



**DEVELOPMENT OF A PAVEMENT CONDITION RATING
(PCR) BY CONSIDERING BOTH EXPERT OPINION AND
CURRENT METHODS FOR MAINTENANCE MANAGEMENT
IN THE UNITED KINGDOM: A CASE STUDY OF ROAD
SECTION IN NOTTINGHAM**

By

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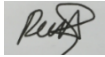
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DECLARATION

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ABSTRACT

Transportation system significantly takes part in an aspect of life that allows products or passengers to go places and conduct business. Transportation networks have a strategic position regarding planned country development. Pavements are just one part of the transportation system, and yet it is by far the most important component. Because pavements deteriorate over time owing to traffic, time and environmental factors. To prevent or reduce the rate of deterioration and to extend the life of pavement, 'Pavement Management System (PMS)' has been developed.

There are many approaches to process these through some steps such as inventory definition, pavement inspection, condition assessment, condition prediction, condition analysis and work planning, respectively. The information of condition analysis is usually converted into a condition index or rating. The condition of distress index is denoted as 'Pavement Condition Rating (PCR)' in this research project. The PCR constitutes the distress types, severities and extends. Those all different type of distress quantity into a single number. This number represents the condition state of network level, shows when maintenance is needed, for considering the prioritisation.

An approach is used considering both expert opinion and current methods mentioned in literature review in order to determine the PCR for each section. The approach requires usage of severity level and calculation of extent. The level of severity weight provides the relative importance of individual distress whilst the calculation of extent provides the quantity of individual distress. These contribute to prioritise which deterioration should be maintained first and also to illustrate the distribution of extent over entire road section. This research project aims the development of a PCR and prediction of importance level of individual distress for the United Kingdom.

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ABBREVIATIONS

AASHTO	American Association of State Highway Officials
AC_Index	Alligator Crack Index
ALDOT	The Alabama State Department of Transportation
ARAN	Automated Road Analyser
CS	Condition Score
CVI	Course Visual Inspection
DeIDOT	The Delaware Department of Transportation
DVI	Detailed Visual Inspection
FHWA	Federal Highway Administration
GDOT	The Georgia Department of Transportation
INDOT	The Indiana Department of Transportation
IRI	International Roughness Index
LC_Index	Longitudinal Crack Index
MDOT	The Mississippi Department of Transportation
NCHRP	National Cooperative Highway Research Program
NCDOT	The North Carolina Department of Transportation
NYSDOT	The New York State Department of Transportation
ODOT	The Oregon Department of Transportation
ODOT	The Ohio Department of Transportation
OI	Overall Index
Pat_Index	Patching/Pothole Index
PCR	Pavement Condition Rating
PMS	Pavement Management System
QC	Quality Control
RCI	Roughness Condition Index
RCI	Road Condition Indicator
Rut_Index	Rutting Index
SCANNE R	Surface Condition Assessment for the National Network of Roads
SCR	Surface Condition Rating
SCRIM	Sideway-force Coefficient Routine Investigation Machine
SFC	Sideway-force Coefficient
SR	Surface Rating
TC_Index	Transverse Crack Index
TMIS	Transportation Management Information System
TRACS	TRAffic Speed Condition Surveys
TxDOT	The Texas Department of Transportation
UK	United Kingdom
UKPMS	United Kingdom Pavement Management System
US	United States
VDOT	The Virginia Department of Transportation
WSDOT	The Washington State Department of Transportation

1. INTRODUCTION

1.1. Background

Pavement Management System (PMS) is a tool to make informed decisions about the maintenance and rehabilitation of a pavement network. All pavements deteriorate over time due to traffic and environmental problems. There is a need to develop a PMS to be aware of the condition of individual distress (deterioration) and control the budget as the distress deteriorates. This is because earlier treatments can reduce the total repair cost rather than later.

This understanding of PMS requires formulating a Pavement Condition Rating (PCR) and its functions in a PMS. The need for PCR is to define the current state condition of pavement, to identify the correct time for maintenance, to decide prioritisation regarding ranking and to predict the future state condition of the pavement. Several case calculations and applications for PCR are analysed to obtain an approach to the development of a PCR-based on both expert opinion and current methods used in worldwide to enhance prediction of the importance level of distress for road maintenance management in the UK which will be the aim of the project. This study addresses;

- The PCR can be developed from the severity, and the extent of the deterioration occurred on the road section.
- The prediction of the importance level of individual distress in each road section.
- Finally, the necessity for PMS to show having wider acceptance than current technics and investigating scientifically it as the best utilisation of the tool in the decision-making process.

1.2. Aims and Objectives of the Research

1.2.1. Hypothesis

This investigation is based on the approach stated by The State University of New Jersey Pavement Engineering, Pavement Condition Rating Module (2016) and Ohio State Department of Transportation Pavement Condition Rating Manual.

The relationship between the defined severity and the calculated extent of deterioration express the 'Deduct Values' of the selected road section's deterioration quantity. Deduct values are the numbers which compute the rating based on defined severity and calculated extent values. The level of severity depends on the importance of the individual distress. It totally depends on the condition of the pavement. The expert from Nottingham County Council helped to assign the level of severity weights based on the condition of occurrence to each cell in the failure matrix of each distress. The PCR is obtained by subtracting the deduct values.

Finally, the results are compared with Highway Agencies condition survey observations in the UK.

1.2.2. Aims of the Research

The investigation aims to develop a PCR by considering both expert opinion and current methods to enhance prediction of the importance level of distress for road maintenance management for the United Kingdom.

1.2.3. Objectives of the Research

In line with the aim as mentioned earlier of the research, the primary objectives of the study are defined as:

- To conduct a visual survey to map the extent of deterioration of the road section.
- To compute the average progression behaviour model based on distress parameters.
- To link the progression of distress on the road for the future maintenance need prioritisation.

1.2.4. Research Methodology

The first step of the methodology intends to find the deduct value of the occurred distress on the road section. Assigning the deduct values are based on expert opinion with following considerations:

- Severity level is defined by considering how bad the distress is (Low/Medium/High) and calculated with a relevant importance measurement
- Extent is calculated by considering the quantity of the distress
- Together these two parameters describe a great deal of a particular distress. This process is done for each type of distress that occurred on the road section.

Then, the next step is to compute the PCR value by subtracting the deduct values from 100 percent quality of road condition.

1.2.5. Report Layout

Chapter 1

The focus of the project is placed in a historical context. It is followed by a thorough background to the need for PCR and its function in PMS. Then, the need for PCR in road management applications is given. The aim, objectives and methodology of the research are also presented.

Chapter 2

This chapter covers the review of previous work literature. The importance of PMS, condition surveys, condition data collection methods and the current equations for calculating the PCR are implemented.

Chapter 3

This chapter presents the developed methodology for the case study in Nottingham. The data collection process, data management with related formulas and the outcome of the project are observed.

Chapter 4

The results and discussion are presented and analysed in this chapter. Also, the results are compared with UK Highway Agencies condition survey observations.

Chapter 5

This chapter provides the further recommendations for future research work.

2. LITERATURE REVIEW

The aim of this literature review is to clarify the topics and determine the gap in the area of Pavement Condition Rating (PCR) regarding PMS requirements. It contributes to the

research project by providing a principle approach; with appropriate use of relevant references. In general, the summary of this literature review will identify some methods of on the calculation PCR. Therefore, the first objective of this literature review is to understand how PCR is calculated differently and what kind of equations in each state has found based on the road deterioration mechanism, the collection of deterioration data and methods of measurements. And it also encompasses the requirements for decision making of the PCR equations.

2.1. The Importance of Transportation System

Transportation infrastructure plays a crucial role in the economy of a country. The significant investment owned by a city and a country is their pavement function. It is "more valuable, contributes more direct benefit to economic efficiency, and has a higher cost of replacement than sewer systems, water systems, public buildings, and treatment plants" (Polhill, 1982). It is obvious that citizens are also quite mindful of the condition of pavements than other infrastructure needs (Polhill, 1982). For this, every country has to develop a management system to keep the normal situation of their pavement roads. This management system must include the significant points which are inventory, financing and implementation. These actions will allow the agencies in countries to get the primary purpose of developing a management system.

2.2. The Overview of Pavement Management System

PMS should be pursued for the analysis and design of pavement rehabilitation and budget control strategies. There is quite a few functional definition of PMS in the context of pavement rehabilitation. As stated by Asghar in 1994 adapted from Maynard in 1986, -"It is a system that will produce a multi-layer program for pavement rehabilitation to utilise available funds in the most cost-effective manner. The degree of sophistication required to accomplish this can range from the "lone engineer" equipped with an eyeball, pad, pencil and file cabinet to an externally complex computerized system which relies on data gathered by gadgets and produces rehabilitation programs untouched by human, let alone engineering, hands"- (Asghar, 1994).

Another definition was indicated by Asghar in 1994 adapted from the first Roads and Transportation Association of Canada Guide RTAC in 1977, - "The fundamental purpose of a pavement management system is to achieve the best value possible for the available funds and to provide safe, comfortable and economic transportation. This is accomplished by comparing investment alternatives both at the network and project levels, coordinating design, construction, maintenance and evaluation activities, and making efficient use of existing practices and knowledge. It, therefore, encompasses a broad spectrum of activities including the planning or programming of investments, design, construction, maintenance, and the periodic evaluation of performance"- (Asghar, 1994).

As well as mentioned in National Cooperative Highway Research Program (NCHRP) Synthesis 203 regarding the definition of PMS adapted from AASHTO Guidelines - "PMS is a set of tools or methods that can assist decision-makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in a serviceable condition" -(NCHRP Synthesis 203, 1994).

PMS provides the potential solutions to develop the main objective of improving road conditions and reducing pavement maintenance costs simultaneously. It is a process which must keep a balance between sustained performance and increased maintenance costs (Wilde, J.W., Thompson, L. and Wood, T.J., 2014). The performance of pavement decreases as the pavement ages, as represented in Figure 2.1 (Polhill, 1982). Phases in the life of the pavement, emphasising the need for proper maintenance, preventing road infrastructure deterioration, and maintaining a specified level of service (Asghar, 1994).

Differing pavement structures, traffic loads, soil and environmental conditions and maintenance practises affect the shape of this curve (Polhill, 1982). Inappropriate and all-time maintenance efforts can lead to earlier maintenance or reconstruction needs and are an uneconomical drain on scarce funds. The maintenance assessment should, therefore, include quantitative road network information in the database with properly defined standards, and systematic procedures for monitoring and evaluating pavement performance. Projects should be prioritised according to the maintenance assessment (Asghar, 1994).

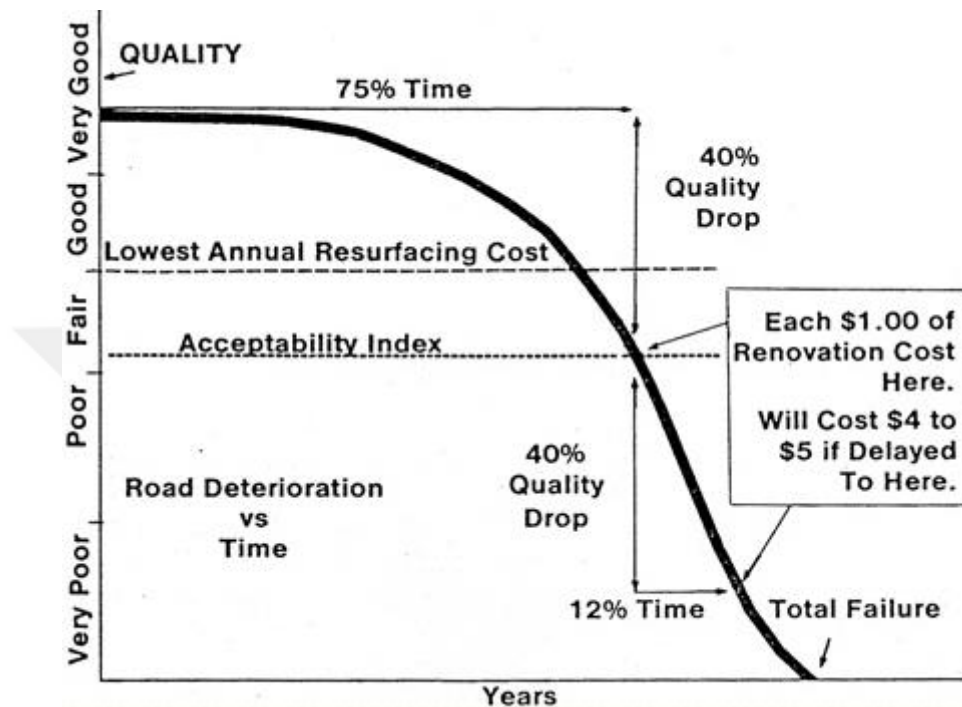


Fig 2. 1: Pavement Serviceability and Pavement Life Relationships (Polhill, 1982)

To recapitulate, “The use of pavement management is to identify and prioritise maintenance and rehabilitation needs and assists agencies in determining cost-effective treatment strategies” (Karasahin, 2014). The Figure 2.2 illustrates that while maintenance costs increase as serviceability declines. Thus, it can be seen determining cost-effective treatment strategies are depends on serviceability level. Serviceability level, based on pavement surveys related to the condition, is the major component of PMS which is structured to make decision-making strategies at a different type of management levels (NCHRP Synthesis 203, 1994).

The design of PMS provides objective information and useful data for analysis so that road managers can make more consistent, cost-effective, and defensible decisions related to the preservation of a pavement network (Vitulo, 2009). While a PMS cannot make final decisions, it can provide the basis for an informed understanding of the possible consequences of alternative decisions. It should not be forgotten that a PMS does not make decisions, managers do.

One of the general frameworks of PMS phase is to assess the pavement needs in a particular time interval. This process helps to evaluate the current condition and make an inference of future needs of road network infrastructure.

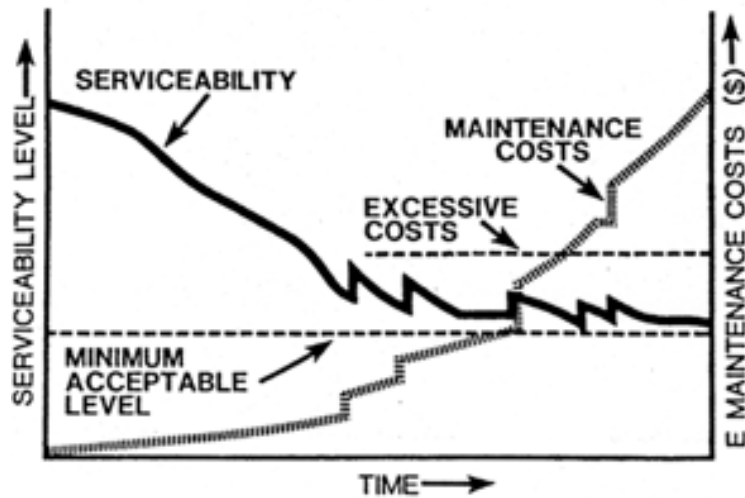


Fig 2. 2: The Relationship between Maintenance Cost and Serviceability (Polhill, 1982)

The Figure 2.3 (Schacke, 1987) below provides an idea of the condition of a pavement and the type of maintenance that may be required over time. It demonstrates there are two levels of maintenance. The first – routine maintenance is carried when the deterioration is not significant to result in any noticeable reduction in the performance of the pavement, but the present flows can lead to greater problems. The second type of maintenance as referred to as preventative maintenance. It is a typical performance curve, representing performance prediction of the roadway (Asghar, 1994).

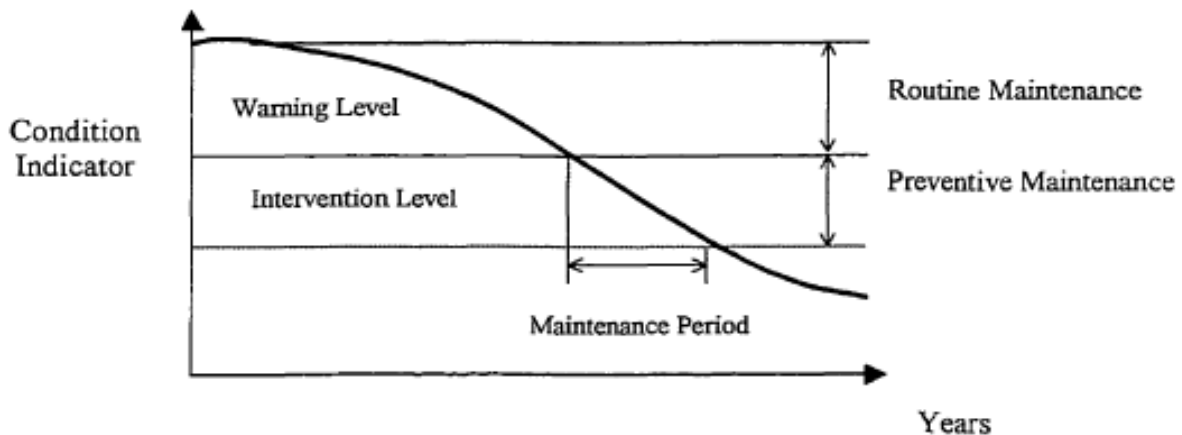


Fig 2. 3: Performance Curve Relating Pavement Condition Rating to the Age of the Pavement (Schacke, 1987)

All these points to the fact that pavement management refers to the decision-making process, as discussed above, helps highway authorities to keep in mind the variety of considerations and detailed inputs that have affected the development of pavement management systems throughout history. Figure 2.4 shows the summary of the components of the pavement management system (Gallagher, 2009).

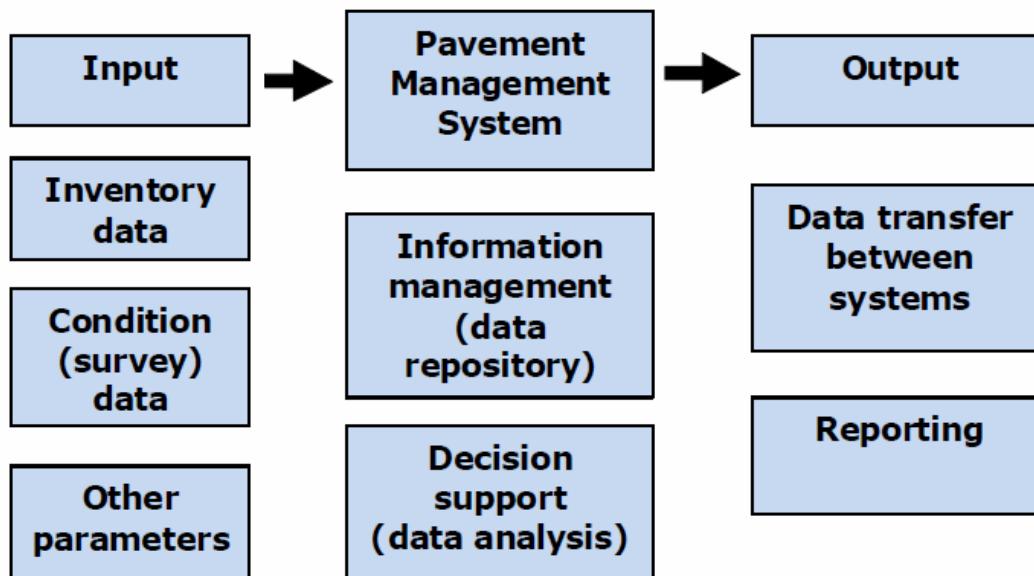


Fig 2. 4: Components of Pavement Management System (Gallagher, 2009)

In the United Kingdom PMS is a computer based system that aims for the cost-effective management of a road network. It consists of a different system of visual data collection, data analysis and consideration of budget allocation. These all data are combined with different type of condition surveys

The United Kingdom Pavement Management System (UKPMS) is a computer system that was designed for the economic management of the structural maintenance budget of a road network and dates back to the early 1980's. It incorporates a new system of visual data collection, data analysis, and budget allocation for all roads and has combined data from different types of condition surveys. Other significant features include the ability to project condition data into the future; this enables the user to take account of the economics of alternative maintenance treatments when deciding where and what treatments should occur. The core philosophy of UKPMS is to defer treatments where it is cost-effective and safe to do so and to give priority instead to preventive maintenance. The UKPMS provides standards for the assessment and recording of network condition and the planning of investment and maintenance on roads, kerbs, footways and cycle tracks within the UK. UKPMS provides a framework for combining the systematic collection of data with the decision-making processes necessary to optimise resources for the maintenance and renewal of pavements, including the generation of programmes of works and corresponding budgets. It is used by local authorities in the UK for the management of roads and for the production of performance indicators that are used nationally (Scott Wilson Group OLC 2007).

