A Case Study of Investigation the impact of International Roughness Index in developing pavement deterioration model in the United Arab Emirates

دراسة أثر معامل الخشونة في التنبؤ بمعدل انحلال الطرق في دولة الامارات العربية المتحدة

by

KHAMIS ALI OBAID ALSHEHYARI

A dissertation submitted in fulfilment

of the requirements for the degree of

MSc PROJECT MANAGEMENT

at

The British University in Dubai

Prof. Boussabaine Halim

October 2017

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Abstract

Pavements characterized as an important infrastructure all over the world. As we all know UAE is becoming day to day famous over the worldwide therefore they are investing and focusing how to construct in a large network. Throughout the study, I have notified the core aim of this project is to find and demonstrate any correlation between some pavement condition parameters as can be IRI, rutting, deflection and cracking and to know if this hypothetical correlation can be used to determine and predict the behavior of some of them based in the knowledge of only one.

Arabic Abstract

يعتبر رصف الطرق بأنه البنية التحتية الهامة في جميع أنحاء العالم، وكما نعلم جميعاً أن دولة الإمارات العربية المتحدة أصبحت اليوم من الدول الشهيرة في جميع أنحاء العالم ولذلك فهي تستثمر وتركز على كيفية بناء شبكة كبيرة. خلال هذه الدراسة، فأن الهدف الأساسي من هذا المشروع هو إيجاد وإثبات أي ارتباط بين بعض مميزات حالة الاسفلت مثل معدل الخشونة الدولية، الاخاديد، الانحراف والشقوق ومعرفة ما إذا كان هذا الارتباط الافتراضي يمكن استخدامه للتحديد والتنبؤ بسلوك بعض منها على أساس معرفة واحد فقط.

Acknowledgements

In the name of Allah, the most merciful and beneficial. Thanks to Allah and Peace by upon his last and final Prophet, the teacher of the humanity and on those who follows his path.

I would like also to give my warm appreciation to my professor Dr. Halim for his encouragement, help and support throughout my Master study. His patience, passion, expert and skillful guidance made this work possible.

Special thanks to my work colleague Daniel Llort, who devises made this dissertation more solid and sound. Also Administration for supporting project funding I would like to express my appreciation to him.

The study has really helped me to explore more knowledgeable information related to my job which will help me in the future.

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Chapter One

1.1 Introduction

Roads management is a big task for administrations and concessionaries nowadays. High levels of service established for the road assets and its control has become critical and difficult to manage. The big amount of data need to be processes, analyzed and storage in proper way but also at fast speed in order to improve the maintenance and operation conditions. Without a doubt, pavements are one vital element to control in roads (especially asphalts). Representing in general cases in between 80 to 90% of the investment amount to keep them in operational conditions has become a critical task to keep the traffic flow in safety conditions for all users.

Several tools have been developed during the last years in order to perform a proper roads maintenance and operation, but related to PMS (Pavement Management Systems), models run from the data collected from the pavements. This data is basically structural (cracks and deflection) and comfort (IRI and Rutting) parameters. And this information will be applied to the models contained in that PMS in order to get the proper output of activities to do during the coming years to keep the asphalts in a certain level of service.

In order to collect the most information for pavement condition, to have most accurate maintenance plan is necessary to have and operate high performance devices. Data collection has evolved from almost manual methods to collect in mobile devices almost at 80Km/hr or deflections performing around 30Km in an 8 hours shift (if separation between points is approximately 200m).

This data collection can be done in continuous way for almost all pavement condition parameters (IRI, Rutting, Cracking) and almost in continuous mode by the deflectometer (from 20m o 200m). Collect information in continuous way generates a lot of information. All information obtained on site needed to be integrated by obtaining the average of the measurements and applied to the desired sections. Once this information is collected and integrated, needed to be applied to the corresponding sections of the road from which were collected, and then the models contained in the PMS should run to get the previously mentioned output. The output will indicate basically what activities to do in order to keep a previously defined level of service, when to apply that activities and how much they will cost, indicating the time these activities will keep (at least) the expected and defined level of service.

The described activities constitute the basic scope of the PMS output, but some more advanced will calculate the social and environmental cost, if the proper information is loaded. In definitive and as per the description above there are two main components to get a proper maintenance plan: the quality on the data collected and the validity of the models within the PMS, from those both the data collection, process and storage requires some months in a medium size network with approximately 700Km length of center line (around 4 to 6 months).

Sometimes the distribution of tasks, the progress reached in the knowledge of the network, budget or a combination of them force the corresponding agency to modify the original plan for data collection. These modifications make the corresponding agency to assume that in those locations where the data were not collected the information will be lost. Is definitely obvious that some parameters are connected with each other, since once rutting appears IRI will be modified and depending on the defect value, cracks will appear and of course the structural capacity of that asphalt will be affected too. But, how much?

There are some references about correlation in between some parameters, published from some interesting researches, but not all parameter involved (mentioned before) interact at the same time in those researches. This project has the main objective of looking for the multiple correlation as mentioned in the previous paragraph and to look for the better adjustment of the two best related parameters (IRI and Rutting considering this last one as the independent value, from the observation of the networks in UAE carrying heavy loads in great amount making appear rutting almost in first place of all roads defects. Rutting can appear in small amounts without modifying IRI). If these correlations work and show that there are reliable, a good methodology to collect information can be studied to be developed and standardized (at least at UAE roads), a lot of work can be redistributed and performed in fast and reliable way.

As first step is required, to do this study, to select the segment or segments in which the research should be implemented. This first step consists in collect the information available for some real segments of roads and apply the regression methodology in order to start and know a first approach, related to calculate the IRI from Rutting values and after, if it works properly, to determine if some other parameters can be included as multi-parameter analysis. The results indicating a correlation between both parameters Rutting and IRI will allow to extend the study and regressions to other forms rather than the linear one. There are some geometric shapes corresponding to parabolic equations or third or different power and nonlinear equations. Determine if there’s a possibility to predict the value of some parameters from a single one from those related to the pavement condition is very important, and will constitute a powerful tool for technicians to determine some parameters in the roads without measuring.

In order to consider the correlations established as consistent and reliable, is needed first to determine the statistical parameters that will ensure that reliability (value of R, R^2, residual, mean, variance, standard deviation, etc.),and their corresponding values. For that, SPSS® program was used. ANOVA analysis was performed in all cases and the determination of which one of the selected regressions to be studied (quadratic, cubic and power).The proper study in this matter will determine and will help to understand if these type of correlations are feasible and possible.

The data collected was chosen from one of the roads surveyed by the Ministry of Infrastructure Development. It is considered one of the main axles East – West of the country and is highly occupied by trucks during the whole day with loads exceeding the 120ton per truck. The fact that this road has been surveyed before and the results can be contrasted along the models developed is a bigger advantage since a first contrast of information can be obtained without surveying again the road.

This selected road has 74Km in center line total and goes from Sharjah to Al Dhaid and after to Masafi (with the Federal Road number E88). The road connects Sharjah Urban area with the area of the country which has more crushers and some important maritime ports. If this study provides positive results will be important to keep developing it to get different objectives, as can be the total customization of the process to the full network, the knowledge of what parameters won't follow that model anymore due to the pavement conditions or lack of maintenance.

The follow up of this study should be under the research umbrella and should follow a specific existing measurements in order to calibrate historically (backwards) and currently in the present situation in order to obtain an accurate prediction for the future.

There are some other considerations to take into account related to the success of the application of the models. Some practical applications should be taken place in the PMS decision tree or procedures and some introduction of the evolution predictive model, will change the way we apply that data to the PMS maintenance plan (which is the PMS output).

Chapter Two

2. Literature review

2.1 Pavement Management

The efficiency and effectiveness of many civil engineering structures is largely dependent on their management. This ensures that such structures are able to last long and serve the purpose for which they are constructed as well as incur minimum cost. Pavements management system (PMS) describes all the set activities or practices that are coordinated and directed in such a way to ensure the achievement of best value possible in relation to the available funds. It implies that the system aims to efficiently utilize the resources available in order to produce a long lasting and sustainable pavement network. As a management system, PMS is expected to serve the different needs and levels of management. This means that the system must interface the broader requirements in the management of highways and airport as well as other structures incorporated in the pavement network.

The concept of pavement management system was developed as soon as the first pavement was invented. It resulted from the need to ensure that pavement designs, construction and maintenance of pavements was done in such a way that it was cost effective, long lasting and served the needs of its users effectively. As the pavement networks continued to grow rapidly in especially the first half of the twentieth century, PMS became more popular. This management system was coined and largely adopted in pavement structures during the 50s and 60s as the previous procedures in developing and maintaining pavements were proving to be less efficient due to the burgeoning networks (Mubaraki 2010). Civil engineers and other key stakeholders in the construction industry were concerned with developing a more holistic systems approach that would meet the new demands in the pavement structures. The various activities involved in PMS were originally described as “a systems approach to pavement design.” However, expansion of the pavement networks required a system that would ensure that all support tools for the entire range of activities relating to development and maintenance of pavements be adopted. This is what prompted the adoption of PMS as it was seen as a "total pavement management system." PMS can broadly be viewed as a system or interface that involves mutually interacting components of planning, programming, design, construction, maintenance and rehabilitation of pavements (Mubaraki 2010). The chart below provides an overview of the integral components of PMS.

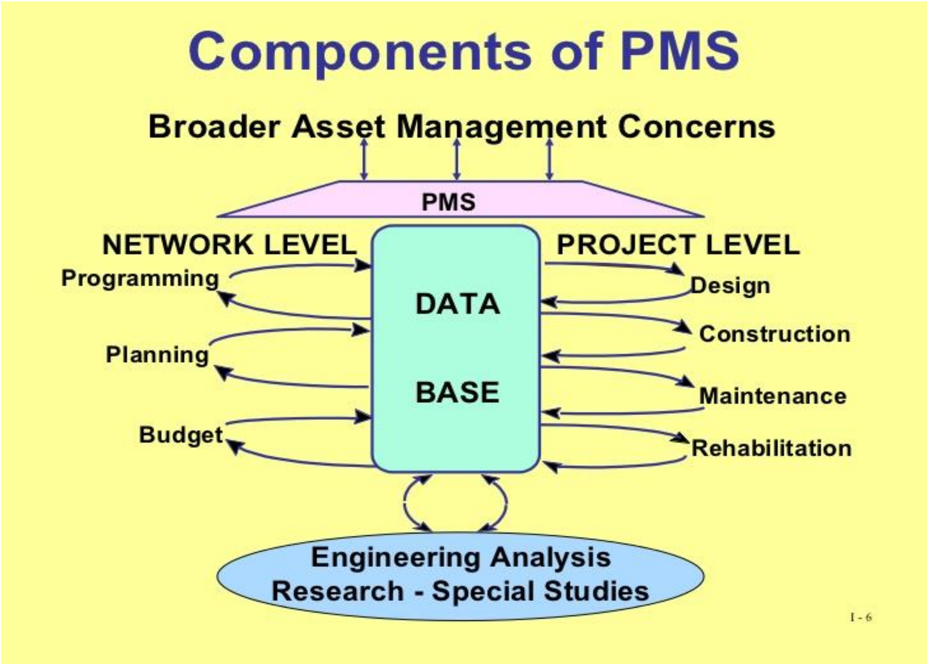

Figure 2.1 Components of PMS

Most of the people and agencies working in the pavement field have not developed a solid agreement in relation to the use of fundamental terminology in the field. However, a close examination of the local experience in this field present five key components of pavement management system. To this end, pavement condition studies were conducted in the mid-60s by some US transportation agencies on the first component (Helali et al. 1996). It is a component whose major concerns are in the advancement and refinement of various measurements in the pavement design, construction and maintenance. The component is also concerned with collection of data relating to these measurements. Databases are the other key components in the PMS. They incorporate all the information relating to pavement right from its design, construction costs, materials, measurements, projected lifetime among other scales and levels of information. Advancement in technology has immensely revolutionized how pavement databases are managed in terms of the amount of data stored, ease of access of such data, as well as manipulation of the same (Mubaraki 2010). Analysis scheme is yet another key component in PMS and closely relates to databases as it defines algorithms of how pavement data can be interpreted in order to develop or create meaningful information from it. Much focus and emphasis has been put in the recent years to facilitate advancement or refinement of optimization algorithms, life-cycle cost analysis and performance prediction. The next key component in PMS is decision criteria which refer to the rules defining how decisions in pavement management are made. Helali et al. (1996) points out that combination of the various components of PMS such as decision criteria, database and analysis scheme is possible through the recently developed computer software. Procedures for implementation are the last key component in PMS and describe methods used in application of management decisions.

The future of pavement management systems appears to be better in terms of adoption of new methods and procedures that will enhance the efficiency and effectiveness of the system. It has continued to experience tremendous evolution over the years since its introduction and large adoption as a management system in the pavement networks during the 60s. Incorporation of various aspects relating to technology in the key components of PMS will particularly contribute to significant changes in future. This is attributed to the fact that technology is constantly going through numerous changes and improvement aspects. Such changes are aimed at creating more efficient and effective systems as well as ones that are largely reliable. In this regard, the huge reliance of technology by pavement filed implies that its future will significantly be affected by the various advancements technology (Haas, Hudson, & Zaniewski 1994). For instance, computer software are already being used in the development of pavement designs, different databases have already been developed and use in the market, analysis schemes have also been enhanced through technology. With the progress and advancements being witnessed in the technology field, pavement management system will also continue to experience development of more sophisticated designs, higher efficiency levels and effectiveness hence lower costs in the construction and maintenance of pavement networks

2.2 International Roughness Index (IRI)

There are various aspects and standards relating to pavement management systems. One of the most common standards is the international roughness index (IRI). This standard is a measure of the pavement roughness which refers to the irregularities characterizing the surface of a pavement. The higher the level or scale of this roughness, the more adversely the effects it has on the ride quality of a vehicle or other users on that particular pavement. This implies that roughness is a significant aspect of the pavement for civil engineers to consider during the design process. Different tools have been developed to measure the IRI of a pavement. However, operation of most of these devices is complicated as they require to be mounted on a full-size automobile. In addition, most of them are relatively expensive. The road management industry and in particular the pavement management system require development of easy, cheap and reliable methods for IRI measurement. The quarter car model has hence been developed as a method of measuring the IRI of a pavement (George, Pajagopal, & Lim 1996). This method employs the strong correlation between the vehicle vibration caused by the road roughness and the in-car Z-axis acceleration. Since the development of IRI in 1986, it has become a well-recognized standard in determining the roughness of a pavement. The use of this standard presents a number of advantages to civil engineers and other individuals involved in the design of pavements such as those on the Ministry of Infrastructure Development. Stability of IRI standard over time and its transferable feature throughout the world are some of the key advantages (George, Pajagopal, & Lim 1996). The graph below indicates the use of pavement condition index (PCI) in determining the roughness index and status of a pavement.

