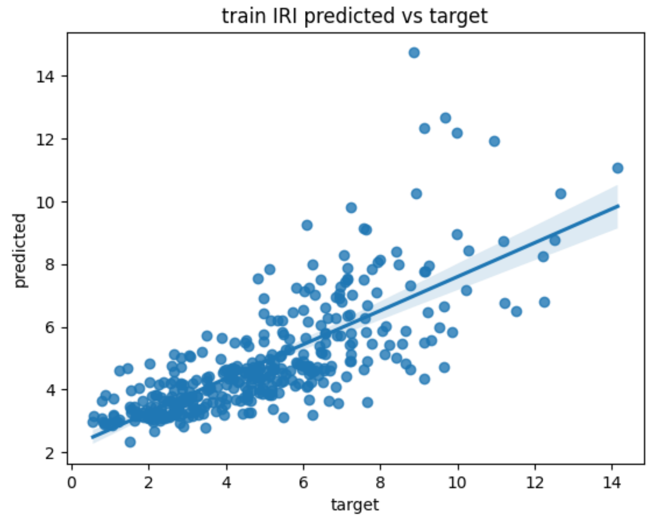

Figure 4.21: Predicted IRI vs target IRI (ANN training set 1)

The plot of predicted IRI with the target IRI for validation based on ANN model for data set 1 is as shown in Figure 4.22 and their relationship is presented in Equation (4.16).

$$IRI_{predicted\_val} = 0.465 * IRI_{target\_val} + 2.659 \qquad (4.16)$$

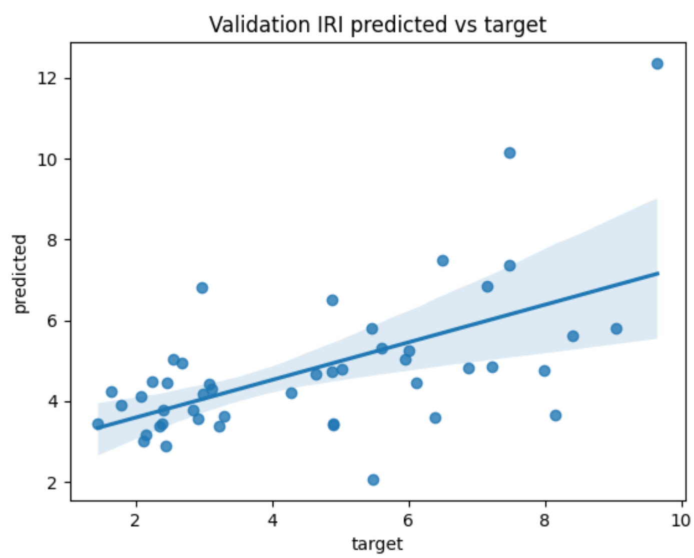

Figure 4.22: Predicted IRI vs target IRI (ANN validation set 1)

The plot of predicted IRI with the target IRI for testing based on regression model for data set 1 is as shown in Figure 4.23 and their relationship is presented in Equation (4.17).

$$IRI_{predicted\_test} = 0.486 * IRI_{target\_test} + 2.537 \quad (4.17)$$

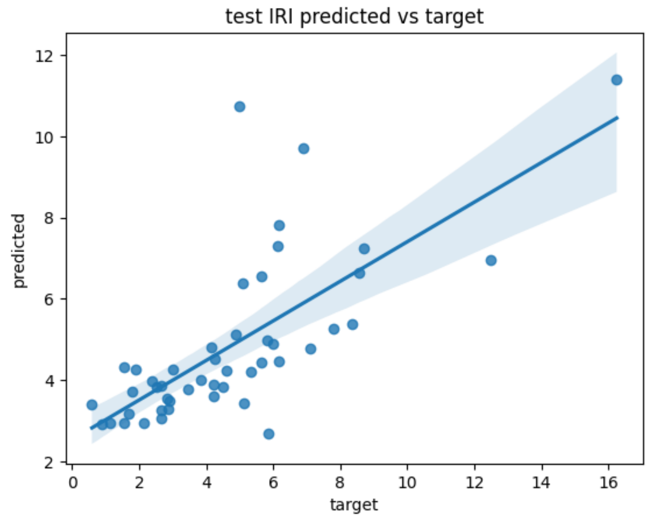

Figure 4.23: Predicted IRI vs target IRI (ANN testing set 1)

The plot of predicted IRI with the target IRI for training based on regression model for data set 2 is shown in Figure 4.24 and their relationship is presented in Equation (4.18).

$$IRI_{predicted\_train} = 0.707 * IRI_{target\_train} + 1.406 \quad (4.18)$$

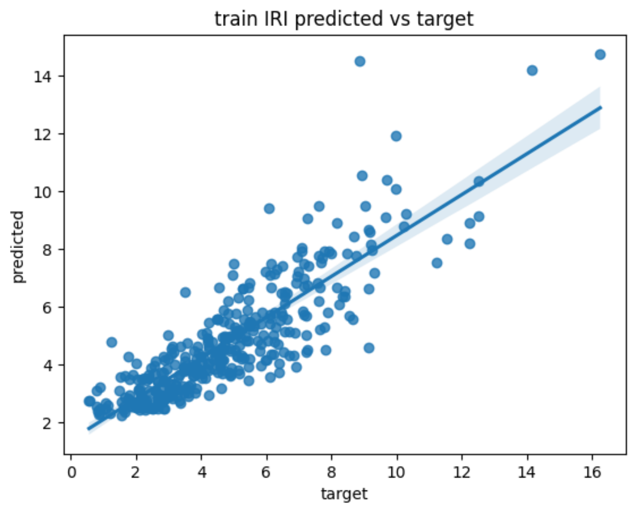

Figure 4.24: Predicted IRI vs target IRI (ANN training set 2)

The plot of predicted IRI with the target IRI for validation based on ANN model for data set 2 is shown in Figure 4.25 and their relationship is presented in Equation (4.19).

$$IRI_{predicted\_val} = 0.905 * IRI_{target\_val} + 0.165 \quad (4.19)$$

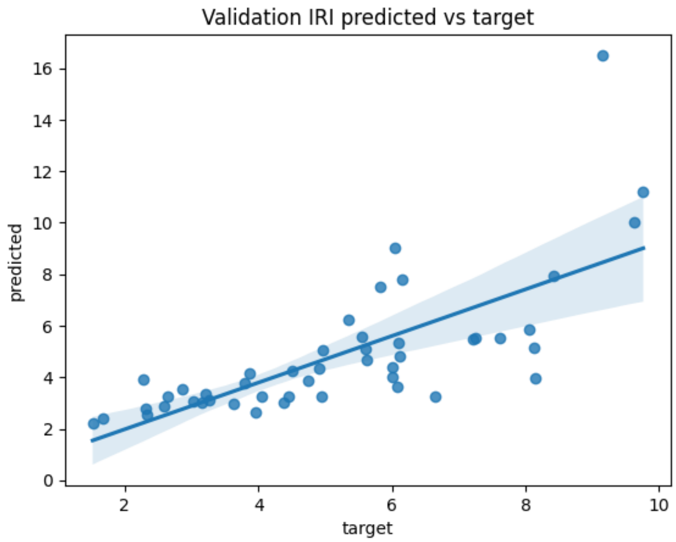

Figure 4.25: Predicted IRI vs target IRI (ANN validation set 2)

The plot of predicted IRI with the target IRI for testing based on regression model for data set 2 is as shown in Figure 4.26 and is presented in form of Equation (4.20)

$$IRI_{predicted\_test} = 1.033 * IRI_{target\_test} - 0.0088 \quad (4.20)$$

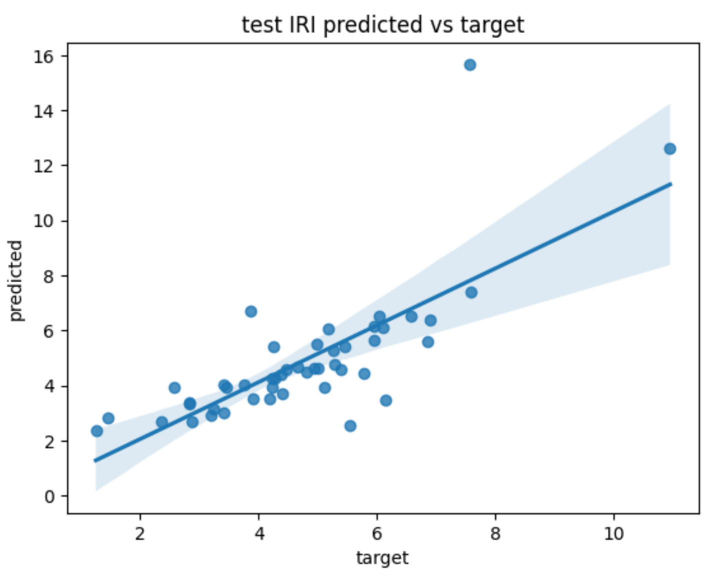

Figure 4.26: Predicted IRI vs target IRI (ANN testing set 2)

4.6 SENSITIVITY ANALYSIS

In a study involving multiple inputs, sensitivity analysis can be considered as one of the rational tools to determine the most important and least important parameters. Sensitivity analysis helps to ascertain the sensitivity of the output based on the change in the corresponding input values or input ranges of values. The sensitivity index can be taken as a parameter ascertained from sensitivity analysis which depicts the relative importance of each parameters individually based on its influence on the output (PCI or IRI in our case). There are various methods and tools in order to carry out the sensitivity analysis for multiple variables as inputs, one of which is the sensitivity analysis proposed by Chang and Liao (2012). It helps to assess the parameters that are most significant and least significant to the change in the outputs based on the collected data. The single value sensitivity index which is used in the study only takes into consideration the variables and the corresponding outputs one at a time and are dependent on the highest value of input along with its corresponding output, the lowest value of input and their corresponding output and the average of inputs and outputs for the course of the analysis. Based on Chang and Liao (2012), the sensitivity index can be as ascertained with the help of Equation (4.21).

$$\mathrm{S.I} = \frac{\mathrm{O2} - \mathrm{O1}}{\mathrm{I2} - \mathrm{I1}} * \frac{\mathrm{Iaverage}}{\mathrm{Oaverage}} \tag{4.21}$$

Where,

I1- Smallest input value

O1- Output (PCI or IRI) corresponding to smallest input value

I2- Largest input value

O2- Output (PCI or IRI) corresponding to largest input value

Iaverage- Average of all non-zero inputs

Oaverage- Average of all outputs corresponding to non-zero input values.

The sensitivity analysis is carried out for both the PCI as well as IRI for both grouping sets in order to determine the sensitivity index. The sensitivity analysis is separately carried out for both grouping sets of PCI respectively and it was followed up by sensitivity analysis of

IRI. From the results, it can be seen that the most sensitive parameter which brings about the most change in the PCI alone is high severity potholes, followed by low severity potholes for both grouping sets. It is followed by high severity surface deformations and high severity rutting in grouping 1 whereas it is followed by high severity alligator cracking and high severity rutting in grouping 2. The sensitivity Index calculation of various parameters of PCI grouping set 1 and grouping set 2 are shown in Table 4.9 and Table 4.10, respectively.

Table 4.9: Sensitivity Index calculation of various parameters of PCI grouping set 1

Parameters	I2	Iavg	I1	PCI of I1 (O1)	PCIavg (Oavg)	PCI of I2 (O2)	(O2-O1)/(I2-I1)	Iavg/Oavg	Sensitivity index
AC1	4.26	0.66	0.03	72	58.76	50	-5.201	0.011	-0.058
AC2	11.97	0.92	0.015	84	51.21	45	-3.262	0.018	-0.059
AC3	12.5	0.85	0.034	84	50.3	18	-5.294	0.017	-0.089
BE1	2.77	0.544	0.015	86	60.82	54	-11.615	0.009	-0.104
BE2	5.6	0.766	0.03	72	56.31	56	-2.873	0.014	-0.039
BE3	4.56	0.8	0.01	87	57.68	34	-11.648	0.014	-0.162
D1	1.91	0.406	0.021	78	55.795	62	-8.470	0.007	-0.062
D2	2.6	0.472	0.01	60	59.143	32	-10.811	0.008	-0.086
D3	3.2	0.446	0.012	58	54.24	34	-7.528	0.008	-0.062
F1	1.2	0.21	0.005	46	48.44	16	-25.105	0.004	-0.109
F2	0.9	0.11	0.001	84	48.31	10	-82.314	0.002	-0.187
F3	0.7	0.129	0.001	82	40.25	0	-117.310	0.003	-0.376
G1	1.2	0.34	0.01	64	54.45	58	-5.042	0.006	-0.031
G2	1.62	0.316	0.003	64	55.32	52	-7.421	0.006	-0.042
G3	2	0.372	0.001	82	53.21	36	-23.012	0.007	-0.161
H1	2.4	0.389	0.008	54	58.46	24	-12.542	0.007	-0.083
H2	3.2	0.746	0.009	58	53.58	35	-7.208	0.014	-0.100
H3	3.08	0.571	0.041	62	48.87	35	-8.885	0.012	-0.104

Table 4.10: Sensitivity Index calculation of various parameters of PCI grouping set 2

Parameters	I2	Iavg	I1	PCI of I1 (O1)	PCIavg (Oavg)	PCI of I2 (O2)	(O2-O1)/(I2-I1)	Iavg/Oavg	Sensitivity index
A1	2.5	0.514	0.015	54	57.69	50	-1.610	0.009	-0.014
A2	7.65	0.703	0.04	68	56.50	45	-3.022	0.012	-0.038
A3	2.48	0.546	0.01	64	51.98	20	-17.814	0.011	-0.187
B1	2.3	0.634	0.11	40	60.32	35	-2.283	0.011	-0.024
B2	4.32	0.73	0.03	64	56.46	56	-1.865	0.013	-0.024
B3	4.56	0.736	0.05	62	58.88	41	-4.656	0.013	-0.058
C1	3.01	0.57	0.03	72	58.88	50	-7.383	0.010	-0.071
C2	4.32	0.7	0.015	74	56.48	49	-5.807	0.012	-0.072
C3	12.5	0.705	0.03	92	56.28	18	-5.934	0.013	-0.074
D1	1.91	0.406	0.021	78	55.79	62	-8.470	0.007	-0.062
D2	2.6	0.472	0.01	60	59.14	32	-10.811	0.008	-0.086
D3	3.2	0.446	0.012	58	54.24	34	-7.528	0.008	-0.062
E1	2.4	0.39	0.015	86	58.8	58	-11.740	0.007	-0.078
E2	4.2	0.53	0.02	60	56.57	37	-5.502	0.009	-0.052
E3	3.75	0.63	0.01	87	57.17	45	-11.230	0.011	-0.124
F1	1.2	0.21	0.005	46	48.44	16	-25.105	0.004	-0.109
F2	0.9	0.11	0.001	84	48.31	10	-82.314	0.002	-0.187
F3	0.7	0.129	0.001	82	40.25	0	-117.310	0.003	-0.376
G1	1.2	0.34	0.01	64	54.45	58	-5.042	0.006	-0.031
G2	1.62	0.316	0.003	64	55.32	52	-7.421	0.006	-0.042
G3	2	0.372	0.001	82	53.21	36	-23.012	0.007	-0.161
H1	2.4	0.389	0.008	54	58.46	24	-12.542	0.007	-0.083
H2	3.2	0.746	0.009	58	53.58	35	-7.208	0.014	-0.100
H3	3.08	0.571	0.041	62	48.87	35	-8.885	0.012	-0.104

The results of sensitivity index for PCI are also illustrated with the help of bar diagrams in Figure 4.27 and Figure 4.28 for grouping sets 1 and 2, respectively.

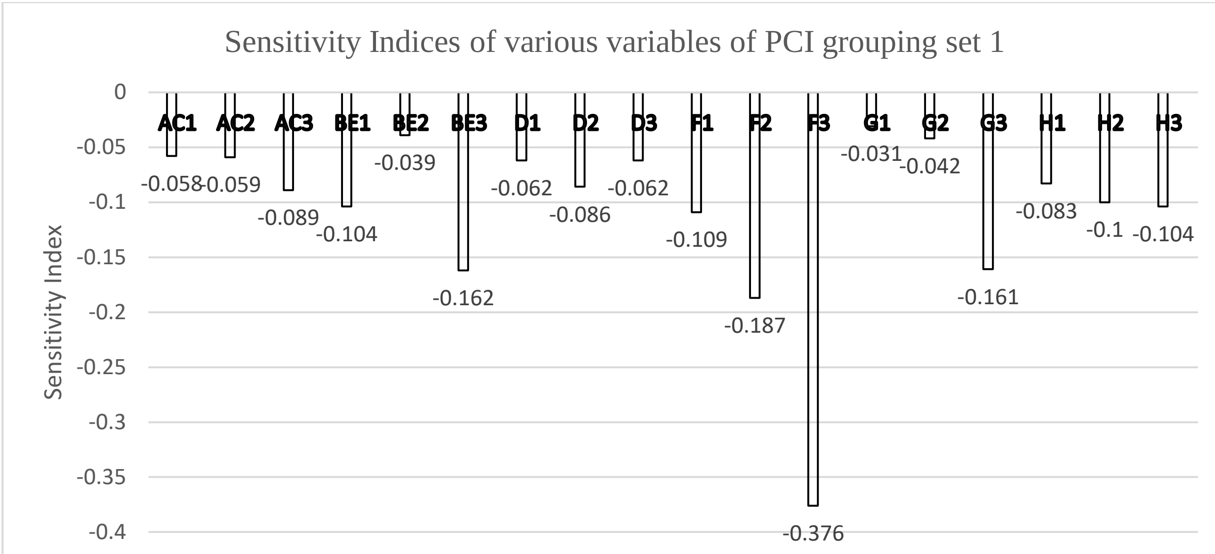

Figure 4.27 : Sensitivity Indices of various parameters of PCI grouping set 1

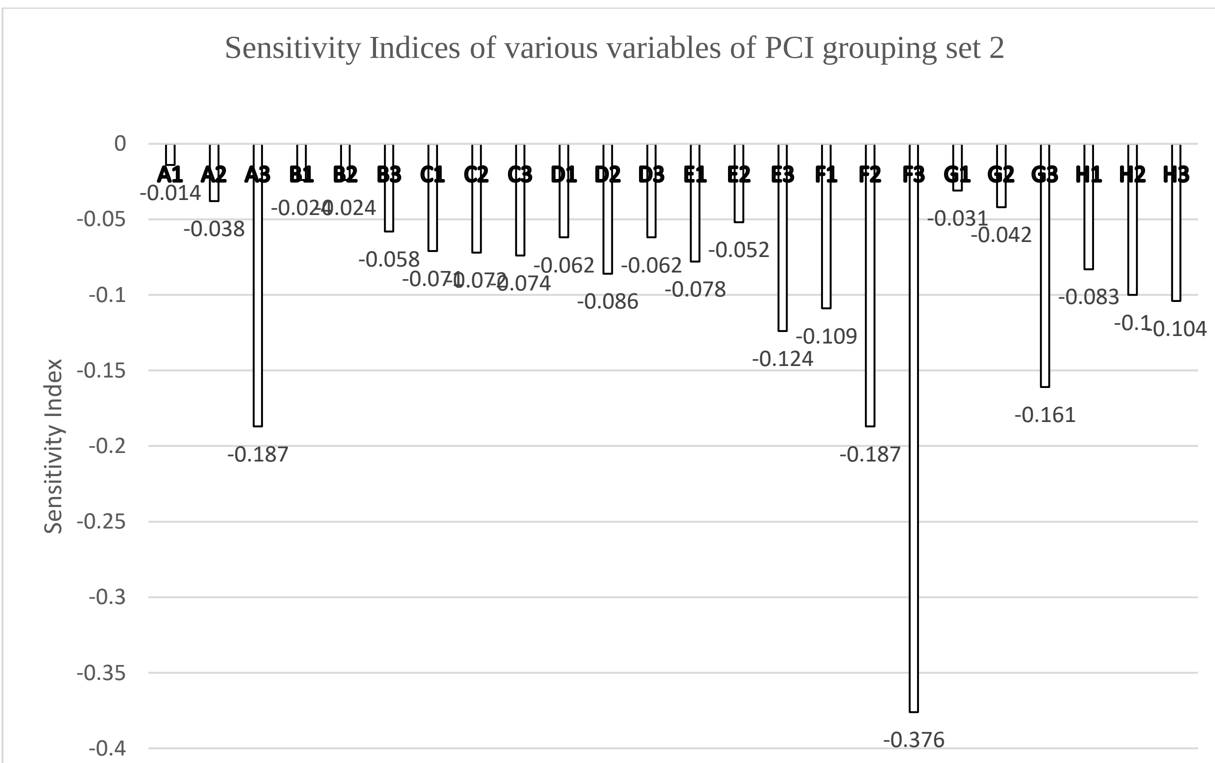

Figure 4.28: Sensitivity Indices of various parameters of PCI grouping set 2

The sensitivity analysis is similarly carried out for both grouping sets of IRI following the similar procedure as that of the PCI. The sensitivity analysis is presented in the form of Table 4.11 and Table 4.12 for grouping sets 1 and grouping sets 2 of IRI, respectively.

Table 4.11: Sensitivity Index calculation of various parameters of IRI grouping set 1

Parameters	I2	Iavg	I1	IRI of I1 (O1)	IRIavg (Oavg)	IRI of I2 (O2)	(O2-O1)/(I2-I1)	Iavg/Oavg	Sensitivity index
AC1	3.05	0.638	0.03	3.11	4.957	4.98	0.619	0.129	0.080
AC2	11.97	0.91	0.015	2.12	5.09	7.56	0.455	0.179	0.081
AC3	12.5	0.804	0.034	2.12	5.2	9.15	0.564	0.155	0.087
BE1	2.4	0.41	0.015	2.6	5.66	5.26	1.115	0.072	0.081
BE2	5.6	0.71	0.03	4.55	5.13	6.45	0.341	0.140	0.048
BE3	4.56	0.75	0.01	2.12	4.98	5.45	0.732	0.151	0.110
D1	1.83	0.28	0.021	2.85	5.85	6.23	1.868	0.048	0.089
D2	2.6	0.3	0.01	4.99	4.89	9.15	1.606	0.061	0.099
D3	3.2	0.6	0.012	5.78	5.41	9.11	1.045	0.111	0.116
F1	1.2	0.16	0.005	6.71	5.91	11.56	4.059	0.027	0.110
F2	0.9	0.1	0.001	1.45	6.2	9.99	9.499	0.016	0.153
F3	0.7	0.106	0.001	2.01	7.17	16.25	20.372	0.015	0.301
G1	1.2	0.34	0.01	5.63	5.37	4.27	-1.143	0.063	-0.072*
G2	1.62	0.31	0.003	7.58	5.47	6.93	-0.402	0.057	-0.023*
G3	2	0.34	0.001	3.11	5.57	5.14	1.016	0.061	0.062
H1	2.22	0.359	0.008	6.38	4.95	5.47	-0.411	0.073	-0.030*
H2	3.2	0.68	0.009	5.78	5.677	6.9	0.351	0.120	0.042
H3	3.08	0.54	0.01	5.1	6.25	7.79	0.876	0.086	0.076

NOTE: * Represents parameters which are highly affected by other inputs rather than the input in consideration.