The general principles of condition surveys regarding data collection for PMS are discussed in the next chapter.

2.3. Pavement Condition Survey

A PMS must have usable, accurate, and timely (current) information to produce credible results (Anon, 2016). As stated by Haas & Hudson (1978) "a PMS consists of some set of tools or methods that help the decision makers in identifying optimum strategies to extend pavement life". Pavement management has two main operating levels. One of them is to determine network and the second one is planning the project. In general

determining the network, division depends on how pavement of function condition is and the road which statesmen often use.

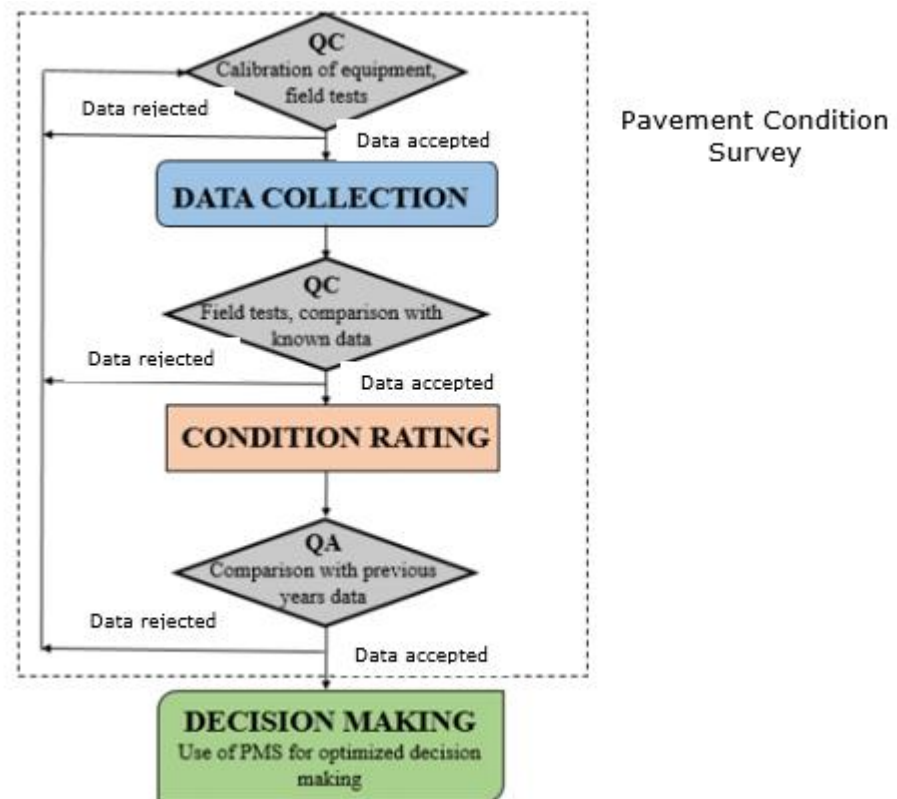


Fig 2. 5: Pavement Management Process (Nii O. Attoh-Okine, 2002)

Figure 2.5 above shows that pavement condition survey is a part of the pavement management process which includes the decision-making procedures. The first step is the Quality Control (QC) step which requires calibration of equipment and random field tests. After the results of the field tests are accepted, data collection takes place. QC is done after data collection to ensure acceptable data quality. Corrective actions involving calibration and rating is done when results of QC are not acceptable. Condition ratings are then carried out on the data. Before data is fed to decision-making and optimisation tools or sent to management, quality assurance is done again to ensure that the results are coherent.

Condition surveys have been specifically aimed to determine the amounts of using resources by assisting management in making informed decisions. Responsible agencies must rely on a PMS to define priorities for maintenance and rehabilitation. As they have limited amount of funding available for maintenance of pavements, quality criteria need to be updated periodically using basic statistical tools. All quality management procedures must be well documented to help improve future data quality control and assurance procedures. With quality and reliable data, pavement management will allow, and this will ultimately lead to efficient use of pavement assets. Pavement Condition Surveys refer to activities performed to give an indication of the serviceability and physical conditions of road pavements (Nii O. Attoh-Okine and S. M., 2002).

A Condition Survey has three most important aspects, namely; data collection, condition rating and quality management. It is the process of collecting data to determine the structural integrity, distresses, skid resistance, and overall riding quality of the pavement. Traditionally, maintenance or engineering personnel relied on experience and

visual inspections to schedule maintenance. The problems with that technique are that experience is difficult to transfer from one person to another and decisions made using similar data often vary considerably.

The key point, to get consistent and reliable results in the survey, is to reduce the differences in the definition of defects on the road and to gain useful recording information in a consistent way (The Texas State Department of Transportation Pavement Design Manual, 2011). Useful summarised information can be obtained from pavement performance analysis by looking at the reliable pavement condition survey (Auburn University, 2006). As the fundamental purpose of the pavement condition survey is to serve different details of physical pavement condition regarding serviceability (Attoh-Okine & Adarkwa, 2013). It includes not only the type of distress that has occurred but also its severity, its extent and the location. The serviceability level, obtained from condition surveys, expresses the pavement condition ratings which are used as a fair basis of comparison for different pavements. In other words, pavement condition ratings allow for a more objective comparison of two or more pavement sections. This becomes important when prioritising maintenance and rehabilitation project (Nii O. Attoh-Okine and S. M., 2002).

Data obtained from condition surveys can be used for long-term budget planning. The survey data of past and present conditions can be used to project future conditions and this serves as a guide for management during allocation of funds for future works as mentioned in the flow diagram. With condition ratings, management decisions are no longer based on sentiments and hunches but rather on the valuable and reliable information provided by the condition ratings. The frequency of surveys also gives a shape to some factors. These factors are the type of pavement, the age of pavement, sound condition, and the average of daily traffic, axle loadings, drainage characteristics, and weather factors (Nii O. Attoh-Okine and S. M., 2002).

Taking into all process of the importance of condition surveys consideration, an agency should be aware of the following flow diagram (Figure 2.6) that must be paid attention.

The first step of conducting condition surveys which are data collection for PMS is discussed in the next chapter.

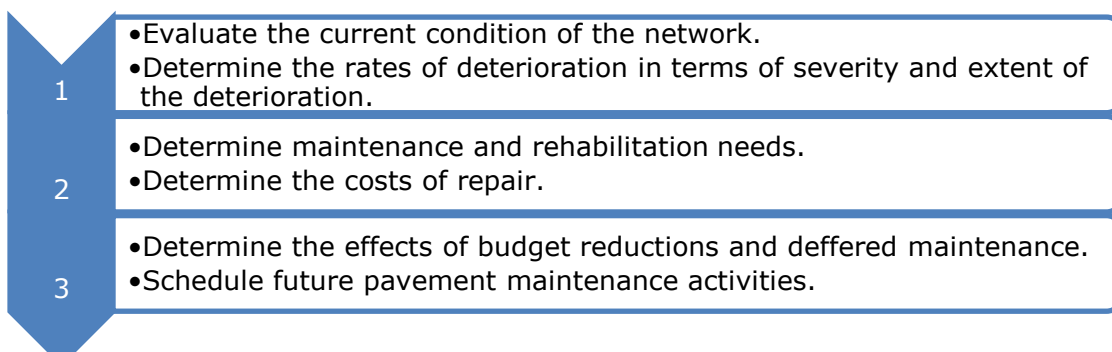


Fig 2. 6: Flow Diagram for the Aspect of Pavement Condition Surveys (Anon, 2016)

2.4. Surveys Data Collection

Many years later, nearly the same results of pavement behaviour and performance are described by US Department of Transportation Practical Guide for Quality Management of Pavement Condition Data Collection Report (2013) based on "pavement structural design, climate, traffic, materials, subgrade, and construction quality. All these factors give a shape to results of pavement condition survey". Due to this, many factors determine the ability of the pavement, for example, the density of deterioration are on pavement surface (Auburn University, 2006).

The surveys data collection is quite an important step to achieving “the best treatment option and the best time to apply maintenance” (Gallagher, 2009). Much information about the condition of a network can be obtained through pavement condition survey data collection with the scientific results. There are two types of data collection methods. These are Manual Surface Data Collection and Automated Surface Data Collection Method. In this section, the different methods of collection are presented.

2.4.1. Manual Surface Data Collection

Manual surface data collection is described by The British Colombia Ministry of Transportation and Infrastructure Construction Maintenance Branch, (2012) routinely managed during the detailed evaluations that are taken out for pavement rehabilitation projects. Although a manual survey is not yet often useful, it is the most basic one (Thom, 2008). The responsible person looks with eyes, making notes. If the information recorded by hand, it is manual. However, the visual survey is also a kind of manual surface data collection. The goal of these surveys is to create a more precise result of the pavement deterioration in society to define suitable rehabilitation treatments. “The person does the manual surface distress mapping method by walking and getting the visual results on the pavement section” (British Colombia Ministry of Transportation and Infrastructure Construction Maintenance Branch, 2012). Figure 2.7 shows an example of manual data collection method by measuring deterioration sizes on the surface.

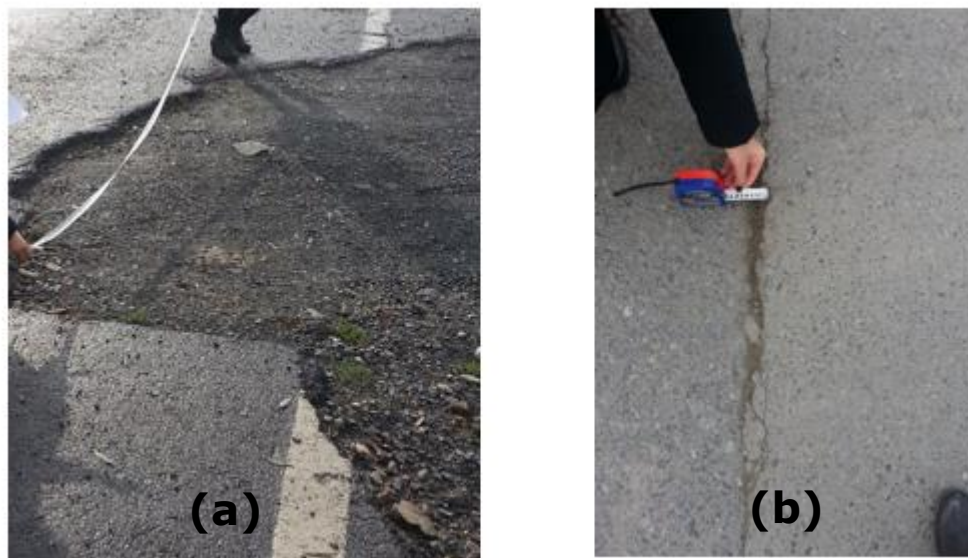


Fig 2. 7: Manual Data Collection Method by Measuring the Surface Deteriorations

((a) Ravelling and (b) Cracking) (Turkey, 2014)

In general, there are three types of manual pavement condition data collection. As described by Auburn University (2004) these are Walking Survey, Windshield Survey and Walking + Windshield Survey. In Walking Survey a person walks on the road to get the visual results while in Windshield Survey is done by driving along the road. The pavement is rated by walking as well as driving in Walking + Windshield Survey. In the US, The Delaware Department of Transportation (DelDOT), The Georgia Department of Transportation (GDOT), The North Carolina Department of Transportation (NCDOT), The Oregon Department of Transportation (ODOT) and The Virginia Department of Transportation (VDOT) collect data using manual methods.

As described in the United Kingdom Pavement Management System (UKPMS) manuals there are two types of UKPMS visual surveys. The Coarse Visual Inspection (CVI) survey is intended to be a course, rapid survey, usually carried out from a slow-moving vehicle

that allows a large part of a highways authority's road network to be assessed each year. CVI is the standard survey used to produce the Best Value Performance Indicators on the condition of local authorities' roads as required by the government, and which allows comparisons to be made between authorities by the overall condition of their carriageways (UKPMS, 2007).

The second type of manual surface in the UK is the Detailed Visual Inspection (DVI) survey is a more comprehensive survey, with defects identified by a larger number of more detailed classifications. The DVI is a walked survey that provides much more detailed information than the CVI and is typically targeted at lengths already identified as defective and potentially in need of treatment either by the CVI or from other sources of information. It is envisaged that a more detailed engineering survey would be carried out before maintenance schemes being implemented. The DVI records are measured areas or lengths for a wider range of more tightly defined defects (than for CVI), aggregated within short subsections, 20 metres in length by default. The defects collected for DVI are described to a closer level of detail than CVI. To ensure broad consistency between the two surveys, a single CVI defect is usually equivalent to some DVI defects. It is intended that DVI is used where more detailed information is required to support and validate treatment decisions and scheme identification, supplementing CVI data; it may also be used on a cyclical basis for parts of the network where a more detailed routine visual assessment is required or where driven surveys are not possible. If DVI surveys are to be used to produce Best Value Performance Indicators, then they should be converted to CVI-equivalent data using the UKPMS Conversion Software (UKPMS, 2007).

There are some drawbacks to conducting manual surveys. For instance, it is time-consuming and sometimes dangerous to investigate. Moreover, it can be difficult to convert from pictures to words (Thom, 2015). It needs much more attention and much more experience to define the deterioration.

2.4.2. Automated Surface Data Collection

The automated surface data collection is in a state of quick evolution, which is the most reasonable alternative for highway agencies. While measuring something on the road, it can be "repeatable, reproducible, consistent and reliable" (Thom, 2015). This type of collection is much quicker and less dangerous. Collection procedure is explained by Auburn University (2004) as the information was collected and stored using technology installed in a vehicle. There are more than one automated vehicles which assist in identifying condition of pavement deterioration. In some cases, they are similarly trying to get the same final results, individual pavement condition data. But according to Gallagher (2009), "each of the different condition measurement includes different tools so the results from each tool may not be comparable".

There are numerous types of data collected by automated and the technology used to collect it. These are surface distress, rutting, ride and texture. In general, as distinguished by Transportation Research Report (2008) between automated and manual data collection techniques, ride smoothness and wheel path rutting are measured mechanically by lasers. Pavement cracking is measured through visual observation performed by experienced survey staff.

Although it can be done by driving and that makes it safety survey, there are some disadvantages of automated surveys. Before starting the survey, the crew should be fully acknowledged what they physically measure and what this measurement means. Without having a reasonable idea, completing the survey may not make sense for the calculation of pavement condition (FHMA 2013).

In the UK, the condition of pavement is also surveyed by automated data collection methods. These are SCANNER (Surface Condition Assessment for the National Network

of Roads) (see Figure 2.9) Surveys and SCRIM (Sideway-force Coefficient Routine Investigation Machine) (see Figure 2.8) Surveys.

SCANNER Surveys are high-speed surface condition surveys, based on the Highways Agency TRACS Contract and developed to be suitable for the Principal Road Network. SCANNER collects the following data (UKPMS, 2007):

- 3-Dimensional Spatial Co-ordinates
- Road Geometry
- Survey Speed
- Longitudinal Profile
- Wheel path Rutting
- Texture Profile
- Cracking

Additionally, measures of edge condition and transverse unevenness are being developed (UKPMS, 2007). The SCANNER survey lays out the Road Condition Indicator (RCI) based on the collected data which will play major role investigation of consistency of the measurements (Benbow and Wright, 2008).

There is also a machine which is called by SCRIM. "It measures the wet skidding resistance of the road network". The standard testing speed for the machine is 50km/h and skidding resistance values for the nearside wheel track only (usually the location of the lowest skidding resistance) are recorded as the average for each 10m section. The principle of the machine is that a test wheel, mounted mid-machine in line with the nearside wheel track and angled at 20° to the direction of travel, is applied to the road surface under a known load. A controlled jet of water wets the road surface immediately in front of the test wheel, so that when the vehicle moves forward, the test wheel, while rotating freely in its plane (thus allowing uniform wear on its test wheel tyre), slides in the forward direction on a wet road surface. The force generated by the resistance to sliding is related to the wet skidding resistance of the road surface and measurement of this sideways component allows the Sideway Force Coefficient (SFC) to be calculated.

SCRIM surveys are processed differently from other surveys types within UKPMS, in that they make use of "Functional" defects. These defects always prompt treatment if they are below the target threshold. The treatment that is suggested will depend on upon what other defects, from other surveys, exist at the same location.

Further information is available in the SCANNER Specification. It is intended that traffic speed surveys will be further developed for used on local roads over the coming years.



Fig 2. 8: SCRIM (Parry, 2015)



Fig 2. 9: SCANNER (SCANNER User Guide and Specification Volume1, 2011)

Table 2. 1: Comparison of Automated and Manual Pavement Data Collection Methods (Attoh-Okine & Adarkwa, 2013)

	Automated Data Collection	Manual Data Collection
Time	Reduces data collection times	Longer data collection times
Safety	Much safer means of collecting data	Personnel at risk collecting data
Objectivity	Objective measurements	Usually subjective since it depends on experience of personnel
Cost	Very expensive equipment costs	Relatively less expensive
Data Size	Vast amounts of data collected & stored depending on capacity of equipment	Agencies may only be able to collect smaller amounts of data at a time
Data Handling	Not subject to transcription errors	Subject to transcription errors
Employers	Suitable in agencies seeking to downsize number of employees	Source of employment for rating staff
Coverage	May cover footprint of data collection vehicle. Multiple runs sometimes needed to cover entire road width	Inspectors can cover entire width of road section relatively easier

The Table 2.1 above illustrates the proper summary of comparison of automated and manual pavement data collection methods. The two methods are compared in terms of time, the safety of staff, objectivity of measurements, cost, data size, handling and employers' point of view. An agency's preference for one of these approaches or even a combination of them is based on the amount of financial resources and human capital it has as well as the level of detail and accuracy of data required.

2.5. Pavement Distress Indices

Pavement distress indices for road management have been developed and calibrated to better represent individual road typologies (Rivera, 2015). The definition of dependent

variables of a pavement section is considered a score that quantifies the performance (Anon, 2016). As described by US Department of Transportation Practical Guide for Quality Management of Pavement Condition Data Collection Report (2013), there are many reasons for evaluating pavement distress indices. It involves the problem of relating distress to performance. Within the design subsystem, the major models involved predict pavement behaviour. When this response, such as stress or deformation, reaches a limiting value of the material involved, "distress occurs in the form of fracture or permanent deformation". This distress represents materials failure but does not constitute 'failure' of the pavement. Pavement failure occurs when the accumulated distress reduces the serviceability level below and acceptable level for the users of the facility (Thom, 2015).

The pavement distress indices will be represented as a 'Pavement Condition Rating (PCR)' in the research project. As described by FHMA (2013), there are various aspects of pavement condition which directly affects pavement distress indices. These are structural capacity, structural integrity, roughness, skid resistance, the rate of deterioration, and required maintenance, obtained from data collection process. To get the pavement condition distress indices accurately, these aspects should be considered. In this research project, the pavement distress indices named as Pavement Condition Rating (PCR).

2.5.1. Need for Pavement Condition Rating

PCR is used in pavement management systems for the following four basic reasons (Deighton, R. and Sztraka, J., 1995):

- ❖ Trigger treatments;
- ❖ Calculate life-cycle costs
- ❖ Evaluate the network condition
- ❖ Make use of the same relative scale between systems

Trigger Treatments; PMS needs to know when treatment is feasible to apply the correct maintenance regarding operationally and economically perspectives (Anon, 2016). This consideration process helps where decisions are necessary. For example; with a treatment such as a 'thin overlay', a condition rating is needed to indicate when a road is in a condition that makes applying a 'thin overlay' feasible.

Calculate life-cycle costs; PCR helps calculate better cost estimates regarding pavement management strategies. This can serve a better approach using cost projections. For example; it costs more to fill cracks on a road with many cracks than on a road with few cracks. Or it costs more to fill potholes on a road with many potholes than on a road with few potholes.

Evaluate the network condition; The individual condition indices used for calculations within a PMS are one-dimensional. They only describe one measure of condition. For example; ride index or a fatigue index. But the composite indices, like PCR, allows comparison of roads with different distress data.

