IDENTIFICATION OF ROAD DEFECTS, CAUSES OF ROAD DETERIORATION AND RELATIONSHIP AMONG THEM FOR BITUMEN PENETRATION MACADAM ROADS IN SRI LANKA

BY

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Thesis submitted to the Department of Civil Engineering of the University of Moratuwa in Partial Fulfillment of the requirement for the Degree of Master of Science

Supervised by

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Dedication

To My Mother & Father

For their continuous dedication and encouragement for all the endeavors towards my advancement.
Declaration

This thesis is a report on the research work carried out in the Department of Civil engineering, University of Moratuwa, Sri Lanka, during January 2003 to August 2004. This submission is original and does not have any materials previously published or written by any others anywhere, except where citing is made.

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Abstract

The study was particularly concentrated on identifying the causes of road deterioration, road defects and determining the most important parameters which could be used to predict the rate of deterioration particularly in Bitumen penetration macadam roads.

A comprehensive literature review was conducted with literature related to both local an international context to determine the road deterioration factors, road defects, rate of deterioration .....etc both locally and foreign countries. Moreover, the literature review was accompanied with the road condition surveys where sophisticated equipments were used in developed countries while manual data collection methods were used in developing countries like ours.

In achieving the above objectives, a suitable surface condition survey form was developed. Surface condition survey form was accompanied with road surface information, road geometry, sand sealing history and road deformations. Traffic data and sand sealing history were obtained from Provincial Road Development Authority (PRDA) and the rest was obtained by field observations. Data collection was carried out in selected Bitumen penetration macadam roads for about nine months.

Cracks, potholes, edge defects, depressions, corrugations are the significant road defects observed in the field. Traffic, age, road geometry, weather, drainage, construction quality as well construction material, maintenance policy play the major role as road deteriorate agents.

Potholes and cracks were mainly considered in the field observations of road deformations. The data was analysed by using the statistical softwares SPSS and SAS. Category data was used for data analysis and statistical tests were carried out to check the significance of the road deterioration agents. It was found that both potholes and cracks were having significant relationship with age as well as traffic.
Acknowledgement

The author wishes to extend her sincere gratitude to Vice Chancellor, Dean Engineering and the Senate Research Committee of University of Moratuwa for considering the research proposal favorably and granting the necessary fund.

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The author wishes to thank the following parties outside the university: Asian Development Bank for providing necessary funds for this Master of Engineering Project.

Last, but not least, I wish to pay special thanks to my husband Mr. Saman Cooray for his unfailing support and encouragement.

Finally, the author wishes to thank all others who contributed to the completion of this project.

A.S.P.Randu Harischandra
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Chapter 01
1 INTRODUCTION

1.1 Background

Commerce and communication between and within cities are essential to stimulate development. Though, the movement of people, resources and goods are mostly accomplished through roads and highways. The severity of the road degradation emphasizes the importance of seeking deep technical understanding of the parameters causing road surface distresses.

Though, the road network in Sri Lanka is well spread out and almost every part of the country is accessible by roads, it is still having severe problems with road maintenance. In the long run, life cycle cost of the Sri Lankan roads is still quite high.

Road deterioration depends on original design, material types, construction quality, traffic and axle loading, road geometry, pavement age, environment condition, maintenance policy, type of construction etc.

A defect refers to the visible evidence of an undesirable condition in the pavement affecting serviceability, structural condition or appearance. Correct diagnosis of the cause of defects can only be made after careful inspection of the pavement.

The initiation of surface distress such as cracking or raveling marks a significant stage in the deterioration of a pavement. The distress does not occur instantaneously over the entire length of the road under the same conditions. The rate of deterioration usually accelerates with an abrupt increase in traffic volume or extreme environmental changes. (Florida DOT, 2000)

Effective maintenance is the most important part for minimize road deterioration. Work activities such as routine maintenance, preventative techniques, resealing, overlaying significantly help to minimize road deterioration.
1.2 Research Objective

"The main objective of this study is to identify factors affecting road deterioration, common road defects and develop relationships between magnitude of defects and factors affecting them.

- To determine the significant parameters that could be used to predict the rate of deterioration.
- To determine possible relationships between above parameters and level of deterioration.

1.3 Research Methodology

Literature review was conducted to determine the ways and means of road deterioration and to identify how others have tackled similar problems.

In developed countries such as UK, Canada, USA, sophisticated equipments are used for road condition surveys. Due to resource limitation to gather sufficient information, in Sri Lanka manual data collection method is adopted and hence an appropriate road surface condition survey form was developed for data collection purpose.

Required data for a road condition survey was identified through the literature review. Road condition survey was carried out in selected roads in Moratuwa area throughout nine months period for detailed inspection of road defects. Survey locations were selected on the basis of availability of historic data such as sand sealing history, average daily traffic. The data collection was also included average daily traffic, drainage structure data, construction and maintenance history and factors influencing road deterioration in roads.
1.4 Main Findings

Age of the surface dressing and the traffic load on the road found to be the most significant parameters affecting the road condition.

The following relationships were developed based on the field study.

1. The road deterioration factor of potholes with age.
2. The road deterioration factor of crack (Area of block affected) with age.
3. The road deterioration factor of potholes with traffic.
4. The road deterioration factor of crack (Area of block affected) with traffic.

1.5 Guide to report

Chapter 1 of this report gives an introduction to the study. The background, objectives, methodology, main findings and guide to the report are included in this chapter.

Chapter 2 gives summary of the literature review on road defects and road deterioration factors.

Chapter 3 describes the evaluation of Surface Condition for road defects. It includes evaluation methods, data collection and data analysis.

Chapter 4 describes the development of road deterioration factors. It includes theories on analysis and development of a mathematical models and work carried out to develop road deterioration factors.

Chapter 5 gives the conclusions of the study and identifies future research requirements.
Chapter 02
Chapter 2

2 LITERATURE REVIEW

2.1 Introduction

This chapter gives the summary of literature review on road network in Sri Lanka, road defects and causes of road deterioration.

2.2 Road Network in Sri Lanka

The road network in Sri Lanka is well spread out and almost every part of the country is accessible by road. The total length of the road network, as had been assessed in 2003, is 97,285.9 km (see Table 2.1), and, the average density of roads exceeds 1.5 km / sq. km.

However, these roads were developed to suit the needs of the times, are narrow and are generally of poor alignment, in the context of present day requirements.

The network consisted of a set of classified roads belonging to the Central Government, and other roads that belong to the Local Authorities and Departments, such as Irrigation, Forestry and Plantations. The classified roads have been designated as A, B, C, D and E. A represents the primary /trunk roads and B the main roads. C, D, and E represent the lower order roads in the system, which are essentially link roads.

In January 1990, the C, D and E class roads were handed over to the newly established Provincial Councils, and the A and B class roads, along with the roads providing access to places of national importance, were categorized as National Highways. RDA presently manages only the National Highways, which add up to 11, 660 km. (TED, 2003) is given in Table 2.2.
Table 2.1- Road length in Sri Lanka (TED, 2003)

<table>
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<th>Province</th>
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<td><strong>TOTAL</strong></td>
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<td><strong>97,285.90</strong></td>
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2.3 Road Defects

Highway defects include damage to all surfaces, i.e., footways, carriageways, verge etc. The most common are on footways and potholes in carriageways. However, there are many other types of defects including broken and missing covers on manholes, drains etc., damage signs, loose kerbs, etc. in footways and verge sides.

Each of the defect types has been grouped into one of the following broad modes of pavement distress.

- Cracks
- Potholes
- Deformations such as ruts, depressions, corrugations etc.
- Edge defects

2.3.1 Cracks

Cracks are fissures resulting from partial or complete fractures of the pavement surface. Cracking of road pavement surfaces can happen in a wide variety of patterns, ranging from isolated single cracks to an interconnected pattern extending over the entire pavement surface.

The detrimental effects associated with the presence of cracks are manifold and include:

- Loss of waterproofing of the pavement layers.
- Loss of load-spreading ability of the cracked material.
- Pumping and loss of fines from the base course.
- Loss of riding quality through loss of surfacing.
- Loss of appearance.

The loss of load-spreading ability and waterproofing will usually lead to accelerated deterioration of the pavement condition. Factors which lead to cracking include:
- Fatigue life of the surfacing exceeded.
- Age embrittlement of the surfacing.
- Reflection of cracking in underlying layers (longitudinal, block, transverse cracking).
- Shrinkage.
- Poor construction techniques.

Crack patterns, alone or linked with deformation, are useful in assessing causes. As cracks promote water entry, they can be the primary cause of a range of secondary defects (deformation and potholes).

Crack types:
- Meandering CM
- Transverse CT
- Longitudinal CL
- Diagonal CD
- Block CB
- Crocodile CR
- Crescent shaped CC

Figure 2.1 – Crack types (A guide to the visual assessment of pavement Condition, 1987)
2.3.2 Block cracking:

Block cracking, when confined to the bituminous surfacing, is usually the final stage of cracking due to thermal stresses. These cracks almost always start at the top of the surfacing and propagate downwards.

Figure 2.2 – Block cracking
2.3.3 Crocodile cracking:

Crocodile or fatigue cracking is a series of interconnecting cracks caused by fatigue failure of the asphalt surface under repeated traffic loading.

Crocodile cracking occurs only in areas subjected to repeated traffic loading, such as wheel paths. Therefore it would not occur an entire area unless the entire was subjected to traffic loading. Crocodile cracking is considered as a major structural distress and is usually accompanied by rutting.

Figure 2.3 – Crocodile cracking (A guide to the visual assessment of pavement Condition, 1987)
2.3.4  Longitudinal cracking:

Thermal stresses can cause cracks to appear along poor longitudinal construction joints and in areas of severe temperature gradients, such as the edge of road markings. In their early stages neither of these types of crack is particularly serious; however, if left unsealed, the cracks will eventually spread into the wheel paths where they will result in more serious deterioration.

Where longitudinal and transverse cracks occur in combination, they are likely to be either reflection cracks propagating from a lower stabilized layer or cracks caused by thermal or shrinkage stresses in the asphalt.

Longitudinal cracks caused by sub grade movement will generally be quite long and can meander across the carriageway. They can occur because of poor construction, swelling in plastic sub grade or embankment materials, and the settlement or collapse of embankments. Cracks caused by the slippage of an embankment will often occur in semicircular patterns and both these and cracks caused by sub grade movement will often be associated with a vertical displacement across the crack.

Figure 2.4 – Longitudinal cracking (A guide to the visual assessment of pavement Condition, 1987)
2.3.5 Transverse cracking:

This form of cracking is often associated with longitudinal cracks and, in severe cases, block cracking.

If the transverse cracks are irregularly or widely spaced they are likely to have been caused by some form of construction fault. Differential vertical movement caused by consolidation or secondary compaction adjacent to road structures and culverts can cause transverse cracks in the surfacing. These cracks will be associated with a poor longitudinal road profile caused by the differential movement.

Transverse cracks confined to the surfacing and occurring at more regular and shorter spacing are probably caused by thermal or shrinkage stresses. This type of cracking will most likely occur in areas subjected to high diurnal temperature changes, such as desert regions, and will be exacerbated by poor quality surfacing materials. When cracks occur after many years of good performance it is likely that progressive hardening of the binder has made the surfacing more ‘brittle’ and therefore more susceptible to cracking. Thermal stresses can also cause cracks to open up at transverse construction joints.