In both grouping sets, the most sensitive parameters affecting IRI is found to be high severity potholes which is followed by medium severity potholes. Low severity patching and low and medium severity rutting are obtained as the least significant parameters from the sensitivity analysis of IRI and its parameters.

Table 4.12: Sensitivity Index calculation of various parameters of IRI grouping set 2

Parameters	I2	Iavg	I1	IRI of I1 (O1)	IRIavg (Oavg)	IRI of I2 (O2)	(O2-O1)/(I2-I1)	Iavg/Oavg	Sensitivity index
A1	2.5	0.51	0.015	5.65	5.05	6.31	0.266	0.101	0.027
A2	7.65	0.69	0.04	4.38	5.28	7.56	0.418	0.131	0.055
A3	2.48	0.45	0.02	3.24	5.77	7.26	1.634	0.078	0.127
B1	2.1	0.58	0.11	8.12	4.57	8.42	0.151	0.127	0.019
B2	4.32	0.75	0.03	4.68	4.41	6.45	0.413	0.170	0.070
B3	4.56	0.69	0.05	4.19	4.67	7.99	0.843	0.148	0.124
C1	3.01	0.55	0.03	4.36	5.33	6.98	0.879	0.103	0.091
C2	4.32	0.69	0.015	3.33	5.9	6.96	0.843	0.117	0.099
C3	12.5	0.70	0.03	2.12	5.15	9.15	0.564	0.136	0.077
E1	2.4	0.37	0.015	2.6	5.65	7.79	2.176	0.067	0.146
E2	4.2	0.51	0.03	4.55	5.16	7.07	0.604	0.099	0.060
E3	3.75	0.6	0.01	2.12	5.15	5.46	0.893	0.117	0.104
D1	1.83	0.28	0.021	2.85	5.85	6.23	1.868	0.048	0.089
D2	2.6	0.3	0.01	4.99	4.89	9.15	1.606	0.061	0.099
D3	3.2	0.6	0.012	5.78	5.41	9.11	1.045	0.111	0.116
F1	1.2	0.16	0.005	6.71	5.91	11.5	4.059	0.027	0.110
F2	0.9	0.1	0.001	1.45	6.2	9.99	9.499	0.016	0.153
F3	0.7	0.10	0.001	2.01	7.17	16.2	20.372	0.015	0.301
G1	1.2	0.34	0.01	5.63	5.37	4.27	-1.143	0.063	-0.072*
G2	1.62	0.31	0.003	7.58	5.47	6.93	-0.402	0.057	-0.023*
G3	2	0.34	0.001	3.11	5.57	5.14	1.016	0.061	0.062
H1	2.22	0.35	0.008	6.38	4.95	5.47	-0.411	0.073	-0.030*
H2	3.2	0.68	0.009	5.78	5.677	6.9	0.351	0.120	0.042
H3	3.08	0.54	0.01	5.1	6.25	7.79	0.876	0.086	0.076

The results for sensitivity index for IRI are also illustrated with the help of bar diagrams in Figure 4.29 and Figure 4.30 for grouping sets 1 and 2, respectively.

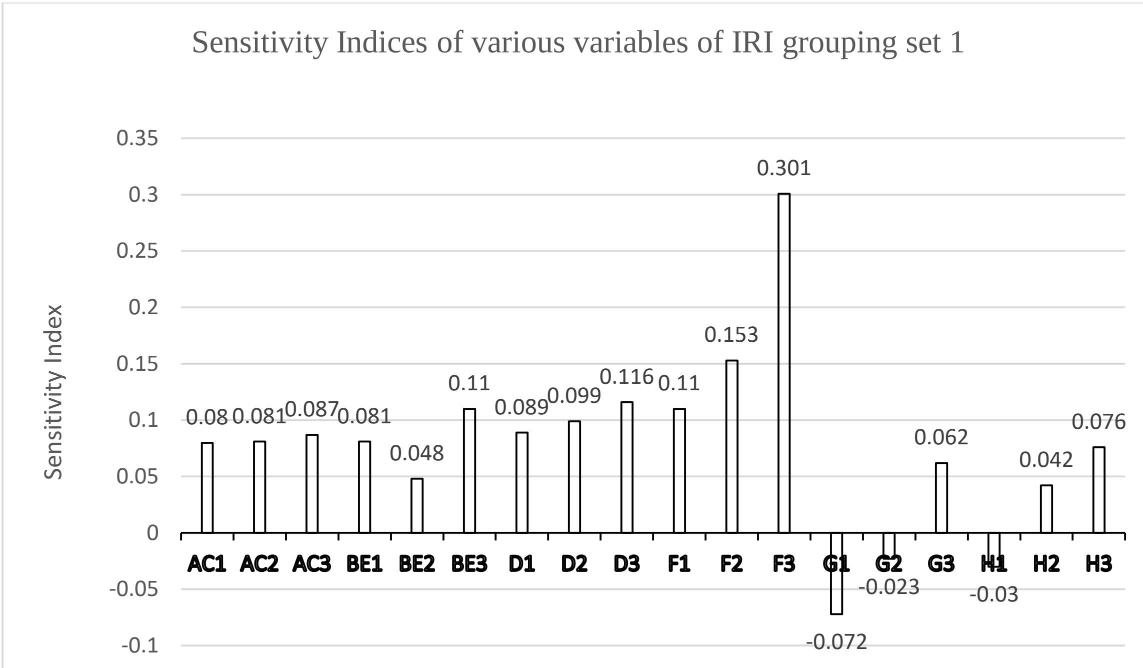

Figure 4.29: Sensitivity Indices of various parameters of PCI grouping set 1

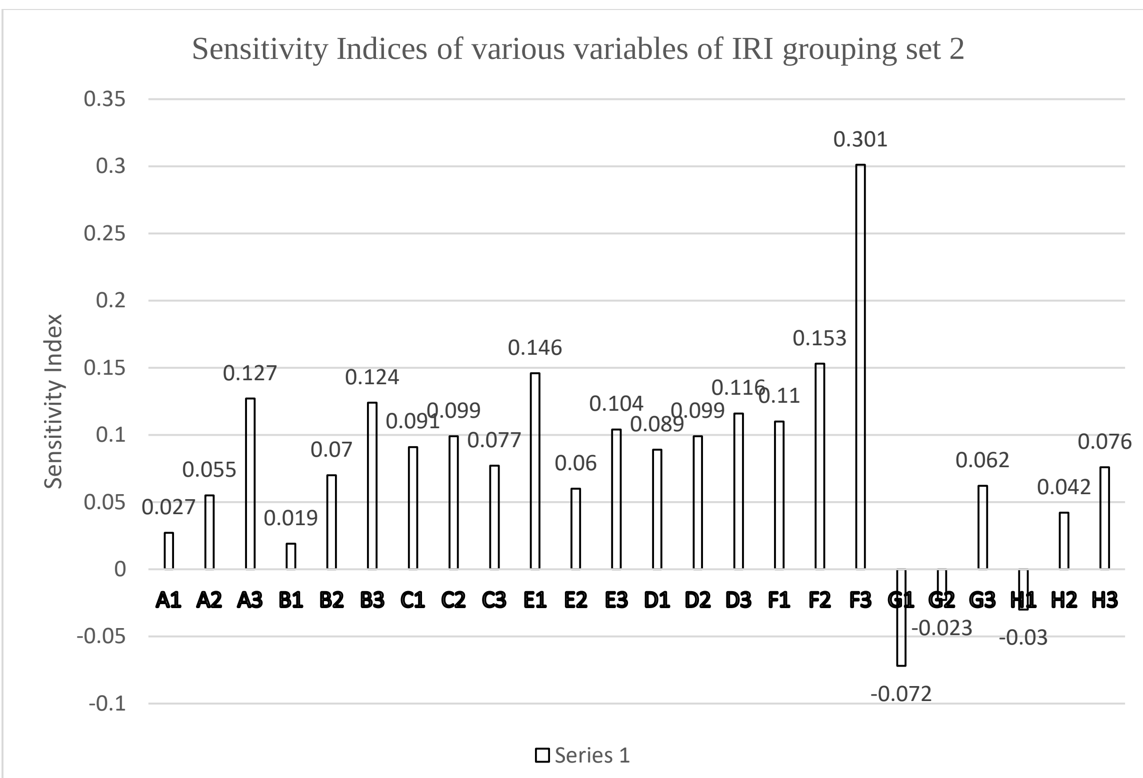

Figure 4.30: Sensitivity Indices of various parameters of IRI grouping set 2

CHAPTER 5: RELATIONSHIP BETWEEN PCI AND IRI

5.1 General

Based on the collected data of IRI with the help of RoadRoid application and PCI calculated with the help of distress evaluated through visual inspection survey, the relationship between the IRI and the corresponding PCI is developed. In order to do so, the PCI-IRI matching is carried out as per visual cues and markings set during the road inspection survey. The visual cues are identified with the help of video taken during the process of IRI survey using RoadRoid. After data matching, the PCI and IRI are listed in tabular format as shown in APPENDIX VI.

5.2 PCI-IRI Model

The relationship between the PCI and IRI is evaluated based on the data using excel 2016 software. Initially the linear relationship between the PCI and IRI is evaluated with the help of data analysis tool-pack through add-ins of the excel software. During the development of the model, PCI is taken as the dependent variable and IRI is taken as the independent variable. The relationship is evaluated for 95 % confidence limit which is the default value in the toolpack. Using the scatterplot of excel, the plot between the PCI as well as the IRI is plotted with IRI in horizontal axis and PCI in the vertical axis. The regression equation is then developed for linear regression model and Polynomial regression model with the help of the data analysis toolpack in excel. The linear model is converted into polynomial regression model by developing the polynomial trend line of order 2 and order 3 in trend line properties. The regression model is also checked for higher degree polynomials but, it presented with the problem of over fitting of the model.

The coefficient of determination i.e R^2 value is determined as 0.7281 for linear regression model whereas, the coefficient of determination is determined as 0.7857 and 0.7858 for polynomial regression model of order 2 and order 3 respectively. Similarly, the R^2 value found to be 0.7489 for logarithmic regression model. The scatter plots with linear, logarithmic and polynomial trend line are as shown in Figure 5.1, Figure 5.2, Figure 5.3 and Figure 5.4 respectively. For the collected set of data, the polynomial regression models are found to be slightly more accurate in predicting the relationship between the PCI and the IRI as it has higher coefficient of determination by a small amount. The regression equations for linear regression model, logarithmic regression models and polynomial regression models are represented by the Equation 5.1, Equation 5.2, Equation 5.3 and Equation 5.4 respectively as follows:

Linear relationship between PCI and IRI is as shown in Figure 5.1 and represented in equation (5.1)

$$\text{PCI} = \begin{cases} -7.7046 \times \text{IRI} + 100, & \forall \quad \text{IRI} < 12.979\ \text{m/km} \\ 0, & \text{Otherwise} \end{cases} \tag{5.1}$$

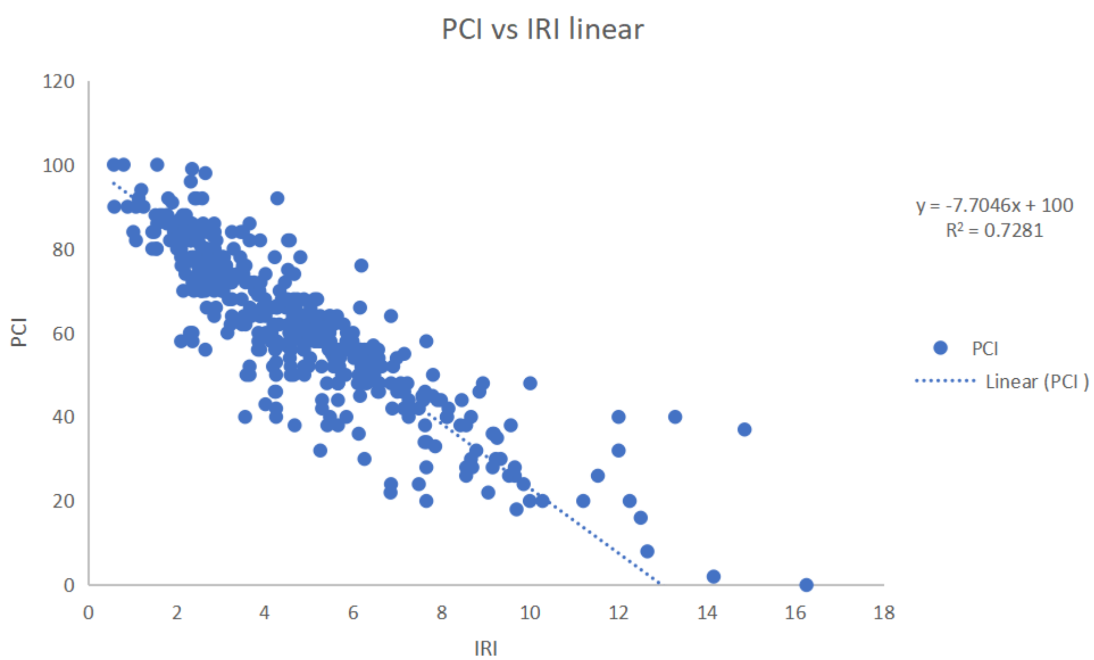

Figure 5.1: PCI vs IRI linear relationship

Logarithmic relationship between PCI and IRI is shown in Figure 5.2 and represented by Equation (5.2)

$$PCI = \begin{cases} 100, & \forall \ IRI \leq 1.147 \ \ m/km \\ -29.45 \text{ x } \ln(IRI) + 104.05, & \forall \ 1.147 < IRI < 34.23 \ m/km \\ 0, & \text{Otherwise} \end{cases} \quad (5.2)$$

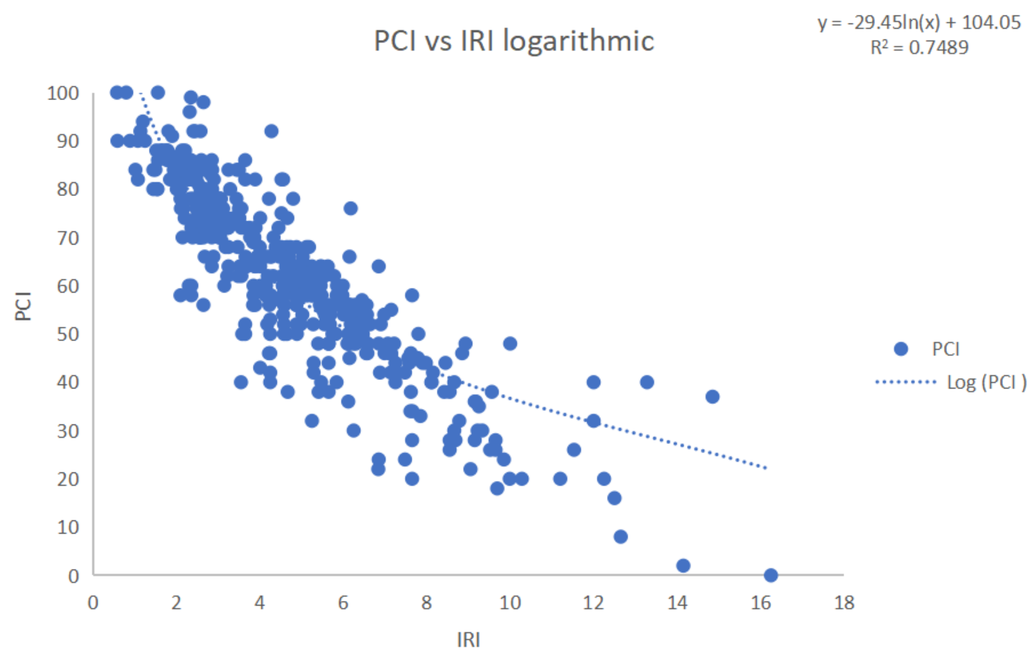

Figure 5.2: PCI vs IRI logarithmic relationship

Polynomial relationship of order 2 between PCI and IRI is shown in Figure 5.3 and represented by Equation (5.3)

$$PCI = \begin{cases} 0.2544 \text{ x } IRI^2 - 9.5505 \text{ x } IRI + 100, & \forall \ IRI < 18.77 \ m/km \\ 0, & \text{Otherwise} \end{cases} \quad (5.3)$$

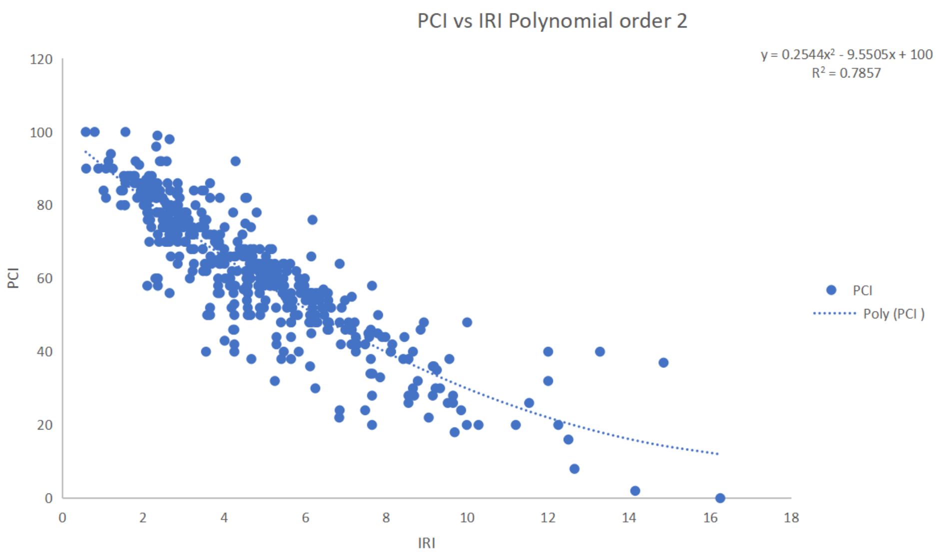

Figure 5.3: PCI vs IRI polynomial relationship of degree 2

Polynomial relationship of order 3 between PCI and IRI is as shown in Figure 5.4 and represented by Equation (5.4)

$$PCI = \begin{cases} 0.0027 \text{ x } IRI^3 + 0.2086 \text{ x } IRI^2 - 9.3852 \text{ x } IRI + 100, & \forall \text{ IRI} < 16.92 \text{ m/km} \\ 0, & \text{Otherwise} \end{cases} \tag{5.4}$$

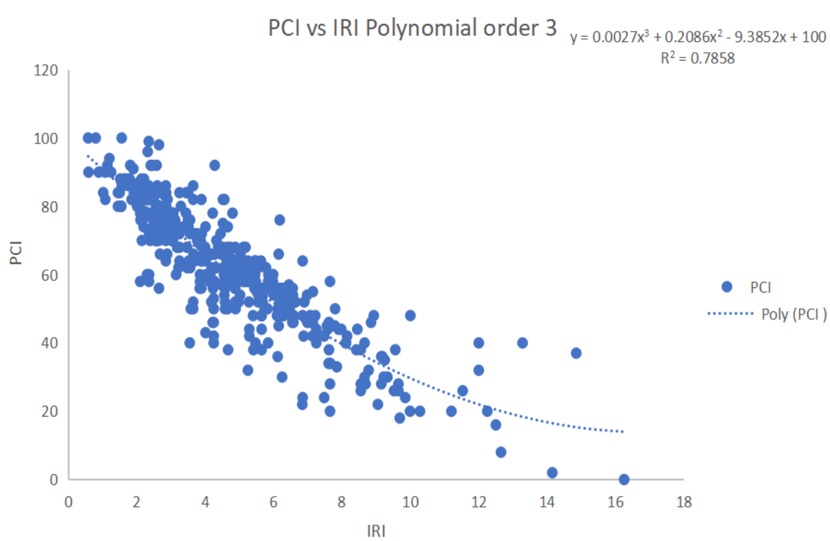

Figure 5.4: PCI vs IRI polynomial relationship of degree 3

Table 5.1 and Table 5.2 show result of regression and ANOVA respectively. The maximum coefficient of determination ($R^{2)}$ of relationship between the PCI and IRI with IRI as independent variable and PCI as dependent variable is determined to be 0.7858 when the relationship between the variables is taken as polynomial of order 3 which shows relatively good correlation between the variables. The scatter plot represented in all the figures shows that the relationship between PCI and IRI is negatively correlated i.e the increase in IRI value results in the decrease in PCI value of the pavement section in consideration and vice versa.

Table 5.1: Regression Test Results

Regression Statistics	
Multiple R	0.873
R Square	0.7281
Adjusted R Square	0.7280
Standard Error	8.696
Observations	468

Table 5.2: ANOVA test results

	df	*SS*	*MS*	*F*	*p-value*
Regression	1	113287.699	113287.699	1498.273468	$1.10x\ 10^{-147}$
Residual	466	35235.268	75.612		
Total	467	148522.967			

CHAPTER 6: CONCLUSION AND FUTURE WORKS

6.1 Conclusion

The assessment of current condition of the pavement is one of the most important tasks for maintenance planning of any roads. If the roads are not assessed and maintained properly, the cost of maintenance grows exponentially. The condition of pavement can be evaluated with the help of the Pavement Condition Index and International Roughness Index which are both associated with the distresses occurring in the pavement and therefore were the focus of the study. The distress data was collected for the section in consideration through manual visual inspection survey and the corresponding PCI was determined with the help of specifications provided in ASTM 6433. The IRI of the section in consideration was evaluated with the help of RoadRoid application after validation using Romdas Z-250 reference profiler. The regression and ANN model were developed in this thesis work for the evaluation of the Pavement Condition Index and International Roughness Index. These indices were taken as dependent variables whereas the distresses responsible for causing the deterioration of the pavement and increase in pavement roughness were taken as independent variables. 2 groupings of distresses were used for model development incorporating 18 (grouping set 1) and 24 (grouping set 2) independent variables, respectively. With the motive to improve the accuracy of the model, ANN model was developed to evaluate both PCI as well as IRI using feed forward back propagation technique with ReLU as activation function. The models were developed with learning rate of 0.01 and varying the number of neurons in the hidden layer and the number of iterations to repeat the learning process so as to ascertain the models with maximum accuracy. The sensitivity analysis of PCI as well as IRI was carried out to find out the most important input parameters for both PCI as well as IRI. Finally, the relationship between the PCI and IRI values was evaluated with the help of linear, logarithmic and polynomial regression technique based on the collected data. The numerical results from the models can be summarized as follows:

- The linear regression model was chosen as best regression model as it yielded least MSE among regression models of various degree for both PCI as well as IRI.
- The linear regression model for PCI yielded coefficient of determination of 0.600 and 0.606 in training and testing of grouping set 1 and 0.621 and 0.603 for training and testing of grouping set 2 whereas, the coefficient of determination was found to be 0.599 and 0.543 for training and testing of grouping set 1 of IRI and 0.614 and 0.616 for training and testing of grouping set 2 of IRI using regression.
- Both PCI and IRI regression models with 24 variables outperformed the corresponding regression models with 18 variables.
- The coefficient of determination of the developed ANN model for PCI showed improved coefficient of determination of 0.857, 0.715 and 0.747 for training, validation and testing for grouping set 1 and 0.852, 0.810 and 0.670 for training, validation and testing for grouping set 2 indicating that ANN provided with better fit for the collected data in order to evaluate the PCI value.
- ANN model for the evaluation of IRI yielded coefficient of determination of 0.559, 0.518 and 0.536 in training, validation and testing for grouping set 1 whereas it was found to be 0.699, 0.597 and 0.595 for grouping set 2 not significantly different from that of the linear models of IRI in both cases.
- The relationship between PCI and IRI presented with negative correlation i.e the increase in IRI value yielded in reduction in the PCI and vice versa. The R^2 value using linear, logarithmic and polynomial regression model were 0.7281, 0.7489 and 0.7858 respectively which showed good correlation between IRI and PCI.