As mentioned above the condition ratings are used as a basis for comparing the performance of two road sections. Most importantly, they help agencies to determine the extent and severity of pavement defects and estimate the cost of repair and rehabilitation and prioritise treatment procedures. They are also used as a basis for planning budgets. Condition rating indexes also have in a way reduced the political pressure that formed a greater part of the decision-making process (Anon, 2016).

2.6. Methods of Condition Assessment and Calculation

2.6.1. Pavement Condition Deterioration Mechanism

A pavement deterioration is defined regarding decreasing the serviceability level caused by the development of cracks and ruts (Adlinge S.S. and Gupta A.K., 2015). A deterioration mechanism should include significant variables of the pavement. These are the construction, design, structure, material, time and traffic, environment and maintenance history. The general performance and also the deteriorated performance is usually identified by its facility to "provide a safe, smooth and comfortable ride" (Haas et al., 1978). More detailed, as defined by Pavement Condition Rating Procedure Report (1979), it can be seen that the level of pavement deterioration is a function of type of distress, severity of distress (width of cracks, depth of ruts, etc.) and density of distress (in a percentage of total pavement area). Each of these distress levels has a quite substantial effect on how the overall condition of pavement surface deterioration mechanism determined.

The results obtained from surveys and investigations, together with the other observed condition data and information for the road section give idea for finding the following points out (Design Manual for Road and Bridges, HD30/08, 2008):

- ❖ The nature, extent and degree of the defects;
- ❖ The probable causes of the defects;
- ❖ Whether the defects are in the surface or are structural;
- ❖ The types of remedial treatment needed.

A major part of the interpretation process for deterioration mechanism is the comparison of the different types of data and to note where they support or conflict with each other. It is usual to find that for at least part of the scheme length there are inconsistencies between the data (Design Manual for Road and Bridges, HD30/08, 2008). It is also dependent on "engineering perspective" (Hong, 2007).

2.6.2. Requirements for Decision Making For PCR

The assessment of the distress manifestations of the pavement section is based on "the severity and extent of deterioration" (Federal Highway Administration, 2006). Collecting roughness, distress manifestations, structural capacity and skid resistance are the first requirements of decision making (Design Manual for Road and Bridges, HD30/08, 2008).

Pavement condition rating involves quantifying the condition of pavement value depending on a chosen scale or index. Most universal condition ratings or indexes are based on from 0 to 100 scale. The rating index selected by an agency depends on the agency's available resources and its ability to address pavement issues prevalent area as presented by The Delaware Centre for Transportation (2013).

In general, the PCR method described within this chapter based on deducting values which are written above. Although the general approach is almost the same, the results of ratings could be different. To identify this problem The Texas Department of Transportation (TxDOT) and The Federal Highway Administration (FHWA) used "t-test and scatter plots to set up this fact" presented by Delaware Centre for Transportation, University of Delaware (2013). Selected pavement condition ratings and indexes were used to study on 9642 pavement sections. The selected ratings and indexes were the TxDOT's Distress Score and Condition Score (CS), Oregon DOT's Overall Index (OI), Minnesota DOT's Surface Rating (SR) and Ohio DOT's Pavement Condition Rating (PCR). When compared these ratings and indexes measurements it can be seen that all of them are quite different from each other, t-test showed. The various cases of mathematical expressions DOTs have based on different type of measuring distresses. For instance, the while average rut depth is used by Overall Index, the percentage area and the severity are used by Distress Score. The Overall Index can be formulated Equation (2.1) (Coplantz, 2013) as follows:

$$(\text{Overall Index})_{\text{Rut depth}} = 1.00 - A \times (\text{Measured Distress/Maximum Distress}) \times B \quad (2.1)$$

The coefficient A and exponent B represent the relative impact of the type and severity of each distress. After computing the overall index for each distress severity and distress type using Equation (1), complex index factor can be calculated.

Regarding with the other instance, the Distress Score (DS) for Continuously-Reinforced Concrete Pavement (CRCP) can be formulated Equation (2.2) below:

$$DS = 100 \times (U_{\text{Spall}} \times U_{\text{Punch}} \times U_{\text{PCPat}} \times U_{\text{ACPat}}) \quad (2.2)$$

Where DS = Distress Score

U_{Spall} = Utility value for Spalled Cracks
 U_{Punch} = Utility value for Punchouts
 U_{PCPat} = Utility value for Concrete Patches
 U_{ACPat} = Utility value for Asphalt Patches

Another point of difference is climatic conditions. Because “climate change has the potential to impact long-term road pavement performance” (Qiao et al., 2015). In some regions, there could be huge temperature changes among daytime and night, so, in that case, it is quite important to consider the measurement of cracking. From this, it may be directly linked to determine the equation. Finally, it has emerged that looking through the collected data of each state of the US could give an approachable way to define the evaluation of condition rating.

2.6.3. The Federal Highway Administration (FHWA)

The Federal Highway Administration collects, as explained by FHWA Pavement Distress Identification Manual (2006), the road surface condition for rutting and roughness (IRI) data using an automated data collection vehicle called ARAN (Automated Road Analyser). The other surface distresses, such as transverse cracks, longitudinal cracks, alligator cracks and patching/potholes, determined from digital video images. Each of these surfaces distresses assigned a calculated surface distress index. The calculations of these all indexes are also explained in this manual within details. These are;

- Transverse Crack Index (TC_Index)
- Longitudinal Crack Index (LC_Index)
- Alligator Crack Index (AC_Index)
- Patching/Pothole Index (Patch_Index)
- Rutting Index (Rut_Index)

IRI is given a calculated Roughness Condition Index (RCI), is directly calculated by equation (2.3);

$$RCI = 32 \times [5 \times (2.718282^{(-0.0041 \times \text{AVG IRI})})] \quad (2.3)$$

Where the AVG IRI is average of Left IRI and Right IRI measurements for the interval.

Using these each surface indexes there can be defined the Surface Condition Rating (SCR) below equation (2.4);

$$SCR = 100 - [(100 - AC_Index) + (100 - LC_Index) + (100 - TC_Index) + (100 - Patch_Index) + (100 - Rut_Index)] \quad (2.4)$$

Finally the overall PCR value is calculating by equation (2.5);

$$\text{PCR} = (0.60 \times \text{SCR}) + (0.40 \times \text{RCI}) \quad (2.5)$$

The values 0.60 and 0.40 are function as weights in the formula.

2.6.4. The Alabama State Department of Transportation (ALDOT)

The Alabama State Department of Transportation uses a Pavement Condition Rating for calculating the condition of the pavement. The rating equation was developed by Glover, T.C. et al. in 1985 by considering minor maintenance, overlays or structural rehabilitation. As explained by Auburn University (2013) thirty-one inspectors had 1086 visits on the road. After the surveys in the field, they examined and evaluated the results by the method which is still being used by ALDOT. The equation (2.6) is:

$$\begin{aligned} \text{PCR} = & 95.5727 - 5.5085 (5.0\text{-ROUGH}) - 1.5964 \text{LNALL1} \\ & - 1.9629 \text{LNALL2} - 2.9795 \text{LNALL3} - .01630 \text{PAT2RD} \\ & - .07262 \text{BLK2RD} - .2220 \text{AVGOUT} - 3.4948 \text{RAVL31} \\ & - 7.5269 \text{RAVL32} - 11.2297 \text{RAVL33} - .03032 \text{LONG12} \\ & - .05484 \text{LONG34} - .53050 \text{TRAN12} - .69736 \text{TRAN34} \end{aligned} \quad (2.6)$$

where,

ROUGH = roughness or present serviceability index
 LNALL1 = ln (level 1 alligator cracking + 1.0)
 LNALL2 = ln (level 2 alligator cracking + 1.0)
 LNALL3 = ln (level 3 alligator cracking + 1.0)
 PAT2RD = patching (level 2 + level 3), ≤ 400 ft²
 BLK2RD = block cracking (all levels summed), ≤ 400 ft²
 AVGOUT = outer wheel path rutting (all locations averaged), 10-2 inches
 RAVL31 = severe localized ravelling (Code: 0 = none, 1 = present)
 RAVL32 = severe wheel path ravelling (Code: 0 = none, 1 = present)
 RAVL33 = severe entire lane ravelling (Code: 0 = none, 1 = present)
 LONG12 = longitudinal cracking (level 1 + level 2), ft
 LONG34 = longitudinal cracking level 3, ft
 TRAN12 = transverse cracking (level 1 + level 2), number of cracks
 TRAN34 = transverse cracking level 3, number of cracks

There is another PCR that ALDOT is using for alternative PCR which is considered also the age of pavement at that time presented by Bell (2015). The equations based on four metrics. These are;

1) For public perception, it is **IRI (Roughness)**;

It is basically based on MRI (Mean Roughness Index). The MRI is the average of wheel path IRI values reported for a given segment or lot (see the equations (2.7), (2.8) and (2.9)).

$$\text{MRI} \leq 50 \text{ in./mi} \quad \text{Index}_{\text{roughness}} = 100 \quad (2.7)$$

$$\text{If; } 50 \text{ in./mi} < \text{MRI} \leq 170 \text{ in./mi} \quad \text{Index}_{\text{roughness}} = \frac{170 - \text{MRI}}{170 - 50} \times 100 \quad (2.8)$$

$$\text{MRI} > 170 \text{ in./mi} \quad \text{Index}_{\text{roughness}} = 0 \quad (2.9)$$

2) For structure, it is **Wheel path cracking**;

It is basically based on Wheelpath cracking values (see the equation (2.10));

$$\text{Index}_{\text{cracking}} = \frac{52.8 - \text{Wheelpath_Sum}}{52.8} \times 100 \quad (2.10)$$

3) For safety, it is **Rutting**;

It is basically based on MRUT(Mean Rutting). The MRUT is total rutting values (see the equations (2.11), (2.12) and (2.13)).

$$\mathbf{MRUT} \leq 0.08 \text{ in.} \quad \mathbf{Index}_{\text{rutting}} = 100 \quad (2.11)$$

$$\mathbf{If;} \quad 0.08 \text{ in.} < \mathbf{MRUT} \leq 0.40 \text{ in.} \quad \mathbf{Index}_{\text{rutting}} = \frac{0.40 - \mathbf{MRUT}}{0.40 - 0.08} \times 100 \quad (2.12)$$

$$\mathbf{MRUT} > 0.40 \text{ in.} \quad \mathbf{Index}_{\text{rutting}} = 0 \quad (2.13)$$

4) For priority of maintenance, it is Age of coating

$$\mathbf{If;} \quad \mathbf{AGE} \leq 16 \text{ years} \quad \mathbf{Index}_{\text{age}} = \frac{16 - \mathbf{AGE}}{16} \times 100 \quad (2.14)$$

$$\mathbf{AGE} > 16 \text{ years} \quad \mathbf{Index}_{\text{age}} = 0 \quad (2.15)$$

Related to these metric the general PCR equation (2.16) is showed below:

$$PCR = \frac{(\text{Indexroutness} + \text{Indexrutting} + \text{Indexcracking} + \text{Indexage})}{4} \quad (2.16)$$

The advantages of this method are noted by (Bell, 2015) there is no gap between new in-service pavement condition. Because in this equation the difference index is age. Also, each metric allows for more detailed decision making.

2.6.5. Ohio State Department of Transportation (ODOT)

Ohio Department of Transportation is measuring the possible benefits and restrictions associated with transitioning from a manual to automated collection and automated, semi-automated, or manual data processing or identification of pavement distresses (including severities and extents) as reported by Federal Highway Administration Final Report (2013). ODOT has been using Pavement Condition Rating to identify the distress of pavement and then to compile them into that rating since 1985. The PCR is described by The Ohio Department of Transportation Manual (2006) directly related to investigating pavement distress. This pavement condition rating method is a kind of process for providing identification and characterization of pavement condition after the investigation. It is widely available and has been used in many investigational studies. The mathematical equation for PCR includes all deterioration of distress types, severity and extent. These components' multiplication provide a deduct value. The equation (2.17) is as follows:

$$PCR = 100 - \sum_i^n (\text{Deduct})_i \quad (2.17)$$

where,
n=number of distress

Deduct values are the numbers that stand for the effects of distresses have on a pavement's structural equivalent and sustainable surface condition. A deduct value a "function of the weight of distress, severity and extent" (The Ohio Department of Transportation Manual, 2006). Each stress type must be defined to evaluate. Most distress types occur at different levels of severity description which also must be detailed enough to choose the scale. The Summary of PCR Deduct Values (Pavement Condition Evaluating Manual, Ohio, 2001) is provided in Appendix A.

The PCR value has from 0 to 100 range, which represents the condition of the pavement. After PCR is calculated the condition of pavement can be determined by looking the scale which is shown in Figure 2.10 below. The scale is used for PCR.

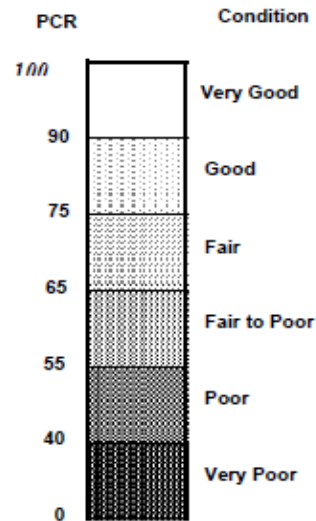


Fig 2. 10: Pavement Condition Rating (PCR) Scale (Pavement Condition Evaluating Manual, Ohio, 2001)

However, previous studies have been showing that Saraf and Madizadeh (1992) developed as described by FHWA in Ohio Condition Rating Method (2008) 40 different PCR equations to evaluate the condition of the pavement. In that case the PCR value dependent on age with various types of pavement. Because different types of pavement have different rates of deterioration. Also, these equations developed by not considering include (1) functional class based on traffic levels, design thicknesses, and construction specifications, (2) district jurisdiction which includes variations in climate, materials that used, traffic levels and maintenance applications. Consequently, these all different equations may provide accurate, current pavement condition ratings but may not provide precise predictions. In these equations, they assumed that the condition of pavement is a mapping of traffic load, pavement thickness, estimated modulus of elasticity of subgrade and each pavement layer. The 15 equations out of the 40 equations, due to its availability, are shown in Table 2.2.

2.6.6. Washington State Department of Transportation

Washington State Department of Transportation (WSDOT) has conducted a visual condition survey in their highway system as mentioned by Mubarak (2010). While they are surveying the roads, they consider some general inspection procedures as described by WSDOT Manual (1992). The WSDOT has been using PCR to identify the condition of the pavement. The components of pavement condition rating are followed by the type of defect (distress), the severity of the defect and the extent of to which the road surface is affected by the defect (WSDOT Manual, 1992). The generic definition of type, severity and extent are described for flexible and rigid pavement separately. The rating considerations are widely explained in WSDOT Manual 1992.

For flexible pavements and rigid pavements, the condition survey is completing by following the manual's distress explanations. The developed Pavement Condition Rating (PCR) is described by The Northwest Technology Transfer Centre Pavement Management Guide (1994) a quantity of the detected pavement surface distress and ranges from 100 (no distress) to 0 or below (extensive surface distress). In general, the WSDOT collects, defined by Guide for Local Agencies Pavement Managers (1994), alligator cracking, longitudinal cracking, patching, ravelling and transverse cracking. Also, there is another point occurs that the rating is based on two predominant of four other distresses. For example, alligator cracking and the second one is the most dominant of four other distresses. When all of the distress deterioration indexes are totalled to modify the pavement condition, the most predominant deterioration is determined to find out its percentage.

Table 2. 2: Existing Performance Prediction Equations (from ODOT Pavement Design and Rehabilitation Manual Section 101-1)

<u>Type of Pavement</u>	<u>Equations</u>
RIGID PAVEMENT	
<i>Minor Rehabilitation</i>	
All Overlays with and without Repairs	PCR=96 - 3.7(AGE)
CPR	PCR=96.2 - 7(AGE)
New Rigid Pavement & Unbonded Concrete Overlay	PCR=99.1 - 0.9(AGE)
FLEXIBLE PAVEMENT	
<i>Minor Rehabilitation</i>	
Non-Structural Overlay with Minimal Repairs	PCR=98.1 - 3.3(AGE)
Non-Structural Overlay with Repairs	PCR=98.6 - 3.8(AGE)
Structural Overlay with Minimal Repairs	PCR=98.3 - 3.3(AGE)
Generic Minor Rehabilitation(all of the above)	PCR=98.0 - 3.3(AGE)
<i>Major Rehabilitation</i>	
Fractured Slab Technique	PCR=98.0 - 3.4(AGE)
New Flexible Pavement	PCR=99.5 - 2.0(AGE)
COMPOSITE PAVEMENT	
Non-Structural Overlay with Minimal Repairs	PCR=96.1 - 4.0(AGE)
Non-Structural Overlay with Repairs	PCR=96.1 - 3.8(AGE)
Structural Overlay with Minimal Repairs	PCR=96.1 - 4.3(AGE)
Structural Overlay with Repairs	PCR=96.1 - 3.3(AGE)
Generic Minor Rehabilitation(all of the above)	PCR=96.0 - 3.7(AGE)
New Composite Pavement	PCR=96.6 - 3.3(AGE)

Finally to evaluate the PCR for there has been using the PCR tables. By looking these tables, PCR is identified by, locating the distress and percentage range of those distresses.

PCR is indicated by Mubarak (2010) principally dictated by measures of the extent and severity of pavement surface cracking. The final pavement condition rating (PCR) equation (15) is a blend of the visual rating and ride rating:

$$\text{PCR} = [100 - \Sigma D] [1.0 - 0.3 \{ \text{CPM}/5000 \}^2] \quad (2.18)$$

Where ΣD is the sum of the detect values, and CPM is the counts per mile.

Apart from mentioned approach above, PCR is also used by other states in the US. Similarly, they have been using the same PCR to identify the condition of the pavement. The Indiana Department of Transportation (INDOT) is using PCR to summarise the data. As described in INDOT Research Final Report (2010) the type and severity distress on existing pavement are central points in selecting a treatment. INDOT collects IRI, rutting, cracking and faulting data for their pavement condition surveys.

The New York State Department of Transportation (NYSDOT) is using PCR and also they are considering Dominant Distress to summarise condition data. The distress of IRI, rut and faulting are collected by this state.

To sum up, the relevance of PCR calculation methods is clearly supported by the current findings in each state in the US. These data suggest that calculation of PCR can be achieved through analysing the deterioration mechanism. The reasons of how determined the mechanism will be restated by at the end of this review.

2.7. Data Management in the UK

The calculation methods have been defined for all states in the US above. Now in this section, it has been found the concepts of developing a PCR as the aim of this project to explore the relationship between past studies on PCR equations in the US and current research and approaches to data management in the UK. Considering the advantages in corresponding the behaviour of exact condition and usefulness for the measurement of both approaches are required to be able to detail the investigation. For these reasons, first of all, the manual issued by Highway Authorities in the UK is examined to describe the general procedure for assessing the need for maintenance of pavements. Based on the manual, the survey observations for unclassified roads and classified roads are investigated to understand the general approach to determining the pavement condition.

The calculation of CVI provides the assessment of condition for unclassified roads. CVI gives an appropriate visual condition by using an index calculated using a different approach to work along with employed CHART. There is a need for involvement from DVI surveys which are to be used to produce Best Value Performance Indicators; then they should be converted to CVI-equivalent data using the UKPMS Conversion Software (UKPMS, 2007). This is followed by UKPMS processing which considers four key steps which together create the defect measurements and provide the calculation of CVI (Department for Transport, 2016). The key steps are namely;

- ❖ Chopping to form Rating Lengths
- ❖ Calculating Defect Ratings
- ❖ Calculating Condition Indices
- ❖ Merging to form Defect Lengths

The calculation of RCI is carried out by taking account into considering the steps with significant parameters. These are;

- ❖ Rutting
- ❖ Longitudinal Profile Variance
- ❖ Texture
- ❖ Cracking

The empiric formula of RCI consist of the parameters above and is given below:

$$RCI = w_R \times C_R + w_{3mLPV} \times C_{3mLPV} + w_{10mLPV} \times C_{10mLPV} + w_r \times C_r + w_c \times C_c \quad (2.19)$$

where, for instance, w_R is the weighting given to rutting and C_R is the contribution to the RCI from rutting.

