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Decision support system for the remediation of flexible road pavements in local government

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Decision Support System for the Remediation of Flexible Road Pavements in Local Government

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THESIS CERTIFICATION

CERTIFICATION

I, Matthew Mendes Apolo, declare that this thesis, submitted in partial fulfilment of the requirements for the award of Masters of Engineering (Research), in the Department of Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Matthew M. Apolo

12 May 2015

ABSTRACT

This thesis investigates the development of a decision support system for the remediation of road infrastructure in local government, specifically flexible pavements. Augmenting theoretical knowledge with the heuristics and procedural knowledge of experienced road asset managers and road engineers, the software program “PaveMaint SELECT” was created to assist local government organisations in the maintenance and management planning of their road networks.

An extensive literature review was undertaken on the characteristics, performance and the deterioration modes of flexible pavements along with suitable remediation practices necessary to prolong the life of those pavements. A further review was undertaken on decision making practices in road asset management and maintenance, including a review of data collection and quality evaluation processes both in literature and through that of an initial case study of a New South Wales local government organisation.

The “PaveMaint SELECT” program was then tested in a series of field interviews and case studies from experienced local government road asset managers and road engineers. Through validation and refinement stemming from system testing, the final “PaveMaint SELECT” program is able to effectively provide recommendations that replicate real-world decisions made by experienced local government road practitioners.

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1 INTRODUCTION

1.1 The Problem with Road Pavements

Road pavements represent a significant proportion of the asset pool managed by local government organisations in Australia. Local government road networks primarily consist of flexible pavements, while small proportions of rigid and segmental block pavements are also found in some road networks (Shackel and Pearson 1991; BTE 2001; Austroads 2009).

In 1991 Local Government Authorities (LGAs) in Australia spent in the order of $1.5 billion yearly on roads (Mulholland and Metcalf 1991). Between 1997-98 local government road spending totalled $2.7 billion (BTE 2001), while in 2012-13 the local government portion of spending on roads was $6.2 billion of an overall $19.4 billion of roads nationwide (BITRE 2013).

Despite this level of considerable spending, many LGAs in Australia, and indeed State and Federal levels of government as well, are reporting budgetary shortfalls in their road maintenance budgets. For example, in the year 2012/13 Shoalhaven City Council alone (a local government on the south coast of New South Wales) reported a road maintenance budget deficit in the order of $1 million; similarly other LGAs and road administrators in Australia and around the world are suffering the same issue (Chan et al. 1994; Chootinan et al. 2006; Abo-Hashema and Sharaf 2009; Ferreira et al. 2009; Fletcher 2009). This shortfall, coupled with the increasing cost of resources, demonstrates the importance of ensuring the effective and efficient management of roads at the local government level (Fletcher 2009; Malam and Lubulwa 2011).

The design life of a road pavement is determined as a balance between ensuring its effectiveness under expected current and future demand, while meeting existing budgetary, social and environmental constraints, to produce the most efficient pavement possible (Austroads 2012). To effectively manage the performance and life of these road assets means identifying appropriate remediation options and assessing how each will affect current and future deterioration behaviour and cost over the pavement's design life (Ferreira et al. 2002; Picado-Santos et al. 2004).

The complexity of the road asset management problem lies within the road network itself. Within a road network there are many segments to consider and for any given road segment there will be multiple defects and for every defect there is often more than one possible remediation option able to be selected. Without taking into regard the various types of pavements, the resulting number of permutations of '*defect, action and residual future effect*' is enormous (Ferreira et al. 2002).

Typically, the road asset management team collectively possesses the knowledge and experience to administer this complex asset management problem. However, while some individuals within the team may possess advanced skills, the remaining team members are often still developing theirs. The problem therein is whether those lesser experienced members can continue to develop their own knowledge and skills so as to be positive contributors to the team and its decision making processes.

In other fields of engineering decision making, such as the conceptual design problem explored by Lemass in 2004, and particularly in medicine, decision support systems (DSS) have been the solution to the problem of ensuring expert knowledge is consistently applied by all professionals and practitioners with various levels of experience and knowledge.

A DSS can serve not only as an accelerated learning tool for those still in the formative stages of their careers but can serve as a convergence check between engineers' intuition and a structured systematic assessment that converges one or two feasible solutions. In addition, a DSS can also help prevent decisions being made in isolation and, through integration of isolated databases, will allow the asset management team to make better informed decisions.

The purpose of this study is to develop a decision support system for the remediation of the flexible road infrastructure in local government.

1.2 Research Question and Hypothesis

1.2.1 Background

There have been many different approaches studied to address the road asset management problem, and many of these have focussed on the use of optimisation techniques to achieve this. However, the acceptance and general application of these approaches has been quite low, making them less than useful (Mulholland and Metcalf 1991).

Meanwhile, Decision Support Systems (DSS) have been an adequate and well received method for providing support and accelerated organisational learning in medicine, engineering design and utility service operations to name a few (Allen 1996; Lemass 2004; Degaspari 2012). Recently, studies have been undertaken to better understand the usefulness of DSS for specific road maintenance activities, however, little has been done by way of knowledge-based DSS for complete road network pavement management.

1.2.2 Research Question

In the establishment of a decision support system for the pavement management of road networks in local government, the research question that this study will address is:

'Can organisational intelligence be used to effectively and efficiently plan for road remediation in combination with established theory?'

That is, are the decisions made by road asset managers (and their teams) effective in comparison to written theory on road remediation and efficient in terms of lifecycle and network spending; and can the heuristic and organisational knowledge that the road asset manager applies as the expert be learnt and implemented through a decision support tool to ensure current and future decisions are consistent with sound expert knowledge and organisational principles.

1.2.3 Hypothesis

The development of the decision support system proposed above is aimed at improving pavement management at the local road level while providing road asset managers with a tool to effectively plan and manage short to long-term remediation actions for the life of the road.

Through the investigation of local government case studies and validation from experienced road asset managers and road engineers, this study will seek to address whether their experiential knowledge is adequate in dealing with the road asset management problem. It will investigate whether there is too much reliance on experiential knowledge for road management decision making and whether organisations can continue to benefit from valuable experiential knowledge after their experienced staff have left. Therefore, the hypothesis for this study is:

'A DSS can successfully combine experiential, procedural and theoretical knowledge to improve the quality of decision making'

1.3 Methodology

1.3.1 Theoretical Approach

The theoretical approach to this study will be a mixed approach using case study methodology grounded in quantitative data and statistical analysis. That is, this study will focus on the actions and performance of the existing Shoalhaven City Council road network via a statistical analysis of data, while also being a practical study that investigates an existing phenomenon within its real-life context and addresses the situation in which the boundaries between phenomenon and context are not clear (Yin 1993; Meyer 2001).

The case study methodology is widely used; however, an often criticised limitation within a quantitative study such as this one is that isolated case studies consisting of a single augmentation is seen as limiting the value of the research (Yin 1993; Meyer 2001). In order to address these concerns, as well as to provide further rigour (and calibration), other cases from outside the Shoalhaven will also be investigated, tested and reported in this study.

1.3.2 Methods and Experimental Design

This study will follow three distinct stages of work: *Task Profiling*, *Decision Support System Prototype Development* and *System Testing and Refinement*.

Stage 1: Task Profiling

This stage involves the acquisition of data from Shoalhaven City Council (the initial case study), analysis of road network database information and identifying trends on deterioration, decision making and correlation of future planning with actual network behaviour.

Also involved in this stage is the study of various existing pavement management systems and decision support systems (DSS), as well as a thorough review of current documented pavement design and maintenance processes and procedures, which will be used to identify 'what else' is happening in this field and to identify where and why these may not be completely effective in this case study.

The objective of this stage is to identify 'what' is happening and 'why'. The knowledge drawn from this will directly influence the decisions made in the prototype DSS design.

Stage 2: Decision Support System Design and Prototype Development

The second stage of this research project involves formulating the DSS and producing the model for use. Using the information obtained in Stage 1, this step involves deriving the procedural and statistically analysed behaviour of the road asset management team (Chapter 3), augmented by system improvements via theoretical knowledge also explored in Stage 1 (Chapter 2).

The objective of this stage is to develop the analytical decision support system to assist with future road maintenance and rehabilitation decisions.

Stage 3: System Testing and Refinement

The final stage of the study will be to assess the decision support system against field interviews with experienced road asset managers and road engineers from a wide

range of local government organisations and test the performance of the DSS against case studies of real world problems from local government road networks and their solutions.

By ensuring that the system can effectively replicate the pavement management decisions that are generally considered to be more successful, greater confidence can be placed in the system's capabilities.

1.4 Research Scope, Anticipated Outcomes and Limitations

1.4.1 Scope

The purpose of this study is to develop a decision support system for the remediation of the flexible road infrastructure in local government. The research undertaken has been conducted in the context of local government areas within New South Wales (NSW) Australia from a mix of metropolitan, regional and rural local government areas. In doing so, the research provides a focus on flexible pavement asset types, excluding both rigid and segmental block pavements because they represent only a small proportion of road pavements in NSW local government.

Through the implementation of the decision support system developed in this study, local government road asset managers and engineers will be able to augment their own decision making and that of their team. Aimed at solving the significant industry problem by assisting in the assimilation process from theoretical to procedural knowledge; the resulting benefits will be consistent asset management and maintenance decisions being made across entire road networks that are both technically effective and efficient in terms of cost and resource usage.

1.4.2 Outcomes

By using data obtained from the Shoalhaven City Council road network (and others) this study aims to produce a decision support system for the remediation of ageing road infrastructure for local government. By learning the organisational and expert knowledge held by road asset managers and their teams, the resulting DSS will provide effective and efficient solutions to the pavement remediation problem.

1.4.3 Limitations

The limitations of this study will mainly exist around flexible pavement types, as well as environment and climatic conditions of the Shoalhaven and surrounding regions.

The Shoalhaven only has certain road pavements in its road network database. While these are a good representation of those found in a typical network, they are by no means a complete representation of all possible road networks in other local government areas. Similarly, with the Shoalhaven being located on the south coast of New South Wales, climatic variation is not significant and certainly not as extreme as other parts of Australia and the world.

However, through field interviews and diverse case studies from multiple New South Wales local government organisations, these limitations can be substantially overcome.

Finally, potential issues associated with group decision making situations and the impact of interdependencies between various factors on decision outcomes have not been considered as they fall outside scope of this study.

1.5 Research Significance

The implementation of a complete road network database with a flexible and intuitive decision support system (DSS) will assist road asset managers and their teams in effectively and efficiently administering the roads in their road network.

In the past, studies have sought to respond to the road maintenance and management problem by focussing primarily on optimisation techniques that use complex and 'black-box-like' algorithms to predict current and future pavement condition and to provide an 'optimum' remediation solution. Alternatively, this proposed study will focus on knowledge or case-based decision support to assist in the planning of road maintenance and management activities. This approach has not been previously explored in past studies and provides a demonstration system that can spawn future systems that can rely on rich asset data, as well as intuitive logic and decision making processes.

Different to previous studies, the proposed Decision Support System accepts the past procedures of optimisation, but acknowledges their limitations, to build a framework designed to replicate and improve upon bounded rationality.

The author will also draw a unique link between the road maintenance decision making paradigm and the well-explored engineering design process, which has not been outlined in previous studies.

Therefore, a knowledge-based DSS, similar to those described by Allen (1996), Lemass (2004) and Sugumaran et al. (2010), that is also informed by the structured/semi-structured engineering design process, should act as a useful tool to address the prioritisation issues associated with the planning of maintenance and rehabilitation of roads with varying demand profiles and different pavement types.

1.6 Thesis Structure

This thesis is presented in seven chapters providing an in-depth exploration of the development of the decision support system for the remediation of flexible road pavements in local government in the following structure:

- Chapter 1 – Introduction
- Chapter 2 – Road Pavement Engineering
- Chapter 3 – Task Profiling: Decision Making And Its Role In Road Asset Management
- Chapter 4 – System Development: Prototype Decision Support System
- Chapter 5 – System Testing: Field Interviews And Case Studies
- Chapter 6 – System Validation And Refinement
- Chapter 7 – Conclusion And Recommendations

Chapter 2 presents a literature review on the state of the art for the structure, performance and remediation of both sealed and unsealed flexible road pavements. This chapter provides a comprehensive review and catalogue of all defects known to afflict all types of flexible pavements, as well as their causes. It further details remediation practices suitable for the treatment of defects, and for which defects each remediation option is most suitable.

Chapter 3 provides a continuation of the literature review. Focussed on *task profiling*, it is a review of the decision making problem associated with effective road asset management and the tools and processes currently utilised to assist a road asset manager or road engineer in their road asset decision making. In addition, this chapter provides an exploration of the initial case study of the Shoalhaven City Council road network and asset management procedures which are a critical aspect in the *task profiling* stage and ultimately shape the creation of the decision support system developed in this study.

Chapter 4 outlines the design and development of the prototype decision support system for the remediation of flexible pavements, named *PaveMaint SELECT version 0.1*. This chapter represents the second stage of the study and outlines how the literature review and initial case study of Shoalhaven City Council presented in the preceding chapters have shaped the creation of the *PaveMaint SELECT version 0.1* program in readiness for system testing.

The *system testing and refinement* stage of this study is presented in Chapter 5 and Chapter 6. *System testing* is discussed in Chapter 5 which presents a detailed exploration of the field interviews and case studies upon which the prototype decision support system was tested. Building upon the system testing data from the preceding chapter, Chapter 6 provides a comprehensive examination and discussion of the data obtained from the field interviews and case studies (both in validation and in divergence) providing critical *system refinement* and the development of the final decision support system program, *PaveMaint SELECT version 1.0*.

The final chapter of this thesis presents the conclusions drawn from the research undertaken in this study, as well as recommendations for the possible implementation of the *PaveMaint SELECT* program and potential future work for further development of the decision support system.

2 ROAD PAVEMENT ENGINEERING

2.1 Introduction

This chapter will explore the structural, physical and behavioural aspects of road pavements. Focussing on both sealed and unsealed flexible pavements, this chapter will discuss the structural components of road pavements, the known/documented modes of failure and distress of flexible pavements and finally the repair solutions and techniques used in rehabilitating road pavements.

2.2 Road Pavements

There are three fundamental types of road pavement that are typically considered by public authorities in the construction of their road networks: flexible, rigid and segmental block pavements (Shackel and Pearson 1991; Austroads 2009). While road networks are often diverse, being made up of a combination of flexible, rigid and segmental block pavements, the flexible pavement category has the largest representation in local government road networks compared to rigid or segmental block pavements (Misra et al. 2003; Manager 2011). Within the category of flexible pavements it is also important to distinguish between sealed and unsealed pavements, where the presence of a sealed surface (or lack thereof) affects the wear and behaviour of the pavement (Shackel and Pearson 1991; Austroads 2009).

Flexible pavements are so called since the granular materials used in their construction allow the pavement structure to elastically deform under load, more so than stiffer rigid pavements that typically do not allow these types of deformations (Austroads 2009). While flexible pavements are typically constructed from unbound granular materials, the evolution of pavement technology has resulted in the more prevalent use of modified or alternate materials in pavement construction and/or remediation. This includes the use of stabilised (bound or modified) materials to improve strength characteristics as well as the use of recycled materials that have their own unique characteristics (Austroads 2009; Saride et al. 2010).

The design life of a road pavement is determined as a balance between ensuring effectiveness under expected current and future demand, while meeting existing budgetary, social and environmental constraints, to produce the most efficient pavement possible (Austroads 2012). However, with time, fluctuations in traffic

loads and changing environmental conditions, a number of defects commonly eventuate that reduce the expected life of a pavement (see Sections 2.2 and 2.3). This study is focussed on the determination and treatment of those defects to ensure road pavements meet their desired minimum life span. The selection and determination of pavement replacement options at the end of a pavement's life cycle are not considered in this study.

2.2.1 Sealed and Unsealed Flexible Pavements

A sealed flexible pavement is a pavement constructed from compacted, bound or stabilised granular materials that consists of essentially four common components: wearing surface (wearing course), base course, subbase and subgrade as illustrated in Figure 2.1 below. Unsealed flexible pavements mirror the structure of a sealed pavement, with the main notable differences being the exclusion of a wearing course as well as different behavioural characteristics (Austroads 2009; Austroads 2009).

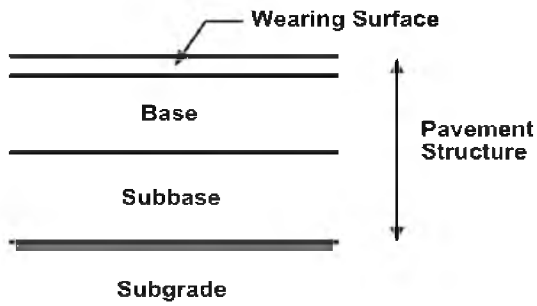


Figure 2.1 – Typical Flexible Pavement Structure (Austroads 2009)

Austroads (2009) describes the pavement subgrade as the natural formation material that is trimmed and compacted during pavement construction. Where this natural material is considered to be unsuitable for use, particularly for heavy duty roads, it may be replaced with a select material; that is, further material is placed over the subgrade prior to the construction of the subbase.

The role of the subbase is to provide sufficient support of the base while reducing stresses and strains on the subgrade. It is a load carrying layer of the road pavement and since it is lower in the pavement structure, it carries a lower proportion of stresses and therefore (for economic reasons) is generally constructed from lower quality material. The base course is the primary load carrying layer of the pavement.

It is designed to transfer the vertical and horizontal stresses of the traffic to the lower layers of the pavement structure (Austroads 2009).

The wearing course is primarily the weather proof surface for the road whose role is to withstand environmental effects (for example, moisture and dust), while maintaining its integrity under the prevailing loading conditions (USAAF 1989; Austroads 2009).

Thin wearing surfaces, less than 50 millimetres are not considered to provide structural benefit to the road pavement; these generally include spray sealed or hot mix asphalt (HMA) surfaces (Austroads 2006; Austroads 2009; Austroads 2009; Austroads 2009). Thick, or full depth, HMA surfaces greater than 50 millimetres thickness will provide a structural function within the pavement (Austroads 2006; Austroads 2009; Austroads 2009).

It should be noted that during construction, prime and seal (or primerseal) application is used as a construction method to protect the newly constructed pavements prior to the eventual application of the final permanent seal. This temporary seal is intended to carry traffic for a maximum one to three year period and is considered to be a construction practice only (Austroads 2009). Therefore, it is not considered as a part of this study.

2.2.2 Alternative Pavement Materials

2.2.2.1 Stabilisation of Unbound Granular Materials

The addition of a stabilising binder or cementitious additive to an unbound granular material will result in a pavement material with improved stiffness characteristics and can be generally referred to as a stabilised material. These stabilised materials may be considered *modified* when they have been improved or corrected without significantly increasing the tensile strength of the material, where the unconfined compressive strength (UCS) remains below 1.5MPa (Austroads 2006; Austroads 2009). Significantly increasing the tensile strength properties of the material (UCS greater than 1.5MPa) will result in a material that is considered to be *bound* (White and Gnanendran 2002; Austroads 2006; Austroads 2009).

While this associated increase in strength capacity of the pavement materials will obviously modify the structure of the pavement, the changes are not significant enough to be able to class the pavement as being rigid. Therefore, for the purpose of this study, flexible pavements that have undergone stabilisation treatments, for example cement or lime stabilisation, of one or more layers of the pavement structure may still be considered flexible pavements (Austroads 2006; Jitsangiam and Nikraz 2008).

2.2.2.2 Recycled and Substitute Pavement Materials

In some cases, road pavements may be constructed from recycled or secondary products in lieu of conventional materials, where they are seen as having advantages in the conservation of natural resources, energy and the environment as well as a reduction in life-cycle costs (Austroads 2009; Saride et al. 2010).

Examples include the use of recycled industrial slag by-product and reclaimed asphalt, which have been prevalent around the world for decades. While the characteristics of these products vary from conventional materials, typically featuring an increase in strength characteristics or bound properties, they do not alter the structure of the pavement sufficiently to change the overall pavement behaviour or performance (Byers et al. 2004; Saride et al. 2010). Therefore, for the purpose of this study they are to be assessed in terms of their equivalent pavement structure. That is, for example, a flexible pavement with one or more layers of granulated blast furnace slag will continue to be considered a flexible pavement.

2.2.3 Rigid and Segmental Block Pavements

While rigid and segmental block pavements do not fall within the scope of this study, it is important to note their differences. Rigid pavements (also referred to as concrete pavements) share a similar structure to flexible pavements, consisting of a base (albeit concrete), subbase and subgrade as illustrated in Figure 2.2 below.

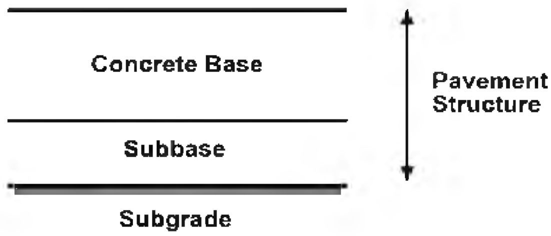


Figure 2.2 – Typical Rigid Pavement Structure (Austroads 2009)

Segmental block pavements are roads constructed using vitreous clay or high strength concrete pavers (segmental blocks) placed over a base/subbase/subgrade pavement structure, as illustrated in Figure 2.3; where the discontinuous nature of the block surfacing allows the structure to behave in a flexible manner (Shackel and Pearson 1991; Giummarra 1995; Austroads 2009; Fletcher 2009; Soutsos et al. 2011).

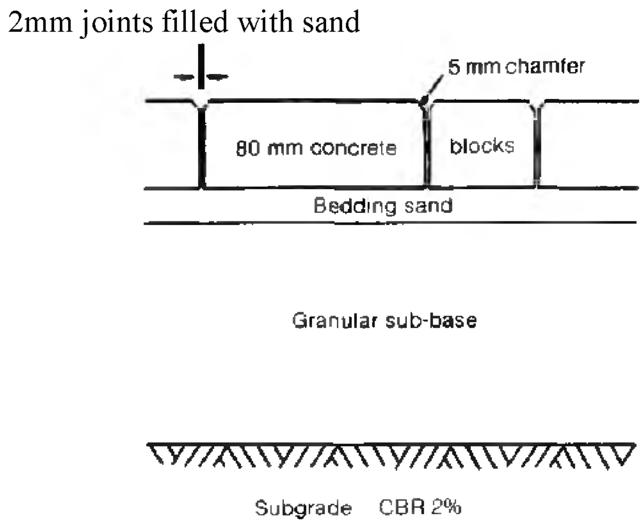


Figure 2.3 – Typical Section of Segmental Block Pavement (Barber and Knapton 1979)

While rigid and segmental pavement types do not form part of the decision support system proposed in this study, a review of the failure mechanisms associated with these pavements is presented in Appendix A for completeness and assistance with possible future work.

2.3 Typical Defect Types

Road pavements suffer from a number of common defects and deterioration modes ranging from surface texture deficiencies, cracking and deformation (Evans et al. 1990; ESB 1998; NDOR 2002; Austroads 2009; Austroads 2009; HYD 2009). Each

defect or deficiency has its own distinguishable appearance and behaviour characteristics, however many share the same, or similar, causes and can occur independently or in combination with other defects.

As described earlier in Section 2.1.1, sealed and unsealed flexible pavements share a fundamentally similar structure and accordingly share some similar visual defects. However, as discussed herein, their differences are significant enough that the mechanisms that trigger these defects vary and thus the cause of, for example, corrugations in a sealed flexible pavement will not be the same mechanism for corrugations in an unsealed flexible pavement.

2.3.1 Surface Texture Deficiencies

Surface texture provides ride quality, user safety and satisfaction in addition to protecting the underlying pavement, and therefore has a significant impact on the serviceability of a road (Austroads 2009; HYD 2009). Surfaces that have deficiencies present a significant risk to road user safety and impact on user satisfaction, but only some reflect an issue of pavement structural integrity. Surface texture deficiencies include the loss of surfacing materials, the loss of macrotexture (texture of the road surface) and microtexture (texture of the aggregate itself) through the mechanisms described below (Slimane et al. 2008; Austroads 2009; HYD 2009; Elunai et al. 2011).

2.3.1.1 Oxidation

Oxidation of bituminous surfaces is the "gradual hardening of the bituminous binder" (Austroads 2009) through environmental and atmospheric conditions and is commonly associated with the age of the surface (Austroads 2009; Prapaitrakul et al. 2009; Austroads 2010).

While in its developing stages oxidation is not visibly apparent; in sprayed sealed surfaces oxidation of the bituminous binder leads to cracking or aggregate loss (as shown in Figure 2.4), and for asphalt (asphaltic concrete) surfaces, binder hardening from oxidation can result in raveling and loss of aggregate materials (Austroads 2009; Jin 2012). This will leave the pavement more susceptible to moisture

intrusion, which leads to more severe defects such as potholes and others discussed in this review (Austroads 2006; Austroads 2009; Austroads 2009).

Figure 2.4 – Pavement Oxidation with Associated Cracking (RPC 2011)

2.3.1.2 Stripping

Primarily an issue with sprayed seals, stripping is the loss of surface texture through the separation of aggregate from binder that leads not only to poor skid resistance, but also aggregate loss, which as illustrated in Figure 2.5 can result in further structural pavement defects such as potholes (Evans et al. 1990; Austroads 2006; Austroads 2009). The stripping affect begins from the bottom of the bituminous/asphalt layer and progresses up to the surface. When it begins at the top and progresses downward it is referred to as raveling (PavementInteractive 2007).

Figure 2.5 – Stripping of Asphalt Pavement under Chip Seal (Wood and Cole 2013)

Stripping can be caused by a defective/incorrect binder and aggregate system, use of an absorptive aggregate, moisture ingress, excessive voids, thermal variation or from

the nature of the traffic loading on the surface, that is, high speed and/or heavy vehicles (Kerh et al. 2005; Austroads 2006; PavementInteractive 2007).

2.3.1.3 Aggregate Polishing

Aggregate polishing has a significant impact on road user safety and skid resistance. Sometimes referred to as the loss of surface texture, it is commonly found in the wheel paths of traffic lanes, and as the name suggests, it is the smoothing and rounding of the wearing surface aggregate as shown in Figure 2.6 (Geller 1996; Austroads 2006; Ahammed and Tighe 2008; Austroads 2009; HYD 2009).

Figure 2.6 – Polished Aggregate in 40 year old Seal (PavementInteractive 2010)

This surface defect can be caused by incorrect or inadequate aggregate selection, surface age or higher than expected traffic volume or traffic stresses (Geller 1996; Austroads 2006; Austroads 2009; Austroads 2009; HYD 2009; PavementInteractive 2010; Chen et al. 2011).

2.3.1.4 Flushing

Flushing (also referred to as bleeding) is the partial (or complete) submersion of the surface aggregate into the binder mixture in a sealed pavement, resulting in a slippery surface with low macrotexture and skid resistance (Austroads 2006; Austroads 2008; HYD 2009). Flushing and aggregate polishing both share a visibly shiny surface; however, flushing is distinguished by a noticeable blackness, illustrated in Figure 2.7, which comes from the bitumen being almost completely exposed at the surface (HYD 2009; Kodippily et al. 2012).

Figure 2.7 – Flushing in a Road Pavement (RoadScience 2013)

Flushing can occur during hot weather when the bituminous binder fills the aggregate voids and then expands onto the pavement surface; and since it is not reversible during cold weather, the binder will accumulate on the pavement surface over time (Kodippily et al. 2012).

Other possible causes include excessive binder content on the surface or underlying surfaces, poor mix design, aggregate penetration into underlying low strength pavements, softening of the binder or spillages or accumulation of oil from vehicles (Austroads 2006; Austroads 2008; HYD 2009).

2.3.1.5 Raveling

Raveling is the loss of both aggregates and binder from the pavement surface which results in surface disintegration where visibly loose pieces of aggregate sit on the road surface (Austroads 2006; HYD 2009; Mo et al. 2009; PavementInteractive 2009). It is considered to be at its worst when those pieces make the surface rough enough to be noticeable to motorists driving on the road (ESB 1998).

Sealed Flexible Pavements

Raveling can be the result of inadequate construction practices including insufficient binder content, inadequate aggregate preparation (dusty and unprimed aggregates affect adhesion to binder), improper aggregate mix (insufficient fine aggregates in surface matrix), aggregate segregation, overheated surface mix, inadequate initial compaction and selection of unsound aggregates that deteriorate under traffic or environmental conditions (ESB 1998; Austroads 2006; HYD 2009; Mo et al. 2009; PavementInteractive 2009). In-situ causes of raveling can arise from binder

oxidation, traffic loading and softening of the bituminous binder due to fuel or oil accumulation – this is especially prevalent in areas where traffic is regularly stopped, such as intersections with traffic lights or stop signs (Austroads 2006; HYD 2009; PavementInteractive 2009). An example of raveling in sealed pavements is illustrated in Figure 2.8 below.