Figure 2.5 – Transverse cracking
2.3.6 Potholes

Potholes are bowl-shaped depressions in the pavement surface resulting from the loss of wearing course and base course material. They generally have sharp edges and nearly vertical sides at the top of the hole. Potholes are produced when traffic abrades small pieces of the pavement surface, weaken surface defects (cracking, delamination etc.) allowing entry of the water. These spots disintegrate because of the weakening of the base course or poor quality surfacing. Free water collecting in the hole and the underlying base accelerates its development. These are the most common road defect in bituminous penetration macadam roads.

Figure 2.6 – Potholes
2.3.7 Deformations

Deformation is the change in a road surface from the constructed (intended) profile. Deformation may occur after construction due to vehicle traffic (load associated) or environmental (non-load associated) influences. In some cases, deformation may be built into a new pavement owing to inadequate control.

Deformation is an important element of pavement condition. It may directly influence the riding quality of a pavement (roughness and water ponding leading to loss of skid resistance) and may reflect structural inadequacies. Deformation may occur, the foremost of which are:

- Corrugations DC
- Depressions DD
- Rutting DR
- Shoving DS

These are described in detail in the following sections.

The dominant attribute is always vertical displacement. For reasons of standardization and convenience, the vertical displacement is the maximum depth obtainable under a 1.2 m straight edge (usually the depth at the point of maximum curvature).

Figure 2.7 - Deformations (A guide to the visual assessment of pavement Condition, 1987)
1. **Shoving / Corrugations**

Shoving is a permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic loading. When traffic pushes against the pavement, it produces a short, abrupt permanent deformation of wave-shape in the pavement surface. This distress normally occurs in unstable pavement or base. This type of deformation is not visible in bitumen penetration macadam roads.

*Possible causes:*

Inadequate quality of base material for prevailing climatic and traffic conditions.
Most common in dry season.

2. **Ruts and Depressions**

Ruts can occur in the wheel tracks of vehicles, depressions can occur in local areas. Depressions are localized pavement areas with elevations lower than these of the surrounding pavement. Depressions are created by settlement of foundation soil (base failure) or area result of improper construction.

*Possible causes:*

- Insufficient underground or pavement strength for the traffic being carried.
- Inadequate stability of the bituminous surfacing materials.
2.3.8 Edge Defects

These defects occur along the interface of a bituminous surface pavement and the shoulder, and are most significant where the shoulder is unsealed. For convenience they are considered to be a defect of the bituminous surfacing and not of the shoulder material. They may occur locally or may be continuous over a length of road. These defects frequently happen on one side of the roadway, or tire wear and attrition. The detrimental effects of edge defects include:

- Reduction of pavement width.
- Loss of quality of ride and possible loss of control of vehicle.
- Channeling of water at the edge of the pavement leading to erosion of shoulder.
- Water entry into base.

The principal defect types:

- Edge break
- Edge Drop-Off

Figure 2.8 – Edge Defects (A guide to the visual assessment of pavement Condition, 1987)
2.4 Causes of Road deterioration

Progressive general deterioration can be due to a number of causes, either in isolation or combination; some of them are:

- Traffic volume & axle loading
- Pavement age
- Environmental conditions
- Road geometry
- Drainage
- Construction quality
- Maintenance policy selected

Out of these causes of road deterioration, due to resource limitation, age, traffic, road geometry and drainage were focused.

2.4.1 Ageing and Weathering:

Bitumen and tar age from the moment that they are incorporated into a mix. This is caused by oxidation, which hardens the binder. In road mixes, as a rule of thumb, bitumen below a penetration of 20 is at the end of its life. Loss of binder efficiency and brittleness, prevent the material from containing the stresses imposed by traffic leading to the development of cracks. This process is most obvious in the wearing course where the surface receives most air and sunlight. The condition can be assessed during inspection by noting changes in the color of the bituminous binder, from the initial black to a light grey. Chipping will be more prominently exposed and many will have been plucked out. If handled pieces of the surfacing will probably disintegrate, and individual stones can be dislodged due to loss of adhesive properties in the binder. (Atkinson, 1990)
2.4.2 Environment

The climate of Sri Lanka, particularly in the wet zone, is generally humid and the average temperature varies from a high of about 30 - 35° C in the flat and rolling country varies a low of about 8 - 12° C in the hilly and mountainous areas. (Senanayake, 1994)

Sri Lanka receives rain from two monsoonal seasons and is heaviest in the central and south western areas, referred to as the Wet Zone, where the rainfall is generally in excess of 2000 mm per year, and in some places exceeds 4000 mm. The dry zone areas of North West and South East normally get rainfall in the order of 1000 mm or less per year. (Senanayake, 1994)
2.4.3 Deterioration caused by poor drainage

Localized pavement failures are often caused by the poor design or maintenance of side and cut-off drains and cross drainage structures. When side drains and culverts silt up, water ponds against the road embankment eventually weakening the lower pavement layers.

Conversely, if the water velocity in the side drain is too high it erodes the road embankment and shoulders. More general failures occur when there is no drainage within the pavement layers themselves. Paved roads do not remain water proof throughout their lives and if water is not able to drain quickly, it weakens the lower pavement layers and results in rapid road failure.

Figure 2.9 – Poor Drainage
2.4.4 Traffic:

Traffic Volume:

The deterioration of paved roads caused by traffic results from both magnitude of the individual wheel loads and the number of times these loads are applied. For pavement design purposes it is necessary to consider not only the total number of vehicles that will use the road but also the wheel roads (or, for convenience, the axle loads) of these vehicles. The loads imposed by private cars do not contribute significantly to the structural damage. For the purposes of structural design, cars and similar sized vehicles can be ignored and only the total number and the axle loading of the heavy vehicles that will use the road during its design life need to be considered. In this context, heavy vehicles are defined as those having an unladen weight of 3000 kg or more. In some circumstances, particularly for lightly trafficked roads, construction traffic can be a significant component of overall traffic loading and the designs should take this into account. (Road note 31, 1993)
2.5 Summary:

The paved highways in Sri Lanka are about 32,000 km and rests of the roads are gravel and earth roads. Different types of road deteriorating identified in paved roads like deformations, cracks, surface texture deficiencies, edge defects, potholes and their possible causes were identified as the most visible defects in bitumen penetration macadam roads.

Ageing and weathering, environment (temperature, moisture), drainage and traffic were identified as road deterioration causes. However due to resource limitation and limited time period, age, traffic load, drainage data were only considered in this study.
Chapter 03
3 Surface Condition Survey

3.1 Introduction

Though potholes, cracks, surface texture, aggregate polishing, rutting were considered for the survey, it was realized that only potholes and cracks play an important role in road deterioration in Sri Lankan context (See the Appendix B for the details). In order to determine the extent to which road deterioration factors affect for road defects specially potholes and cracks a surface condition survey was carried out. First the development of the surface condition survey form is discussed; this includes literature survey about survey form. Secondly, data collection by actual survey is presented. Thirdly, data analysis is described.

3.2 Surface Condition Survey Form

It is important to be aware of what other researchers' have used to collect surface condition information available (Surveys, Experimental research, Case studies etc.) and to understand how they work, analyzed and concluded their advantages and disadvantages. It would be useful to consider a number of forms such that it is most likely to meet the objectives of this research. (Refer Appendix A for format of survey form)

A literature survey was conducted to find out how others have tackled similar problems. Most researchers' idea was preparation of initial surface condition form can be done with extensive review of literature & general knowledge of the subject but with the aid of that it is necessary to conduct pilot survey for the preparation of final surface condition form.

The form developed for recording the surface condition data is shown in Appendix A. It is designed to be as flexible as possible since the nature of paved road deterioration varies depending on number of factors such as the type of construction, climate and traffic levels. There are however, a number of defects that tend to be common to all road pavements and these are described in Table 3.1.
A defect refers to the visible evidence of an undesirable condition in the pavement affecting serviceability, structural condition or appearance. Correct diagnosis of the cause of defects can only be made after careful inspection of the pavement by an observer on foot, as s/he can view the defects at various angles, heights and distance. Special care should be taken when inspecting in unfavorable conditions. Defects such as fine cracks and fine crazing are more difficult to see when road surfaces are wet although they often show up well as the road dries out, and when inspecting with strong sun behind.

The survey form used for field reporting was consistent with the intended method of processing (Computer).

Some observed defects were not fall into any particular defect type. This may be due to simplification of defect types on one hand and to the existence of multiple defects (eg. a combination of cracking…) on the other.

Indexes were selected to 1-3, as it is practicable to measure the extent of defects such as potholes, cracks. The extent of cracking is defined as in Table 3.2. The extent of cracking need to be recorded irrespective of intensity (severity). (Refer figure 3.1, 3.2 and 3.3). If two or three levels of severity exist within one distressed area, considered the entire area at the highest severity present.
Table 3.1 – Terms on the surface condition form

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Name</td>
<td>The accepted road name</td>
</tr>
<tr>
<td>Form No.</td>
<td>Numbers to run consecutively</td>
</tr>
<tr>
<td>Date</td>
<td>Day / month / year</td>
</tr>
<tr>
<td>Inspector</td>
<td>Name of Inspector</td>
</tr>
<tr>
<td>Surfacing</td>
<td>Type (Bitumen penetration macadam roads or other roads)</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Availability (Yes / No)</td>
</tr>
<tr>
<td>Chainage</td>
<td>0+000  . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .</td>
</tr>
<tr>
<td>Road width</td>
<td>The width should be measured &amp; recorded at the beginning of each form.</td>
</tr>
<tr>
<td>Crack type</td>
<td>Consider all together</td>
</tr>
<tr>
<td>Crack extent</td>
<td>Index 1 - 3 (Refer Table 3.2)</td>
</tr>
<tr>
<td>Crack position</td>
<td>Index 1 - 3 (Refer Table 3.3)</td>
</tr>
<tr>
<td>Crack width</td>
<td>Index 1 - 2 (Refer Table 3.4)</td>
</tr>
<tr>
<td>Surface Texture</td>
<td>Index 1 - 3 (Refer Table 3.5)</td>
</tr>
<tr>
<td>Aggregate polishing</td>
<td>Index 1 - 3 (Refer Table 3.6)</td>
</tr>
<tr>
<td>Potholes</td>
<td>Index 1 - 3 (Refer Table 3.7)</td>
</tr>
<tr>
<td>Drain</td>
<td>Index 1 - 6 (Refer Table 3.8)</td>
</tr>
</tbody>
</table>

Surface condition survey form need to be easy to use in the field when data is collected. It needs to support for fast, accurate and complete data collection. In view of that, the form needs to be simple but support to accommodate all the necessary information correctly. It needs to have general information about the inspected road including surface type, shoulder availability, etc. In addition to that crack extent, position, width needs to be clearly noted and in order to get an idea about their extent an index is given as in the chart as explained in 3.2.1.
Similarly, the data on rutting, potholes and drainage can be collected and their further details are given as an index as described in section 3.2.1 to 3.2.5.

3.2.1 Cracking

The assessment of cracking should fulfill two objectives. First, it should identify whether the road pavement is suffering from load or non-load associated distress. Secondly, it should establish whether the severity of cracking will affect the performance of road surface (Rolt et al, 1996).

These objectives are best achieved by identifying four characteristics of the cracking.

- Type
- Extent
- Position
- Width

**Severity of cracks:**

![Severity of cracks](image-url)

Figure 3.1 Low severity  Figure 3.2 Medium severity  Figure 3.3 High severity
**Extent of the defect (cracks):**

Table 3.2 - Extent of the defects (cracks)

<table>
<thead>
<tr>
<th>Area of block affected * 100</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of selected road section</td>
<td></td>
</tr>
<tr>
<td>&lt; 10%</td>
<td>1</td>
</tr>
<tr>
<td>10% - 50%</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 50%</td>
<td>3</td>
</tr>
</tbody>
</table>

**Position:**

The position of the cracking was recorded. The cracking can be confined to the verge side, road center and entire carriageway.