The weighting values are reported by Benbow and Wright (2008) in Transportation Research Laboratory Report.

2.8. Conclusion

When a new pavement is constructed, it has a high quality. If performance drops due to both adverse weather conditions and traffic, some deteriorations will, however, occur over time. To extend the life of the pavement, maintenance should be planned in such a

way that intervention is carried out at the right time. That continuous system assessment and improvement require developing a PMS to help make a better approach to budget regarding engineering and extension of life (Karasahin, 2014).

Conducting a PMS is a function and process of decision making for pavement maintenance. The importance of the road, budget, data management and experience in decision making are the primary components of PMS. Mostly in this chapter, the approach of management system regarding its requirements and the general point the demand for pavement rating have been examined. About data management, as aforementioned, most agencies in the US have some rating procedures for the deteriorated pavement surfaces. Highway agencies are using these rating methods to make decisions for the network maintenance. The purpose of using these ratings is not only for an individual surface but also the whole pavement network. They have a picture of the condition of the whole network. When they determine some level and mechanism of deterioration, it is possible to get an idea of developed pavement rating based on different type of distress and then the deterioration mechanism on the pavement surface. The agencies in different countries prefer to create their mechanism system. Because they are constructing different classes of roads and deteriorating in different ways. For instance, Highway agencies in the UK have got their system. They deal with the road profile such as transverse profile edge defects, longitudinal for ride quality, etc. On the other hand Highway Agencies in the US, they just concern about some deterioration levels just on the surface, not for the cross section (road profile). This affects the maintenance management processes.

There are various deterioration parameters to be considered for analysing PCR and how it is determined in each agency depends on the methods of condition assessment. In addition to this, it is important to say that by taking account into parameters consideration, there are no just one performance criteria in the modelling of deterioration mechanism. For instance, in the US, some state departments of transportation agencies agree on collecting data assisted in making a decision on condition of the pavement.

The aspect of decision making on PCR is mostly dependent upon the occupation of distress in the place of the region as well as their importance collection measurement of deterioration. As mentioned in this chapter there is an indicated table given as a summary of the each state's collecting data, which are currently using PCR, and the UK's data that they are collecting without using PCR. It can be noticed from the TABLE 3 that some state departments of transportation agencies in the US agree on which data are assisted in making a decision on PCR.

Table 2. 3: Summary table with the states and all the different types of collected distress

The Highway Agency in the US (FHWA)	Roughness (IRI)	Rutting	Cracking	Faulting	Fretting	Friction (Texture)	Ravelling	Patching
Alabama	x	x	x				x	
Ohio	x	x	x				x	
Washington	x	x	x					
Indiana	x	x	x	x				
Mississippi	x	x	x	x				
New York	x	x		x				
The Highway Agency in The UK		x	x		x	x		

Looking through the Table 2.3, we can say which data has been collected as a deterioration measurements that their equations are included in the US. It can be seen that their primarily important measurement is roughness which means that it is a kind of

predominant measurement. Rutting and cracking are the secondary importance measurements. These are all the pavement performance indicators that influence on the condition of the pavement and so assist in developing pavement condition rating. Looking at the UK's importance measurements, they do not measure the roughness. They measure the friction (texture) which can give an idea about any loss of texture. This will help to develop a deterioration mechanism based on their coefficients. It is measured as profile variance (SCRIM). For instance, this approach could be from cracking on the pavement surface. The depth or width of a layer which can increase due to loss of aggregate. These points of strategies are taking into account in next chapters to reach the final aim of this project.



3. METHODOLOGY

To achieve the overall objective of developing a pavement condition rating for road network maintenance to serve as a decision support tool to assist in improving the efficiency of making decisions; the following procedure was followed:

3.1. Determination of Road Network

A PMS allows for the prioritisation of maintenance projects based on cost and condition ratings and other factors such as traffic. It further can be used for selecting and ranking of projects for the upcoming budget year, as well as for long-term financial planning. There are some priority assessment models in current applications which commonly considers the benefit/cost ratio. As mentioned by Falls et al. (1994) the costs of pavement management implementation can be expressed as a percentage of the total value of the road network or the total rehabilitation budget or both. The actual implementation costs can be readily estimated from industry standards for data collection, software, consultant fees, and in-house staff time. However, the benefits directly attributable to the implementation of a PMS are difficult to estimate. A portion of the savings in both user cost and increased network asset value can be attributed to the rehabilitation expenditure regardless of the system used to program the improvement (Falls et al., 1994).

In this project, the road network has been chosen by the Nottingham County Council for investigating the proposed aim. The study was conducted on the B Class Road called B6464 Broadgate in Beeston. Beeston is a town in Nottinghamshire, England. It is 3.4 miles (5.5 km) south-west of Nottingham city centre. Although typically regarded as a suburb of the City of Nottingham, and officially designated as part of the Nottingham Urban Area, for local government purposes it is in the borough of Broxtowe, lying outside the City's unitary authority area. The road that runs between the town centre of Beeston and University Park is called Broadgate (Wikipedia, 2016). The location of the study area is shown in Figure.

The second study area is unclassified road network called Broadgate Avenue in Beeston. It is in the residential area and having less traffic load per day comparing with the B Class Road. The location of the study area is shown in Figure 3.1 and Figure 3.2. Reasons for conducting studies on these sections were to determine the PCR values, determine the reactive action the relevant maintenance authority had taken to prevent further deterioration and lastly to develop a preventative maintenance strategy that could be used to prevent future deterioration.

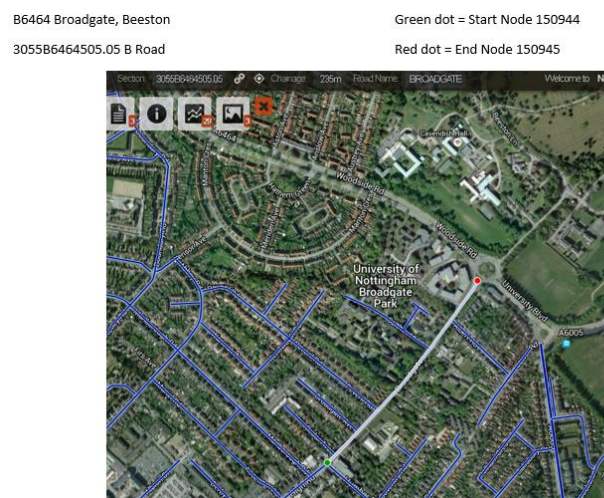


Fig. 3. 1: The Location of Case Study Area (Google Earth, 2016)

Unclassified Road, 3055U0121511 Broadgate Avenue, Beeston
 Green dot = Start Node 89165
 Red dot = End Node 102964

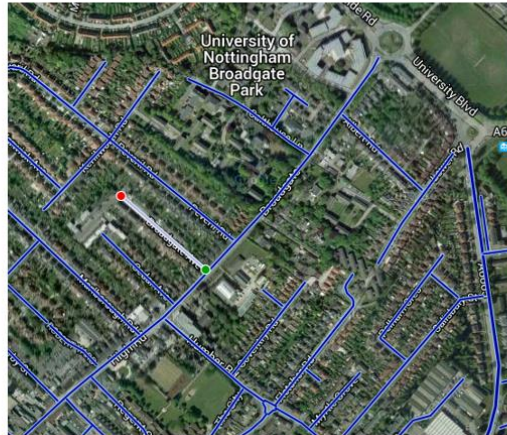


Fig. 3. 2: The Location of Case Study Area (Google Earth, 2016)

3.2. Visual Survey Details

The survey is carried out with by Health and Safety legislation and with appropriate traffic management by the Traffic Signs Manual Chapter 8. (Adopted by Department for Transport/Highways Agency Department for Regional Development (Northern Ireland) Transport Scotland Welsh Assembly Government). The survey is carried out with the relevant definitions and procedures described in Highways Agency Design Standards HD 29/08 Data for Pavement Assessment. Also, the conduction of visual inspection in this study was performed by guidelines contained in the United Kingdom Pavement Management System (UKPMS) user manual Volume 2 Chapter 1, Chapter 3, Chapter 5, Chapter 6 and Chapter 7. The visual inspection was achieved through the conduction of assessments by trained myself and one of my friend on the site where visible distresses were recorded on inspection sheets. We are not expected to make decisions about the cause of defects, required treatments or to make other engineering judgements. Objectivity and consistency are paramount considerations in carrying out the visual inspection. Distresses were defined by recording of their key features, the so-called attributes of distresses, namely the type, severity (degree) and extent of the occurrence. Type of distress refers to the different modes of distress for example cracking or bleeding. The degree of a particular distress is a measure of its severity and the measure of how widespread the distress occurs over the length of the road segment, called as its extent are collected on the road network.

As explained in the UKPMS user manual Volume 2 Chapter 3, the start and end node are located in the data collection on the road network. Definition of the start and end point of sections needs to be defined by the network model before any data collection is undertaken. All data collection must be conducted consistently with the network model. Conduction is started from the unclassified road section, Broadgate Avenue. The first step taken towards conduction of assessments involved breaking down of the road length into segments of 10 m in length. The reasons for dividing the road length into sections was to narrow down the road network for easy identification of the distress occurrence per specific location over the road length and also for easy prioritisation for maintenance and rehabilitation requirements. Section 1 starts with the point number 19 towards to the point number 18. There are 18 sections on this network. The illustration of the subsections is shown in Figure 3.3.

Inspection is then continued from the B Class Road Network, B6464 Broadgate. Due to the heavy traffic, we were not able to collect the data on the pavement section. The observations were taken from the footpath. The division of the road network was also done from the footpath. Section 1 starts with the point number 1 towards to the point number 2. There are 53 sections on this network. The illustration of subsections is shown in Figure 3.4.

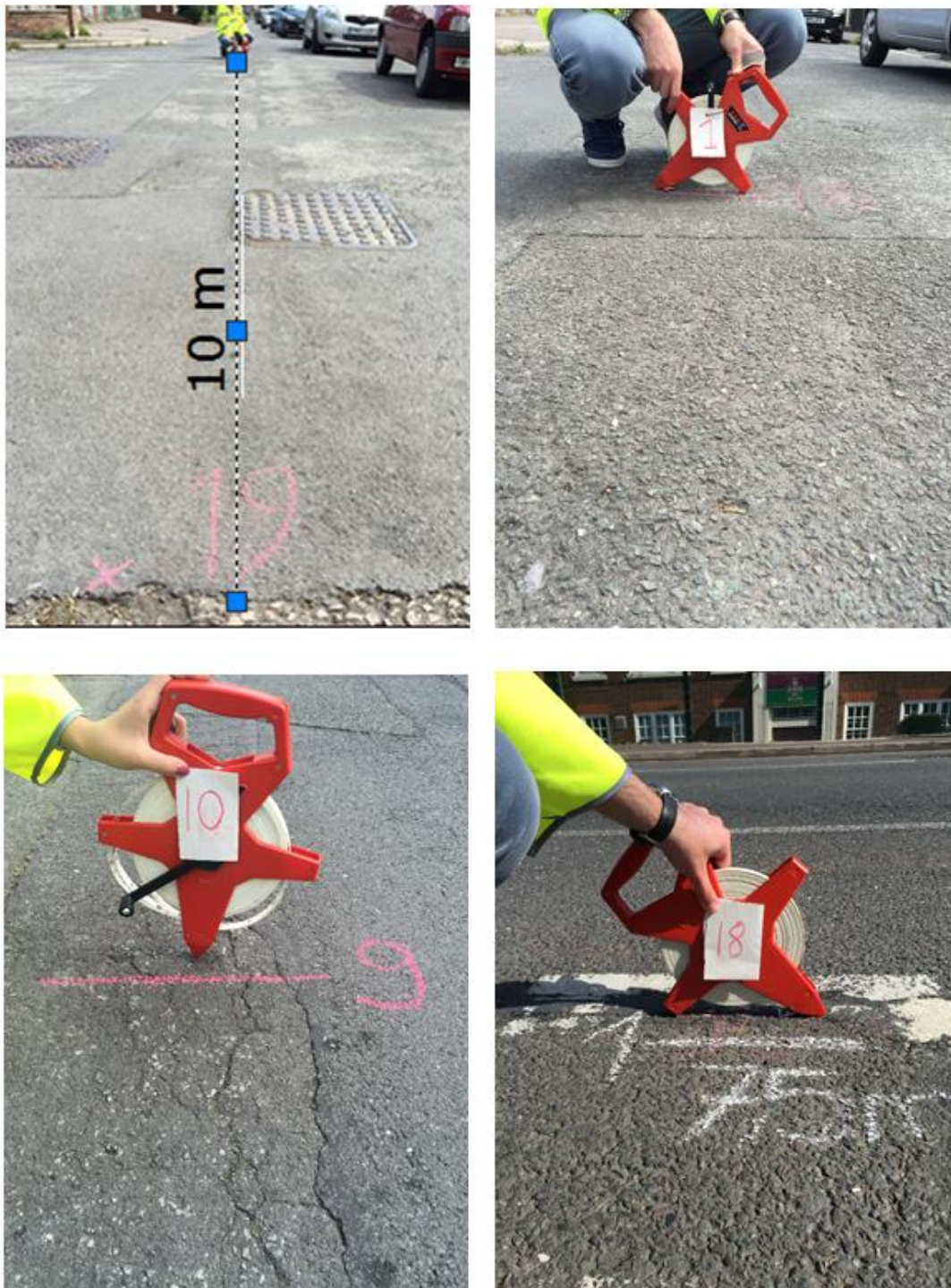


Fig. 3. 3: Illustration of Subsections Broadgate Park Avenue



Fig. 3. 4: Illustration of Subsections B6464 Broadgate

$$RCI = w_R \times C_R + w_{3mLPV} \times C_{3mLPV} + w_{10mLPV} \times C_{10mLPV} + w_r \times C_r + w_C \times C_C$$

3.3. Data Collection of Selected Part of Case Study Area

Pavement condition data is a critical component of a pavement management system. It is this data, collected consistently and over a period, that enables the characterization of a current network condition, triggering of pavement preservation and rehabilitation treatments and strategies, and prediction of future conditions. Network condition data—combined with inventory, traffic, and cost data—allows a pavement management

system to analyse and compare pavement sections to find the most cost-effective and beneficial combination of sections and treatments.

In this case, the data was collected for combining and converting into PCR to describe the current condition. As mentioned in the methodology of this project, the magnitude of the impact of data variability on characterization of the current condition depends on many factors; including the distress deduct values for rating calculation and the manner in which quantities of distresses are determined (Linda M. P., McGovern, G. and Zimmerman, K. A., 2013).

Data is being collected while walking and noting the existing surface distress for both Broadgate Avenue and B6464 Broadgate networks. Distresses were recorded on paper with their sizes. There was a fairly standard set of condition data typically collected, including random cracking, longitudinal cracking, transverse cracking, bleeding, ravelling and rutting(if it was visible). While conducting the network the inspection guidelines, Pavement Surface Condition Rating Manual by The British Columbia Ministry of Transportation and Infrastructure, Distress Identification Manual for the Long-Term Pavement Performance Project by Strategic Highway Research Program National Research Council and the UKPMS User Manual Volume 2: Visual Data Collection for UKPMS by the UK Roads Liaison Group were followed for distress identification, extent calculation and rating severity.

3.3.1. Distress Identification

Distress Identification is the primary step to conduct a beneficial pavement management plan. It should give an approximate shape while making decision-making process regarding budget determination. While conducting the visual survey in the network section, measurements of defects identified in a reasonable way to consider minimum condition requirement. There are not universal manuals for procedures to be monitored or equipment to be used for identifying pavement distress. Due to this unstandardized perspective, the type and cost of maintenance, rehabilitation and reconstruction will be influenced by the type, extent and severity of distress (The State University of New Jersey, 2016).

Agencies routinely survey the pavement network for distresses defined by the local PMS manual. Distress classifications vary among agencies and pavement types but typically include cracking, rutting/faulting, roughness, texture and other evidence of anomalies in mix components. The FHWA revealed rutting, faulting and cracking as the dominant forms of distresses that are being collected by many highway agencies (Schram,2008).

As described in the UKPMS User Manual Volume 2: Visual Data Collection for UKPMS Chapter 6. Section 3. DVI Defect Definitions, key points on overall distress identification is demonstrated in Table 3.1. It identifies various types of pavement distress for the network section conducted. Provided with each distress was a located on the road network. The general agreement for the ability of the pavement to sustain traffic loads in a safe and smooth manner is adversely affected by the occurrence of observable distress (Pavement Condition Evaluation Manual, 2001).

As mentioned Table 2.1 (literature review chapter) the level of distress is considered as three main type which is low medium and high (Ohio Pavement Condition Evaluating Manual, 2001). This helps to identify the current condition of road section classification by taking account into consideration of both UKPMS User Manual Volume 2: Visual Data Collection for UKPMS and Ohio Pavement Condition Evaluating Manual. The combination of these contributes to classify the road sections sensitively before calculation starts.

Areas, lengths and deeps where some surface deterioration occurred were observed and recorded. While measuring the defects on the road sections, the invar tape was

Table 3. 1: Distress Identification (UKPMS User Manual Volume 2: Visual Data Collection for UKPMS, 2007)

Distress	Definition	Recorded as
Wheel Track Major Cracking	Wide single cracking or multiple cracking/coarse crazing >2mm occurring within the wheel tracks.	Lane length in metres.
Wheel Carriageway Major Cracking	Wide single cracking or multiple cracking/coarse crazing with visible crack width occurring in any part of the surface course.	Area in square metres.
Wheel Carriageway Minor Cracking	Fine cracking or crazing less than 2mm in width.	Area in square metres.
Transverse/Reflection cracking (major)	Single transverse cracks.	Lane length in metres.
Transverse/Reflection cracking (minor)	Single transverse cracks with spalled joints at regular spacing or multiple cracks at regular spacing.	Lane length in metres.
Edge Deterioration (Cracking) (major)	Cracking or fretting in the surface course, confined to the carriageway edge.	Area in square metres.
Edge Deterioration (Cracking) (minor)	Disintegration of the edge of the carriageway to a depth below the surface course or deformation greater than 20mm confined to the carriageway edge.	Area in square metres.
Whole carriageway major chip loss	Extensive loss of surface applied chippings having more than one third of the chippings within the area of the defect missing.	Area in square metres.
Whole carriageway minor chip loss	Limited loss of surface applied chippings with less than one third of the chippings within the area of the defect missing.	Area in square metres.
Wheel track rutting	Depression of the surface course in the vehicle wheel paths relative to the remainder of the surface course.	Depth in millimetres.
Not Defective	The feature is present but free from defects.	Length.

used for dividing the road sections, measuring tape was used for measuring the size of each defect and chalk was used for marking and drawing the start and end points of each defect.

For Broadgate Avenue road network, the failures are found caused by spalling of reseals or overlays around cracks mechanical damage to the surfacing and localised loss of surfacing owing to poor bonding with the underlying layer. In some sections edge cracking was visible. The reason for that occurrence is that the road networks is quite narrow for traffic flow due to being a residential area. There are house owner's private cars parked. The problem of facing the edge cracking also depend on not enough maintenance on the road shoulders. It was also observed that chip loss was occurred in some places which cause the reduction in skid resistance. Visual observations also showed that rutting appeared, but not quite visible and measurable for visual inspections.

For B6464 Broadgate road network, there are such similar deterioration types occurred with Broadgate Avenue. These failures are traffic induced and mean to be increased in the wheel paths. The level of some surface deteriorations in some places is significantly visible such as random cracking, longitudinal cracking, transverse cracking and chip loss. There are severe rutting defects appeared in some sites but due to the limitations of visually measurement equipment it was not able to be detected and measured.

The visual inspection distress condition results are shown in Figure 3.5 and Figure 3.6 below with relevant photographs for both Broadgate Avenue and B6464 Broadgate network.