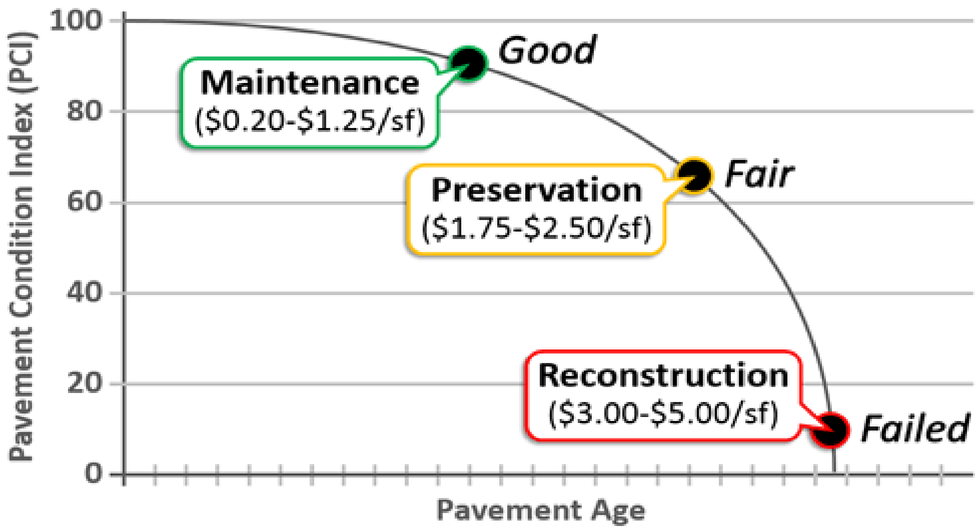

Figure 2.2 Pavement condition index with respect to pavement age

2.3 Rutting

There are different failures that characterize pavements once they are complete and already in use by vehicles and trucks. Rutting is one of the major failures. This type of pavement failure refers to the surface depression that occasionally occurs along the wheel path. The road is seen to exhibit some uplifts or shearing along the main path of wheels for vehicles using it. It is mainly evident during the rainy season and in areas where a pavement covers a relatively marshy or water logged underground. Rutting is largely classified into two types namely sub-grade and mix rutting (Jackson, Deighton, & Huft 1996). Sub-grade occurs when the pavement surface is characterized with wheel path depressions as a result of compaction due to loading. The pavement hence settles into the sub-grade. Mix rutting on the other hand occurs when there are mix or compaction design problems for the pavement. Rutting is derived from the fact that the wheel path is the main point of contact between the vehicles using the pavement and its surface. It implies that most of the weight carried by a vehicle on the pavement is distributed to the ground through the wheel path. This creates various points of weakness on the pavement along the wheel path especially after a rainy season where the ground is softened by the perforation water. With vehicles continuing to use this pavement and loading the points of weakness, shearing and uplifts of some section soft the pavement occurs and are described as rutting. This leads to a permanent deformation of the pavement surface. The problem with ruts is causing vehicle hydroplane which presents a danger to pavement users. This occurs when the ruts eventually turn into large surface depressions that may ultimately be filled with water. Various causes of ruts have been identified which include insufficient compaction of the pavement's layers or sub-grade during construction. The other major cause is the improper mix design of the materials used in the pavement construction (Huang 1993). Fatigue and rutting curves must be drawn as shown in the figure below to help determine a balanced design point.

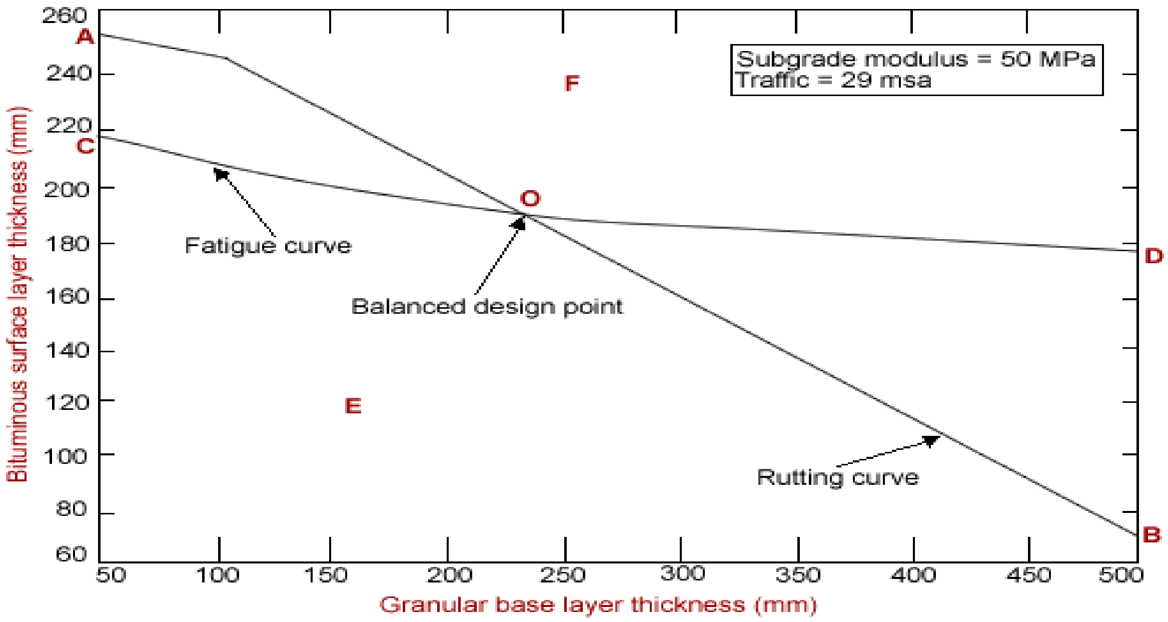

Figure 2.3 Fatigue and Rutting Curves (Jackson, Deighton, & Huft 1996)

2.4 Deflection

Pavement surface deflection is yet another key aspect to be considered by civil engineers in the design process for pavements and roads. Measurements relating to surface deflection are very important as they form the basis of evaluating the flexibility and rigidity of a pavement structure in relation to load transfer (Barrie &Paulson 992). Despite the availability of other methods to measure these pavement design elements, deflection has proven to be a suitable option in the evaluation of pavements due to the fact that its shape and magnitude are a function of the type and volume of traffic on that pavement. In addition, pavement surface deflection is a function of the structural section of the pavement which implies that it is dependent of the effects of temperature and moisture on the structure of that pavement. These relationships allow pavement designers and civil engineers to develop calculation procedures that help them in the determination of elements such as pavement structural layer stiffness as well as the resilient modulus of the sub-grade. The measurements obtained pavement surface deflections are utilized in these calculations. Back calculation is one of the most commonly used calculation method that involve the use of surface deflection. In addition, these measurements are non-destructive as engineers do not need to rip off a section of the pavement to evaluate its structure. There are three broad categories of test equipment used in deflection measurements namely static, steady state and impact load deflections (Huang 1993). The measurements involve identifying the scale of vertical deflection distance of the load in multiple locations along the pavement. The Benkelman beam is one of the most widely used devices used in the measure of surface deflections.

2.5 Cracking

Cracks are common a problem and challenge faced by civil engineers in the pavement management. Cracking is described as one of the pavement failures. There are various elements that have been identified to cause cracks on roads and pavements. Fatigue failure is among the most common causes of cracking. It results for the continuous loading of the pavement due to the passage of vehicles, trucks and cargo on its surface. When the pavement layers cannot handle the large tensile stress originating from such loading, the layers give in through development of one or more longitudinal cracks on the pavement surface (Hudson, Hass, & Darly 1979). This type of cracking is generally described as classical or bottom-up fatigue cracking. Through the repeated loading and more cracking effects, the surface of the pavement is eventually characterized by cracks that may form a pattern that is almost similar to the back of a crocodile. Cracks are classified as a pavement problem as they not only symbolize structural failure, but also increase its roughness and allow easy infiltration of water into the pavement layers. In addition, they weaken the pavement surface and may deteriorate further and result to the development of a pothole. Some of the major causes of cracks on pavements include inadequate structural design and poor construction as well as increase in loading hence tensile stress on the pavement layers. Poor drainage along the pavement is also another major cause of development of cracks (George, Pajagopal & Lim, L 1996)

2.6 Friction

Friction is one of the key forces in relation to the enhancement of motion. It is the force that allows the tires on a vehicle's wheel to have grip on the pavement surface to allow movement. In addition, this force is critical during the breaking process of a vehicle where adequate level of friction prevents it from skidding during the process. It is hence a crucial factor of consideration in the design and construction of any pavement. Safety factors in particular put much emphasis on the incorporation of various aspects of friction in the pavement design process. Extensive and thorough understandings of the various factors affecting friction on a pavement are required in the design of safer roads. This also involves the materials, equipment and construction techniques that dictate the ultimate friction on the initial and long term scales. It further requires a clear understanding of various engineering and economic tradeoffs associated with these techniques and materials (Hajek, Phang, Prakesh, & Wong 1985). These include aspects such as cost-benefit analysis in the utilization of one friction strategy over the other. The pavement surfaces should hence be designed in such a way that it provides the appropriate co-efficient of friction in order to achieve the desired level of safety for its users. This incorporates designs in the construction of a new pavement or rehabilitation of an already existing pavement. Appropriate combination of macro- and micro-texture is hence required in the achievement of adequate friction. This implies that pavement designers should be able to strike a complex balance between pavement roughness and the right co-efficient of friction. It means that the surface roughness should not be very high to exhibit the extreme levels of adverse effects it has nor should be too low to compromise the safety of pavement users (Hunt & Bunker 2001).

2.7 Pavement Distresses

The design, construction and maintenance of pavements are focused at ensuring that the pavement is able to provide several year of satisfactory service. However, due to the numerous distresses experienced by pavements, this is usually not the case. Such pavement distresses lead the damage of pavement layers and surface which is translated into shorter life cycle for the road or pavement, poor services as well as increased cost of maintenance. There are various types of pavement distresses; some are exhibited on the pavement surface while others are found with the structural layers of the pavement (Garcia-Diaz & Riggins 1985). Some of the common types of distresses include fatigue cracking and rutting as described above. Others are bleeding, corrugation, longitudinal cracking, raveling, potholes, stripping, etc. Bleeding is a pavement distress characterized by a film of asphalt binder that appears as a shiny, glass-like reflecting surface on the pavement (Hajek, Phang, Prakesh, & Wong 1985). This film is often slippery when wet while sticky on drying. Corrugation on the other hand is a ripple-like distortion that appears on the pavement surface and is usually perpendicular to the direction of traffic. It is regularly found in sections of the pavement where traffic constantly starts or stops or areas where the pavement structural layers borders a rigid object.

Raveling pavement distress is characterized by loose debris, high roughness and water collection on the raveled sections.

Each of the pavement distress has its leading causes. However, some of the common causes for most of these distresses include poor structural designs, insufficient compaction of pavement layers, improper mix design, poor construction, improper drainage systems, increase in loading, decrease in the pavement load support characteristics, poor pavement joint construction, mechanical dislodging due to wear and tear, etc (Garcia-Diaz & Riggins 1985). The solutions to each of these distresses lie in identifying its leading cause and developing a remedy for it. For instance, the rutting distress is largely caused by insufficient compaction of the pavement structural layers, improper mix design and poor drainage system. In this regard, the solution to this distress is largely based on ensuring that there is sufficient compaction during the pavement construction process. The design of the materials used in the construction of pavements furthermore needs to be done correctly in the appropriate ratios to ensure durability (Hudson, Hass, & Darly 1979). Drainage along the pavement should further be observed to ensure that there are no marshy sections developing along the pavement as this result to high level of water infiltration and result to softening of the pavement underlying layers. Proper observance and address of each of these key factors causing rutting will ensure that this type of distress does not occur. This approach should be applied in the case of each of the other pavement distresses hence providing solutions to all of them.

Pavement management system (PMS) is at the heart of enhancing that such solutions are found in an effective efficient way. This is largely attributed to the fact that PMS has developed into various levels and models that address each of the needs and steps needed in finding solutions to such pavement distresses (Bennett 1996). The two major structural PMS levels are the system/network and project levels. The pavement network encompasses the network/system level and is the focus of high-level decisions with regard to policy development, planning and budgetary issues. This level allows managers to significantly consider an analysis of program/budget relation that provides greatest cost-benefit ratio. Project level on the other hand is concerned with smaller sections of the broad pavement network. This implies that this level focuses on lower-level decisions relating to unit cost in pavement condition, their maintenance, reconstruction and rehabilitation (MR&R). These levels of PMS are supported through the various evolution models. There are three major evolution models that have been developed; pavement condition analysis and priority assessment models that support the project level approach and the network optimization models that support network level approach (Helali, Kazmieroweski, Bradbury, & Karan 1996). Pavement condition analysis is the simplest of the three evolution models. It focuses on aggregation of all the information relating to pavement condition in order to identify and adopt the most appropriate MR&R strategy. Priority assessment model on the other hand I concerned with the improvement of pavement condition. It hence puts into consideration the prediction of future conditions. This model allows managers to make a transition from the low level decisions into high level decisions. Network optimization model is the third and high level decision model. It incorporates the evaluation of the broad and more sophisticated pavement network. This allows the managers to identify and adopt the optimum network management strategy (Harper & Majidzadeh 1993).