Table 3.3 - Crack Position

<table>
<thead>
<tr>
<th>Position</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verge side</td>
<td>1</td>
</tr>
<tr>
<td>Road center</td>
<td>2</td>
</tr>
<tr>
<td>Entire carriageway</td>
<td>3</td>
</tr>
</tbody>
</table>

**Width:**

The measurement of crack width is difficult, but it is important as it is important to find the extent of deterioration. Four categories of cracks were recommended as per the crack width (Paterson, 1987). They are;

1. - crack width < 1mm
2. - 1mm < crack width < 3mm
3. - crack width > 3mm
However, in this research study, due to practical reasons (difficult to observe small changes of crack widths once a month) crack widths were observed and categorized as small crack width and large crack widths.

Table 3.4 – Crack Width

<table>
<thead>
<tr>
<th>Width</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small crack width (upto 3mm crack width)</td>
<td>1</td>
</tr>
<tr>
<td>Large crack width (over 3mm crack width)</td>
<td>2</td>
</tr>
</tbody>
</table>

3.2.2 Surface texture

The ability of the bituminous surfacing to provide the required skid resistance is governed by its macro texture and micro texture. The macro texture of the surfacing, as measured by its texture depth, contributes particularly to wet skidding resistance at high speeds by providing drainage routes for water between the tire and the road surface. The categories were shown in Table 3.5 (CSRA, 1992).

Table 3.5 – Visual assessment of surface texture

<table>
<thead>
<tr>
<th>Texture</th>
<th>Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine (F)</td>
<td>1</td>
<td>The surfacing is smooth and the coarse aggregate (if present) in the surfacing is not visible, eg a sand seal, fine slurry seal.</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>2</td>
<td>The road has a smooth appearance and will generally comprise aggregate. If present, any coarse aggregate is visible but the surface does not appear coarse because of fine aggregate between the coarse particles, eg a new 6mm single surface dressing or 13/6mm double surface dressing.</td>
</tr>
<tr>
<td>Coarse (C)</td>
<td>3</td>
<td>The surfacing has a coarse appearance, with coarse aggregate clearly visible, eg a new 13mm surface dressing.</td>
</tr>
</tbody>
</table>
In this study, the surface texture was observed and realized that the surface texture would not change significantly during the research period. Hence the results were not analyzed.

### 3.2.3 Aggregate Polishing

The macro texture of the surfacing, as measured by the resistance to polishing of the aggregate, is the dominant factor in wet skidding resistance at lower speeds. (Department of Transport, 1994a). When marginal quality aggregate have been used or if increased traffic flows have resulted in an increased state of polish, skid resistance will be reduced. The quantitative assessment will depend on the judgment of the observer, and given in Table 3.6 (NITRR, 1985).

#### Table 3.6 – Visual assessment of aggregate polishing.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
<th>Description</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harsh (H)</td>
<td>&gt;75</td>
<td>Stones very harsh, edges sharp to touch.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>55 -75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angular (A)</td>
<td>45 -55</td>
<td>Stones sharp and angular but not harsh.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>35 -45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smooth (S)</td>
<td>&lt;35</td>
<td>Stones rounded and smooth to the touch.</td>
<td>3</td>
</tr>
</tbody>
</table>

1. Skid resistance value (SRV) measured by the portable skid resistance tester (RRL, 1969)
2. Harsh stones have surfaces that are rough to the touch.

Although, the aggregate polishing conditions were observed during the research (shown in figure 4, 5, 6), they were not analyzed since there was no significant change during the research period.
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Figure 3.4 Harsh surface

Figure 3.5 Angular surface

Figure 3.6 Smooth surface
3.2.4 Potholes

The gathered information of potholes were analyzed and presented in chapters 3 & 4.

Table 3.7. – Extent of potholes.

<table>
<thead>
<tr>
<th>Potholes (% length affected)</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10%</td>
<td>1</td>
</tr>
<tr>
<td>10% - 30%</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 30%</td>
<td>3</td>
</tr>
</tbody>
</table>

3.2.5 Drainage

Poor drainage causes water to pond on the road surface as well as on the shoulder. Drainage becomes a problem when ditches and culverts are not in good condition to direct and carry runoff water because of improper shape of maintenance.

Table 3.8. – Availability of drains.

<table>
<thead>
<tr>
<th>Drain</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left side</strong></td>
<td></td>
</tr>
<tr>
<td>• No</td>
<td>1</td>
</tr>
<tr>
<td>• Open</td>
<td>2</td>
</tr>
<tr>
<td>• Close</td>
<td>3</td>
</tr>
<tr>
<td><strong>Right side</strong></td>
<td></td>
</tr>
<tr>
<td>• No</td>
<td>4</td>
</tr>
<tr>
<td>• Open</td>
<td>5</td>
</tr>
<tr>
<td>• Close</td>
<td>6</td>
</tr>
</tbody>
</table>
3.2.6 Pilot Survey

A pilot survey helps to clarify the extent to which both qualitative and quantitative approaches could be used so that new form could emerge. The boundaries of the surface condition form were identified clearly after undertaking the pilot survey, and the research became more focused. It is extremely important to do pilot surveys, not only to ensure that the some inspections are ambiguous and answerable but also to check whether any aspect has been overlooked.

Initially for the pilot survey, five surveys were conducted with different participants. Explanations were carried out in two steps, so that the participants can easily fill the surface condition form. Two steps carried out are;

1. Road inspection system,
2. Data entering system

During this process their comments were obtained to clarify the points, whether any more items should be added, changed or deleted, whether it is understood by the respondent.
3.3 Data Collection

Data collection was done under four sub sections.

1. General Information,
2. Information about selected roads,
3. Other researchers' Information

3.3.1 Data collection - "General Information"

Data is collected by sampling, observing and interviewing road inspectors. Five metal and tar roads from Moratuwa area were selected for the data collection. Some roads had three observation sections and others had two sections depending on surface quality. Distresses were visually observed. In addition to the distressed areas the good surface sites (recently resealed) have also been evaluated. The assessment was continued for nine month with monthly observations.

First, selected roads were divided into 100m length sections. Some of the sections are identical to each other with their distress availability. Select one of the identical sections for monthly observations.
3.3.2 Data collection – Information about selected roads

Although no universal system exists to evaluate and assess a road pavement condition, the data collection evaluations need to include:

1. Traffic counts.
2. Construction and maintenance history.
3. Drainage structures data.

The data below was collected from Provincial Road Development Authority (PRDA) of Western province. Average daily traffic was obtained for the following roads by PRDA records.

Table 3.9. Roads details (Bitumen Penetration Macadam roads)

<table>
<thead>
<tr>
<th>Road name</th>
<th>Carriage Width</th>
<th>Average Daily Traffic</th>
<th>Last sand sealed year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dammadara road</td>
<td>5.00m</td>
<td>2940</td>
<td>1998 June</td>
</tr>
<tr>
<td>Maligawa road</td>
<td>4.87m</td>
<td>3442</td>
<td>2002 June</td>
</tr>
<tr>
<td>Willorawatta road</td>
<td>4.87m</td>
<td>4266</td>
<td>1998 June</td>
</tr>
<tr>
<td>St. Anthony road</td>
<td>4.87m</td>
<td>4408</td>
<td>2002 June</td>
</tr>
<tr>
<td>Piliyandala-Henamulla road</td>
<td>5.50m</td>
<td>4320</td>
<td>1999 June</td>
</tr>
</tbody>
</table>
3.4 Data Analysis and Results

The collected data should be analysed in order to find the significant road deterioration factors, the relationship of these factors with identified road defects. This is to be done using statistical analysis.

3.4.1 Cross tabulation and measures of Association: Cross tabs

Chi-squared Test for Association between Two Variables

A categorical variable is a variable, which has different levels. (Everitt, 1977). Chi-squared test will be used to assess the association between two categorical variables.

Table 3.10. Contingency table of factor A by factor B

<table>
<thead>
<tr>
<th>Variable A</th>
<th>Variable B</th>
<th>C1</th>
<th>C2</th>
<th>Cj</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>F11</td>
<td></td>
<td></td>
<td></td>
<td>R1.</td>
</tr>
<tr>
<td></td>
<td>F12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>F11</td>
<td></td>
<td></td>
<td></td>
<td>R1.</td>
</tr>
<tr>
<td></td>
<td>F12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>C1</td>
<td></td>
<td></td>
<td></td>
<td>C.1</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td></td>
<td></td>
<td></td>
<td>C.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>C.j</td>
</tr>
</tbody>
</table>

Observed frequencies for different levels of A and B are given in Table 3.10. Since there are I rows and J columns this is a I × J contingency table.
Hypothesis:

$H_0$: There is no association between factor A and factor B.
$H_1$: There is an association between factor A and factor B.

Expected frequency for cell with $i^{th}$ level of A and $j^{th}$ level of B is calculated as follows.

$$E_{ij} = \frac{(i^{th} \text{ row total} \times j^{th} \text{ column total})}{\text{Grand Total}} = \frac{(R_i \times C_j)}{N}$$

Test statistic for chi-squared test is defined as;

$$X^2 = \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

where $O_{ij}$ = Observed frequency of $ij$th cell and $E_{ij}$ = Expected frequency of $ij$th cell

For a $I \times J$ contingency table degrees of freedom,

$$df = (I-1) \times (J-1)$$

Rejection Criteria:

Test statistic $X^2$ is assumed to follow a chi-squared distribution on $p= (I-1) \times (J-1)$ degrees of freedom. If $X^2 > \chi^2_{a,p}$ $H_0$ is rejected at $\alpha\%$ significance level.

The conclusion for the test:

If $H_0$ is rejected, it can be concluded that factor A and factor B are associated at $\alpha\%$ significance level.
Limitations of Chi-squared Test

- Chi-squared test is valid when all the expected frequencies are greater than or equal to 5. When expected counts are less than 5, categories can be combined to apply the test.

- When degrees of freedom is 1 (i.e. for a 2 x 2 contingency table) Yate's correction should be made.

\[ i.e. \chi^2 = \sum (|O_{ij} - E_{ij}| - 1/2)^2 / E_{ij} \]

Tests: The Fisher's Exact Test

The Fisher's exact test also uses for testing independence in 2 x 2 or higher dimensional contingency tables. The test is based on the hyper geometric distribution. It is most useful when the total sample size and the expected values are small. SPSS calculates this test when the sample size in a 2 x 2 table is 20 or less, but for higher dimension, SAS must be used. (Freedman et. al. 1988)
3.4.2 Data analysis and Results – General Information

Most of the data was categorized before the analysis since they are qualitative measures. Chi-square test was carried out for the analysis to check the significances of the causes of road deterioration such as age, cumulative traffic, availability of drains, road width with some road defects such as potholes, crack width...etc.

3.4.3 Data analysis and Results – Information about Recode data

All data was recoded before analysis as follows.

3.4.3.1 Age (Observed Time Period):

Following data was categorized until it comes to a significant relationship with other considered road defects.

<table>
<thead>
<tr>
<th>Age (Months)</th>
<th>Recode age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>
3.4.3.2 Cumulative traffic after last sand sealing:

Recoding of the cumulative traffic was performed. Available traffic data was categorized in the following way until it comes to a significant relationship with other considered road defects.