6.2 Directions for Future Work

The work can be continued in order to achieve better results for the developed model and for the optimization of the developed model.

- The model can be further optimized using other tools of machine learning including Genetic Algorithm, Deep Neural Networks and so on.

- The pavement distress data can be collected in yearly basis which can help in the utilization of the model for PCI prediction and development of survivor curves and pavement performance curves over time.
- Since the ANN model of IRI is not yet satisfactory, separate groupings of distresses can be formulated and used for model development.

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APPENDIX A: PYTHON GENERATED ANN CODE FOR PCI AND IRI PREDICTION

```
import pandas as pd
import matplotlib.pyplot as plt
from tensorflow.keras import Sequential
from tensorflow.keras.optimizers import Adam
from sklearn.preprocessing import StandardScaler
from tensorflow.keras.layers import Dense
from sklearn.model_selection import train_test_split
from tensorflow.keras.losses import  MeanSquaredError
import seaborn as sns
import scipy

def scale_datasets(x_train, x_test):

  """
  Standard Scale test and train data
  Z - Score normalization
  """
  standard_scaler = StandardScaler()
  x_train_scaled = pd.DataFrame(
      standard_scaler.fit_transform(x_train),
      columns=x_train.columns
  )
  x_test_scaled = pd.DataFrame(
      standard_scaler.transform(x_test),
      columns = x_test.columns
  )
  return x_train_scaled, x_test_scaled

df = pd.read_csv('new-pci-thesis-cleaned.csv')

x = df.drop('PCI',axis=1)
y = df.PCI
```

```
x_train, x_test, y_train, y_test = train_test_split(x, y, train_size=0.9, random_state=seed_value)
x_train_scaled, x_test_scaled = scale_datasets(x_train, x_test)

hidden_units = 12

learning_rate = 0.01
# Creating model using the Sequential in tensorflow
def build_model_using_sequential():
  model = Sequential([
    Dense(hidden_units, kernel_initializer='normal', activation='relu'),
    Dense(1, kernel_initializer='normal', activation='relu')
  ])
  return model
# build the model
model = build_model_using_sequential()

# loss function
mse = MeanSquaredError()
model.compile(
    loss=mse,
    optimizer=Adam(learning_rate=learning_rate),
    metrics=['mse' ]
)

# train the model
history = model.fit(
    x_train_scaled.values,
    y_train.values,
    epochs=40,
    batch_size=32,
    validation_split=0.2
)
def plot_history(history, key):
  plt.plot(history.history[key])
  plt.plot(history.history['val_'+key])
  plt.xlabel("Epochs")
```

```
  plt.ylabel(key)
  plt.legend([key, 'val_'+key])
  plt.show()

# Plot the history
plot_history(history, 'mse')

x_test_prediction = model.predict(x_test_scaled)
x_train_prediction = model.predict(x_train_scaled)
model.evaluate(x_test_scaled,y_test)

test_mse = model.evaluate(x_test_scaled,y_test)[0]

import numpy as np

test_r2 = 1- test_mse / np.var(y)
train_r2 = 1 - (history.history['mse'][-1]) / np.var(y)
validation_r2 = 1 - (history.history['val_mse'][-1] / np.var(y))
print(f"test_r2 = {test_r2}")
print(f"train_r2 = {train_r2}")
print(f"validation_r2 = {validation_r2}")

import seaborn as sns
ax = sns.regplot(x=y_test ,y= x_test_prediction,)
ax.set(title = 'test PCI predicted vs target', xlabel='target', ylabel='predicted')
#calculate slope and intercept of regression equation

slope, intercept, r, p, sterr = scipy.stats.linregress(x=ax.get_lines()[0].get_xdata(),
                                                       y=ax.get_lines()[0].get_ydata())
print(f"line: y = {slope} * x + {intercept}")
ax = sns.regplot(x=x_test_prediction, y=y_test)
ax.set(title = 'test PCI predicted vs target', xlabel='predicted', ylabel='target')
ax = sns.regplot(x=y_train, y= x_train_prediction)
ax.set(title = 'train PCI predicted vs target', xlabel='target', ylabel='predicted')

slope, intercept, r, p, sterr = scipy.stats.linregress(x=ax.get_lines()[0].get_xdata(),
                                                       y=ax.get_lines()[0].get_ydata())
print(f"line: y = {slope} * x + {intercept})
```

APPENDIX B: SAMPLE DATASET 1 FOR REGRESSION AND NEURAL NETWORK TRAINING, TESTING AND VALIDATION OF PCI

S.N	AC1	AC2	AC3	BE1	BE2	BE2	D1	D2	D3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI
1	0	3.8	0	0.32	0	0	0	0	0	0	0	1.01	0	0	0	0	0	1.55	36
2	0	1.59	0	1.7	0	0	0	0	0	0	0	0.09	0	0	0	2.22	0	1.25	56
3	0	0.93	0	0.75	3.64	0	0.74	0	0	0	0	0.6	0	0	0.26	0	0	0.33	46
4	0	11.97	2.99	0	1.22	0	0	0.43	0	0	0.25	0	0	0	0	0	2.97	0	45
5	0	1.33	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0.32	0	87
6	0	0.21	0	0.93	1.04	0	0	0	0	0	0.09	0	0	0	0.04	0	0	0.32	56
7	0	1.52	0	0	0.74	0	0.21	0	0	0	0	0	0	0	0	0	2.54	0	64
8	0	1.37	0	0	0	0	0	0	0	0	0	0	0	0.32	0	0	0	0	75.5
9	0	0.17	0	0	1	0	0	0	0	0	0.03	0	0	0	0.11	0	0	0.45	68
10	0	4.65	0	0	0	0	0	0	0	0	0	0.34	0.6	0	0	0	0	0	53
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
12	0	0.24	0.16	0	1.2	1.03	0	0	0.82	0	0.02	0	0	0	0	0	0	0	69
13	0	3.35	0	0	0	0	0.45	0	0	0	0	0.52	0	0	0	0	0	0	56
14	0	2.28	0	0	0.61	0	0	0	0	0	0.09	0	0	0	0	0	0	0	62
15	0	0.55	0	0	0	1.28	0	0.5	0	0	0.22	0	0	0	0	0	0	0	75
16	0	0.37	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	1.57	0	70
17	2.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99
18	0.42	2.128	0	0.6	5.6	0.96	0	0.212	0	0	0	0	0.56	0	0	0	3.08	0.6	56
19	0	2.086	3.36	0	0.88	0.96	0	0.46	0	0	0	0	0	0.9	0	0	1.4	0.18	48
20	2.28	0.992	0.204	0	3.21	0	0.18	0.412	0	0	0	0	0.82	0	0.84	0	3.2	0.8	52
21	0	1.34	0	1.22	1.72	1.44	0	0.408	0	0	0.4	0	0	1.62	0	0	0.6	0	52
22	0	1.232	0.42	0	2.424	1.34	0	0	1.074	0	0	0.12	0	0	0.64	0	0	0	28
23	0	0.86	1.63	2.4	0	2.84	0	1.33	0	0	0	0	0	0	0.42	0	0	3.08	45
24	1.842	0	1.28	0	1.96	0	0	0	0	0	0	0	0	0	0.82	0	2.42	0	50
25	1.22	1.84	0.42	0	1.22	0.82	0	0	0	0	0	0	0	0	0	0	0.92	0.2	62
26	0	0	1.82	0	1.5	0	0	0.28	0.08	0	0.42	0	0	0	0	2.4	2.2	1.2	24
27	1.62	1.86	0.62	0	0	0	0	0	0	0	0	0	0	0	0	1.2	1.2	0	64
28	2.4	0	0.84	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	2.8	58

S.N	AC1	AC2	AC3	BE1	BE2	BE2	D1	D2	D3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI
29	0	0	1.82	0	0.52	0	0.68	0	3.2	0	0	0	0	0	0	0	0	0.4	43
30	0	3.32	1.78	0	1.2	0	0	0	0	0	0	0	0	0	0	0	0.72	0	56
31	0	1.36	2.48	0	1.28	2.42	0.72	0.52	0	0	0.62	0	0	0	0	0	2.48	0	20
32	1.32	4.9	0	0	1.2	2.84	0.8	1.72	0	0	0	0	0	1.22	0	0	0	0	60
33	0.6	1.2	0.8	0.8	0	0	0.92	0.6	0	0	0	0.24	0	0	0	0	0	0	28
34	0	0.58	1.72	0	0	2.4	0	2.2	0	0	0	0.12	0	0	0	0	2.48	0	28
35	0.92	0	1.34	0	1.22	1.72	0	0	0.408	0.52	0	0.4	0	0	1.62	0	0	0.6	8
36	0	0.6	2.6	0	3.2	2.3	0	0	0.8	0	0	0.2	0	0	0	0	2.6	0	16
37	0	2.4	0.6	2	4.2	0	0	0	1.55	0	0	0	0	0	0	0	0	0	48
38	0	0	4.4	0	0	0	0	0	0.4	0	0	0	0	0	2	0	0	0	36
39	0	1.1	0	0	0	2.6	0	2	0	0	0.9	0	0	0	0	0	0	0	10
40	3	0	3.2	0	0.45	0	0	1.5	0	0	0	0	0	0	0	0	0	0	50
41	0.6	1.45	0	0	0	0	1.5	2.6	0	0	0	0	0	0	0	0	0	0	62
42	0	0.5	1.8	0	0.4	0	1.8	0	0	0	0	0	0	0	0.6	0	2.6	0	40
43	0	2	0	0	0	2.6	0.6	0	0	0	0	0	0	0	0	0	1.5	0	68
44	0	0.6	1.2	0	1.2	0	1.3	0	0	0	0	0.6	0	0	0	0	0	0	4
45	0	0.9	1.9	0	0	0	0.9	0	0	0	0.5	0	0	0	0	0	0	0	26
46	1.6	1.93	0.5	0	0	0	0	0	0.4	1.2	0	0	0	0	0.5	0	0	0	20
47	1.1	1.1	2.3	2.1	1.2	0	0	0	1	0	0	0	0	0	0	0	0	0	38
48	0	0.56	4.42	0	0	0.316	0.66	0.15	0	0	0	0.6	0	0	0	0	0	0	10
49	0.36	1.2	0.81	0	0.99	0	0.59	0	0.355	0	0	0	0	0	0.6	0	0	0.66	36
50	0.56	2.36	0	0.15	0	0	0	0.32	0.88	0.6	0	0	0	0	0.66	0	0	0.152	28
51	0	0	0.78	0	0	0	0.81	0	0	0	0	0	0	0	0	0	0.15	0	82
52	1.43	0	1.2	0	0.65	0	0	0	0	0	0	0	0	0.23	0	0	0	0.65	60
53	0.65	1.21	0	0	0	0	0	1.46	0.66	0	0	0	0	0	0	0	0	0.15	58
54	1.16	1.22	0.772	0.155	0.15	0	0	0.3	0	0	0	0	0.2	0	0	0	0.778	0	84
55	1.4	2.3	2.12	0	0	0	0.65	0	0	0	0	0	0	0	0.6	0	0	0	50
56	1.5	4.81	2.4	1.4	1.4	0	1.7	0	0	2.1	0.15	0	0	0	0.5	0	0	0	16
57	1.1	1.96	3.75	0	1.05	0	0	0	0.96	0	0.09	0	0	0	0	0	0	0	38
58	0	3.6	0.15	0	0	0	0	0	0.14	0	0	0	0	0	0	0	0	0	64
59	0.54	2.2	0.96	0	0	4.56	0.78	0	0	0	0.15	0	0	0	0	0	0	0	44
60	0.4	0	3.15	0	1.1	0	0	0.9	0	0	0.06	0	0	0	0	0	0	0	66
61	0	0	1.4	0	0	1.5	0.15	0	0	0	0	0	0	0	0	0	1.3	0	62
62	0	2.1	0	0	0	1.1	0.15	0.25	0.45	0	0	0	0	0.15	0	0	0	0	54
63	1.2	0.7	0.25	0	1.2	0	0.78	0	0.45	1.2	0.05	0	0	0	0	0	0.2	0.3	32
64	1.02	0.5	4.06	0	0	2.1	0.17	0.11	0	0	0	0	0	0	0.52	0	0	0	46
65	0.9	1.05	0	0	2.1	0	0	0	0.65	0	0	0	0	0.26	0	0	0	0	86

S.N	AC1	AC2	AC3	BE1	BE2	BE2	D1	D2	D3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI
66	0	0.9	1.35	0	0	0.2	0	0	0.12	0	0.15	0	0	0	0	0	0.52	1.3	33
67	0	1	1.43	0	0.6	1.3	0.51	0	0.15	0	0	0	0	0	0	0	0	0	55
68	2.4	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0.26	0.45	0	0.26	68
69	0.12	3.1	0	0	0.8	0.5	0	0.06	0.104	0	0	0	0	0.156	0	0	0	0	64
70	1	1.2	1.27	0	0	0	0	0.35	0.31	0.01	0.08	0	0	0	0	0	1.5	0	52
71	0.9	0.42	0.75	0	0	0.7	0	0.55	0	0	0	0	0	0	0.65	0	0	0	64
72	0.577	1.7	0.15	0	0.4	0.6	0	0.23	0.8165	0.23	0.01	0	0	0.21	0	0	0	0	52
73	0.23	1.32	1.83	0	0.11	0	0.25	0	2.22	0	0	0	0	0	0	0	1.2	0	52
74	1.1	2.5	0.81	0	0	0	0	0.366	0	0.12	0	0	0	0	0	0.12	0	0.6	56
75	0	1.49	1.03	0	0.4	0.7	0	0.3	0.16	0	0	0	0	0	0.08	0	0.15	0	50
76	0	2	0	0	0.5	0.65	0.56	0	0.99	0.18	0	0	0	0.12	0	0	0	0	42
77	1.25	1.8	0.89	0	0.32	0	0	0.66	0.5	0	0.06	0	0	0	0	0	0.15	0	60
78	1.2	1.1	3.33	0	1.4	0	0	0.79	0	0	0	0	0	0	0	0	0	0	57
79	0	1.63	1.25	0	0	1.46	0	0.89	1.92	0.16	0	0	0	0	0.45	0	0	0	26
80	1.5	0.23	0.5	0	0.6	0.45	0.12	0.32	1.19	0	0	0	0	0.13	0	0	0.62	0	58
81	0.4	3.76	2.77	0	0.83	0	0	0	0	0	0.01	0	0	0	0	0.26	0.46	0	60
82	0	0	0.4	0.15	0.7	0.9	0	0.23	0	0.6	0	0	0	0	0	0	0	0	45
83	0	0	1.96	0	0	1.5	0	1.16	1.35	0	0	0	0	0	0.23	0	0	0	36
84	0	1.8	1.79	0	0	0	0	0	1.85	0	0.02	0	0	0.48	0	0	0	0	50
85	0.056	1.42	0.65	0	2.118	2.4	0.23	0	0	0.05	0.02	0	0	0	0	0.78	0	0	52
86	0	1.9	0	0	2.6	1.45	0	0.15	0.74	0	0	0	0	0	0.48	0	0	0	46
87	0	0.6	4.1	0	0	0	0	0.66	0	0.26	0	0	0	0	0	0	0	0	38
88	0	1.515	0	0.89	1.1	2.1	0	0.22	0.95	0	0.05	0	0	0.95	0	0	0	0	48
89	0	1.35	2	0	0	1.8	0	0.45	0.56	0.3	0	0	0	0	0	0	1.26	0	42
90	0.15	0.8	0	0	0	2.05	0.78	0.66	0	0	0	0	0.12	0	0	0	0	0	87
91	0	0.6	1.12	0	0	1.5	0	0	0.23	0	0.09	0	0	0	0	0	0	0	52
92	0	0.56	0.58	0	0	1.2	0	0.65	0.12	0.15	0	0	0	0	..45	0	1.25	0	40
93	0	0.08	0	0.23	0	0.45	0	0.1	0	0	0	0	0	0	0	0	0	0	92
94	0.95	0.9	12.5	0	1.22	0	0.15	2.6	0.15	0	0.15	0	0	0.15	0	0	0	0	22
95	0	0	0.78	0	0	0.81	0	0	0.12	0.065	0	0	0	0	0.05	0.9	0.4	0.56	54
96	0	0.66	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	76
97	0	0	1.84	1.4	0.66	1.05	0	0.78	0	0	0.26	0	0	0	0	0	0	0	38
98	0	0	0	0	0	0	0	0	0.26	0	0	0	0	0	0.65	0	0	0	64
99	0	0.98	0	0	0.15	0	0	0.9	0	0.156	0	0	0	0	0	0	0	0	70
100	0.45	0	0.95	1.115	0	0.45	0	0	0	0	0.22	0	0	0	0	0	0	0	44
101	0	0	0	0	0	0	0	0.01	0.13	0.98	0	0	0	0.156	0.48	0	0	0	64
102	0.665	3.05	0.995	0	0.11	0	0	0	0	0	0.15	0	0	0	0	0	0	0	34

APPENDIX C: SAMPLE DATASET 2 FOR REGRESSION AND NEURAL NETWORK TRAINING, TESTING AND VALIDATION OF PCI

S.N	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI
1	0	1.45	0	0	0	0	0	2.35	0	0	0	0	0.32	0	0	0	0	1.01	0	0	0	0	0	1.55	36
2	0	1.47	0	0	0	0	0	0.12	0	0	0	0	1.7	0	0	0	0	0.09	0	0	0	2.22	0	1.25	56
3	0	0.8	0	0.75	2.91	0	0	0.13	0	0.74	0	0	0	0.73	0	0	0	0.6	0	0	0.26	0	0	0.33	46
4	0	7.65	0	0	0	0	0	4.32	2.99	0	0.43	0	0	1.22	0	0	0.25	0	0	0	0	0	2.97	0	45
5	0	0.1	0	0	0	0	0	1.23	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.32	0	87
6	0	0.07	0	0.65	1.04	0	0	0.14	0	0	0	0	0.28	0	0	0	0.09	0	0	0	0.04	0	0	0.32	56
7	0	1.52	0	0	0.74	0	0	0	0	0.21	0	0	0	0	0	0	0	0	0	0	0	0	2.54	0	64
8	0	1.05	0	0	0	0	0	0.32	0	0	0	0	0	0	0	0	0	0	0	0.32	0	0	0	0	76
9	0	0.04	0	0	1	0	0	0.13	0	0	0	0	0	0	0	0	0.03	0	0	0	0.11	0	0	0.45	68
10	0	1.88	0	0	0	0	0	2.77	0	0	0	0	0	0	0	0	0	0.34	0.6	0	0	0	0	0	53
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
12	0	0	0	0	0	1.03	0	0.24	0.16	0	0	0.82	0	1.2	0	0	0.02	0	0	0	0	0	0	0	69
13	0	0	0	0	0	0	0	3.35	0	0.45	0	0	0	0	0	0	0	0.52	0	0	0	0	0	0	56
14	0	2.24	0	0	0.23	0	0	0.04	0	0	0	0	0	0.38	0	0	0.09	0	0	0	0	0	0	0	62
15	0	0	0	0	0	0.87	0	0.55	0	0	0.5	0	0	0	0.41	0	0.22	0	0	0	0	0	0	0	75
16	0	0	0	0	0	0	0	0.37	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	1.57	0	70
17	0	0	0	0	0	0	2.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99
18	0.42	0	0	0.6	4.32	0	0	2.128	0	0	0.212	0	0	1.28	0.96	0	0	0	0.56	0	0	0	3.08	0.6	56
19	0	0.88	0	0	0	0.96	0	1.206	3.36	0	0.46	0	0	0.88	0	0	0	0	0	0.9	0	0	1.4	0.18	48
20	0.58	0.68	0.20	0	2.4	0	1.7	0.312	0	0.18	0.412	0	0	0.81	0	0	0	0	0.82	0	0.84	0	3.2	0.8	52
21	0	0.92	0	0	1.72	0.92	0	0.42	0	0	0.408	0	1.22	0	0.52	0	0.4	0	0	1.62	0	0	0.6	0	52
22	0	0.604	0	0	1.22	0.84	0	0.628	0.42	0	0	1.074	0	1.204	0.5	0	0	0.12	0	0	0.64	0	0	0	28
23	0	0	0.42	0	0	2.42	0	0.86	1.21	0	1.33	0	2.4	0	0.42	0	0	0	0	0	0.42	0	0	3.08	45
24	1.84	0	1.28	0	1.28	0	0	0	0	0	0	0	0	0.68	0	0	0	0	0	0	0.82	0	2.42	0	50
25	1.22	0.62	0	0	0	0.82	0	1.22	0.42	0	0	0	0	1.22	0	0	0	0	0	0	0	0	0.92	0.2	62
26	0	0	1.82	0	0.52	0	0	0	0	0	0.28	0.08	0	0.98	0	0	0.42	0	0	0	0	2.4	2.2	1.2	24
27	1.62	1.22	0	0	0	0	0	0.64	0.62	0	0	0	0	0	0	0	0	0	0	0	0	1.2	1.2	0	64
28	0	0	0.84	0	0	0	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	2.8	58
29	0	0	0.82	0	0.52	0	0	0	1	0.68	0	3.2	0	0	0	0	0	0	0	0	0	0	0	0.4	43
30	0	0.92	1.78	0	1.2	0	0	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.72	0	56
31	0	0	2.48	0	0	2.42	0	1.36	0	0.72	0.52	0	0	1.28	0	0	0.62	0	0	0	0	0	2.48	0	20
32	0	2.48	0	0	1.2	0	1.32	2.42	0	0.8	1.72	0	0	0	2.84	0	0	0	0	1.22	0	0	0	0	60
33	0	0	0	0.8	0	0	0.6	1.2	0.8	0.92	0.6	0	0	0	0	0	0	0.24	0	0	0	0	0	0	28
34	0	0	0	0	0	2.4	0	0.58	1.72	0	2.2	0	0	0	0	0	0	0.12	0	0	0	0	2.48	0	28
35	0	0	0.92	0	0	1.72	0.92	0	0.42	0	0	0.408	0	1.22	0	0.52	0	0.4	0	0	1.62	0	0	0.6	8
36	0	0	0	0	3.2	0	0	0.6	2.6	0	0	0.8	0	0	2.3	0	0	0.2	0	0	0	0	2.6	0	16
37	0	2.4	0	2	0	0	0	0	0.6	0	0	1.55	0	4.2	0	0	0	0	0	0	0	0	0	0	48
38	0	0	1.6	0	0	0	0	0	2.8	0	0	0.4	0	0	0	0	0	0	0	0	2	0	0	0	36
39	0	0	0	0	0	2.6	0	1.1	0	0	2	0	0	0	0	0	0.9	0	0	0	0	0	0	0	10