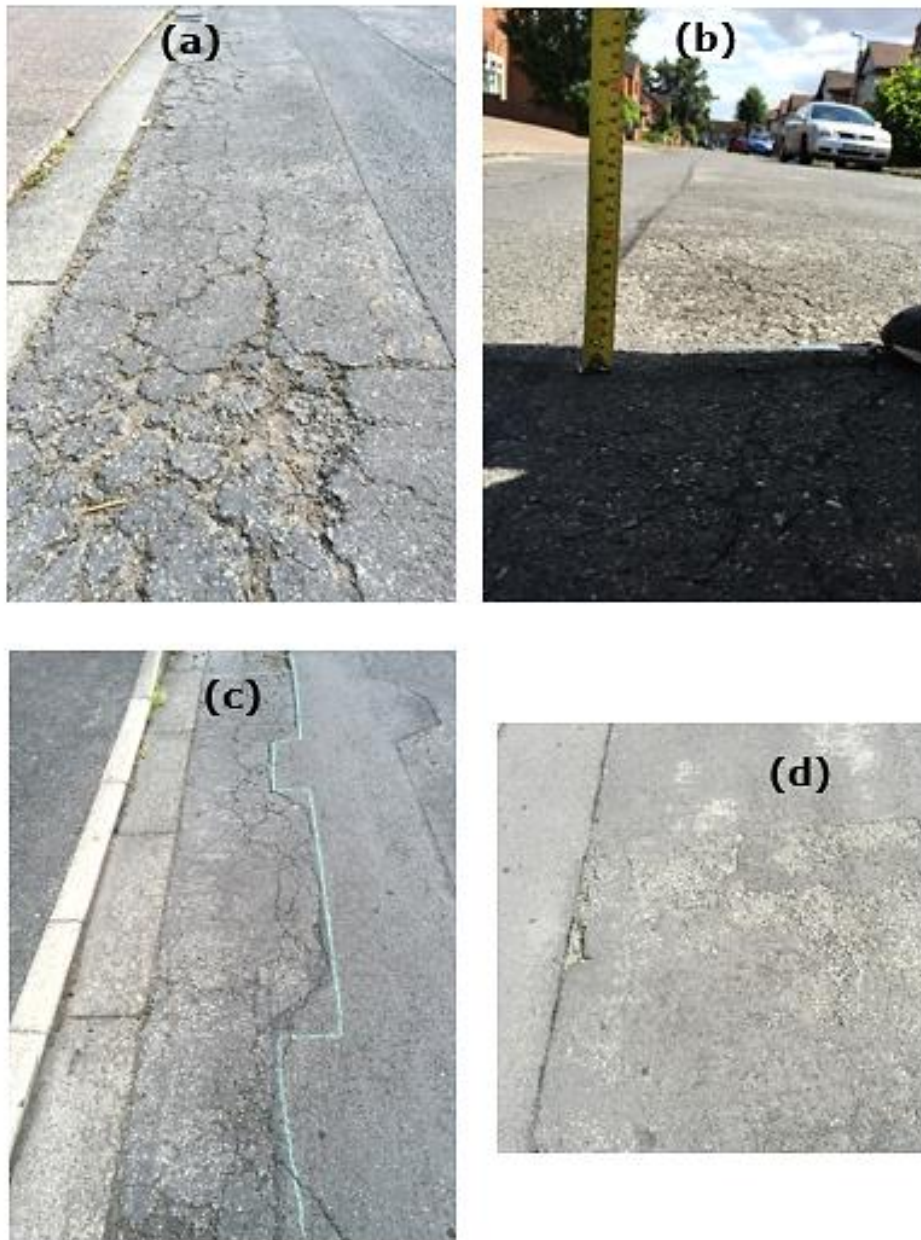


Fig. 3. 5: Illustration of Distress Condition Results in Broadgate Avenue

a) Edge Cracking b) Ravelling c) Edge Cracking d) Chip Loss

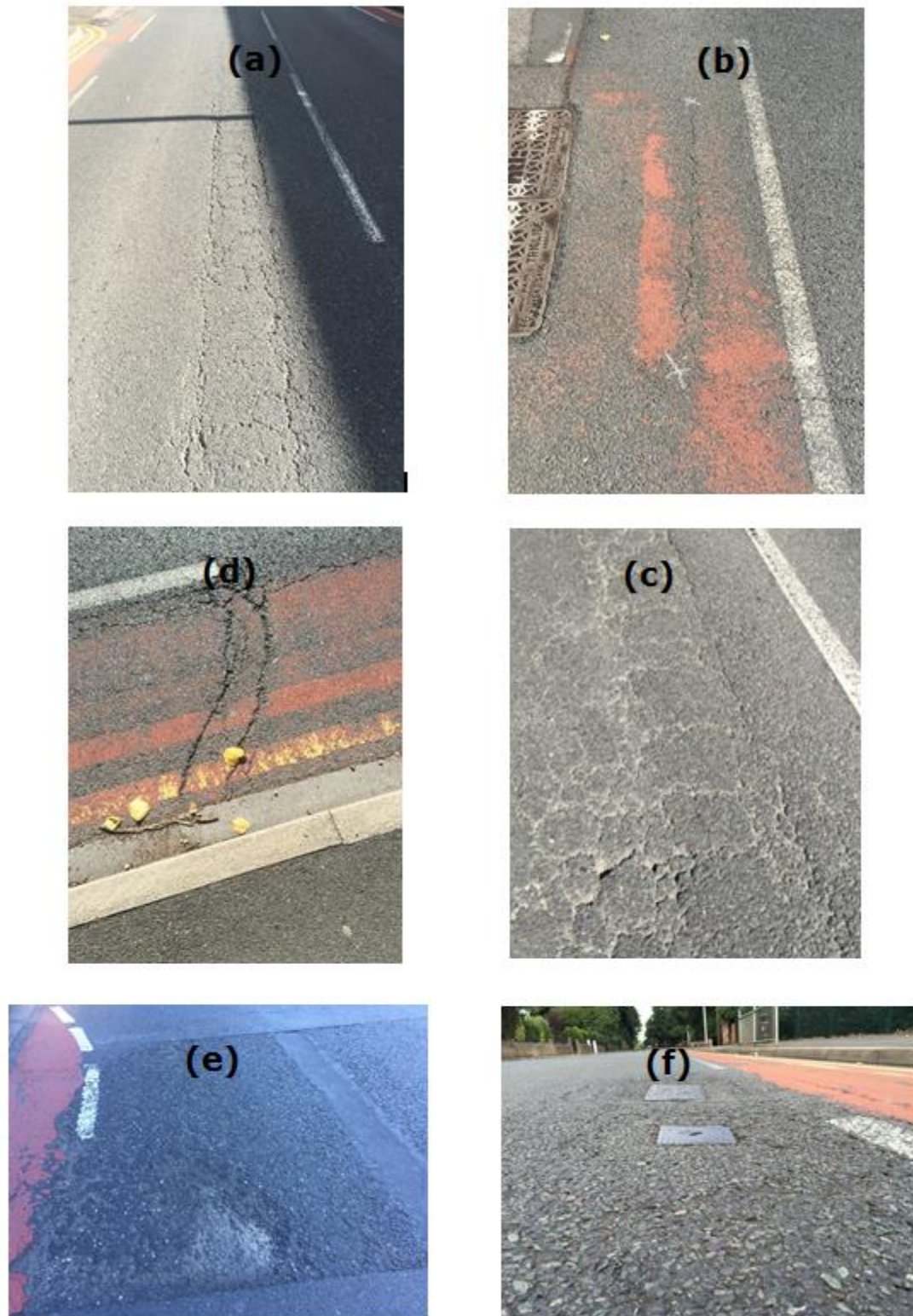


Fig. 3. 6: Illustration of Distress Condition Results in Broadgate Avenue

a,d) Random Cracking, b) Longitudinal Cracking, c) Transverse Cracking, e,f) Chip loss

3.4. Data Analysis

Data is analysed through two steps namely data management and pavement condition analysis. And then the results will be compared with pavement condition survey observations adopted from Nottinghamshire County Council Highway Assets and Development in Chapter 4. The steps are discussed in detail below.

3.4.1. Data Management

A database using a simple Microsoft Excel software was developed. To make data input easier, the database was designed to look the same as the site data collection paper.

The method used to compute PCR relies on upon the summation of deduct values for each type of observed distress. Deduct values describe regarding its severity and extent. The calculation of extent and the definition of severity are discussed in detail below.

3.4.1.1. Extent Calculation

The following are key points on each extent calculation considered. Firstly each deterioration recorded as its relevant unit of measurement individually. As the main purpose of the visual inspection is not to collect precise measurements of distress information, but to predict the rough area/length measurements of each distress types we visually observe in the section we are inspecting. Secondly, all of the distresses are collected, the percent range of their extent are calculated using the Microsoft Excel software. The quantity of the extent level is calculated with the following formula:

If recorded distress is area based;

$$Extent = \left(\frac{\text{Area of each distress measurement}}{\text{Area of road section}} \right) \times 100 = \text{percent} \quad (3.1)$$

If recorded distress is length based;

$$Extent = \left(\frac{\text{Length of each distress measurement}}{\text{Length of road section}} \right) \times 100 = \text{percent} \quad (3.2)$$

For example if we have a 510 cm x 130cm size random cracking and 700 cm x 1000 cm total area of road section, the result would be:

$$\left(\frac{510 \times 130}{700 \times 1000} \right) \times 100 = 9,47 \%$$

Or for example if we have a 200 cm of longitudinal cracking and 1000 cm total length of road section, the result would be:

$$\left(\frac{200}{1000} \right) \times 100 = 20 \%$$

The all Microsoft excel data base is attached in Appendix A and Appendix B for both Broadgate Avenue Network and B6464 Broadgate Network.

3.4.1.2. Severity Determination

The severity of distress indicates how bad the distress is over the entire road section. Expert opinion, Ohio Pavement Condition Evaluating Manual and UKPMS User Manual for Visual Data Collection are combined for assigning the level of severity for each distress on the each road section, as Low/Medium/High. To observe a quantity for severity, a weighting formula is developed. The type of particular distress on the entire road section

(by UKPMS) and the importance of this specific distress's weight (by Ohio Pavement Condition Evaluating Manual) are combined for evaluating the other distresses on the same road section. The weight values are adopted from the Ohio Pavement Condition Evaluating Manual, shown in Table 1. As a result of an analytical algorithm, that table provides quantified weights for assigning the level of severity. The severity factors vary from 0.2 to 1.00, depending on the distress type and severity level. By looking at the road section's photographs, first of all, the type is observed for each distress considering by UKPMS. Then by using the table1, the importance of particular distress is adopted as a quantified value. These two steps are followed to estimate the severity of all distress occurred on the every 10m section. The developed formula is shown below:

$$Severity(\beta) = \frac{\frac{\text{Extent of each distress} \times \text{Its Severity Weight}}{\sum (\text{Cracking Areas or Lengths in Road Section})}}{\sum (\text{Severity Weights of Distresses})} \times 100 = \text{percent} \quad (3.3)$$

As an example I assumed that we have already calculated 9,47% extent of one random cracking and based on Table 1, the level of this cracking is considered as 'low' level occurrence which is 0,4 in a cell of the excel spreadsheet. The calculation is followed by multiplication of them for each deterioration observed from the data collection. The total area of all area based cracking is added all together in a different cell. Next step is to add all different level of severity weights together in another cell. For this instance the total area is 216750 cm² and the total weights are 3,1 so the final step is calculating the severity value for that deterioration which is shown below:

$$\frac{\left(\frac{9,47 \times 0,4}{216750} \right)}{3,1} \times 100 = 3,94 \%$$

Severity weight is the maximum number of deductible points for each different distress type. This is a relative term of formula which gives a way for ranking the importance of that individual distress on the section. By this formula, we can notice which deterioration we should give priority. It helps to predict the importance of each deterioration on the specific road section. It is evident that while evaluating a network with poor condition, that particular severity would have a lower deduct value, but the same crack in the network with the excellent condition would have a higher deduct value. So it gives the relative importance of that individual distress over entire the network.

The all Microsoft Excel data base is attached in Appendix A and Appendix B for both Broadgate Avenue Network and B6464 Broadgate Network.

3.4.2. Pavement Condition Rating Analysis

The rating method is based on the visual condition assessment so the visual condition analysis is carried out on pavement distress data collected through it. The main aim of the analysis is to evaluate the PCR which is used to determine the general condition of the pavement. Regarding severity and extent values a great deal of deduct value is calculated. Deduct value is used to compute the rating based on found severity and calculated extent values. It totally depends on the condition of the pavement surface. The mathematical expression for deduct value is as follows:

$$Deduct Value (\alpha) = \frac{(Extent \times Severity)_i}{\sum_{i=1}^n (Extent \times Severity)} \times 100 = \text{percent} \quad (3.4)$$

For example, if we have 9,47% extent and 3,94% severity for a random cracking in one section and in-network the multiplication of the whole extent and severity value is

2138983,358%, the following result would give the deduct value for that specific distress on the entire section:

$$Deduct\ Value\ (\alpha) = \frac{(9,47 \times 3,94)}{2138983,358} \times 100 = 0,174767552\ \%$$

Deduction for each distress type is calculated by using the formula above. After calculating the all deduct values for each occurrence, PCR is calculated by using the following mathematical expression:

$$PCR = 100 - \sum_{i=1}^n (Deduct\ Values)_i \quad (3.5)$$

For example if the total deduct value for the section is 6,262310895 %, the following result gives the PCR for that section:

$$PCR = 100 - 6,262310895 = 93,7376891\ \%$$

A PCR scale has been developed to describe the pavement condition using the PCR numbers calculated from the equation above. The all Microsoft Excel database is attached in Appendix A and Appendix B for both Broadgate Avenue Network and B6464 Broadgate Network.

The scale has ranged from 0 to 100; a PCR of 100 represents a pavement with no observable deterioration and very good condition. That means the surface has a low-level severity weight with 0 % extent value. A PCR of 0 represents a pavement with lots of noticeable deterioration and very poor condition. That means the surface has a high-level severity weight with reasonable high percent extent value. The adopted range regarding condition of pavement surface for PCR is shown with the following rating:

0 < PCR < 40 → *Failed* (0 – 10), *Serious*(10 – 25), *Very Poor*(25 – 40)

40 < PCR < 70 → *Poor* (40 – 55), *Fair* (55 – 70)

70 < PCR < 100 → *Satisfactory* (70 – 85), *Good* (85 – 100)

For each PCR gives acceptable conditions for maintenance whether it is reaching to worrying level or not, once decisions are made. While some pavements may only exhibit a single distress, in many cases the pavement will exhibit several distresses. Treatment selection should be based on the summary of all distress types, the importance of severity level and extent value which is represented by PCR.

After calculations and analysis, the results are discussed in next chapter.

4. RESULTS AND DISSCUSSION

This chapter begins with the steps of arranging the collected data through considering used analysing methods to apply the ultimate formula. The analysing process performance which is mainly the quality of PCR depends on the good quality input data collected from the survey. Calculations are performed consecutively based on the collected data. The scaling of CVI and RCI is different from calculated PCR. Both CVI and RCI converted into the same scale as PCR before moving on the correction of calculated PCR analysis made by the available result from Nottinghamshire County Council condition survey observations whereas the method used in this project is different. The reason for the need of comparison is because the types of deterioration should meet with their observations during classification of deterioration.

After classification of deterioration, the importance measurements are required significantly. Regarding that Nottinghamshire County Council is having difficulty in estimating severity level of individual deterioration. Considering the need of this, the weight of distress severity, which is adopted from Ohio Department of Transportation Pavement Condition Evaluation Manual, is taken into account as severity level of deterioration through expert opinion.

After identifying the type, the level of severity and combining them with extent factors for each distress, all involved data with their availability are applied to the formula mentioned in methodology part. And also given as;

$$PCR = 100 - \sum_i^n \left[\left(\left(\frac{\text{Area or length of each distress measurement}}{\text{Area or Length of road section}} \times 100 \right) \times \left(\frac{\text{Extent of each distress} \times \text{Its severity Weight}}{\frac{\sum (\text{Cracking Areas or Lengths in Road Section})}{\sum (\text{Severity Weights of Distress})} \times 100} \right) \right) \right] i \times 100$$

Total Deduct Value (4.1)

As a result of this formula, the PCR is found as a single number for each road section. The calculations and results are given in detail in Appendix B and Appendix C. These followed by finding similarity percentage between calculated PCR and converted PCR from both CVI (for Broadgate Avenue) and RCI (for B6464 Broadgate).

For the Broadgate Avenue, it can be seen that the similarity is considerably high. Plus, it can be assumed that there is a positive correlation between visual survey observation (CVI) and founded PCR in the same road sections (Figure 4.1).

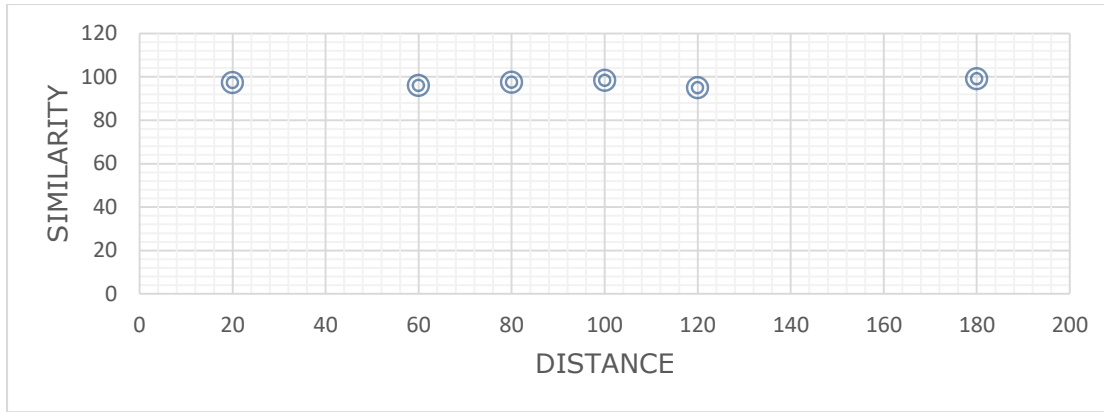


Fig 4. 1: The similarity between calculated PCR and converted PCR from CVI for Broadgate Avenue

For the B6464 Broadgate, it can be seen that the similarity is not as high as Broadgate Avenue (Figure 4.2). It is obvious that the calculation of RCI is depending on some parameters which are rutting, longitudinal profile variance, texture and cracking. While applying the formula considering only extent and severity for cracking is not sufficient to represent suitable comparison, on contrast it can be used to show reasons why it is not matching clearly with RCI results.

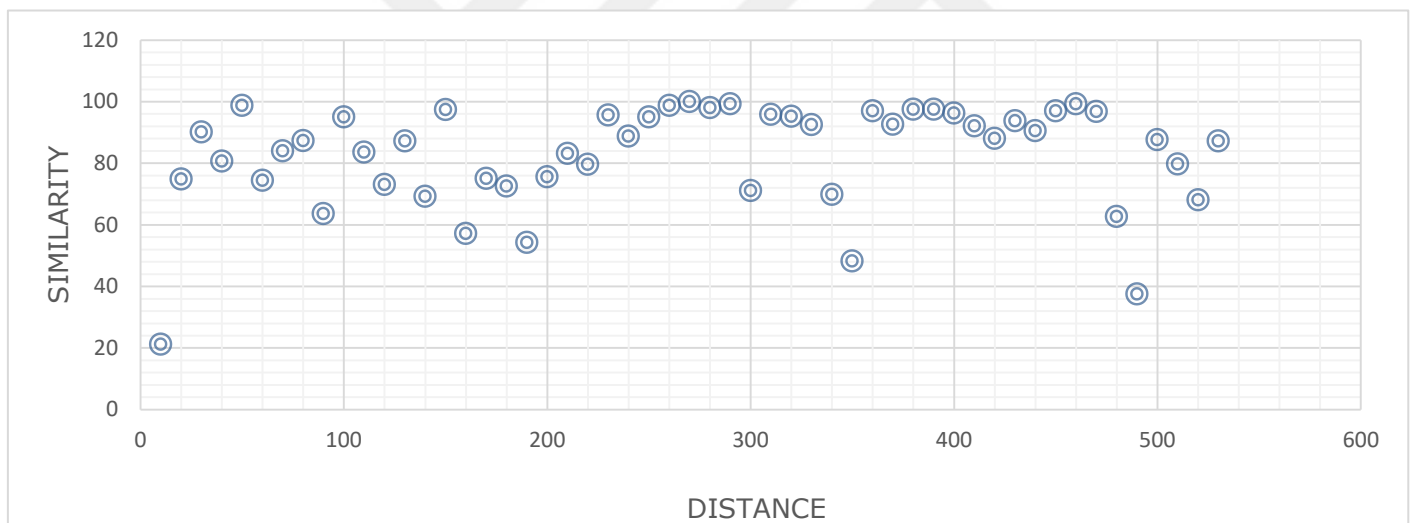


Fig 4. 2: The similarity between calculated PCR and converted PCR from RCI for B6464 Broadgate

In visual surveys and machine surveys, there is some subjectivity. Various opinions from different experts on the level of the severity, the machine surveys would be more producible and have more advantages regarding usefulness. However, the medium level of severity is the challenging part of decision-making process. The machine surveys would give quick results but would not help to reduce the challenging while the distress severity is being identified as medium. Although the opinions are subjective and machine surveys based on automatically measurement. The both PCR and CVI correspond similar distribution. Because the consideration of parameters is roughly the same. More apparently, rutting and texture do not play a significant role on the unclassified road. The Comparison between Calculated PCR and Converted PCR from CVI for Broadgate Avenue can be seen in Appendix D. Similarly both values do not take into account rutting and texture.