Figure 2.8 – Raveling in a Spray Sealed Asphalt Pavement (RoadScience 2013)

Unsealed Flexible Pavements

Raveling is associated with a loss of fines, since the fines in an unsealed pavement represent the binder of the pavement surface matrix, their loss leads to the exposure of surface aggregate which not only results in a coarse surface with increased noise, roughness and permeability, but increases the likelihood of further raveling which decreases skid resistance due to loose aggregates (ESB 1998; Jones 1999; Austroads 2009). An example of raveling in an unsealed pavement is shown in Figure 2.9 below.

Figure 2.9 – Raveling in an Unsealed Pavement (QDMR 1999)

2.3.1.6 Delamination

This surface deficiency is the loss of bond between the wearing surface and the base course layer in sealed pavements that leads to low shear resistance to traffic stresses (Austroads 2006; HYD 2009). It is the total removal, or peeling off, of areas of the asphalt wearing course, with a clear delineation between the wearing course and the pavement base course layer below which is illustrated in Figure 2.10 (Austroads 2006; FDOT 2014).

Figure 2.10 – Delamination of an Asphalt Sealed Pavement (FDOT 2014)

Possible causes of delamination include construction deficiencies such as an inadequately clean or improperly tack coated pavement surface prior to placing the asphalt, or insufficient thickness or stability in the asphalt placement; as well as being a common fault arising from patch repairs of failed pavements (Austroads 2006; HYD 2009). It also arises from in-situ causes such as water seepage through the surface which weakens the bond between the layers, failure of a lower layer or may result from significant damage to the surface from improper usage or traffic loading (Austroads 2006; PavementInteractive 2008; HYD 2009).

2.3.1.7 Pumping

Pumping is distinguished by the presence of pavement fines on the surface of the surface of a sealed pavement (shown in Figure 2.11). It is not a breakdown of the pavement wearing surface, rather a result of moisture movements within a pavement that cause erosion of the subbase or base course material. It is commonly associated with cracking, where the cyclic loading of traffic movement forces the fine particles

to migrate upwards towards the surface and the presence of cracking allows these fines to escape the pavement through the surface (Alobaidi and Hoare 1999).

Figure 2.11 – Pavement Fines Present on Road Surface due to Pumping (PavementInteractive 2009)

2.3.1.8 Loss of Fines

Loss of fines, related to unsealed flexible pavements, is considered the first sign of wearing (Austroads 2009). Caused by traffic action and climatic conditions, it is the loss of fine particles (finer than 0.425 millimetres) and is evident in a road that produces large or excessive plumes of dust in windy conditions or when trafficked such as that shown in Figure 2.12 (ESB 1998; Jones 1999; Austroads 2009; Edvardsson 2009).

In addition to road user safety, there are number of health issues surrounding the resulting airborne dust generated from the loss of fines (Jones 1999).

Figure 2.12 – Road Experiencing Loss of Fines (NRC 2014)

2.3.2 Cracking

Cracking is identified as one or more visible discontinuities or fissures radiating along the surface of a pavement. Affecting pavements with a sealed surface, it is considered to be unplanned and uncontrolled and will not necessarily extend through the entire thickness of a pavement (Austroads 2006; HYD 2009). The condition of pavement surfaces is an important guide to the overall condition and future performance of the pavement structure, and the onset of surface cracking has been recognised as an indicator of overall pavement condition (Loria-Salazar 2008).

Cracking can be a result of deformation, fatigue, ageing, underlying movement, shrinkage or poor construction. Outlined in Table 2.1, along with the mechanisms of crack development, causes of cracking can be related to continued traffic loading or attributed to environmental factors such as ultra-violet (UV) radiation that causes oxidation as well as thermal expansion/contraction and moisture changes that increase movement in the pavement layers (Austroads 2006; HYD 2009).

Table 2.1 – Usual relationships between cracking categories, dominant causes, and mechanisms for development (Austroads 2006)

Category	**Dominant Causes**	**Mechanisms for crack development**	
Load	Traffic loading	Fatigue	Reflection
Non-load	Environment	Shrinkage	
	(e.g. moisture, vegetation,	Settlement	

	material properties and sunlight)	Temperature changes
		Bitumen oxidation

Crack openings increase the likelihood of moisture infiltration to the pavement base and subgrade, which not only exacerbates the progression of structural cracking, but can also lead to other pavement failure modes, such as rutting and pumping (Loria-Salazar 2008; Peshkin et al. 2009). The physical size (length, fissure opening width) and appearance (pattern, percentage of overall pavement affected) of the cracking represent different risks to pavement life and performance; and subsequently require different remediation responses (Loria-Salazar 2008; HYD 2009). Peak road management bodies in Australia and New Zealand and the United States of America (Austroads and AASHTO respectively) consider four classes of cracking relating to the severity (width) of the fissure opening, which are summarised in Table 2.2.

Table 2.2 – Cracking Classification by Fissure Opening Width (Austroads 2006)

Industry Body Classification		**Definition**
Austroads	**AASHTO**	
Fine Cracks	Class 1	Cracks with an average width of 1mm or less
Medium Cracks	Class 2	Cracks with an average width of 1mm to 3mm
Wide Cracks	Class 3	Cracks with an average width greater than 3mm wide without *spalling* (as defined in Class 4)
Spalled Cracks	Class 4	Cracks where fragments of the surfacing adjacent to the cracks are lost

The physical appearance (length, shape and pattern) of pavement cracking will also provide a strong indication of underlying pavement issues and probable failure modes (Austroads 2006; Peshkin et al. 2009). The occurrence of cracking on a

pavement surface is not only evidence of bitumen surface deterioration but can also represent the first visible manifestation of underlying pavement issues such as pavement structure and sub-structure defects.

Cracking types are identified and described by their dominant geometric structure and include block cracking, crocodile cracking, diagonal cracking, longitudinal cracking, meandering cracking, transverse cracking, and crescent-shaped cracking (Austroads 2006; Loria-Salazar 2008; HYD 2009; Peshkin et al. 2009) as illustrated in Figure 2.13 below and described in the following sections.

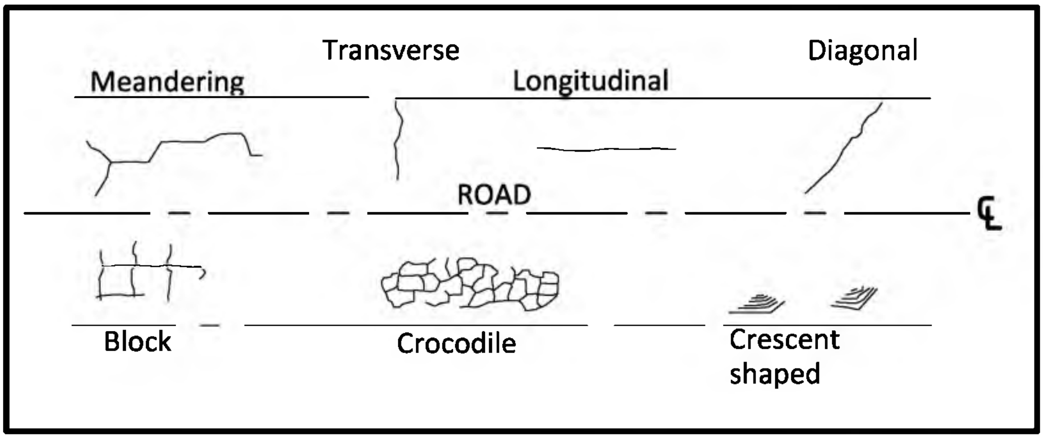


Figure 2.13 – Types of cracking defects in sealed flexible pavements (Austroads 2006)

2.3.2.1 Block Cracking

Block cracking is a series of interconnected cracks that form quasi-symmetrical polygons (cells) that are square or rectangular in shape, with cell sizes larger than 200-300mm. It generally occurs over a large area of pavement and will often affect an entire segment of road (Austroads 2006; HYD 2009).

Block cracking can be attributed to one or any of the following: hardening and shrinkage of the bituminous surface; fatigue in an aged and brittle wearing course; reflection from joints or discontinuities associated with an underlying bound base, subbase or subgrade layer; or loss of subbase or subgrade support (NDOR 2002; Austroads 2006; HYD 2009).

2.3.2.2 Crocodile Cracking

Crocodile cracking is a series of interconnected (or interlaced) cracks that form irregular shaped cells that are smaller than 300mm in nominal diameter (Austroads 2006; HYD 2009). This cracking type takes its name from its appearance which resembles the pattern of crocodile (or alligator) skin, and is also referred to as alligator or polygon cracking or 'crazing' (NDOR 2002; Austroads 2006).

Crocodile cracking regularly occurs within wheel paths and can be mainly attributed to traffic loading (Austroads 2006). It can be initialised from other cracking defects present on the pavement, such as block cracking, or it can be associated with issues such as saturation of underlying pavement layers; fatigue (ageing and brittleness of the bituminous wearing course); or inadequate pavement thickness or compaction (NDOR 2002; HYD 2009).

2.3.2.3 Diagonal Cracking

Diagonal cracking is unconnected cracking that generally follows an alignment diagonal to the direction of the pavement, it is neither parallel or perpendicular to traffic flow (HYD 2009). While mainly an issue for rigid pavements, flexible pavements with bound pavement layers may also be affected by this cracking type (Austroads 2006).

Causes of diagonal cracking include reflection from joints or discontinuities associated with an underlying bound base, subbase or subgrade layer; differential settlement from adjacent embankments, cuttings or structures; tree roots; or disturbance from underground service installation (Austroads 2006; HYD 2009).

2.3.2.4 Longitudinal Cracking

Longitudinal cracking can be a single isolated crack or a series of cracks that generally follow an alignment that is parallel to the direction of flow of traffic. While longitudinal cracks are considered to be unidirectional they may also feature shorter cracks which radiate from the main crack in a diagonal or perpendicular direction in what is referred to as 'branching' (Austroads 2006; HYD 2009).

When represented as a single crack, causes will include reflection from joints or discontinuities associated with an underlying bound base, subbase or subgrade layer; bitumen hardening; early developing slips (for roads located on slopes); or poor work practices such as poorly constructed asphalt surfacing joint and reflection from joints where pavement widening works have been undertaken (NDOR 2002; Austroads 2006; HYD 2009).

In a series or group of parallel cracks, the causes of longitudinal cracking will include movement and heaving of expansive subgrades, early developing slips (for roads located on slopes), cyclical failure of the pavement edge or differential settlement occurring at a cut/fill plane on an embankment (Austroads 2006; HYD 2009).

2.3.2.5 Transverse Cracking

Transverse cracking will radiate perpendicular to the alignment of traffic flow and can occur singularly or in a series of parallel cracks (Austroads 2006).

It can be caused by a construction joint or shrinkage in asphalt surfacing; reflection from joints or discontinuities associated with an underlying bound base, subbase or subgrade layer; differential settlement occurring at a cut/fill plane on an embankment; or movement in underlying pavement (NDOR 2002; Austroads 2006; PavementInteractive 2006; HYD 2009).

2.3.2.6 Meandering Cracks

Meandering cracks are unconnected, singular discontinuities that, as the name suggests, follow an undefined and multidirectional alignment (Austroads 2006). Primarily a function of excessive moisture in the underlying pavement, common causes include: weakening due to pavement saturation; shrinkage of pavement subgrade due to tree roots; reflected shrinkage cracks from bound base and subbase materials; or disturbance from underground service installation (Austroads 2006).

2.3.2.7 Crescent-Shaped Cracking

Crescent-shaped (or slippage) cracking is representative of shear movements in pavement surfaces (HYD 2009). Also named according to its appearance, this

cracking type is evident by its half-moon, or curve, shaped alignment, which may occur as a singular crack or in a group of concentric cracks, and is commonly associated with shoving in an asphalt pavement surface. While associated with shoving along wheel paths, the causes of this defect type can be due to poor construction techniques such as dragging by paver when laying asphalt at low temperatures, or inadequate bond between asphalt wearing course and pavement base course due to dust, dirt, oil or the absence of a tack coat; excessive shear forces due to braking and acceleration movements; or due underlying pavement layers with low densities and stiffness (Austroads 2006; Austroads 2006; HYD 2009).

2.3.3 Deformation

Deformation is the change in shape and profile of a pavement surface caused by movement or failure of underlying pavement layers or a shear failure of the pavement surface itself (Austroads 2006). Of course, for flexible pavements some elastic deformation is expected (within limits) and is in fact a design feature of such pavements (Austroads 2012). It is the excessive elastic deformation and more permanent plastic deformation that affect the performance, and ultimately the life span, of a road pavement (Austroads 2006; Austroads 2012). Excessive elastic deformation becomes a problem when it causes cracking of the sealed surface leading to the issues discussed in Section 2.2.2 (Austroads 2012).

The issues surrounding plastic deformation are that the deformed shape may be more susceptible to holding water (ponding) which poses a safety risk to vehicles due a decrease in skid resistance, but also it will affect the ride quality (roughness) of the road (Austroads 2006). Plastic deformation may present itself as rutting, depressions, corrugations, shoving, potholes, edge breaks, soft spots, erosion channels, spalling, joint faulting, rocking, blow-up or swell as discussed below.

2.3.3.1 Rutting

Rutting, as illustrated in Figure 2.14, is the vertical deformation of pavement that occurs in the regular wheel paths, aligned parallel to the flow of traffic (ESB 1998; Austroads 2006; PavementInteractive 2008; HYD 2009). Rutting is considered to have a length-to-width ratio greater than 4:1 and is a measurement of the maximum

vertical displacement at any section of the road. It is considered to be slight when it is less than 12 millimetres deep, moderate when it is less than 25 millimetres deep and considered severe when it is greater than 25 millimetres deep as it will affect the ability of a vehicle to steer with ease (ESB 1998).

Sealed Flexible Pavements

Rutting is commonly found in wheel paths subject to high stress traffic loading which is common in climbing lanes, roundabouts and at intersections with slow heavy traffic (Austroads 2006). It can be associated with settlement of underlying pavement layers, plastic deformation of the bituminous surface and structural failure of the subgrade. It can also be attributed to construction deficiencies where inadequate compaction leads to poor density of any or all pavement layers, or from an inappropriate asphalt mix in HMA pavements that feature poor grading, excessive binder content, excessive natural sands, inadequate maximum aggregate size or aggregates with poor microtexture (Austroads 2006; Austroads 2007; PavementInteractive 2008; Austroads 2009).

Unsealed Flexible Pavements

Sometimes referred to as *dry rutting*, it is prevalent in dry environments and caused by loss of material from regular or heavy traffic, but can also be due to high moisture content in the subsurface soil or base (Austroads 2009; Edvardsson 2009).

(PavementInteractive 2008)

(Publitek 2014)

Figure 2.14 – Examples of Rutting in Sealed and Unsealed Pavements

2.3.3.2 Depressions

A depression in a pavement is a localised area of a sealed pavement surface that has deformed downwards below the original constructed surface level – see Figure 2.15 (Austroads 2006; HYD 2009; PavementInteractive 2009). Depressions may not necessarily be confined to wheel paths as they may in fact cross several, and are particularly noticeable immediately following rain when they fill with water, creating a safety hazard for vehicles that will experience a loss in skid resistance (HYD 2009; PavementInteractive 2009).

Depressions are generally caused by a volume change in the subgrade or sub-base materials due to recent service trenches, soft and poorly compacted areas, embankment movements, change in moisture content within pavement materials or the erosion of the underlying pavement layers (ESB 1998; Austroads 2006; HYD 2009; OSU 2012).

Figure 2.15 – Large Depression on a Sealed Pavement (OSU 2012)

2.3.3.3 Corrugations

Corrugations are a wave-like plastic deformation of the pavement surface, with distortion perpendicular to the direction of traffic flow (PavementInteractive 2006; Austroads 2009; HYD 2009). They are distinguished by regularly and closely spaced undulations, or ripples, spaced usually 500 millimetres to 1 metre apart as illustrated in Figure 2.16 below. Corrugations represent significant deformation of the pavement that can rapidly lead to failure (Austroads 2006; HYD 2009).

Figure 2.16 – Typical Wave-Like Deformation of Pavement Corrugations on an Unsealed Pavement (LGAM 2014)

Often, corrugations are worsened by drivers who "adapt their travelling velocity so that the vehicle suspension system will obtain the best possible resonance with the already existing road corrugation periodicity, which further increases the amplitude of the corrugation" (Edvardsson 2009).

Sealed Flexible Pavements

Corrugations are caused by inadequate stability in the surface or base courses, excessive moisture in the subgrade, low air voids in pavement (particularly surface) layers or in roads on steep uphill or downhill gradients exacerbated by the braking of heavy traffic (Austroads 2006; PavementInteractive 2006; HYD 2009).

Unsealed Flexible Pavements

Corrugations are formed in dry pavements under traffic load where the loose surface is firstly displaced, then arranged in waves set up in response to vehicle mass and speed of tyre movements (Austroads 2009; Edvardsson 2009). Edvardsson (2009) suggests that corrugations in unsealed pavements arise from existing surface irregularities and are common in granular materials with:

- particle sizes greater than 5 millimetres;
- low plasticity; and
- have either limited fines or have lost fines.

2.3.3.4 Shoving

Shoving, like corrugations, is a plastic deformation of a pavement, but with distortion parallel to the direction of traffic flow (HYD 2009). It affects sealed pavements and is described as the bulging of the pavement with an abrupt wave at the surface which is clearly shown in Figure 2.17 and represents significant deformation of the pavement which will quickly lead to its failure, particularly when the pavement abuts rigid structures such as kerb and gutter (Austroads 2006; PavementInteractive 2006; HYD 2009).

Shoving primarily stems from construction or design issues, where the use of surface and base layers with unstable and poor strength characteristics are unable to perform under frequent stopping and starting of vehicles, particularly at intersections. However, in situ causes can be attributed to excessive moisture in the subgrade (Austroads 2006; PavementInteractive 2006; HYD 2009).

Figure 2.17 – Shoving at a Busy Intersection (PavementInteractive 2006)

2.3.3.5 Potholes

Potholes are local failures, described as bowl-shaped depressions, where the wearing surface has disintegrated (or displaced) leaving the underlying pavement layers exposed to traffic and weather – see Figure 2.18 (Austroads 2006; PavementInteractive 2007).

Sealed Flexible Pavements

Potholes are common in pavements with thin surface layers, but are rarely observed in pavements with surface layers 100 millimetres or greater in thickness (Austroads

2006; PavementInteractive 2007). They commonly develop as a result of other defects, particularly those that affect the integrity of the pavement surface such as raveling and cracking which allows moisture to enter the pavement (Austroads 2006). Crocodile cracking also has a significant affect on the progression of pothole failures, where the small cells of bituminous surface that arise from this cracking type are easily dislodged by traffic (PavementInteractive 2007).

Unsealed Flexible Pavements

Potholes in unsealed pavements are significantly accelerated in the presence of water and traffic loads, more so than that in sealed pavements which benefit from the protection of a waterproof membrane (Austroads 2009; Edvardsson 2009). Their occurrence may also be due to previous potholes that have not been repaired to sufficient depth or compaction. This results in a permanent pothole nucleus that allows future degradation (Edvardsson 2009).

Developing after Significant Rain

Crocodile Cracking with associated Pothole

Figure 2.18 – Typical Pothole Development (PavementInteractive 2007)

2.3.3.6 Patching Failure

Patching failure is the deterioration of a hot and cold mix asphalt (H/CMA) patching repair. The deterioration of a H/CMA patching repair can arise from improper repair techniques as well as further deterioration of underlying or adjoining pavement materials (ESB 1998).

It is considered to be slight when the surface of the patch is level with the pavement and shows no sign of deterioration. It is considered moderate when the patch has

begun to deteriorate but not sufficiently to require a vehicle to reduce its speed, and it is considered to be severe when the patch has deteriorated enough to cause a driver to reduce the speed of their vehicle (ESB 1998).

Figure 2.19 – Failing Patch Repair with Pumping (OSU 2012)

2.3.3.7 Edge Breaks

Edge breaks occur near the shoulder of sealed pavements (the edge of the road), parallel to the direction of traffic flow as shown in Figure 2.20 (Austroads 2006). They can result in a reduction of the effective pavement width, the loss of ride quality and reduced user safety. Aligned in a longitudinal direction, the raised lip of an edge break can channel water runoff from the road, leading to erosion of the road shoulder as well as increasing the likelihood of lateral water entry into the pavement base (Austroads 2006).

Figure 2.20 – Edge Break of a Spray Sealed Pavement (LGAM 2014)

2.3.3.8 Soft Spots

Soft spots are associated with unsealed flexible pavements, where excessive silt or clay content in the pavement material makes the road surface reactive to water ingress (Austroads 2009; Edvardsson 2009). They are localised areas where aggregate segregation and excessive moisture causes the pavement to deform under traffic load and almost always form in combination with other types of defects (Edvardsson 2009).

A similar, or subset, condition called 'surface gouging' (see Figure 2.21) is a result of soft spots that affect a much greater area, and indeed may extend over an entire road segment. Surface gouging is associated with rutting and results in a surface that is instantly slippery in wet conditions, and if allowed to progress further will leave the road inaccessible (Austroads 2009).

Figure 2.21 – Surface Gouging on an Unsealed Pavement (Austroads 2009)

2.3.3.9 Erosion channels

Erosion channels are formed on the surface of an unsealed flexible pavement and are caused by flow of water along or over the road (Austroads 2009). These channels represent the loss of pavement material through transportation in high velocity water runoff, primarily during periods of rain, and are common on roads with steep gradients and/or an insufficient crown (Austroads 2009; OEH 2012).

Steep gradients give rise to longitudinal erosion channels, where water runoff favours longitudinal flow in preference to that in the transverse direction promoted by the road crown (Austroads 2009). However, erosion channels can also occur perpendicular to the road alignment; where they begin in areas with lower compaction (such as the shoulder) and progress towards the road pavement, or can be caused from local depressions that initially hold the water and eventually carves its own drainage path (Austroads 2009).

Erosion channels are more common in pavements with a high content of fines and small aggregate sizes, more so than a well-graded pavement mix containing aggregate 19 millimetres in size or larger (Austroads 2009).

Figure 2.22 – Longitudinal and Transverse Erosion Channels on an Unsealed Pavement (Austroads 2009)

2.4 Pavement Remediation Treatments and Practices

2.4.1 Introduction

As there are many varied defects that affect flexible pavements, similarly there are multiple remediation options to rectify these defects. Treatment selection will depend on the pavement type (sealed or unsealed) but they may generally be classified in two distinct categories: surface treatments or structural treatments. Structural treatments essentially require the replacement of the failed section of pavement and generally provide a complete repair to the affected area; however they can often be quite expensive. On the other hand, surface treatments can be quite cost-effective but they generally only treat one symptom of many possible failure mechanisms (Irfan et al. 2009).

These treatments, their uses and their relative costs are discussed further below and summarised in Table 2.4, which will form the basis of DSS development and implementation.

2.4.2 Surface Treatments

2.4.2.1 Rejuvenation Seals

Rejuvenation seals are a form of spray seal formulated with a bituminous rejuvenation product to act as both binder and a rejuvenation medium (Giummarra

1995; Holleran 2005; Austroads 2009). The rejuvenation product is designed to "replace lost oils and soften aged and cracked bitumen or asphalt" (Holleran 2005), thereby extending the life of the existing binder. Its application also provides for the possible addition of further surface aggregate to replace any losses that have occurred during the life of the existing seal (Giummarra 1995; Holleran 2005).

Rejuvenation seals are considered beneficial in the treatment of oxidation of bituminous surfaces where the pavement is still considered structurally sound and its application is considered a preventative measure (Holleran 2005). However, when applied in combination with additional aggregate it may be used for the treatment of cracking (where the combination with aggregate serves as mass crack filler) and raveling of bituminous surfaces (Chiu and Lee 2006; Cleaver 2012).

2.4.2.2 Spray Seal

A spray seal is often considered a construction technique in itself where it is used as the bituminous surface in spray sealed roads as discussed earlier. However, the use of a spray seal treatment may also be a suitable remediation method for all sealed flexible pavements, restoring the waterproof membrane as well as replenishing other desirable surface characteristics such as skid resistance (Giummarra 1995; Austroads 2009).

A spray seal may be a suitable treatment for conditions such as stripping and flushing or to abate the further incidence of oxidation in bituminous surfaces, although in the case of stripping it will be used in combination with other treatments required to remedy the root cause of the problem in the underlying pavement (PavementInteractive 2007; Austroads 2009; HYD 2009). It is also used in the treatment of aggregate polishing, where the new surface aggregates restore the desired microsurface required for proper skid resistance (Austroads 2009; HYD 2009).

2.4.2.3 Slurry Surfacing

A slurry surface (shown in Figure 2.23) is the application of a bituminous mixture containing cementitious binder, sands, filler and graded aggregate (to a maximum 7 millimetre stone size), which is placed over the existing surface on low speed traffic

areas (less than 70 kilometres per hour) and in thicknesses less than 12 millimetres (Parish and Mackenzie 1994; Austroads 2009). Slurry surfacing includes microsurfacing, slurry seal and cape seal treatments and the selection of one of the three alternatives will be subject to detailed design (Austroads 2009; Fuxiao et al. 2010).

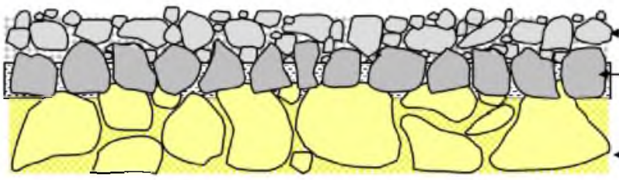


Figure 2.23 – Application of Slurry Seal Treatments (Austroads 2009)

Slurry surfacing may be used in the treatment of aggregate polishing, as well as oxidation, rutting, crocodile cracking, longitudinal cracking, transverse cracking, flushing and raveling in sealed flexible pavements (Hicks et al. 2000; HYD 2009)

2.4.2.4 Asphalt Resurfacing

Asphalt resurfacing involves the application of an asphalt surface over an existing asphalt or spray sealed pavement. In the case of a non-structural overlay (a thin application less than 25 millimetres) it is used to improve ride quality and reinstate the pavement surface integrity, whereas a structural overlay (a thick application greater than 50 millimetres) will also be used to strengthen and stiffen the pavement surface (Austroads 2007). While it is not always necessary to remove the existing surface it is usually desirable to do so, often to maintain the level of the roadway to ensure drainage and shoulder/verge transition is maintained, but it is also useful at preventing further or reflective deformation (Giummarra 1995).

Asphalt overlays can be used in the remediation of delaminations, corrugations, aggregate polishing, flushing, oxidation, rutting, raveling, block cracking, crescent-shaped cracking, crocodile cracking, longitudinal cracking and transverse cracking in sealed flexible pavements, or as an addition to a rigid pavement suffering from any type of surface texture deficiency (Hicks et al. 2000; Austroads 2009; HYD 2009).

It is important to note that there is more than one type of asphalt overlay, including dense graded, fine gap graded, stone mastic and open graded asphalt, and the

selection of one asphalt overlay type is the result of a detailed design and analysis of the root cause of the defect (Austroads 2009). The detail of this design process is outside the scope of this study.

2.4.2.5 Crack Sealing

Crack sealing involves either placing a bituminous sealant over a crack or filling a crack with bitumen emulsion. Crack sealing is most effective when the crack is routed prior to sealing. This provides a greater surface area for sealant adhesion as well as alleviating stresses along dilapidated edges and crack ends, resulting in a longer repair life and improved waterproofing (Giummarra 1995; SAMI 1999).

It is considered a suitable treatment for all types of cracking in sealed flexible pavements. However, it is considered to be only a temporary treatment for block, crocodile and crescent-shaped cracking, all of which require further or more complete remediation (Giummarra 1995; HYD 2009).

2.4.2.6 Grading

While common in the construction of new roads, grading is considered an important maintenance activity for unsealed flexible pavements and particularly beneficial at improving the smoothness of the surface (Austroads 2009). Named after the plant item used to undertake this activity, grading is designed to recover pavement materials that have been transported or dislodged to reshape the road back to its desired profile (Skorseth and Selim 2000; Giummarra 2005; Austroads 2009; OEH 2012).

It is the process of first cutting pavement material from the shoulder with the grader blade to form windrows of pavement material on the road, which are then shaped to the desired profile during subsequent passes and compacted (Giummarra 2005; Austroads 2009). However, care must be taken to not cut too deep so as to introduce unsuitable materials from the subgrade into the pavement (Skorseth and Selim 2000; Giummarra 2005).

Grading is a versatile remediation option; suitable for all types of defects in unsealed flexible pavements except for the treatment of soft spots, but due to its destructive

nature grading alone is not considered suitable for pavements with a rigid, bound or waterproof surface (ESB 1998; Skorseth and Selim 2000; Giummarra 2005; Austroads 2009; Edvardsson 2009; OEH 2012).