S.N	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI
40	2.5	0	0	0	0	0	0.5	0	3.2	0	1.5	0	0	0.45	0	0	0	0	0	0	0	0	0	0	50
41	0	1	0	0	0	0	0.6	0.45	0	1.5	2.6	0	0	0	0	0	0	0	0	0	0	0	0	0	62
42	0	0	1.2	0	0	0	0	0.5	0.6	1.8	0	0	0	0.4	0	0	0	0	0	0	0.6	0	2.6	0	40
43	0	1.2	0	0	0	2.6	0	0.8	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	68
44	0	0	0	0	1.2	0	0	0.6	1.2	1.3	0	0	0	0	0	0	0	0.6	0	0	0	0	0	0	4
45	0	0	1.4	0	0	0	0	0.9	0.5	0.9	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	26
46	0	1.43	0	0	0	0	1.6	0.5	0.5	0	0	0.4	0	0	0	1.2	0	0	0	0	0.5	0	0	0	20
47	0	0	0	2.1	0	0	1.1	1.1	2.3	0	0	1	0	1.2	0	0	0	0	0	0	0	0	0	0	38
48	0	0	2.32	0	0	0.15	0	0.56	2.1	0.66	0.15	0	0	0	0.166	0	0	0.6	0	0	0	0	0	0	10
49	0	1.2	0	0	0.99	0	0.36	0	0.81	0.59	0	0.355	0	0	0	0	0	0	0	0	0.6	0	0	0.66	36
50	0	0	0	0.15	0	0	0.56	2.36	0	0	0.32	0.88	0	0	0	0.6	0	0	0	0	0.66	0	0	0.15	28
51	0	0	0	0	0	0	0	0	0.78	0.81	0	0	0	0	0	0	0	0	0	0	0	0	0.15	0	82
52	0	0	1.2	0	0.65	0	1.43	0	0	0	0	0	0	0	0	0	0	0	0	0.23	0	0	0	0.65	60
53	0	0	0	0	0	0	0.65	1.21	0	0	1.46	0.66	0	0	0	0	0	0	0	0	0	0	0	0.15	58
54	0	0	0	0	0	0	1.16	1.22	0.772	0	0.3	0	0.155	0.15	0	0	0	0	0.2	0	0	0	0.78	0	84
55	0	0	2.12	0	0	0	1.4	2.3	0	0.65	0	0	0	0	0	0	0	0	0	0	0.6	0	0	0	50
56	0	2.01	0	0	1.4	0	1.5	2.8	2.4	1.7	0	0	1.4	0	0	2.1	0.15	0	0	0	0.5	0	0	0	16
57	1.1	0	0	0	1.05	0	0	1.96	3.75	0	0	0.96	0	0	0	0	0.09	0	0	0	0	0	0	0	38
58	0	1.5	0	0	0	0	0	2.1	0.15	0	0	0.14	0	0	0	0	0	0	0	0	0	0	0	0	64
59	0	0	0.96	0	0	4.56	0.54	2.2	0	0.78	0	0	0	0	0	0	0.15	0	0	0	0	0	0	0	44
60	0	0	0	0	0	0	0.4	0	3.15	0	0.9	0	0	1.1	0	0	0.06	0	0	0	0	0	0	0	66
61	0	0	1.4	0	0	1.5	0	0	0	0.15	0	0	0	0	0	0	0	0	0	0	0	0	1.3	0	62
62	0	2.1	0	0	0	0	0	0	0	0.15	0.25	0.45	0	0	1.1	0	0	0	0	0.15	0	0	0	0	54
63	1.2	0.2	0	0	1.2	0	0	0.5	0.25	0.78	0	0.45	0	0	0	1.2	0.05	0	0	0	0	0	0.2	0.3	32
64	0.9	0	2.1	0	0	2.1	0.12	0.5	1.96	0.17	0.11	0	0	0	0	0	0	0	0	0	0.52	0	0	0	46
65	0	0	0	0	2.1	0	0.9	1.05	0	0	0	0.65	0	0	0	0	0	0	0	0.26	0	0	0	0	86
66	0	0.9	1.2	0	0	0.2	0	0	0.15	0	0	0.12	0	0	0	0	0.15	0	0	0	0	0	0.52	1.3	33
67	0	0	0.9	0	0.6	0	0	1	0.53	0.51	0	0.15	0	0	1.3	0	0	0	0	0	0	0	0	0	55
68	2.4	0	0	0	0	0	0	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0.26	0.45	0	0.26	68
69	0	2.5	0	0	0.8	0.5	0.12	0.6	0	0	0.06	0.104	0	0	0	0	0	0	0	0.16	0	0	0	0	64
70	0	0	0	0	0	0	1	1.2	1.27	0	0.35	0.31	0	0	0	0.01	0.08	0	0	0	0	0	1.5	0	52
71	0.9	0	0.3	0	0	0.7	0	0.42	0.45	0	0.55	0	0	0	0	0	0	0	0	0	0.65	0	0	0	64
72	0.4	0.6	0	0	0.4	0	0.177	1.1	0.15	0	0.23	0.816	0	0	0.6	0.23	0.01	0	0	0.21	0	0	0	0	52
73	0	0	0	0	0	0	0.23	1.32	1.83	0.25	0	2.22	0	0.11	0	0	0	0	0	0	0	0	1.2	0	52
74	0	0.9	0	0	0	0	1.1	1.6	0.81	0	0.366	0	0	0	0	0.12	0	0	0	0	0	0.12	0	0.6	56
75	0	0	0.8	0	0.4	0.7	0	1.49	0.23	0	0.3	0.16	0	0	0	0	0	0	0	0	0.08	0	0.15	0	50
76	0	0.8	0	0	0.5	0	0	1.2	0	0.56	0	0.99	0	0	0.65	0.18	0	0	0	0.12	0	0	0	0	42
77	0	0.6	0	0	0	0	1.25	1.2	0.89	0	0.66	0.5	0	0.32	0	0	0.06	0	0	0	0	0	0.15	0	60
78	1.2	0	0.9	0	1.4	0	0	1.1	2.43	0	0.79	0	0	0	0	0	0	0	0	0	0	0	0	0	57
79	0	1.4	0	0	0	0.8	0	0.23	1.25	0	0.89	1.92	0	0	0.66	0.16	0	0	0	0	0.45	0	0	0	26
80	1.5	0	0.5	0	0.6	0	0	0.23	0	0.12	0.32	1.19	0	0	0.45	0	0	0	0	0.13	0	0	0.62	0	58
81	0	1.5	0	0	0.5	0	0.4	2.26	2.77	0	0	0	0	0.33	0	0	0.01	0	0	0	0	0.26	0.46	0	60
82	0	0	0.4	0	0.7	0.9	0	0	0	0	0.23	0	0.15	0	0	0.6	0	0	0	0	0	0	0	0	45
83	0	0	0.6	0	0	0	0	0	1.36	0	1.16	1.35	0	0	1.5	0	0	0	0	0	0.23	0	0	0	36

S.N	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI
84	0	0.8	0	0	0	0	0	1	1.79	0	0	1.85	0	0	0	0	0.02	0	0	0.48	0	0	0	0	50
85	0	0	0.5	0	1.4	2.4	0.056	1.42	0.15	0.23	0	0	0	0.718	0	0.05	0.02	0	0	0	0	0.78	0	0	52
86	0	1.9	0	0	2.6	0	0	0	0	0	0.15	0.74	0	0	1.45	0	0	0	0	0	0.48	0	0	0	46
87	0	0	0.7	0	0	0	0	0.6	3.4	0	0.66	0	0	0	0	0.26	0	0	0	0	0	0	0	0	38
88	0	1.2	0	0	1.1	2.1	0	0.315	0	0	0.22	0.95	0.89	0	0	0	0.05	0	0	0.95	0	0	0	0	48
89	0	1.2	0	0	0	0	0	0.15	2	0	0.45	0.56	0	0	1.8	0.3	0	0	0	0	0	0	1.26	0	42
90	0	0	0	0	0	1.9	0.15	0.8	0	0.78	0.66	0	0	0	0.15	0	0	0	0.12	0	0	0	0	0	87
91	0	0.6	0	0	0	1.5	0	0	1.12	0	0	0.23	0	0	0	0	0.09	0	0	0	0	0	0	0	52
92	0	0	0	0	0	0	0	0.56	0.58	0	0.65	0.12	0	0	1.2	0.15	0	0	0	0	..45	0	1.25	0	40
93	0	0	0	0	0	0	0	0.08	0	0	0.1	0	0.23	0	0.45	0	0	0	0	0	0	0	0	0	92
94	0	0.9	0	0	0	0	0.95	0	12.5	0.15	2.6	0.15	0	1.22	0	0	0.15	0	0	0.15	0	0	0	0	22
95	0	0	0	0	0	0	0	0	0.78	0	0	0.12	0	0	0.81	0.06	0	0	0	0	0.05	0.9	0.4	0.56	54
96	0	0	0	0	0	0	0	0.66	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	76
97	0	0	0	1.25	0	0	0	0	1.84	0	0.78	0	0.15	0.66	1.05	0	0.26	0	0	0	0	0	0	0	38
98	0	0	0	0	0	0	0	0	0	0	0	0.26	0	0	0	0	0	0	0	0	0.65	0	0	0	64
99	0	0	0	0	0	0	0	0.98	0	0	0.9	0	0	0.15	0	0.15	0	0	0	0	0	0	0	0	70
100	0	0	0	0.555	0	0	0.45	0	0.95	0	0	0	0.56	0	0.45	0	0.22	0	0	0	0	0	0	0	44
101	0	0	0	0	0	0	0	0	0	0	0.01	0.13	0	0	0	0.98	0	0	0	0.15	0.48	0	0	0	64
102	0	2.45	0.85	0	0	0	0.665	0.6	0.145	0	0	0	0	0.11	0	0	0.15	0	0	0	0	0	0	0	34
103	0	0	0	0.56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
104	0	0	0	2.3	0	0.56	0	0.45	0.7	0	0.796	1.28	0.47	0.55	0	0	0.12	1.2	0	0	0.11	0.48	0	0	34
105	0	0.25	1.23	0	0.98	0	0.6	0.87	1.3	0	0.26	0.32	0	0.58	0.23	0.05	0.06	0.01	0	0	0.12	0.23	0	0.26	34
106	0.5	0	0	0	0.26	2.3	0.23	0	0.23	0.43	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	82
107	0	0	0.5	0.15	0	0	0.66	0	0	0	0	0	0	0.5	0	0.1	0	0.03	0	0	0	0	0	0	58
108	0	0.11	0	0	0.66	0	0	0.32	1.3	0	0	0	0.14	0	0	0	0.05	0	0	0	0	0	0	0	36
109	0.07	0	0	0	0.26	2.5	0.65	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0.23	0	0	1.2	36
110	0	0	0	0	0	0	0.22	1.2	0.12	0	0	0	0	0	0	0.13	0	0.05	0	0	0	0.25	0	0	50
111	0	0.66	0.36	0	1.23	0	0.6	0	0.15	0.3	0.1	0	0	0	0.2	0	0	0	0	0.5	0	0	0	0	62
112	0.6	0	0	0	0	0	0	0	1.5	0	0	0	0.25	0	0	0	0.01	0	0	0	0	0	0	0	88
113	0	0	0	0	0	0	0.8	1.11	0	0	0	0	0	0	0	0.23	0	0.05	0	0	0	0	0	0.25	44
114	0	0.65	0.1	0	1.22	0	0	0	0	0	0.2	0.2	0	0	0	0	0	0	0	0	0.01	0.26	0	0	74
115	0	0	0	0	0	0	0.5	0.12	0.23	0	0	0.12	0.36	0	0	0	0	0	0	0.6	0	0	0	0	70
116	0.3	0	0	0	0	0	0	0.23	0.69	0	0.3	0.15	0	0	0	0.1	0.02	0.01	0	0	0	0	0	0	54
117	0	1.23	0.1	0	0.33	0	0.68	0	0	0	0	0	0	0	0	0.12	0	0.02	0	0	0	0	0	0.55	54
118	0	0	0	0	0	0	0	0	0.33	0.2	0	0	0	0	0	0.01	0	0.01	0	0	0.14	0	0	0	76
119	0.4	0	.0.16	0.25	0	0.78	0.81	1.25	0.12	0.1	0	0.79	0	0	0.6	0	0	0.1	0	0.12	0	0	1.2	0	32
120	0	0.12	0	0	0.32	1.25	0	0.49	0.23	0.21	0.49	0	0.45	0	0	0.1	0	0.2	0.25	0	0	0	0	0	28
121	0	0	0	0	0	0	1.23	0.36	0	0	0.1	0	0	0	0	0	0.02	0.7	0	0	0	0	0	0.44	0
122	0.3	0	0	0	0	1.23	0.5	0	0.9	0	0	0	0	0	0	0	0	0.6	0	0	0	0	0	0	2
123	0	0	0.6	0	0.62	0	0.756	1.23	0	0	0	0.11	0.15	0	0.15	0	0	0	0	0.23	0.15	0.23	0	0	62
124	0	0	0	0.66	0	0	1.23	0.25	0.7	0	1.01	0	0	0	0	0	0.12	0	0.12	0	0	0	0	0	58
125	0.2	1.23	0	0	0	0	0	0.56	0	0.513	0.3	0.83	0	0	0	0.1	0	0.6	0	0	0	0	0	0.55	8
126	0.1	0	0.06	0	0	1.56	0	0.2	0.14	0	0	0	0	0	0	0	0	0.04	0	0	0	0	1.4	0	54
127	0.5	0	0	0.12	1.23	0	0.12	1.22	0.12	0.12	0.122	0.45	0	0	0	0	0	0	0	0.35	0.01	0	0	0	70

APPENDIX D: SAMPLE DATASET 1 FOR REGRESSION AND NEURAL NETWORK TRAINING, TESTING AND VALIDATION OF IRI

S.N	AC1	AC2	AC3	BE1	BE2	BE3	D1	D2	D3	F1	F2	F3	G1	G2	G3	H1	H2	H3	IRI
1	0	0.08	0	0.23	0	0.45	0	0.1	0	0	0	0	0	0	0	0	0	0	1.13
2	0.42	0.06	0.56	0.12	0.46	0.15	0	0.62	0	0	0	0	0	0.05	0	0	0	0	3.75
3	0	0.66	0	0.32	0.66	0	0	0.43	0.12	0	0	0	0	0	0	0.11	0.66	0	3.48
4	0.25	1.1906	0.662	0	0.15	0.32	0.021	0.216	0	0	0	0	0	0	0	0	0	0	2.85
5	0	0	0	0.55	0.33	0.64	0.21	0.55	0.05	0	0	0	0	0.15	0.66	0	0.66	0	3.94
6	0.21	1.05	0.45	0	0	0.12	0.3	0.66	1.21	0	0	0	0	0	0	0.23	0	0	5.83
7	0	0	0	0	0.96	1.35	0	0.55	0	0	0.01	0	0	0.08	0	0	0	0.6	4.47
8	0	0.14	0.98	0.66	0.32	1.42	0.66	0.36	0	0	0	0	0	0	0	0	0	0	4.19
9	0.66	0.7	0.66	0	0	0.67	0.6	0	0	0	0	0	0	0	0	0	0	0	4.32
10	1.2	0.13	0.262	0.1	0.1	0.27	0.023	0.12	0.23	0	0.01	0	0	0	0	0	0	0	3.51
11	1.308	0.712	0.3976	0	0	0	0.4	0.12	0	0	0	0	0	0	0	0	0	0	2.58
12	0.515	0	0.28	0.68	0	1.62	0.362	0	0	0	0.165	0	0	0	0.165	0	0.51	0	3.38
13	0	0.32	0	0	0	0	0.51	0	0.33	0	0.07	0	0	0	0.6456	0.1	0	0	4.22
14	0.3	0.67	0.2	0.89	0.23	0	0	0.52	0.15	0	0	0	0	0	0.63	0.11	0.85	0	4.63
15	1.2	0	0	0.23	0	0	0.2	0.12	0	0.04	0	0.02	0	0	0	0	0.22	0.3	4.55
16	0	0.11	0.15	0	0.51	0.623	0.71	0.031	0.3	0	0	0	0	0	0	0	0	0	4.18
17	0.874	0.26	0.15	0	0.6	0.85	0	0.16	0	0.007	0	0	0	0	0	0	0	0	4.01
18	0	0.321	0	0	0.75	0.23	0	0	1	0.66	0	0	0	0.23	0.15	0.56	0	0.6	4.84
19	0	0.9	0.3	0	0.23	0.76	0	0.3	0.91	0	0	0	0	0.33	0	0.23	0	0	6.25
20	0.1	0.49	0.3	0	0.7	0.09	0.147	0	0.6	0.005	0	0	0	0	0	0	0	0.8	6.71
21	0	2.13202	0	0.12	0.2	0.501	0.6	0.6	0.3	0	0	0	0	0	0.2	0	0	0	5.42
22	0	0.23	0	0	0.58	0.26	0	0	0.23	0	0	0	1.2	0	0.33	0.23	0.14	0	4.27
23	1.2	1.1	3.33	0	1.4	0	0	0.79	0	0	0	0	0	0	0	0	0	0	4.48
24	0.45	1.036	0.22	0	2.6	0	0.74	0.58	0.345	0	0	0	0	0	0	0	0	0	3.07
25	0.6	0.6	0.12	0.15	0	0.14	0	0	0	0	0	0	0	0	0.001	0	0	0	2.34
26	0.05	0.32	0	0	1.46	0	0	1.24	0	0	0	0	0	0	0	0	0	0	3.15
27	0.6	0.6	0.12	0.15	0	0.14	0	0	0	0	0	0	0	0	0.001	0	0	0	2.35
28	1.36	0	0.11	0	0.145	0.22	0.12	0	0.62	0	0	0	0	0	0	0	0	0	6.2
29	0	0	0.32	0	0	0.2	0.12	0	0.23	0.09	0.02	0.02	0.11	0.23	0	0.11	0.12	0	6.9
30	0.12	0.6	0.42	0	0.06	0.66	0	0	1.17	0.01	0	0	0	0.3	0	0	0	0	7.77
31	0.98	0	0	0.26	1.42	0	0.12	0.212	0	0	0	0.06	0	0.15	0.56	0	0.65	0	7.22

S.N	AC1	AC2	AC3	BE1	BE2	BE3	D1	D2	D3	F1	F2	F3	G1	G2	G3	H1	H2	H3	IRI
32	0.33	0.6	1.521	0	0	0	0.051	0	0	0	0	0.08	0	0	0.15	0	0	0	8.41
33	0	0	1.2	0	0.78	0.11	0	0	0.2	0	0.2	0	0	0	0.33	0	0	0.32	8.77
34	1.476	0.6	0.95	0.32	0.62	1.41	0	1.166	0.126	0	0.01	0.12	0	0.05	0.15	0	0.2	0.2	9.22
35	0.56	0.5	1.26	0.66	0	0.08	0	0.48	0	0	0	0	0	0	0	0	0	0	2.40
36	0	1.11	0	0.11	0.67	0.77	0	0.2	0.23	0.04	0.09	0	0	0	0.22	0.15	0	0	8.12
37	1	0	1.01	0.23	0	0.32	0.2015	0.5	1.12	0	0	0	0	0	0	0	0	0	3.5
38	0	0.66	0.6	0.78	0	0	0.6	0	0.1	0	0	0.2	0	0.11	0	0	0.15	0	11.21
39	1.2	0.6	1.15	0	0	0.3	0.78	0.25	1.02	0	0	0.23	0	0	0	0.01	0.3	0	12.52
40	0	0	0	0.15	0	0.11	0.66	0.66	0	0	0	0	0	0	0	0	0.28	0	2.31
41	0.15	0.459	0.63	0	0	0.4	0	0.63	0.15	0	0	0	0	0	0.15	0.33	0	0	2.05
42	0	0.015	0.0321	0	0.6	0	0	0.26	0	0	0	0	0	0	0	0	0	0	2.12
43	0.05	0	0.756	0	0.31	0	0.68	0	0.23	0	0	0	0	0	0	0	0	0	1.90
44	0	0	0	0.2	0	0.09	0	0	0	0.01	0	0	0.3	0	0	0	0.2	0	1.52
45	1	1.25	0.645	0.66	0.23	0	0.2	0.5	0	0	0	0	0	0.99	0.19	0	0	0.5	6.05
46	0	0.3	0.6	0.6	0	0.4	0	0	0.2	0	0.12	0	0	0	0	0	0	0.08	6.01
47	0	0.63	1.38	0	0	0.25	0.126	0	0	0	0.1	0	0	0.33	0	0	0	0	5.85
48	0.1	0.2	0.2	0	0	1.56	0	0	0	0	0	0.04	0	0	0	0	1.4	0	6.35
49	0.23	1.32	1.83	0	0.11	0	0.25	0	2.22	0	0	0	0	0	0	0	1.2	0	6.5
50	0.056	1.42	0.65	0	2.118	2.4	0.23	0	0	0.05	0.02	0	0	0	0	0.78	0	0	6.45
51	0	1.49	1.03	0	0.4	0.7	0	0.3	0.16	0	0	0	0	0	0.08	0	0.15	0	6.7
52	0	1.8	1.79	0	0	0	0	0	1.85	0	0.02	0	0	0.48	0	0	0	0	6.15
53	0.71	0.6	0	0	2.16	0.512	0	0.76	0.6	0	0	0	0	0	0.99	0.85	0	1.56	7.15
54	0	0.93	0	0.75	3.64	0	0.74	0	0	0	0	0.6	0	0	0.26	0	0	0.33	7.62
55	0.45	0	0.95	1.115	0	0.45	0	0	0	0	0.22	0	0	0	0	0	0	0	7.65
56	1.5	2.4	0	0.1	1.2	0.1	0	0	0	0	0.01	0.05	0	0	0	0	0	0	7.56
57	0	0.5	1.8	0	0.4	0	1.8	0	0	0	0	0	0	0	0.6	0	2.6	0	7.93
58	0	0.56	0.58	0	0	1.2	0	0.65	0.12	0.15	0	0	0	0	..45	0	1.25	0	7.61
59	0	3.8	0	0.32	0	0	0	0	0	0	0	1.01	0	0	0	0	0	1.55	8.86
60	1	0.15	0.8	0	0.33	1.98	0.15	0	0.44	0	0	0.08	0	0.3	0	0.47	0	0	8.24
61	0.89	0	0.63	0	2.75	0	0	0.85	0.717	0	0	0.06	0.15	0.22	0	0	0.66	0	11.53
62	0	0	4.4	0	0	0	0	0	0.4	0	0	0	0	0	2	0	0	0	8.93
63	0	0.6	1.12	0	0	1.5	0	0	0.23	0	0.09	0	0	0	0	0	0	0	6.64
64	0	0	1.6	0	1.35	0	0	0	0	0.6	0	0.06	0.66	0	0.23	0.55	0	0	10.27
65	0	1.91	0.22	0	0.6	0.26	0.43	0	0.15	0.01	0	0.3	0	0	0	0	0	0	12.5
66	0.74	1.12	0.56	0	1.14	0	0.816	2.28	0	0.09	0	0.11	0.3	0	0.74	0	0	0.66	9.15
67	0.37	0	1.05	1.455	0.23	0	0	0	0.45	0	0	0.1	0	0	0	0	2.3	0	9.05
68	0.65	1.2	1.53	0	1	0.5	0.51	0	0	0	0.33	0	0	0	0.32	0	0.65	0	9.97
69	0.95	0.9	12.5	0	1.22	0	0.15	2.6	0.15	0	0.15	0	0	0.15	0	0	0	0	9.15
70	0	1.36	2.48	0	1.28	2.42	0.72	0.52	0	0	0.62	0	0	0	0	0	2.48	0	9.99
71	2.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.89
72	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0.12	1.2