Some reasons used method is not considerably working with RCI results. It is because of the approach based on different parameters. Cracking does not mainly affect the RCI values. The parameters and weightings used in RCI calculation given in Appendix E. As it can be seen from the table and the definition of RCI calculation formula, in some sections where there are more cracking rather than rutting, the results tend to match with calculated PCR (Figure 4.2). At some sections, it cannot be seen similar tendency such as at the beginning of B6464 Broadgate. According to data adopted by Nottinghamshire County Council the section where PCR and RCI disagree is because RCI puts a significant weight on rutting and texture (Appendix D). Cracks are easy to see in visual inspection whereas ruts are not. There are very rough sections which from the visual inspection is less apparent. Because it is difficult to observe it visually. So that could be the reason why calculated PCR is different from the RCI. It is obvious that the visual inspection is less reliable while the appearance of rutting or texture is high.



5. FURTHER RECOMMENDATIONS

As mentioned above, there are some challenges in identifying the distress severity whether it is medium or not based on expert opinion. It can be easy if there are more severity consideration than just three (Low/Medium/High). It is possible to say that considering also very low and very high levels could lead found the formula to give more sensitive results whereas it is not feasible involving this with the machine surveys. As an advantage of found formula instead of considering the section severity, individual deterioration severity is used. These could also overcome the difficulty that Nottinghamshire County Council have been struggling recently. In addition to this, while considering the budget cost effectively, having more sensitively identified deterioration could help prioritising of maintenance.

The historical data was not available for this project. If it was, working with historical data could contribute to not only prioritising but also enhance performance monitoring of network condition. The method can be improved by using survey machines observations for enlarging the consideration of the formula.



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APPENDIX A: The Summary of PCR Deduct Values (Pavement Condition Evaluating Manual, Ohio, 2001)

SUMMARY OF PCR DEDUCT VALUES

<u>Distress Type</u>	<u>Distress Weight</u>	<u>Severity</u>			<u>Extent</u>			<u>Total</u>
		<u>L</u>	<u>M</u>	<u>H</u>	<u>O</u>	<u>F</u>	<u>E</u>	
Raveling (Flexible/Composite)	10	.3	.6	1	.5	.8	1	_____
Bleeding (Flexible/Composite)	5	.8	.8	1	.6	.9	1	_____
Corrugations (Flexible)	5	.4	.8	1	.5	.8	1	_____
Rutting (Flexible/Composite)	10	.3	.7	1	.6	.8	1	_____
Potholes/Debonding (Flex./Comp.)	10	.4	.7	1	.5	.8	1	_____
Patching (All Pavement Types)	5	.3	.6	1	.6	.8	1	_____
Settlement (All Pavement Types)	10	.5	.7	1	.5	.8	1	_____
Crack Seal Deficiency (Flex./Comp.)	5	1	1	1	.5	.8	1	_____
Wheel Track Cracking (Flexible)	15	.4	.7	1	.5	.7	1	_____
Longitudinal Joint Cracking (Flex.)	5	.4	.7	1	.5	.7	1	_____
Longitud. Cracking (Comp./JC/CRC)	5	.2	.6	1	.4	.8	1	_____
Edge Cracking (Flexible)	5	.4	.7	1	.5	.7	1	_____
Random Cracking (Flexible)	5	.4	.7	1	.5	.7	1	_____
Block & Transverse Cracking (Flex.)	10	.4	.7	1	.5	.7	1	_____
Transverse Crack (Comp./JC/CRC)	15	.4	.7	1	.5	.8	1	_____
Pumping (Comp./JC/CRC)	15	.7	.7	1	.3	.7	1	_____
Faulting (Jointed Concrete)	10	.4	.7	1	.5	.8	1	_____
Surface Deterioration (JC/CRC)	10	.4	.7	1	.6	.8	1	_____
Total Deduct								_____
100 - Total Deduct = PCR								_____
Flex	Flexible Pavement							
Comp	Composite Pavement							
JC	Jointed Reinforced Concrete or Jointed Concrete Pavement							
CRC	Continuously Reinforced Concrete Pavement							



APPENDIX B: Calculation of PCR for Broadgate Avenue

Section1 (0-10)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	1800			528000		0.340909	100	0.3	3000	3000	0.966495	
Section2 (10-20)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	
A1	3160	30360		528000		0.598485	2.97383776	1.4	177.9797	33144.57392	10.60037	
A2	27200					5.151515	63.993977		32966.59			
Section3 (20-30)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	67.13434
Not Defective											0	
Section4 (30-40)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	
A1	1120	41350		528000		0.212121	0.53204353	2.8	11.28577	11110.39272	5.363093	
A2	30450					5.767045	18.4099154		10617.08			
A3	4380					0.829545	2.64812576		219.6741			
A4	5400					1.022727	2.56520988		262.351			
L1	0.045454545		0.045455		1000	0.004545	100	0.3	45.45455	45.45454545		
Section5 (40-50)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	
A1	1120	41350		528000		0.212121	0.53204353	2.8	11.28577	11110.39272	9.223929	
A2	30450					5.767045	18.4099154		10617.08			
A3	4380					0.829545	2.64812576		219.6741			
A4	5400					1.022727	2.56520988		262.351			
L1	0.045454545		0.045455		1000	0.004545	100	0.3	45.45455	45.45454545		
Section6 (50-60)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	
A1	12500	12500		528000		2.367424	100	0.4	23674.24	23674.24242	6.711773	

Section9 (80-90)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	7540	18640		528000		1,42803	14,709325	1,1	2100,536	10067,10812	5,264959	
A2	11100					2,102273	37,8950449		7966,572			
Section10 (90-100)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	88,02362
A1	4950	58929		528000		0,9375	2,09998473	3,2	196,8736	6081,039483	6,711421	
A2	3150					0,596591	0,66817696		39,86283			
A3	18880					3,575758	4,00481936		1432,026			
A4	23925					4,53125	8,88118541		4024,287			
A5	8024					1,519697	2,55307234		387,9896			

Section11 (100-110)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	7050	7050		528000		1,335227	100	0,4	13352,27	13352,27273	3,78544	90,03114
Section12 (110-120)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	
A1	6000	23820		528000		25,18892	6,7170445	1,5	16919,51	278098,7549	6,183423	
A2	17820					74,81108	34,9118388		261179,2			

Section13 (120-130)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective											0	
Section14 (130-140)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	
Not Defective											0	
Section15 (140-150)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	95,64336
L1	0,225		0,225	0	1000	0,0225	100	0,3	225	225	0,063789	
Section16 (150-160)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	
A1	7995	7995		528000		1,514205	100	0,4	15142,05	15142,04545	4,29285	

Section17 (160-170)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	36000	36000		528000		6,818182	100	0,7	68181,82	68181,81818	19,32991	74,44156
Section18 (170-180)	Area/Length of Deterioration (cm²/cm)	Total Area (cm²)	Total Length (cm)	Area of Road Section (cm²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	
A1	11600	11600		528000		2,19697	100	1	21969,7	21969,69697	6,228526	

APPENDIX C: Calculation of PCR for B6464 Broadgate

Section1 (0-10)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	66300	216750		700000		9,471428571	3,94686907	3,1	3738,248848	707546,0165	0,174767552	93,7376891
A2	26000			700000		3,714285714	1,547791792		574,8940943		0,026876978	
A3	32000			700000		4,571428571	1,904974514		870,8454919		0,040713056	
A4	22000			700000		3,142857143	0,654834989		205,8052823		0,00962164	
A5	20400			700000		2,914285714	2,428842505		707,8341014		0,033092081	
A6	28050			700000		4,007142857	1,669829222		669,124424		0,031282358	
A7	22000			700000		3,142857143	0,982252484		308,7079234		0,01443246	
L1	80		1089		1000	8	2,098911119	0,7	1679,128952	12687432,77	0,078501263	
L2	200				1000	20	20,98911119		41978,2238		1,962531576	
L3	120				1000	12	6,296733569		7556,080283		0,353255684	
L4	139				1000	13,9	5,470287288		7603,699331		0,35548193	
L5	320				1000	32	12,59346714		40299,09484		1,884030313	
L6	230				1000	23	12,06873934		27758,10049		1,297724005	

Section2 (10-20)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	63000	63000		700000		9	100	0,7	90000	9000000	4,207606369	94,8681518
L1	300		645		1000	30	1,162790698	0,4	3488,372093	1976937,984	0,163085518	
L2	260				1000	26	6,046511628		15720,93023		0,734972069	
L3	85				1000	8,5	0,658914729		560,0775194		0,026184286	

Section3 (20-30)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	45000	45000		700000		6,428571429	100	0,7	64285,71429	6428571,429	3,005433121	88,5477283
L1	140		680		1000	14	4,117647059	0,5	5764,705882	18067647,06	0,269506813	
L2	230				1000	23	40,58823529		93352,94118		4,364360332	
L3	80				1000	8	4,705882353		3764,705882		0,176004449	
L4	230				1000	23	33,82352941		77794,11765		3,636966944	
Section4 (30-40)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	22800	25800		700000		3,257142857	44,18604651	0,8	14392,02658	1464119,601	0,672844252	94,4215822
A2	3000			700000		0,428571429	5,813953488		249,1694352		0,011648966	
L1	510		860		1000	51	14,8255814	0,8	75610,46512	10468023,26	3,534878607	
L2	100				1000	10	11,62790698		11627,90698		0,543618394	
L3	150				1000	15	8,720930233		13081,39535		0,611570693	
L4	100				1000	10	4,360465116		4360,465116		0,203856898	
Section5 (40-50)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	20700	42150		700000		2,957142857	19,64412811	1,2	5809,049314	844478,9019	0,271579921	87,2245965
A2	12000			700000		1,714285714	9,489916963		1626,842908		0,076056829	
A3	9450			700000		1,35	7,473309609		1008,896797		0,047167118	
L1	200		1450		1000	20	3,448275862	0,8	6896,551724	26481896,55	0,322421944	
L2	270				1000	27	18,62068966		50275,86207		2,350455972	
L3	750				1000	75	25,86206897		193965,5172		9,068117176	
L4	230				1000	23	5,948275862		13681,03448		0,639604531	

Section6 (50-60)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	36000	63650		700000		5,142857143	20,83764005	1,9	10716,5006	1209179,666	0,501009069	97,5150334
A2	14000			700000		2	4,630586679		926,1173358		0,04329708	
A3	7800			700000		1,114285714	2,579898292		287,4743812		0,013439767	
A4	5850			700000		0,835714286	1,934923719		161,7043394		0,007559869	
L1	120		490		1000	12	2,448979592	1	2938,77551	4106122,449	0,137391228	
L2	110				1000	11	8,979591837		9877,55102		0,461787184	
L3	110				1000	11	8,979591837		9877,55102		0,461787184	
L4	150				1000	15	12,24489796		18367,34694		0,858695177	

Section7 (60-70)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	12600	56200		700000		1,8	7,473309609	1,2	1345,19573	1244162,006	0,06288949	93,5651788
A2	35200			700000		5,028571429	20,87781732		10498,55957		0,490820068	
A3	8400			700000		1,2	4,982206406		597,8647687		0,027950885	
L1	80		1560		1000	8	1,398601399	1,1	1118,881119	12519813,52	0,052309015	
L2	80				1000	8	1,398601399		1118,881119		0,052309015	
L3	100				1000	10	1,165501166		1165,501166		0,054488557	
L4	1000				1000	100	11,65501166		116550,1166		5,448855697	
L5	300				1000	30	1,748251748		5244,755245		0,245198506	

Section8 (70-80)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	17100	17100		700000		2,442857143	100	0,4	24428,57143	2442857,143	1,142064586	96,2911157
L1	280		1280		1000	28	1,682692308	1,3	4711,538462	5490384,615	0,220269992	
L2	280				1000	28	3,365384615		9423,076923		0,440539983	
L3	560				1000	56	6,730769231		37692,30769		1,762159933	
L4	80				1000	8	1,923076923		1538,461538		0,071924895	
L5	80				1000	8	1,923076923		1538,461538		0,071924895	

The results were deemed and showed that the method of RCI calculation does not consider the entire assessment of pavement deterioration. Based on the struggle of giving an expert opinion on deterioration condition (Low/Medium/High), secondly, the study aims to suggest easier and more sensitive way of determination of the level of severity as well as the necessity of finding a less subjective way of recording the pavement condition.

Section 9 (80-90)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	3000	52850		700000		0,428571429	1,419110691	1,6	60,8190296	1106043,046	0,002843362	96,2994969
A2	39600			700000		5,657142857	18,73226112		10597,10772		0,49542731	
A3	7000			700000		1	3,311258278		331,1258278		0,015480524	
A4	3250			700000		0,464285714	1,537369915		71,3778889		0,003337001	
L1	280		1510		1000	28	3,708609272	1	10384,10596	6809271,523	0,485469226	
L2	280				1000	28	3,708609272		10384,10596		0,485469226	
L3	280				1000	28	3,708609272		10384,10596		0,485469226	
L4	500				1000	50	6,622516556		33112,58278		1,54805238	
L5	170				1000	17	2,251655629		3827,81457		0,178954855	

Section10 (90-100)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	23100	29350		700000		3,3	39,35264055	0,8	12986,37138	1393702,847	0,60712821	93,0670187
A2	6250			700000		0,892857143	10,64735945		950,6570942		0,044444343	
L1	130		1870		1000	13	1,158645276	0,6	1506,238859	13435828,88	0,070418447	
L2	230				1000	23	2,049910873		4714,795009		0,220422239	
L3	350				1000	35	3,11942959		10918,00357		0,51042957	
L4	760				1000	76	13,54723708		102959,0018		4,813455019	
L5	400				1000	40	3,565062389		14260,24955		0,666683521	

Section11 (100-110)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	12600	31150		700000		1,8	16,17977528	1	2912,359551	540374,914	0,136156251	92,0167265
A2	7150			700000		1,021428571	6,886035313		703,3593213		0,03288288	
A3	11400			700000		1,628571429	10,97913323		1788,030268		0,083592528	
L1	250		1540		1000	25	4,058441558	0,4	10146,1039	16535714,29	0,474342349	
L2	100				1000	10	1,623376623		1623,376623		0,075894776	
L3	250				1000	25	4,058441558		10146,1039		0,474342349	
L4	940				1000	94	15,25974026		143441,5584		6,706062388	

Section12 (110-120)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	8400	28400		700000		1,2	10,75544174	1,1	1290,653009	1409475,032	0,060339554	89,2332229
A2	20000			700000		2,857142857	44,81434059		12804,09731		0,598606682	
L1	500		830		1000	50	30,12048193	0,2	150602,4096	21620481,93	7,040840645	
L2	330				1000	33	19,87951807		65602,40964		3,066990185	

Section13 (120-130)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	4500	42100		700000		0,642857143	2,375296912	1,8	152,6976586	601414,8098	0,007138796	98,2206686
A2	3850			700000		0,55	1,524148852		83,82818686		0,003919067	
A3	16150			700000		2,307142857	14,91818422		3441,838216		0,160910004	
A4	17600			700000		2,514285714	9,290050145		2335,784036		0,109200664	
L1	300	660			1000	30	5,681818182	0,8	17045,45455	3204545,455	0,796895146	
L2	240				1000	24	4,545454545		10909,09091		0,510012893	
L3	60				1000	6	3,409090909		2045,454545		0,095627417	
L4	60				1000	6	3,409090909		2045,454545		0,095627417	

Section14 (130-140)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	4200	7800		700000		0,6	26,92307692	0,6	1615,384615	280219,7802	0,07552114	92,2012402
A2	3600			700000		0,514285714	23,07692308		1186,813187		0,055484919	
L1	450		1670		1000	45	1,418216199	1,9	6381,972896	16401197,6	0,298364776	
L2	200				1000	20	0,630318311		1260,636621		0,058936252	
L3	700				1000	70	22,06114088		154427,9861		7,219690868	
L4	200				1000	20	0,630318311		1260,636621		0,058936252	
L5	60				1000	6	0,56728648		340,3718878		0,015912788	
L6	60				1000	6	0,56728648		340,3718878		0,015912788	

Section15 (140-150)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	12600	54100		700000		1,8	3,327171904	2,1	598,8909427	259635,0925	0,027998859	94,2684757
A2	3400			700000		0,485714286	1,197077722		58,14377507		0,00271829	
A3	4000			700000		0,571428571	1,408326732		80,47581325		0,003762339	
A4	17600			700000		2,514285714	4,647478215		1168,508808		0,054629168	
A5	6000			700000		0,857142857	1,584367573		135,8029349		0,006348948	
A6	10500			700000		1,5	3,696857671		554,5286506		0,02592487	
L1	120		120		1000	12	100	0,6	120000	12000000	5,610141826	

Section16 (150-160)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
A1	10800	51800		700000		1,542857143	4,905746082	1,7	756,8865384	580052,5616	0,03538534	94,24618
A2	24000			700000		3,428571429	8,17624347		2803,283476		0,131056816	
A3	3000			700000		0,428571429	0,340676811		14,60043477		0,000682588	
A4	14000			700000		2	11,12877583		2225,755167		0,104056685	
L1	300		660		1000	30	22,72727273	0,2	68181,81818	11727272,73	3,187580583	
L2	240				1000	24	18,18181818		43636,36364		2,040051573	
L3	60				1000	6	4,545454545		2727,272727		0,127503223	
L4	60				1000	6	4,545454545		2727,272727		0,127503223	

Section17 (160-170)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	β x Extent (%)	Σ(β x Extent) (%)	α (Deduct Value) (%)	PCR
L1	200		600		1000	20	16,66666667	0,2	33333,33333	16666666,67	1,558372729	92,2081364
L2	400				1000	40	33,33333333		133333,3333		6,233490918	

Section18 (170-180)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section19 (180-190)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	32900	32900		700000		4,7	100	0,3	47000	4700000	2,197305549	95,81611
L1	320		490		1000	32	9,329446064	0,7	29854,22741	4249271,137	1,395720415	
L2	85				1000	8,5	7,434402332		6319,241983		0,295432031	
L3	85				1000	8,5	7,434402332		6319,241983		0,295432031	

Section20 (190-200)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	11200	11575		700000		1,6	67,73218143	1	10837,14903	1084235,575	0,506649525	94,5806912
A2	375			700000		0,053571429	0,971922246		5,206726319		0,000243421	
L1	90		440		1000	9	13,63636364	0,6	12272,72727	10507575,76	0,573764505	
L2	350				1000	35	26,51515152		92803,0303		4,338651349	

Section21 (200-210)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
L1	1000		1110		1000	100	30,03003003	0,6	300300,3003	30756756,76	14,03939396	85,6208527
L2	110				1000	11	6,606606607		7267,267267		0,339753334	

Section22 (210-220)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	12900	12900		700000		1,842857143	100	0,4	18428,57143	1842857,143	0,861557495	88,7321515
L1	930		1970		1000	93	11,80203046	1,6	109758,8832	22258883,25	5,131357514	
L2	930				1000	93	11,80203046		109758,8832		5,131357514	
L3	110				1000	11	2,791878173		3071,06599		0,143575965	

Section23 (220-230)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	4800	4800		700000		0,685714286	100	0,7	6857,142857	685714,2857	0,320579533	62,278475
L1	800		800		1000	80	100	0,6	800000	80000000	37,40094551	