2.8 Pavement Design

Pavement design is a very integral aspect in the construction and maintenance of various roads and other pavement structures. Development of designs is the starting point for civil engineers in the establishment of any structure they are involved in. The main objective of pavement design is to provide a descriptive outline of the most fundamental aspects or features relating to pavement construction (AASHTO 2001). The design provides the characteristics of the pavement with the concern of other factors surrounding the construction, maintenance and use of that pavement put into consideration. This implies that the design envisions the completed pavement and its impact or effects on various elements and people even before the pavement construction I commenced. Barrie &Paulson (1992) points out that some of the external parameters that must be put into consideration by pavement designs include the environment, traffic loading, and sub-grade characteristics. There are two major or widely used types of pavement design namely the mix and structural design. Some of the most fundamental parameters that pavement designers must put into consideration include flexibility of pavement ESAL equation, determination of resistance value, environment and temperature variation, shrinking and swelling soils, traffic loading among others (HDM-4 Manual 2001). Various regions have embarked on enhancing their approach to pavement designs. United Arab Emirates is one of the regions that have made significant strides towards this step. The Gold Coast City Council is yet another region that has put in place a number of changes to their pavement design requirements (Al-Suleiman, Kheder, & Al-Masaeid 1992). These designs are more concerned about meeting current standards in the international scale in regard to costs and materials among others.

2.9 Specifications

The major characteristic of a pavement captured in its design largely encompass its specifications. They are the most fundamental elements that must be considered in the design, construction, maintenance and rehabilitation of a pavement. In this regard, they form a basis for civil engineers and designers to produce an exact match or an improvement of the pavement described by the client (Adel, Thomas, & Michael 1996). Examples of some pavement specifications are captured through the statement of the coefficient of friction of pavement safety purposes, flexibility of pavement ESAL equation, statement of environment and temperature variation, determination of shrinking and swelling soils, traffic loading, etc

(Christine 1996). Adherence of pavement specifications ensures that what is designed and constructed is a match to the expectations of the client.

2.10 Materials

The design, construction, maintenance and rehabilitation of pavements involve the use of diverse range of materials. Darter (1980) indicates that selection of these materials requires the civil engineers to put into consideration a number of factors including the durability of the pavement, safety for its users, its efficiency and effectiveness as well as the cost involved. In this regard, civil engineers are concerned with acquiring the best information relating to the thickness, type and strength of each of the materials used. This is particularly so due to the fact that materials selected and used in pavement construction are the major determinants of its characteristics (Barrie & Paulson1992). The data about these materials is hence put in the database as required in the pavement management system. A few agencies in the pavement management field focus at having this information for all their sections relating to pavement construction. However, many of these agencies develop individual models by grouping the various sections together.

2.11 Environments

There are numerous environmental factors that affect the design and construction of pavements in a particular region. These factors also have a significant level of impact on the maintenance and rehabilitation procedures for the pavement as well as cost aspects. Different regions have varied environmental conditions that are largely dictated by its weather during a particular period and the climate. Weather stations provide the relevant information in relation to the environmental conditions. In this regard, the model developed in the design and construction of pavement may differ from one region to the other if the two regions do not have the same environmental conditions (Huang 1993). However, for all pavements with a particular region that is affected by or exhibits uniform conditions in relation to the environmental factors, a model for the local area may be developed. Such a model may appear to neglect the environment when adopted in the construction of one pavement or the other. Consideration of various factors relating to the environment result to variation in age projection of a pavement. The older sections of a pavement will hence appear to show more influence of the environment due to the fact that they have been under the exposure to it for a relatively longer period of time. In most cases, pavement age is largely affected by the various environmental factors including erosion and solar radiation among others (Garcia-Diaz & Riggins 1985). Modifiers are adopted by some agencies in developing their model by considering condition prediction as a function of age. The pavement management systems (PMS) require the adjustment of prediction model for different environmental zones.

2.12 Traffic load

Though there are a number of factors civil engineers and other stakeholders in the pavement management field consider as having an effect on pavement design and performance, traffic load is inarguably one of the most fundamental factors. This key element is characterized by traffic volume, axle configuration and load, tyre pressure, repletion of axle load and speed of the vehicle (Harper & Majidzadeh 1993). PMS requires proper formulation and investigation of traffic loading during the development of a pavement design. However, axle loads in PMS have not received adequate focus to ensure that it is largely adopted as one of the variables of pavement condition prediction. The fact that loadings make the biggest contribution in relation to the factors that affect damages of most pavement sections, traffic load is constantly used as an independent variable in the development of condition prediction equations. The other independent variable that is sometimes combined with traffic loads in these calculations is the factor of age. This is particularly drawn from the need of agencies to determine the number of years the pavement is projected or predicted to work efficiently. Some models consider traffic load as a factor whose main impact is reflected in the rate of pavement condition change (Barrie &Paulson 1992). In this case, such change is considered or expressed as function of time which is used as the independent variable.

Traffic loading is largely measured in terms of the number and types of vehicles using a particular pavement. Small cars for instance will comprise low levels of traffic loading while the presence of large trucks will constitute heavy or huge traffic load. In addition, the time of traffic also affects the rating of pavement traffic load. With numerous vehicles being along the pavement for a significant duration of time, they are said to constitute a large traffic load that when the vehicles are only on the pavement for a short duration of time. For instance, when vehicles are moving along the pavement with significant levels of speed such that they do not take long on the pavement, such situations are considered to have a lower magnitude of traffic load. Large pavement network is also significant in helping in the distribution of traffic loading on the pavements in a particular region (Butler, Carmichael, & Flanagan 1985). Regions with poorly developed pavement network implies that the few pavements available are expected to handle all the traffic load found in that region hence result into very high traffic loading being witnessed. As earlier pointed out, heavy loads such as trucks significantly contribute to presence of large traffic loading.

2.13 Pavement age

The design and construction of any pavement must put into consideration its expected life cycle which define the age it is projected to efficiently. It is a major concern for civil engineers and other stakeholders in the pavement management field. They are keen at ensuring that the pavement design, its cost, projected age, efficiency and structural adequacy, serviceability and the measure of ride ability provide a relative match. This implies that the pavement service output is able to signify the value for the input made during its construction, maintenance and rehabilitation processes (Mubaraki 2010). Pavements that provide a large duration of time of effective and efficient services without the need of constant incurrence of additional costs are most desired and acceptable among designers in the pavement management fields. Such pavements are able to withstand the various types of distresses resulting from the traffic loading for a long period. The longer the pavements age the higher the level of acceptability of that design.

All pavement works deteriorate with time at an increasing rate. At first, very few distresses can be noticed, and it stays in a relatively good condition. Gradually, the defect becomes more noticeable making it easier for subsequently distresses (‘Pavement life cycle 2012). For instance, if a crack forms on the pavement, it becomes easier for water to filtrate through and hence weakening the subgrade. In this regard, the pavement undergoes through several stages from its original design to the end of its useful life where it requires renovation.

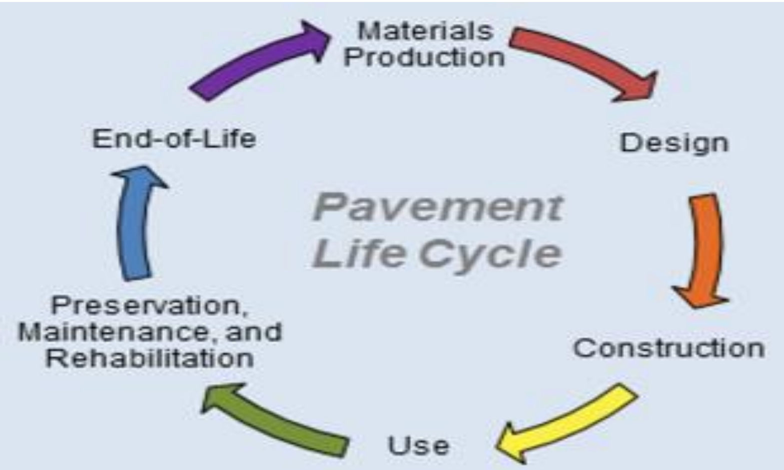

Figure 2.4 Pavement Life-cycle stages.

The initial step in pavement life-cycle is material production (‘Pavement life cycle assessment framework’ 2014). This stage includes various steps in the acquisition of materials used to make pavements including mining and crude oil extraction. Additionally, it also entails the processing of the required materials such as refining, mixing, and manufacturing of materials. Another critical undertaking at this stage is the transportation of the materials to their destination.

The next stage is the design which entails identifying the functional as well as the structural use of the pavement in a particular site. Some criteria to consider include the subgrade, traffic, type of climate and the existing pavement structure. Moreover, it is important to determine the structural composition of the pavement. Besides, the accompanying materials used together with the pavement are a critical consideration.

Construction is another stage that includes all the processes and equipment associated with building of the original pavement. Also, this step entails mobilization and demobilization of material to and from the site. Additionally, use and recycling of energy is a factor deliberated at this point. Other aspects at this juncture are work zone speed, the traffic, and diversions.

The next one is the use phase which is the duration in which the pavement is in service. The pavement is interacting with human and vehicle traffic. The other critical component in this point is its impact on the environment. Other considerations in the use stage are pavement structure that affects fuel economy and permeability that consequently impacts storm water or runoffs ('Life cycle assessment of pavement' 2014).

Maintenance and preservation are the last stage. These activities are performed on the pavement throughout its life to increase its serviceability. Some of the maintenance caution taken on the pavement is the filling of the cracks to prevent further damage. Also, regulation of traffic loads in public transport is another way of preserving pavement (Huang & Parry 2014).

The last stage of the pavement cycle is referred to as End of Life. It involves the ultimate nature and consequent reuse. It paves the way for reconstruction and rehabilitation of that particular pavement structure. The information about the remaining materials is collected and used in the new pavement construction. In a rare situation, the materials may be directed to fill a landscape (Santero et al. 2011).

Pavement structures when well-constructed are serviceable to a considerable span of time. Nevertheless, it should undergo the stages mentioned above. In connection to that, the effort that can be done to expand its life cycle is to use it and prompt maintenance whenever required. In this way, the lifespan increases in comparison to when it is abandoned without any preservation.

Chapter Three

3. Modeling and Data Analysis

3.1 Argumentative statement

Roads in service are subjected to continuous pass of vehicles axles, asphalts (and more specifically pavements) were calculated for that purpose and to support and provide service to a certain number of axles before the end of their useful life.

There are some international accepted parameters to measure the comfort and safety for road users and they are related in some extend depending on different factors on the moment for calculation. Some of them are structural (as cracks and deflections) some represent the comfort for the user (as rutting and IRI) and some others are directly referred to safety (as Friction and Macrotexture). In this chapter we are going to analyze if there is any correlation between the two parameters referred to the user's comfort and, if this correlation exists, then we will try to represent it.

3.2 Use of SPSS® (Statistical Package for the Social Science)

The use of a powerful statistics analysis tool will be used in order to process the input data and determine the best adjustment and correlation between both mentioned variables. Final process output will allow to determine if, the correlation we are looking for exists and what is the best one amongst all the possibilities. SPSS® was property of *SPSS, Inc*, until 2009. In that year IBM acquired it.

3.3 Hypothetical statement

The analysis is going to be performed in the slow lane of Road E-**88 (Sharjah – Dhaid - Masafi).** It is the intention of this analysis to demonstrate that if a relation between Rutting and IRI exists, and how this relation can be expressed in a way that, any estimation in the response of one of the parameters can be performed.

3.4 Analyzed Sample

The analyzed sample was created from the available data collected by high performance devices. In this way, those parameters are collected in continuous way, then the values are integrated in 10m sections within the lane, along the total length of the road. As can be seen in the below example from point 0+000 to 0+100.

Road 1			
Origin	End	IRI	RUTT
0+000	0+010	0.83	1.22
0+010	0+020	0.73	1.24
0+020	0+030	0.69	0.83
0+030	0+040	0.67	0.72
0+040	0+050	0.7	1.02
0+050	0+060	0.7	1.16
0+060	0+070	0.69	1.07
0+070	0+080	0.71	1.01
0+080	0+090	0.72	1.03
0+090	0+100	0.65	0.62

For this study, the pairs of data (Payment condition Parameters) were integrated for second time, in sections which length were 500m. The final analysis was performed in a 74 pair of data as can be seen below from the data input in SPSS. The 37Km road will be then represented by those 74 points, which are the average of the values contained in each section of 500m length.

3.5 Descriptive Statistics

The data collected in this study involved four main road parameters including deflection, rutting, IRI, and cracking. In each of the four cases, 74 measurements were taken from a 37 km stretch of pavement and the descriptive statistics summarized in table 3.1 as shown.

Table 3.1 Descriptive statistics of all research variables

Descriptive statistics (Quantitative data):				
Statistic	**IRI**	**RUTT**	**DEFF**	**Crack**
Number of observations	74	74	74	74
Minimum	0.640	0.600	12.890	0.010
Maximum	1.150	2.920	31.470	2.030
1st Quartile	0.803	1.138	19.513	0.120
Median	0.900	1.565	21.485	0.725
3rd Quartile	0.958	1.888	24.760	0.920
Mean	0.885	1.584	22.046	0.628
Variance (n-1)	0.015	0.308	16.101	0.239
Standard deviation (n-1)	0.124	0.555	4.012	0.489

From table 3.1 above, it is noted that deflection values (DEFF) demonstrates the largest standard deviation from the mean hence suggesting that the data set for the variable largely fluctuated compared to the rest. Nonetheless, the other variables were realized to exhibit reasonable levels of data consistency. The four sets of data were represented in figure 3.1 and figure 3.2 to help in understanding the overall trend before engaging in analysis.