S.N	AC1	AC2	AC3	BE1	BE2	BE3	D1	D2	D3	F1	F2	F3	G1	G2	G3	H1	H2	H3	IRI
73	0.15	0	1.63	0	0	0	0.5	0.15	0	0	0.23	0	0.36	0	0.25	0	0	0.78	7.1
74	0.45	0	0	0	0.23	0	0.32	0.62	0.556	0.31	0	0	0	0	0	0	0.45	0	7.23
75	3.05	0.48	0.6	0.6	0.23	0.17	0.12	0	0.37	0.4	0	0	0	0	0	0	0	0	6.98
76	0.8	0.8	0.33	0	0.62	0	0	0.3	0.15	0	0	0	0	0.15	0.56	0	0	0.5	6.88
77	1.23	0.36	0	0	0	0	0	0.1	0	0	0.02	0.7	0	0	0	0	0	0.44	16.25
78	0.8	0	0.9	0	0	1.23	0	0	0	0	0	0.6	0	0	0	0	0	0	14.15
79	0	1.515	0	0.89	1.1	2.1	0	0.22	0.95	0	0.05	0	0	0.95	0	0	0	0	7.25
80	0.6	0	0.765	0	0.85	0.51	0.656	0.6	0.15	0	0.08	0	0	0	0.96	0	0.6	0	7.15
81	0.27	0.55	0.6	0	0	3.75	0.215	0.71	0	0	0.07	0	0	0.55	0	0	0.18	0	5.46
82	0.3	0.23	0.69	0	0	0	0	0.3	0.15	0.1	0.02	0.01	0	0	0	0	0	0	6.38
83	0.68	1.23	0.1	0	0.33	0	0	0	0	0.12	0	0.02	0	0	0	0	0	0.55	6.11
84	0.54	2.2	0.96	0	0	4.56	0.78	0	0	0	0.15	0	0	0	0	0	0	0	7.99
85	1.2	0	0.9	0	0	0	0.36	0.4	0	0	0.2	0	0.36	0	0	0.15	0	0.6	7.22
86	0.64	0	0	0	0.18	0	0	0.145	0	0	0	0	0	0	0	0	0	0	2.48
87	0	1.11	0.66	0	0	0	0.75	0.15	0.3	0	0	0	0	0.45	0.05	0	0	0	6.12
88	1.842	0	1.28	0	1.96	0	0	0	0	0	0	0	0	0	0.82	0	2.42	0	6.25
89	3	0	3.2	0	0.45	0	0	1.5	0	0	0	0	0	0	0	0	0	0	6.31
91	0.25	0.54	1.15	0	0.6	0	0.9	0.26	0	0.3	0	0	0.66	0	0	0.11	0	0	5.18
92	0	1.8	1.79	0	0	0	0	0	1.85	0	0.02	0	0	0.48	0	0	0	0	5.82
93	0.45	0	0.11	0	0	0	0	0.15	0.14	0	0	0.07	0	0	0	0	0	0.15	6.12
94	1.02	0.5	4.06	0	0	2.1	0.17	0.11	0	0	0	0	0	0	0.52	0	0	0	7.28
95	0.36	1.2	0.81	0	0.99	0	0.59	0	0.355	0	0	0	0	0	0.6	0	0	0.66	9.15
96	0	0	1.96	0	0	1.5	0	1.16	1.35	0	0	0	0	0	0.23	0	0	0	9.18
97	1.2	0.7	0.25	0	1.2	0	0.78	0	0.45	1.2	0.05	0	0	0	0	0	0.2	0.3	10.95
98	0.6	1.2	0.8	0.8	0	0	0.92	0.6	0	0	0	0.24	0	0	0	0	0	0	12.22
99	0	0.9	1.35	0	0	0.2	0	0	0.12	0	0.15	0	0	0	0	0	0.52	1.3	10.22
100	0.3	0	1.05	0	1.23	0	0	0.68	0	0	0	0.26	0	0	0	0	0	0.96	12.23
101	1.5	1.96	0.2	1.65	0	0.15	0	0	0	0	0	0.15	0	0	0	0	0	0	9.25
102	0.665	3.05	0.995	0	0.11	0	0	0	0	0	0.15	0	0	0	0	0	0	0	9.65
103	0	0.43	1.3	0.14	0.66	0	0	0	0	0	0.05	0	0	0	0	0	0	0	9.15
104	0	2	0	0	0.5	0.65	0.56	0	0.99	0.18	0	0	0	0.12	0	0	0	0	8.15
105	0	1.35	2	0	0	1.8	0	0.45	0.56	0.3	0	0	0	0	0	0	1.26	0	8.47
106	0	1.9	0	0	2.6	1.45	0	0.15	0.74	0	0	0	0	0	0.48	0	0	0	7.15
107	0.8	1.11	0	0	0	0	0	0	0	0.23	0	0.05	0	0	0	0	0	0.25	7.8
108	0	11.97	2.99	0	1.22	0	0	0.43	0	0	0.25	0	0	0	0	0	2.97	0	7.56
109	0.22	1.2	0.12	0	0	0	0	0	0	0.13	0	0.05	0	0	0	0.25	0	0	6.52
110	0.6	0	0	0	0	0.45	0	0	0	0	0.25	0	0	0	0	0	0	0	7.9
111	0	0	0.4	0.15	0.7	0.9	0	0.23	0	0.6	0	0	0	0	0	0	0	0	6.15
112	0.21	0	0	0.454	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.56
113	0.62	0.66	0.662	0	0	0.54	0.51	0.6	0	0	0	0.08	0	0	0	0.451	0	0	8.15
114	0	0.65	1.8	0	2.1	0	0.21654	0.23	0.6	0	0	0	0	0	0.23	0	0	0	8.05

APPENDIX E: SAMPLE DATASET 2 FOR REGRESSION AND NEURAL NETWORK TRAINING, TESTING AND VALIDATION OF IRI

S.N	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	IRI
1	0	0	0	0	0	0	0	0.08	0	0	0.1	0	0.23	0	0.45	0	0	0	0	0	0	0	0	0	1.13
2	0	0	0.56	0	0.15	0.15	0.42	0.06	0	0	0.62	0	0.12	0.31	0	0	0	0	0	0.05	0	0	0	0	3.75
3	0	0.66	0	0.32	0	0	0	0	0	0	0.43	0.12	0	0.66	0	0	0	0	0	0	0	0.11	0.66	0	3.48
4	0.25	0	0	0	0.15	0	0	1.1906	0.662	0.021	0.216	0	0	0	0.32	0	0	0	0	0	0	0	0	0	2.85
5	0	0	0	0.55	0	0	0	0	0	0.21	0.55	0.05	0	0.33	0.64	0	0	0	0	0.15	0.66	0	0.66	0	3.94
6	0	0.25	0	0	0	0	0.21	0.8	0.45	0.3	0.66	1.21	0	0	0.12	0	0	0	0	0	0	0.23	0	0	5.83
7	0	0	0	0	0.96	0.12	0	0	0	0	0.55	0	0	0	1.23	0	0.01	0	0	0.08	0	0	0	0.6	4.47
8	0	0	0.32	0.66	0	0.15	0	0.14	0.66	0.66	0.36	0	0	0.32	1.27	0	0	0	0	0	0	0	0	0	4.19
9	0	0.58	0.66	0	0	0	0.66	0.12	0	0.6	0	0	0	0	0.67	0	0	0	0	0	0	0	0	0	4.32
10	1.2	0.13	0	0	0.1	0	0	0	0.262	0.023	0.12	0.23	0.1	0	0.27	0	0.01	0	0	0	0	0	0	0	3.51
11	0	0.55	0	0	0	0	1.308	0.162	0.3976	0.4	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0	2.58
12	0	0	0.28	0	0	0.66	0.515	0	0	0.362	0	0	0.68	0	0.96	0	0.165	0	0	0	0.165	0	0.51	0	3.38
13	0	0	0	0	0	0	0	0.32	0	0.51	0	0.33	0	0	0	0	0.07	0	0	0	0.64	0.1	0	0	4.22
14	0	0.15	0	0.89	0	0	0.3	0.52	0.2	0	0.52	0.15	0	0.23	0	0	0	0	0	0	0.63	0.11	0.85	0	4.63
15	1.2	0	0	0.23	0	0	0	0	0	0.2	0.12	0	0	0	0	0.04	0	0.02	0	0	0	0	0.22	0.3	4.55
16	0	0	0	0	0	0.32	0	0.11	0.15	0.71	0.031	0.3	0	0.51	0.303	0	0	0	0	0	0	0	0	0	4.18
17	0.52	0	0	0	0	0	0.354	0.26	0.15	0	0.16	0	0	0.6	0.85	0.007	0	0	0	0	0	0	0	0	4.01
18	0	0.211	0	0	0	0.23	0	0.11	0	0	0	1	0	0.75	0	0.66	0	0	0	0.23	0.15	0.56	0	0.6	4.84
19	0	0	0	0	0.23	0.56	0	0.9	0.3	0	0.3	0.91	0	0	0.2	0	0	0	0	0.33	0	0.23	0	0	6.25
20	0	0.24	0	0	0.6	0	0.1	0.25	0.3	0.147	0	0.6	0	0.1	0.09	0.005	0	0	0	0	0	0	0	0.8	6.71
21	0	2.1	0	0	0	0.3	0	0.03202	0	0.6	0.6	0.3	0.12	0.2	0.201	0	0	0	0	0	0.2	0	0	0	5.42
22	0	0.23	0	0	0.51	0.15	0	0	0	0	0	0.23	0	0.07	0.11	0	0	0	1.2	0	0.33	0.23	0.14	0	4.27
23	1.2	0	0.9	0	1.4	0	0	1.1	2.43	0	0.79	0	0	0	0	0	0	0	0	0	0	0	0	0	4.48
24	0	0	0	0	0	0	0.45	1.036	0.22	0.74	0.58	0.345	0	2.6	0	0	0	0	0	0	0	0	0	0	3.07
25	0	0.3	0	0.15	0	0	0.6	0.3	0.12	0	0	0	0	0	0.14	0	0	0	0	0	0.001	0	0	0	2.34
26	0	0.32	0	0	0	0	0.05	0	0	0	1.24	0	0	1.46	0	0	0	0	0	0	0	0	0	0	3.15
27	0	0.3	0	0.15	0	0	0.6	0.3	0.12	0	0	0	0	0	0.14	0	0	0	0	0	0.001	0	0	0	2.35
28	1.23	0	0	0	0	0	0.13	0	0.11	0.12	0	0.62	0	0.145	0.22	0	0	0	0	0	0	0	0	0	6.2
29	0	0	0.32	0	0	0.2	0	0	0	0.12	0	0.23	0	0	0	0.09	0.02	0.02	0.11	0.23	0	0.11	0.12	0	6.9
30	0	0	0.23	0	0	0.66	0.12	0.6	0.19	0	0	1.17	0	0.06	0	0.01	0	0	0	0.3	0	0	0	0	7.77
31	0.98	0	0	0	0.53	0	0	0	0	0.12	0.212	0	0.26	0.89	0	0	0	0.06	0	0.15	0.56	0	0.65	0	7.22
32	0	0	1.2	0	0	0	0.33	0.6	0.321	0.051	0	0	0	0	0	0	0	0.08	0	0	0.15	0	0	0	8.41
33	0	0	1.2	0	0	0	0	0	0	0	0	0.2	0	0.78	0.11	0	0.2	0	0	0	0.33	0	0	2.05	8.77
34	0.11	0	0.95	0	0.62	0.33	1.366	0.6	0	0	1.166	0.126	0.32	0	1.08	0	0.01	0.12	0	0.05	0.15	0	0.2	0.2	9.22
35	0	0	0	0.66	0	0	0.56	0.5	1.26	0	0.48	0	0	0	0.08	0	0	0	0	0	0	0	0	0	2.40
36	0	1.11	0	0.11	0.12	0	0	0	0	0	0.2	0.23	0	0.55	0.77	0.04	0.09	0	0	0	0.22	0.15	0	0	8.12
37	0	0	1.01	0.23	0	0.32	1	0	0	0.2015	0.5	1.12	0	0	0	0	0	0	0	0	0	0	0	0	3.5

S.N	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	IRI
38	0	0.66	0	0.12	0	0	0	0	0.6	0.6	0	0.1	0.66	0	0	0	0	0.2	0	0.11	0	0	0.15	0	11.21
39	1.2	0	0.3	0	0	0	0	0.6	0.85	0.78	0.25	1.02	0	0	0.3	0	0	0.23	0	0	0	0.01	0.3	0	12.52
40	0	0	0	0.15	0	0	0	0	0	0.66	0.66	0	0	0	0.11	0	0	0	0	0	0	0	0.28	0	2.31
41	0	0	0	0	0	0.4	0.15	0.459	0.63	0	0.63	0.15	0	0	0	0	0	0	0	0	0.15	0.33	0	0	2.05
42	0	0	0	0	0.6	0	0	0.015	0.0321	0	0.26	0	0	0	0	0	0	0	0	0	0	0	0	0	2.12
43	0.05	0	0	0	0.08	0	0	0	0.756	0.68	0	0.23	0	0.23	0	0	0	0	0	0	0	0	0	0	1.90
44	0	0	0	0.2	0	0.09	0	0	0	0	0	0	0	0	0	0.01	0	0	0.3	0	0	0	0.2	0	1.52
45	0	0.65	0	0	0	0	1	0.6	0.645	0.2	0.5	0	0.66	0.23	0	0	0	0	0	0.99	0.19	0	0	0.5	6.05
46	0	0.3	0	0.6	0	0.4	0	0	0.6	0	0	0.2	0	0	0	0	0.12	0	0	0	0	0	0	0.08	6.01
47	0	0	0	0	0	0	0	0.63	1.38	0.126	0	0	0	0	0.25	0	0.1	0	0	0.33	0	0	0	0	5.85
48	0.1	0	0.06	0	0	1.56	0	0.2	0.14	0	0	0	0	0	0	0	0	0.04	0	0	0	0	1.4	0	6.35
49	0	0	0	0	0	0	0.23	1.32	1.83	0.25	0	2.22	0	0.11	0	0	0	0	0	0	0	0	1.2	0	6.5
50	0	0	0.5	0	1.4	2.4	0.056	1.42	0.15	0.23	0	0	0	0.718	0	0.05	0.02	0	0	0	0	0.78	0	0	6.45
51	0	0	0.8	0	0.4	0.7	0	1.49	0.23	0	0.3	0.16	0	0	0	0	0	0	0	0	0.08	0	0.15	0	6.7
52	0	0.8	0	0	0	0	0	1	1.79	0	0	1.85	0	0	0	0	0.02	0	0	0.48	0	0	0	0	6.15
53	0.11	0	0	0	0.96	0.512	0.6	0.6	0	0	0.76	0.6	0	1.2	0	0	0	0	0	0	0.99	0.85	0	1.56	7.15
54	0	0.8	0	0.75	2.91	0	0	0.13	0	0.74	0	0	0	0.73	0	0	0	0.6	0	0	0.26	0	0	0.33	7.62
55	0	0	0	0.555	0	0	0.45	0	0.95	0	0	0	0.56	0	0.45	0	0.22	0	0	0	0	0	0	0	7.65
56	0	2.4	0	0	1.2	0	1.5	0	0	0	0	0	0.1	0	0.1	0	0.01	0.05	0	0	0	0	0	0	7.56
57	0	0	1.2	0	0	0	0	0.5	0.6	1.8	0	0	0	0.4	0	0	0	0	0	0	0.6	0	2.6	0	7.93
58	0	0	0	0	0	0	0	0.56	0.58	0	0.65	0.12	0	0	1.2	0.15	0	0	0	0	..45	0	1.25	0	7.61
59	0	1.45	0	0	0	0	0	2.35	0	0	0	0	0.32	0	0	0	0	1.01	0	0	0	0	0	1.55	8.86
60	0	0	0	0	0	0.48	1	0.15	0.8	0.15	0	0.44	0	0.33	1.5	0	0	0.08	0	0.3	0	0.47	0	0	8.24
61	0	0	0.63	0	2.6	0	0.89	0	0	0	0.85	0.717	0	0.15	0	0	0	0.06	0.15	0.22	0	0	0.66	0	11.53
62	0	0	1.6	0	0	0	0	0	2.8	0	0	0.4	0	0	0	0	0	0	0	0	2	0	0	0	8.93
63	0	0.6	0	0	0	1.5	0	0	1.12	0	0	0.23	0	0	0	0	0.09	0	0	0	0	0	0	0	6.64
64	0	0	0.9	0	0	0	0	0	0.7	0	0	0	0	1.35	0	0.6	0	0.06	0.66	0	0.23	0.55	0	0	10.27
65	0	1.65	0	0	0	0.26	0	0.26	0.22	0.43	0	0.15	0	0.6	0	0.01	0	0.3	0	0	0	0	0	0	12.5
66	0	0.52	0	0	0.15	0	0.74	0.6	0.56	0.816	2.28	0	0	0.99	0	0.09	0	0.11	0.3	0	0.74	0	0	0.66	9.15
67	0.04	0	1.05	1	0	0	0.33	0	0	0	0	0.45	0.455	0.23	0	0	0	0.1	0	0	0	0	2.3	0	9.05
68	0	1.2	1.3	0	1	0.05	0.65	0	0.23	0.51	0	0	0	0	0.45	0	0.33	0	0	0	0.32	0	0.65	0	9.97
69	0	0.9	0	0	0	0	0.95	0	12.5	0.15	2.6	0.15	0	1.22	0	0	0.15	0	0	0.15	0	0	0	0	9.15
70	0	0	2.48	0	0	2.42	0	1.36	0	0.72	0.52	0	0	1.28	0	0	0.62	0	0	0	0	0	2.48	0	9.99
71	0	0	0	0	0	0	2.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.89
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0	0.12	1.2
73	0	0	1.26	0	0	0	0.15	0	0.37	0.5	0.15	0	0	0	0	0	0.23	0	0.36	0	0.25	0	0	0.78	7.1
74	0.45	0	0	0	0	0	0	0	0	0.32	0.62	0.556	0	0.23	0	0.31	0	0	0	0	0	0	0.45	0	7.23
75	0.04	0	0	0.6	0	0	3.01	0.48	0.6	0.12	0	0.37	0	0.23	0.17	0.4	0	0	0	0	0	0	0	0	6.98
76	0	0.8	0	0	0.62	0	0.8	0	0.33	0	0.3	0.15	0	0	0	0	0	0	0	0.15	0.56	0	0	0.5	6.88
77	0	0	0	0	0	0	1.23	0.36	0	0	0.1	0	0	0	0	0	0.02	0.7	0	0	0	0	0	0.44	16.25
78	0.3	0	0	0	0	1.23	0.5	0	0.9	0	0	0	0	0	0	0	0	0.6	0	0	0	0	0	0	14.15
79	0	1.2	0	0	1.1	2.1	0	0.315	0	0	0.22	0.95	0.89	0	0	0	0.05	0	0	0.95	0	0	0	0	7.25
80	0	0	0	0	0.85	0.15	0.6	0	0.765	0.656	0.6	0.15	0	0	0.36	0	0.08	0	0	0	0.96	0	0.6	0	7.15
81	0	0	0	0	0	0	0.27	0.55	0.6	0.215	0.71	0	0	0	3.75	0	0.07	0	0	0.55	0	0	0.18	0	5.46
82	0.3	0	0	0	0	0	0	0.23	0.69	0	0.3	0.15	0	0	0	0.1	0.02	0.01	0	0	0	0	0	0	6.38
83	0	1.23	0.1	0	0.33	0	0.68	0	0	0	0	0	0	0	0	0.12	0	0.02	0	0	0	0	0	0.55	6.11
84	0	0	0.96	0	0	4.56	0.54	2.2	0	0.78	0	0	0	0	0	0	0.15	0	0	0	0	0	0	0	7.99