2.4.2.7 Reshaping and Shallow Stabilisation

Reshaping involves the shallow scarification of the road surface, which allows the pavement surface aggregates and fines to be blended back to a desirable grading and profiled to an appropriate crown (Skorseth and Selim 2000; Austroads 2009).

This operation can be undertaken in conjunction with the application of liquid binders when a shallow stabilisation of the pavement surface is required (Austroads 2009).

Similar to grading, reshaping and shallow stabilisation is suitable for all types of defects in unsealed flexible pavements except for the treatment of soft spots, but not considered suitable for pavements with a rigid, bound or waterproof surface (Skorseth and Selim 2000; Austroads 2009).

2.4.2.8 Ripping

Ripping can best be described as a combination of reshaping and grading. Like reshaping, the surface is scarified to allow remixing and blending of the existing pavement fines and aggregates (Andrews 2010; Shoalhaven 2014). However, the surface is not simply scarified at its surface; instead large metal teeth called tines penetrate the surface to a depth up to 150 millimetres, and the surface is then shaped with the grader blade and compacted (Andrews 2010; Moya et al. 2011; Shoalhaven 2014).

While also utilised as a construction technique, ripping is an effective remediation technique for all defects that occur on unsealed flexible pavements, with the exception of soft spots which require a deeper pavement repair. Much in the same way as grading, ripping is also not a suitable remediation technique for rigid, bound or sealed pavements (Edvardsson 2009).

2.4.3 Structural Treatments

2.4.3.1 Hot and Cold Mix Asphalt Patching

Patching is the replacement of a failed section of a sealed flexible pavement to its full depth with either hot or cold mix asphalt to reinstate the pavement with sufficient strength (Evans et al. 1990). It is the repair of a local (smaller) area within a segment of road with hot mix asphalt (hot mix) material. Cold mix asphalt (cold mix) patches are selected for temporary or emergency repair measures, where a more permanent (or costly) repair is required for the larger road segment (ESB 1998).

Temporary patching requires the removal of all debris and loose material from the affected area, filling the void with the cold mix and compacting so that it is level with the surrounding pavement surface. More permanent patching will involve excavating the affected area in a square or rectangular cuboid, removing all loose material and debris from the patch area and filling and compacting with hot mix (Giummarra 1995; ESB 1998; Austroads 2009; HYD 2009).

Pothole repair commonly uses a cold mix patching treatment where the deficiency is treated to reinstate the serviceability of the road surface. Hot mix patching is used for the repair of delaminations, shoving, rutting, depressions, edge breaks, crescent-shaped cracking and crocodile cracking as well as a more permanent repair of potholes (ESB 1998; HYD 2009).

2.4.3.2 Full Flexible Pavement Replacement

A full flexible pavement replacement is the removal of the affected pavement to its full depth and replacement with suitable flexible pavement materials. These materials may include granular materials discussed in Section 2.1.1 and may also include recycled materials such as profile chippings and others as discussed in Section 2.1.2.2. This remediation technique completely removes the failed pavement section, and in the case where original construction has been substandard or existing subgrades have deteriorated over time, it may improve the original performance of the pavement (Austroads 2009; McMahon 2010; Austroads 2012).

This type of remediation action is suitable for all flexible pavement defects except for those that only affect the surface of the pavement, where, mainly for cost efficiency, a surface treatment would be better suited.

2.4.3.3 Deep Lift Asphalt

A deep lift asphalt repair involves the placement of a thick asphalt layer over an existing pavement or subgrade. It differs significantly from an asphalt resurfacing treatment in that it is much thicker (greater than 100 millimetres) and is not simply placed over an existing pavement to reinstate the wearing course; rather it will be used to either replace the existing base course or the entire pavement structure. The asphalt layer is desired due to its greater tolerance to plastic deformation and its greater resistance to high traffic loads, in excess of $1x10^6$ ESA (equivalent standard axles) during its design life (Austroads 2009; McMahon 2010; Austroads 2012).

Deep lift asphalt repairs are cost prohibitive in the treatment of surface defects alone, where a surface treatment would be better suited. They are only suitable for sealed flexible pavements and perform best where subgrade support is good and moisture and saturation of underlying pavement layers and the subgrade are not an issue. Therefore, they are considered suitable in the treatment of corrugations, shoving, potholes, patching failure or block, diagonal, longitudinal or transverse cracking.

2.4.3.4 In-Situ Stabilisation

An in-situ stabilisation treatment follows the construction processes of stabilised pavements discussed in Section 2.1.2.1, where the existing failing pavement material (including its subgrade) is recycled and its life extended by stiffening said materials with a cementitious admixture. However, in-situ stabilisation is not considered a suitable remediation treatment for small areas, it is a large operation that uses heavy machinery and is therefore not appropriate for small localised areas (Bullen 1996; Kodikara and Yeo 2005; Manager 2011).

This type of remediation treatment is suitable for all flexible pavements where defects cover a large area, preferably an entire segment, to promote economies of scale. It can be used to remedy any defect condition though, mainly for cost

efficiency considerations, it would not be preferred in the treatment of surface defects alone, where a surface treatment would be better suited.

2.4.3.5 Lean Mix Concrete

A lean mix concrete treatment is the replacement of one of the existing pavement layers (usually the subbase) with low strength concrete, typically with a characteristic 28 day compressive strength of 5 megapascals. Its primary use is to bridge poor subgrades and should be used for larger areas where the extremities of the concrete subbase extend through to the edge of the traffic lane to avoid future reflective cracking in trafficable areas (McMahon 2010; Manager 2011; Austroads 2012).

Lean mix concrete treatments are suitable primarily for sealed flexible pavements and used to remediate defects caused by subgrade failures, namely rutting, depressions, corrugations or block or meandering cracking.

2.4.3.6 Pavement Nourishment

Pavement nourishment is broadly the importation of further pavement materials to top-up or improve the integrity of a road pavement. It is necessary in the remediation of soft spots in unsealed flexible pavements, which need to be completely removed and replaced to avoid redevelopment of surface depressions (Edvardsson 2009). Please note: through Case Study exploration discussed in Chapter 5, it was determined that Pavement Nourishment is more commonly referred to in the industry as a "Gravel Resheet".

2.4.4 Treatment Selection and Suitability

The various array of defects and their suitable remediation actions, as described in Section 2.2 and Section 2.3, is a complex relationship. That is, one defect may have several remediation options and similarly one remediation option may treat multiple defect types.

A review of the available literature discussed in Sections 2.2 and 2.3 has shown a distinct absence of studies linking all the possible defects associated with flexible pavements with their respective suitable remediation options. Rather, previous

studies have focussed on either: quantifying the deterioration mode of one or more specific defecs; or the exploration and refinement of specific remediation techniques in response to one defect mechanism. To address the need to link suitable remediation treatments to pavement defects, the author has distilled the knowledge gained through the literature review to succinctly summarise the relationship between defects and available remediation techniques, which is presented in Table 2.3 and in turn, will form the basis of the DSS developed as a focus of this study.

Table 2.3 – Suitability of Available Remediation Actions for Flexible Pavements

Pavement Defect Type	Suitability of Remediation Options[1] (✓ = Possible Suitable Remediation Solution)													
	Asphalt Resurfacing	Hot/Cold Mix Asphalt Patching	Spray Seal	Slurry Seal	Crack Sealing	Rejuvenation Seal	Full Flexible Pavement Replacement	Deep Lift Asphalt	In-Situ Stabilisation	Lean Mix Concrete	Pavement Nourishment	Grading	Reshaping & Shallow Stabilisation	Ripping
Sealed Flexible Pavements														
Aggregate Polishing	✓		✓	✓										
Block Cracking				✓	✓	✓	✓	✓	✓	✓				
Corrugations	✓						✓	✓	✓	✓				
Crescent-Shaped Cracking		✓			✓	✓								
Crocodile Cracking	✓	✓		✓	✓	✓	✓		✓					
Delamination	✓	✓												
Depressions		✓					✓		✓	✓				
Diagonal Cracking	✓				✓	✓	✓	✓	✓					
Edge Break		✓												
Flushing	✓		✓	✓										

[1] Refer Section 2.2 and Section 2.3

Table 2.3 – Suitability of Available Remediation Actions for Flexible Pavements (*continued*)

Pavement Defect Type	Suitability of Remediation Options[2] (✓ = Possible Suitable Remediation Solution)													
	Asphalt Resurfacing	Hot/Cold Mix Asphalt Patching	Spray Seal	Slurry Seal	Crack Sealing	Rejuvenation Seal	Full Flexible Pavement Replacement	Deep Lift Asphalt	In-Situ Stabilisation	Lean Mix Concrete	Pavement Nourishment	Grading	Reshaping & Shallow Stabilisation	Ripping
Sealed Flexible Pavements (cont.)														
Longitudinal Cracking	✓			✓	✓	✓	✓	✓	✓					
Meandering Cracks	✓				✓	✓	✓			✓				
Oxidation	✓		✓	✓		✓								
Patching Failure	✓	✓					✓	✓						
Potholes		✓					✓	✓	✓					
Pumping							✓		✓					
Raveling	✓			✓		✓								
Rutting	✓	✓		✓			✓		✓	✓				
Shoving		✓					✓	✓	✓					
Stripping			✓											

[2] Refer Section 2.2 and Section 2.3

Table 2.3 – Suitability of Available Remediation Actions for Flexible Pavements (*continued*)

Pavement Defect Type	**Suitability of Remediation Options**[3] (√ = Possible Suitable Remediation Solution)													
	Asphalt Resurfacing	Hot/Cold Mix Asphalt Patching	Spray Seal	Slurry Seal	Crack Sealing	Rejuvenation Seal	Full Flexible Pavement Replacement	Deep Lift Asphalt	In-Situ Stabilisation	Lean Mix Concrete	Pavement Nourishment	Grading	Reshaping & Shallow Stabilisation	Ripping
Sealed Flexible Pavements (cont.)														
Transverse Cracking	√			√	√	√	√	√	√					
Unsealed Flexible Pavements														
Corrugations											√	√	√	√
Depressions							√		√					
Erosion Channels							√				√	√	√	√
Loss of Fines											√	√	√	√
Potholes							√		√		√	√	√	√
Raveling											√	√	√	√
Rutting							√		√		√	√	√	√
Soft Spots							√		√		√			

[3] Refer Section 2.2 and Section 2.3

The costs associated with the aforementioned remediation activities are dependent on location and distance to available quarry materials. Therefore it is difficult to quantify an exact broad cost, rather Table 2.4 provides a summary of relative costs for each remediation activity taken from Fletcher (2009) and McMahon's (2010) case studies of Wollongong City Council as well as from the initial case study of Shoalhaven City Council, local government areas located on the south coast of New South Wales.

Table 2.4 – Relative Costs of Remediation Activities

Remediation Treatment	**Nominal Cost**
Asphalt Resurfacing	\$24-\$28/m^2 (Shoalhaven 2014)
Crack Sealing	~\$12/m (SCC case study 2014)
Deep Lift Asphalt	~\$78/m^2 (McMahon 2010)
Full Flexible Pavement Replacement	\$140-\$210/m^2 (McMahon 2010)
Grading	\$1.3/lin.m (Shoalhaven 2014)
Hot/Cold Mix Asphalt Patching	\$15-\$25/m^2 (SCC case study 2014)
Lean Mix Concrete	\$114-\$119/m^2 (McMahon 2010)
Pavement Nourishment	\$10/m^2 (Shoalhaven 2014)
Rejuvenation Seal	\$2-5/m^2 (Fletcher 2009)
Reshaping and Shallow Stabilisation	\$4-\$6/m^2 (SCC case study 2014)
Ripping	\$3-\$5/m^2 (SCC case study 2014)
Slurry Seal	\$3-\$8/m^2 (Fletcher 2009)
Spray Seal	\$7/m^2 (Shoalhaven 2014)
In-Situ Stabilisation	~\$50/m^2 (McMahon 2010)

It should be noted that Table 2.4 is a presentation of preliminary data as indicated at the time of the literature review. These rates will be subject to critical review and refinement during the system development and refinement stages of this study.

2.5 Summary

A typical local government road network is predominantly made up of flexible pavements, sealed and unsealed, and while they may also feature rigid and segmental block pavements they represent quite a small area compared to flexible pavements. While there are some similarities between rigid and segmental block pavements with flexible pavements, the failure mechanisms in those pavement types differ significantly, due to their structural properties and may be well suited to future development of this proposed decision support system into a model for all road pavements.

Flexible pavements suffer from a wide variety of defect types, from surface texture deficiencies and cracking, to the deformation of the pavement structure. Despite their similarity in structure, the mechanisms from which these defects arise within sealed and unsealed flexible pavements is often quite different, where it can be seen that the absence of a hardy weatherproof membrane (such as the wearing course of a sealed flexible pavement) leaves the unsealed flexible pavement more susceptible to moisture and traffic induced deficiencies. That is, defects such as rutting and corrugations (for example) are induced by structural failure or movement of underlying sealed flexible pavement layers, whereas for unsealed flexible pavements they are caused by weather and surface losses under normal traffic loads and conditions.

Accordingly, while remediation activities available for each pavement type are also similar, the absence of a sealed wearing course allows the use of lower cost alternatives such as grading, ripping or shallow stabilisation. Such activities on a sealed pavement would not be as cost-effective due to the cost of removing and reinstating the wearing course. Therefore, in the maintenance of sealed flexible pavements there is a large focus on preserving and remediating the bituminous surface as well as remediating or replacing the failed sections of the pavement structure to avoid further deterioration. This is reflected in Table 2.3 which presents the various defect types alongside their suitable remediation options.

Therefore, with so many possible defects that have the potential to affect any given segment of pavement, and the combination of remediation alternatives available to

fix the issues, the road asset manager is required to make a large number of decisions to benefit not only the road network, but also the organisation and the community. How these decisions are made is explored further in Chapter 3.

3 TASK PROFILING: DECISION MAKING AND ITS ROLE IN ROAD ASSET MANAGEMENT

3.1 Introduction

The focus of this study is to design a decision support tool (decision support system or DSS) to assist road asset managers and their staff conceptualise and develop effective and efficient road maintenance engineering decisions, otherwise referred to as 'pavement management'.

The concept of road asset management has been in existence since the advent of the road itself. Dating back to the era of the Roman Empire, the principles of firm road construction and on-going maintenance arose due to the need to transport large infantry, supplies and equipment, which was key to the rise and long term success of the empire (Thompson 1997). Today, the role of the road remains equally (if not more) important, providing significant economic and social benefits to the community (Bartlett and Shirey 2011).

It is the role of asset managers and their staff (the asset management team) to ensure the quality and performance of the assets under their control (Picado-Santos et al. 2004; Chootinan et al. 2006). In order to achieve this, the asset management team is required to exercise sound engineering judgement over the life of their assets, balancing technical effectiveness and fiscal efficiency along with social expectations and acceptance (Kaspura 2012).

In 1991 Local Government Authorities (LGAs) in Australia spent in the order of $1.5 billion yearly on roads (Mulholland and Metcalf 1991). Between 1997-98 local government road spending totalled $2.7 billion (BTE 2001), while in 2012-13 the local government portion of spending on roads was $6.2 billion of an overall $19.4 billion of roads nationwide (BITRE 2013).

In the year 2012/13 Shoalhaven City Council reported a road maintenance budget deficit in the order of $1 million which is an issue affecting many LGAs in Australia, and indeed State and Federal levels of government as well (Chan et al. 1994; Chootinan et al. 2006; Abo-Hashema and Sharaf 2009; Ferreira et al. 2009; Fletcher 2009). This shortfall, coupled with the increasing cost of resources, demonstrates the

importance of ensuring the effective and efficient management of roads at the local government level (Fletcher 2009; Malam and Lubulwa 2011).

3.2 The Decision Making Problem

Road asset managers and their staff (known as the road asset management team) face the problem that "*the development of a multi-year pavement maintenance program is highly dependent on the ability to estimate future pavement conditions*" (Zimmerman 1995).

Road asset managers are typically senior staff members who have demonstrated years of experience and expertise in the field of road design and/or road maintenance programming and/or road construction. They are often considered experts in their field with a high level of conceptualisation skill. However, the remaining structure of the road asset management team can vary from organisation to organisation, although usually it will feature members that have varying degrees of conceptualisation skill, from the junior (or novice) to the expert, as illustrated in Figure 3.1 below from an analogous *Engineering Design Process* presented by Lemass (2004).

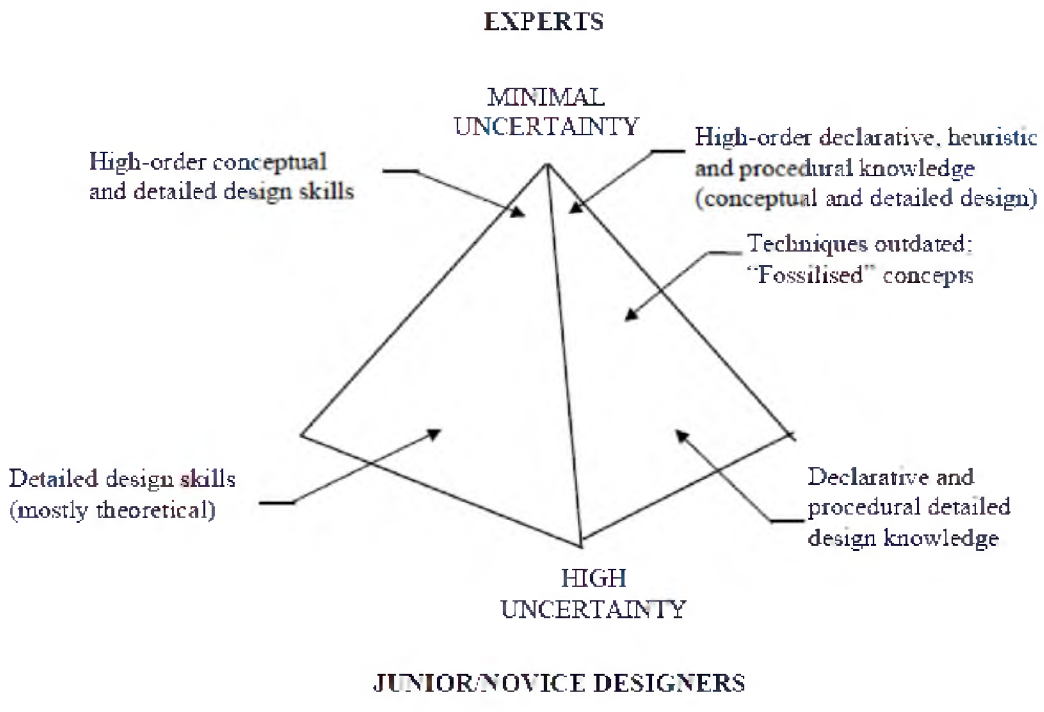


Figure 3.1 – The Design Expertise Pyramid (Lemass 2004)

In the road asset management environment it is ultimately the role of the road asset manager to apply their own expert, heuristic and tacit knowledge of the problem, the organisation, and other pertinent intricacies of the road network, to determine the most suitable solution to the problem; and in doing so, they will often empower their staff to acquire the same knowledge and decision making skills (Zimmerman 1995; Picado-Santos et al. 2004; Abo-Hashema and Sharaf 2009).

Therefore, the road asset management team work within the context of their organisation to make decisions that either maximise network performance, maximise the cost-effectiveness of maintenance activities, minimise road user cost, minimise the present worth of the total maintenance cost, or use any other permutation of these principles (Chootinan et al. 2006).

The difficulty for the road asset management team making road management decisions is described by Ferreira (2002), who gives the example of a small 20 segment road network. That study included a probabilistic assessment of the occurrences of defects in a Lisbon road network and quantified that over a short, four year cycle, the number of possible individual alternative remediation options would be in the order of 2.2×10^{76}. Examples such as these have provided the impetus for researchers to investigate better decision making tools (Ferreira et al. 2002; Picado-Santos et al. 2004; Chootinan et al. 2006).

Another tool that is used to not only illustrate the complex array of remediation options but also assist in the decision making process is decision tree analysis. Decision trees are classifiers that relate states of being with options or decisions that *branch* out to child states of being, forming a hierarchy named a tree (Kingsford and Salzberg 2008; Abo-Hashema and Sharaf 2009; Kang et al. 2010).

Decision tree analysis of the pavement management problem provides a good illustrative tool to demonstrate the interaction between problems (as they are defined) and final solutions. In pavement management, decision trees are mostly presented for individual distresses rather than entire pavement segments to avoid the complex combinations encountered by Ferreira (2002). Figure 3.2 provides an example of a decision tree for an individual defect (aggregate polishing), summarised by the

author from the reviewed literature presented in Sections 2.2 and 2.3 (specifically Table 2.3); while Figure 3.3 provides a decision tree analysis of the complex combinations between defects and remediation options over an Egyptian highway pavement presented by Abo-Hashema and Sharaf (2009) which also confirms Ferreira's (2002) high order quantification of the problem presented above.

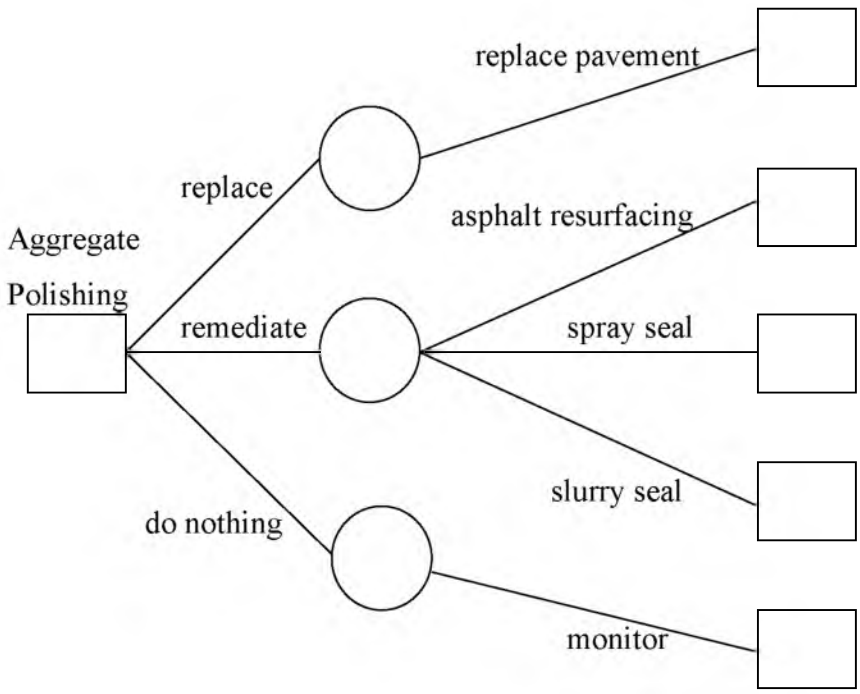


Figure 3.2 – Decision tree for aggregate polishing in sealed flexible pavements

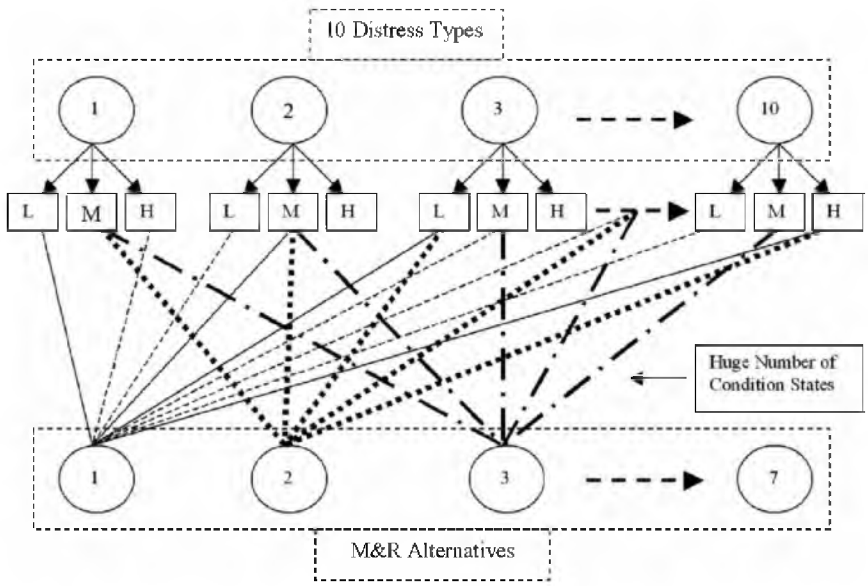


Figure 3.3 – Schematic illustration of the relationship between distress levels and maintenance alternative (Abo-Hashema and Sharaf 2009)

3.3 Road Asset Management Decision Making Systems

In the late 1960's Pavement Management Systems (PMS) emerged as the solution to the road management problem (Markow et al. 1987). Essentially a system of maintenance planning, a PMS is a computerised instrument that aims to facilitate conceptual and detailed decision making for road maintenance (Chan et al. 1994; Markow 1995; Abo-Hashema and Sharaf 2009). In 1985 there were less than 10 Australian local government areas with a PMS in place, but with the advent and increased use of computers they are considered common place for all road networks (Mulholland and Metcalf 1991; Finn 1998; Abaza et al. 2004).

Picado-Santos et al. (2004) suggested that an effective PMS consists of a basic structure that includes road network data collection, quality evaluation and decision making. Extrapolating on Lemass' (2004) study of the engineering design process, it can be seen that what is considered an effective PMS also share some very strong similarities with the engineering design process. In his study, Lemass defined the engineering design process in two distinct phases; conceptual design and detailed design (Lemass 2004), where maintenance decision making is much akin to the conceptual design phase that consists of three sub-phases: design-work-scope clarification, ideation (conceptualisation) and concept embodiment (preliminary sizing and costing); where it can be seen that that:

- "Design-work-scope clarification" would relate to the function of 'road network data collection',
- "Ideation (Conceptualisation)" would encompass road pavement 'quality evaluation'; and
- "Concept embodiment (preliminary sizing and costing)" would result in suitable remediation option 'decision making'.

These concepts are discussed in further detail below and demonstrate that the road asset manager is essentially required to be what Lemass (2004) termed as a skilled "conceptual designer".

3.3.1 Road Network Data Collection

The road network is made up of all the individual roads owned and/or controlled by the LGA or roads administrator, where individual roads within the road network are divided into *segments* that are generally defined by chainage distance from a specific point of intersection with another road within the network. A segment of road will be defined in terms of:

- age/date of original construction,
- materials – type and thicknesses,
- traffic loading characteristics, and
- historical maintenance and rehabilitation actions.

(Lamptey et al. 2008; Fletcher 2009; Manager 2011)

Segments allow the road to be divided into smaller *manageable* lengths of pavement, where localised deterioration and anomalies can be better identified and not masked by long lengths of road that could otherwise be in good condition. (Chan et al. 1994; Fwa et al. 1994; Fwa et al. 1996; Ferreira et al. 2002; Picado-Santos et al. 2004; Chootinan et al. 2006; Fletcher 2009).

In the aforementioned study by Lemass (2004), the *design-work-scope clarification* phase of design is where initial data collection of the design requirements is acquired and where a clear statement of the real problem is formulated. This correlates directly with the function of road network data collection.

The road network database contains descriptive and historical information about the road network (in its segments), such as geographical data (segment locations and lengths), pavement structure and foundation characteristics, geometrical data (lane width, shoulder width and median width), roadside environment characteristics (table drains, kerb and gutter, and the like) and maintenance history (Picado-Santos et al. 2004). The database tells the 'story' of the road segments within the network. It is designed to be a live document, storing all the historical and present-day knowledge of each road segment.

The road network database holds the current information regarding pavement integrity. From this, and much similar to the *design-work-scope clarification* design phase, a problem statement for the road segment can easily be formulated. The fundamental difference between the problem statements generated through the road network database as opposed to that interpolated from a client's project brief lies in its objectivity.

Cross (2000) and Lemass (2004) describe a project or design brief as being "*very aptly called that - it is a very* ***brief*** *statement!*" and often the client themselves are unclear about exactly what it is they require. The road network database does not require such subjective interpretation. That is, the failure mechanisms of road pavements and their physical manifestations are well documented, as outlined earlier in this dissertation; as such there is relatively more certainty in the problem statements generated from the road network database than from an uncertain client.

Therefore, the road network database will objectively define the condition of the road network. However, the road asset management team are now required to define and evaluate what this information means. In order to assist the road asset management team to better understand the condition of their road networks, many PMS utilise quality evaluation tools in combination with the road network database.

3.3.1.1 Road Network Data Collection at Shoalhaven City Council

Shoalhaven City Council (SCC) is a local government located on the south coast of NSW. The Shoalhaven area has approximately 2,500 kilometres of roads; 2,100 kilometres of which are owned and/or controlled by SCC and the remaining 400 kilometres are owned and controlled by state or federal governments (Manager 2011).