Table 3.12 Recode data (Cumulative traffic after last sand sealing)

<table>
<thead>
<tr>
<th>Cum. traffic after last s/s</th>
<th>Recode cum. traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5,500,000</td>
<td>1</td>
</tr>
<tr>
<td>5,500,000 – 6,500,000</td>
<td>2</td>
</tr>
<tr>
<td>6,500,000 – 8,000,000</td>
<td>3</td>
</tr>
<tr>
<td>&gt;8,000,000</td>
<td>4</td>
</tr>
</tbody>
</table>

3.4.3.3 Drain:

Recode drain 1 indicates the observation where both side of the drains were not functioning properly whereas recode drain 2 indicates the road drains functioning one side correctly. Recode drain 3 represented the observations where both sides of the drains are functioning properly.

Table 3.13 Recode data (Drain)

<table>
<thead>
<tr>
<th>Drain</th>
<th>Recode drain</th>
</tr>
</thead>
<tbody>
<tr>
<td>L/No and R/No</td>
<td>1</td>
</tr>
<tr>
<td>L/No and R/C</td>
<td>2</td>
</tr>
<tr>
<td>L/C and R/No</td>
<td>3</td>
</tr>
<tr>
<td>L/C and R/C</td>
<td></td>
</tr>
<tr>
<td>L/No and R/O</td>
<td></td>
</tr>
<tr>
<td>L/O and R/No</td>
<td></td>
</tr>
<tr>
<td>L/O and R/C</td>
<td></td>
</tr>
<tr>
<td>L/C and R/O</td>
<td></td>
</tr>
<tr>
<td>L/O and R/O</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 3

Where;

L/No and R/No  ::= No drains in both left and right hand sides
L/No and R/C   ::= No drains in left hand side, closed drain in right hand side
L/C and R/No   ::= No drains in right hand side, closed drain in left hand side
L/C and R/C    ::= Closed drains in left and right hand sides
L/No and R/O   ::= No drains in left hand side, open drain in right hand side
L/O and R/No   ::= Open drains in left hand side, no drain in right hand side
L/O and R/C    ::= Open drains in left hand side, closed drain in right hand side
L/C and R/O    ::= Closed drains in left hand side, open drain in right hand side
L/O and R/O    ::= Open drains in both left and right hand sides
3.4.4 Data analysis and Results – Other Information

Data analysis was done to find the road deterioration causes which are significant and find the road deterioration factors for above significant causes and selected road defects.

1. To find the road deterioration causes which are significant, category analysis (See Appendix C) was carried out.

2. To find the road deterioration factors for above significant causes and selected road defects, regression analysis (See Appendix D) was carried out.

1) Category analysis:
Table 3.14 shows analysis and results of age with pothole propagation.

Table 3.15 - Results – Potholes Vs Age Cross tabulation

Pothole data and age were subjected to chi square test by using SPSS and SAS and obtained the following results.

Table 3.14 Age Vs Pothole (% of length affected)

<table>
<thead>
<tr>
<th>Recode age</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of length affected</td>
<td>22.2</td>
<td>33.3</td>
<td>44.4</td>
</tr>
</tbody>
</table>

Table 3.15 Pothole Vs Age cross tabulation

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>12.341</td>
<td>4</td>
<td>0.015 &lt; 0.05</td>
</tr>
</tbody>
</table>
Since the observed significance level in Table 3.15 is very small (Based on Potholes and Age) the hypothesis that potholes and age are independent is rejected. In other words it can be concluded that there is a relationship between age and potholes. As the pearson chi-square value is considerably larger and significance level is less than 0.05, there is an association between potholes and age.

![Total pothole % Vs Recode age](chart3.1.png)

Chart 3.1 Total pothole % Vs Recode age

The above graph shows the graphical representation of the occurrence of the potholes against the age.
Table 3.16 shows analysis and results of age with crack (% area affected).

Table 3.17 - Results – Crack (% area affected.) Vs Age

Cracks data and age were subjected to chi square test and obtained the following results.

Table 3.16 Age Vs Cracks (% of area affected)

<table>
<thead>
<tr>
<th>Recode age</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of area affected.</td>
<td>22.2</td>
<td>33.3</td>
<td>44.4</td>
</tr>
</tbody>
</table>

Table 3.17 Cracks Vs Age cross tabulation

<table>
<thead>
<tr>
<th>Value</th>
<th>df</th>
<th>Asymp. sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>30.438</td>
<td>4</td>
</tr>
</tbody>
</table>

Since the observed significance level in Table 3.17 is very small (Based on Potholes and Age) the hypothesis that potholes and age are independent is rejected. That means there is a relationship between age and cracks.

As the pearson chi-square value is considerably larger and significance of the value is less than 0.05, there is an association between cracks and age.
Chart 3.2. Cracks (% Area affected%) Vs Recode age

The above graph shows the graphical representation of the occurrence of the cracks against the age.
Table 3.18 shows analysis and results of collected survey data of recode cumulative traffic after last sand sealing with pothole propagation.

Table 3.19 - Results – Potholes Vs Cumulative traffic Cross tabulation

Potholes data and traffic data were subjected to chi square test.

Table 3.18 Cumulative traffic Vs Pothole (% of length affected)

<table>
<thead>
<tr>
<th>Recode cumulative traffic</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of length affected</td>
<td>9</td>
<td>27</td>
<td>30</td>
<td>42</td>
</tr>
</tbody>
</table>

Table 3.19 Pothole Vs Cumulative traffic cross tabulation

<table>
<thead>
<tr>
<th>Value</th>
<th>df</th>
<th>Asymp. sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>17.546</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

Since the observed significance level in Table 3.20 is very small (Based on Potholes and Cumulative traffic) the hypothesis that potholes and Cumulative traffic are independent is rejected. That means there is a relationship between traffic and potholes.

As the pearson chi-square value is considerably larger and significance of the value is less than 0.05, there is an association between traffic and potholes.
Chart 3.3. Total pothole% Vs Recode cumulative traffic

The above graph shows the graphical representation of the occurrence of the potholes against the traffic in bitumen penetration macadam roads.
Table 3.20 shows analysis and results of collected survey data of recode cumulative traffic with crack (Area of block affect.%).

Table 3.21 - Results – Crack (% Area affected.) Vs Traffic

Cracks data and traffic data were subjected to chi square test.

Table 3.20 Cumulative traffic Vs Cracks (% of area affected)

<table>
<thead>
<tr>
<th>Recode cumulative traffic</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% within area affected.</td>
<td>8.30</td>
<td>25.0</td>
<td>27.8</td>
<td>38.9</td>
</tr>
</tbody>
</table>

Table 3.21 Cracks Vs Cumulative traffic cross tabulation

<table>
<thead>
<tr>
<th>Value</th>
<th>df</th>
<th>Asymp. sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>19.797</td>
<td>6</td>
</tr>
</tbody>
</table>

Since the observed significance level in Table 3.21 is very small (Based on Cracks and cumulative traffic) the hypothesis that cracks and traffic are independent is rejected. That means there is a relationship between cracks and traffic.

As the pearson chi-square value is considerably larger and significance of the value is less than 0.05, there is an association between cracks and traffic.
Chart 3.4. Cracks (Area of block affected %) Vs Recode cumulative traffic

The above graph shows the graphical representation of the occurrence of the potholes against the traffic in metal and tar type roads.
3.5 Conclusion:

The chi-square test is a test of independence; it provides little information about the strength or form of the association between two variables. The magnitude of the observed chi-square depends not only on the goodness of fit of the independence model, but also the sample size.

When the probability is small enough (Usually less than 0.05 or 0.01), the hypothesis that the two variable are independent is rejected.

Hence, the analysis showed that there is a relationship between potholes against age as well as cumulative traffic after last sand sealing. Similarly, crack extent also has the same relationship with age as well as traffic.

Higher the age, higher the potholes as well as cracks. Similarly, the same results were obtained with potholes and cracks against traffic.
4 Development of Road Deterioration Factors

4.1 Introduction

Several reasons caused for propagation of cracks and formation of potholes such as traffic, age, road geometry, drains etc. With the available data for the causes of failure the statistical package, SPSS gives a error command indicating a wide range of data is required for the analysis.

Therefore for this analysis using this package was considered separately acts on the particular defect at a time. So, the causes age and traffic were considered to be act separately on the propagation of cracks and formation of potholes and hence the models were derived.

Since most of the data considered is qualitative measures the analysis was done by using ordinal regression methods.

4.2 The objectives and methodologies:

The main focus of this chapter is to develop road deterioration rates with respect to different contributory factors. In order to achieve the above object, the following methods were adopted.
4.2.1 Contingency tables with ordered categories

Logits for an ordinal response:

Ordinal regression method can be used to find out relationship between two variables which one or both variable is a categorical variable.

Suppose each response is categorized as being one of \( C_1, \ldots, C_k \) categories. A response in \( C_i \) is “Better” (With respect to the response variable being considered that one in \( C_j \) if \( i < j \)).

For an ordinal response variable one way of defining logits is in terms of the continuation ratio.

For a response in \( i \) categories, there are \((i-1)\) continuation ratios. For the situation considered;

\[
\begin{align*}
P_{ijk} &= \text{Probability of having } C_i \text{ for an observation with explanatory variable } j,k. \\
Q_{ijk} &= \text{Probability of having } C_i \text{ or better for an observation with explanatory variable } j,k. \\
R_{ijk} &= \frac{1 - \sum P_{l,j,k}}{1 - Q_{ijk}} \\
R_{ijk} &= \frac{P_{ijk}}{\sum P_{l,j,k}}
\end{align*}
\]

There are two types of models under this category.

1. Continuation ratio model.

   When one of the two variables is a continuous variable this model can be used. When fitting models between age with other categorized defects such as potholes, cracks this method can be used since age is a continuous variable.

2. Proportional odds model.
When two variables are categorized variables this model can be used to fit the models. Eg. Potholes with traffic (Both are categorical variables)

4.2.1.1 The continuation Ratio Model:

Using these continuation Ratios \((I - 1)\) different logistic models can be fitted. One for each \(R_{ij}\) model \(i\);

\[
\log_e (R_{ij}) = \alpha_i + \beta_{ij}^A
\]

Where,
\[
i = 1, 2, \ldots, (1 - 1)
\]
\[
j = 1, 2, \ldots, J
\]

Eg: When \(I=3\) and \(J=5\),

**Model 1:**

\[
\log_e (R_{1ij}) = \alpha_1 + \beta_1^A
\]

Compares \(C_1\) with \(C_2\) and \(C_3\)

**Model 2:**

\[
\log_e (R_{2ij}) = \alpha_2 + \beta_2^A
\]

Compares \(C_2\) with \(C_3\).

Where,

\[
R_{ijk} = \frac{P_{ijk}}{\sum P_{1ij,k}}
\]

\(P_{ijk}\) = Probability of the minor with category group \(j\) having category group \(i\).

\(\alpha_i\) = Overall mean of the \(i^{th}\) data set.

\(i= 1: C_1, C_2+C_3; \quad i=2: C_2,C_3\)

\(\beta_{ij}\) = Effect of the \(j^{th}\) level of the category the \(i^{th}\) data set. The effect of the category \(i\) can be separately assessed for the two sets of data.
4.2.1.2 The Proportional Odds Model:

I category response variable and two explanatory variable A and B having levels J and K respectively.