S.N	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	IRI
85	0	0	0	0	0	0	1.2	0	0.9	0.36	0.4	0	0	0	0	0	0.2	0	0.36	0	0	0.15	0	0.6	7.22
86	0	0	0	0	0.18	0	0.64	0	0	0	0.145	0	0	0	0	0	0	0	0	0	0	0	0	0	2.48
87	0	1.11	0	0	0	0	0	0	0.66	0.75	0.15	0.3	0	0	0	0	0	0	0	0.45	0.05	0	0	0	6.12
88	1.842	0	1.28	0	1.28	0	0	0	0	0	0	0	0	0.68	0	0	0	0	0	0	0.82	0	2.42	0	6.25
89	2.5	0	0	0	0	0	0.5	0	3.2	0	1.5	0	0	0.45	0	0	0	0	0	0	0	0	0	0	6.31
90	0	0	0.8	0	0.4	0.7	0	1.49	0.23	0	0.3	0.16	0	0	0	0	0	0	0	0	0.08	0	0.15	0	6.55
91	0	0	0	0	0	0	0.25	0.54	1.15	0.9	0.26	0	0	0.6	0	0.3	0	0	0.66	0	0	0.11	0	0	5.18
92	0	0.8	0	0	0	0	0	1	1.79	0	0	1.85	0	0	0	0	0.02	0	0	0.48	0	0	0	0	5.82
93	0	0	0	0	0	0	0.45	0	0.11	0	0.15	0.14	0	0	0	0	0	0.07	0	0	0	0	0	0.15	6.12
94	0.9	0	2.1	0	0	2.1	0.12	0.5	1.96	0.17	0.11	0	0	0	0	0	0	0	0	0	0.52	0	0	0	7.28
95	0	1.2	0	0	0.99	0	0.36	0	0.81	0.59	0	0.355	0	0	0	0	0	0	0	0	0.6	0	0	0.66	9.15
96	0	0	0.6	0	0	0	0	0	1.36	0	1.16	1.35	0	0	1.5	0	0	0	0	0	0.23	0	0	0	9.18
97	1.2	0.2	0	0	1.2	0	0	0.5	0.25	0.78	0	0.45	0	0	0	1.2	0.05	0	0	0	0	0	0.2	0.3	10.95
98	0	0	0	0.8	0	0	0.6	1.2	0.8	0.92	0.6	0	0	0	0	0	0	0.24	0	0	0	0	0	0	12.22
99	0	0.9	1.2	0	0	0.2	0	0	0.15	0	0	0.12	0	0	0	0	0.15	0	0	0	0	0	0.52	1.3	10.22
100	0	0	0.45	0	0	0	0.3	0	0.6	0	0.68	0	0	1.23	0	0	0	0.26	0	0	0	0	0	0.96	12.23
101	0	1.56	0	1.65	0	0	1.5	0.4	0.2	0	0	0	0	0	0.15	0	0	0.15	0	0	0	0	0	0	9.25
102	0	2.45	0.85	0	0	0	0.665	0.6	0.145	0	0	0	0	0.11	0	0	0.15	0	0	0	0	0	0	0	9.65
103	0	0.11	0	0	0.66	0	0	0.32	1.3	0	0	0	0.14	0	0	0	0.05	0	0	0	0	0	0	0	9.15
104	0	0.8	0	0	0.5	0	0	1.2	0	0.56	0	0.99	0	0	0.65	0.18	0	0	0	0.12	0	0	0	0	8.15
105	0	1.2	0	0	0	0	0	0.15	2	0	0.45	0.56	0	0	1.8	0.3	0	0	0	0	0	0	1.26	0	8.47
106	0	1.9	0	0	2.6	0	0	0	0	0	0.15	0.74	0	0	1.45	0	0	0	0	0	0.48	0	0	0	7.15
107	0	0	0	0	0	0	0.8	1.11	0	0	0	0	0	0	0	0.23	0	0.05	0	0	0	0	0	0.25	7.8
108	0	7.65	0	0	0	0	0	4.32	2.99	0	0.43	0	0	1.22	0	0	0.25	0	0	0	0	0	2.97	0	7.56
109	0	0	0	0	0	0	0.22	1.2	0.12	0	0	0	0	0	0	0.13	0	0.05	0	0	0	0.25	0	0	6.52
110	0	0	0	0	0	0.45	0.6	0	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	7.9
111	0	0	0.4	0	0.7	0.9	0	0	0	0	0.23	0	0.15	0	0	0.6	0	0	0	0	0	0	0	0	6.15
112	0	0	0	0	0	0	0.21	0	0	0	0	0	0.454	0	0	0	0	0	0	0	0	0	0	0	0.56
113	0	0	0.262	0	0	0.54	0.62	0.66	0.4	0.51	0.6	0	0	0	0	0	0	0.08	0	0	0	0.451	0	0	8.15
114	0	0.65	0	0	0.6	0	0	0	1.8	0.21654	0.23	0.6	0	1.5	0	0	0	0	0	0	0.23	0	0	0	8.05
115	0	0	0	0	2.1	0	0	1.3	0	0	0.03	1.3	0	0	0	0	0	0	0	0.15	0	0.15	0	0	8.35
116	0	0.15	0.5	0	0	0	0	0.62	1.3	0.9	0.74	0	0	0.65	0	0.3	0	0	0	0	0	0	0	0	8.40
117	0	0	0	2.1	0	0	1.1	1.1	2.3	0	0	1	0	1.2	0	0	0	0	0	0	0	0	0	0	8.42
118	0	0.56	0	0	1.2	0	0.21	0.23	0.53	0	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	2.93
119	0	1.2	0	0	0	0	0.26	0	0.12	0	0	0	0.151	0	0	0	0	0	0	0	0	0	0	0	3.4
120	0	0	0	0	0	0	0.291	0	0.17	0.1232	0.515	0.7	0	0	0	0	0	0	0	0	0.015	0	0	0	3.51
121	0	0	0	0	0	0	0.47	0	0.12	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0	0	3.04
122	0	0	0	1.23	0	0.23	0	0.15	0	0.2	0.21	0.351	0	0.255	0.565	0	0	0	0	0	0.008	0	0	0	2.59
123	0	0	0.23	0	0	0	0.031	0.12	0.15	0	0	0.32	0.3	0	0	0	0	0	0	0	0	0	0	0	2.89
124	0	0	0	0	0.18	0	0.64	0	0	0	0.145	0	0	0	0	0	0	0	0	0	0	0	0	0	2.53
125	0	0.55	0	0	0	0	0	0	0.15	0	0	0.151	0	0	0	0	0	0	0	0	0	0	0	0	2.65
126	0	0.12	0	0	0	0	0.03	0.2	0	0	0	0	0	0	0	0.12	0	0	0	0.005	0	0	0	0	3.11
127	0	0	0.23	0	0	0	0	0	0.23	0.1	0.15	0.13	0	0	0	0	0	0	0	0	0	0	0.04	0	3.05
128	0	0	0.32	0	0	0	0.242	0	0.432	0.155	0.12	0.15	0.12	0	0	0.02	0	0	0	0	0	0	0	0	3.29
129	0	0	0	0	0	0.11	0	0	0.25	0.15	0.19	0.123	0	0	0	0	0	0	0	0	0	0	0	0	3.96
130	0	0	0.3	0	0	0	0	0	0.342	0.12	0.1	0.11	0	0.11	0	0	0	0	0	0	0	0	0	0	3.22
131	0	0	0.1	0	0	0	0.321	0.21	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0.137	0.11	2.64

APPENDIX F: PCI AND IRI DATA FOR RELATIONSHIP DEVELOPMENT

12	IRI	PCI	S.N	IRI	PCI	S.N	IRI	PCI	S.N	IRI	PCI	S.N	IRI	PCI
1	2.12	87	41	5.03	66	81	2.34	82	121	6.11	54	161	2.83	83
2	1.56	100	42	3.15	60	82	4.45	74	122	6.11	55	162	3.01	78
3	4.52	75	43	3.22	62	83	3.89	82	123	3.65	52	163	2.66	84
4	3.87	70	44	9.14	48	84	6.2	50	124	5.95	58	164	2.38	84
5	6.15	56	45	7.23	48	85	4.25	46	125	4.38	68	165	1.79	88
6	4.53	62	46	8.58	50	86	4.25	40	126	6.85	76	166	3.51	74
7	4.83	64	47	8.65	50	87	7.22	48	127	6.88	74	167	2.78	72
8	6.9	52	48	16.25	0	88	5.41	38	128	4.52	66	168	2.77	84
9	5.44	56	49	14.15	2	89	5.25	32	129	5.46	60	169	2.75	88
10	4.51	68	50	7.25	48	90	9.22	30	130	3.25	64	170	2.59	86
11	5.02	62	51	4.89	50	91	4.56	82	131	3.74	74	171	1.25	90
12	4.01	43	52	5.46	58	92	8.12	40	132	0.8	100	172	3.84	69
13	4.78	64	53	6.38	54	93	6.65	40	133	4.89	64	173	3.85	70
14	4.65	60	54	6.11	58	94	8.55	26	134	2.07	87	174	4.5	67
15	4.25	53	55	5.29	44	95	7.65	20	135	1.76	88	175	4.7	66
16	4.88	56	56	7.22	48	96	2.31	82	136	4.69	64	176	4.66	74
17	4.18	52	57	4.28	92	97	2.05	84	137	2.86	80	177	4.6	66
18	7.79	45	58	3.75	72	98	4.25	66	138	2.85	64	178	5.84	58
19	5.65	48	59	3.48	74	99	2.39	78	139	2.65	56	179	3.84	56
20	6.45	56	60	5.44	78	100	3.85	58	140	4.68	64	180	4.56	60
21	5.08	62	61	3.94	66	101	3.98	72	141	5.26	60	181	5.65	48
22	4.18	58	62	7.45	54	102	2.46	82	142	4.94	62	182	5.1	62
23	6.15	56	63	4.47	66	103	3.05	70	143	4.82	64	183	5.26	58
24	3.01	75.5	64	7.45	58	104	4.94	60	144	7.07	48	184	5.18	68
25	4.73	68	65	4.32	62	105	4.19	62	145	5.34	60	185	1.68	88
26	2.32	82	66	3.51	74	106	2.3	86	146	2.36	58	186	3.25	84
27	2.85	86	67	2.58	80	107	3.59	74	147	6.48	52	187	4.8	78
28	3.77	70	68	3.38	74	108	3.47	68	148	5.16	60	188	2.3	60
29	2.36	60	69	4.22	65	109	2.35	86	149	6.14	54	189	3.11	76
30	2.55	70	70	4.63	64	110	2.96	91	150	5.48	58	190	3.05	78
31	5.23	62	71	4.84	62	111	2.17	82	151	5.18	60	191	3.29	80
32	5.13	60	72	4.18	64	112	3.01	70	152	5.39	58	192	3.96	66
33	3.9	72	73	4.01	74	113	3.18	68	153	6.57	54	193	3.22	74
34	6.18	76	74	4.84	58	114	2.39	84	154	3.89	56	194	4.52	82
35	3.65	82	75	6.25	50	115	2.85	70	155	2.45	92	195	4.98	58
36	2.27	86	76	8.85	46	116	5.38	60	156	4.15	58	196	2.15	82
37	2.87	74	77	5.42	58	117	4.42	62	157	2.1	78	197	3.45	84
38	2.89	76	78	4.27	58	118	3.88	69	158	2.1	80	198	4.56	54
39	4.45	72	79	4.48	57	119	5.32	64	159	2.53	74	199	1.81	92
40	3.58	50	80	3.07	78	120	6.95	50	160	2.81	80	200	2.1	58

S.N	IRI	PCI	S.N	IRI	PCI	S.N	IRI	PCI	S.N	IRI	PCI	S.N	IRI	PCI
201	1.56	86	244	2.48	82	287	4.85	62	330	2.52	74	373	7.12	46
202	2.86	84	245	5.28	52	288	3.02	70	331	5.69	54	374	3.65	72
203	3.55	40	246	6.25	50	289	4.59	56	332	2.17	76	375	1.55	80
204	5.78	62	247	6.31	56	290	4.88	68	333	4.63	64	376	3.52	64
205	6.08	56	248	6.55	48	291	4.45	68	334	7.98	44	377	4.22	46
206	2.41	92	249	6.18	52	292	4.65	68	335	6.56	56	378	2.20	74
207	1.86	86	250	5.82	50	293	5.12	68	336	6.98	54	379	7.25	44
208	1.94	84	251	6.12	48	294	5.55	52	337	6.41	52	380	4.15	66
209	5.4	48	252	7.28	42	295	4.15	60	338	2.85	74	381	4.28	66
210	3.65	86	253	9.15	36	296	5.99	60	339	6.00	56	382	4.65	66
211	2.32	96	254	9.18	36	297	5.48	56	340	4.65	62	383	4.02	60
212	2.58	92	255	12	32	298	2.44	78	341	4.33	70	384	2.99	74
213	3.5	84	256	7.65	28	299	2.85	74	342	4.85	64	385	3.25	68
214	1.90	86	257	7.85	33	300	4.88	60	343	4.14	60	386	2.65	76
215	1.52	88	258	10.28	20	301	4.56	58	344	4.11	60	387	2.01	80
216	4.58	56	259	9.25	35	302	4.98	64	345	4.00	68	388	1.08	90
217	6.01	54	260	13.28	40	303	2.85	72	346	2.68	80	389	5.65	44
218	5.85	60	261	14.85	37	304	4.56	66	347	5.15	58	390	4.98	52
219	6.35	54	262	8.15	42	305	6.15	56	348	5.98	58	391	1.02	84
220	10	48	263	9.56	38	306	7.65	58	349	8.66	30	392	3.05	70
221	6.45	57	264	7.15	46	307	3.5	76	350	12.65	8	393	5.25	58
222	3.65	50	265	7.8	50	308	1.08	82	351	6.99	46	394	3.66	66
223	6.15	48	266	7.56	45	309	2.63	74	352	7.48	42	395	5.65	38
224	7.15	55	267	4.58	52	310	4.58	58	353	9.52	26	396	6.88	42
225	7.62	46	268	7.9	44	311	2.39	70	354	5.68	52	397	4.88	52
226	8.45	44	269	6.15	45	312	0.58	100	355	3.56	72	398	5.12	58
227	5.65	48	270	2.65	98	313	2.65	74	356	6.58	46	399	5.23	58
228	4.67	38	271	5.29	42	314	1.54	80	357	6.12	54	400	7.25	40
229	7.61	34	272	5.84	40	315	2.68	66	358	3.22	72	401	5.74	50
230	6.12	36	273	5.65	56	316	4.55	60	359	8.78	32	402	8.55	28
231	12	40	274	5.47	40	317	1.45	80	360	11.20	20	403	3.45	74
232	11.53	26	275	8.42	38	318	2.15	70	361	9.65	28	404	3.15	72
233	8.93	48	276	2.93	78	319	1.14	92	362	9.85	24	405	4.95	64
234	6.64	52	277	3.4	74	320	4.87	56	363	4.58	50	406	6.22	54
235	12.25	20	278	3.51	74	321	2.66	78	364	6.85	24	407	6.85	64
236	12.5	16	279	3.04	78	322	2.84	78	365	4.88	64	408	6.15	66
237	9.15	28	280	2.59	80	323	2.48	76	366	6.55	46	409	6.44	56
238	9.05	22	281	2.89	66	324	2.9	82	367	5.88	56	410	9.69	18
239	6.25	30	282	2.53	81	325	5.48	64	368	9.65	26	411	9.33	30
240	6.84	22	283	2.65	72	326	6.25	56	369	7.48	24	412	4.23	56
241	9.99	20	284	2.84	76	327	5.14	64	370	8.55	38	413	3.23	72
242	2.35	99	285	3.12	76	328	3.14	74	371	7.14	42	414	4.25	42
243	1.2	94	286	2.55	76	329	2.00	86	372	4.85	58	415	4.25	50

S.N	IRI	PCI	S.N	IRI	PCI	S.N	IRI	PCI	S.N	IRI	PCI
416	7.66	34	430	7.11	46	443	2.41	84	456	1.5	84
417	2.56	70	431	6.58	48	444	2.33	78	457	2.14	78
418	2.65	72	432	5.25	64	445	2.00	86	458	1.45	84
419	4.89	50	433	5.63	64	446	1.85	82	459	3.25	72
420	8.66	40	434	5.12	60	447	1.62	88	460	1.78	86
421	8.69	28	435	5.45	64	448	2.08	82	461	2.11	76
422	5.32	62	436	3.56	76	449	2.66	80	462	4.89	58
423	6.58	48	437	4.22	78	450	2.32	82	463	2.21	88
424	5.65	54	438	7.58	44	451	2.15	84	464	2.58	70
425	6.85	48	439	2.33	86	452	2.01	84	465	0.59	90
426	5.45	58	440	2.01	82	453	2.88	76	466	0.89	90
427	7.62	38	441	2.25	84	454	2.6	86	467	2.65	72
428	5.44	58	442	2.65	78	455	2.15	86	468	2.88	78

APPENDIX G: MODEL CALCULATED PCI AND IRI VS FIELD BASED VALUES FOR DIFFERENT PCI AND IRI MODELS

ANN based testing PCI set for grouping set 1(field measured vs model evaluated PCI)

AC1	AC2	AC3	BE1	BE2	BE3	D1	D2	D3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI predicted from ANN set1	Field PCI
1.23	0.25	0.7	0.66	0	0	0	1.01	0	0	0.12	0	0.12	0	0	0	0	0	51.23	58
0.25	0.52	0.1	0	0.1	0	0	0.11	0	0	0	0	0	0	0	0.01	0.05	0	83.74	84
0.872	0	0.941	0	0.15	0.85	0	0.12	1.061	0.23	0.51	0	0	0.51	0.565	0	0.612	0	13.23	18
0	0.9	1.9	0	0	0	0.9	0	0	0	0.5	0	0	0	0	0	0	0	26.61	26
0	0	0.78	0	0	0	0.81	0	0	0	0	0	0	0	0	0	0.15	0	77.54	82
0.15	1.8	0.63	0	0.91	0	0	1.27	0	0	0	0	0	0.566	0	0.62	0	0	64.35	70
2.4	0	0.84	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	2.8	73.43	58
0.9	1.05	0	0	2.1	0	0	0	0.65	0	0	0	0	0.26	0	0	0	0	77.63	86
0.62	1.22	0.12	0.12	1.23	0	0.12	0.122	0.45	0	0	0	0	0.35	0.01	0	0	0	59.61	70
1.04	0.515	1.03	0.65	1.03	0	0.6	0.33	0.32	0	0.001	0	0	0	0	0	0	0	62.84	70
0.9	0	0.75	0.12	0.32	1.65	0	0	0.5	0	0	0	0	0	0	0	0	0	60.91	74
0	0	0	0	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0.12	87.06	94
0.15	1.18	0	0.233	0.43	0.47	0.15	0	0	0	0	0	0	0	0	0	0	0	78.43	84
0	0.22	0	0.55	0.54	0.45	0	0	0	0	0.055	0	0	0	0	0	0	0	71.83	76
0.6	0.23	0.6	0	0.2	0	0	0.76	0	0.04	0	0	0	0	0	0	0	0	72.00	80
0.18	0.3301	1.23	0	0	0.12	0	0.032	0	0.09	0	0	0	0.05	0	0.33	0	0.01	60.04	62
0.15	0	0	0.15	0.63	0.54	0	0.1	0	0	0	0	0	0	0	0	0	0	83.32	90
0.762	0.15	0.15	0	0	1.086	0.63	0	0	0	0.04	0.02	0.32	0.15	0	0	0	0	55.88	54
0.2	0	0.1	0	0.656	0.516	0	0.1	0	0	0	0	0	0	0	0	0	0	82.40	78
0.32	0.39	0.14	0	0.62	0.652	0	0.58	0.626	0	0	0	0	0	0	0	0	0	61.82	80

0	0	0.52	0	0.3	0.32	0	0	0	0	0	0	0	0	0	0	0	0	81.68	72
0.15	0.25	0	0	0	0.15	0.77	0.51	0	0	0	0	0	0	0	0	0	0	82.94	72
0.23	0.45	1.81	0	0.2	0	0.33	0	0.69	0	0.01	0.4	0.25	0	0	0	0.25	0	18.01	14
0.031	0.12	0.38	0.3	0	0	0	0	0.32	0	0	0	0	0	0	0	0	0	76.29	78
1.376	0.21	0.42	0.6251	0	0.44	0	0.15	0.252	0	0	0	0	0	0	0.35	0	0	68.00	70
0.66	1.1612	0.85	0	0	0	0.82	0	0.52	0	0.12	0	0.32	0	0	0.3	0	0.5	36.68	50
1.308	0.712	0.3976	0	0	0	0.4	0.12	0	0	0	0	0	0	0	0	0	0	77.11	80
0.15	0.36	0	0.32	0	2.51	0	0.15	0	0	0	0	0	0	0	0.15	0	0	84.70	80
0.685	1.85	0.11	0	1.261	0.37	0.15	0.44	0.25	0	0.001	0.005	0	0	0	0	0	0	60.26	54
0	2.64	0	0	0	2.13	0.52	0.51	0	0.15	0	0	0	0	0.51	0	0	0	51.18	48
0.665	3.05	0.995	0	0.11	0	0	0	0	0	0.15	0	0	0	0	0	0	0	31.77	34
0	0.88	1.55	0	0	0	0	0.62	0.11	0	0	0.06	0	0.11	0	0	0	0	43.67	44
0.67	0.23	0.57	0	0	2.12	0.34	0	0	0	0	0	0	0	0	0	0	0	72.03	76
0	3.8	0	0.32	0	0	0	0	0	0	0	0.4	0	0	0	0	0	1.55	32.90	36
0	0.51	0	0	0	0	0	0.61	0	0.008	0	0	0	0	0	0	0	0	84.96	86
0	2	0	0	0	2.6	0.6	0	0	0	0	0	0	0	0	0	1.5	0	56.86	68
2.03	2.5415	0.48	0.51	0	0	0	0.7	0	0.15	0	0	0.33	0	0	0	0	0	54.68	62
0	1.14	0.65	0	0	0.6	0.125	0.66	0	0	0	0.05	0	0	0	0	0	0	53.78	46
0.3	0	0	0	0	0	0	0	0	0	0	0	0	0.11	0.6	0.015	0.15	0	70.36	74
0	0.232	0.2	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	76.17	72
1.73	1.6	0.26	0	0	0.5	0.15	0.63	0.123	0	0	0	0	0	0	0	0	0	67.84	66
0.23	0	0	0.23	0.12	0.52	0.15	0.23	0.44	0	0	0	0	0	0	0	0	0	72.34	56
0.33	1.55	0.582	0	0.77	0	0.63	0	0.63	0	0	0.23	0	0	0	0	0	0	22.02	24
0	0.9	1.35	0	0	0.2	0	0	0.12	0	0.15	0	0	0	0	0	0.52	1.3	35.08	33
0.41	0	0.12	0.151	0	0.56	0	0	0	0	0	0	0	0	0	0	0	0	82.71	86
0	0	0.48	0	0	0	0	0	0.5	0	0.13	0	0	0	0	0	0	0.5	45.45	60
0.12	0.52	1.81	0	0.15	0	0	0	0	0	0	0.05	0	0	0	0	0	0	52.80	50
0	1.91	0.22	0	0.6	0.26	0.43	0	0.15	0.01	0	0.3	0	0	0	0	0	0	16.65	16
0	0.5	1.38	0.47	0.11	0.11	0	0	0	0	0	0.06	0	0	0	0	0	0	49.17	44
0.6	1.38	1.71	0.41	0	1.85	0.5	0.62	0.05	0.1	0	0.06	0	0.51	0	0	0	0	26.42	30