Detailed in Section C.2 of Appendix C, this initial case study found that SCC maintains its road network data with two objectives in mind: risk-based management to ensure the immediate safety of its road users; and strategic management that considers the whole-of-life performance of its roads in relation to its entire network. In order to achieve these objectives "Roads Inspectors" are employed to routinely surveil the road network and capture its condition by recording defects into

proprietary software databases Merit™ (risk-based management) and Conquest™ (strategic management) (Manager 2011; Manager 2012).

In order to develop a standard and to ensure consistency in the method in which data is collected throughout the Shoalhaven, SCC has developed Asset Management Plans for both its sealed and unsealed roads. The Asset Management Plans set standards that reflect a mixture of the asset's, the community's and the organisation's risk tolerance for the condition of the pavement. In doing so, these Plans outline inspection frequencies for their respective pavement types (depending on the road's classification) which are summarised in Table 3.1 and Table 3.2.

Table 3.1 – Inspection Frequency of Sealed Roads at Shoalhaven City Council (Shoalhaven 2014)

Road Hierarchy Category	Hazard/Risk Identification Inspection Interval	Distribution of Inspections
Sealed Arterial	Monthly*	12 in any 12 month period
Sealed Collector	6 Monthly	2 in any 12 month period
Sealed Local	12 Monthly	1 in any 12 month period

Table 3.2 - Inspection Frequency of Unsealed Roads at Shoalhaven City Council (Shoalhaven 2014)

Road Hierarchy Category	Hazard/Risk Identification Inspection Interval	Distribution of Inspections
Collector	6 Monthly	2 in any 12 month period
Local	12 Monthly	1 in any 12 month period

Once recorded into the database, the Road Asset Manager is then able to begin evaluating a road pavement's quality to ascertain whether any remediation actions may be required.

3.3.2 Quality Evaluation

A quality evaluation tool allows the cumulative information stored within the road network database to be reviewed over the entire network and allow the asset manager to best plan the management of their roads. Asset managers have limited resources at their disposal (budget, workforce and organisational constraints, among others), so quality evaluation is integral to the maintenance planning of a road network (Chan et

al. 1994). Using the road network database as described in Section 3.3.1, the specific defects and their severities are documented for each segment of road and are used to describe the pavement condition (Fwa et al. 1994; Fwa et al. 1996; Ferreira et al. 2002), but in order to effectively manage overall pavement performance and maximise life across the entire network with limited resources, the asset manager is required to objectively assess road pavement quality.

Lemass (2004) describes the second phase of design as being the *ideation (conceptualisation)* phase, whereby the designer begins to develop concepts from many varied ideas. That is, a number of solutions are developed without any commitment to one particular course of action. Similarly, in the quality evaluation stage of the road asset maintenance process the condition of the road network becomes apparent and the road asset manager can begin to conceptualise possible suitable maintenance and rehabilitation actions.

As discussed in the previous chapter, different defect types will affect pavement performance and pavement life in different ways and likewise defect severity will also have varying effects on a pavement (Fwa et al. 1996; Ferreira et al. 2002; de Solminihac et al. 2003; Picado-Santos et al. 2004; Chootinan et al. 2006). Therefore, a tool the asset manager will use in quality evaluation is to numerically represent pavement condition by calculating its Pavement (or Present) Serviceability Index (PSI) – also referred to as the Pavement Condition Index (PCI) within some organisations (Picado-Santos et al. 2004).

Exact methods for calculating the PSI will vary depending on the intricacies and goals of the particular management system. However, generally for a segment in the road network database the PSI is a calculation from all the various recorded pavement defects in that segment of road, factoring the defects and their severities based on their known ability to affect pavement performance and life.

3.3.2.1 Pavement Serviceability Index

The PSI calculation will vary from organisation to organisation and is applied as a mix of known and documented pavement behaviour described above, but will also incorporate organisation-specific intelligence from their own local area. For example,

a system developed in Portugal for Lisbon City Council in partnership with the University of Coimbra calculates PSI for a segment of road at time *t* in Equation 3.1 (Picado-Santos et al. 2004).

$$PSI_t = 5e^{(-0.0002598IRI_t)/4} - \frac{0.002139}{4}R_t^2 - 7 \times 0.03(C_t + S_t + P_t)^{0.5}$$

Equation 3.1

where:

IRI_t is the pavement longitudinal roughness in year t (mm/km);

R_t is the mean rut depth in year t (mm);

C_t is the total cracked pavement area in year t ($m^2/100\ m^2$);

S_t is the total pavement disintegrated area (with potholes and raveling) in year t ($m^2/100\ m^2$); and

P_t is the pavement patching area in year t ($m^2/100\ m^2$)

It can be seen from Equation 3.1 that a PSI calculation is based on individual defects and their severities and can also rely on other ride quality measurements such as roughness and degree of patching. Roughness and patching, along with skid resistance are quality evaluation measures that give an insight to the overall performance of the pavement and assist in formulating an effective PSI (Picado-Santos et al. 2004; Manager 2011). Table 3.3 illustrates the different levels of defect degradation and their relative importance on the Pavement Serviceability Index for a road network located in Lisbon, Portugal; while Figure 3.4 (devised by the author) describes the way in which quality measurements influence the PSI evaluation process.

Table 3.3 – Adopted area/value for the degradation levels considered in the PSI calculation – Lisbon road network (Picado-Santos et al. 2004)

Degradation type	Gravity levels	Degradation level description	Adopted area/value
Cracking	Level 1	Isolated cracks	0.5 m × cracking length
	Level 2	2 mm < ramified crack opening < 4 mm	2.0 m × cracking length
	Level 3	Ramified crack opening > 4 mm	Segment width × cracking length
Alligator cracking	Level 1	Crack opening < 2 mm and width > 20 cm	Segment width × cracking length
	Level 2	Crack opening < 2 mm and width < 20 cm, or crack opening between 2 and 4 mm, or crack opening > 4 mm and width > 40 cm	Segment width × alligator cracking length
	Level 3	Crack opening > 4 mm and width < 40 cm	Segment width × alligator cracking length
Ravelling	Level 1	Width < 30 cm	0.5 m × degrad. length
	Level 2	30 cm < width < 100 cm	2.0 m × degrad. length
	Level 3	Width > 100 cm	Segment width × degradation length
Potholes	Level 1	Maximum depth < 2 cm	0.5 m × degrad. length
	Level 2	2 cm < maximum depth < 4 cm	2.0 m × degrad. length
	Level 3	Maximum depth > 4 cm	Segment width × degradation length
Patching	Level 1	Well executed	$\frac{1}{4}$ segment width × degradation length
	Level 2	Low-quality action or deficient finishing	$\frac{1}{2}$ segment width × degradation length
	Level 3	Badly executed	Segment width × degradation length
Rutting	Level 1	Maximum depth < 10 mm	10 mm
	Level 2	10 mm < maximum depth < 30 mm	30 mm
	Level 3	Maximum depth > 30 mm	50 mm
Longitudinal roughness	Level 1	A user in a passenger vehicle does not feel vibrations	IRI = 2000 mm/km
	Level 2	A user in a passenger vehicle can feel small vibrations occasionally	IRI = 3500 mm/km
	Level 3	A user in a passenger vehicle can feel small vibrations along almost all the segment and/or serious vibrations can be felt occasionally	IRI = 5500 mm/km

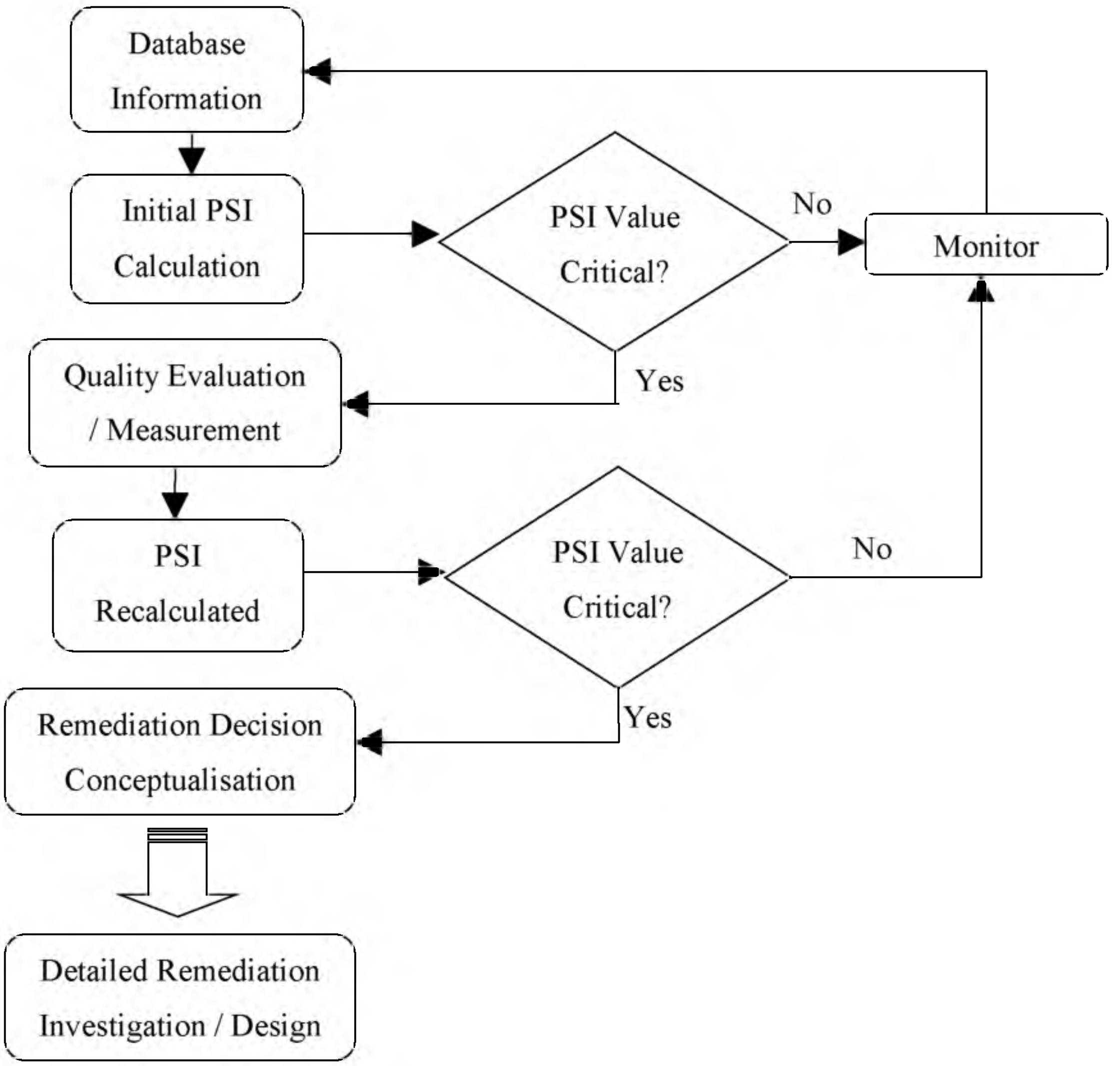


Figure 3.4 - Pavement Serviceability Evaluation Process

Pavement Roughness

Pavement roughness is a measurement of the number of deflections a vehicle will experience while travelling over a pavement surface, a measurement of the degree in which the road surface deviates from the intended longitudinal profile. Rather than the quantification of an individual defect, it is the cumulative measurement of all defects that are measurable from the surface of the pavement and provides a strong indication of the overall condition of the road (Xu and Yong 1993; Austroads 2007).

In Australia, the traditional NAASRA measurement of roughness was discontinued in 2007 in favour of the International Roughness Index (IRI). The IRI is a

measurement of vertical displacement of the test vehicle/apparatus (illustrated in Figure 3.5 below) in the units of metres per kilometre (Austroads 2007).

Figure 3.5 – Typical Roughness Measurement Vehicle/Apparatus (FUGRO 2012)

There are two predominant methods for measuring roughness, *quarter-car model* and *half-car model*, however, only the quarter-car model is endorsed in Australia (Austroads 2007). The half-car model measures the roughness of both wheel paths within a lane simultaneously, whereas the quarter-car model measures the roughness of each individual wheel path within a lane independently, then the roughness of the lane is calculated as prescribed by Austroads (2007), presented in Equation 3.2.

$$Lane\ IRI_{qc} = \frac{Single\ Wheelpath\ IRI_{qc}(inner) + Single\ Wheelpath\ IRI_{qc}(outer)}{2}$$

Equation 3.2

The roughness measurement provides a numeric correlation to observed ride quality. Table 3.4 illustrates a typical correlation between measured roughness (IRI) and the ride quality that may be observed by a driver or passenger of a vehicle, and is described in plain language that is easily interpreted by a non-technical person (Fletcher 2009).

Table 3.4 – Ride quality with IRI (KCC 2007)

Range of IRI	NAASRA	Ride Quality	Roughness Rating
Less than 2.69	0-70	Very smooth ride	Excellent
2.69 to 5.33	70-140	Few minor bumps encountered	Good
5.33 to 7.60	140-200	Small up and down movement, reasonably comfortable driving	Fair
7.60 to 9.48	200-250	Constant up and down movement, feel rough in trucks, low comfort	Poor
9.48 to 11.37	250-300	Uncomfortable driving, severe up and down and sideways movement. Good control of steering must be maintained. Reduction in speed may be required	Very Poor

Patching

Patching as a quality measure is an assessment of the quantity of sealed flexible pavement (number of repairs and percentage of overall pavement surface area) containing hot or cold mix asphalt (H/CMA) patching repairs (Picado-Santos et al. 2004; Manager 2011). While a H/CMA patching repair, as discussed earlier, is designed to remedy defects found in a segment of road, no matter how well the repair is functioning, it will never function as well as the original pavement section (Geller 1996). Therefore a large patching value indicates a substandard pavement (Fletcher 2009).

The patching value (P or P_t) is provided as a percentage that indicates the proportionate area of H/CMA patching to the overall area of a road segment (Manager 2011), and is simply give by Equation 3.3.

$$P = \frac{\sum(Area\ of\ H/CMA\ patching\ repair)}{Total\ area\ of\ pavement\ segment} \times 100$$

Equation 3.3

Patching may also be described in terms presented earlier for Equation 3.1, as $m^2/100m^2$, however the practicality of this will depend on the road network database and the length of the segments that are defined therein. Therefore for ease of

operation, expressions of P as illustrated in Equation 3.3 are preferred (Manager 2011).

Skid Resistance

Skid resistance refers to the friction generated between the tyre of a vehicle and the pavement surface it is travelling on (ARRB 2002; Austroads 2011). It is greatly affected by surface texture and its deficiencies (discussed in Section 2.2.1), particularly microtexture and macrotexture, and has a significant impact on road user safety (ARRB 2002; Austroads 2011).

All the commercially available skid resistance measurement apparatuses utilise the same basic principle, where rubber (either a tyre or a slider) is forced to slide across a wetted road surface under an applied load, where the horizontal resisting force of the sliding rubber is measured and factored by the vertical load (Austroads 2009; Austroads 2011).

In Australia and New Zealand, there are two main types of skid resistance measurement methods, the continuous network and the portable site measurement methods. Continuous network measurement methods include SCRIM (Sideways-Force Coefficient Routine Investigation Machine), GT (Grip Tester) and ROAR (Norsemeter Road Analyser and Recorder), described below (Austroads 2009; Austroads 2011):

- SCRIM uses a free rotating smooth rubber tyre angled at 20 degrees, placed under a 200 kilogram vertical load and attached to a test vehicle moving at a fixed speed. With the tyre placed at an angle to the travel path, it will impart a lateral force to the vehicle, where this lateral force can be correlated to skid resistance.
- GT uses a three-wheeled trailer (one smooth test wheel and two bogey wheels), where the test wheel is geared down to a fixed slip ratio and both the vertical load and traction force on the axle are measured to be correlated with skid resistance.
- ROAR utilises software packages to test either fixed or variable slip traction. Also using a smooth tyre, it is controlled using a linear braking system that is

incrementally applied until fully locked, where the maximum slip speed can be measured as well as maximum vertical load and traction forces on the axle. From these measurements the coefficient of friction can then be derived.

Portable site measurement methods include the Portable or British Pendulum Tester (PPT or BPT), Direct Friction Tester (DF) and Vericom, described below:

- PPT is the most commonly used portable skid resistance apparatus in Australia. It uses a rubber slider mounted on a pendulum arm that is inclined to approximately 20° and mounted on a spring. After releasing it from its top (horizontal) position, the rubber slides along the pavement surface and produces a maximum incline reading as the pendulum passes to the other side of its arc. This incline reading is corrected for temperature, converted to skid resistance value (SRV) that is derived into friction coefficients (Austroads 2009).
- A DF comprises a horizontal spinning disc with three rubber sliders; the disc is lowered onto the road surface under a fixed load and the torque resistance measured can then be converted to a coefficient of friction (Austroads 2009).
- Vericom is an in-car accelerometer that measures forward acceleration on the test vehicle when it is braked heavily from a fixed speed. The time taken to come to a complete stop and the associated gravitational forces can then be correlated to friction coefficients (Austroads 2009).

Currently there is no specific equipment designed to measure the skid resistance of unsealed flexible pavements as these roads have a dynamic surface that makes it difficult to predict skid resistance (Lea and Jones 2007; Austroads 2009). Accordingly, the measurement of skid resistance on these roads will be subject to interpretation from the asset manager, or their staff, where they will look to identify deficiencies in inter-surface friction or observe sliding on thin layers of loose material or ploughing through thick layers of loose material (Lea and Jones 2007). It should also be noted that, while difficult to measure, Lea and Jones (2007) quantified that the preferred range of coefficients of friction on unsealed flexible pavements should fall between 0.40 to 0.85, with the lower value being a conservative figure.

The values of skid resistance, roughness and patching can then be incorporated into the PSI calculation, along with other defect measurements to give the asset manager an objective value in which to draw comparisons of deterioration along all segments of the road network and are then able to make decisions at network level.

Surface Deflection

Surface deflection measurement is used to determine the structural capacity of a flexible pavement (Sangpetngam et al. 2011). It is measured by a variety of test methods including Loadman, Falling Wight Deflectometer (FWD), Nuclear Density Meter, Clegg Hammer or the more common Benkelman Beam test (Pidwerbesky 1997; Sangpetngam et al. 2011). However, surface deflection measurement is not typically used in the determination of the PSI; rather, it is used to determine the design requirement of the selected remediation treatment, illustrated in the last stage of Figure 3.4 (Pidwerbesky 1997; Picado-Santos et al. 2004; Manager 2011; Sangpetngam et al. 2011). Further, the detail design of remediation treatments is not considered as part of this study; accordingly, surface deflection measurement (specifically Benkelman Beam testing) is not discussed further in this study.

3.3.2.2 Quality Evaluation at Shoalhaven City Council

As explored in the initial case detailed in Section C.2 of Appendix C, it was found that following the data collection phase and through the utilisation of databases, SCC is capable of continuously evaluating the quality of their road network through the use of a number of tools.

The SCC road network is divided by its segments of approximately 500 metre lengths. Upon entering the collected defect data for each segment into the database, the Road Asset Inspector provides each defect a score against its severity between 1 and 5 to describe its current condition utilising the scoring system outlined in Table 3.5 (Manager 2011; Manager 2012).

Table 3.5 – Defect Severity Scoring for Shoalhaven City Council Road Asset Management

Defect Severity Score	Description
1	Excellent
2	Fair
3	Satisfactory
4	Poor
5	Unsatisfactory

Based on the organisational intelligence held regarding the local nuances of the road network and the relative impact of the various defect types, the Road Asset Manager at SCC is able to prioritise the segments of road most in need of remediation. An example of this is the fact that in the Shoalhaven only four major defect types (shown in Table 3.6) are considered to be the most critical to their pavement performance. This coupled with a calculation for what SCC terms an "Average Condition Score" (otherwise referred to in this study as the PSI) for each segment, utilising the defect severity score and a defect weighting assigned from the values shown in Table 3.6 such that:

$$ACS = \sum \frac{(S_i W_i)}{W_T}$$

Equation 3.4

where:

ACS is the Average condition Score, which is comparable to *PSI* (the pavement serviceability index);

S_i is the severity score of individual recorded defects;

W_i is the weighting of the individual defect type given by Table 3.6; and

W_T is the sum of the defect weightings, which Table 3.6 shows will be a constant value of 8

(Manager 2011)

Table 3.6 – Defect Weighting used in Shoalhaven City Council Road Asset Management

Defect Type	Weighting
Cracking	2
Patching (m^2/m of road)	3
Binder/Stone loss	1
Rutting/Deformation	2
Total	**8**

Another quality evaluation tool used in the Shoalhaven is considered from a risk-based perspective, where the Asset Management Plans (AMPs) described in Section 3.3.1.1 are supplemented by Risk Management Procedures (RMPs) which outline quality thresholds that reflect a mixture of the asset's, the community's and the organisation's risk tolerance for the quality of the pavement. Relying on organisation knowledge, the AMPs and RMPs list "recording levels" for defect severities to prescribe the minimum allowable tolerance for road quality, whereby intervention (in the form of remediation) is required. Table 3.7 and Table 3.8 outline the recording levels for defects in sealed and unsealed roads respectively in the Shoalhaven (Manager 2012).

Table 3.7 – Defect Intervention Thresholds for Sealed Roads at Shoalhaven City Council (Shoalhaven 2014)

Hazard Code	Hazard Description	Recording Level
1200	Pot holes and Edge Breaks	150mm in diameter or 150mm from design edge of seal both at least 50mm deep
1240	Surface Irregularity	40mm above Design level of road
1250	Edge drop-off	50mm below Design level of road
1280	Spilled or Loose Material	Any granular material deeper than 10mm And 1 sq metre in area

Table 3.8 – Defect Intervention Thresholds for Unsealed Roads at Shoalhaven City Council (Shoalhaven 2014)

Hazard Code	Hazard Description	Recording Level
1400	Pot holes	300mm in diameter and deeper than 75mm
1430	Slippery Surface	No gravel or gravel with excessive fine particles
1450	Corrugations	30mm high and more than 10 metres In length along the centreline
1480	Loose Material	50 mm deep in windrows or Objects over 75mm
1490	Scour/Rock Outcrop	50mm in height or depth
1591	Tree Obstruction	Overhanging onto road past edge of formation

With the knowledge of the pavement's Average Condition Score and/or the exceedence of the Asset Management Plan/Risk Management Procedure quality thresholds, SCC is then able to begin the decision making process for that segment of road.

3.3.3 Decision Making

The third module of a PMS is the decision making process, where the asset manager's role is to minimise the expected costs of remediation works, while ensuring the road network maintains its expected quality standards (Picado-Santos et al. 2004). Its difficulty lays in the programming of maintenance activities over the entire road network given limited funds and resources available; therefore, how the asset manager evaluates the condition of roads in comparison to the others in the network, and prioritises remediation actions, may have a significant impact on future planning (Chootinan et al. 2006).

Again drawing on Lemass' (2004) study of the design process, it is outlined that the third phase of conceptual design, the *concept embodiment* phase, is where the most likely solution candidates from the *ideation* phase are given preliminary sizing and costing. This concept embodiment allows decisions to be made based on the best solution (or solutions) that can then be recommended for detailed assessment. Road maintenance is quite similar in this regard; the decision making module of the PMS requires the road asset manager to review the maintenance demand of the road

network, following its quality evaluation, and determine all the possible remediation options that can be undertaken across the entire network.

3.3.3.1 Optimisation

Many forms of PMS have been developed as a solution to the road asset management problem. A focus on PMS has been to optimise the decision making process by predicting future pavement deterioration behaviour, sometimes to almost an infinite number (Chan et al. 1994; Fwa et al. 1996; Ferreira et al. 2002; Picado-Santos et al. 2004; Chootinan et al. 2006; Ferreira et al. 2009; Ferreira 2011; Pan et al. 2011).

Utilising the quality evaluation from all the road segments within the road network, a typical PMS will ask the user (the road asset management team) to define what is considered optimal for their organisation. Relying on a database of organisational resources (budget, labour, equipment etc) the PMS will will *solve* the decision by applying the user nominated constraints of maximising network performance or maximising the cost-effectiveness of maintenance activities or minimising road user cost or minimising the present worth of the total maintenance cost or any other constraint nominated by the user (Chootinan et al. 2006).

The *solving* function of a PMS is reliant on high-end mathematic calculations that result in an explosion of potential alternative defect and remediation option permutations. As such, culling methods including Markov Chains, Genetic Algorithms, Fuzzy Regression or other similarly effective theories are relied upon to control this explosion and produce a single, finite and absolute solution (Chan et al. 1994; Fwa et al. 1996; Ferreira et al. 2002; Picado-Santos et al. 2004).

Shortcomings of Optimisation Techniques

Within the engineering community, the acceptance of PMS (particularly optimisation) has been quite tenuous. They are quite often inflexible (lack the ability to adapt to the nuances of local environments and loads), inconsistent (due to the nature of these culling techniques, the same answer may not necessarily be replicated in any given run) and they require large amounts of processing power in order to properly evaluate the correct amount of mathematical permutations (Picado-Santos et al. 2004; Chootinan et al. 2006; Wu and Flintsch 2009; de la Garza et al. 2011). This

problem is compounded in the knowledge that the multiobjective criteria routines necessary to solve these large multi-dependency problems are highly sensitive to the selection of the correct type of algorithm in the initial development stages – incorrect algorithm selections can lead to high uncertainty in a model's solutions and outcomes. (Oliveira et al. 2010).

Another important factor affecting the acceptance of optimisation routines in PMS is their resultant single finite and absolute solution to the problem. As described earlier, optimisation is concerned with maximising an objective determined by the user, it does not deal with the questions of where that objective comes from and what conditions it must satisfy (Hazelrigg 2003). These are considerations experienced road asset managers face with real-world problems that quite often do not have one single *correct* answer (Hazelrigg 2003; Olewnik and Lewis 2005; Dandy 2008). The term 'satisficing' was coined by Simon (1996) to describe the phenomenon where it is uncommon for single, finite solutions to exist. Rather, as discussed in Chapter 2 and presented in Table 2.3, *bounded rationality* dictates that there are multiple suitable solutions to any one problem. Compounding this issue is the *black-box* nature of these PMS, where the user is unable to interrogate and/or validate the inner processes and equations and there is the notion that the "*ultimate solution can be no better than the original equations, and if these fail to represent physical systems properly, the final mathematical solution will be non-optimal*" (Blanning and King 1991; Lemass 2004).

The intrinsic limitations of optimisation techniques in the context of road asset management exist around the exponential 'explosion' of potential asset defects and the numerous remediation options available. The combination of an asset team with varying experiential knowledge, coupled with the intricacies of organisational and procedural knowledge that must be applied, are a critical shortcoming in the use of optimisation in road asset management decision making.

This is the potential strength of Decision Support Systems that provide the user with a full range of highly ranked solutions and that demonstrate the strength of one possible solution over another.

3.3.3.2 Decision Making at Shoalhaven City Council

Outlined in Section C.2 of Appendix C and previously discussed in Sections 3.3.1.1 and 3.3.2.2, the data collection and quality evaluation processes undertaken by Shoalhaven City Council allow the asset management team to make remediation decisions for their road network.

Decision making at Shoalhaven City Council is reliant on the expertise and knowledge of the road asset manager, who will issue a project brief to the operational sections of the organisation to undertake detailed design of a specific solution, or to investigate a range of acceptable remediation options with the intent of ensuring optimal performance and maximising budget expenditure across the road network (Manager 2011).

From the risk based approach, the maintenance manager responds to defects having minimum recording levels described in Table 3.7 and Table 3.8 with a set of predefined maintenance and repair options to ensure the short-term safety and serviceability of a segment of road. Examples of such repairs include pothole patching, gravel patching and grading, among others (Manager 2012).

3.4 Decision Support Systems

"*The concept of decision support systems (DSS) originated with the work of Gorry and Scott-Morton (1971) in the early 1970s. They defined a DSS as an interactive computer system that helps decision makers solve unstructured or semi-structured decision problems using data and models*" (Sugumaran and DeGroote 2010).

Decision Support Systems (DSS), like PMS, seek to facilitate optimal long-term and short-term resources management, but rather than those that utilise optimisation routines, they are highly interactive, user friendly and flexible (Allen 1996; Sugumaran and DeGroote 2010). They remain popular in engineering and medicine where it is acknowledged that operator satisfaction with computer software is a key aspect for successful DSS implementation (Allen 1996).