The Model;

\[ \log \left( \frac{P_{ijk}}{1 - Q_{ijk}} \right) = \alpha_i + \beta_j^A + \beta_k^B \]

Where;
- \( i = 1, 2, \ldots, I - 1 \)
- \( j = 1, 2, \ldots, J \)
- \( k = 1, 2, \ldots, K \)

Assume that the effect of the explanatory variable A and B on the odds of response below category I.

The log odds of response below category \( i \) for a person with level \( j, k \) for A and B respectively is equal to:

\[ \log \left( \frac{Q_{ijk}}{1 - Q_{ijk}} \right) = \alpha_i + \beta_j^A + \beta_k^B \]

The log odds of response below category \( i \) for a person with level \( j', k' \) for A and B respectively is equal to:

\[ \log \left( \frac{Q_{ij'k'}}{1 - Q_{ij'k'}} \right) = \alpha_i + \beta_j^{A'} + \beta_k^{B'} \]

The log odds ratio for response below category \( i \) for a level \( j \) and \( k \) to person with level \( j' \) and \( k' \) for A and B respectively is;
\[ \log \left\{ \frac{Q_{ijk} \left( 1 - Q_{ijk'} \right)}{Q_{ij'k'} \left( 1 - Q_{ijk} \right)} \right\} = (\beta_j^A - \beta_j^A) + (\beta_k^B - \beta_k^B) \]

This says the log of the odds ratio is a constant.
4.3 Development of deterioration factor, Pothole Vs age

In order to obtain this factor under ordinal regression method continuation ratio model was used. The statistical software which is called SPSS was mainly used.

Following two models were obtained from the analysis.

**Model 1:**

\[
\log \left( \frac{P_{ij}}{P_{2j} + P_{3j}} \right) = 0.303 + 0.2 \text{ (age)}
\]

\[
R_{ij} = \frac{P_{ij}}{P_{2j} + P_{3j}}
\]

Where;

\( P_{ij} = \) Probability of response i for an observation with explanatory variable j

i = pothole categories; 1,2,3

1 = Low potholes ( % of length affected < 10 % )

2 = Medium potholes ( % of length affected; 10% - 30% )

3 = High potholes ( % of length affected > 30% )

j = Age
Compares low potholes with medium and high potholes.

Table 4.1 Model 1: Compares low potholes with medium and high potholes.

<table>
<thead>
<tr>
<th>Age</th>
<th>Model 1</th>
<th>Ratio (R_{ij})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>\log \left( \frac{P_{11}}{P_{21} + P_{31}} \right) = 0.303 + 0.2 (1)</td>
<td>1.65</td>
</tr>
<tr>
<td>2</td>
<td>\log \left( \frac{P_{12}}{P_{22} + P_{32}} \right) = 0.303 + 0.2 (2)</td>
<td>2.02</td>
</tr>
<tr>
<td>3</td>
<td>\log \left( \frac{P_{13}}{P_{23} + P_{33}} \right) = 0.303 + 0.2 (3)</td>
<td>2.47</td>
</tr>
<tr>
<td>4</td>
<td>\log \left( \frac{P_{14}}{P_{24} + P_{34}} \right) = 0.303 + 0.2 (4)</td>
<td>3.01</td>
</tr>
<tr>
<td></td>
<td>( \log \left( \frac{P_{15}}{P_{25} + P_{35}} \right) = 0.303 + 0.2 (5) )</td>
<td>3.68</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6</td>
<td>( \log \left( \frac{P_{16}}{P_{26} + P_{36}} \right) = 0.303 + 0.2 (6) )</td>
<td>4.49</td>
</tr>
<tr>
<td>7</td>
<td>( \log \left( \frac{P_{17}}{P_{27} + P_{37}} \right) = 0.303 + 0.2 (7) )</td>
<td>5.49</td>
</tr>
<tr>
<td>8</td>
<td>( \log \left( \frac{P_{18}}{P_{28} + P_{38}} \right) = 0.303 + 0.2 (1) )</td>
<td>6.70</td>
</tr>
<tr>
<td>9</td>
<td>( \log \left( \frac{P_{19}}{P_{29} + P_{39}} \right) = 0.303 + 0.2 (9) )</td>
<td>8.19</td>
</tr>
</tbody>
</table>
$R_{ij} \text{ Vs Age}$

$y = 1.3529e^{0.2x}$

Chart 4.1 Pothole Vs Age (Model 1)

$P_{lj} / (P_{2j} + P_{3j})$ indicates the number of occurred low potholes per occurred both medium and large potholes per selected roads.

As per the graph, the above ratio increases in an exponential relationship of $1.3529e^{0.2\text{age}}$. It indicates the increase of value of $P_{lj}$ compared to $(P_{2j}+P_{3j})$. In other words, possibility of occurrence of low type of potholes is greater than that of medium and large potholes. This may be due to several reasons. In maintaining a road, it is a common practice in giving the priority to treat large potholes. Otherwise vehicles can’t move on roads freely.

Due to continuous maintenance surface treatment of the Sri Lankan roads, most of the large potholes and some of the medium potholes were treated periodically and hence it is practically difficult to find the exact time duration for the conversion of small potholes to the larger potholes. The period for conversion (from small to medium and
from medium to large) can be practically obtained by selecting some road sections without any maintenance and observing the surface for larger time period.
Model 2:

$$\log \left( \frac{P_{2j}}{P_{3j}} \right) = 1.965 + 0.2 \text{ (age)}$$

Compares medium potholes with high potholes.

Table 4.2 Model 2: Compares medium potholes with high potholes.

<table>
<thead>
<tr>
<th>Age</th>
<th>Model 1</th>
<th>Ratio (R_{ij})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$$\log \left( \frac{P_{21}}{P_{31}} \right) = 1.965 + 0.2 \text{ (1)}$$</td>
<td>8.71</td>
</tr>
<tr>
<td>2</td>
<td>$$\log \left( \frac{P_{22}}{P_{32}} \right) = 1.965 + 0.2 \text{ (2)}$$</td>
<td>10.64</td>
</tr>
<tr>
<td>3</td>
<td>$$\log \left( \frac{P_{23}}{P_{33}} \right) = 1.965 + 0.2 \text{ (3)}$$</td>
<td>13.00</td>
</tr>
<tr>
<td></td>
<td>Expression</td>
<td>Value</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>4</td>
<td>( \log \left( \frac{P_{24}}{P_{34}} \right) = 1.965 + 0.2 \times 4 )</td>
<td>15.88</td>
</tr>
<tr>
<td>5</td>
<td>( \log \left( \frac{P_{25}}{P_{35}} \right) = 1.965 + 0.2 \times 5 )</td>
<td>19.39</td>
</tr>
<tr>
<td>6</td>
<td>( \log \left( \frac{P_{26}}{P_{36}} \right) = 1.965 + 0.2 \times 6 )</td>
<td>23.69</td>
</tr>
<tr>
<td>7</td>
<td>( \log \left( \frac{P_{27}}{P_{37}} \right) = 1.965 + 0.2 \times 7 )</td>
<td>28.93</td>
</tr>
<tr>
<td>8</td>
<td>( \log \left( \frac{P_{28}}{P_{38}} \right) = 1.965 + 0.2 \times 8 )</td>
<td>35.33</td>
</tr>
<tr>
<td>9</td>
<td>( \log \left( \frac{P_{29}}{P_{39}} \right) = 1.965 + 0.2 \times 9 )</td>
<td>43.16</td>
</tr>
</tbody>
</table>
(P2j / P3j ) indicates the number of occurred medium potholes per one occurred large potholes per selected roads.

As per the graph, the above ratio increases in an exponential relationship of $7.1325e^{0.2\text{Age}}$. It indicates the increase of value of P2j compared to P3j. In other words, possibility of occurrence of medium type of potholes is greater than that of large potholes. This may be due to several reasons. In maintaining a road, it is a common practice in giving the priority to treat large potholes. However, in the same time small potholes may be converted to medium potholes resulting higher number of medium potholes.
Due to continuous maintenance surface treatment of the Sri Lankan roads, most of the large potholes and some of the medium potholes were treated periodically and hence it is practically difficult to find the exact time duration for the conversion of small potholes to the larger potholes. The period for conversion (from small to medium and from medium to large ) can be practically obtained by selecting some road sections without any maintenance and observing the surface for larger time period.
4.4 Development of deterioration factor, Crack extent Vs age

In order to obtain this factor under ordinal regression method continuation ratio model was used. The statistical software which is called SPSS was mainly used.

Following two models were obtained from the analysis.

Model 1:

\[
\log \left( \frac{C_{1j}}{C_{2j} + C_{3j}} \right) = 2.827 + 0.449 \text{ (age)}
\]

Compares crack extent 1 with crack extent 2 and crack extent 3.

Table 4.3 Model 1: Compares crack extent 1 with crack extent 2 and crack extent 3

<table>
<thead>
<tr>
<th>Age</th>
<th>Model 1</th>
<th>Ratio (R_{ij})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[ \log \left( \frac{C_{11}}{C_{21} + C_{31}} \right) = 2.827 + 0.449 \text{ (1)} ]</td>
<td>26.47</td>
</tr>
<tr>
<td>2</td>
<td>[ \log \left( \frac{C_{12}}{C_{22} + C_{32}} \right) = 2.827 + 0.449 \text{ (2)} ]</td>
<td>41.47</td>
</tr>
<tr>
<td>3</td>
<td>[ \log \left( \frac{C_{13}}{C_{23} + C_{33}} \right) = 2.827 + 0.449 \text{ (3)} ]</td>
<td>64.97</td>
</tr>
<tr>
<td>4</td>
<td>( \log \left( \frac{C_{14}}{C_{24} + C_{34}} \right) = 2.827 + 0.449 \times 10^1 )</td>
<td>101.79</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>( \log \left( \frac{C_{15}}{C_{25} + C_{35}} \right) = 2.827 + 0.449 \times 10^1 )</td>
<td>159.49</td>
</tr>
<tr>
<td>6</td>
<td>( \log \left( \frac{C_{16}}{C_{26} + C_{36}} \right) = 2.827 + 0.449 \times 10^1 )</td>
<td>249.88</td>
</tr>
<tr>
<td>7</td>
<td>( \log \left( \frac{C_{17}}{C_{27} + C_{37}} \right) = 2.827 + 0.449 \times 10^1 )</td>
<td>391.50</td>
</tr>
<tr>
<td>8</td>
<td>( \log \left( \frac{C_{18}}{C_{28} + C_{38}} \right) = 2.827 + 0.449 \times 10^1 )</td>
<td>613.38</td>
</tr>
<tr>
<td>9</td>
<td>( \log \left( \frac{C_{19}}{C_{29} + C_{39}} \right) = 2.827 + 0.449 \times 10^1 )</td>
<td>961.02</td>
</tr>
</tbody>
</table>
Chart 4.3 R_{ij} Vs Age (Model 1)

\{C_{1j} / (C_{2j} + C_{3j})\} indicates the number of occurred medium cracks (crack extent 2) per one occurred both medium and large cracks (crack extent 3) per selected roads.

As per the graph, the above ratio increases in an exponential relationship of $16.894e^{0.449\times \text{age}}$. It indicates the increase of value of $C_{1j}$ compared to $(C_{2j} + C_{3j})$. In other words, possibility of occurrence of low type of cracks (crack extent 1) is greater than that of medium and large cracks. This may be due to several reasons. In maintaining a road, it is a common practice in giving the priority to treat large cracks.