Section24 (230-240)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section25 (240-250)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section26 (250-260)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section27 (260-270)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section28 (270-280)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
L1	85		170		1000	8,5	25	0,6	21250	4250000	0,993462615	98,0130748
L2	85				1000	8,5	25		21250		0,993462615	

Section29 (280-290)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	21000	21000		700000	1000	3	100	0,3	30000	3000000	1,402535456	98,5974645

Section30 (290-300)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	16250	16250		700000	1000	2,321428571	100	0,3	23214,28571	2321428,571	1,085295294	98,9147047

Section31 (300-310)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section32 (310-320)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
L1	200		705		1000	20	5,673758865	0,5	11347,51773	6986524,823	0,530509865	96,7337171
L2	65				1000	6,5	5,531914894		3595,744681		0,168105314	
L3	440				1000	44	12,4822695		54921,98582		2,567667748	

Section33 (320-330)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section34 (330-340)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section35 (340-350)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	4200	17600		700000		0,6	5,303030303	1,8	318,1818182	431944,4444	0,014875376	99,7980609
A2	2400			700000		0,342857143	5,303030303		181,8181818		0,008500215	
A3	11000			700000		1,571428571	24,305555556		3819,444444		0,178563542	

Section36 (350-360)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	4900	4900		700000		0,7	100	0,4	7000	700000	0,327258273	91,6512232
L1	220	570			1000	22	12,86549708	0,3	28304,09357	17157894,74	1,323249826	
L2	350				1000	35	40,93567251		143274,8538		6,698268749	

Section37 (360-370)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	1600	3200		700000		0,228571429	25	0,8	571,4285714	57142,85714	0,026714961	99,9465701
A2	1600			700000		0,228571429	25		571,4285714	57142,85714	0,026714961	

Section38 (370-380)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section39 (380-390)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section40 (390-400)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section41 (400-410)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section42 (410-420)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section43 (420-430)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section44 (430-440)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	3200	8800		700000		0,457142857	25,45454545	1	1163,636364	269090,9091	0,054401375	90,5239604
A2	5600			700000		0,8	19,09090909		1527,272727		0,071401805	
L1	200		200		1000	20	100		200000		9,350236377	

Section45 (440-450)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
Not Defective												100

Section46 (450-460)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	12000	12000		700000		1,714285714	100	0,7	17142,85714	1714285,714	0,801448832	99,1985512

Section47 (460-470)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	20000	20000		700000		2,857142857	100	0,4	28571,42857	2857142,857	1,335748054	98,6642519

Section48 (470-480)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	6500	77100		700000		0,928571429	4,817491199	0,7	447,3384685	9280160,936	0,020913602	95,6614151
A2	70600			700000		10,08571429	91,5693904		92354,27089		4,317671316	

Section49 (480-490)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	22750	99650		700000		3,25	5,371742274	1,7	1745,816239	1335740,638	0,081618973	99,3755255
A2	5400			700000		0,771428571	2,231339099		172,1318733		0,008047369	
A3	4400			700000		0,628571429	0,77919778		48,9781462		0,002289786	
A4	67100			700000		9,585714286	11,88276615		11390,48013		0,532518408	

Section50 (490-500)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	170000	170000		700000		24,28571429	100	0,3	242857,1429	24285714,29	11,35385846	88,6461415

Section51 (500-510)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\Sigma(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	170000	170000		700000		24,28571429	100	0,3	242857,1429	24285714,29	11,35385846	88,6461415

Section52 (510-520)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	19500	51000		700000		2,785714286	20,58823529	1,3	5735,294118	901990,9502	0,268131778	89,8939363
A2	18200			700000		2,6	8,235294118		2141,176471		0,100102531	
A3	13300			700000		1,9	6,018099548		1143,438914		0,053457121	
L1	1000	1460			1000	100	17,86777844	2,3	178677,7844	20714711,14	8,353397597	
L2	260				1000	26	7,74270399		20131,03038		0,941149463	
L3	200				1000	20	4,169148303		8338,296605		0,389825221	

Section53 (520-530)	Area/Length of Deterioration (cm ² /cm)	Total Area (cm ²)	Total Length (cm)	Area of Road Section (cm ²)	Length of Road Section (cm)	Extent (%)	β (Severity) (%)	Total Weight	$\beta \times \text{Extent}$ (%)	$\sum(\beta \times \text{Extent})$ (%)	α (Deduct Value) (%)	PCR
A1	19600	48600		700000		2,8	6,721536351	2,4	1882,030178	81927376,05	0,087987135	54,1195398
A2	10800			700000		1,542857143	3,703703704		571,4285714		0,026714961	
A3	5600			700000		0,8	1,920438957		153,6351166		0,007182623	
A4	12600				1000	1260	6,481481481		816666,6667		38,18013187	
L1	280	1120			1000	28	5,769230769	2,6	16153,84615	16210164,84	0,7552114	
L2	610				1000	61	20,9478022		127781,5934		5,973940515	
L3	230				1000	23	7,898351648		18166,20879		0,849291731	

APPENDIX D: Comparisons between RCI Observations and PCR Results

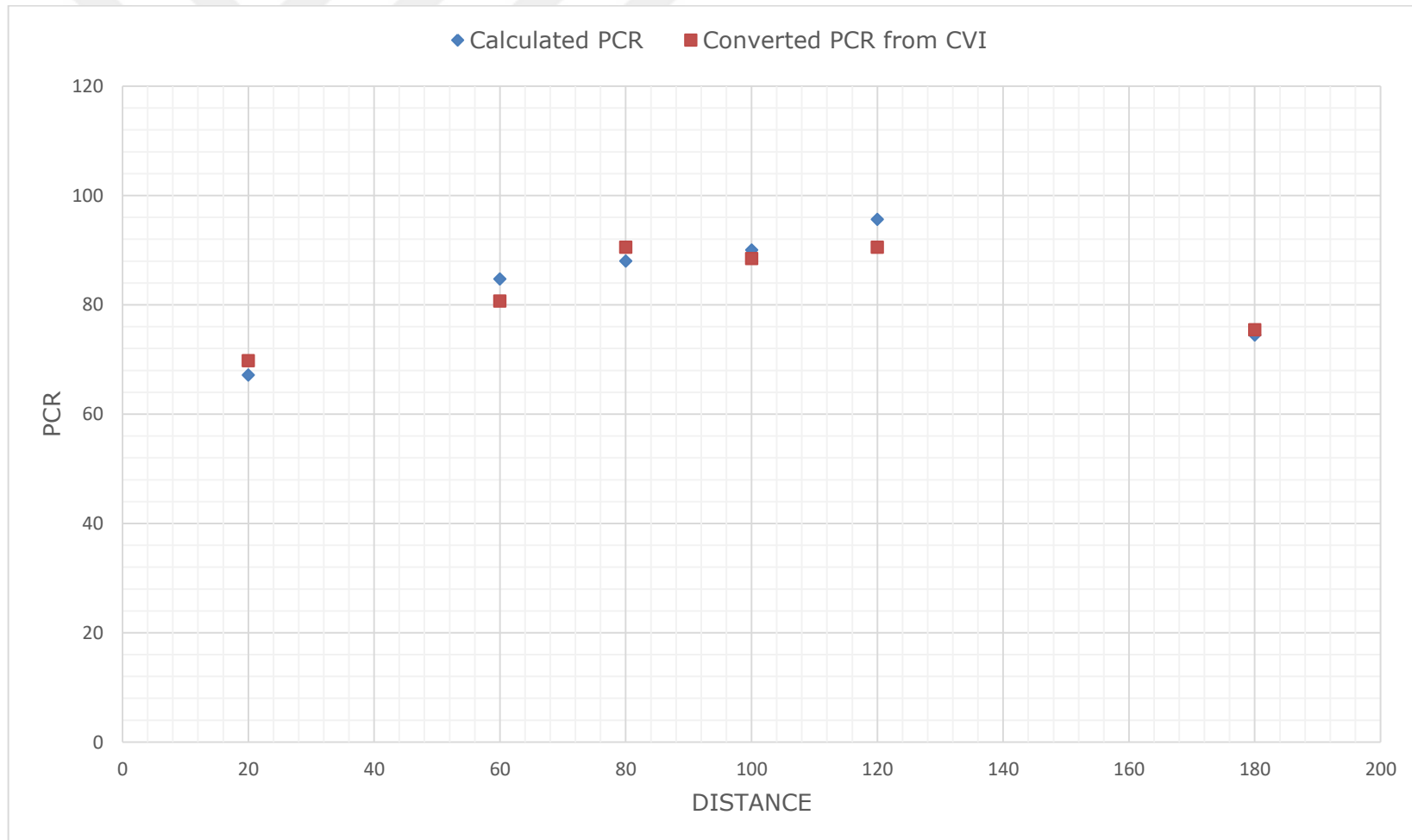


Figure 1: Comparison between Calculated PCR and Converted PCR from CVI for Broadgate Avenue Network (Unclassified Road)

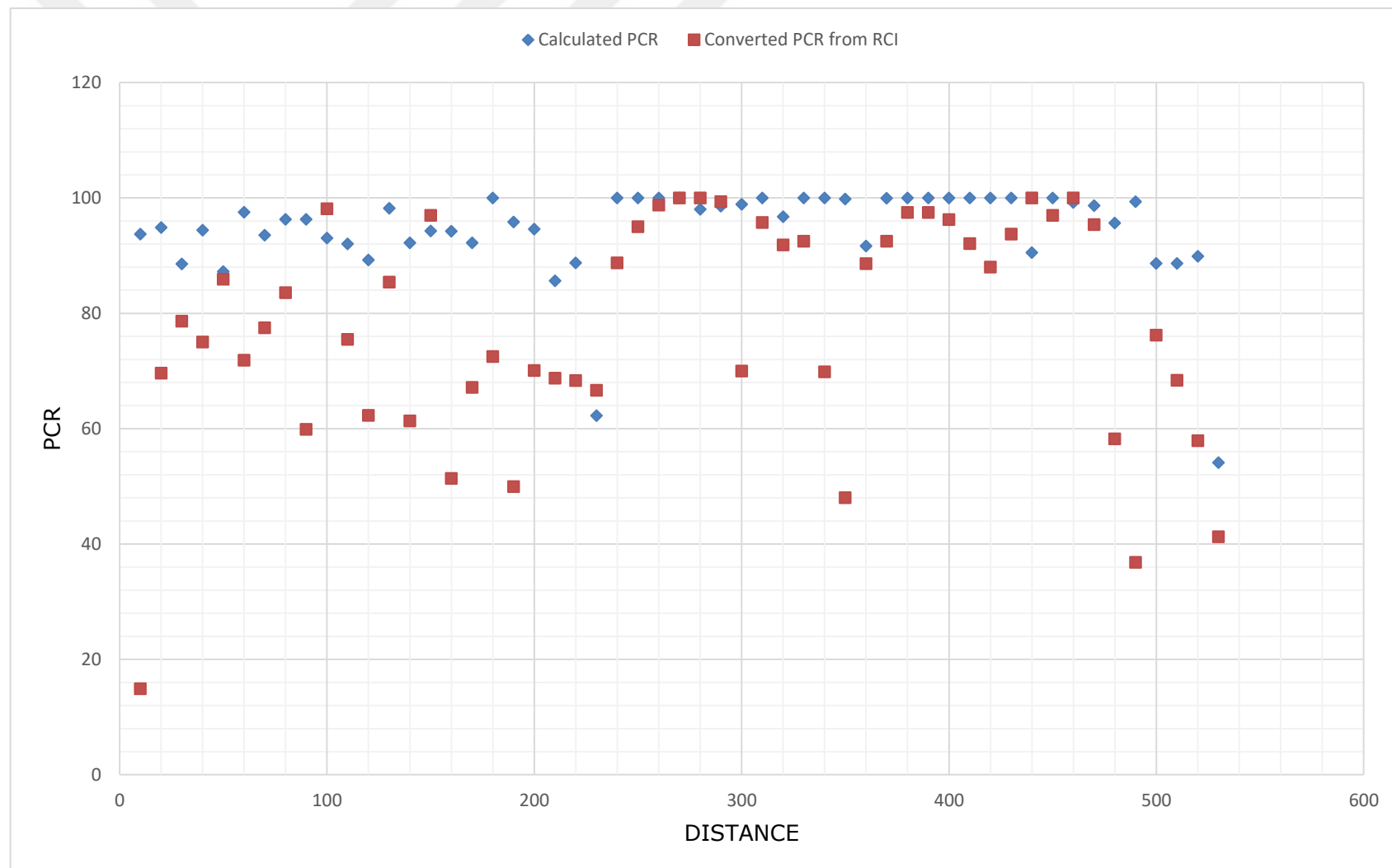


Figure 2: Comparison between Calculated PCR and Converted PCR from RCI for B6464 Broadgate Network (B Class Road)

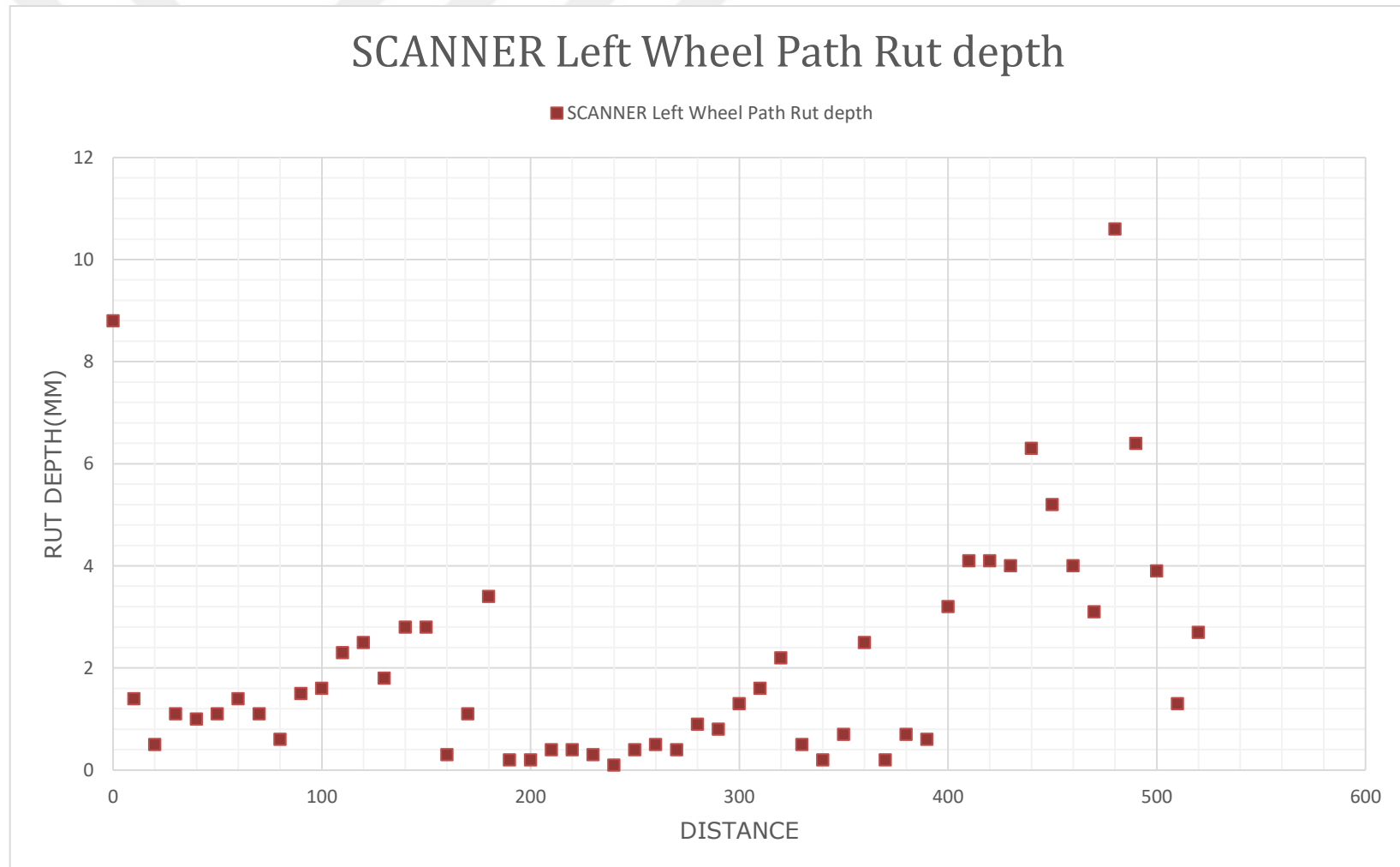


Figure 3: Measured rut depth currently used in the SCANNER RCI versus distance for B6464 Broadgate Network

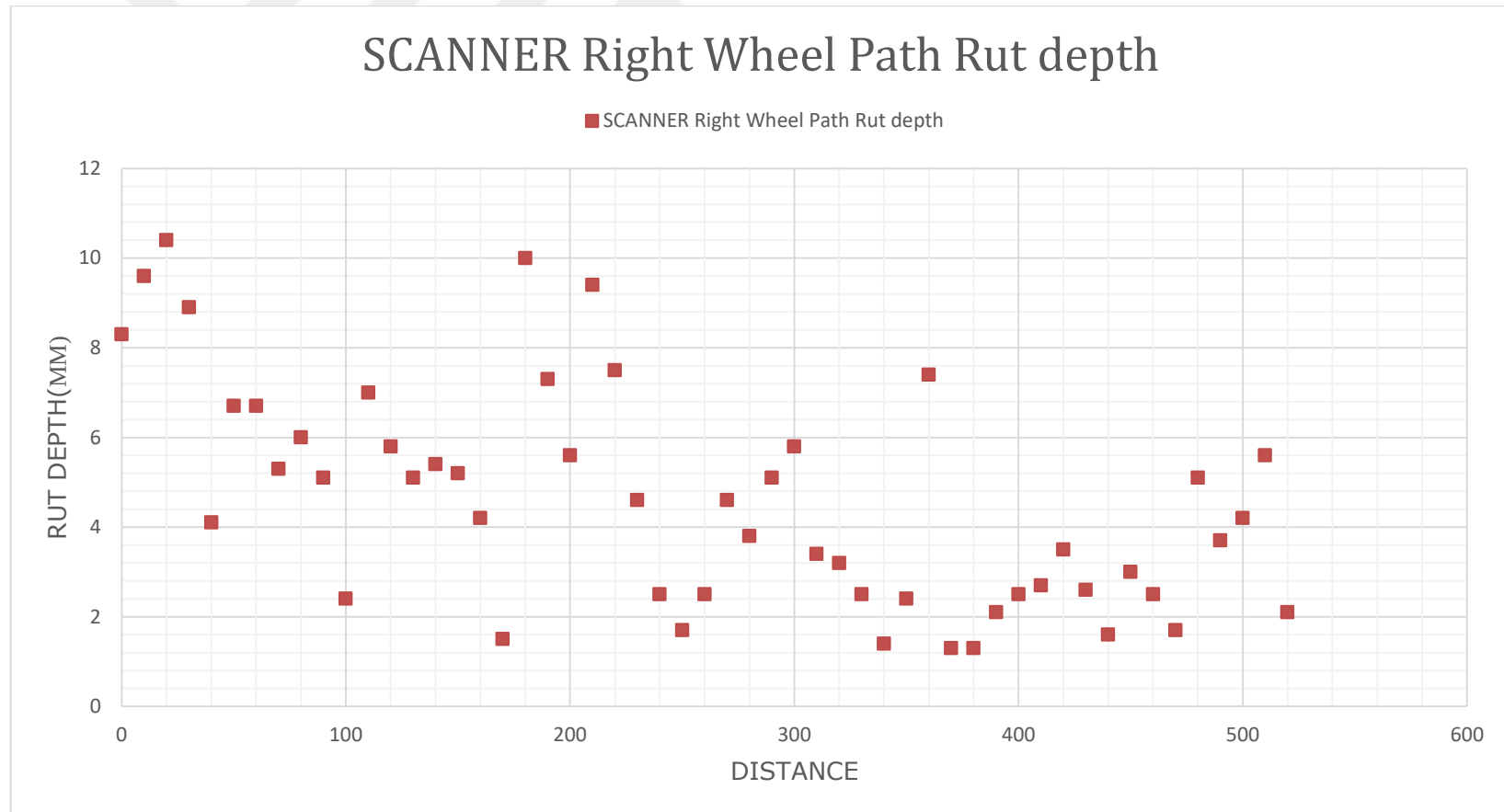


Figure 4: Measured rut depth currently used in the SCANNER RCI versus distance for B6464 Broadgate Network