Some of the features that distinguish a DSS from an optimisation PMS were summarised by from Turban and Frenzel (1992):

- A DSS can be used to address ad hoc, unexpected problems
- A DSS can provide valid representation of the real world system (including the modelling of semi-structured and unstructured problems)
- A DSS can provide decision support within a short time frame
- A DSS can evolve as the decision-maker learns more about the problem
- DSS can be developed by non-data processing professionals

It allows the user to analyse complex problems with the aid of organisational and domain knowledge, whereby the organisational and domain knowledge base can be flexibly maintained to keep to date with current demands and behaviours, via an expert panel, suitably qualified to judge the technical effectiveness and efficiency, as well as the organisational intelligence of the DSS (Lemass 2004; Sugumaran and DeGroote 2010).

Importantly, a DSS does not make the decisions for the user; rather, it presents the user with a summary of the possible suitable solutions, removing (or pruning) those that the user has ruled out via their responses and ranking the solutions based on their compliance with user nominated importance and priorities (Allen 1996; Hazelrigg 2003; Olewnik and Lewis 2005; Abo-Hashema and Sharaf 2009; Beedles 2009; Fletcher 2009).

Hazelrigg (2003) discussed the pitfalls of many of the methods previously used in deriving the decision making process of a DSS and postulated ten rules that an effective DSS should adhere to:

1. The method should provide a rank ordering of candidate options;
2. The user should be allowed to determine their own preferences; that is, the method should not impose its own preferences over the user's;
3. The method should permit the comparison of the alternatives. In the context that all engineering decision making is surrounded by uncertainty, the method should allow for comparison of the possible solutions and the variables that lead to the DSS outcome;
4. The method should be independent of the discipline of engineering and manufacture for the product or system in question;

5. If the method recommends alternative A when compared to the set of alternatives $S = \{B, C, D, \dots\}$, then it should also recommend A when compared to any reduced set S_R, such as $\{C, D, \dots\}$ or $\{B, D, \dots\}$ or $\{D, \dots\}$, and continuing;
6. The method should make the same recommendation regardless of the order in which the design alternatives are considered;
7. The method itself should not impose conditions on the solution/s;
8. The method should be such that the addition of a new alternative should not make existing alternatives appear less favourable;
9. Where possible, the method should make use of as much relevant information available, particularly when the data leads to minimising uncertainty surrounding any alternative;
10. The method should be logical and consistent; that is, it should not contradict itself and it should make maximum use of available information when selecting alternatives.

Using the guidance of Hazelrigg (2003) discussed above, the DSS proposed for this study builds upon the principles of what was earlier referred to as effective PMS, consisting of road network data collection, quality evaluation and decision making. Utilising the information stored within the organisation's existing road network database and incorporating the quality evaluation typically stored therein, the DSS will assist the road asset management team in decision making. Again reflecting on the analogous *Engineering Design Process* presented by Lemass (2004), Figure 3.6 illustrates the position of the DSS in a pavement management conceptual design framework.

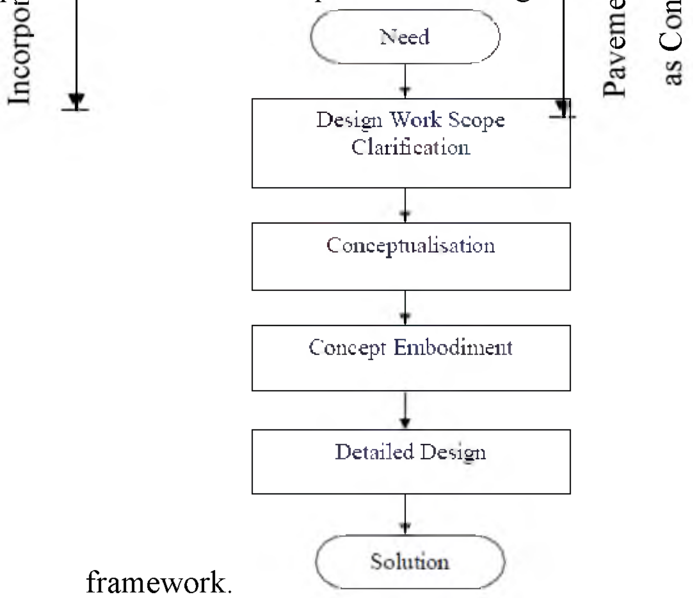


Figure 3.6 – Function of DSS in a 'Pavement Management as Conceptual Design' Process – adapted from Lemass (2004)

The framework presented by Lemass (2004) explored the plethora of state of the art decision support systems utilised in the engineering decision making paradigm. Amongst the review of DSS modes available, popular systems commonly considered include *Rule-Based*, *Model-Based* and *Case-Based* systems.

Rule-Based systems are founded in heuristic knowledge, while Model-Based systems rely on deep fundamental knowledge of the problem to provide decision solutions (Holtzman 1989; Klein and Methlie 1995; Li 1996). Case-Based systems differ from Rule-Based systems in that they do not simply rely on heuristics. Instead, they utilise the successful decisions from similar cases in the system database and augment the outputs to suit the new problem (Zhao and Maher 1988; Riesbeck and Schank 1989; Kolodner 1992; Leake 1994).

The model developed by Lemass and subsequent systems primarily used rule based logic to develop equation based deterministic outputs. The equations represented technical data and output was verified through both passive and interactive comparisons.

In the selection of the appropriate decision support framework adopted for this study, it was important to build on the task profiling undertaken in the initial phase of this research to represent the heuristic knowledge of experienced road asset managers. These case-based results are solution-concept focussed, in stark contrast to the dimensional output which rule-based systems must generate by nature.

3.5 Research Question Development

Chapter 2, specifically Section 2.3, Section 2.4 and Table 2.3, outlined the significant and common problems with road pavements. Therein, the need for systematic consideration of the defects that may arise in road pavements, their cause and their potential solutions was established.

Further, Section 3.2 discussed the well-documented problem associated with road network asset decision making and its exponentially divergent prioritisation considerations. However, despite the numerous attempts to implement "intelligent" systems help "solve" the decision making problem (discussed in Section 3.3), through the initial case study exploration the hypothesis was formulated that experienced road asset managers and engineers possess the knowledge and experience to make effective and efficient road asset remediation decisions. This ultimately led to the research question that asks, by documenting and implementing the knowledge and decision making process of experienced road asset managers and engineers through the types of decision support systems explored in Section 3.4:

"Can organisational intelligence be used to effectively and efficiently plan for road remediation in combination with established theory?"

3.6 Summary

Road asset managers are considered to be experts in their field and are required to apply technical knowledge with their own heuristic experiences to solve problems, all the while empowering their staff to acquire this same knowledge and experience. As a team, road asset managers and their staff are required to identify problems within their road network and solve them in an efficient and effective manner.

A review of the literature in the fields of pavement management and decision making identifies an implicit link between pavement management decision making and the conceptual engineering design process discussed by Lemass (2004). To the author, this link appears to provide a fundamental framework to making sound pavement management decisions, a link that is not explored or discussed within the literature.

Also discovered through the literature review and task profiling stage is the process upon which pavement serviceability is evaluated by local government road asset management teams. This road asset decision making process is illustrated in Figure 3.4, which was devised by the author and provides the context surrounding the road asset management decision making paradigm.

This study proposes to develop a Decision Support System (DSS) that incorporates the benefits arising from structured Pavement Management Systems, utilising road

network database and quality evaluation tools to inform a decision making system built upon the conceptual design framework and the expert knowledge of experienced road asset managers. Further, through incorporation with the existing road asset management decision making process outlined in Figure 3.4, the proposed DSS will provide the road asset management team with a decision making tool that can be used to validate and confirm their own decisions, while also educating the less experienced members of the *team* via accelerated learning tools embedded within the DSS.

To ensure technical effectiveness, the proposed DSS will build upon and refine the matrices presented in Table 2.3 to develop decision trees for each individual defect type, based on literature and case based research, to formulate the DSS for the remediation of flexible pavements in local government.

4 SYSTEM DEVELOPMENT: PROTOTYPE DECISION SUPPORT SYSTEM

4.1 Development of a Decision Support System for Flexible Pavements

"PaveMaint SELECT" is a Decision Support System developed to assist road asset managers and engineers in the conceptualisation of road remediation decision making for both sealed and unsealed flexible pavements. It is aimed to integrate PaveMaint SELECT with existing organisational systems, such as Pavement Management Systems (PMS), building upon the identified need to remediate a segment of road by assisting with the decision of which remediation option to explore in further detail.

Figure 4.1 (overleaf) builds upon the road asset decision making process previously presented in Figure 3.4 (devised by the author from the literature review and task profiling from the initial Shoalhaven City Council case study) and highlights how PaveMaint SELECT is now an additional tool that could be utilised in conjunction with existing organisational systems to achieve improved and consistent remediation option decision outcomes.

4.2 Decision Support System Framework

DSS are used to aid decision making where conflicting objectives lead to complex uncertainties (Fernández et al. 2005; Olewnik and Lewis 2005). The DSS developed for this study seeks to provide a user-friendly computer based environment that utilises a mathematical model to draw upon data identified by the user to assist in their road maintenance decision making process. Focussing on both sealed and unsealed flexible pavements and founded on the defect/remediation option relationship presented by the author in Table 2.3, PaveMaint SELECT will be an additional tool (among those illustrated in Figure 4.1) that can assist road engineers (whether they be asset managers, maintenance engineers or technicians) involved in the assessment, selection and implementation of road remediation activities to better conceptualise and recommend works that are both appropriate and consistent with engineering literature and experiential knowledge.

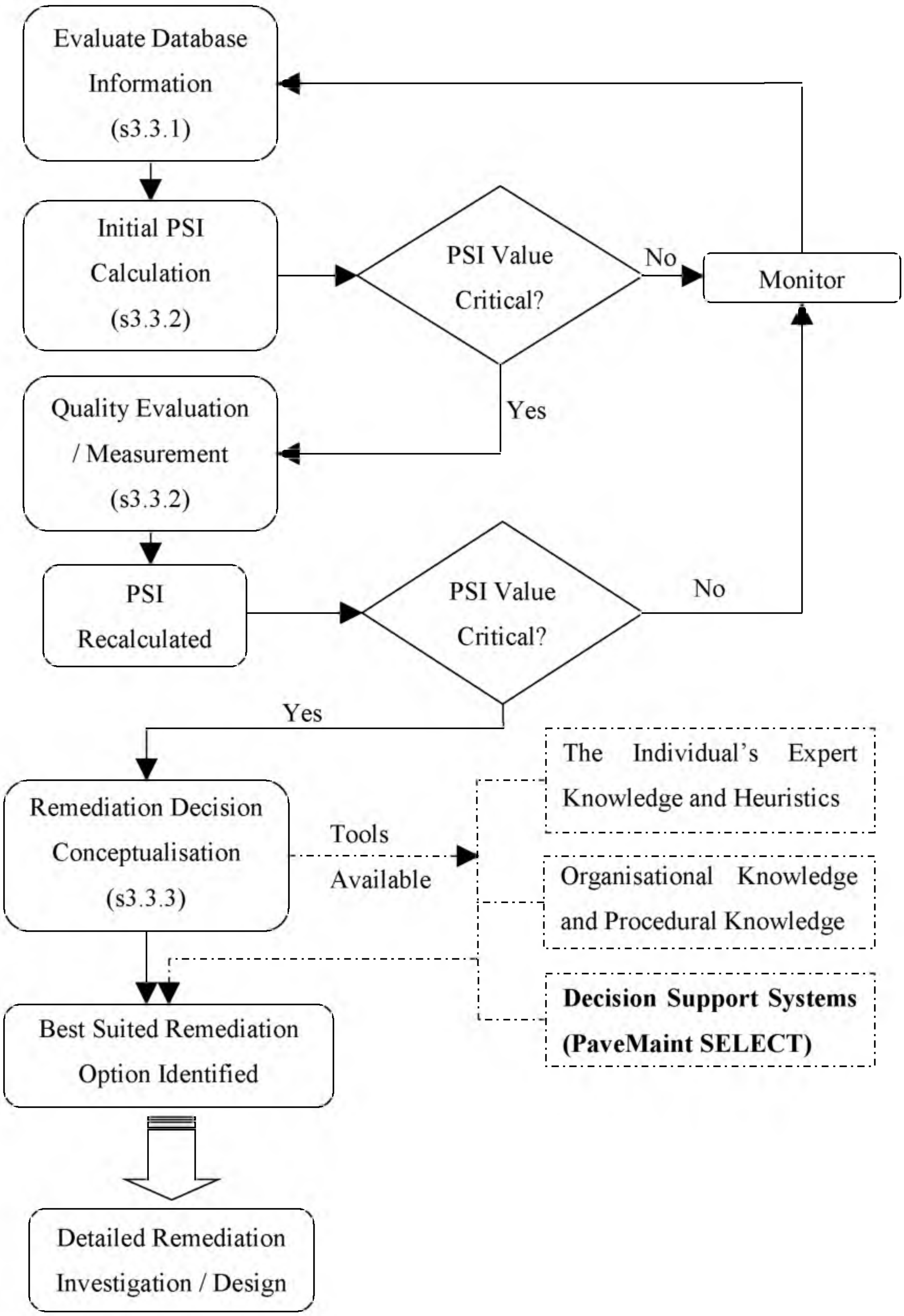


Figure 4.1 – Pavement Serviceability Evaluation Augmented with Remediation Decision Conceptualisation Tools

In order to perform effectively, the DSS program must be structured in a logical manner that should replicate both the conscious and subconscious stages of thinking that an experienced road asset manager or engineer would consider in their decision making process. Due to the uniqueness of individuals, it is not envisaged that there will be one, single, finite "logic" that could possibly be employed. However, the author considers the conceptual design framework presented by Lemass (2004), as discussed in Section 3.4, to be a suitable basis to model this DSS that would suit most practitioners. However, this will be tested further and refined through wider case study analysis.

Another consideration critical to the effectiveness of the DSS program is that not all users will be equally skilled or proficient in road asset management and maintenance problems. As discussed in Section 3.2 and illustrated in Figure 3.1 previously, it is expected that road asset management teams will comprise a mix of highly experienced "expert" engineers and asset managers, combined with junior or novice team members with very little knowledge and expertise in road asset management. In order to combat and bridge disparate knowledge situations such as these, tools can be incorporated into the DSS program to cultivate learning while the user explores the problem they are trying to solve. The notion of "accelerated learning" supports the inclusion of such tools to create learning experiences that are different and engaging, which can be achieved by capturing expert knowledge and utilising it to generate appropriate training materials (Greenbaum 1999; Hoffman et al. 2009). As such, the proposed framework for the DSS program will incorporate accelerated learning tools (*ALT*'s) at all stages to inform the user as they utilise the program.

Figure 4.2 illustrates the framework of the prototype road remediation DSS ("PaveMaint SELECT") which the author believes will best replicate the logic described, providing users with the ability to add salient information at the appropriate stages of the process. The critical inclusion of a feedback loop at the final stage of the process will allow the user to review their identified constraints and weightings or the dominant defect selected, and in doing so will aid the user to better understand the process that leads to the recommended outcomes, while also assisting with future DSS refinement and customisation.

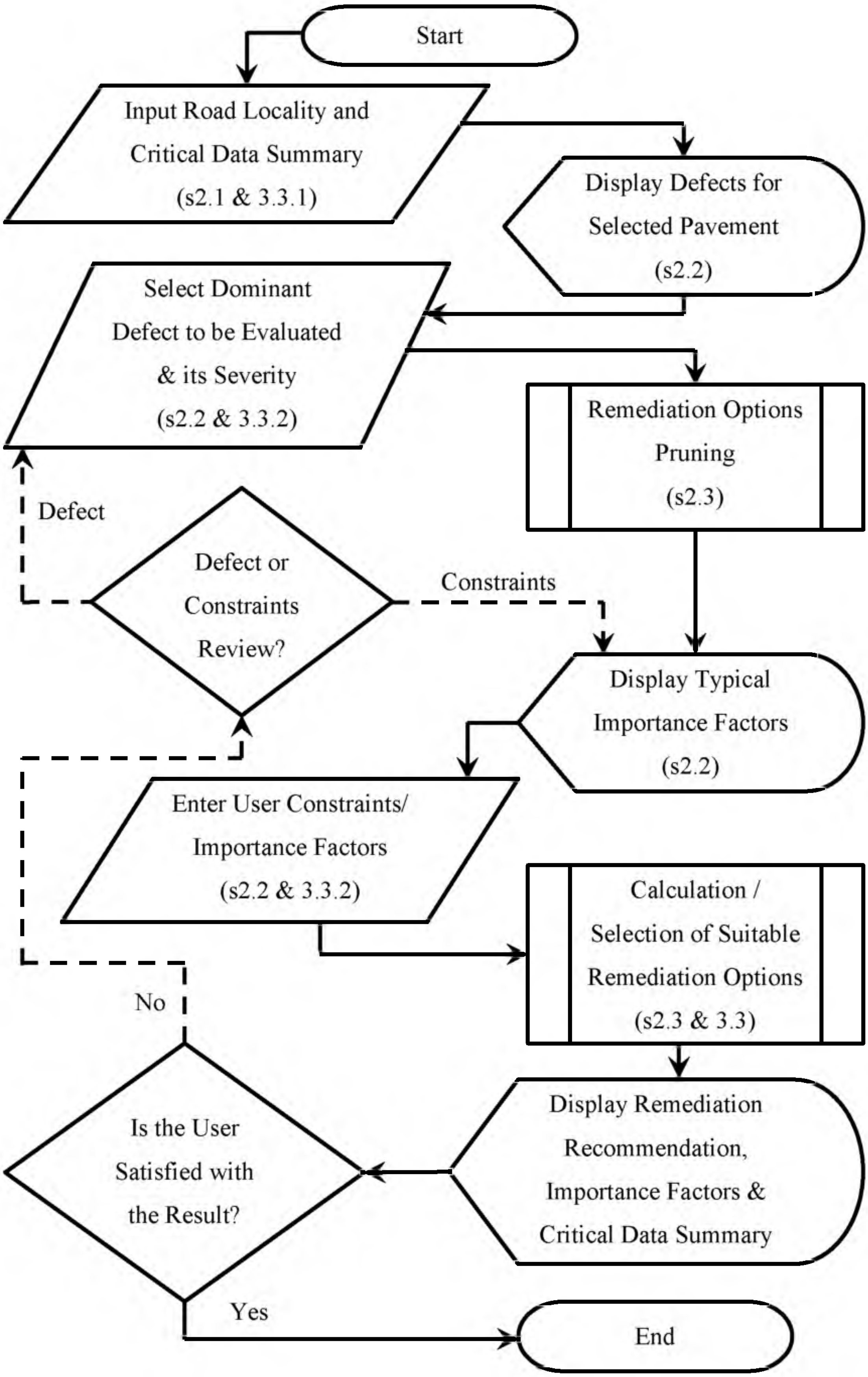


Figure 4.2 – Proposed "PaveMaint SELECT" DSS Software Framework

4.3 DSS Programming Environment Selection

There are many programming environments in which the proposed DSS program could be designed. In fact, a simple internet search reveals results for programming languages such as C/C++, Java, Python as well as various versions of HTML (or HyperText Markup Language) among others. However, in consideration of the most suitable program environment, the author believes that (as discussed in Section 3.4) the strength of a DSS over other models and optimisation routines is that it should be able to be easily customisable to accurately reflect the nuances of the organisation utilising it. Programming a DSS in those languages discussed above would require the system administrator (the road asset manager or road maintenance engineer for example) to be proficient in programming or alternatively require them to engage experts to maintain the system for them.

For the reasons outlined above, PaveMaint SELECT is programmed in Visual Basic for Applications (VBA) which launches from a macro-enabled Microsoft™ Excel™ (herein referred to as Excel) spreadsheet. The primary reason for selecting VBA is its simplicity, ease of use and readily available access where, in this modern age, almost all local government organisations will have access to Excel as an essential tool. Moreover, through experiential knowledge the author believes that most engineers are proficient in at least the basic functions of Excel because it offers a rich and functional environment to undertake daily tasks. Therefore, combining the ease of an Excel-based database with a highly functional VBA interface will ensure PaveMaint SELECT is a powerful tool that can be used by any local government organisation.

4.4 PaveMaint SELECT User Interface

4.4.1 Launching PaveMaint SELECT

PaveMaint SELECT is a VBA program embedded in a macro-enabled Excel file named *PaveMaint SELECT v0.1.xlsm* (found in the Compact Disc provided with this thesis). Upon launching the spreadsheet the user is presented with a simple "Startup" screen shown in Figure 4.3 directing the user to follow simple instructions to launch the program.

Figure 4.3 – PaveMaint SELECT Startup Screen

Once the user has enabled macro functionality on the spreadsheet, by selecting "START" the VBA program launches and the user is shown an introduction screen with explanatory notes on the program along with an *ALT* on what a flexible pavement is and its context in this DSS. This process is illustrated in Figure 4.4 which demonstrates the screen output when the user selects the "What Are Flexible Pavements?" *ALT*.

Upon selecting the option "Begin" from the introduction screen, the user is directed to commence the data input and dominant defect selection process discussed in Section 4.4.2.

Figure 4.4 – PaveMaint SELECT Introduction Screen with *Accelerated Learning Tool*

4.4.2 PaveMaint SELECT Data Input and Defect Selection

The PaveMaint SELECT data input screen, shown in Figure 4.5 and titled "Road Details", prompts the user to input identifying characteristics such as the name, locality and segment of road to be analysed by the program. While these do not assist the program to formulate a recommended remediation output, this input has two important current and future functions:

1. It provides an identifying critical data summary for the "Solutions Sheet" (output) that will allow the user to print and/or save the results to ensure a documented transparent process, and
2. It also provides for future database integration with existing systems. That is, as part of the anticipated future development of PaveMaint SELECT, these fields may be augmented to display a predetermined list populated from an organisational asset database allowing for better links with existing corporate systems, ensuring that these decisions will not be undertaken in isolation.

The fourth data input field on the "Road Details" screen prompts the user to identify the traffic load characteristics of the subject segment of road. The determination of traffic load is calculated on known or estimated *Equivalent Standard Axles* (ESA) whose purpose, along with identifying the class of road, is to ascertain the loading characteristics which will assist in the pruning and selection of appropriate remediation options. Traffic load is selected from a predetermined list of typical ESA thresholds, shown in Figure 4.6, extrapolated from the literature (Chapter 2) as well as the initial case study of Shoalhaven City Council (Chapter 3) and features an *ALT* for ESA calculation.

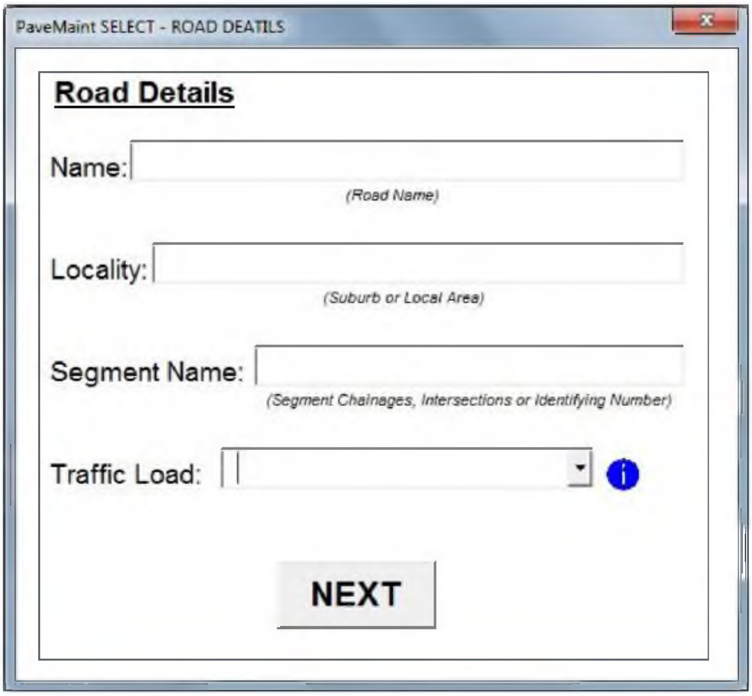


Figure 4.5 – PaveMaint SELECT "Road Details" Input Screen

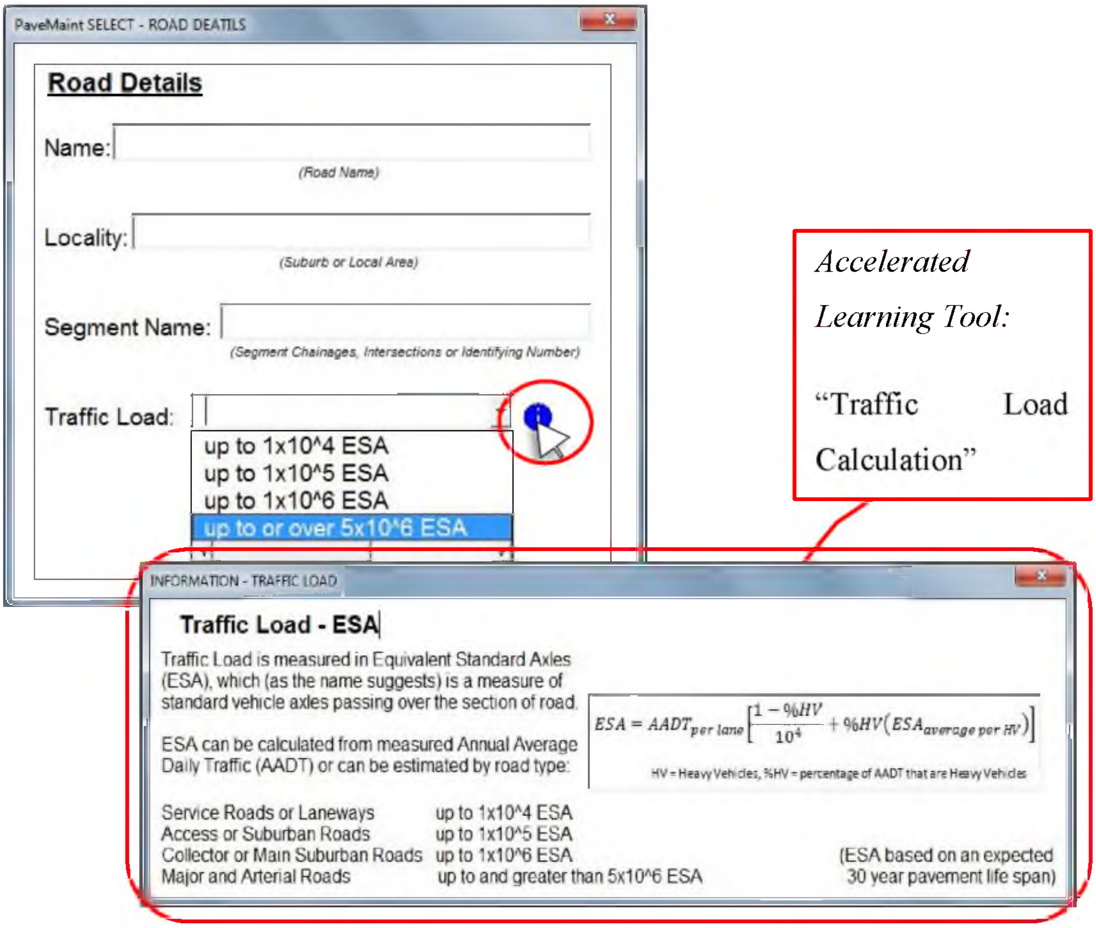


Figure 4.6 – Road Details Traffic Load Selection with *Accelerated Learning Tool*

To avoid errors in data entry, mainly insufficient or missing data, the VBA is programmed such that screens will not advance unless all fields of the preceding screen are complete.

An example of this behaviour is shown in Figure 4.7, where the user has clicked on the "Next" button of the "Road Details" screen before completing all the fields on the screen. Note: this behaviour is consistent for all screens throughout PaveMaint SELECT and detailed in Appendix B.

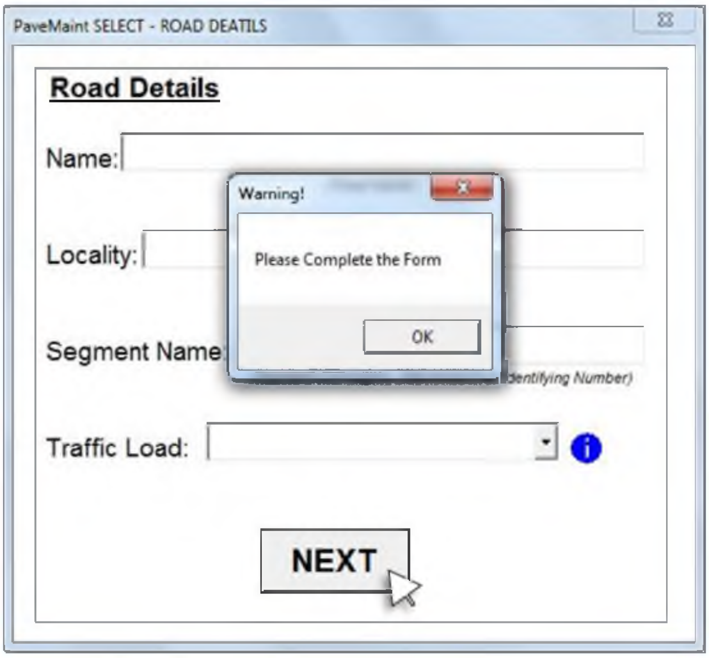


Figure 4.7 – PaveMaint SELECT Warning Screen for an Incomplete Form

Upon clicking the "Next" button, the "Surface Type" screen is displayed, which prompts the user to select from three different surface types: Asphaltic Concrete; Bituminous Spray Seal; or Unsealed. Figure 4.8 shows the "Surface Type" screen, which features three *ALT*'s that the user can select. Each of the *ALT*'s are fully presented in Appendix B.