Due to continuous maintenance surface treatment of the Sri Lankan roads, most of the large cracks and some of the medium cracks were treated periodically and hence it is
practically difficult to find the exact time duration for the conversion of small cracks to the larger cracks. The period for conversion (from small to medium and from medium to large) can be practically obtained by selecting some road sections without any maintenance and observing the surface for larger time period.
Model 2:

\[ \log \left( \frac{C_{2j}}{C_{3j}} \right) = 5.623 + 0.449 \text{ (age)} \]

Compares crack extent 2 with crack extent 3.

Table 4.4 Model 2: Compares crack extent 2 with crack extent 3.

<table>
<thead>
<tr>
<th>Age</th>
<th>Model 1</th>
<th>Ratio (R_{ij})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>\log \left( \frac{C_{21}}{C_{31}} \right) = 5.623 + 0.449 (1)</td>
<td>433.55</td>
</tr>
<tr>
<td>2</td>
<td>\log \left( \frac{C_{22}}{C_{32}} \right) = 5.623 + 0.449 (2)</td>
<td>679.26</td>
</tr>
<tr>
<td>3</td>
<td>\log \left( \frac{C_{23}}{C_{33}} \right) = 5.623 + 0.449 (3)</td>
<td>1064.22</td>
</tr>
<tr>
<td></td>
<td>( \log \left( \frac{C_{24}}{C_{34}} \right) = 5.623 + 0.449 \times 4 )</td>
<td>1667.36</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>( \log \left( \frac{C_{25}}{C_{35}} \right) = 5.623 + 0.449 \times 5 )</td>
<td>2612.33</td>
</tr>
<tr>
<td>6</td>
<td>( \log \left( \frac{C_{26}}{C_{36}} \right) = 5.623 + 0.449 \times 6 )</td>
<td>4092.86</td>
</tr>
<tr>
<td>7</td>
<td>( \log \left( \frac{C_{27}}{C_{37}} \right) = 5.623 + 0.449 \times 7 )</td>
<td>6412.47</td>
</tr>
<tr>
<td>8</td>
<td>( \log \left( \frac{C_{28}}{C_{38}} \right) = 5.623 + 0.449 \times 8 )</td>
<td>10046.70</td>
</tr>
<tr>
<td>9</td>
<td>( \log \left( \frac{C_{29}}{C_{39}} \right) = 5.623 + 0.449 \times 9 )</td>
<td>15740.62</td>
</tr>
</tbody>
</table>
(C2j / C3j) indicates the occurred medium cracks (crack extent 2 (10% - 30%)) per one occurred high cracks (crack extent 3 (> 30%)) per selected roads.

As per the graph, the above ratio increases in an exponential relationship of $276.72e^{0.449\times\text{age}}$. It indicates the increase of value of C2j compared to C3j. In other words, possibility of occurrence of crack extent 2 is greater than that of crack extent 3.

This may be due to several reasons. In maintaining a road, it is a common practice in giving the priority to treat large cracks. However, in the same time small cracks may be converted to medium cracks (crack extent 2) results higher number of medium cracks.
Due to continuous maintenance surface treatment of the Sri Lankan roads, most of the large cracks and some of the medium cracks were treated periodically and hence it is practically difficult to find the exact time duration for the conversion of small cracks to the larger cracks. The period for conversion (from small to medium and from medium to large) can be practically obtained by selecting some road sections without any maintenance and observing the surface for larger time period.
4.5 Development of deterioration factors; Pothole Vs Traffic

The result indicates that the effect of the traffic of the roads of the grade of potholes is highly significant. In order to examine the form of association between traffic and severity of potholes the parameters estimates examined. SPSS gives the following parameter estimates.

Models 1 and 2:

Table 4.5, Models 1 and 2, Pothole Vs Traffic

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_1 ) (Pothole Extent =1)</td>
<td>-1.571</td>
<td></td>
</tr>
<tr>
<td>( X_2 ) (Pothole Extent =2)</td>
<td>0.209</td>
<td></td>
</tr>
<tr>
<td>(Traffic) (_1)</td>
<td>2.372</td>
<td>0.09</td>
</tr>
<tr>
<td>(Traffic) (_2)</td>
<td>-2.12</td>
<td>0.12</td>
</tr>
<tr>
<td>(Traffic) (_3)</td>
<td>-1.53</td>
<td>0.22</td>
</tr>
<tr>
<td>(Traffic) (_4)</td>
<td>0</td>
<td>Constant</td>
</tr>
</tbody>
</table>

As 0.09 is very much less than one this indicates that a more traffic makes the severity of potholes worse.

In order to obtain these factors under ordinal regression method proportional odds model was used. The statistical software which is called SPSS was mainly used. Following models were obtained from the analysis.
Models:

\[
\log \left\{ \frac{P_{11}}{1 - P_{11}} \right\} = -1.571 - 2.372 \quad (a)
\]

\[
\log \left\{ \frac{P_{12}}{1 - P_{12}} \right\} = -1.571 - 2.120 \quad (b)
\]

\[
\log \left\{ \frac{P_{13}}{1 - P_{13}} \right\} = -1.571 - 1.53 \quad (c)
\]

\[
\log \left\{ \frac{P_{14}}{1 - P_{14}} \right\} = -1.571 \quad (d)
\]

\[
\log \left\{ \frac{P_{21}}{1 - P_{21}} \right\} = 0.209 - 2.372 \quad (e)
\]

\[
\log \left\{ \frac{P_{22}}{1 - P_{22}} \right\} = 0.209 - 2.120 \quad (f)
\]

\[
\log \left\{ \frac{P_{23}}{1 - P_{23}} \right\} = 0.209 - 1.530 \quad (g)
\]

\[
\log \left\{ \frac{P_{24}}{1 - P_{24}} \right\} = 0.209 \quad (h)
\]
4.6 Development of deterioration factors; Crack extent Vs Traffic

The result indicates that the effect of the traffic of the roads of the grade of crack extent is highly significant. In order to examine the form of association between traffic and severity of crack extent the parameter estimates examined. SPSS gives the following parameter estimates.

**Model 1 and 2:**

Table 4.6 Model 1 and 2, Crack extent Vs Traffic

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1$ (Crack Extent =1)</td>
<td>$5.678 \times 10^{-2}$</td>
<td></td>
</tr>
<tr>
<td>$X_2$ (Crack Extent =2)</td>
<td>2.548</td>
<td></td>
</tr>
<tr>
<td>(Traffic)_1</td>
<td>-21.163</td>
<td>$6.44 \times 10^{-10}$</td>
</tr>
<tr>
<td>(Traffic)_2</td>
<td>-0.463</td>
<td>0.63</td>
</tr>
<tr>
<td>(Traffic)_3</td>
<td>-0.325</td>
<td>0.72</td>
</tr>
<tr>
<td>(Traffic)_4</td>
<td>0</td>
<td>Constant</td>
</tr>
</tbody>
</table>

As $6.44 \times 10^{-10}$ is very much less than one this indicates that a more traffic makes the severity of crack extent worse.

In order to obtain these factors under ordinal regression method proportional odds model was used. The statistical software which is called SPSS was mainly used. Following models were obtained from the analysis.
Models:

\[ \log \left( \frac{C_{11}}{1 - C_{11}} \right) = 5.678 \times 10^{-2} - 21.163 \quad (a) \]

\[ \log \left( \frac{C_{12}}{1 - C_{12}} \right) = 5.678 \times 10^{-2} - 0.463 \quad (b) \]

\[ \log \left( \frac{C_{13}}{1 - C_{13}} \right) = 5.678 \times 10^{-2} - 0.325 \quad (c) \]

\[ \log \left( \frac{C_{14}}{1 - C_{14}} \right) = 5.678 \times 10^{-2} \quad (d) \]

\[ \log \left( \frac{C_{21}}{1 - C_{21}} \right) = 2.548 - 21.163 \quad (e) \]

\[ \log \left( \frac{C_{22}}{1 - C_{22}} \right) = 2.548 - 0.463 \quad (f) \]

\[ \log \left( \frac{C_{23}}{1 - C_{23}} \right) = 2.548 - 0.325 \quad (g) \]

\[ \log \left( \frac{C_{24}}{1 - C_{24}} \right) = 2.548 \quad (h) \]
4.7 Conclusion

Possibility of extent of low potholes is greater than that of medium and high potholes with respect to the age (with observed time). Then, the extent of medium type of potholes and cracks is greater than that of large potholes and cracks with age.

Then, possibility of extent of low cracks (crack extent 1) is greater than that of medium and high cracks with age. The extent of medium cracks (crack extent 2) is greater than that of large cracks (crack extent 3) with age.

As 0.09 is very much less than 1 this indicates that more traffic makes the severity of potholes.

As $6.44 \times 10^{-10}$ is very much less than one this indicates that a more traffic makes the severity of crack extent worse.
Chapter 05
Chapter 5

5 Conclusion and Future work

5.1 Summary and Conclusions

The main objectives of this study were to identify the road deterioration factors, road defects and to determine the most important parameters that could be used to predict the rate of deterioration and develop relationship among them. The study was particularly concentrated on bitumen penetration macadam roads.

A comprehensive literature review was conducted with literature related to both local an international context to determine the road deterioration factors, road defects, rate of deterioration .....etc both locally and foreign countries. Moreover, the literature review was accompanied with the road condition surveys where sophisticated equipments were used in developed countries while manual data collection methods were used in developing countries like ours.

A surface condition survey was carried out to determine the extent to which the road deterioration factors such as potholes; cracks were contributed for road defects in particularly in metal and tar roads. An initial surface condition data form was designed to be as flexible as possible since the nature of paved road deterioration varies depending on the factors such as type of construction, climate and traffic level. It included the possible road defects with their type, extent and position. A pilot survey was conducted for the preparation of final surface condition form.

Initially for the pilot survey, five surveys were conducted with four different participants. Explanations were carried out in both road inspection system and data entering system, so that the participants can easily fill to the surface condition form. This process was used to clarify the points, whether any more things should be added or deleted, whether it is understood by the respondent. All in all, pilot test survey was extremely important not only to ensure that the same inspections are ambiguous and unanswerable but also to check that nothing has been overlooked.

Five bitumen penetration macadam roads in Moratuwa area were used to collect the data. Data was collected by sampling, observing and interviewing road inspectors.
Distresses were observed visually. In addition to the distressed areas the excellent surface sites (recently resealed) have also been evaluated. The assessing was done by once a month for nine months. Moreover, all pavement structure data, traffic counts, construction and maintenance history data and drainage structure data were accompanied with the observations, through Provincial Road Development Authority (PRDA), Western province.

Data analysis was undertaken using statistical analysis softwares called SPSS and SAS.

In data analysis of general information, most of the data was grouped before the analysis. Chi-square test was carried out for the analysis to check the significance of the road deterioration agents such as cumulative traffic, availability of drains, road width with some road defects such as potholes, crack width with the statistical softwares like SPSS and SAS.

Road defects such as potholes and cracks are significant with deterioration factors such as age, traffic.

Relationship of $Y=1.3529 \cdot e^{0.2age}$ was achieved when compare low potholes with medium and high potholes against time.

Relationship of $Y=7.1325 \cdot e^{0.2age}$ was achieved when compare medium potholes with high potholes against age.

Relationship of $Y=16.894 \cdot e^{0.449age}$ with was achieved when compare crack extent 1 with crack extent 2 and 3 against time.

Once crack extent 2 was compared with crack extent 3 against time, a relationship of $Y=276.72e^{0.449age}$ was achieved.
5.2 Future work

Due to constraints of time, this study could not cover certain aspects adequately. The following could be recommended for future work.