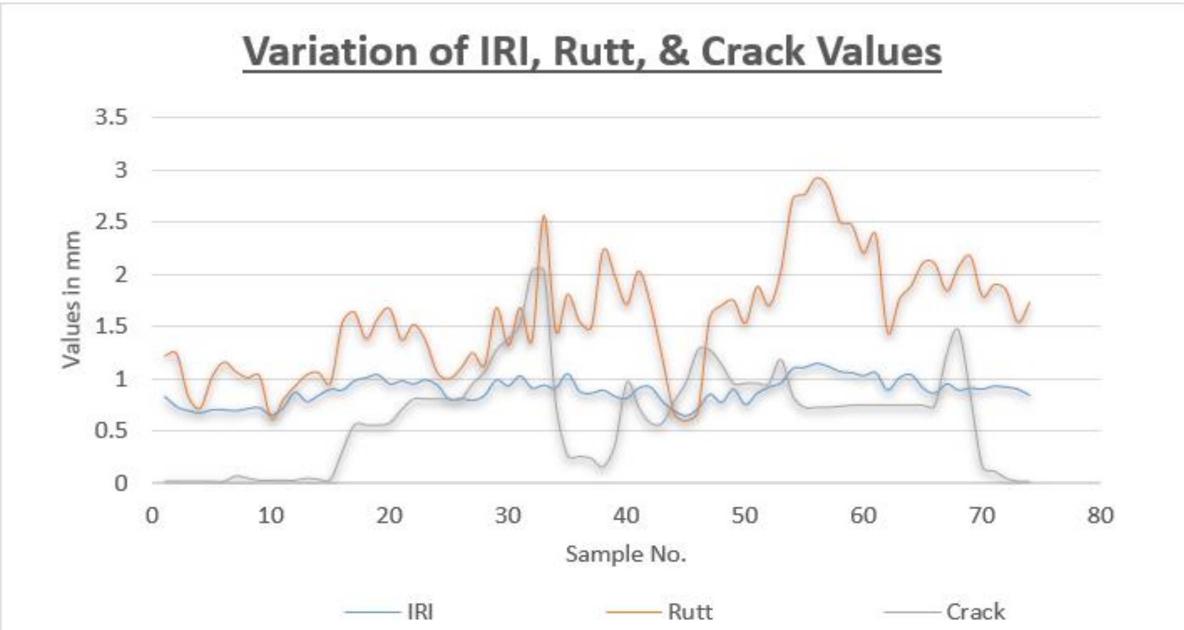

Figure 3.1 Variation of IRI, rutt, and crack values.

From figure 3.1 above, it is noted that IRI exhibits a rather horizontal trend and remains relatively constant throughout the stretch section of the pavement which was consisdered. Additionally, the relatively low value of IRI at averagely 0.885 is an indication of the overall pleasant state of the pavement. On the other hand, sharp fluctuations are noted in the data of rutting ranging from a high of 2.92 to a low of 0.6 mm. Clearly, the non-uniform distribution of the data especially in the rear section of the pavement susggests that the middle to the end part of the pavement section selected for analysis was pronouncly affected by deep grooves (rut) caused by heavy loaded vehicles. Similarly, cracking on the pavement section was realized to be littled on the first sections of the pavement but became more pronounced from the middle to the end sections. Based on the descriptive chart in figure 3.1, one may conclude that there is a relationship between cracking and rutting due to similarity of their respictive graphs. However, in-depth analysis is need to truly confirm such a hypothesis.

Meanwhile, in figure 3.2 depicting the variation of deflection along the pavement section, it is observed that pronounced variations of deflections occur mainly from the middle to the end part of the pavement which reinform idea from the figure 1 results. In particular, just like the rutting and cracking, massive changes in deflection begin at the 30^{th} measurement and end at the 70^{th} measurement. Certainly, this increases the need to conduct an analysis seeking to find a relationship between the four variables.

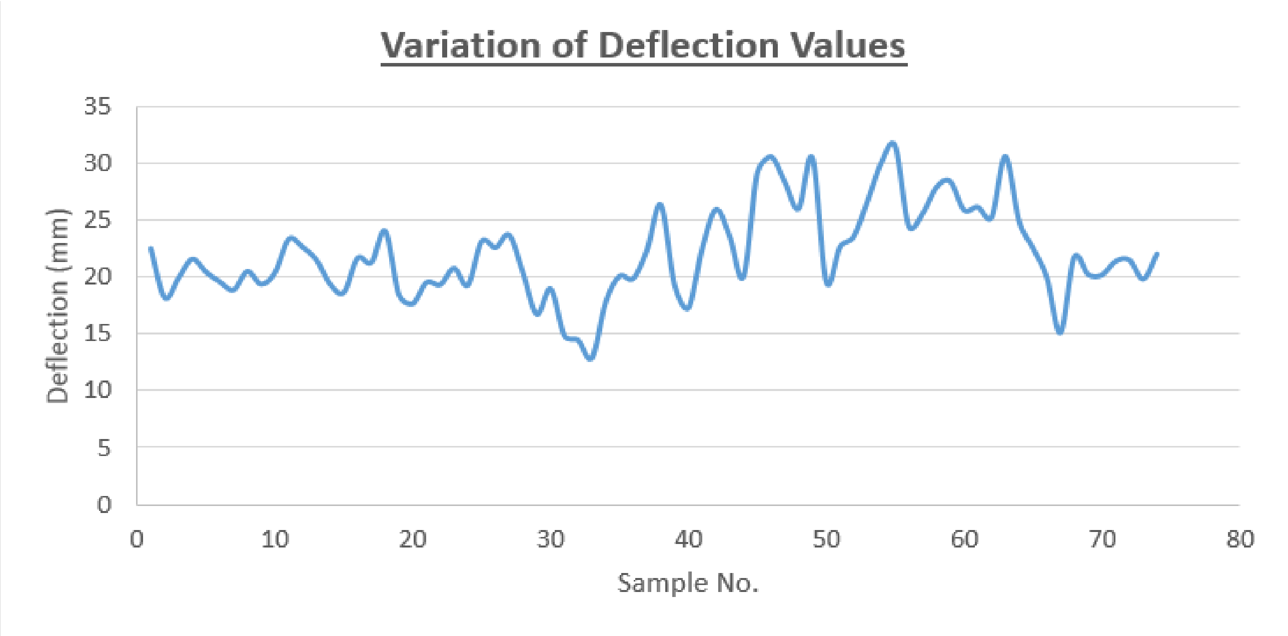

Figure 3.2 variation of deflection values.

3.6 Dependent and Independent Variables

Generally, international roughness index (IRI) is a road system management indicator which consideration the elevation-longitudinal relationship of a pavement and has a significant influence on the comfort, safety, cost, and speed of travel by road users. In this research, the focus was directed towards investigating the relationship between IRI and rutting.

- The dependent variable in this case is noted to be IRI since it is noted to be a factor which is affected by many variables.
- The independent variable in the case study is rutting because it is taken as one of the factors which influence the value of IRI.

To fully understand the relationship between IRI and rutting, linear and non-linear correlation analyses were done. In each of the analyses, Pearson's correlation coefficient R was obtained to help in understanding how the dependent and independent variables were connected to each other. The data analyses carried out included;

- Linear regression analysis

- ANOVA
- Quadratic correlation
- Cubic correlation
- Power correlation

In a nutshell, the model description of data analyzed in this study is captured in table 3.2 and 3.3

Table 3.2 Model Description

Model Name		MOD_1
Dependent Variable	1	IRI
Equation	1	Linear
	2	Quadratic
	3	Cubic
	4	Power[a]
Independent Variable		RUTT
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

The model requires all non-missing values to be positive.

Table 3.3 Case Processing Summary

	N
Newly Created Cases	0
Forecasted Cases	0
Excluded Cases	0
Total Cases	74

3.7 Linear Regression Analysis

3.7.1 Modelling IRI to RUTT

The underlying reason of carrying out Pearson's correlation analysis is to determine whether or not there exists a significant statistical relation between rutting and IRI. Therefore, the basic regression equation used is;

Y = b0 + b1X………………………………equation 1

Where; y = IRI (dependent variable); X = rutting (independent variable)

b0 & b1 = correlation coefficients.

Results

After analysis, the correlation graph was obtained as shown in figure 3.3

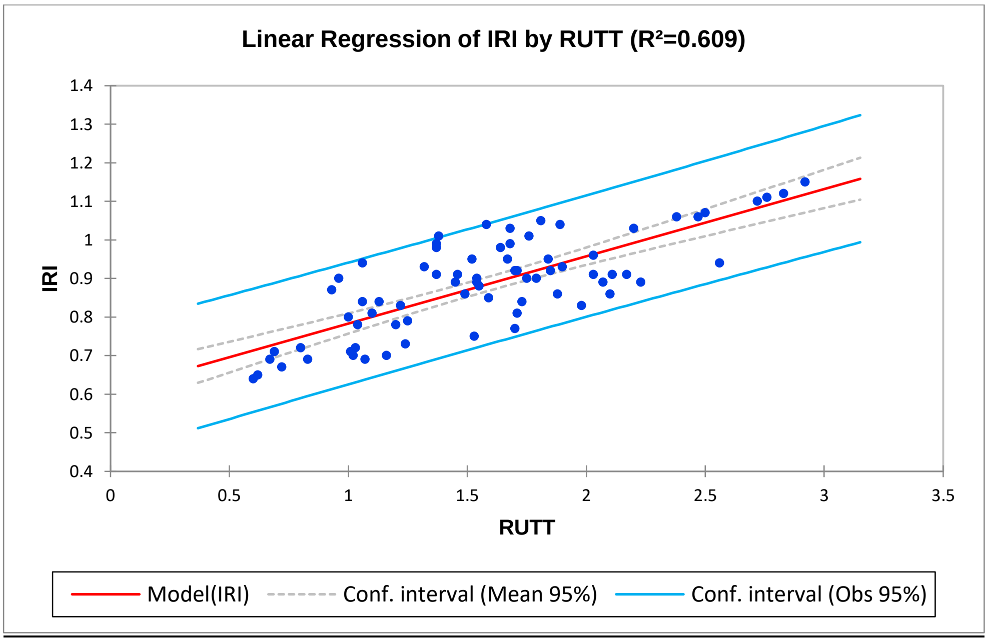

Figure 3.3 Linear Regression of IRI by Rutting

The results of regression coefficient were also captured in table 3.4 below.

Table 3.4 Regression Coefficient Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.781	.609	.604	.078

Table 3 .4 results indicate that RUTT and IRI are correlated with a value of R = 0.781 which proves a strong positive correlation. From the analysis, it is realized that the R-squared correlation coefficient between IRI and rutting is 0.609. Certainly, this indicates a fairly strong predictive variance between the two variables and suggests that up to 60.9% of IRI values can be accurately predicted using the rutting variables. The graph in figure three proves these results since it is observed that a large portion of the data is conglomerated along the trend line and demonstrates a strong positive correlation between IRI and rutting. To further confirm these results analysis of variance (ANOVA) was done to find the correlation of variance of the two data sets. The ANOVA results are summarized in table 3.5 below.

Table 3.5 ANOVA Results for Linear Regression Model

	Sum of Squares	df	Mean Square	F	Sig.
Regression	.684	1	.684	112.349	.000
Residual	.439	72	.006		
Total	1.123	73			

From table 3.5 above, it is noticed that Sig. value .000 i.e. $p<0.05$. As a result, a conclusion is made that the means of the RUTT and IRI data sets were statistically different. Clearly, this confirms the idea that IRI is affected by many other factors apart from RUTT.

At the same time, the various standardized and unstandardized coefficients were captured in table 3.6. The standard error represents the average distance of the observed values from the trend line. As such, small values are preferred because they show that the precision of the data gathered in the research. In the table 6 results, it is noted that the standard error for RUTT was 1.6%. This implies that the predictions for the data can be made above 95% significance level and up to 96.8%. The less standard error value is critical because it means all the RUTT data lies within two standard errors.

Table 3.6 Standardized and Unstandardized Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
RUTT	.174	.016	.781	10.599	.000
(Constant)	.609	.028		22.062	.000

Eventually, the linear equation connecting IRI and RUTT was obtained to be;

IRI = 0.609 + 0.174*RUTT……………………………………equation 2.

Where IRI units are in (m/Km) while Rutting units are in (mm). Equation 2 indicates that the possible minimum value of IRI for the pavement section is0.609 m/Km but increases proportionately at a rate of 0.174 m/Km per mm of rutting.

[BH1] 1. Chart

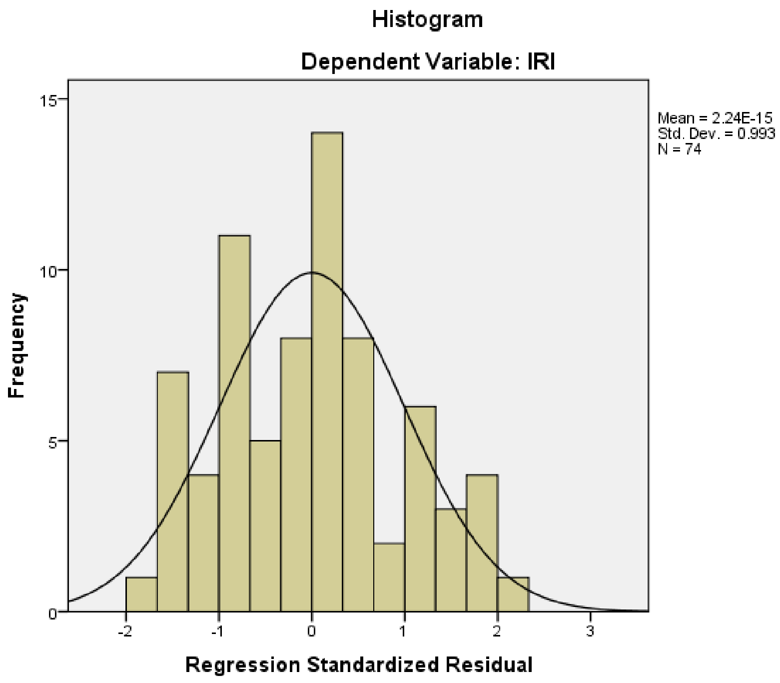

Figure 1.1 Histogram of the frequency of the regression standardized residuals

The figure above shows the residual histogram. The histogram is used for assessing the residual normality. The figure shows that standardized residuals follows the normal curve pattern. This suggests that the residual is acceptable and the normality assumption is not violated.