ANN based testing PCI set for grouping set 2(field measured vs model evaluated PCI)

A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI predicted from ANN set 2	Field PCI
0.52	0	0	0	0	0.52	0.666	0	0.51	0.15	0.32	0	0	0	0.62	0	0	0	0	0	0	0	0	0	75.93	72
0	0	0	0	0.85	0.15	0.653	0.33	0.74	0.32	0.96	0.72	0	0	0.66	0	0	0	0	0	0.6	0	0	0	46.31	62
0	0	0	0	1.21	0	0	0.42	0.07	0	0	0.156	0.015	0.32	0	0	0	0	0	0	0	0	0	0	77.66	86
0	0.626	0.22	0	0	0	0	0	0	0	0	0.63	0	0.84	0.51	0	0	0	0	0	0	0	0	0	60.79	68
0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0.11	0.6	0.015	0.15	0	77.92	74
1.842	0	1.28	0	1.28	0	0	0	0	0	0	0	0	0.68	0	0	0	0	0	0	0.82	0	2.42	0	53.91	50
0.15	0	0	0	0.15	0.15	0	0	0.621	0.513	0.62	0	0	0.51	1.026	0	0	0	0	0.32	0	0	0	0	67.57	74
0	0	0	0.15	0.66	0	0	0.63	0.52	0	0.56	0.621	0	0	1.01	0	0.15	0	0	0	0	0	0	0	39.12	46
0	0	0	0	0.18	0	0.64	0	0	0	0.145	0	0	0	0	0	0	0	0	0	0	0	0	0	87.70	82
0	0	0	0.3	0.54	0	0	0.22	0	0	0	0	0.25	0	0.45	0	0.055	0	0	0	0	0	0	0	76.17	76
0	0	0	0	0	0	0	0	0.78	0	0	0.12	0	0	0.81	0.065	0	0	0	0	0.05	0.9	0.4	0.56	58.74	54
0	0	0	0	0.65	0	0.12	0.3026	0.1	0	0.85	0.25	0	0	0	0	0	0.01	0	0	0	0	0.552	0	69.91	68
0	2.5	0	0	0.8	0.5	0.12	0.6	0	0	0.06	0.104	0	0	0	0	0	0	0	0.156	0	0	0	0	59.98	64
0	0	0.6	0	0	0	0	0.95	0.5	0.23	0.6	0.8	0	1.6	0	0	0	0.1	0	0	0	0	0	0	37.57	18
0	1.52	0	0	0.74	0	0	0	0	0.21	0	0	0	0	0	0	0	0	0	0	0	0	2.54	0	67.31	64
0.015	0	0.32	0	0	0	0.81	0	1.17	0	0	0.15	0	0.55	0.74	0	0.08	0	0	0	0.02	0	0	0	52.02	54
0	0	0.45	0	0	0	0.3	0	0.6	0	0.68	0	0	1.23	0	0	0	0.26	0	0	0	0	0	0.96	16.79	20
0	0	0	0	0.96	0.12	0	0	0	0	0.55	0	0	0	1.23	0	0.01	0	0	0.08	0	0	0	0.6	62.28	66
0	0	0	0	0.15	0	0	0.1	0	0	0.41	0.1	0	0	0.15	0.01	0	0	0	0	0	0	0	0	84.47	80
0.3	0	0	0	0	0	0	0.23	0.69	0	0.3	0.15	0	0	0	0.1	0.02	0.01	0	0	0	0	0	0	61.49	54
0	0.24	0	0	0.6	0	0.1	0.25	0.3	0.147	0	0.6	0	0.1	0.09	0.005	0	0	0	0	0	0	0	0.8	48.23	46
0	0	0	0.2	0	0.09	0	0	0	0	0	0	0	0	0	0.01	0	0	0.3	0	0	0	0.2	0	81.39	88
0	1.2	0	0	0	0	0.26	0	0.12	0	0	0	0.151	0	0	0	0	0	0	0	0	0	0	0	76.53	74

0	0	0	0	0	0.11	0	0	0.25	0.15	0.19	0.123	0	0	0	0	0	0	0	0	0	0	0	0	63.80	66
0	0	0.25	0	0	0.55	0	0	0	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0	0	81.02	80
0	0	1.6	0	0	0	0	0	2.8	0	0	0.4	0	0	0	0	0	0	0	0	2	0	0	0	35.84	36
0	0	0	0	0	0	0	0	0.125	0	0	0.15	0	0	0	0	0	0	0	0	0	0	0	0	86.49	92
0	2.4	0	0	1.2	0	1.5	0	0	0	0	0	0.1	0	0.1	0	0.01	0.05	0	0	0	0	0	0	51.35	44
0	0.3	0	0.6	0	0.4	0	0	0.6	0	0	0.2	0	0	0	0	0.12	0	0	0	0	0	0	0.08	57.92	56
0	0.65	0	0	0.6	0	0	0	1.8	0.21654	0.23	0.6	0	1.5	0	0	0	0	0	0	0.23	0	0	0	43.61	40
0	0	0.55	0	1.2	0	0	0.52	0.66	0	0	0.51	0	0	0.45	0	0.05	0.05	0	0	0	0	0	0	32.35	26
0	0	0.26	0	0	0	0	1.46	0.9	0.1	0.3	0.26	0	0	0.69	0	0.03	0	0.3	0.3	0	0	0	0.45	52.49	50
0	0.52	0	0	0	0	0	0	0.51	0	0.85	0	0	0.45	0.63	0	0	0	0.045	0	0.51	0	0	0	65.21	60
0	0	0	0	0	0.85	0	1.241	0	0	0	0.731	0	0.63	0	0	0	0	0	0	0	0	0	0	59.81	83
0.5	0	0	0	0.26	2.3	0.23	0	0.23	0.43	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	79.70	82
0	0	0	0	0	0	0.552	0	1.35	0.65	0.55	0	0	0.345	0	0	0	0	0	0	0	0	0	0	71.06	78
0	0.33	0	0	0	2.44	0.562	0	0.33	0.25	0.31	0	0	0	0	0	0	0	0	0	0	0	0	0	79.45	76
0	0	0	0	0.15	0	0.15	0.55	0	0.23	0.32	0	0	0.32	0	0.01	0	0	0	0	0.22	0	0	0	76.67	76
0	0.32	0	0	0	0	0.6	0.8	0.15	0.23	0.22	0.14	0	0	0.23	0	0.06	0.12	0	0	0	0	0	0	32.42	36
0.05	0	0	0	0.08	0	0	0	0.756	0.68	0	0.23	0	0.23	0	0	0	0	0	0	0	0	0	0	72.34	86
0.11	0.1	0	0	0	0	0.51	0.81	1.69	0	0.35	0.61	0.11	0.33	0	0	0	0	0	0	0.51	0	0	0	47.94	40
0	0	0.4	0	0.7	0.9	0	0	0	0	0.23	0	0.15	0	0	0.6	0	0	0	0	0	0	0	0	38.15	45
0	0	0	0	0	0	0.12	0.51	0	0	0	0	0	0.32	0	0	0.01	0	0	0	0	0	0	0	85.57	90
0.52	0	0	0.65	0.55	0	0.52	0.515	1.03	0.6	0.33	0.32	0	0.48	0	0	0.001	0	0	0	0	0	0	0	54.15	70
0	0.55	0	0	0.15	0.6	0	0.85	0.55	0.32	0.9	0.215	0.15	0	0.15	0	0.05	0	0	0	0	0	0	0	57.43	58
0	0	0.14	0	0	0.23	0	0	0.35	0	0.11	0.4	0	0	0.12	0	0	0	0	0	0	0	0	0	73.01	56
0	0	0	0	0	0.41	0.32	0.15	0	0.15	0.26	0.66	0	0	0	0	0	0	0	0	0	0	0	0	68.62	78

Regression based testing PCI set for grouping set 1(field measured vs model evaluated PCI)

AC1	AC2	AC3	BE1	BE2	BE3	D1	D2	D3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI predicted from regression set 1	Field PCI
0	0.26	0.62	0.65	1.51	0	0.21	0.32	0.23	0	0	0	0	0.01	0	0	0	0	68.88	58
0.52	0.32	0.221	0	2.14	0	0	0.12	0	0	0	0	0	0	0	0	0	0	69.41	74
0.52	0.15	2.22	0	1.37	1.21	0	0.541	0.18	0	0	0	0.52	0.05	0.52	0	0	0	43.20	48
1.2	0.6	1.15	0	0	0.3	0.78	0.25	1.02	0	0	0.23	0	0	0	0.01	0.3	0	21.08	20
0	1.9	0	0	2.6	1.45	0	0.15	0.74	0	0	0	0	0	0.48	0	0	0	52.07	46
0.73	0	0.23	0	0.26	2.3	0.43	0	0	0	0	0	0	0.2	0	0	0	0	64.21	82
0	0	0	0.15	0	0.11	0.66	0.66	0	0	0	0	0	0	0	0	0.28	0	83.94	82
0	1.241	0	0	0.63	0.85	0	0	0.731	0	0	0	0	0	0	0	0	0	63.09	83
0.27	0	0	0.1	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	76.28	90
0	0.25	0	0	0.55	1.441	0	0	0	0	0	0.01	0	0	0	0	0	0	70.66	72
0	0.63	0	0	2.6356	0.75	0.31	0.7255	0.2	0	0	0	0	0.33	0	0	0	0	62.93	64
2.28	0.992	0.204	0	3.21	0	0.18	0.412	0	0	0	0	0.82	0	0.84	0	3.2	0.8	32.92	52
0	0	0	0	0.96	1.35	0	0.55	0	0	0.01	0	0	0.08	0	0	0	0.6	64.43	66
0	0.99	1.59	0	1.9	2.96	0.22	0.7	0.23	0	0.06	0	0	0.23	0	0	0	0	44.10	38
0.12	0	0.14	0	0	0	0	0.11	0	0	0	0	0	0	0	0	0	0	75.84	88
0.64	0	0	0	0.18	0	0	0.145	0	0	0	0	0	0	0	0	0	0	74.85	82
0.51	0	0.15	0.15	0	0.32	0	0.26	0.65	0	0	0	0	0	0	0	0	0	66.55	56
0.5	0.12	0.23	0.36	0	0	0	0	0.12	0	0	0	0	0.6	0	0	0	0	71.77	70
0.412	0.26	0.11	0	0	1.37	0.66	0	0.1	0	0	0.032	0	0.2	0	0	0	0	64.24	56
0.26	1.102	2.05	0.78	0	0.93	0.85	0	0	0.01	0	0.02	0	0	0	0	0	0	58.45	52
0	0.26	0.38	0.32	0	0	0	0.62	0.69	0	0	0.051	0	0	0	0	0	0	62.77	32
0.22	0	0	0	1.476	1.84	0	0.372	0.35	0	0.05	0.005	0	0	0	0	0.66	0	58.51	56
0.15	0.48	0.32	0	1.2	0	0.66	0	0	0	0	0.148	0	0	0	0	0	0	37.61	34
0	0.14	0.98	0.66	0.32	1.42	0.66	0.36	0	0	0	0	0	0	0	0	0	0	66.38	66
0.23	0.45	1.81	0	0.2	0	0.33	0	0.69	0	0.01	0.4	0.25	0	0	0	0.25	0	19.36	14

0	0	0.125	0	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0	84.65	92
0.4	0	0.15	0	0.45	0	0	0	0	0	0	0	0.6	0.45	0	1.33	0	0	67.21	78
0	0.82	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11	0.12	0	75.88	82
0	0.9	0.3	0	0.23	0.76	0	0.3	0.91	0	0	0	0	0.33	0	0.23	0	0	58.94	50
1.65	0.75	0.11	0	0	0.99	0.29	0	0.1	0	0	0.14	0	0.33	0	0	0	0.66	47.63	32
0	0	0.33	0	0	0	0.2	0	0	0.01	0	0.01	0	0	0.14	0	0	0	72.32	76
2.4	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0.26	0.45	0	0.26	64.38	68
0.062	0.265	0.38	0	0	0	0	0	0	0.05	0.01	0	0.85	0	0	0	0	0	64.53	70
0.61	0	0.46	0	0.63	0	0.26	0.35	0	0.01	0.1	0.04	0	0	0	0	0.32	0	49.39	44
1.29	0.6	0	0	0	0.8	0	0.75	0	0	0	0	0	0	0	0	0	0	69.42	74
0.95	0.9	12.5	0	1.22	0	0.15	2.6	0.15	0	0.15	0	0	0.15	0	0	0	0	22.42	22
0.25	0.11	0	0	0.23	0.3	0	0	0.32	0	0	0	0	0	0	0	0	0	71.22	58
0.2	1.232	1.6	0	0.5665	0.61	0	0	0.5	0.01	0	0	0	0	0.5	0	0	0.656	46.37	48
0.15	1.203	0	0.5	0	0	0.33	0.176	0	0.15	0	0.051	0	0	0	0	0	0	68.54	28
0.32	0.975	0.89	0	0.5	1.25	0	0.63	0	0	0	0	0.66	0	0.15	0.52	0	0	56.67	56
0.12	0.3026	0.1	0	0.65	0	0	0.85	0.25	0	0	0.01	0	0	0	0	0.552	0	68.49	68
1.83	0.6	0.12	1.85	0.12	0	0.22	0.34	0	0.04	0.01	0.4	0.45	0	0	0.15	0	0	39.12	18
0.51	0	0	0.35	0.6	0.12	0	0.1	0	0	0	0	0	0	0.52	0	0	0	71.24	72
0	1.3	0	0	2.1	0	0	0.03	1.3	0	0	0	0	0.15	0	0.15	0	0	55.18	40
0	2.13202	0	0.12	0.2	0.501	0.6	0.6	0.3	0	0	0	0	0	0.2	0	0	0	64.97	58
0.15	0.36	0	0.32	0	2.51	0	0.15	0	0	0	0	0	0	0	0.15	0	0	70.12	80
0	0.42	0.07	0.015	1.53	0	0	0	0.156	0	0	0	0	0	0	0	0	0	71.27	86
1.11	0.51	0	0	0.03	0.356	0	0.25	0.25	0	0	0	0	0	0	0	0	0	69.03	60
0	1.63	1.25	0	0	1.46	0	0.89	1.92	0.16	0	0	0	0	0.45	0	0	0	31.82	26
0	0.66	1.28	0	0.145	0	0	0.12	0	0	0	0	0	0	0	0	0	0.644	62.54	62
0	0	0	0	0	0.11	0.12	0	0	0	0	0	0	0	0	0	0	0	76.47	96

Regression based testing PCI set for grouping set 2(field measured vs model evaluated PCI)

A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	PCI predicted from regression set 2	Field PCI
0	0	0.6	0	0.62	0	0.756	1.23	0	0	0	0.11	0.15	0	0.15	0	0	0	0	0.23	0.15	0.23	0	0	61.97	62
0	0	0.52	0	0	0	0.11	0.93	0.85	0.3	0.32	0.52	0	0	0	0.14	0	0	0.32	0.15	0	0	0.16	0	53.29	42
0	0.12	0	0	0	0	0.03	0.2	0	0	0	0	0	0	0	0.12	0	0	0	0.005	0	0	0	0	74.08	72
0	0	0	0	0.15	0	0.872	0	0.941	0	0.12	1.061	0	0	0.85	0.23	0.51	0	0	0.51	0.565	0	0.612	0	6.08	18
0	0	1.4	0	0	0	0	0.9	0.5	0.9	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	22.85	26
0	0	0	0	0	0	0	0	0.78	0.81	0	0	0	0	0	0	0	0	0	0	0	0	0.15	0	72.11	82
0	0	0	0	0	0.11	0	0	0.25	0.15	0.19	0.123	0	0	0	0	0	0	0	0	0	0	0	0	74.15	66
0	0	0.84	0	0	0	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	2.8	30.09	58
0	0	0	0	2.1	0	0.9	1.05	0	0	0	0.65	0	0	0	0	0	0	0	0.26	0	0	0	0	58.82	86
0.1	0	0.06	0	0	1.56	0	0.2	0.14	0	0	0	0	0	0	0	0	0.04	0	0	0	0	1.4	0	69.70	54
0	0	0	0	0	0	0	0	0.721	0	0	0	0	0	0.1	0	0	0.003	0	0	0	0	0	0	74.28	84
0	0	0.32	0	0	0.2	0	0	0	0.12	0	0.23	0	0	0	0.09	0.02	0.02	0.11	0.23	0	0.11	0.12	0	63.98	46
0	0	0	0	0	0.23	0.22	0.5	0	0	0.22	0	0	0.03	0	0	0	0	0.5	0	0	0	0	0	72.08	86
0.25	0	0	0	0	0	0	0	0.8	1.8326	0	0.7	0	0	0.6	0.15	0	0	0	0	0	0	0	0.15	50.71	42
0	0	0	0.3	0.54	0	0	0.22	0	0	0	0	0.25	0	0.45	0	0.055	0	0	0	0	0	0	0	71.69	76
0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0	0.12	75.90	94
0	0	0.3	0	0	0	0.18	0.3301	0.93	0	0.032	0	0	0	0.12	0.09	0	0	0	0.05	0	0.33	0	0.01	67.97	62
0	0	0	0.15	0.63	0.21	0.15	0	0	0	0.1	0	0	0	0.33	0	0	0	0	0	0	0	0	0	74.25	90
0	0	0	0	0.85	0.15	0.6	0	0.765	0.656	0.6	0.15	0	0	0.36	0	0.08	0	0	0	0.96	0	0.6	0	51.73	50
0.2	0	0.1	0	0.656	0.516	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	73.85	78
0	0.52	0	0	1.24	0	0.34	0.23	0.23	0	0.15	0	0	0	0	0	0	0	0	0	0	0.41	0	0	72.21	76
0	0	0.52	0	0.15	0	0	0	0	0	0	0	0	0.15	0.32	0	0	0	0	0	0	0	0	0	69.41	72
0.56	0	0	0	0	0.632	0.145	0	0	0	0	0.06	0	0	1.58	0	0	0	0	0	0	0.32	0.47	0	65.67	82
0	0	0	1.25	0.2	0.45	0	0.2	0.3	0	0	0	0	0.15	0.15	0	0	0	0	0	0	0	0	0	80.44	86
0	0	0.23	0	0	0	0.031	0.12	0.15	0	0	0.32	0.3	0	0	0	0	0	0	0	0	0	0	0	70.09	78
0.15	0.25	0.15	0	0	0	1.07	0.55	1.22	0	0.336	0	0	0	0.12	0	0.52	0	0.25	0	0.215	0	0	0.65	19.97	26

0	0	0	0	0	0	0.66	1.1612	0.85	0.82	0	0.52	0	0	0	0	0.12	0	0.32	0	0	0.3	0	0.5	46.67	50
0	0.48	0	0	0	0	0	0.22	0.15	0	0	1.2	0	0	0.32	0	0	0	0	0	0	0	0	0	57.74	46
0.633	0.53	0.3	0	0.11	0.51	0.62	0	0	0	0	0	0	0.11	0.63	0	0	0	0.216	0	0	0	0	0	62.44	64
0.56	0.15	0.11	0	0.32	0	0.25	0.44	0.23	0	0.42	0.12	0.13	0	0.44	0	0	0	0	0	0	0	0	0	66.68	66
0	0	0	0	0	0.77	0	2.64	0	0.52	0.51	0	0	0	1.36	0.15	0	0	0	0	0.51	0	0	0	58.14	48
0	2.45	0.85	0	0	0	0.665	0.6	0.145	0	0	0	0	0.11	0	0	0.15	0	0	0	0	0	0	0	47.94	34
0	0.6	0.32	0	0	0	0	0.28	1.23	0	0.62	0.11	0	0	0	0	0	0.06	0	0.11	0	0	0	0	60.55	44
0.12	0	0.25	0	0	0	0.55	0.23	0.32	0.34	0	0	0	0	2.12	0	0	0	0	0	0	0	0	0	58.43	76
0	1.45	0	0	0	0	0	2.35	0	0	0	0	0.32	0	0	0	0	0.4	0	0	0	0	0	1.55	22.73	36
0	0	0	0	0	0.85	0	1.241	0	0	0	0.731	0	0.63	0	0	0	0	0	0	0	0	0	0	64.26	83
0	1.2	0	0	0	2.6	0	0.8	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	68.30	68
0.22	0.5	0	0	0	0	1.81	2.0415	0.48	0	0.7	0	0.51	0	0	0.15	0	0	0.33	0	0	0	0	0	58.01	62
0	0.74	0	0	0	0	0	0.4	0.65	0.125	0.66	0	0	0	0.6	0	0	0.05	0	0	0	0	0	0	64.53	46
0.032	0	0	0	0	0	0.21	0.33	0.14	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	70.22	82
0	0.262	0	0	0	0	0	0	1.32	0	0.15	0	0	0	0.94	0	0	0	0	0	0	0	0	0	67.39	72
0	0	0.26	0	0	0	0	0	0	1.23	0	0	0	0.6	0	0	0	0	0	0.12	0.455	0.12	0	0	66.36	72
0	0	0	0	0	0.41	0.23	0	0	0.15	0.23	0.44	0.23	0.12	0.11	0	0	0	0	0	0	0	0	0	68.80	56
0	0.232	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	72.82	72
0	0.9	1.2	0	0	0.2	0	0	0.15	0	0	0.12	0	0	0	0	0.15	0	0	0	0	0	0.52	1.3	36.56	33
0	0	0	0	0	0	0.41	0	0.12	0	0	0	0.151	0	0.56	0	0	0	0	0	0	0	0	0	72.45	86
0	0.6	0	1.22	0.15	0	0	0.6	0	0	0.1	0.63	0	0	0	0	0	0	0.22	0	0	0	0.455	0	50.39	54
0	0.3	0	0	0	0	0.12	0.22	1.81	0	0	0	0	0.15	0	0	0	0.05	0	0	0	0	0	0	55.48	50
0	0	0	0	0.65	0	0.3	0.26	0.22	0.3	0.56	0.45	0	0.4	0	0	0	0	0	0.87	0	0	1.25	0	61.30	58
0	0	0.66	0.15	0.11	0	0	0.5	0.72	0	0	0	0.32	0	0.11	0	0	0.06	0	0	0	0	0	0	42.44	44
0.1	0.6	0.5	0	0	0	0.5	0.78	1.21	0.5	0.62	0.05	0.41	0	1.85	0.1	0	0.06	0	0.51	0	0	0	0	42.07	30