Figure 4.8 – PaveMaint SELECT Road "Surface Type" Selection Screen

The “Surface Type” screen and all screens following this screen feature a “Back” button that allows the user to navigate, adjust and refine their data as the program is being used. That is, in the case of the “Surface Type” screen (Figure 4.8), if the user were to select the “Back” button, they would be presented with the “Road Details” screen (Figure 4.5). However, all data previously entered will be saved and easily edited or adjusted.

Once the user has made a selection of one of the three surface types and then clicks on the “Next” button, the program (with reference to the knowledge database inbuilt in the spreadsheet discussed further in Appendix B) selects all the possible defect types associated with that pavement and surface type (previously explored in Section 2.2) and displays the “Major Defect Type” selection screen illustrated in Figure 4.9, Figure 4.10 and Figure 4.11 for asphaltic concrete, bituminous spray seal and unsealed pavements respectively. An *ALT* has been developed for each defect type, Figure 4.12 is provided as an example that illustrates an *ALT* for flushing as the major defect type in a bituminous spray sealed pavement. The comprehensive list of all major defect type *ALT*’s is provided in Tables B.1, B.2 and B.3 of Appendix B.

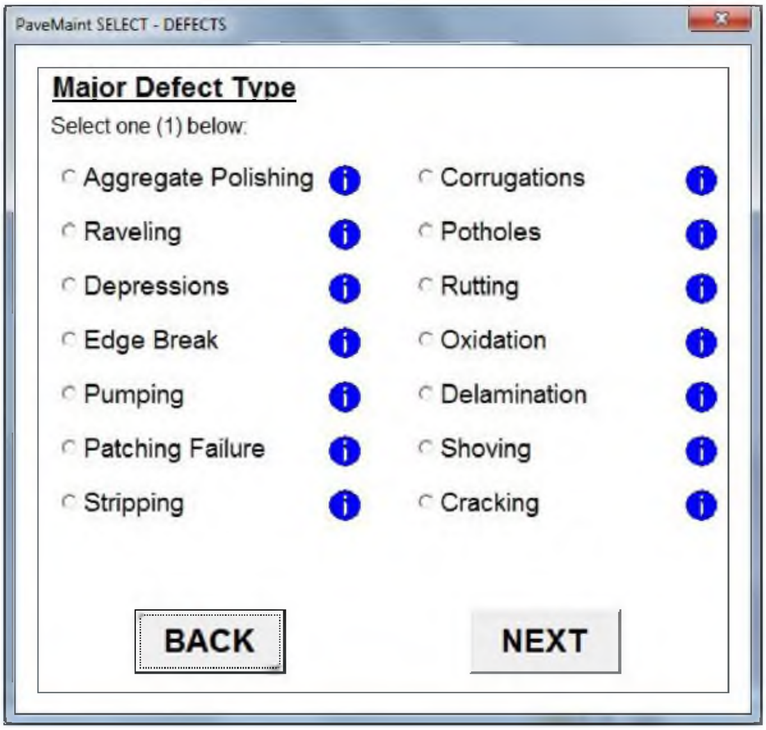


Figure 4.9 – PaveMaint SELECT Asphaltic Concrete Surfaced Pavements “Major Defect Type” Selection Screen

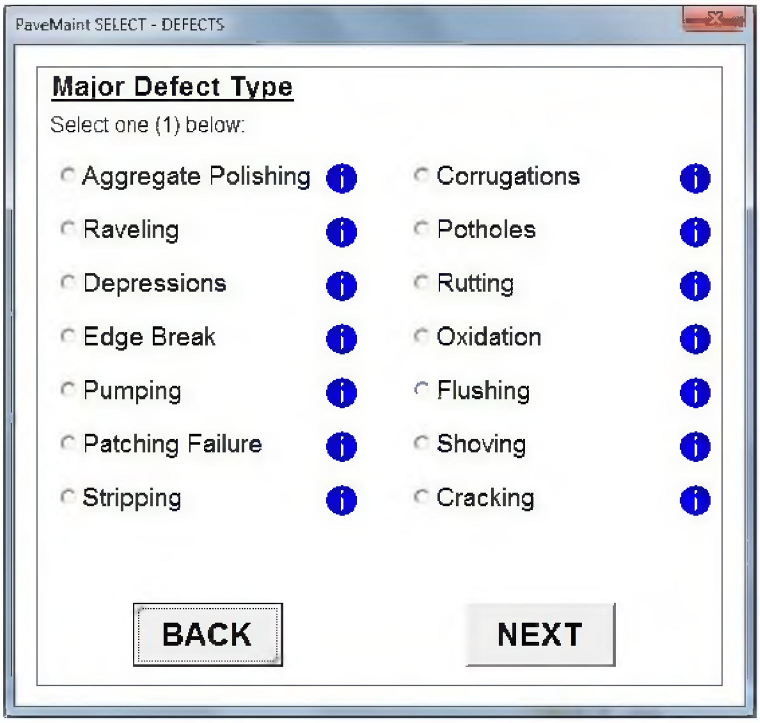


Figure 4.10 – PaveMaint SELECT Bituminous Spray Sealed Pavement "Major Defect Type" Selection Screen

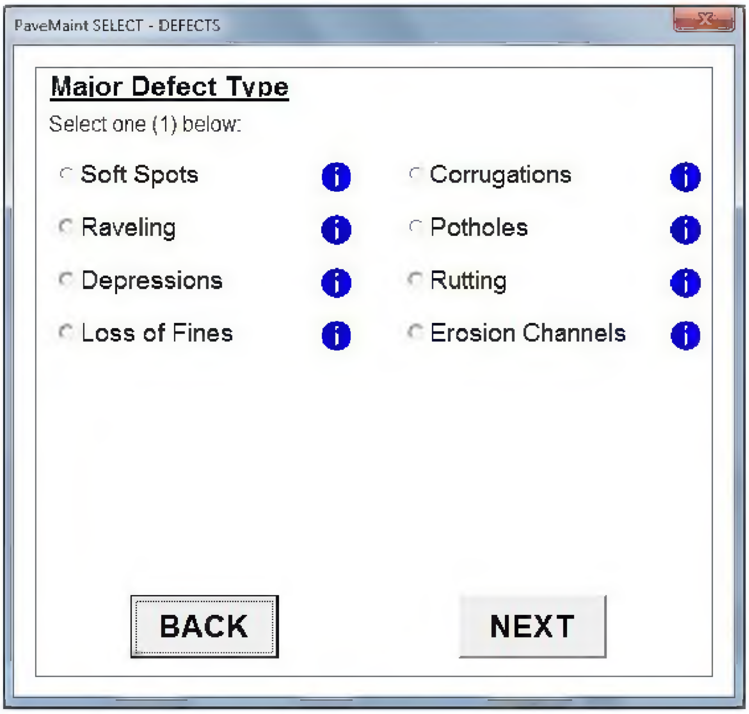


Figure 4.11 – PaveMaint SELECT Unsealed Pavement "Major Defect Type" Selection Screen

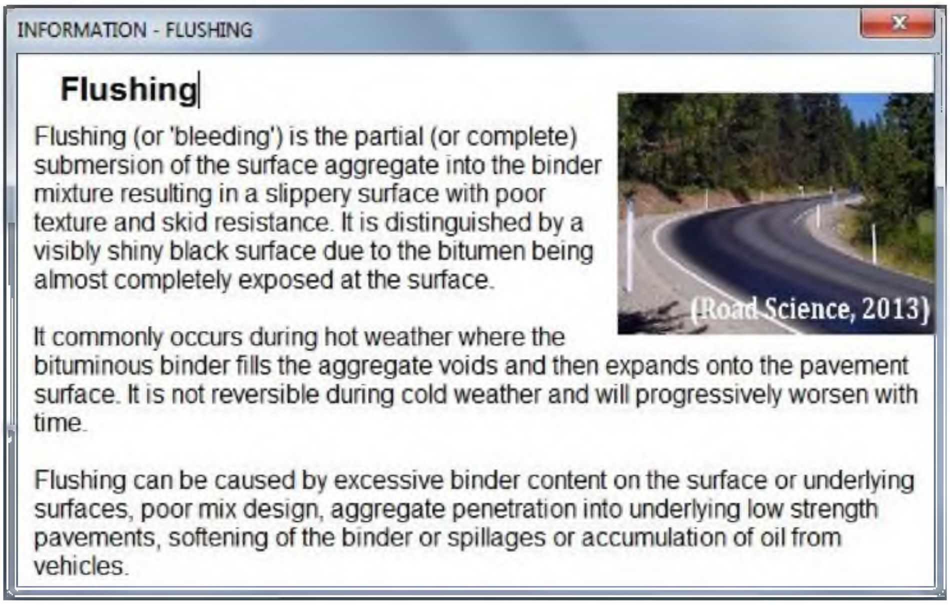


Figure 4.12 – *Accelerated Learning Tool* for Flushing as a Major Defect Type on a Bituminous Spray Sealed Pavement

By selecting any defect other than "Cracking" to be assessed and clicking "Next" to proceed, the user will then be directed to the subsequent "Defect Severity" screen.

However, as a result of the discussion in Section 2.2.2, it was felt necessary to provide an additional screen detailing the various types of cracking for asphaltic concrete and bituminous spray seal surfaces separately. That is, should the user wish to address a form of cracking in their pavement, they would select the "Cracking" option from the "Major Defects" screen and click "Next" which will display the "Cracking Type" selection screen.

Figure 4.13 and Figure 4.14 illustrate the "Cracking Type" defect selection screen for asphaltic concrete and bituminous spray seal surfaced pavements respectively. From this screen the user can select the type of cracking they wish to assess, again assisted with defect-specific *ALT*'s. Once a type of cracking is selected, the user will then also be directed to the "Defect Severity" screen.

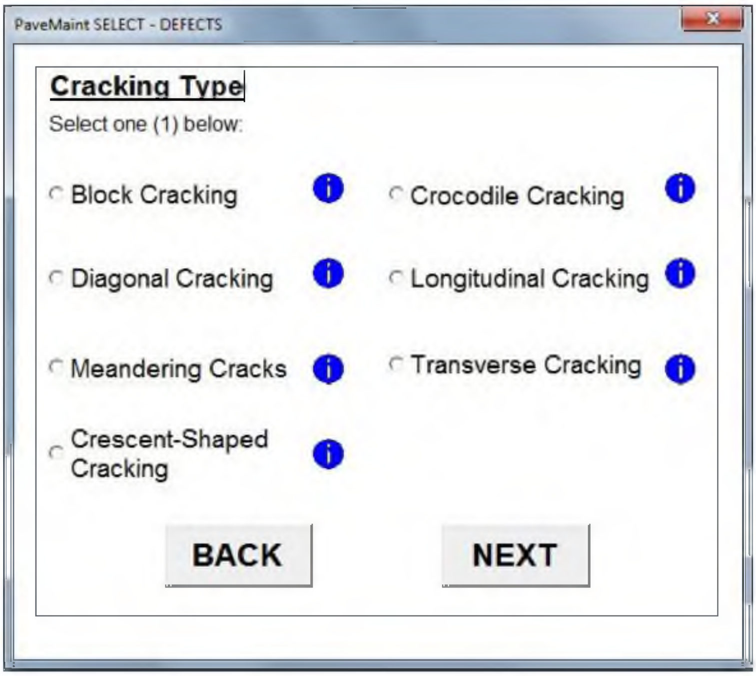


Figure 4.13 – PaveMaint SELECT Asphaltic Concrete Pavement “Cracking Type” Selection Screen

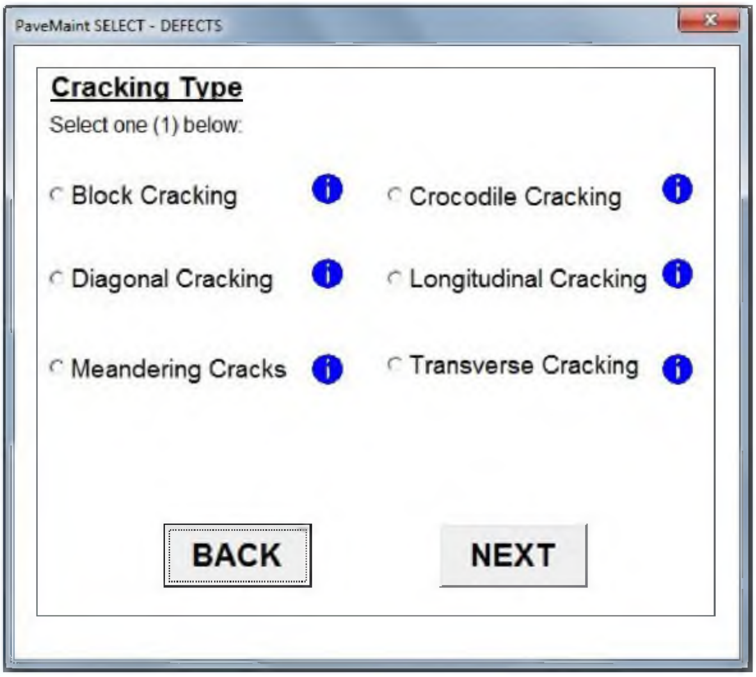


Figure 4.14 – PaveMaint SELECT Bituminous Spray Seal Pavement “Cracking Type” Selection Screen

4.4.3 PaveMaint SELECT Defect Severity Evaluation

Selection of defect severity is based on the methodology used by Shoalhaven City Council described in the preliminary case study presented in Section 3.3.2.2. That is, the scoring of a defect's severity relies on a scale of one (1) to five (5); where a value of "1" represents a defect that is present in the pavement but is only slight and shows no immediate sign of danger to the road user, while a value of "5" represents a defect that is so severe that the pavement in that area is considered unserviceable and may be dangerous to users of the road. *ALT*'s are incorporated into the Defect Severity selection screen to provide the user with both a qualitative description and, where possible, a quantitative measure on which to base their selection. This is illustrated in Figure 4.15 for the example of a pothole defect in an unsealed pavement. A complete list of the Defect Severity screens corresponding with each individual defect type is provided in Figures B.18 to B.40 (inclusive) of Appendix B.

The defect severity selection is a critical stage in the PaveMaint SELECT decision support system. The *ALT*'s developed for the "Defect Severity" screens are based on a combination of the literature presented in Chapter 2 and the experiential and organisational knowledge explored through the initial case study of Shoalhaven City Council previously discussed in Sections 3.3.1.1, 3.3.2.2 and 3.3.3.2. By incorporating both quantitative and qualitative data, the "Defect Severity" screens are intended to emulate the considerations required to effectively evaluate defect deterioration and will therefore be subject to testing and refinement through case study exploration.

Furthermore, a defect's severity will ultimately guide the selection of the appropriate remediation options recommended by the program. For example, if a defect's severity is considered "slight" (value of 1), PaveMaint SELECT will not recommend the user take any action unless the aesthetic appeal of the area is considered to be of critical importance and when costs are not a high priority. Conversely, a severity of "unserviceable" (value of 5) will always yield a minimum of one remediation option regardless of any other user constraint.

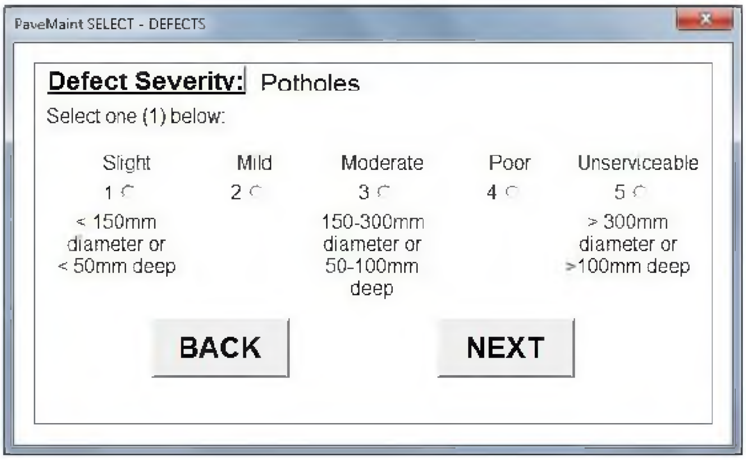


Figure 4.15 – PaveMaint SELECT Defect Severity Selection for Potholes in Unsealed Pavements

4.4.4 PaveMaint SELECT User Constraint Determination

In the last stage of the PaveMaint SELECT program, the user is required to nominate the constraints that would influence their decision making. Based on the parameters discussed in Section 3.2, the two "User Constraints" screens require the user to nominate statements that best reflect the applicable:

- financial constraints (Figure 4.16);
- expectations for the longevity of the repair or the remaining life span of the segment of pavement (Figure 4.16);
- resourcing constraints affecting the organisation's ability to undertake the repair (Figure 4.17); and
- importance of the aesthetic appearance for that segment of road and/or repair (Figure 4.17).

The statements provided in the User Constraints selection screens are designed to replicate the considerations road asset managers and engineers must account for before determining any course of action. They are structured in a manner that is consistent with the *Task Profiling* stage of this research and which the author believes will maximise their relevance to multiple organisations; that is, they are not quantitative statements, the statements are broad and allow the user to make the selection that best applies to their own organisation.

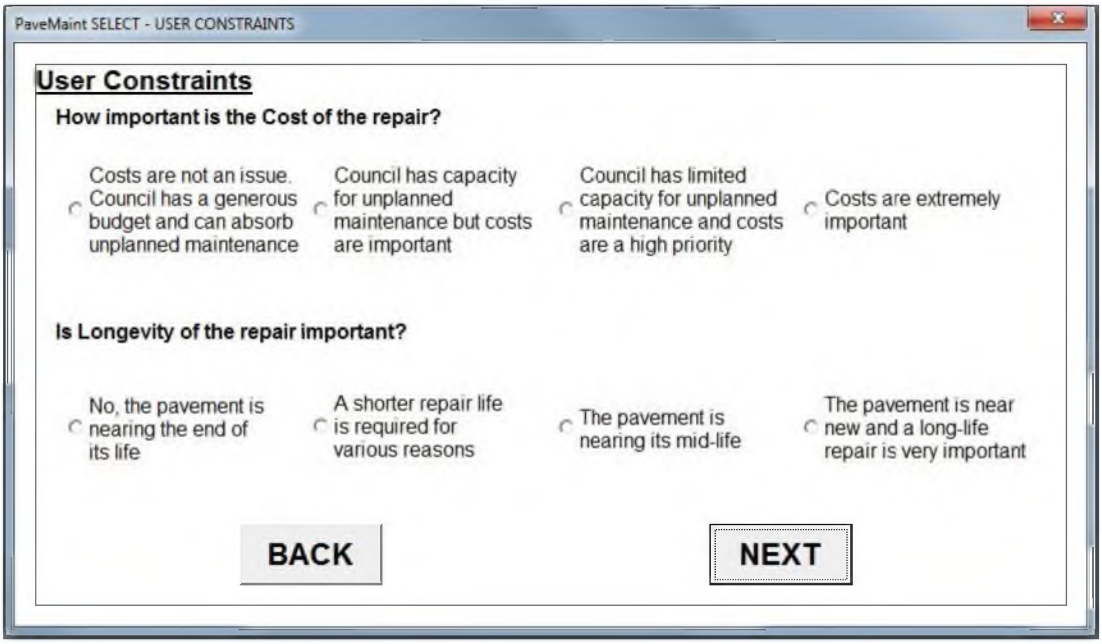


Figure 4.16 – PaveMaint SELECT User Constraints Selection Screen (1)

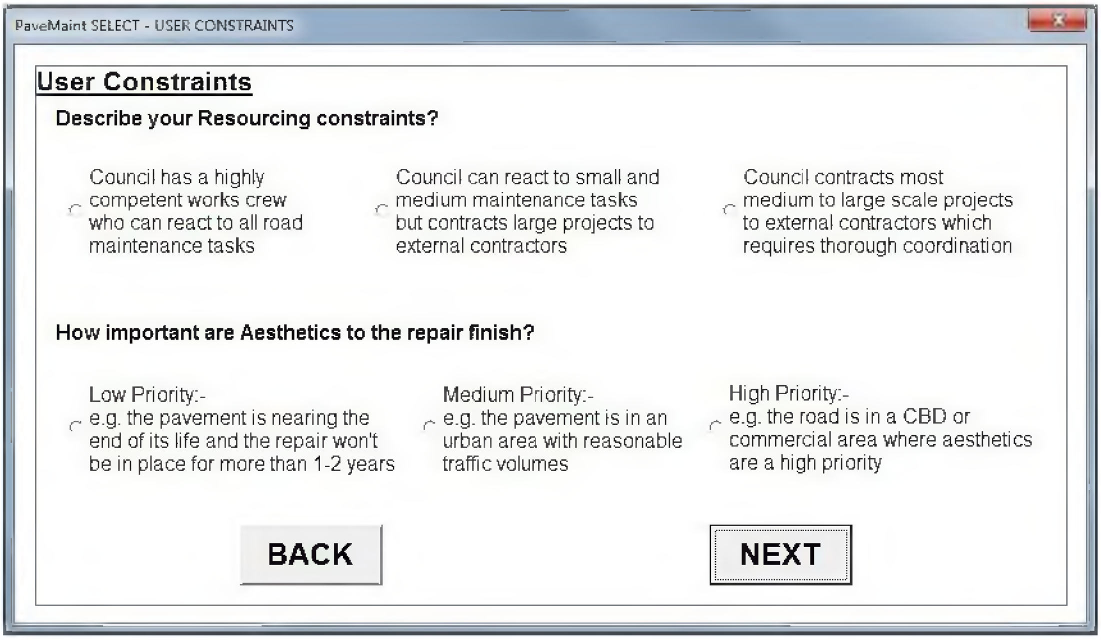


Figure 4.17 – PaveMaint SELECT User Constraints Selection Screen (2)

It could be argued that some of the constraints will be constant for the same organisation which would raise the question for the necessity of these screens. The author contends that the intent of these screens is to acknowledge such situations where, for example, every organisation will seek to spend the least amount of money and maximise their expenditure across their entire road network. However, even this statement will be made relative to a number of factors including the organisation's total budget, what period of the financial year the decision is being made, what other projects are currently programmed for the remaining financial year, or any combination of these along with many other considerations. Therefore, continuing this example, while the organisation may have a modest budget, it may not have a substantial works program for the coming year, compared to other years, and may elect to be able to expend a greater proportion of its budget for a more substantial repair or conversely the organisation may have quite a significant works program to implement and will therefore need to balance more carefully the cost of remediation with its other constraints. Accordingly, both the format and the effectiveness of the "User Constraints" screens will be further validated through system testing.

4.4.5 PaveMaint SELECT End of Program

The final screen of the programmed VBA portion of PaveMaint SELECT (as shown in Figure 4.18) is essentially an information screen that notifies the user that they have completed the input stages of the program and provides a final opportunity to go back and amend any of their selections, or to proceed and view the results of the evaluation. It is important to note that this is not necessarily the last opportunity the user will have to adjust their selections; it is simply the last opportunity the user will have to make changes within the current VBA environment for the dominant defect selected and further opportunity for refinement is provided within the "Solutions Sheet".

Should the user select "make changes", they will simply be directed back to the preceding screen where they will be able to review and adjust their selections; however, should the user select "view results" the VBA program interface will close and the user will be presented with the "Solutions Sheet" displayed in a worksheet

within the same Excel workbook that the program was launched. An example of the Solutions Sheet is provided in Figure 4.19.

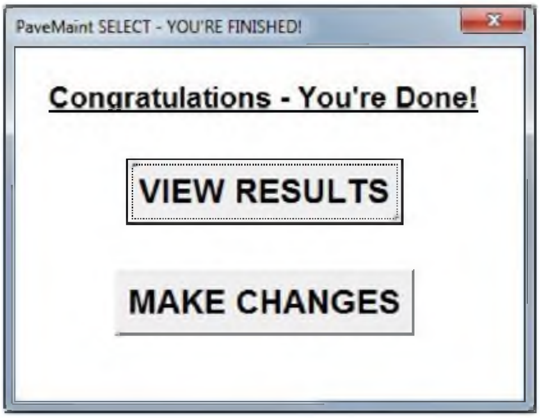
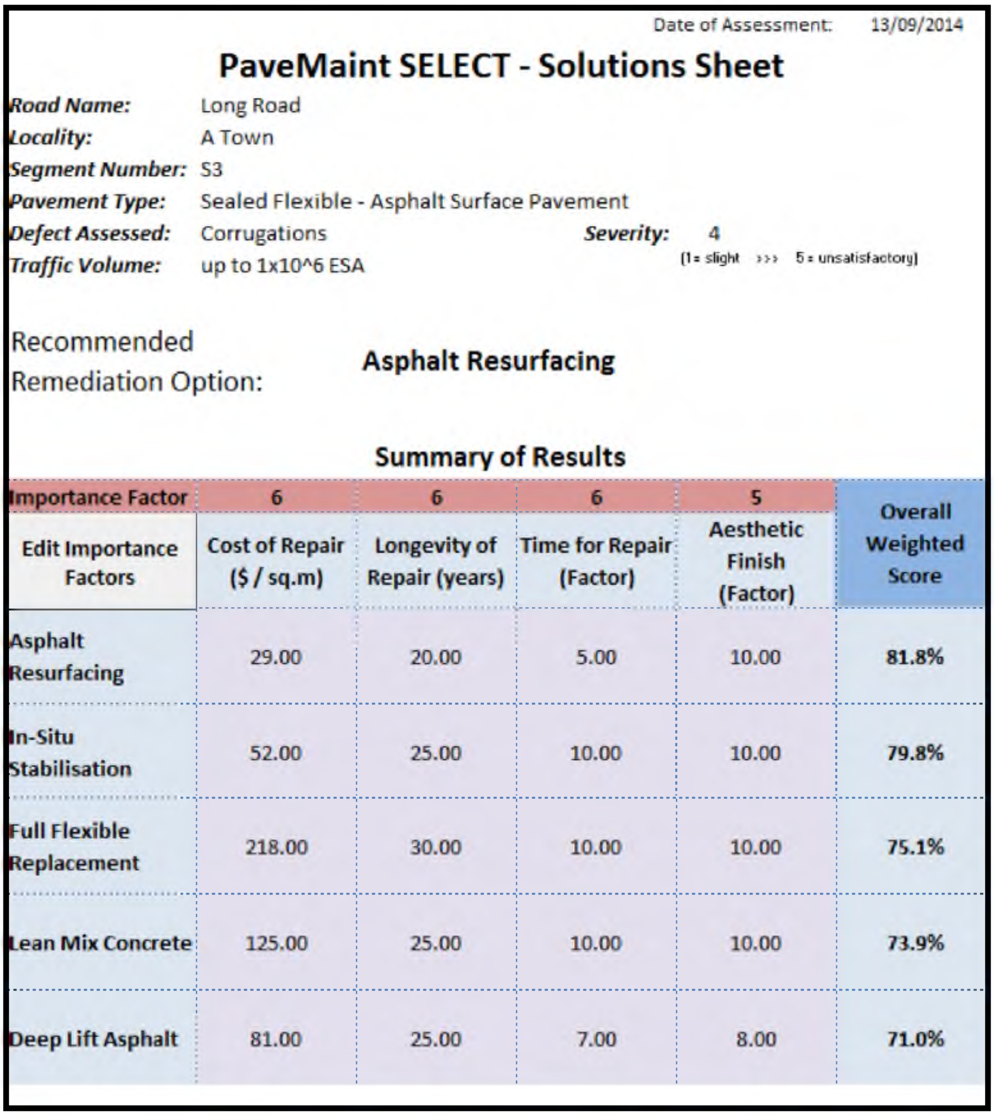


Figure 4.18 – PaveMaint SELECT End of Program / View or Edit Results Screen



Date of Assessment: 13/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Long Road		
Locality:	A Town		
Segment Number:	S3		
Pavement Type:	Sealed Flexible - Asphalt Surface Pavement		
Defect Assessed:	Corrugations	*Severity:*	4
Traffic Volume:	up to 1x10^6 ESA		(1= slight >>> 5= unsatisfactory)

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	6	6	6	5	Overall Weighted Score
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	
Asphalt Resurfacing	29.00	20.00	5.00	10.00	81.8%
In-Situ Stabilisation	52.00	25.00	10.00	10.00	79.8%
Full Flexible Replacement	218.00	30.00	10.00	10.00	75.1%
Lean Mix Concrete	125.00	25.00	10.00	10.00	73.9%
Deep Lift Asphalt	81.00	25.00	7.00	8.00	71.0%

Figure 4.19 – PaveMaint SELECT Solutions Sheet (Example: Corrugations with Severity "Poor")

4.5 PaveMaint SELECT Solutions Sheet

The solutions sheet provides a summary of the information the user has input through the VBA screens, and drawing on the information stored within the Excel file's knowledgebase, it proposes a list of potential treatment options and indicates which of those is the most suitable treatment solution based on the user's constraints. Presented in the form of a '*data-sheet*', its purpose is to concisely present all the pertinent information required in the decision making process and describe the factors that have led to the ultimate selection of one remediation option; in a format that can be easily saved, printed and filed for record keeping purposes.