1. The data collection should be done for few years continuously. So that results would be much more reliable. On top of this, this result then can be used for time series analysis which would finally useful in computing costs using software called Sri Lanka Pavement Management System (SLPMS). This will immensely helpful to the local authorities to take decision pricing, budgetary planning etc.

2. This study can be further extended to study about different road surfacing. This may be quite useful in deciding the maintenance strategies of future highways in Sri Lanka.

3. Due to continuous maintenance surface treatment of the Sri Lankan roads, most of the large potholes, cracks and some of the medium potholes, cracks were treated periodically and hence it is practically difficult to find the exact time duration for the conversion of small potholes or cracks to the larger potholes or cracks. The period for conversion (from small to medium and from medium to large) can be practically obtained by selecting some road sections without any maintenance and observing the surface for larger time period.
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## Appendix A – Form of road surface condition

<table>
<thead>
<tr>
<th>Road Name</th>
<th>Form #</th>
<th>Date</th>
<th>Inspector</th>
<th>Shoulder</th>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td>Surfacing</td>
<td>Blumen Penetration Macadam roads or other</td>
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<td>Traffic count</td>
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<td>Medium</td>
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<td>Entire Carriageway</td>
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<td>No Crack width</td>
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<td>Fine</td>
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Page 82
Appendix B
### Appendix B – Collected data from selected roads

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<th>Extent</th>
<th>Position</th>
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<th>Agg.polis</th>
<th>Rutting</th>
<th>Potholes</th>
<th>Drain(L)</th>
<th>Drain(R)</th>
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| D1s,5m | 2940 | 5644800     | 5 5 100     | 2 4 2 2 1 1 2 5
| D1s,6m | 2940 | 5733000     | 6 5 100     | 2 4 2 2 1 1 2 5
| D1s,7m | 2940 | 5821200     | 7 5 100     | 3 2 2 2 1 1 2 5
| D1s,8m | 2940 | 5909400     | 8 5 100     | 3 2 2 2 1 1 2 5
| D1s,9m | 2940 | 5997600     | 9 5 100     | 3 2 2 2 1 1 2 5
| D2s,1m | 2940 | 5292000     | 1 5 100     | 1 1     | 2 2 1 | 1 2 5   |
| D2s,2m | 2940 | 5380200     | 2 5 100     | 1 1     | 2 2 1 | 1 2 5   |
| D2s,3m | 2940 | 5468400     | 3 5 100     | 1 1     | 2 2 1 | 1 2 5   |
| D2s,4m | 2940 | 5556600     | 4 5 100     | 1 1     | 2 2 1 | 3 2 5   |
| D2s,5m | 2940 | 5644800     | 5 5 100     | 1 1     | 2 2 1 | 3 2 5   |
| D2s,6m | 2940 | 5733000     | 6 5 100     | 1 1     | 2 2 1 | 3 2 5   |
| D2s,7m | 2940 | 5821200     | 7 5 100     | 1 1     | 2 2 1 | 3 2 5   |
| D2s,8m | 2940 | 5909400     | 8 5 100     | 1 1     | 2 2 1 | 3 2 5   |
| D2s,9m | 2940 | 5997600     | 9 5 100     | 1 1     | 2 2 1 | 3 2 5   |
| D3s,1m | 2940 | 5292000     | 1 5 100     | 1 1 1 2 1 1 | 2 5
| D3s,2m | 2940 | 5380200     | 2 5 100     | 1 1 1 2 1 1 | 2 5
| D3s,3m | 2940 | 5468400     | 3 5 100     | 1 1 1 2 1 1 | 2 5
| D3s,4m | 2940 | 5556600     | 4 5 100     | 1 1 1 2 1 1 | 2 5
| D3s,5m | 2940 | 5644800     | 5 5 100     | 1 1 1 2 1 1 | 2 5
| D3s,6m | 2940 | 5733000     | 6 5 100     | 1 1 1 2 1 1 | 2 5
| D3s,7m | 2940 | 5821200     | 7 5 100     | 1 1 1 2 1 1 | 2 5
| D3s,8m | 2940 | 5909400     | 8 5 100     | 1 1 1 2 1 1 | 2 5
| D3s,9m | 2940 | 5997600     | 9 5 100     | 1 1 1 2 1 1 | 2 5
| M1s,1m | 3442 | 6195600     | 1 5 100     | 1 1 1 2 2 1 2 | 3 4
| M1s,2m | 3442 | 6298860     | 2 5 100     | 1 1 1 2 2 1 2 | 3 4
| M1s,3m | 3442 | 6402120     | 3 5 100     | 1 1 1 2 2 1 2 | 3 4
| M1s,4m | 3442 | 6505380     | 4 5 100     | 1 1 1 2 2 1 3 | 3 5
<p>| M1s,5m | 3442 | 6608640 | 5 5 | 100 2.4 2 2 1 3 3 5 |
| M1s,6m | 3442 | 6711900 | 6 5 | 100 2.4 2 2 1 3 3 5 |
| M1s,7m | 3442 | 6815160 | 7 5 | 100 2.4 2 2 1 1 3 5 |
| M1s,8m | 3442 | 6918420 | 8 5 | 100 2.4 2 2 1 1 3 5 |
| M1s,9m | 3442 | 7021680 | 9 5 | 100 2.4 2 2 1 1 3 5 |
| M2s,1m | 3442 | 6195600 | 1 5 | 100 2.4 2 2 1 2 3 6 |
| M2s,2m | 3442 | 6298860 | 2 5 | 100 2.4 2 2 1 3.3 6 |
| M2s,3m | 3442 | 6402120 | 3 5 | 100 2.3 2 2 1 3 3 5 |
| M2s,4m | 3442 | 6505380 | 4 5 | 100 2.3 2 2 2 3 5 |
| M2s,5m | 3442 | 6608640 | 5 5 | 100 2.3 2 2 2 3 5 |
| M2s,6m | 3442 | 6711900 | 6 5 | 100 1 1 2 2 1 1 3 5 |
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| W1s,1m | 4266 | 7678800 | 1 5 | 100 1 1 2 2 1 1 3 4 |
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| W1s,3m | 4266 | 7934760 | 3 5 | 100 1 1 2 2 1 2 3 4 |
| W1s,4m | 4266 | 8062740 | 4 5 | 100 1 1 2 2 1 2 3 4 |
| W1s,5m | 4266 | 8190720 | 5 5 | 100 1 1 2 2 1 3 3 4 |
| W1s,6m | 4266 | 8318700 | 6 5 | 100 1 1 2 2 1 3 3 4 |
| W1s,7m | 4266 | 8446680 | 7 5 | 100 1 1 2 2 1 3 3 4 |
| W1s,8m | 4266 | 8574660 | 8 5 | 100 1 1 2 2 1 3 3 4 |
| W1s,9m | 4266 | 8702640 | 9 5 | 100 1 1 2 2 1 3 3 4 |
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| W2s,3m | 4266 | 7934760 | 3 5 | 100 1 1 2 2 1 1 1 6 |
| W2s,4m | 4266 | 8062740 | 4 5 | 100 1 1 2 2 1 2 1 6 |
| W2s,5m | 4266 | 8190720 | 5 5 | 100 1 1 2 2 1 2 1 6 |
| W2s,6m | 4266 | 8318700 | 6 5 | 100 1 1 2 2 1 2 1 6 |
| W2s,7m | 4266 | 8446680 | 7 5 | 100 1 1 2 2 1 2 1 6 |</p>
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Appendix C
C. Presentation of Survey Data

Recode Age* Pothole Cross tabulation

Case Processing Summary

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Age * Potholes Cross tabulation

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<td>100.0%</td>
</tr>
<tr>
<td>% within Reage</td>
<td>34.3%</td>
<td>37.0%</td>
<td>28.7%</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>% within Potholes</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td></td>
</tr>
</tbody>
</table>
### Chi-Square Tests

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>12.341</td>
<td>4</td>
<td>.015</td>
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<tr>
<td>Likelihood Ratio</td>
<td>15.001</td>
<td>4</td>
<td>.005</td>
</tr>
<tr>
<td>Linear-by-Linear Association</td>
<td>8.866</td>
<td>1</td>
<td>.003</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>108</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.89.
**Appendix C**

**Age * Area of block affected (Cracks): Cross tabulation**

**Area of block affected (%) * Age Cross tabulation**

<table>
<thead>
<tr>
<th>Area of block affected (%)</th>
<th>REAGE</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>&lt;10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td>% within Area of block affected (%)</td>
<td>33.8%</td>
<td>41.5%</td>
</tr>
<tr>
<td>% within REAGE</td>
<td>91.7%</td>
<td>75.0%</td>
</tr>
<tr>
<td>10-50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>% within Area of block affected (%)</td>
<td>5.4%</td>
<td>16.2%</td>
</tr>
<tr>
<td>% within REAGE</td>
<td>8.3%</td>
<td>16.7%</td>
</tr>
<tr>
<td>&gt;50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>% within Area of block affected (%)</td>
<td></td>
<td>50.0%</td>
</tr>
<tr>
<td>% within REAGE</td>
<td>8.3%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Count, Total</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>% within Area of block affected (%)</td>
<td>22.2%</td>
<td>33.3%</td>
</tr>
<tr>
<td>% within REAGE</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**Case Processing Summary**

<table>
<thead>
<tr>
<th>Cases</th>
<th>Valid</th>
<th>Missing</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Percent</td>
<td>N</td>
<td>Percent</td>
</tr>
<tr>
<td>Area of block affected (%) * REAGE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>92.3%</td>
<td>9</td>
<td>7.7%</td>
</tr>
</tbody>
</table>
### Chi-Square Tests

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>30.438a</td>
<td>4</td>
<td>.000</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>33.230</td>
<td>4</td>
<td>.000</td>
</tr>
<tr>
<td>Linear-by-Linear</td>
<td>20.240</td>
<td>1</td>
<td>.000</td>
</tr>
<tr>
<td>Association</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>108</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*3 cells (33.3%) have expected count less than 5. The minimum expected count is 1.33.*

### Symmetric Measures

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Asymp. Std. Error</th>
<th>Approx. T</th>
<th>Approx. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval by Interval</td>
<td>Pearson's R</td>
<td>.435</td>
<td>.072</td>
<td>4.973</td>
</tr>
<tr>
<td>Ordinal by Ordinal</td>
<td>Spearman Correlation</td>
<td>.480</td>
<td>.075</td>
<td>5.631</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>108</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Not assuming the null hypothesis.
*Using the asymptotic standard error assuming the null hypothesis.
*Based on normal approximation.

data fishers;
input x y count;
cards;
1 1 22
1 2 27
1 3 16
2 1 2
2 2 6
```sas
proc freq;
weight count;
tables x*y/chisq exact;
run;
```

The SAS System 12:30 Saturday, April 4, 1998

TABLE OF X BY Y

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Frequency,</th>
<th>Percent ,</th>
<th>Row Pct ,</th>
<th>Col Pct ,</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1, 22, 27, 16, 65</td>
<td></td>
<td>20.37, 25.00, 14.81, 60.19</td>
<td>0.00, 75.00, 33.33,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2, 2, 6, 29, 37</td>
<td></td>
<td>1.85, 5.56, 26.85, 34.26</td>
<td>0.00, 16.67, 60.42,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3, 0, 3, 3, 6</td>
<td></td>
<td>0.00, 2.78, 2.78, 5.56</td>
<td>0.00, 8.33, 6.25,</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>36</td>
<td>48</td>
<td>108</td>
<td>22.22, 33.33, 44.44, 100.00</td>
</tr>
</tbody>
</table>