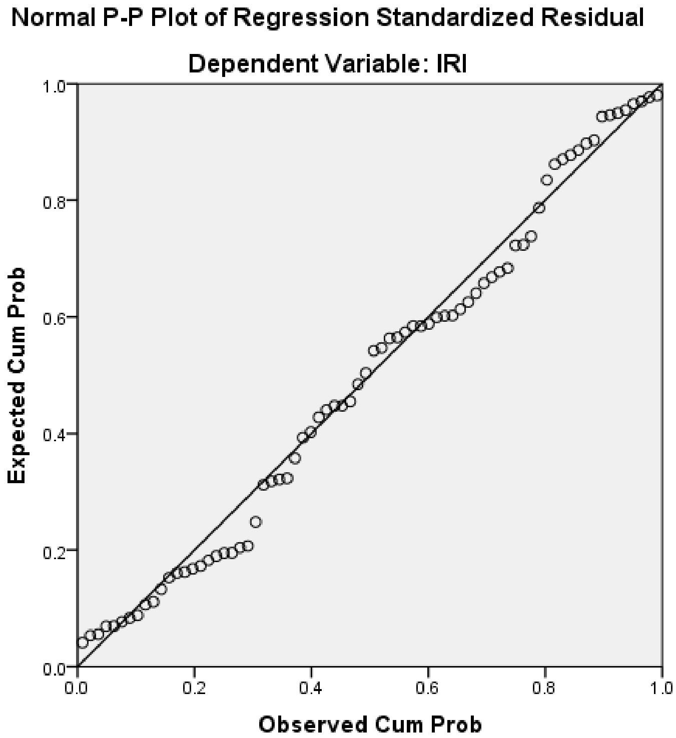

Figure 1.2 Normal P-P plot of regression standardized residual for the observed Cum Porb

The result shown in the plot shown in above figure which demonstrate that the model line is nearly superimposed over the theoretical line. This confirm that the normality assumption is not violated.

3.7.2 Modelling IRI to DEFF and RUTT

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	DEFF, RUTT[b]	.	Enter

a. Dependent Variable: IRI
b. All requested variables entered.

The relationship between IRI to DEFF and RUTT

Table 3.7 Regression coefficient Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.781[a]	.610	.599	.07857	.610	55.455	2	71	.000

a. Predictors: (Constant), DEFF, RUTT
b. Dependent Variable: IRI

Table 3.7 results indicate that IRI to DEFF and RUTT are correlated with a value of R = 0.781 which proves a strong positive correlation. From the analysis, it is realized that the R-squared correlation coefficient between IRI to DEFF and RUTT is 0.610. Certainly, this indicates a fairly strong predictive variance between the three variables and suggests that up to 61% of IRI values can be accurately predicted using the DEFF and RUTT variables. To further confirm these results analysis of variance (ANOVA) was done to find the correlation of variance of the two data sets. The ANOVA results are summarized in table 3.8 below.

Table 3.8 ANOVA Results for Linear Regression Model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.685	2	.342	55.455	.000[b]
	Residual	.438	71	.006		
	Total	1.123	73			

a. Dependent Variable: IRI
b. Predictors: (Constant), DEFF, RUTT

From table 3.8 above, it is noticed that Sig. value .000 i.e. $p<0.05$. As a result, a conclusion is made that the means of the IRI to DEFF and RUTT data sets were statistically different. Clearly, this confirms the idea that IRI is affected by many other factors apart from

DEFF and RUTT. At the same time, the various standardized and unstandardized coefficients were captured in table 3.9. The standard error represents the average distance of the observed values from the trend line. As such, small values are preferred because they show that the precision of the data gathered in the research. In the table 3.9 results, it is noted that the standard error for RUTT was 1.7% and DEFF 0.20%.

Table 3.9 Standardized and Unstandardized Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations		
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part
1	(Constant)	.619	.053		11.635	.000	.513	.725			
	RUTT	.175	.017	.785	10.241	.000	.141	.210	.781	.772	.759
	DEFF	-.001	.002	-.017	-.218	.828	-.005	.004	.182	-.026	-.016

a. Dependent Variable: IRI

Eventually, the linear equation connecting IRI with DEFF and RUTT was obtained to be;

IRI = 0.619 + 0.75 RUTT - 0.001 DEFF ……………………………………equation 2.

Where IRI units are in (m/Km) while Rutting units are in (mm). Equation 2 indicates that the possible minimum value of IRI for the pavement section is 0.609 m/Km but increases proportionately at a rate of 0.175m/Km per mm of rutting and -0.001mm of deflection.

2. Chart

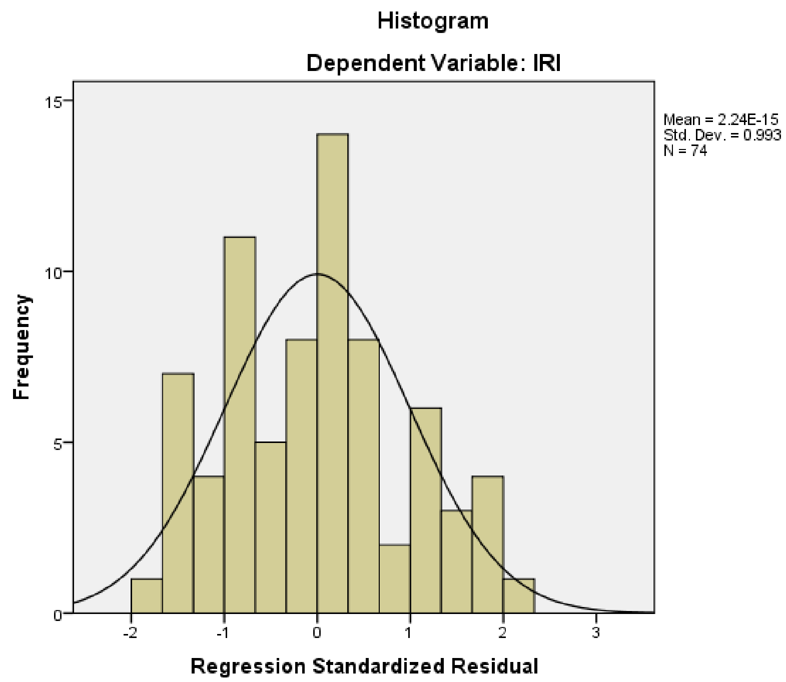

Figure 2.1 Histogram of the frequency of the regression standardized residuals

The figure above shows the residual histogram. The histogram is used for assessing the residual normality. The figure shows that standardized residuals follows the normal curve pattern. This suggests that the residual is acceptable and the normality assumption is not violated.

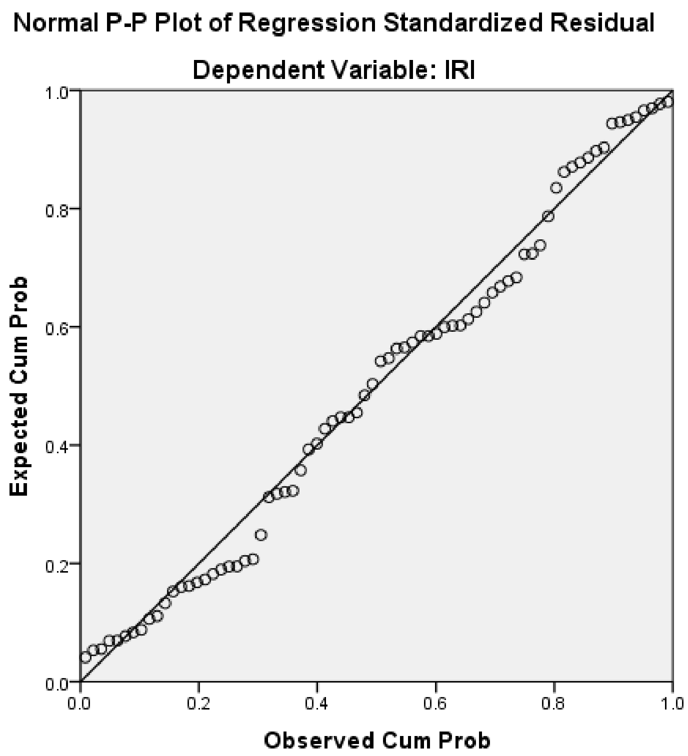

Figure 2.2 Normal P-P plot of regression standardized residual for the observed Cum Porb

The result shown in the plot shown in above figure which demonstrate that the model line is nearly superimposed over the theoretical line. This confirm that the normality assumption is not violated.

3.7.3 Modelling IRI to Cracks and RUTT

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Crack, RUTT[b]	.	Enter

a. Dependent Variable: IRI

b. All requested variables entered.

The relationship between IRI to Cracks and RUTT

Table 3.10 Regression Coefficient Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.785[a]	.616	.605	.07797	.616	56.854	2	71	.000

a. Predictors: (Constant), Crack, RUTT

b. Dependent Variable: IRI

Table 3.10 results shows that IRI to Cracks and RUTT are correlated with a value of R = 0.785 which demonstrates a strong positive correlation. From the analysis, it is realized that the R-squared correlation coefficient between IRI to Cracks and RUTT is 0.616. Definitely, this indicates a fairly strong predictive variance between the three variables and suggests that up to 61.6 % of IRI values can be exactly predicted using the crack and rutting variables. The result since it is observed that a large portion of the data is conglomerated along the trend line and demonstrates a strong positive correlation between IRI to cracks and RUTT. To further confirm these results analysis of variance (ANOVA) was done to find the correlation of variance of the two data sets. The ANOVA results are summarized in table 3.11 below.

Table 3.11 ANOVA Results for Linear Regression Model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.691	2	.346	56.854	.000[b]
	Residual	.432	71	.006		
	Total	1.123	73			

a. Dependent Variable: IRI

b. Predictors: (Constant), Crack, RUTT

From above table 3.11, it is noticed that Sig. value .000 i.e. $p<0.05$. As a result, a conclusion is made that the means of the IRI to Cracks and RUTT data sets were statistically different. Clearly, this confirms the idea that IRI is affected by many other factors apart from Cracks and RUTT. At the same time, the various standardized and unstandardized coefficients were captured in table 3.12. The standard error represents the average distance of the observed values from the trend line. As such, small values are preferred because they show that the precision of the data gathered in the research. In the table 6 results, it is noted that the standard error for Cracks was 0.17% and RUTT 0.20%.

Table 3.12 Standardized and Unstandardized Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations		
	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part
1 (Constant)	.605	.028		21.741	.000	.549	.660			
RUTT	.169	.017	.755	9.737	.000	.134	.203	.781	.756	.716
Crack	.021	.020	.083	1.068	.289	-.018	.060	.320	.126	.079

a. Dependent Variable: IRI

Eventually, the linear equation connecting IRI with Cracks and RUTT was obtained to be;

IRI = 0.605 + 0.169 + 0.21 *RUTT……………………………………equation 2.

Where IRI units are in (m/Km) while Rutting units are in (mm). Equation 2 indicates that the possible minimum value of IRI for the pavement section is 0.605 m/Km but increases proportionately at a rate of 0.169 m/Km per mm of Combined with 0.021 % of cracking.

3. Chart

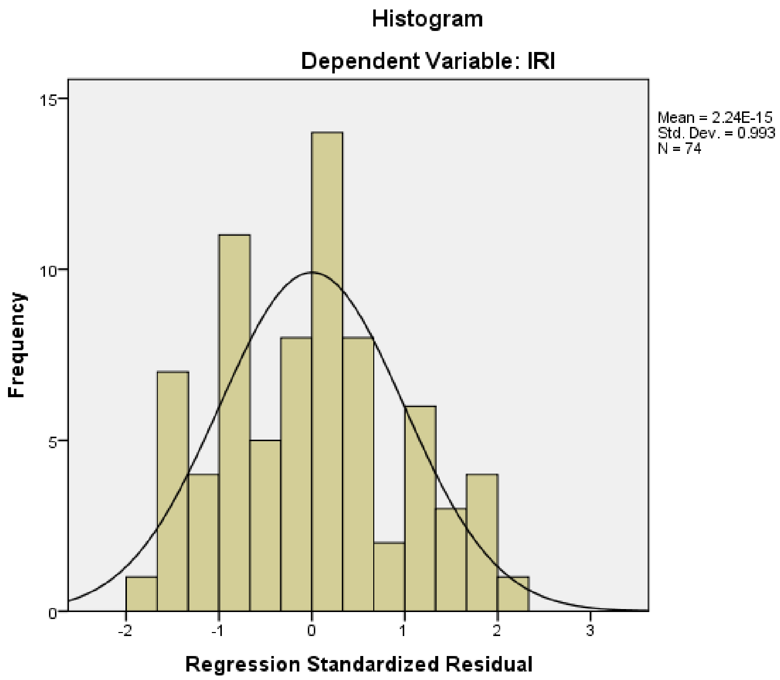

Figure 3.1 Histogram of the frequency of the regression standardized residuals

The figure above shows the residual histogram. The histogram is used for assessing the residual normality. The figure shows that standardized residuals follows the normal curve pattern. This suggests that the residual is acceptable and the normality assumption is not violated.