In addition to its superficial purpose as a '*data-sheet*', the key function of the solutions sheet is to formulate and rank the performance of the remediation solutions for the defect and constraints being assessed and recommend a solution that most suits the user's requirements. The formulation of the PaveMaint SELECT decision support system relies on option pruning (explored further in the discussion of the use and function of the knowledgebase provided in Section 4.6) and the calculation of scoring and weighting products within the worksheet. That is, the worksheet displays the relevant data that is sourced from either the VBA user forms or the system's knowledge base, and calls on that data to score the remediation option's performance against the nominated criteria which is then scored by the user-nominated importance to that criterion. This calculation is given by Equation 4.1 with representative values given as examples from the recommended "Asphalt Resurfacing" remediation option presented in Figure 4.19 earlier for the treatment of corrugations in an asphaltic concrete surfaced flexible pavement.

$$Score_{Tx} = \frac{\sum\left(\left(\frac{C_{p.min}}{C_{px}}\right)C_{Iu}, \left(\frac{E_x}{E_{max}}\right)E_I, \left(\frac{L_x}{L_{max}}\right)L_{Iu}, \left(\frac{T_{min}}{T_x}\right)T_{Iu}, \left(\frac{A_x}{A_{max}}\right)A_{Iu}\right)}{\sum(C_{Iu}, E_{Iu}, L_{Iu}, S_{Iu}, A_{Iu})}\%$$

Equation 4.1

where:

- *$Score_{Tx}$ is the total performance score of remediation option x in comparison to all the other remediation options available, and is calculated as a percentage (Figure 4.19 - $Score_{TAsphalt\ Resurfacing}$ = 81.8%);*

- $C_{p.min}$ *is the minimum present day cost (in Australian dollars) from all the remediation options being assessed (Figure 4.19 -* $C_{p.min} = \$29.00/m^2$*);*
- C_{px} *is the present day cost (in Australian dollars) of remediation option x (Figure 4.19 -* $C_{pAsphalt\ Resurfacing} = \$29.00/m^2$*);*
- C_{Iu} *is the user-nominated importance factor for cost in the decision making process (Figure 4.19 -* $C_{Iu} = 6$);
- E_x *is the system-determined effectiveness of comprehensively remediating the specified defect of remediation option x (Figure 4.19 (hidden cell) -* $E_{Asphalt\ Resurfacing} = 6$*);*
- E_{max} *is the maximum of the system-determined effectiveness factors from all the remediation options being assessed (Figure 4.19 (hidden cell) -* $E_{max} = 10$*);*
- E_I *is the system-determined importance factor for effectiveness of the repair in the decision making process (Figure 4.19 (hidden cell) -* $E_I = 10$*)*;
- L_x *is the expected longevity (in years) of remediation option x before the repair is expected to deteriorate (Figure 4.19 -* $L_{Asphalt\ Resurfacing} = 20$ *years);*
- L_{max} *is the maximum expected longevity (in years) from all the remediation options being assessed (Figure 4.19 -* $L_{max} = 30$ *years);*
- L_{Iu} *is the user-nominated importance factor for the longevity of the repair in the decision making process (Figure 4.19 -* $L_{Iu} = 6$*)*;
- T_{min} *is the minimum time factor (relating to resource capacity available to mobilise a repair) in which the remediation action can be enacted from all the remediation options being assessed (Figure 4.19 -* $S_{min} = 5$*);*
- T_x *is the time factor in which the remediation action can be enacted of remediation option x (Figure 4.19 -* $S_{Asphalt\ Resurfacing} = 5$*);*
- T_{Iu} *is the user-nominated importance factor for the time to enact the repair in the decision making process (Figure 4.19 -* $S_{Iu} = 6$*)*;
- A_x *is the factor for the aesthetic appeal of remediation option x (Figure 4.19 -* $A_{Asphalt\ Resurfacing} = 10$*);*
- A_{max} *is the maximum factor for aesthetic appeal from all the remediation options being assessed (Figure 4.19 -* $A_{max} = 10$*);*
- A_{Iu} *is the user-nominated importance factor for the aesthetic appeal of the repair in the decision making process (Figure 4.19 -* $A_{Iu} = 5$*)*;

It is foreseeable, however unlikely, that more than one option could result with the same highest score; that is, more than one option could be equally considered the highest ranked solution. For this reason, the system is formulated to distinguish between such occurrences by comparing their ranking against the highest user-nominated importance criteria. The numeric formulation of this routine is presented further in Equations B.5 to B.9 (inclusive) of Appendix B. Should this still be unable to separate the equity of two or more highest ranked solutions, then it is considered that any of the "tied" solutions are equally suitable, and the system defaults to a recommendation based on the alphabetical order of the remediation option's name.

Another feature of the solutions sheet is the "Edit Importance Factors" macro button that allows the user to change the numeric value of the Importance Factors for each of the constraints, which is originally populated from the user's selections in the User Constraints stage of the VBA program (Figure 4.20). This feature allows further user refinement of the recommended solutions generated by the system and will assist in its ability to replicate real world decision making.

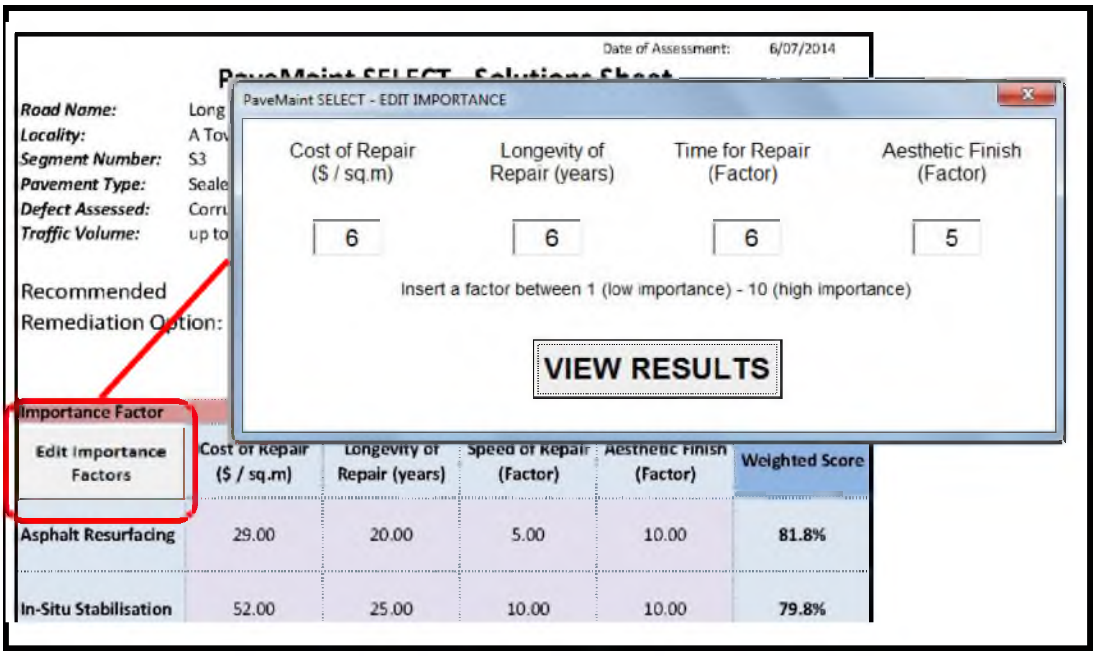


Figure 4.20 – PaveMaint SELECT Edit Importance Factors Screen launched from Macro Button in Solutions Sheet

4.6 PaveMaint SELECT Knowledgebase

As discussed in Section 4.3 previously, the Excel program provides a rich environment that is not only easily used but is capable of storing large amounts of data in a tabular format, and is able to access that data through lookup and referencing functions allowing cross-calculation of multi-criteria problems in a single platform.

The PaveMaint SELECT Excel file is constructed with six worksheets, two that are visible to the user (named "StartUp" and "Results" – discussed in Sections 4.4.1 and 4.4.5 respectively) shown in Figure 4.21 and a further four worksheets (named "AsphKnowledgeBase", "BitKnowledgeBase", "UnSeaKnowledgeBase" and "RemedyKnowledgeBase") shown in Figure 4.22 that are hidden from the user, but able to be accessed by the system administrator and are fully presented in Sections B.12 to B15 (inclusive) of Appendix B.

Figure 4.21 – PaveMaint SELECT Worksheet Arrangement – User Access

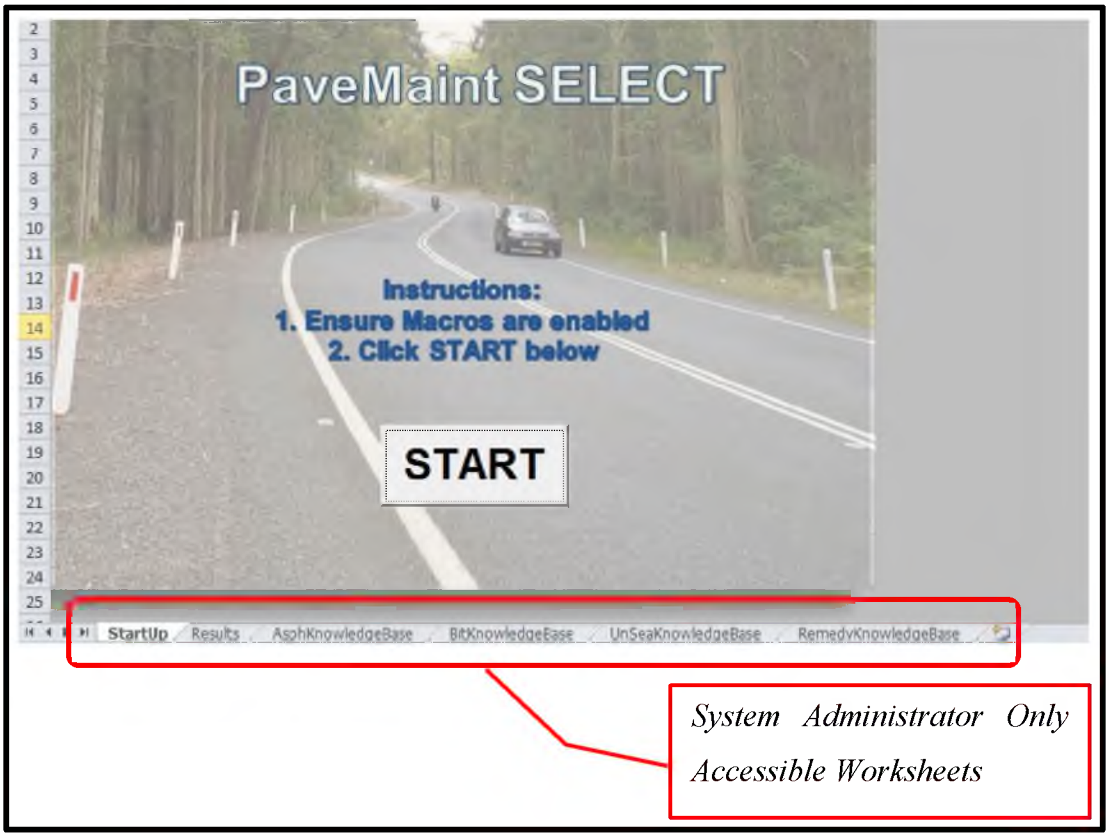
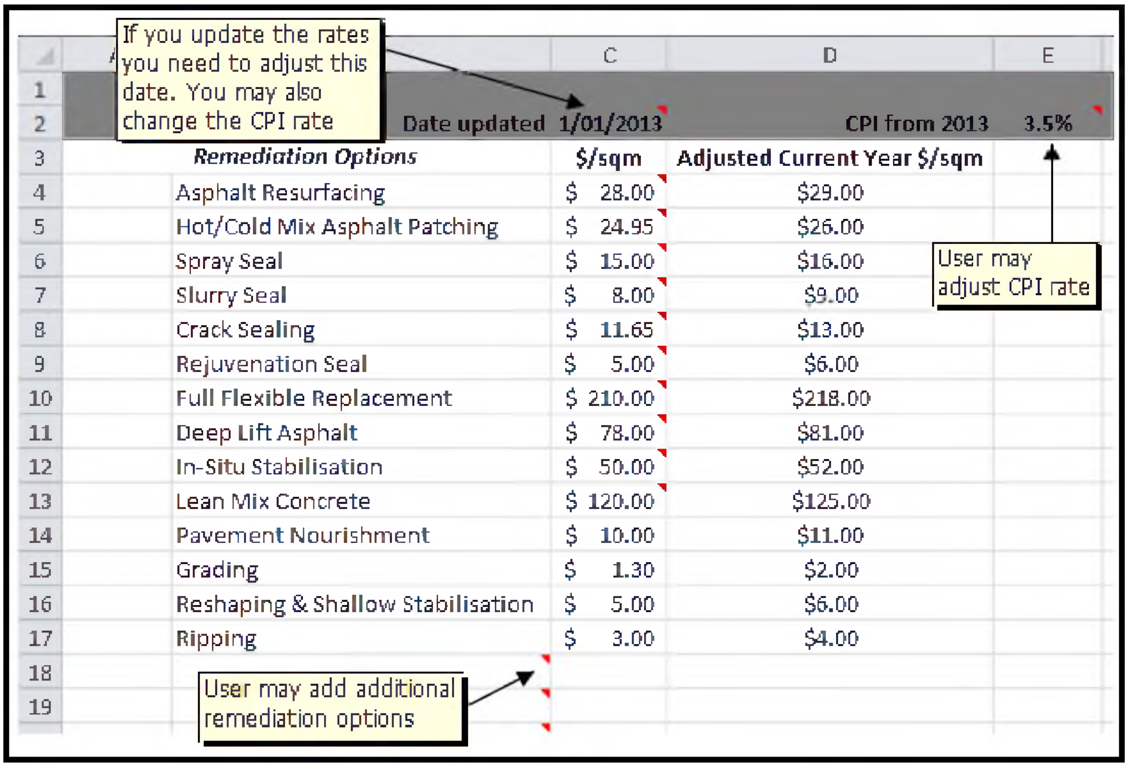


Figure 4.22 – PaveMaint SELECT Worksheet Arrangement – Administrator Access

4.6.1 Knowledgebase – Remediation Options

The worksheet titled "RemedyKnowledgeBase" provides a database of all the suitable remediation options previously discussed in Section 2.3 and presented in Table 2.3. The worksheet is hidden from the user and it is intended that the sheet would only be accessible to the organisation's nominated system administrator who, in order to view the sheet, must input a password to "unprotect" the workbook.

Figure 4.23 illustrates the appearance of the worksheet showing comments that have been incorporated with the respective cells to assist the administrator to properly adjust the worksheet without causing system errors. Column B ("B4:B23") of the worksheet presents the list of remediation options from Table 2.3, while Column C ("C4:C23") provides the respective cost of those remediation options, in accordance with Table 2.4 presented previously. The cells are marked with comment fields describing the reference where the costs were sourced.



	A/B	C	D	E
1				
2	Date updated	1/01/2013	CPI from 2013	3.5%
3	*Remediation Options*	$/sqm	Adjusted Current Year $/sqm	
4	Asphalt Resurfacing	$ 28.00	$29.00	
5	Hot/Cold Mix Asphalt Patching	$ 24.95	$26.00	
6	Spray Seal	$ 15.00	$16.00	
7	Slurry Seal	$ 8.00	$9.00	
8	Crack Sealing	$ 11.65	$13.00	
9	Rejuvenation Seal	$ 5.00	$6.00	
10	Full Flexible Replacement	$ 210.00	$218.00	
11	Deep Lift Asphalt	$ 78.00	$81.00	
12	In-Situ Stabilisation	$ 50.00	$52.00	
13	Lean Mix Concrete	$ 120.00	$125.00	
14	Pavement Nourishment	$ 10.00	$11.00	
15	Grading	$ 1.30	$2.00	
16	Reshaping & Shallow Stabilisation	$ 5.00	$6.00	
17	Ripping	$ 3.00	$4.00	
18				
19				

Figure 4.23 – PaveMaint SELECT "RemedyKnowledgeBase" Worksheet

Administrator access to the worksheet is aimed to enable information to be updated when it becomes available. The remediation knowledgebase allows provision for additional remediation options to be easily added, particularly those unique to the organisation, but also allows the administrator to update the costs of each option on a regular basis. However, the administrator may not be able (or willing) to continuously update the program; to that end, the worksheet incorporates a quasi-automated method for ensuring costs are current regardless if they are updated regularly or otherwise. This is achieved by applying a *growth factor* to the numeric value of each cost.

Cell "C2" of the worksheet contains a date that the system developer (and subsequently the system administrator) has manually input to document the date at which the costs were determined. Cell "E2" contains a percentage growth factor labelled as "CPI" (known as the consumer price index) which can be determined from either the national consumer price index fluctuation for the given period, or similarly the national gross domestic product (GDP) fluctuation. The initial factor of 3.5% selected by the author was taken from a comparison of typical fluctuations for both CPI and GDP for Australia in recent history (ABS 2014).

Column D ("D4:D23") displays the adjusted cost calculated from the formula provided in Equation 4.2.

$$C_p = C_u \times (1 + CPI)^{(t_p - t_u)}$$

Equation 4.2

where:

- *C_p is the present day cost of the remediation option;*
- *CPI is the cost growth factor (percentage figure) that can be determined from the nation's fluctuation in either consumer price index or gross domestic product, or may be a known regional figure reflective of the organisation;*
- *t_p is the present date, or the date upon which the assessment was undertaken (this is determined from the date displayed in Cell "M1" of the "Results" worksheet*);
- *t_u is the date which the remediation costs were last updated (displayed in Cell "C2" of the "RemedyKnowledgeBase" worksheet); and*
- *C_u is the cost of the remediation option at the time (t_u) of updating the "RemedyKnowledgeBase" worksheet.*

For example, the cost of the "Deep Lift Asphalt" remediation option presented earlier in Table 2.4 is approximately \$78.00 per square metre (C_u) in the year 2010 (t_u). Utilising the initial 3.5% growth factor (*CPI*) described earlier, the current (2014) cost of the remediation option (C_p) is given as $C_{2014} = 78 \times (1 + 0.035)^{(2014-2010)}$, where $C_{2014} = \$89.51$ and likewise in the year 2018 the cost of deep lift asphalt is given as $C_{2018} = \$102.71$.

4.6.2 Knowledgebase – Pavement Types

The "AsphKnowledgeBase", "BitKnowledgeBase" and "UnSeaKnowledgeBase" worksheets, found in the PaveMaint SELECT Excel file, contain the knowledgebase data for asphaltic concrete surfaced pavements, bituminous spray sealed pavements and unsealed pavements respectively. The data contained in these worksheets is grounded in the extensive technical review presented earlier in Chapter 2 and Chapter 3, along with data previously provided in Table 2.3 devised by the author. This worksheet provides a comprehensive catalogue of all the possible defects

associated with the pavement type and measures of the known critical degrees of defect deterioration severity; and uses that information to prune (or filter) the suitable list of remediation treatments from the “RemedyKnowledgeBase” (discussed in Section 4.6.1).

The knowledgebase worksheets for the various pavement types also contain the data referenced in Equation 4.1 pertaining to the “effectiveness”, “longevity”, “time” and “aesthetic finish” of the remediation option.

- In the determination of remediation option’s “effectiveness” a consideration was given through the initial case study and assessment by the author on the method in which the treatment is carried out and how thoroughly it will remove or remediate the failure mechanism. A unit-less factor between “10” and “1”; a high numeric factor represents a highly effective repair, while a low numeric factor represents a less effective repair. For example, as shown in Figure B.59 of Appendix B, the selection of a slurry seal treatment to remediate rutting in a bituminous spray sealed flexible pavement has been determined to have an effectiveness of “5” because it is an overlay method that is simply treating the symptom of the defect and not the underlying structural cause. Whereas the effectiveness of the full flexible pavement replacement remediation option has been determined to be “10” because it completely remediates the root cause of the defect.
- “Longevity” is provided in units of years and was determined primarily from a review of the literature, augmented through the initial case study, and is the expected life span of the remediation treatment before further remediation is required.
- “Time” is a unit-less factor representing the remediation option’s resource requirements and the time required to mobilise said resources to undertake the repair. Again looking at the method of the treatment work, this factor represents how soon the organisation would be capable of mobilising plant, equipment, materials and the workforce to react and undertake the repair. A low numeric factor represents a remediation treatment that can be enacted quite quickly, for example, Figure B.59 of Appendix B illustrates that

hot/cold mix asphalt patching has a factor of "1", whereas in-situ stabilisation has a factor of "10" which represents a remediation option that requires a greater period of time to plan the repair and often requires the use of specialist resources.

- The determination of the "aesthetic finish" of a remediation option is perhaps a subjective criterion, but an important one that is expected to require significant calibration throughout the system testing and refinement stage. Through the initial case study it was determined that certain remediation options result in low residual aesthetic appeal for the existing road environment and should not be considered in some instances; also, areas requiring higher degrees of aesthetic appearance might also prompt earlier intervention than otherwise required for slight or mild defect severities.

The relative values of all the user constraint factors will be further validated and refined during system testing.

The first stage of remediation option pruning is derived directly from Table 2.3, where the list of remediation options is propagated adjacent to each of the defect types. The second stage of remediation option pruning takes into consideration the defect severity and user-nominated constraints using conditional criteria. Through the initial case study investigations discussed in Chapter 3 it was discovered that, primarily, defect severity will ultimately influence whether one or any remediation option is selected but this is also augmented by the perceived importance of the aesthetic appeal of the area in which the road is situated.

4.6.2.1 Second Stage Pruning: Slight Defect Severity

Defects considered to be only "slight" (defect severity of "2" or less) would not result in a treatment or a repair; rather, they would continue to be monitored and acted upon only if and when they continue to deteriorate.

4.6.2.2 Second Stage Pruning: Moderate Defect Severity

Some remediation options are so significant that they would not generally be considered unless defect deterioration was quite severe (a severity value of "4" or greater). It was commonly found that when a defect severity was considered

moderate (defect severity of "3" or less), preference was given to treating the defect symptom (referred to as a "repair") rather than more comprehensive treatments such as "Full Flexible Replacement", "In-Situ Stabilisation", "Lean Mix Concrete", "Reshaping and Shallow Stabilisation" or the treatment of a bituminous spray sealed pavement with "Asphalt Resurfacing" which effectively replace the affected pavement. It was therefore determined that such remediation options would be pruned from selection when there were two or more other suitable remediation options available. This is illustrated in Table 4.1, Table 4.2 and Table 4.3 for asphaltic concrete, bituminous spray sealed and unsealed pavements respectively.

Table 4.1 – Remediation Options Pruned from Selection when Defect Severity Considered Moderate or Better – Asphaltic Concrete Surfaced Pavements

Defect Type	**Remediation Options Pruned when Defect Severity < 4**
Corrugations	- Full Flexible Replacement - In-Situ Stabilisation - Lean Mix Concrete
Potholes	- Full Flexible Replacement - In-Situ Stabilisation
Depressions	- In-Situ Stabilisation - Lean Mix Concrete
Rutting	- Full Flexible Replacement - In-Situ Stabilisation - Lean Mix Concrete
Patching Failure	- Full Flexible Replacement
Shoving	- Full Flexible Replacement - In-Situ Stabilisation
Cracking (all types)	- Full Flexible Replacement - In-Situ Stabilisation - Lean Mix Concrete

Table 4.2 – Remediation Options Pruned from Selection when Defect Severity Considered Moderate or Better – Bituminous Spray Sealed Pavements

Defect Type	**Remediation Options Pruned when Defect Severity < 4**
Aggregate Polishing	- Asphalt Resurfacing
Corrugations	- Asphalt Resurfacing - Full Flexible Replacement - In-Situ Stabilisation - Lean Mix Concrete
Raveling	- Asphalt Resurfacing
Potholes	- Full Flexible Replacement - In-Situ Stabilisation
Depressions	- In-Situ Stabilisation - Lean Mix Concrete
Rutting	- Asphalt Resurfacing - Full Flexible Replacement - In-Situ Stabilisation - Lean Mix Concrete
Oxidation	- Asphalt Resurfacing
Flushing	- Asphalt Resurfacing
Patching Failure	- Asphalt Resurfacing - Full Flexible Replacement
Shoving	- Full Flexible Replacement - In-Situ Stabilisation
Cracking (all types)	- Full Flexible Replacement - In-Situ Stabilisation - Lean Mix Concrete

Table 4.3 – Remediation Options Pruned from Selection when Defect Severity Considered Moderate or Better – Unsealed Pavements

Defect Type	**Remediation Options Pruned when Defect Severity < 4**
Corrugations	- Reshaping & Shallow Stabilisation
Raveling	- Reshaping & Shallow Stabilisation
Potholes	- Full Flexible Replacement - In-Situ Stabilisation - Reshaping & Shallow Stabilisation
Rutting	- Full Flexible Replacement - In-Situ Stabilisation - Reshaping & Shallow Stabilisation
Loss of Fines	- Reshaping & Shallow Stabilisation
Erosion Channels	- Full Flexible Replacement - Reshaping & Shallow Stabilisation

4.6.2.3 Second Stage Pruning: High Aesthetic Importance

Whilst defect severity is considered the primary instrument for second stage pruning, it also is heavily dependent on the user's importance for the aesthetic appeal of the road's environment.

It was discovered through the initial case study that when the segment of road is required to have a high aesthetic performance (that is, a *user-nominated importance factor* (A_{Iu}) of "8" or higher) *slight defect severity* pruning discussed in Section 4.6.2.1 earlier is not carried out. Instead, early intervention and treatment of defects is often desired, and even those remediation options discussed in Section 4.6.2.2 as part of the *moderate defect severity* pruning will again become viable solutions.

Another aspect for road segments with a high aesthetic importance is the consideration of the remediation options themselves and their own performance in providing a finished surface that meets that criteria.

“Crack sealing” is the only remediation option that is considered to have substantially poor aesthetic performance that has resulted in its own specific pruning. This is because as a treatment option it does not remove the presence of the defect on the road surface and may in fact exacerbate its visual appearance. An example of this is shown in Figure 4.24 which is taken from the case study exploration discussed in Chapter 5 and in Appendix C, for crack sealing of Dora Street, Hurstville, New South Wales showing that repair can actually be clearly viewed from satellite imagery. Therefore, it is for these reasons that “Crack sealing” is pruned from all selection recommendations when the aesthetic criteria importance factor is greater than a value of “8”.

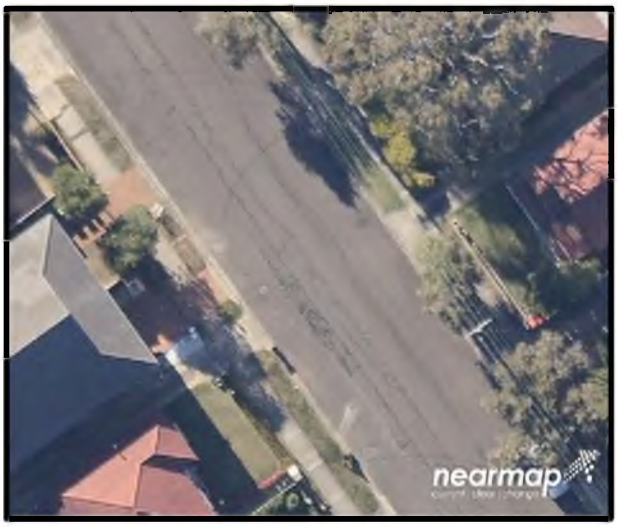


Figure 4.24 – Appearance of Crack Sealing Remediation from Satellite Imagery – Dora Street, Hurstville (NearMap 2014)

4.7 PaveMaint SELECT Prototype Summary

The prototype version of the PaveMaint SELECT decision support system (version 0.1) is a user-friendly Visual Basic for Applications (VBA) program embedded in a comprehensive macro-enable Microsoft™ Excel™ (Excel) spreadsheet database. PaveMaint SELECT is developed from a thorough examination of literature and built upon initial case study exploration that combines technical data with heuristic and procedural knowledge.