Regression based testing IRI set for grouping set 1(field measured vs model evaluated IRI)

AC1	AC2	AC3	BE1	BE2	BE3	D1	D2	D3	F1	F2	F3	G1	G2	G3	H1	H2	H3	IRI predicted from regression 1 model	Field measured IRI
1.23	0.25	0.7	0.66	0	0	0	1.01	0	0	0.12	0	0.12	0	0	0	0	0	5.20	5.39
0.3	0.67	0.2	0.89	0.23	0	0	0.52	0.15	0	0	0	0	0	0.63	0.11	0.85	0	5.15	4.63
0.18	0.3301	1.23	0	0	0.12	0	0.032	0	0.09	0	0	0	0.05	0	0.33	0	0.01	4.03	5.1
0.216	0.3	0.91	0	0.6	0	0	0.36	0.2656	0	0	0	0	0	0	0.02	0	0	3.90	3.74
0.51	0	0.45	0.32	0.48	0.36	0.32	0	0.15	0	0.01	0	0	0.3	0	0.015	0.15	0	4.09	4.66
0	0	0.18	0	0.15	0.36	0.15	0.33	0.15	0	0	0	0	0	0	0	0.15	0	3.33	4.6
1	1.2	1.27	0	0	0	0	0.35	0.31	0.01	0.08	0	0	0	0	0	1.5	0	5.89	6.48
0.32	1.32	0.31	0	0	0.45	0	0.47	0.25	0	0	0.041	0	0	0	0	0	0	4.46	4.6
0	0.33	0	0	0.68	0.48	0.23	0.583	0.1	0	0	0	0	0.23	0	0	0	0	3.44	2.81
0	0.86	1.63	2.4	0	2.84	0	1.33	0	0	0	0	0	0	0.42	0	0	3.08	8.70	7.79
0.78	0.62	1.35	0.51	0	0.21	0	0.84	0	0.62	0	0	0	0.003	0	0	0	0	6.94	7.58
0	2.28	1.391	0	0.1	0.77	0.32	0.514	0	0.08	0	0	0	0	0.15	0	0	0	5.06	5.44
0.74	1.12	0.56	0	1.14	0	0.816	2.28	0	0.09	0	0.11	0.3	0	0.74	0	0	0.66	8.04	9.15
0.61	0	0.46	0	0.63	0	0.26	0.35	0	0.01	0.1	0.04	0	0	0	0	0.32	0	4.95	5.04
0	0.26	0.62	0.65	1.51	0	0.21	0.32	0.23	0	0	0	0	0.01	0	0	0	0	3.93	4.24
0	0	0.721	0	0	0.1	0	0	0	0	0	0.003	0	0	0	0	0	0	3.11	1.5
1.73	0.51	1.48	0.15	0	0	0	0.45	0	0	0	0	0	0	0	0	0	0	4.62	2.25
0.73	0	0.23	0	0.26	2.3	0.43	0	0	0	0	0	0	0.2	0	0	0	0	4.55	2.17
0.26	1.2	0.12	0.151	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.08	3.4
0	0.7	0.15	0	0	0.32	0	0	1.2	0	0	0	0	0	0	0	0	0	5.03	5.08
0	1.49	1.03	0	0.4	0.7	0	0.3	0.16	0	0	0	0	0	0.08	0	0.15	0	4.40	6.55
0	0.66	0.87	0	0	1.73	0	0.51	0	0	0.1	0	0	0	0	0.52	0	0	5.22	4.23
0.6	1.38	1.71	0.41	0	1.85	0.5	0.62	0.05	0.1	0	0.06	0	0.51	0	0	0	0	6.97	9.33
1.4	2.3	2.12	0	0	0	0.65	0	0	0	0	0	0	0	0.6	0	0	0	6.37	6.95
0.15	0	0	0	0	0.37	0	0.17	0	0	0	0	0.32	0	0	0	0	0	2.98	2.15

0.6	0.15	0.52	0	0.51	0	0	0.63	0.65	0	0	0	0	0	0.12	0	0	0	4.78	4.68
0	0.23	1.05	0.1	0.25	0.56	0	0	0	0	0.03	0	0	0	0	0	0.33	0	3.95	5.38
1.43	0.63	0	0	0.15	1.65	0.51	0.36	0	0	0.05	0	0	0	0	0.32	0	0	5.13	4.44
0.495	0	1.46	0	0.4566	0.45	0	0.51	0.145	0	0	0.02	0	0.33	0.621	0	0	0.61	6.23	7.62
0	1.8	1.79	0	0	0	0	0	1.85	0	0.02	0	0	0.48	0	0	0	0	7.47	6.15
0.81	0.59	0.34	0.13	0.32	0.44	0	0.42	0.12	0	0	0	0	0	0	0	0	0	3.94	4.05
0.15	1.8	0.63	0	0.91	0	0	1.27	0	0	0	0	0	0.566	0	0.62	0	0	4.12	4.02
0.15	0.25	0	0	0	0.15	0.77	0.51	0	0	0	0	0	0	0	0	0	0	3.20	3.26
0.4	3.76	2.77	0	0.83	0	0	0	0	0	0.01	0	0	0	0	0.26	0.46	0	5.50	5.26
0.11	0	0.85	0	1.38	1.67	0	0.43	0.21	0	0.01	0	0	0	0.15	0	0	0	4.98	4.86
0.665	3.05	0.995	0	0.11	0	0	0	0	0	0.15	0	0	0	0	0	0	0	5.41	9.65
0	0.35	0.2	0	1.2	1.63	0.12	0.224	0.05	0	0.085	0	0	0	0	0	0.2	0	4.72	5.25
0.762	0.15	0.15	0	0	1.086	0.63	0	0	0	0.04	0.02	0.32	0.15	0	0	0	0	4.63	6.22
0.872	0	0.941	0	0.15	0.85	0	0.12	1.061	0.23	0.51	0	0	0.51	0.565	0	0.612	0	12.72	9.69
0.12	0.51	0	0	0.32	0	0	0	0	0	0.01	0	0	0	0	0	0	0	2.88	2.85
0.53	0.47	0.98	0	0.23	1.05	0.3	0.01	0.11	0.08	0	0	0	0.15	0.04	0	0.25	0.5	5.22	5.13
0	0.37	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	1.57	0	5.66	3.87
0.25	0.54	1.15	0	0.6	0	0.9	0.26	0	0.3	0	0	0.66	0	0	0.11	0	0	5.39	5.18
0.62	1.22	0.12	0.12	1.23	0	0.12	0.122	0.45	0	0	0	0	0.35	0.01	0	0	0	4.39	2.85
0	0.9	1.35	0	0	0.2	0	0	0.12	0	0.15	0	0	0	0	0	0.52	1.3	6.06	10.22
0.98	0	0	0.26	1.42	0	0.12	0.212	0	0	0	0.06	0	0.15	0.56	0	0.65	0	5.53	7.22
0.856	0	1.13	1.3	0.6	0	0	0.22	0	0	0	0	0.2	0.79	0.15	0	0	0.15	4.91	3.07
0.75	0.25	0.67	0	0.58	0.99	0.11	0.78	0	0	0	0	0	0.14	0	0.11	0	0	4.29	5.12
0	0.232	0.2	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	3.19	2.65
0.26	1.102	2.05	0.78	0	0.93	0.85	0	0	0.01	0	0.02	0	0	0	0	0	0	5.44	5.29
0.6	0	0	0	0	0.45	0	0	0	0	0.25	0	0	0	0	0	0	0	5.32	7.9
0.33	0.6	1.521	0	0	0	0.051	0	0	0	0	0.08	0	0	0.15	0	0	0	5.07	8.41
0.27	0.55	0.6	0	0	3.75	0.215	0.71	0	0	0.07	0	0	0.55	0	0	0.18	0	6.17	5.46
1.22	0	0.27	0	0	2.451	0	0.6	0	0	0.02	0	0	0	0	0	0.51	0.15	5.20	5.64
0.52	0.15	2.22	0	1.37	1.21	0	0.541	0.18	0	0	0	0.52	0.05	0.52	0	0	0	6.50	6.58

ANN based testing IRI set for grouping set 2(field measured vs model evaluated IRI)

A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	G3	H1	H2	H3	IRI predicted from ANN 2 model	Field measured IRI
0	0	0	0.66	0	0	1.23	0.25	0.7	0	1.01	0	0	0	0	0	0.12	0	0.12	0	0	0	0	0	5.19	5.39
0	0.15	0	0.89	0	0	0.3	0.52	0.2	0	0.52	0.15	0	0.23	0	0	0	0	0	0	0.63	0.11	0.85	0	5.03	4.63
0	0	0	0	0	0	0	0	0.125	0	0	0.15	0	0	0	0	0	0	0	0	0	0	0	0	2.88	1.08
0	0	0.3	0	0	0	0.18	0.3301	0.93	0	0.032	0	0	0	0.12	0.09	0	0	0	0.05	0	0.33	0	0.01	4.20	5.10
0	0.15	0	0	0.6	0	0.216	0.15	0.91	0	0.36	0.2656	0	0	0	0	0	0	0	0	0	0.02	0	0	3.76	3.74
0	0	0.15	0	0	0.36	0.51	0	0.3	0.32	0	0.15	0.32	0.48	0	0	0.01	0	0	0.3	0	0.015	0.15	0	3.98	4.66
0	0	0	0	0	0	1	1.2	1.27	0	0.35	0.31	0	0	0	0.01	0.08	0	0	0	0	0	1.5	0	5.36	6.48
0	0.56	0	0	0	0	0.32	0.76	0.31	0	0.47	0.25	0	0	0.45	0	0	0.041	0	0	0	0	0	0	4.52	4.60
0	0	0	0	0.45	0	0	0.33	0	0.23	0.583	0.1	0	0.23	0.48	0	0	0	0	0.23	0	0	0	0	3.45	2.81
0	0	0.42	0	0	2.42	0	0.86	1.21	0	1.33	0	2.4	0	0.42	0	0	0	0	0	0.42	0	0	3.08	7.18	7.79
0	0	0	0	0	0	0.78	0.62	1.35	0	0.84	0	0.51	0	0.21	0.62	0	0	0	0.003	0	0	0	0	6.72	7.58
0	0.33	0	0	0.1	0	0	1.95	1.391	0.32	0.514	0	0	0	0.77	0.08	0	0	0	0	0.15	0	0	0	4.75	5.44
0	0.52	0	0	0.15	0	0.74	0.6	0.56	0.816	2.28	0	0	0.99	0	0.09	0	0.11	0.3	0	0.74	0	0	0.66	7.98	9.15
0.61	0	0	0	0	0	0	0	0.46	0.26	0.35	0	0	0.63	0	0.01	0.1	0.04	0	0	0	0	0.32	0	4.84	5.04
0	0	0.62	0.65	1.21	0	0	0.26	0	0.21	0.32	0.23	0	0.3	0	0	0	0	0	0.01	0	0	0	0	4.33	4.24
0	1.2	0	0	0	0	0.26	0	0.12	0	0	0	0.151	0	0	0	0	0	0	0	0	0	0	0	3.29	3.40
0	0.48	0	0	0	0	0	0.22	0.15	0	0	1.2	0	0	0.32	0	0	0	0	0	0	0	0	0	5.05	5.08
0	0	0.8	0	0.4	0.7	0	1.49	0.23	0	0.3	0.16	0	0	0	0	0	0	0	0	0.08	0	0.15	0	4.58	6.55
0	0	0	0	0	0	0	0.66	0.87	0	0.51	0	0	0	1.73	0	0.1	0	0	0	0	0.52	0	0	5.28	4.23
0.1	0.6	0.5	0	0	0	0.5	0.78	1.21	0.5	0.62	0.05	0.41	0	1.85	0.1	0	0.06	0	0.51	0	0	0	0	7.45	9.33
0	0	2.12	0	0	0	1.4	2.3	0	0.65	0	0	0	0	0	0	0	0	0	0	0.6	0	0	0	7.50	6.95
0.15	0	0	0	0	0.25	0	0	0	0	0.17	0	0	0	0.12	0	0	0	0.32	0	0	0	0	0	2.97	2.15
0	1.23	0.1	0	0.33	0	0.68	0	0	0	0	0	0	0	0	0.12	0	0.02	0	0	0	0	0	0.55	4.64	6.11
0	0	0	0	0	0	0.6	0.15	0.52	0	0.63	0.65	0	0.51	0	0	0	0	0	0	0.12	0	0	0	4.70	4.68
0	0	1.05	0	0.15	0.56	0	0.23	0	0	0	0	0.1	0.1	0	0	0.03	0	0	0	0	0	0.33	0	4.53	5.38
0.55	0.63	0	0	0.15	1.65	0.88	0	0	0.51	0.36	0	0	0	0	0	0.05	0	0	0	0	0.32	0	0	4.97	4.44

0	0	0.2	0	0	0	0.495	0	1.26	0	0.51	0.145	0	0.4566	0.45	0	0	0.02	0	0.33	0.621	0	0	0.61	6.19	7.62
0	0.8	0	0	0	0	0	1	1.79	0	0	1.85	0	0	0	0	0.02	0	0	0.48	0	0	0	0	7.29	6.15
0.56	0.15	0.11	0	0.32	0	0.25	0.44	0.23	0	0.42	0.12	0.13	0	0.44	0	0	0	0	0	0	0	0	0	3.96	4.05
0	0	0.12	0	0.55	0	0.15	1.8	0.51	0	1.27	0	0	0.36	0	0	0	0	0	0.566	0	0.62	0	0	4.15	4.02
0.15	0.25	0	0	0	0.15	0	0	0	0.77	0.51	0	0	0	0	0	0	0	0	0	0	0	0	0	3.19	3.26
0	1.5	0	0	0.5	0	0.4	2.26	2.77	0	0	0	0	0.33	0	0	0.01	0	0	0	0	0.26	0.46	0	5.17	5.26
0	0	0.62	0	1.23	1.32	0.11	0	0.23	0	0.43	0.21	0	0.15	0.35	0	0.01	0	0	0	0.15	0	0	0	5.08	4.86
0	2.45	0.85	0	0	0	0.665	0.6	0.145	0	0	0	0	0.11	0	0	0.15	0	0	0	0	0	0	0	6.49	9.65
0	0	0.2	0	0.45	0	0	0.35	0	0.12	0.224	0.05	0	0.75	1.63	0	0.085	0	0	0	0	0	0.2	0	4.89	5.25
0	0	0.15	0	0	0	0.762	0.15	0	0.63	0	0	0	0	1.086	0	0.04	0.02	0.32	0.15	0	0	0	0	4.80	6.22
0	0	0	0	0.15	0	0.872	0	0.941	0	0.12	1.061	0	0	0.85	0.23	0.51	0	0	0.51	0.565	0	0.612	0	12.28	9.69
0	0	0	0	0	0	0.12	0.51	0	0	0	0	0	0.32	0	0	0.01	0	0	0	0	0	0	0	2.78	2.85
0	0	0.6	0	0.23	1.05	0.53	0.47	0.38	0.3	0.01	0.11	0	0	0	0.08	0	0	0	0.15	0.04	0	0.25	0.5	5.25	5.13
0	0	0	0	0	0	0.25	0.54	1.15	0.9	0.26	0	0	0.6	0	0.3	0	0	0.66	0	0	0.11	0	0	5.26	5.18
0.5	0	0	0.12	1.23	0	0.12	1.22	0.12	0.12	0.122	0.45	0	0	0	0	0	0	0	0.35	0.01	0	0	0	4.10	2.85
0	0.9	1.2	0	0	0.2	0	0	0.15	0	0	0.12	0	0	0	0	0.15	0	0	0	0	0	0.52	1.3	6.85	10.22
0.98	0	0	0	0.53	0	0	0	0	0.12	0.212	0	0.26	0.89	0	0	0	0.06	0	0.15	0.56	0	0.65	0	5.27	7.22
0.6	0	0	1.3	0	0	0.256	0	1.13	0	0.22	0	0	0.6	0	0	0	0	0.2	0.79	0.15	0	0	0.15	5.12	3.07
0.21	0	0.23	0	0	0	0.54	0.25	0.44	0.11	0.78	0	0	0.58	0.99	0	0	0	0	0.14	0	0.11	0	0	4.60	5.12
0	0.232	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	3.18	2.65
0	0.88	0	0	0	0.61	0.26	0.222	2.05	0.85	0	0	0.78	0	0.32	0.01	0	0.02	0	0	0	0	0	0	4.98	5.29
0	0	0	0	0	0.45	0.6	0	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	5.07	7.90
0	0	1.2	0	0	0	0.33	0.6	0.321	0.051	0	0	0	0	0	0	0	0.08	0	0	0.15	0	0	0	5.86	8.41
0	0	0	0	0	0	0.27	0.55	0.6	0.215	0.71	0	0	0	3.75	0	0.07	0	0	0.55	0	0	0.18	0	6.49	5.46
0	0	0.12	0	0	0	1.22	0	0.15	0	0.6	0	0	0	2.451	0	0.02	0	0	0	0	0	0.51	0.15	5.49	5.64
0	0.15	0.3	0	0.85	0	0.52	0	1.92	0	0.541	0.18	0	0.52	1.21	0	0	0	0.52	0.05	0.52	0	0	0	6.60	6.58
0.62	0	0	0	0	0.51	0.15	0.3	0	0	0.21	0	0	0	0	0	0.001	0	0	0	0	0	0	0	3.25	1.45
0	0	0	0	0	0	0	0.66	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	2.84	3.15
0.11	0	0	0	0.96	0.512	0.6	0.6	0	0	0.76	0.6	0	1.2	0	0	0	0	0	0	0.99	0.85	0	1.56	7.31	7.15
0	0	0	0	0	0	0	0	0.32	0.15	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	2.80	2.00

0	0	0	0	0	0	0.552	0	1.35	0.65	0.55	0	0	0.345	0	0	0	0	0	0	0	0	0	0	3.91	4.22
0	0	1.2	0	0	0	0	0.5	0.6	1.8	0	0	0	0.4	0	0	0	0	0	0	0.6	0	2.6	0	6.61	7.93
0	0.04	0	0	1	0	0	0.13	0	0	0	0	0	0	0	0	0.03	0	0	0	0.11	0	0	0.45	3.23	4.51
0	0.66	0	0.32	0	0	0	0	0	0	0.43	0.12	0	0.66	0	0	0	0	0	0	0	0.11	0.66	0	3.61	3.48
0	0	0	0.5	0.6	0.18	0	0	0.6	0	0.6521	0	0	0	0.63	0	0	0	0	0	0	0	0	0	3.73	2.75
0	0	0.02	0	0	0	0.12	0	0.12	0	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	2.76	1.62
0	0	0	0.15	0.66	0	0	0.63	0.52	0	0.56	0.621	0	0	1.01	0	0.15	0	0	0	0	0	0	0	5.95	6.25
1.62	1.22	0	0	0	0	0	0.64	0.62	0	0	0	0	0	0	0	0	0	0	0	0	1.2	1.2	0	5.15	4.78
0	0	0	0	1.2	0	0.6	0	0.56	0	1.13	0	0	0	0	0	0	0	0	0	0	0	0	0	3.52	2.89
0	0	0.6	1.2	0	0	0.385	0	0.52	0	0.45	0	0	0	0	0	0	0	0	0	0	0	0	0	4.53	4.18
0	0.77	0	0	0	0	0.11	1.7	1.37	1.06	0.78	0.12	0.615	0.15	0.15	0	0	0	0	0.52	0	0.616	0	0.15	5.12	5.34
0	0	0	0	0.15	0	0.165	0.12	0.5	0	0	0.4	0	0.33	0	0	0	0	0	0	0	0	0	0	3.62	3.05
0	0	0.15	0	0.05	0	0.4	0	0	0	0	0	0	0.4	0	0	0	0	0.6	0.45	0	1.33	0	0	4.12	2.39
0	0.3	0	0.15	0	0	0.6	0.3	0.12	0	0	0	0	0	0.14	0	0	0	0	0	0.001	0	0	0	3.25	2.35
0	0.52	0	0	0.62	0	0	0	0	0	0.6	0.18	0	0	0.26	0	0	0	0	0.55	0	0.15	0.516	0.15	3.98	4.95
0	0	0	0	0	0	0.47	0	0.12	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0	0	3.21	3.04
0	0	0	0	0	0	0	0	0.48	0	0	0.5	0	0	0	0	0.13	0	0	0	0	0	0	0.5	4.91	5.16
0	0.74	0	0	0	0	0	0.4	0.65	0.125	0.66	0	0	0	0.6	0	0	0.05	0	0	0	0	0	0	4.46	4.58
0	0.6	0	0	0	1.1	0.2	0	0.945	0	0.11	0	0.11	0	0	0	0	0	0	0	0	0	0	0	3.77	2.85
0	0	0.56	0	0	0.05	0.85	0.71	0.765	0.1	0	0	0	0.66	0.44	0	0	0	0	0	0	1.25	0	0	5.19	4.19
1.2	0	0	0.23	0	0	0	0	0	0.2	0.12	0	0	0	0	0.04	0	0.02	0	0	0	0	0.22	0.3	4.06	4.55
0	0	0	0	0.63	0	0.52	0	0	0.415	0	0	0	0	0	0	0	0.054	0	0	0	0	0	0	3.67	6.65
0	0	0	0	0	0.45	0.45	0.14	0	0	0.25	0.2	0	0.9	0.55	0.01	0	0	0	0	0	0	0	0	3.88	4.94
0	0.07	0	0.65	1.04	0	0	0.14	0	0	0	0	0.28	0	0	0	0.09	0	0	0	0.04	0	0	0.32	3.84	5.44
0.25	0	0	0	0.15	0	0	1.1906	0.662	0.021	0.216	0	0	0	0.32	0	0	0	0	0	0	0	0	0	3.33	2.85
0	0.36	0	0	0	0	0	1.2956	0.89	0	0.15	0	0	0.11	0.15	0.01	0	0	0	0.3	0	0	0	0	3.54	3.84
0	0	0.12	0	0	0	0.85	0.23	0	0	0.38	0.62	0	0	0	0	0.04	0	0	0	0	0	0	0	4.68	5.81
0	0	0	0	0	0	0.52	0.25	0.15	0	0.15	0	0	0	0.22	0	0	0	0	0	0	0.52	0	0	3.36	3.13
0	0	0.3	0	0	0	0	0	0.342	0.12	0.1	0.11	0	0.11	0	0	0	0	0	0	0	0	0	0	3.41	3.22