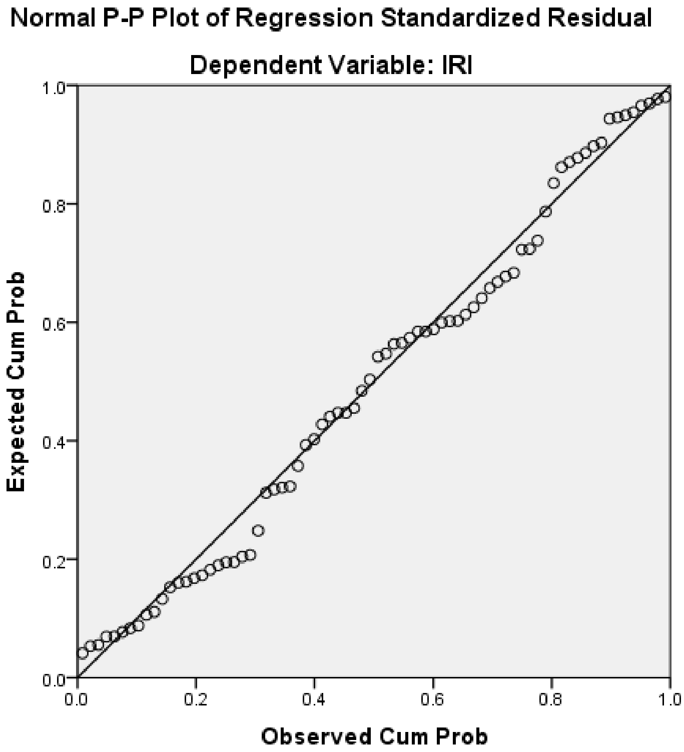

Figure 3.2 Normal P-P plot of regression standardized residual for the observed Cum Porb

The result shown in the plot shown in above figure which demonstrate that the model line is nearly superimposed over the theoretical line. This confirm that the normality assumption is not violated.

3.7.4 Modelling IRI to DEFF and RUTT and Cracks

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	DEFF, Crack, RUTT[b]	.	Enter

a. Dependent Variable: IRI
b. All requested variables entered.

The relationship between IRI to DEFF and RUTT and Cracks

Table 3.13 Regression coefficient Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.785[a]	.616	.599	.07851	.616	37.382	3	70	.000

a. Predictors: (Constant), DEFF, Crack, RUTT
b. Dependent Variable: IRI

Table 3.13 results indicate that IRI to DEFF and RUTT and Cracks are correlated with a value of R = 0.785 which proves a strong positive correlation. From the analysis, it is realized that the R-squared correlation coefficient between IRI to DEFF and RUTT and Cracks is 0.616. Definitely, this indicates a fairly strong predictive variance between the three variables and suggests that up to 6.16% of IRI values can be accurately predicted using the rutting variables. The results as it is observed that a large portion of the data is conglomerated along the trend line and demonstrates a strong positive correlation between IRI to DEFF and RUTT and Cracks. To further confirm these results analysis of variance (ANOVA) was done to find the correlation of variance of the two data sets. The ANOVA results are summarized in table 3.14 below.

Table 3.14 ANOVA Results for Linear Regression Model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.691	3	.230	37.382	.000[b]
	Residual	.432	70	.006		
	Total	1.123	73			

a. Dependent Variable: IRI
b. Predictors: (Constant), DEFF, Crack, RUTT

From table 3.14 above, it is noticed that Sig. value .000 i.e. $p<0.05$. As a result, a conclusion is made that the means of the IRI to DEFF and RUTT and Cracks. Data sets were statistically different. Clearly, this confirms the idea that IRI is affected by many other factors apart from DEFF and RUTT and Cracks.

At the same time, the various standardized and unstandardized coefficients were captured in table 3.15. The standard error represents the average distance of the observed values from the trend line. As such, small values are preferred because they show that the precision of the data gathered in the research. In the table 6 results, it is noted that the standard error for RUTT was 0.21% and DEFF 0.00 %. And crack 0.21%.

Table 3.15 Standardized and Unstandardized Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations		
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part
1 (Constant)	.611	.054		11.360	.000	.503	.718			
RUTT	.169	.018	.757	9.347	.000	.133	.205	.781	.745	.693
Crack	.021	.020	.082	1.045	.300	-.019	.060	.320	.124	.077
DEFF	.000	.002	-.009	-.121	.904	-.005	.004	.182	-.014	-.009

a. Dependent Variable: IRI

Eventually, the linear equation connecting IRI with DEFF and RUTT was obtained to be;

IRI = 0.611 + 0.169 RUTT + 0.021 CRACK + 0.000 DEFF ……………………equation 2.

Where IRI units are in (m/Km) while Rutting units are in (mm). Equation 2 indicates that the possible minimum value of IRI for the pavement section is 0.611 m/Km but increases proportionately at a rate of0.169 m/Km per mm of rutting plus 0.021 per % of cracking.

4. Chart

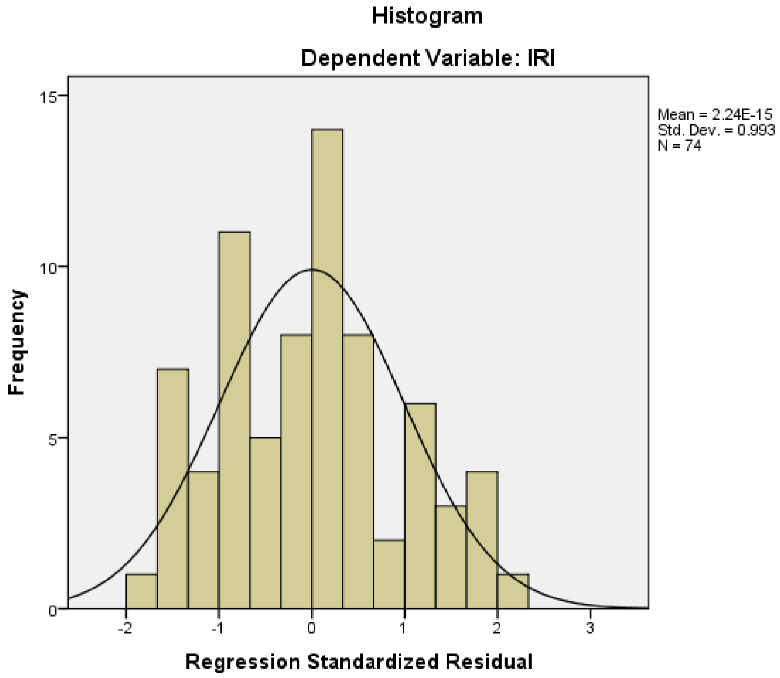

Figure 4.1 Histogram of the frequency of the regression standardized residuals

The figure above shows the residual histogram. The histogram is used for assessing the residual normality. The figure shows that standardized residuals follows the normal curve pattern. This suggests that the residual is acceptable and the normality assumption is not violated.

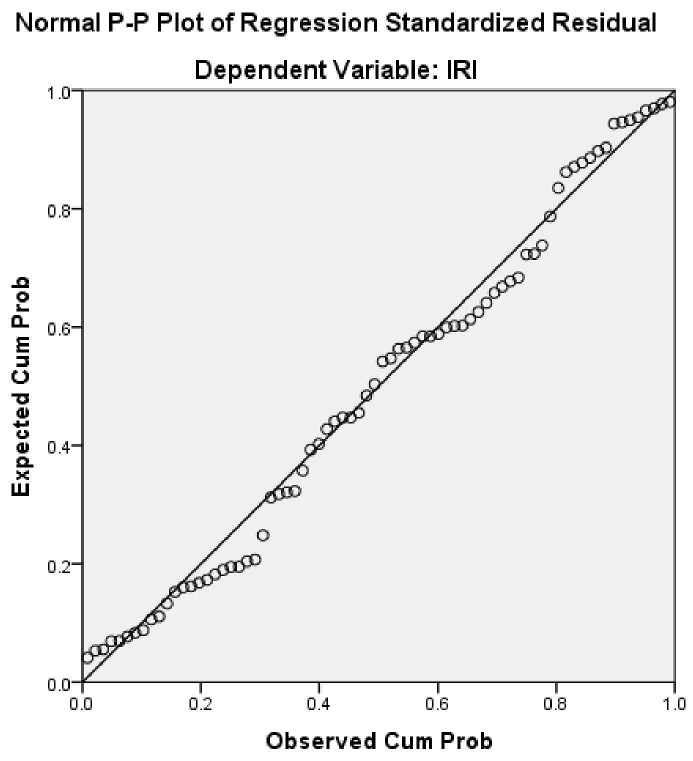

Figure 4.2 Normal P-P plot of regression standardized residual for the observed Cum Porb

The result shown in the plot shown in above figure which demonstrate that the model line is nearly superimposed over the theoretical line. This confirm that the normality assumption is not violated.

3.7.5 Nonlinear Modeling RI to RUTT

3.7.5.1 Quadratic Regression

Looking at the linear regression results, it is noticed that the value of R-square is relatively low. Therefore, a quadratic regression was carried out to determine whether or not it could expose a stronger correlation between RUTT and IRI. Generally, the basic quadratic regression equation used is;

$Y = b_0 + b_1X + b_2X^2$……………………………equation 3

Where; y = IRI (dependent variable); X = rutting (independent variable)

b_0, b_1, & b_2 = correlation coefficients.

Results

The quadratic correlation graph was obtained as shown in figure 3.4.

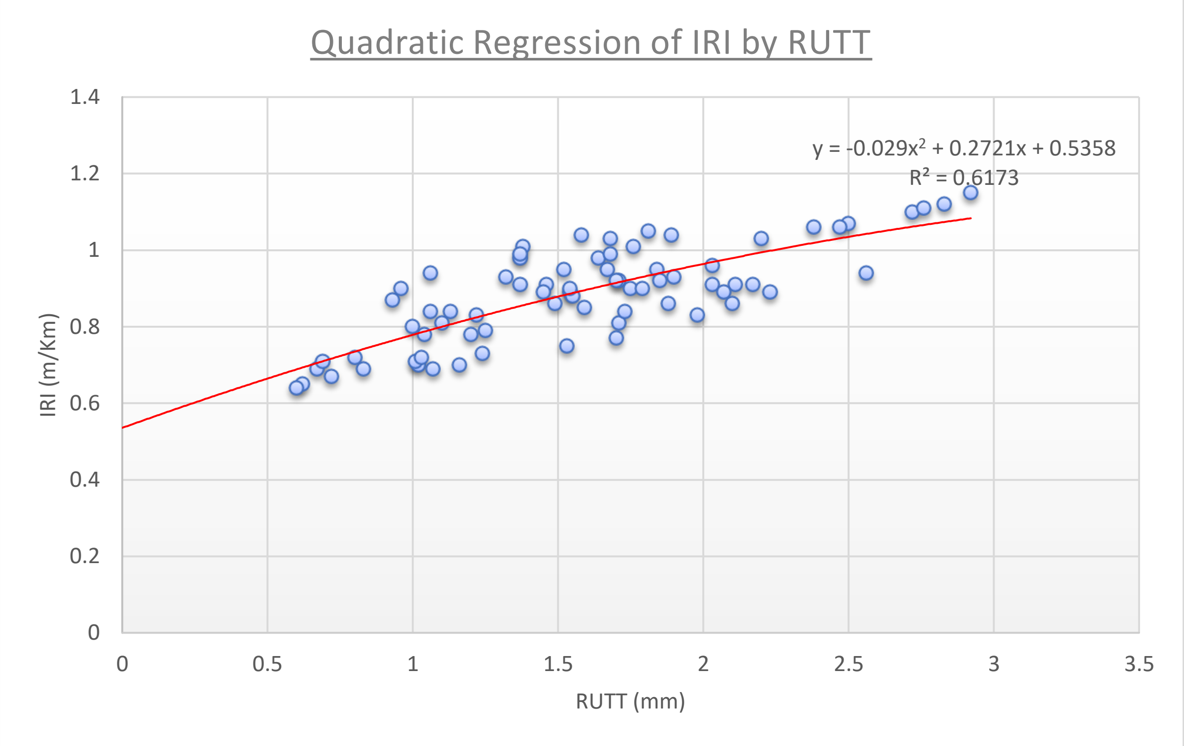

Figure 3.4 Quadratic regression of IRI by RUTT.

The results on regression coefficients were also summarized in table 3.16.

Table 3.16 Regression Coefficient Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.786	.617	.607	.078

From figure 3.4 and table 3.16 several key observation and analysis can be made. First, the quadratic regression demonstrates a relatively higher value of Pearson's R of 0.786 compared to 0.781 in linear regression. This gives the indication that IRI and rutting are best described and predicted through non-uniform means rather than linear relationship. On the same note, the R-square value was noted to be 0.617 which implies that 61.7% of the IRI values could be predicted using the RUTT values in the quadratic equation generated. Still, residual value of 38.3% which cannot be explained using the correlation coefficients is huge and implies that additional analysis should be done to reduce the discrepancy and ensure a more accurate prediction relationship. At the same time, a quadratic relationship between IRI and rutting was obtained from the unstandardized and standardized coefficients shown in table 3.17.

Table 3.17 Standardized and Unstandardized Coefficients

	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	T	
RUTT	.272	.083	1.218	3.295	.002
RUTT ** 2	-.029	.024	-.446	-1.207	.232
(Constant)	.536	.067		8.044	.000

From table 3.17, the quadratic equation connecting IRI and RUTT was obtained to be;

$IRI = 0.536 + 0.272*RUTT - 0.029*RUTT^2$…………………………equation 4.

From equation 4, it is realized that IRI increases at a rate of 0.272 m/Km per mm of Rutting and reduces at a rate of 0.029 m/Km per rutting value.

In addition, a relatively small standard error of 2.4% for the quadratic function is critical in ensuring that over 95% of the observed data fall within 2 standard errors of the trend line. Clearly, this implies that even in quadratic regression, the rutting data is precisely aligned with the line of best fit.

Lastly, to determine whether the in quadratic regression the values of the two data sets were statistically similar, an ANOVA analysis was conducted. The results are shown in table 3.18.

Table 3.18 ANOVA Results for Quadratic Regression Model

	Sum of Squares	df	Mean Square	F	Sig.
Regression	.693	2	.347	57.258	.000
Residual	.430	71	.006		
Total	1.123	73			

Just like in linear regression, it is noted from table 3.18 that the significant value of .000 is less than 0.05 i.e. $p<0.05$. As such, the null hypothesis made that there is values in the two sets of data are similar is rejected and instead, a conclusion is arrived at that the values of RUTT and IRI are significantly different. Certainly, this means that even in quadratic regression, the values of RUTT cannot be used 100% to explain the IRI variable.