Page 90
### STATISTICS FOR TABLE OF X BY Y

<table>
<thead>
<tr>
<th>Statistic</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-Square</td>
<td>4</td>
<td>30.438</td>
<td>0.001</td>
</tr>
<tr>
<td>Likelihood Ratio Chi-Square</td>
<td>4</td>
<td>33.230</td>
<td>0.001</td>
</tr>
<tr>
<td>Mantel-Haenszel Chi-Square</td>
<td>1</td>
<td>20.240</td>
<td>0.001</td>
</tr>
<tr>
<td>Fisher's Exact Test (2-Tail)</td>
<td></td>
<td>8.35E-07</td>
<td></td>
</tr>
<tr>
<td>Phi Coefficient</td>
<td></td>
<td>0.531</td>
<td></td>
</tr>
<tr>
<td>Contingency Coefficient</td>
<td></td>
<td>0.469</td>
<td></td>
</tr>
<tr>
<td>Cramer's V</td>
<td></td>
<td>0.375</td>
<td></td>
</tr>
</tbody>
</table>

Sample Size = 108
## Cumulative Traffic * Potholes Cross tabulation

### Case Processing Summary

<table>
<thead>
<tr>
<th>Cases</th>
<th>N</th>
<th>Percent</th>
<th>N</th>
<th>Percent</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potholes * RECUM.TR</td>
<td>108</td>
<td>92.3%</td>
<td>9</td>
<td>7.7%</td>
<td>117</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

### Potholes * Cumulative traffic Cross tabulation

<table>
<thead>
<tr>
<th>Potholes Low</th>
<th>Count</th>
<th>RECUM TR</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>% within Potholes</td>
<td>16.2%</td>
<td>27.0%</td>
<td>40.5%</td>
</tr>
<tr>
<td>% within RECUM.TR</td>
<td>66.7%</td>
<td>37.0%</td>
<td>50.0%</td>
</tr>
<tr>
<td>Medium</td>
<td>Count</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>% within Potholes</td>
<td>7.5%</td>
<td>22.5%</td>
<td>25.0%</td>
</tr>
<tr>
<td>% within RECUM.TR</td>
<td>33.3%</td>
<td>33.3%</td>
<td>33.3%</td>
</tr>
<tr>
<td>High</td>
<td>Count</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>% within Potholes</td>
<td>25.8%</td>
<td>16.1%</td>
<td>58.1%</td>
</tr>
<tr>
<td>% within RECUM.TR</td>
<td>29.6%</td>
<td>16.7%</td>
<td>42.9%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total</th>
<th>Count</th>
<th>RECUM TR</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>% within Potholes</td>
<td>8.3%</td>
<td>25.0%</td>
<td>27.8%</td>
</tr>
<tr>
<td>% within RECUM.TR</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
### Chi-Square Tests

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>17.546a</td>
<td>6</td>
<td>.007</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>20.515</td>
<td>6</td>
<td>.002</td>
</tr>
<tr>
<td>Linear-by-Linear Association</td>
<td>10.058</td>
<td>1</td>
<td>.002</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>108</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. 3 cells (25.0%) have expected count less than 5. The minimum expected count is 2.58.

### Symmetric Measures

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Asymp. Std. Error²</th>
<th>Approx. Tᵇ</th>
<th>Approx. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval by Interval Pearson's R</td>
<td>.307</td>
<td>.083</td>
<td>3.316</td>
<td>.001c</td>
</tr>
<tr>
<td>Ordinal by Ordinal Spearman Correlation</td>
<td>.312</td>
<td>.087</td>
<td>3.379</td>
<td>.001c</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>108</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.
c. Based on normal approximation.

data fisher;
input x y fre;
cards;
1 1 6
1 2 10
1 3 15
The SAS System 17:23 Tuesday, March 31, 1998

TABLE OF X BY Y

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Frequency,</th>
<th>Percent,</th>
<th>Row Pct,</th>
<th>Col Pct,</th>
<th>1,</th>
<th>2,</th>
<th>3,</th>
<th>4,</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>10, 15, 6</td>
<td>37</td>
<td>5.56, 9.26, 13.89, 5.56, 34.26</td>
<td>16.22, 27.03, 40.54, 16.22,</td>
<td>66.67, 37.04, 50.00, 14.29,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>9, 10, 18, 40</td>
<td>2.78, 8.33, 9.26, 16.67, 37.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>DF</td>
<td>Value</td>
<td>Prob</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-----</td>
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<td></td>
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</tr>
<tr>
<td>Chi-Square</td>
<td>6</td>
<td>17.546</td>
<td>0.007</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood Ratio Chi-Square</td>
<td>6</td>
<td>20.515</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mantel-Haenszel Chi-Square</td>
<td>1</td>
<td>10.058</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fisher's Exact Test (2-Tail)</td>
<td></td>
<td>4.57E-03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phi Coefficient</td>
<td></td>
<td>0.403</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contingency Coefficient</td>
<td></td>
<td>0.374</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cramer's V</td>
<td></td>
<td>0.285</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sample Size = 108
Recode cumulative traffic * Area of block affected Cross tabulation

Case Processing Summary

<table>
<thead>
<tr>
<th>Area of block affected (%) * RECUM.TR</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valid</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Area of block affected (%)</td>
<td>108</td>
</tr>
</tbody>
</table>

Area of block affected (%) * RECUM.TR Crosstabulation

<table>
<thead>
<tr>
<th>Area of block affected (%)</th>
<th>&lt;10%</th>
<th>10-50</th>
<th>&gt;50%</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% within Area of block affected (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% within RECUM.TR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-50 Count</td>
<td>9</td>
<td>18</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>% within Area of block affected (%)</td>
<td>13.8%</td>
<td>27.7%</td>
<td>27.7%</td>
<td>30.8%</td>
</tr>
<tr>
<td>% within RECUM.TR</td>
<td>100.0%</td>
<td>66.7%</td>
<td>60.0%</td>
<td>47.6%</td>
</tr>
<tr>
<td>&gt;50% Count</td>
<td>5</td>
<td>10</td>
<td>22</td>
<td>37</td>
</tr>
<tr>
<td>% within Area of block affected (%)</td>
<td>13.5%</td>
<td>27.0%</td>
<td>59.5%</td>
<td>100.0%</td>
</tr>
<tr>
<td>% within RECUM.TR</td>
<td>18.5%</td>
<td>33.3%</td>
<td>52.4%</td>
<td>34.3%</td>
</tr>
<tr>
<td>Total Count</td>
<td>9</td>
<td>27</td>
<td>30</td>
<td>42</td>
</tr>
<tr>
<td>% within Area of block affected (%)</td>
<td>8.3%</td>
<td>25.0%</td>
<td>27.8%</td>
<td>38.9%</td>
</tr>
<tr>
<td>% within RECUM.TR</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
Chi-Square Tests

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>19.797</td>
<td>6</td>
<td>.003</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>23.901</td>
<td>6</td>
<td>.001</td>
</tr>
<tr>
<td>Linear-by-Linear Association</td>
<td>2.824</td>
<td>1</td>
<td>.093</td>
</tr>
</tbody>
</table>

N of Valid Cases 108

a. 5 cells (41.7%) have expected count less than 5. The minimum expected count is .50.

Symmetric Measures

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Asymp. Std. Error</th>
<th>Approx. rpb</th>
<th>Approx. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval by Interval Pearson's R</td>
<td>.162</td>
<td>.091</td>
<td>1.695</td>
<td>.093</td>
</tr>
<tr>
<td>Ordinal by Ordinal Spearman Correlation</td>
<td>.208</td>
<td>.093</td>
<td>2.192</td>
<td>.031</td>
</tr>
</tbody>
</table>

N of Valid Cases 108

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.
c. Based on normal approximation.

data fisher2;
input x y fre;
cards;
1 1 9
1 2 18
1 3 18
1 4 20
2 1 0

Page 97
proc freq;
weight fre;
tables x*y/chisq exact;
run;

The SAS System 17:23 Tuesday, March 31, 1998 2

**TABLE OF X BY Y**

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Frequency,</th>
<th>Percent,</th>
<th>Row Percent,</th>
<th>Col Percent,</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>18, 18, 20</td>
<td>65</td>
<td>8.33, 16.67, 16.67, 18.52, 60.19</td>
<td>13.85, 27.69, 27.69, 30.77,</td>
<td>100.00, 66.67, 60.00</td>
</tr>
<tr>
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<td>0.00, 66.67, 33.33, 0.00</td>
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Page 98
STATISTICS FOR TABLE OF X BY Y

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Sample Size = 108
Appendix D
1 GENERAL INFORMATION

Pothole & age - Ordinal Regression

Case Processing Summary

<table>
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<tr>
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<td>Potholes</td>
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<tr>
<td>Low</td>
<td>37</td>
<td>34.3%</td>
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<tr>
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Model Fitting Information

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<th>Sig.</th>
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Link function: Logit.

Goodness-of-Fit

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Link function: Logit.
### Pseudo R-Square

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<td>McFadden</td>
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Link function: Logit.

### Parameter Estimates

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Crack width & Age - Ordinal Regression

Case Processing Summary

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<td>No cracks</td>
<td>61</td>
<td>56.5%</td>
</tr>
<tr>
<td>small c.w.</td>
<td>4</td>
<td>3.7%</td>
</tr>
<tr>
<td>large c.w.</td>
<td>40</td>
<td>37.0%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.8%</td>
</tr>
<tr>
<td>Valid</td>
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<td>100.0%</td>
</tr>
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<td>Missing</td>
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<td>Total</td>
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Model Fitting Information

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Link function: Logit.

Goodness-of-Fit

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Link function: Logit.
Appendix D

### Pseudo R-Square

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</thead>
<tbody>
<tr>
<td>Cox and Snell</td>
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<tr>
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<td>McFadden</td>
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Link function: Logit.

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<tr>
<td></td>
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<td></td>
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<td>Lower Bound</td>
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<tr>
<td>Threshold</td>
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Page 103
Pothole & Traffic - Ordinal Regression

Case Processing Summary

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<tr>
<td>Low</td>
<td>37</td>
<td>34.3%</td>
</tr>
<tr>
<td>Medium</td>
<td>40</td>
<td>37.0%</td>
</tr>
<tr>
<td>High</td>
<td>31</td>
<td>28.7%</td>
</tr>
<tr>
<td>RECUM.TR</td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>9</td>
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<tr>
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<tr>
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Model Fitting Information

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Link function: Logit.

Goodness-of-Fit

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<th></th>
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Link function: Logit.
### Appendix D

**Pseudo R-Square**

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<tr>
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Link function: Logit.

**Parameter Estimates**

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<tr>
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<tr>
<td></td>
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<td>Lower Bound</td>
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Link function: Logit.

a. This parameter is set to zero because it is redundant.
Crack width & Traffic - Ordinal Regression

Case Processing Summary

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<th>N</th>
<th>Marginal Percentage</th>
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<tbody>
<tr>
<td>Crack width</td>
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<tr>
<td>No cracks</td>
<td>61</td>
<td>56.5%</td>
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<tr>
<td>less c.w.</td>
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<td>3.7%</td>
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<tr>
<td>more c.w.</td>
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Model Fitting Information

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Link function: Logit.

Goodness-of-Fit

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<td>Deviance</td>
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Link function: Logit.
Pseudo R-Square

<table>
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<th>McFadden</th>
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Link function: Logit.

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<td></td>
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<td>Lower Bound</td>
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<tr>
<td>Threshold</td>
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Link function: Logit.

a. This parameter is set to zero because it is redundant.