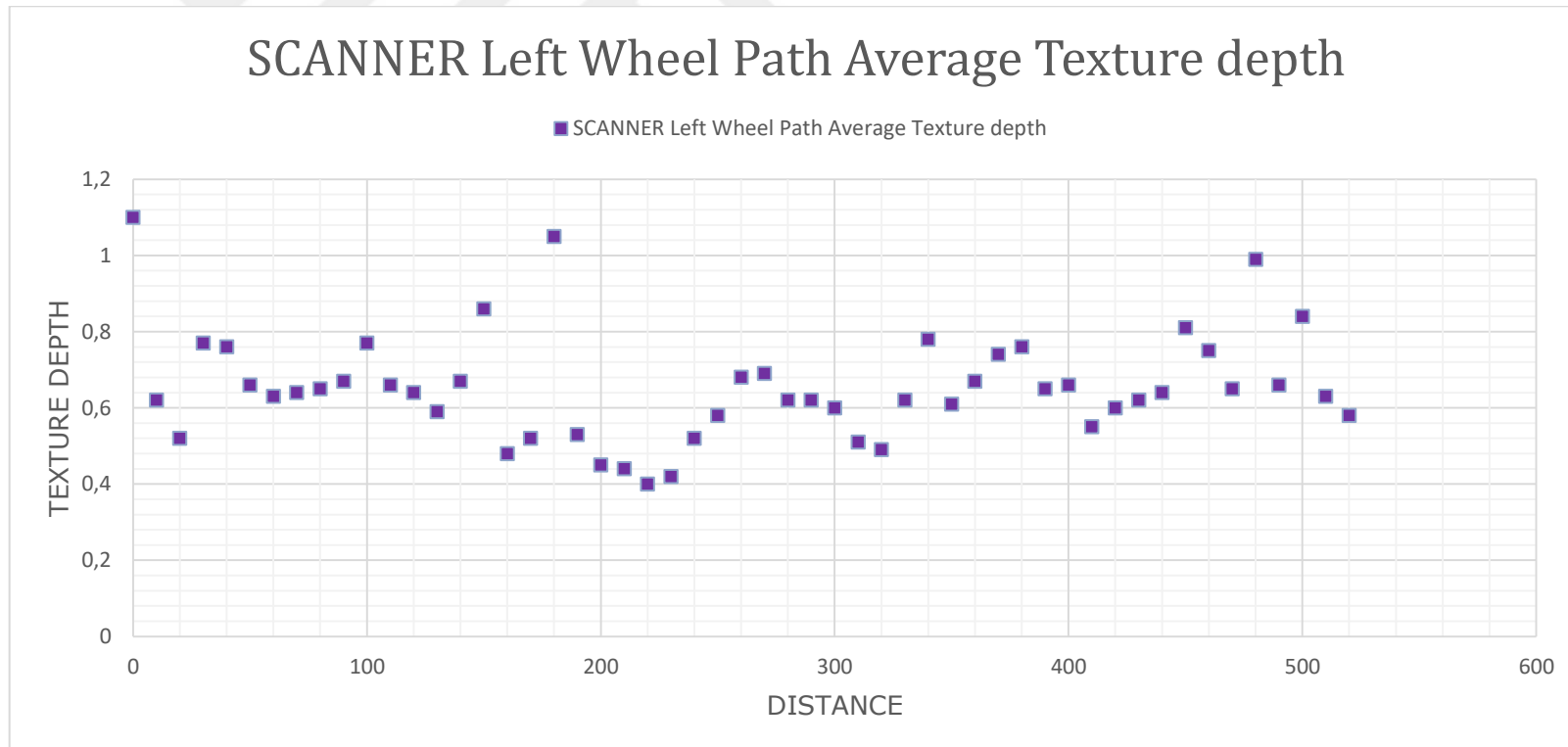


Figure 5: Observed texture depth currently used in the SCANNER RCI versus distance for B6464 Broadgate Network

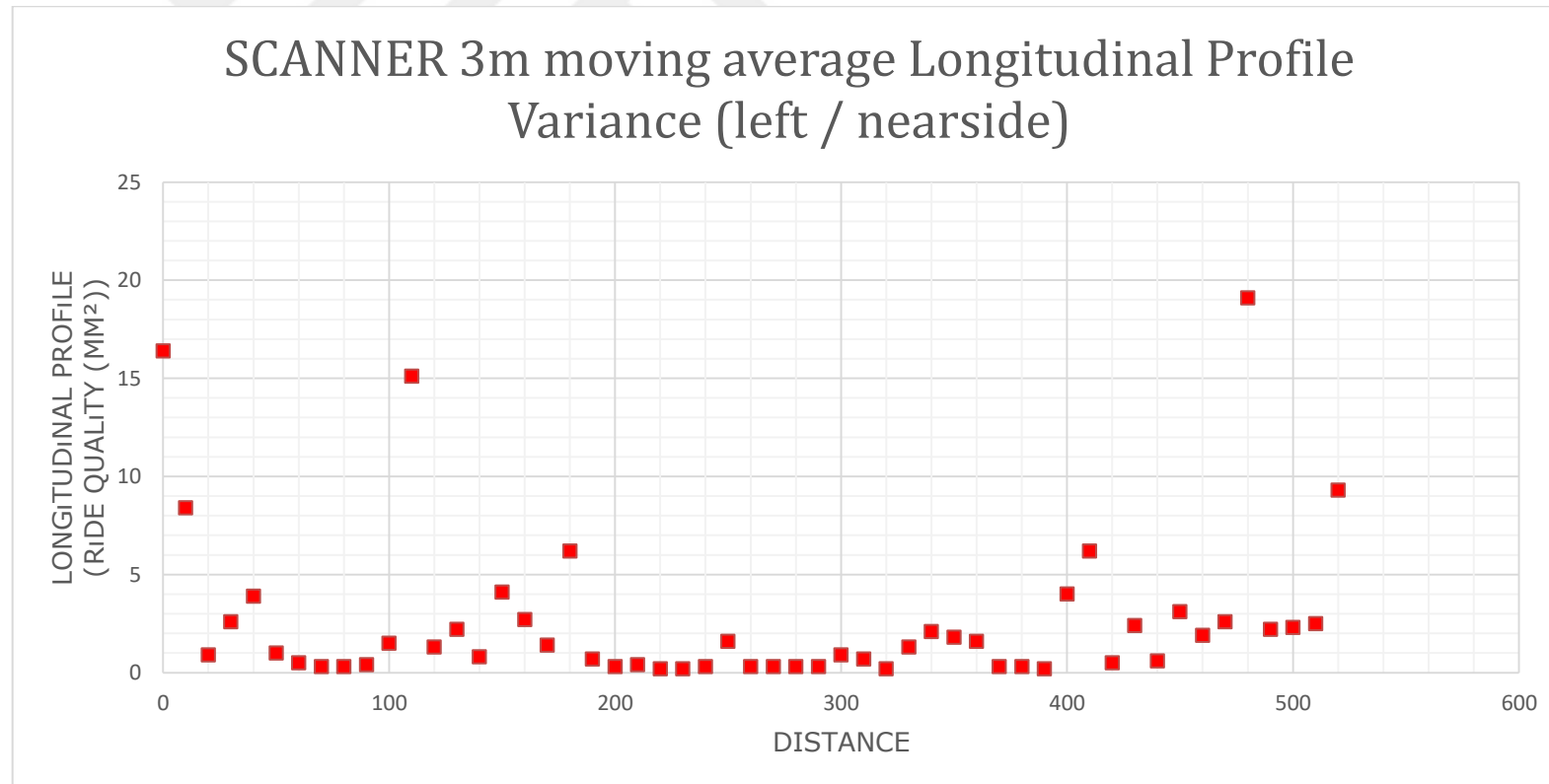


Figure 6: Observed ride quality currently used in the SCANNER RCI versus distance for B6464 Broadgate Network

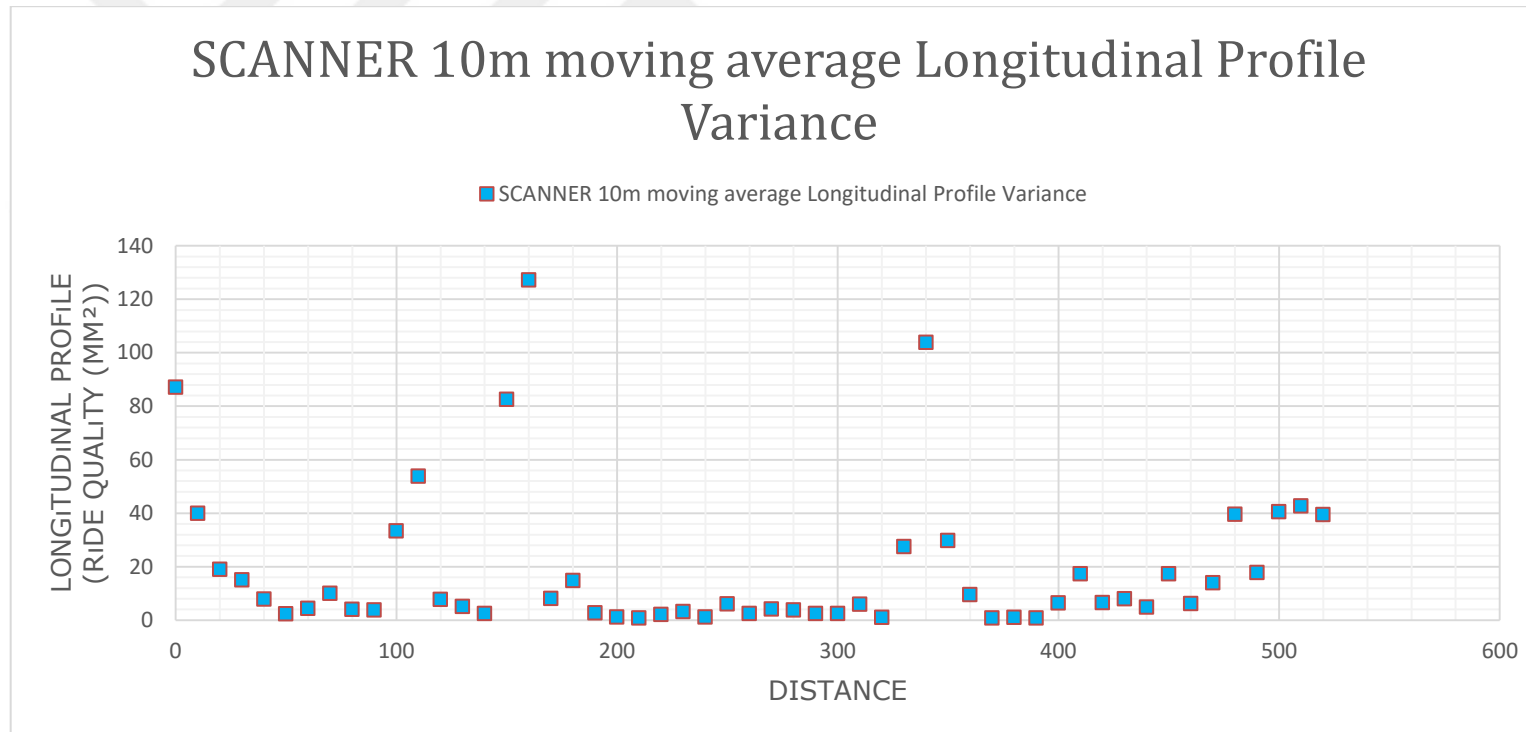


Figure 7: Observed ride quality currently used in the SCANNER RCI versus distance for B6464 Broadgate Network

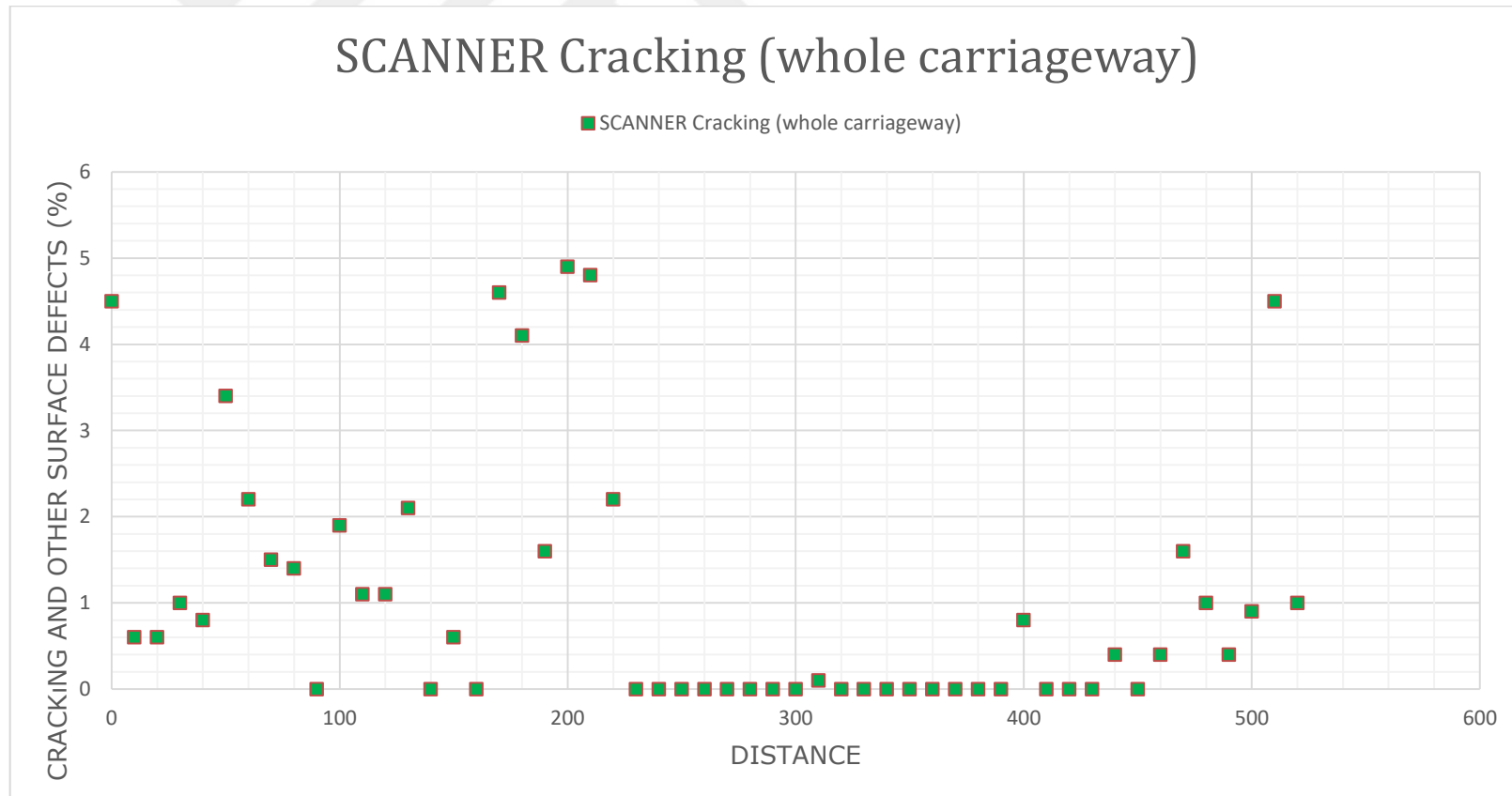


Figure 8: Observed crack intensity used in the SCANNER RCI versus distance for B6464 Broadgate Network

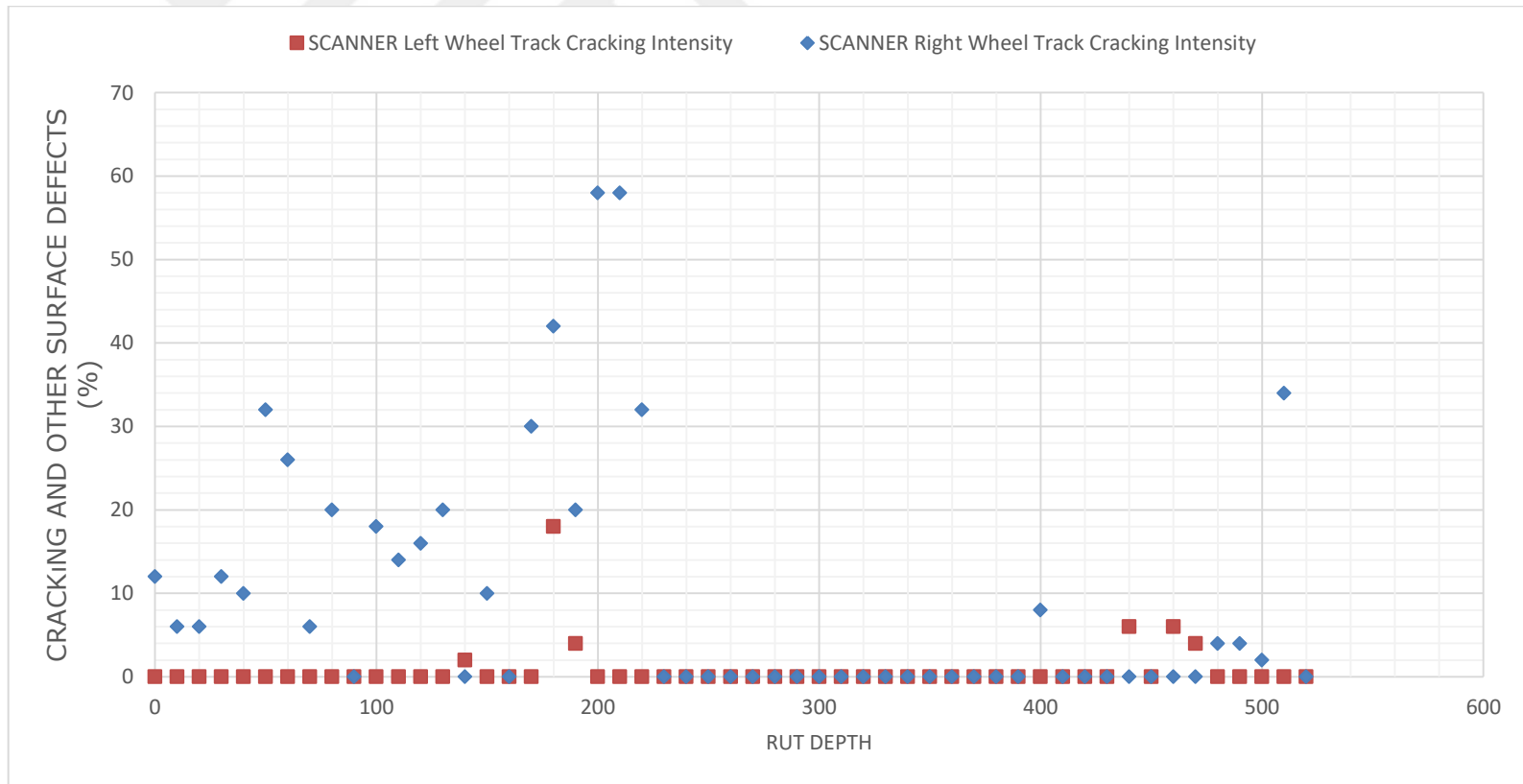


Figure 9: Observed crack intensity over part of the carriageway used in the SCANNER RCI versus distance for B6464 Broadgate Network

APPENDIX E: Parameters, weighting and thresholds used in RCI calculations

Parameter	Weighting	Environment	Road class	Lower Threshold	Upper Threshold
Maximum Rutting	0.9	Rural	A or B	10	20
			C or U	15	30
		Urban	A or B	10	20
			C or U	12	25
3m LPV	0.8	Rural	A or B	4	10
			C or U	15	25
		Urban	A or B	4	10
			C or U	7	17
10m LPV	0.4	Rural	A or B	21	56
			C or U	45	130
		Urban	A or B	21	56
			C or U	45	90
Texture	0.5	Rural and Urban	All	0.6	0.3
Wheeltrack cracking	0.45	Rural and Urban	All	0.5	5
Whole carriageway cracking	0.35	Rural and Urban	All	0.15	2