3.7.5.2 Cubic Regression

A cubic regression was done with the underlying objective of seeking an improvement of the linear and quadratic regression results. The main motivator was to look out for higher values of Pearson's R, R-squared, and p-values. Generally, the basic quadratic regression equation used is; $Y = b_0 + b_1X + b_2X^2 + b_3X^3$……………………………equation 5

Where; y = IRI (dependent variable); X = rutting (independent variable)

b_0, b_1, b_2 & b_3 = correlation coefficients.

Results

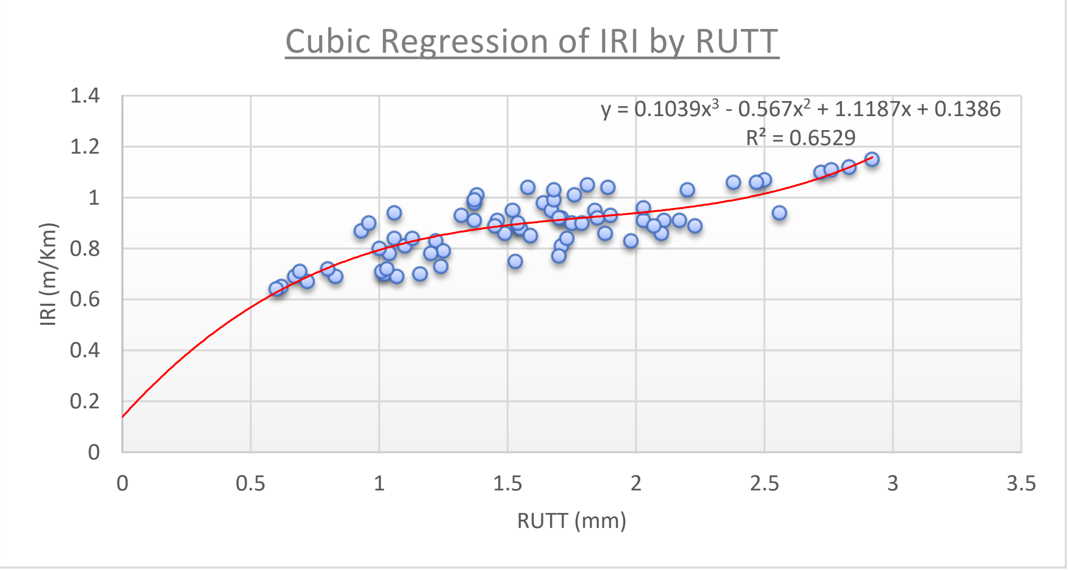

Figure 3.5 Cubic regression of IRI by RUTT.

The results on cubic regression were also summarized in table 3.19 as shown.

Table 3.19 Regression Coefficient Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.808	.653	.638	.075

From table 3.19, it is realized that a strong positive Pearson's coefficient of R = 0.808 defines the cubic regression relationship between IRI and RUTT. Clearly, this demonstrates an increase from 0.781 in linear regression and 0.786 in quadratic regression. As such, it is noted that the cubic regression accurately captures the relationship between IRI and RUTT than the two previous methods. In addition, the R-square value is noted to increase to a value of 0.653. This demonstrates that the cubic regression can be used to predict a larger amount of IRI values using RUTT (65.3%) compared to the lesser values from previous techniques. In order to find the cubic equation showing the IRI-RUTT relationship, table 3.20 values were obtained.

Table 3.20 Standardized and Unstandardized Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
RUTT	1.119	.326	5.007	3.435	.001
RUTT ** 2	-.567	.202	-8.727	-2.806	.006
RUTT ** 3	.104	.039	4.633	2.680	.009
(Constant)	.139	.161		.858	.394

Using the B-coefficients from table 11; the cubic equation connecting RUTT and IRI can be expressed as **IRI = 0.139 + 1.119*RUTT -0.567*RUTT**^{2}**+0.104*RUTT**^{3}..equation 6

Table 3.20 also reveals that the standard error for the cubic function is 3.9%. This means that less than 95% of the observed values fall within 2 standard errors of the trend line. As a result, it is realized that the RUTT cubic function is not as accurate as the quadratic and linear regression functions. At the same time, to check whether there was a significant variation in the means of the two sets of data in cubic regression, ANOVA analysis was done. The results are displayed in table 3.21.

Table 3.21 ANOVA Results for Cubic Regression Model

	Sum of Squares	df	Mean Square	F	Sig.
Regression	.733	3	.244	43.890	.000
Residual	.390	70	.006		
Total	1.123	73			

The table shows that the sig value of 0.000 is still less than the critical value of 0.05 i.e. $p< 0.05$. As a result, a conclusion is made that just like the two previous cases, the cubic regression demonstrates IRI and rutting data sets as two distinct sets with different means. As such, it can be inferred that IRI cubic regression is defined by other parameters other than rutting.

3.7.5.3 Power Regression

After conducting a linear regression and two polynomial regression, the Pearson correlation between rutting and IRI was noted to be still less than 100% and the R-squared value even smaller at 65.3%. Therefore, in order to seek for better ways of improving the figures, a power regression was carried out. The general equation for the power equation entail;

$Y = a*X^b$……………equation 5 Where; y = IRI (dependent variable); X = rutting (independent variable); a & b = correlation coefficients.

The results of the power regression were recorded in table 3.22 as shown.

Table 3.22 Regression Coefficient Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.798	.638	.632	.087

Results

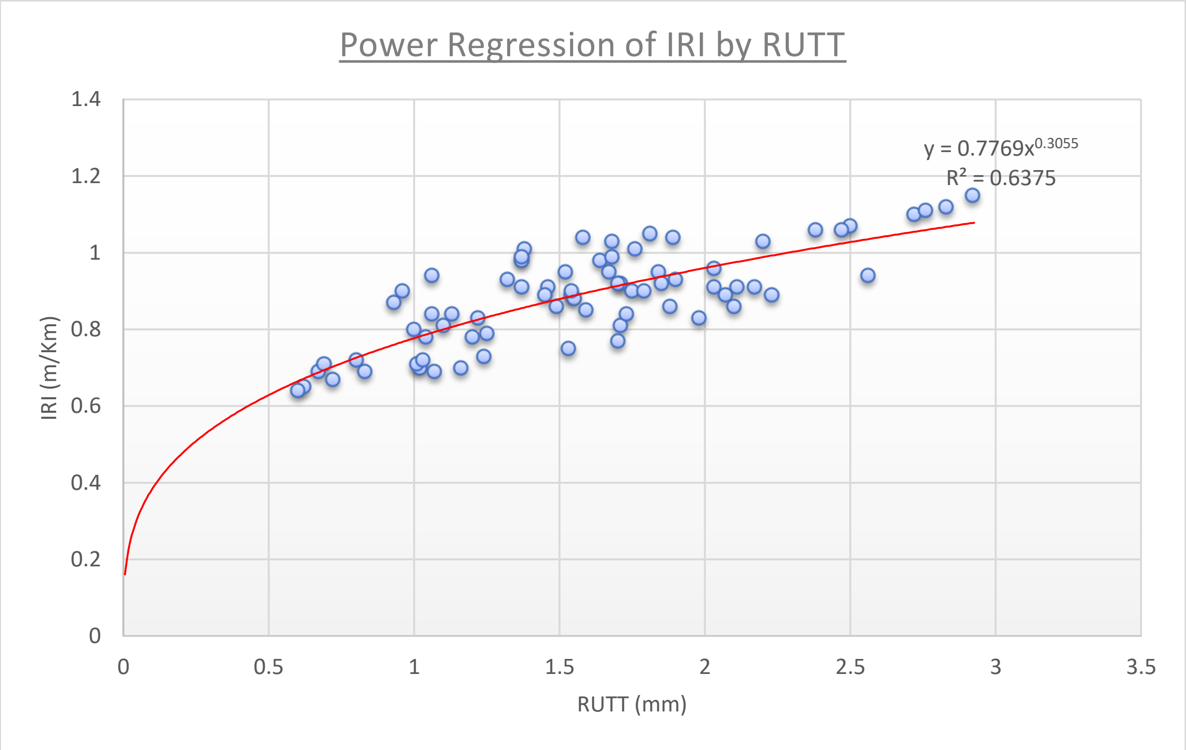

Figure 3.6 Power regression of IRI by RUTT.

From table 3.22 and figure 3.6, it is observed that the power regression shows a strong positive correlation between IRI and RUTT with a Pearson's coefficient of 0.798. However, this value is slightly lower than that obtained by cubic regression. As such, it is realized that the power regression is not as accurate as expected. More than that, table 13 indicates R-square value of 0.638 for power regression. Clearly, this value is also less than the cubic regression value of 65.7%. Therefore, 36.2% of IRI data cannot be predicted using power the power equation. Eventually, it is noted that all regression coefficient values show the cubic regression to be more precise method of describing the relationship between IRI and rutting that the other methods. To get the specific equation connecting IRI and RUTT, the values in table 3.23 were utilized.

Table 3.23 Standardized and Unstandardized Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(RUTT)	.305	.027	.798	11.253	.000
(Constant)	.777	.011		67.902	.000

Using the B-values, the power regression equation was noted to be;

IRI = 0.777*RUTT$^{0.305}$……………………………………….equation 6.

From equation 6, it is noted that IRI increases exponentially with RUTT. At the same time, it is realized that the standard error for the power function is 2.7% implying that less than 95% of observed values lies within 2 standard errors of the power trend line. Clearly, this resonates with the result of cubic regression and a conclusion is reached that the RUTT values in power regression are not accurately aligned on the trend line. Meanwhile, ANOVA analysis was also conducted to help in evaluating the F and p-values. The results were recorded in table 3.24.

Table 3.24 ANOVA Results for Power Regression Model

	Sum of Squares	df	Mean Square	F	Sig.
Regression	.956	1	.956	126.621	.000
Residual	.544	72	.008		
Total	1.500	73			

From table 3.24, it is noted that the p-values still remains at 0.000 which is less than 0.05. Certainly, this confirms the earlier conclusions made that the means of IRI and RUTT are significantly different. Therefore, it is realized that indeed there are other variables which influence the value of IRI other than rutting.

In summary, the main regression data was presented in table 3.25 below.

Table 3.25 Summary of Data

Function	R	R^2	RSS	F
Cubic	0.808	0.653	0.390	43.89
Quadratic	0.786	0.617	0.430	57.258
Linear	0.781	0.609	0.604	112.349
Power	0.798	0.638	0.544	126.621

3.7.6 Summary

Based on the analysis, it is realized that all the regression methods used demonstrated fairly strong values of R-squared and very strong values of R. However, the best technique that can best describe the relationship between IRI and RUTT was realized to be cubic regression. In particular, it showed the highest values of R and R^2 and the lowest values of RSS and F. On the contrary, the linear regression was noted to be the most unreliable for use in predicting values between the two variables. This is because it was observed to exhibit the lowest values of R and R^2 as well as the highest value of RSS. The second most reliable option was the power regression followed by the quadratic regression based on their R-square values depicted in table 16. However the parameter F indicating the difference of the average values of the dependent variable amongst the groups of independent variables is lower. Therefore, it can be considered that the Linear regression better than the power regression.

Chapter Four

4. Discussion

The following part will be related to the discussion of all the aspects already described above regarding the project integral parts. As part of the project some discussion topics can be opened, but there is two clear factors that can be clearly observed from the study:

1) There are no references on this subject and this can be the first one treating this matter. An extended study of this issue should be addressed in order to study the proper and complete customization of these models and the first implementation.
2) In the above case we will find the lack and gap in the standardization part. Having some test that could be contrasted by a independent third party could bring the possibility to develop standards in this matter and, depending on the variable measured then the prediction of the others will be matter of a good defining of:
    - Parameters to be measured
    - Proper definition of the trigger values for the model to works properly
    - Contrasted information by third parties to be certified
    - Direct application and continuous monitoring

Discussion can be opened also in the meaning of how these parameters behavior can be changing depending on some factors don't studied in deep in this project but that definitely play a key role during the application of the model (for example traffic in the roads and their distribution and the evolution of it).

Evolution of the equipment to measure all these parameters should be for example under these standards control since this study was done considering as equipment the one described in the Chapter three (devices as dynamic deflectometer, non-sensitive devices to define and measure cracks different than INNO system and profile meters class 1), are examples of care that should be taken into account during the data acquisition and data migration to the models.

This project had as principal objective to show a clear correlation amongst different condition survey parameters intervening in the analysis and decision making for pavement maintenance activities. Data collection of those parameters (Rutting, IRI, Deflections and Cracking, explained all in Chapter three), need to be carried out in roads (specially at network level) in order to determine the best maintenance procedures needed to afford that maintenance in any of its both possibilities (corrective or preventive).

A demonstrated existing correlation will help to enhance the decision maintenance procedures contained in Pavement Management Systems in order to predict and calibrate the expected behavior of some parameters based on the results obtained from others. It seems logic and obvious that some of them are related (for example rutting and IRI) as can be read in the references included regarding this matter. Existence of some other correlations were not that obvious and were able to be showed during this project obtaining good results that will enhance latter on the recommendations.

For this project purposes, it was considered to get as first step of a bigger research, the correlation between parameters of the corresponding sections each 500m of a 37Km length segment (as can be seen in 3.4).

Once the parameters' values for all the sections were grouped, then a starting simple statistic analysis was performed in order to know what are the main values (mean, standard deviation, variance, maximum and minimum values, first and third quartile). In this step the values as can be appreciated in table 3.1 showed not so much dispersion and consistent values in order to be analyzed by ANOVA procedures described after. Only the cracking seems to have low or null values during some initial interval (as can be seen in table 3.14). This aspect will be considered during the analysis filtering these data and considering values for those parts of the segment in which those values are greater than 0.

General description of the test performed has been described in Chapter two, in which is mentioned too the importance of getting these measurements and values.

To choose the independent variable is necessary to know which phenomenon appears first in the road and affects directly to the rest of them. In this case from the experience and observation in the roads asphalt, can be determined that the first negative effect to be shown is rutting. From the four parameters mentioned above, the appearance of rutting will affect the IRI value of the road in first place (keeping the consideration that both parameters Rutting and IRI are indicative of the comfort for the road users). Therefore an initial stage analyzing only the correlation existing between these two parameters were performed. After, the other 2 were introduced in the scope of the analysis in order to determine if they keep also a correlation with the main independent variable (both parameters were added to the analysis process one after the other).

In first place, as mentioned before, the correlation between Rutting (as independent variable) and IRI was founded and established, represented by a Linear Regression Analysis (using Pearson's method). The regression graphic can be seen in figure 3.3 in Chapter 3. This regression and the parameters associated, show a proper correlation considering that the cloud of points is contained between the boundaries describing a confidence interval of 95%. The equation describing this regression line is also mentioned.

Standardized residual histogram shows a small accumulative value (as described in the analysis in table (3.14) and regression line for those residual values is very adjusted which means this linear regression seems to be perfectly adjusted to the correlation between both parameters.

Once this analysis was performed an introduction of a new variable was done (Deflection) and a similar analysis was carried out to obtain a regression line through the same method. From the process we can conclude that the high R (correlation) and the lower values about the boundaries on the deflection (for a Confidence Level of 95%) means that the introduction of the new variable is possible without commit the accuracy of the regression line. In the same way than before a small accumulative value on the histograms and an almost perfect adjustment to the correlations presented are signs of a good performance of the analyzed case. The descriptive equation for this correlation is also mentioned.

Another analysis introducing the Cracks was performed, obtaining the linear regression and again a good correlation (almost with the same value than the previous one), was obtained showing the same trend than the previous described new variable. Again new low values in the boundaries for the Confidence Level are shown and the points are perfectly contained within the two borders. And also the histograms and regression curves for the accumulative residuals are almost perfect. The equation describing this regression line is mentioned at the end of the paragraph.

When combining all the variables an expected R value similar to the one obtained previously is expected, and confirmed after the analysis. It was expected too, to have a very small values in the boundaries limiting the Confidence level to 95% which after is confirmed. The final equation describing the model is mentioned in the analysis paragraph and again, the residual accumulated values showed in the histogram and the regression are quite accurate and adjusted.

However a nonlinear evaluation was performed with ANOVA analysis and studied for the first two parameters analyzed in the linear regression. The analysis were done by a quadratic, cubic, and power functions. All of them including a description of the function for the regression and the analysis in the corresponding tables.

Quadratic function is showing a good correlation value which is an obstacle choosing this equation to predict the values of IRI based on Rutting. The equation describing the curve is written in the document.

Road 1				LINEAR		QUADRATIC		CUBIC		POWER	
Origin	**End**	**RUTT**	**IRI**	**PREDICTED**	**ERROR**	**PREDICTED**	**ERROR**	**PREDICTED**	**ERROR**	**PREDICTED**	**ERROR**
0+000	0+010	1.22	0.83	0.822	-0.008	0.825	-0.005	0.849	0.019	0.826	-0.004
0+010	0+020	1.24	0.73	0.825	0.095	0.829	0.099	0.853	0.123	0.830	0.100
0+020	0+030	0.83	0.69	0.754	0.064	0.742	0.052	0.737	0.047	0.734	0.044
0+030	0+040	0.72	0.67	0.735	0.065	0.717	0.047	0.690	0.020	0.703	0.033
0+040	0+050	1.02	0.7	0.787	0.087	0.783	0.083	0.801	0.101	0.782	0.082
0+050	0+060	1.16	0.7	0.811	0.111	0.812	0.112	0.836	0.136	0.813	0.113
0+060	0+070	1.07	0.69	0.796	0.106	0.794	0.104	0.815	0.125	0.793	0.103
0+070	0+080	1.01	0.71	0.785	0.075	0.781	0.071	0.798	0.088	0.779	0.069
0+080	0+090	1.03	0.72	0.789	0.069	0.785	0.065	0.804	0.084	0.784	0.064
0+090	0+100	0.62	0.65	0.717	0.067	0.693	0.043	0.640	-0.010	0.672	0.022
ACC ERROR					**0.730**		**0.672**		**0.731**		**0.625**
AVERAGE					**0.073**		**0.067**		**0.073**		**0.063**

The description of the parameters for the cubic function show that the correlation is strong too in order to predict IRI based on Rutting. Regarding the power function we can comment the same than the previous two paragraphs in which we will assume that from the values obtained all functions could provide a proper result.

In order to contrast the models we obtained and compare them with the real values showed in 3.4 Analyzed Sample (MODELING chapter) below can be seen a comparative table for those values:From this small analysis can be seen that the difference in the predictions compared with the original values has not big difference. Calculation of accumulated error and average indicate that any predicted value will be near the real existing one and the difference won't be significant. The comparison and analysis of the data show that, despite the linear regression shows high values of correlation, there are other functions that seemed to be adjusted better to the case this projects is developing.

In first place it looks like the best correlation between two variables is the Cubic one, followed by the Quadratic and then the linear (the power will be the last one). The values showed in table 3.16 and the justifications mentioned below allow us to conclude some points.

Chapter Five

5 Conclusions and Recommendations

5.1 Conclusions

After all analysis explained previously the final conclusions of this project are the ones explained below:

- A strong correlation exist between Rutting and IRI and seems that with a high Level of Confidence IRI can be predicted by using Rutting values. After analyzing the values of R and residual values can be concluded that any of the linear relations can be used to predict values of IRI or values of Deflection and Cracking as well.
- The same level of accuracy exist in the correlation including one more variable as Cracking or Deflection, and predictions of these two values (IRI and Cracking or Deflection) can be done based on Rutting. Predictive functions of these parameters should be calculated in order to obtain a high accuracy prediction.
- A very good and strong correlation was developed in order to predict IRI, Cracking or Deflection based on the Rutting values. Therefore the prediction should be considered as a powerful tool in order to be included in the Pavement Management System as at least an option to predict as well the maintenance plans.
- There are some other correlations that show a better and strong approach to the case when it comes to relate Rutting and IRI (as Cubic or quadratic), anyway the difference as could be seen, between the real values and the predicted ones is not big and significant, and those differences won't affect the final recommendations on maintenance. Even in the difference reaches the maximum expected deviation.

5.1.1 Complete acquisition of regression correlations

The first attempt in relating the Rutting acquired values in order to predict IRI, seemed to have sense and good mathematical behavior. From that first approach a try to relate with a third variable (first trying with Cracks and after with Deflection), gave good results and a similar level of accuracy.

Once the regression obtained in the cases of including a third variable (one at the time) showed same values for correlation and residual values, then a last regression can be tried (including the four of them). This one again showed good correlation values.

Considering that the regression calculations for the first pair of values (IRI and Rutting) gave good values for correlation it seems possible that the inclusion of the other two variables can be possible.

Including those variables by steps (as the previous analysis) one by one, seems also to be the logic steps to be followed, in order to know if the 4 variables can be included in each model. Is strongly recommended to try to follow this procedure with all the previous analyzed type of regressions (Cubic, Quadratic and Power).

5.1.2 Proceed with the same study in a bigger number of road segments

Once one of the roads' pavement condition parameters have been analyzed for an entire lane for a whole road, it seems that the next step to apply is to analyze all lanes for all roads.

This will give a better idea of the power of the regressions found and how they can really be representative of the entire network. Doing this step will allow to have a customized prediction models based on a single parameter.

Therefore if the analysis is going well, there will be 4 different correlations types (linear, cubic, quadratic and power) each one of them analyzing within the type four different variables (Rutting as independent variable, and as independent ones IRI, Cracking and Deflection).

The reason to base all the analysis in the RUTT variable is because this is the first effect appearing in the Federal roads and will be the one influencing directly on the other 3 especially when the affection exists on the asphalt layers. From the maintenance activities performed in the federal road, we can know that the main negative effect in deflections is due to the failure of the wearing course. This issue could be checked during the conventional maintenance activities in which, the road base is extensively in good conditions meaning that the layers of asphalt were the ones failing under the heavy loaded trucks actions.

5.1.3 Contrast the performed analysis with real measurements

Once these models are ready is strongly recommended to contrast and calibrate them. The only way to do that is to obtain real measurements on samples of the roads representing different conditions in the asphalt, as for example, fatigued asphalt, rutted, cracked and apparently health waring course layers.

Obtaining positive results on this matter will allow to create models to obtain and predict important pavement condition parameters before they reach certain level and, in this way, advance actions to be done in asphalt pavement maintenance.

Doing this, a new variable not considered before, as can be different asphalt conditions is in the picture. This aspect will give the possibility of knowing if there is any restriction in the application of the models according with the pavement condition and know what are the limits to have reliable values and, according with the asphalt condition, if these values can be valid or not.

5.1.4 Modification of the PMS

Pavement Management System is a tool in which the condition survey parameters for asphalt can be grouped and analyzed to obtain maintenance plans in short, medium and large term. The most of the current PMS obtain the activities to be performed within the coming years using pre-stablished models (for example those provided by the World Bank) and then adjusting them according measurements are taken in the road, adjusting by steps along the time. Another way to do these plans is to follow predefined decision trees, depending on the results of the measurements and comparing them with trigger values established previously in order to determine the desired minimum level of service of the pavement and, when any of the parameters reach that lower value or pass it, then is time to plan some defined actions to repair the asphalt.

Having tools that allow the technical personnel working in asphalt maintenance to report to the decision makers what to do in short, medium and long term is basic nowadays, since preventive maintenance is taking a more relevant role each time more. The idea of having models that make possible to predict the behavior of condition survey parameters (talking about asphalts) from one single parameter, will make the distribution of data acquisition more easy (in the meaning of deciding where to apply it and when to do that test. And this decision can be related to technical, economical or a combination of both reasons).

The most feasible scenario for the output calculation from the PMS is to combine the three methodologies (the one based in pre-stablished evolution models, the one based on decision trees and the other one, which will be merged in some stage of the PMS life), and study the solutions launched by three of them. Decision should be done in the worst scenario launched by these three methodologies but, as the customization of the pre-stablished models is performing and trending to match the models treated in this project, those outputs should be analyzed and then decide on one of them with enough technical arguments.

So far, it can be confirmed that there’s no references published referring to a single regressions involving all 4 parameters as variables. And there should be said that from this point of view the project here presented is innovative and helpful in the meanings mentioned above.

5.2. Recommendations

The results obtained and the lack of references related to the correlation amongst some parameters representing condition of the pavement, make this study extremely interesting in order to predict some of these parameters values from others.

It will be interesting for any agency dedicated to maintain roads and pavements to know that there are contrasted methods to obtain or predict with a high level of confidence, other necessary and used parameter values.

Restriction of budget or better distribution of measurements in a network and therefore the progress of this study should make very interesting to continue a research line through this aspect.

It is highly recommendable to perform a similar study following the next steps:

1) Complete the acquisition of regression correlations with Cubic, Quadratic and Power forms including Cracks, Deflection and after both as dependent variables of the study.
2) Is recommendable to follow the same study applied to a bigger number of road segments. This will allow to contrast the model considering different conditions.
3) Is highly advisable to perform the final analysis and contrast the results with real measurements.
4) If the trend of the continuation of this project continue, then some modifications on the PMS can be included based on the prediction models obtained from the model described.

Chapter Six

6. Reference

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Appendix

SPSS Road 1 data

Road 1			
IRI	RUTT	DEFF	Crack
0.83	1.22	22.47	0.01
0.73	1.24	18.15	0.01
0.69	0.83	19.89	0.01
0.67	0.72	21.55	0.01
0.7	1.02	20.42	0.01
0.7	1.16	19.55	0.01
0.69	1.07	18.85	0.06
0.71	1.01	20.47	0.04
0.72	1.03	19.35	0.02
0.65	0.62	20.37	0.02
0.72	0.8	23.3	0.02
0.87	0.93	22.6	0.02
0.78	1.04	21.5	0.04
0.84	1.06	19.35	0.03
0.9	0.96	18.63	0.03
0.89	1.54	21.65	0.3
0.98	1.64	21.24	0.55
1.01	1.38	24	0.55
1.04	1.58	18.4	0.55
0.95	1.67	17.63	0.57
0.98	1.37	19.5	0.7
0.95	1.52	19.31	0.8
0.99	1.37	20.75	0.8
0.94	1.06	19.25	0.8
0.8	1	23.1	0.8
0.81	1.1	22.55	0.8
0.79	1.25	23.65	0.95
0.84	1.13	2035	1.06
0.99	1.68	16.71	1.27
0.93	1.32	18.94	1.38
1.03	1.68	14.85	1.52
0.91	1.37	14.45	2.03
0.94	2.56	12.89	2.03
0.91	1.46	17.8	0.76
1.05	1.81	20.05	0.258
0.88	1.55	19.84	0.25
0.86	1.49	22.35	0.23

0.89	2.23	26.29	0.15
0.83	1.98	19.27	0.36
0.81	1.71	17.25	0.96
0.91	2.03	22.47	0.72
0.92	1.71	25.9	0.57
0.78	1.2	23.52	0.57
0.69	0.67	20	0.78
0.64	0.6	29.14	0.96
0.71	0.69	30.52	1.27
0.85	1.59	28.28	1.27
0.77	1.7	25.95	1.13
0.9	1.75	30.4	0.95
0.75	1.53	19.55	0.95
0.86	1.88	22.6	0.95
0.92	1.7	23.52	0.95
0.96	2.03	26.65	1.18
1.1	2.72	30	0.83
1.11	2.76	31.47	0.72
1.15	2.92	24.4	0.72
1.12	2.83	25.55	0.72
1.07	2.5	27.84	0.73
1.06	2.47	28.35	0.74
1.03	2.2	25.85	0.74
1.06	2.38	26.1	0.74
0.89	1.45	25.2	0.74
1.01	1.76	30.55	0.74
1.04	1.89	24.88	0.74
0.91	2.11	22.5	0.74
0.86	2.1	19.95	0.74
0.95	1.84	15.1	1.23
0.89	2.07	21.7	1.46
0.91	2.17	20.2	0.83
0.9	1.79	20.15	0.15
0.93	1.9	21.35	0.11
0.92	1.85	21.47	0.04
0.9	1.54	19.8	0.01
0.84	1.73	22	0.01