Figure 4.1 builds upon the existing pavement serviceability evaluation process identified through task profiling (Figure 3.4) which identified the need for decision support in road asset management. By framing the context surrounding the road asset decision making paradigm, Figure 4.1 demonstrates how a decision support tool such as PaveMaint SELECT can be used in combination with an individual's expert heuristics and organisational knowledge to identify, evaluate and select best suited remediation options.

The framework upon which the prototype PaveMaint SELECT program is structured is presented in Figure 4.2 which was developed from the task profiling stage of the study and designed to replicate the process upon which decision making considerations are deliberated by a *typical* road asset manager or engineer.

Through the development of PaveMaint SELECT, a comprehensive set of accelerated learning tools (*ALT*'s) were designed and developed to provide learning assistance to the user. For experienced road asset managers and engineers, the *ALT*'s will provide a convergence check for their own knowledge and provide an assurance that the program is providing an assessment of conditions that are congruent with their own expectations. For junior or novice members of the road asset management team, the *ALT*'s provide the opportunity to learn and improve their own skills and knowledge while using the program while continuing to contribute to the organisation.

The structure and knowledge of the program exists within a series of knowledgebase worksheets that house the complete information necessary for the program to evaluate pavement defects and remediation options. Key features of the

knowledgebase worksheets are their function in undertaking first and second stage pruning of suitable remediation options based on user nominated values for defect severity and constraints. In addition, Equation 4.2 was developed to build system robustness and introduced into the *Cost* fields of each remediation option. It is used to revaluate the *Cost* of each remediation option, beginning with the base cost (initially input into the database) which is increased by the nominated *growth factor* (based on a combination of consumer price index and gross domestic product fluctuation) to provide a realistic present-day value for the cost of the remediation options.

Finally, the formulation devised to determine the selection of the most suitable remediation options is given by Equation 4.1, which is aided by initial option pruning intelligence incorporated into the spreadsheet database, to provide a numerical evaluation of each option's performance against each of the system's criteria and the user-nominated priorities. Utilising *Importance Factors* adapted from dominant priorities discovered during the task profiling stage, Equation 4.1 employs factors that consider the present *Cost* of the remediation option, the expected *Longevity* that repair will bring, the *Aesthetic* finish of the resulting repair and the *Time* to mobilise and execute the repair. The evaluation considers each remediation option's performance against the *Importance Factors*, along with the system's *Effectiveness* factor, and calculates a score determinate on the user-nominated priority for each *Importance Factor*.

Following the development of the prototype PaveMaint SELECT program, the system will undergo testing and refinement where it is anticipated that the prototype will develop stronger heuristic knowledge to add to and improve the knowledgebase data resulting in decision making that will better represent real world considerations and solutions.

5 SYSTEM TESTING: FIELD INTERVIEWS AND CASE STUDIES

5.1 The Significance of Field Interviews and Case Studies

Case studies are a widely utilised research methodology employed by many to investigate existing phenomena within real-life context and seeks to address the situation in which the boundaries between phenomenon and context are not clear (Yin 1993; Meyer 2001). While commonly associated with qualitative studies, case study methodology is known to be scientifically robust for quantitative studies and provides a high degree of insight for the researcher via the exploration of reality and practice (McGloin 2008).

The purpose of this study is to ascertain the answer to the overall research question: "*can organisational intelligence, in combination with established theory, be used to effectively and efficiently plan road remediation*". That is, are the decisions made by road asset managers (and their teams) effective in comparison to the written theory on road remediation and efficient in terms of lifecycle and network spending; and can the heuristic and organisational knowledge that the road asset manager applies as the expert be learnt and implemented through a decision support tool to ensure current and future decisions are consistent with sound expert knowledge and organisational principles.

Chapter 4 previously outlined the development of the prototype decision support system "PaveMaint SELECT", which is based on an in-depth exploration of the literature surrounding the documented solutions to the road remediation problem and the documented framework upon which road asset management decisions may be made; augmented by the exploration of the preliminary case study of Shoalhaven City Council. In doing so, PaveMaint SELECT demonstrates how written theory can be augmented by heuristic and organisational knowledge to replicate real-world situational decision making for road remediation.

Despite its merits, an often criticised limitation of case studies within a quantitative study such as this one, is that isolated case studies consisting of a single augmentation can be seen to limit the value of the research (Yin 1993; Meyer 2001). In order to address this concern, and to provide further rigour and refinement to the

system, additional cases of individuals from organisations outside Shoalhaven City Council, as well as others within, have also been explored herein and presented in Appendix C.

5.2 Research Participant Recruitment

The author has undertaken this study in conjunction with Shoalhaven City Council, a local government organisation on the south coast of New South Wales Australia, and the University of Wollongong's Local Government Research and Practice Development Consortium (LGRPDC) which is made up of five participating local government organisations also in New South Wales and south of Sydney. The LGRPDC provides for access to valuable research data and resources in a cooperative relationship between organisations within the consortium and to that end, organisations within the LGRPDC were accessible for participant recruitment for research interviews.

However, participants who have taken part in this study were advised in their Participant Information Sheet (see Appendix C) that their contributions would be coded in a manner that meant that they could not be personally identified (for ethical concerns). As such, while participating organisations within the LGRPDC, including the author's own "host organisation" (Shoalhaven City Council) may be easily identifiable, the data obtained from individuals within those organisations who specifically took part in the field interviews have been coded to avoid personal identification. Additionally, the identities of individuals recruited outside of the LGRPDC group of organisations have also had any identifying information removed and coded such that neither they, nor their organisation, can be identified.

Eight individual participants across five organisations have taken part in this study. In addition, there are a further two participants from the host organisation (Participants 0.1 and 0.2) who have been partly discussed earlier in Chapter 3 which outlined the preliminary case study that not only informed the first stage of the study ('task profiling') but aided in the formulation of the prototype PaveMaint SELECT program which was the second, or 'decision support system design and prototype development', stage of the study. The recruitment of the remaining eight participants is critical to this third (and final) stage of the study aimed at verifying and validating

the prototype PaveMaint SELECT against other local government organisations in New South Wales and providing data that can be used to refine the system and ensure that it effectively replicates real world solutions.

Presented herein is a discussion on the case study exploration of selected participant interview data obtained from the eight participants, the complete list and raw data from these research interviews is presented in Appendix C.

5.3 Participant Overview

As described earlier in Section 5.2, experienced road asset managers and engineers responsible for the maintenance and management decisions of local government road networks have participated in the research and data collection stage of this study. Their wide and varied experiential knowledge is critical to the validation and refinement of the PaveMaint SELECT decision support system. Therefore, it is important to review the collective information about the participants and their organisations, in order to ascertain a confidence in the data collected.

5.3.1 Participant's Experience and Knowledge

Participants of this study have demonstrated experience and knowledge in road asset management and engineering with over 85% having more than ten years of experience in this field as either an Asset Manager, Roads Maintenance Engineer, or an Asset Officer or Inspector, and illustrated in Figure 5.1 and Figure 5.2 (overleaf) which are adapted from Table C.8 and Table C.9 in Appendix C, respectively. This represents a highly experienced knowledge-pool with expert opinions and what should be considered to be sound road-asset decision making expertise.

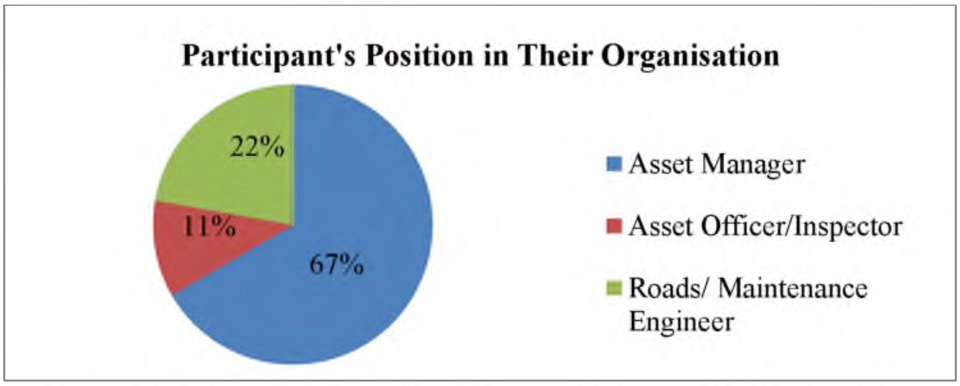


Figure 5.1 – Participants' Indication of Position in their Organisation

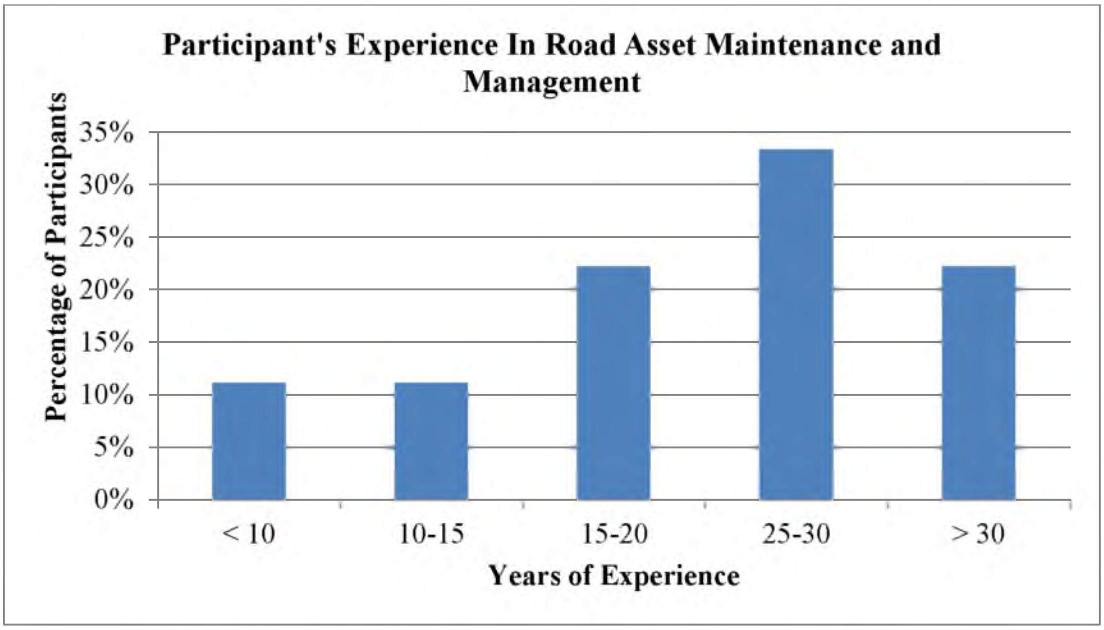


Figure 5.2 – Participants' Indication of Years of Experience in the Field of Road Asset Maintenance and Management

5.3.2 Road Network Information

From the participating organisations, a far majority of the pavements making up their road network are a combination of sealed and unsealed flexible pavements, constituting over 90% of the road networks surveyed. Figure 5.3 (adapted from Tables C.10 and C.11) shows that when asked to identify the dominant pavement type found in their road network (defined by kilometres of overall road length) 100% of respondents indicated that the most common pavement types were flexible pavements (87.5% sealed flexible pavements and 12.5% unsealed flexible pavements). While the indication of the presence of rigid and segmental block pavements was low, there were no other identified pavement types in the road networks, which is in congruence with the literature discussed in Chapter 2. When further asked to describe the percentage make-up of the two most dominant pavement types, Figure 5.4 (based in Table C.12) shows that over 95% of the road networks surveyed consist of flexible pavements as either the primary or second-most common in pavement length, with rigid pavements making up the remaining total of the road networks and segmental block pavements never considered a dominant pavement type in any road network. This supports the decision of the author to focus this research on flexible pavements only.

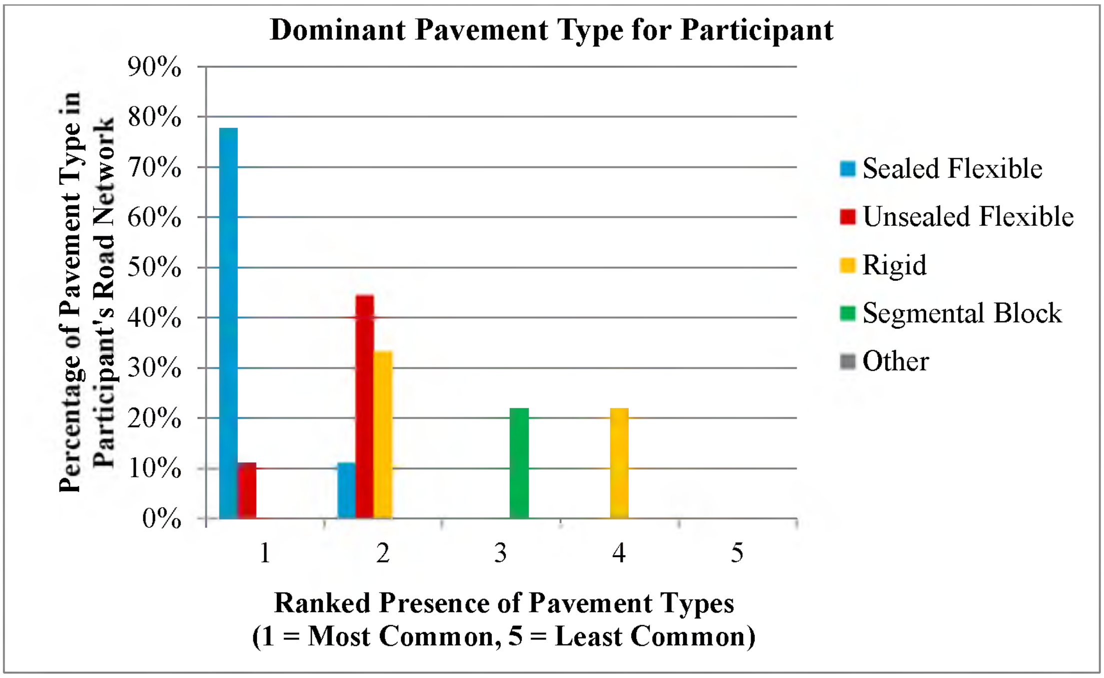


Figure 5.3 – Participants' Indication of the Dominant Pavement Types in the Organisation's Road Network

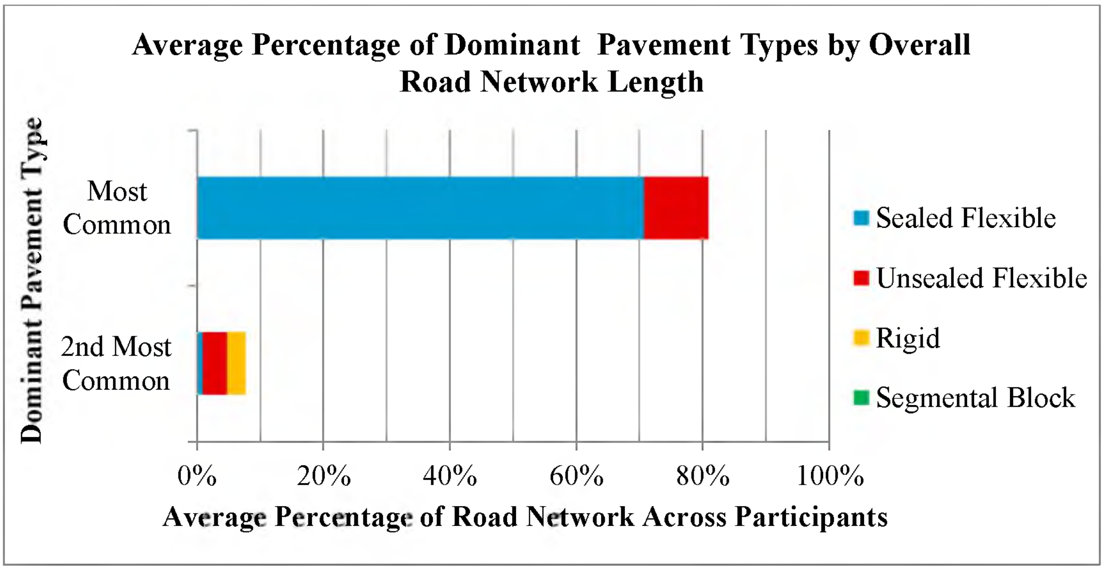


Figure 5.4 – Participants' Indication of the Make Up of the Two-Most Common Pavement Types in their Road Network

Figure 5.5 illustrates the data presented in Table C.13 of Appendix C and shows that for the organisations explored over 87% of the road networks are considered to be performing satisfactorily, and over 60% are considered to be in "Good" condition. While 13% of the road networks are considered to be in "Poor" condition, none are "Failing", but similarly none can be classified as "Excellent".

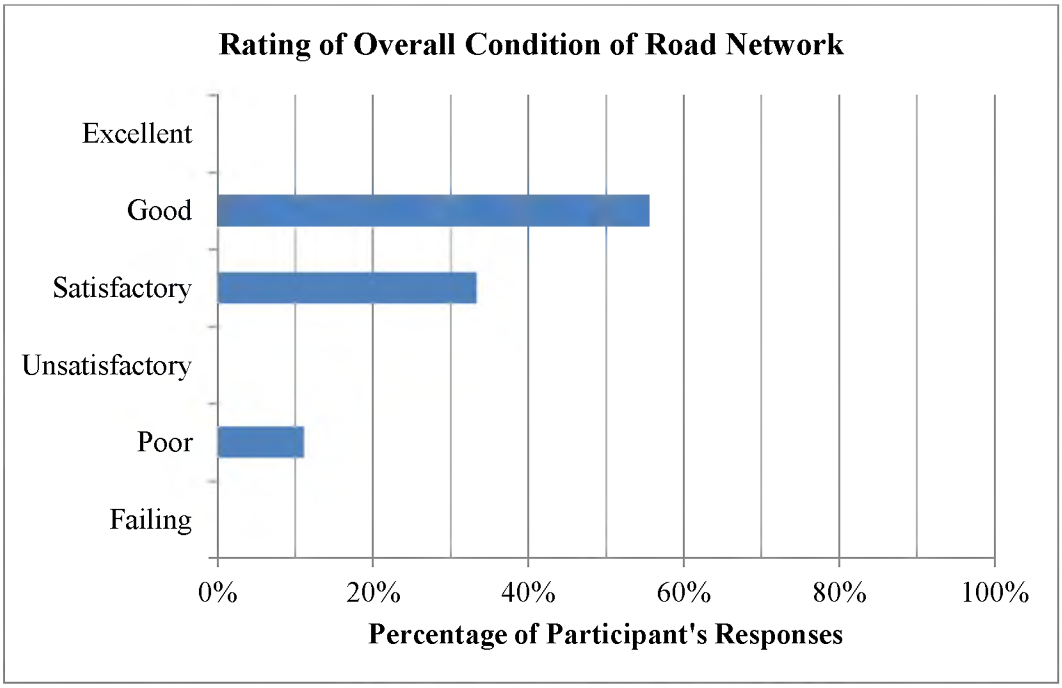


Figure 5.5 – Participants' Indication of the Condition of their Road Network

With a significant majority of the road networks considered to be performing satisfactorily or better, this illustrates that the participants researched in this study have demonstrated experience and expertise in road asset management and have exhibited sound decision making in this area. This also aids the decision to establish and validate the PaveMaint SELECT software with the experiential and heuristic knowledge of these experienced practitioners.

5.3.3 Organisational Constraints and Decision Making

In the complex context of organisational priorities discussed earlier in Section 3.2, road asset managers and engineers are faced with a number of constraints in which they are required to balance. Tables C.14 and C.15 of Appendix C represent the importance of the dominant factors constraining the decision making process for the researched participants and their organisations which is illustrated in Figure 5.6.

Primary constraints considered to influence road asset decision making are: maximising the asset's life, minimising the cost of the repair and maximising the present-day performance of the asset, while user safety is also considered a high priority by a small percentage of the participants. Maximising user satisfaction and minimising resource usage are lower ranked constraints. While political or

reactionary decisions were given a higher priority by a small percentage of the participants, it was generally considered a low priority constraint.

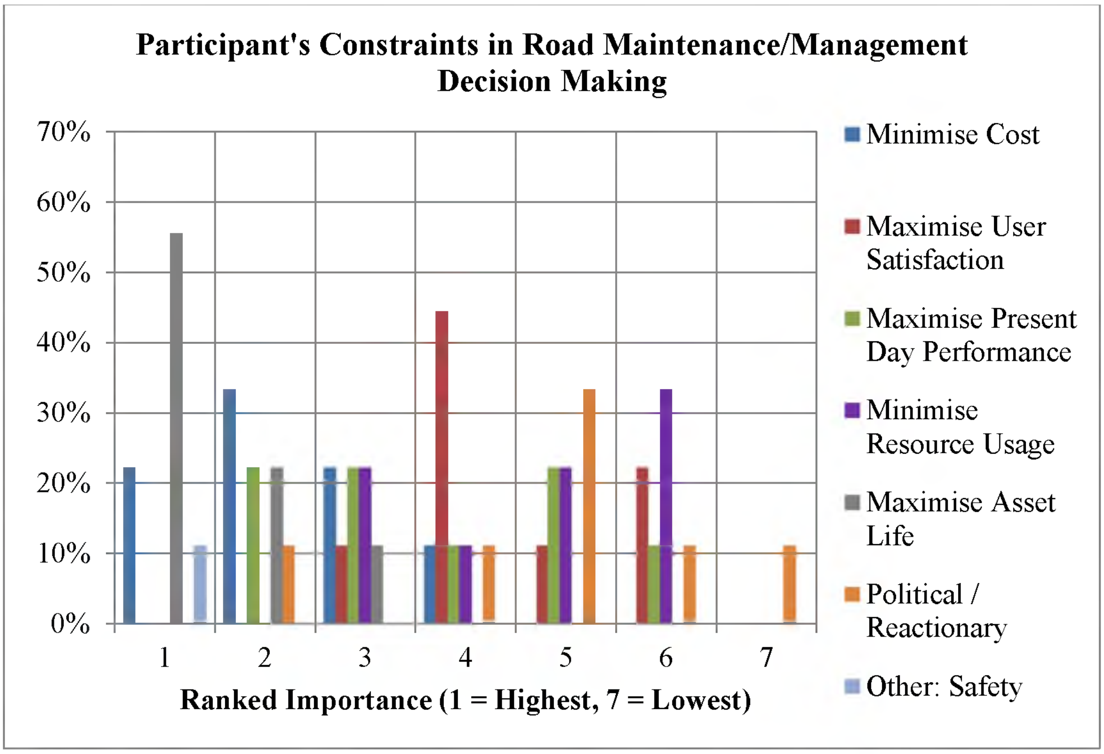


Figure 5.6 – Participants' Indication of Dominant Constraints when considering Road Maintenance and Management

Section 4.4.4 discusses how the PaveMaint SELECT software nominates the dominant user constraints (termed "*Importance Factors*" in the Solutions Sheet) as:

- the cost of undertaking the repair,
- the longevity that the repair will add to pavement life,
- the time required to implement the repair (that is, how soon the repair can be carried out), and
- the desired aesthetic finish of the repair,

There is a direct relationship between the constraints shown in Figure 5.6 and the *Importance Factors* devised for the PaveMaint SELECT decision support system and in some cases it could be argued that certain constraints could be related to multiple *Importance Factors*. For example, the "Maximise User Satisfaction" constraint has a relationship with a combination of the "Aesthetics", "Cost" and "Time" *Importance Factors*.

The requirement to maximise a user's satisfaction could be determined to bring in the user's experience on the cost of maintaining their motor vehicle and that driving on a road in disrepair might lead to the accelerated deterioration of their vehicle, which will lead to increased costs to the user. Similarly, maximising user satisfaction can mean that the user would prefer to see the road repaired in a timely manner and therefore the time to undertake the repair would be of high importance. However, through participant input, it is considered that the constraint of "Maximise User Satisfaction" is actually directly related to the "Aesthetics" *Importance Factor* and that while the other considerations are important, the main objective of this constraint is to improve the visual appearance of the road environment in alignment with the user's expectations. Table 5.1 illustrates the complete list of participant nominated constraints shown in Figure 5.6 and their relationship to the respective *Importance Factors* provided in the PaveMaint SELECT Solutions Sheet.

Table 5.1 – Comparison of User Constraints with PaveMaint SELECT "Importance Factors"

PaveMaint SELECT "Importance Factors"	**Participant Nominated Constraints**
Cost	- Minimise Cost
Longevity	- Maximise Asset Life
Time	- Maximise Present-Day Performance - Minimise Resource Usage - Safety
Aesthetics	- Maximise User Satisfaction - Political / Reactionary

In statements that support the data collected during the *Task Profiling* stage of this study (discussed in Chapter 3 and Section C.2 of Appendix C), the participants indicated that it is very rare that asset managers and engineers make road asset maintenance or management decisions in isolation (that is, it is not often that only one person makes the road management or maintenance decision) but function in a collaborative group with a mixture of input from various members of the team (refer

Table C.16 of Appendix C). For example, 75% of the participants indicated that within their organisations the road asset team is either *comprised of senior and junior members that make decisions collaboratively* (37.5%), or have a team that is *highly experienced where individuals make road management and maintenance decisions independently and effectively* (37.5%). The remaining 25% indicated that their road asset team is comprised of *both senior and junior members, but only senior members are given the opportunity to make asset maintenance and management decisions*.

All participants considered that proactive road asset management and maintenance were a priority for their organisations and that they actively sought to collect data regarding the condition of their roads so that they could plan remediation works across the whole network. It was found, however, that organisational structure and constraints resulted in a varied approach in how each participant achieved this (refer Table C.17 of Appendix C).

The majority of participants (62.5%) stated that their road asset team *has the capacity to plan strategic maintenance, however works are often reprioritised by some external or internal pressures* while a quarter (25%) of the participants said that they *use asset inspections and the network database effectively and are able to prioritise maintenance works strategically; balancing technical, budgetary and social constraints without being required to react to external or internal pressures*. The remaining 12.5% felt that *strategic maintenance planning was desirable when possible, however the budget available means that nearly all road maintenance is completely reactionary and only the worst sections of road are repaired*. Furthermore, approximately half the participants felt that they are required to adapt to often-changing organisational constraints and that depending on annual budgetary pressures or community focus at the time, they might have responded to that question differently. This again concurs with the data collected during the initial case study explored through the *Task Profiling* stage of this study (discussed in Chapter 3 and Section C.2 of Appendix C), and provides more emphasis on the need of a decision support tool such as PaveMaint SELECT.

5.4 Selected Case Studies

The following are a selection of case studies that the author considers to have been influential in the validation as well as refinement of the prototype PaveMaint SELECT decision support system. That is, the following case studies demonstrate aspects of the prototype that provide agreement with the real world decisions made by experienced road asset managers and engineers but also highlight areas for critical refinement. The complete detail of all case studies explored in this study is presented in Section C.4 of Appendix C.

5.4.1 Case Study: Quinns Lane, South Nowra

Presented in Section C.4.1.1 of Appendix C, Quinns Lane in South Nowra is a suburban road constructed from a flexible pavement with a bituminous spray seal wearing course. The eastern, or Worrigee Road, segment was suffering from severe crocodile cracking and numerous patching failure defects. Details of the participant's considerations are presented below.

<u>Treatment Data:</u>

Road Type:	Flexible Bituminous Spray Seal
Traffic Conditions:	Up to 10^5 ESA (for a design life of 30 years)
Dominant Defect:	Crocodile Cracking
Treatment Selected:	Full Flexible Replacement
Severity:	Poor to Unserviceable
Cost Constraint:	2/4
Longevity Required:	4/4
Resource Constraints:	1/3
Aesthetic Constraints:	2/3

The participant indicated that there were at least two defects present "Crocodile Cracking" and "Patching Failure" (shown in Figure 5.7 through to Figure 5.9 inclusive) but considered the former to be the dominant defect requiring treatment. "Crocodile Cracking" was modelled in the prototype PaveMaint SELECT program

(Figure 5.11) which provided a recommendation to undertake "Full Flexible Replacement" as the treatment type. This was in agreement with the participant's own selection and an image of the completed works is shown in Figure 5.10.

Figure 5.7 – Quinns Lane before Treatment Demonstrating Failed Crocodile Cracking with Patching Failure in a Poor to Unserviceable Condition

Figure 5.8 – Quinns Lane before Treatment Demonstrating Failed Crocodile Cracking with Patching in a Poor to Unserviceable Condition

Figure 5.9 – Quinns Lane before Treatment Demonstrating Crocodile Cracking in a Poor Condition

Figure 5.10 – Quinns Lane following Full Flexible Replacement Treatment

Date of Assessment: 18/02/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Quinns Lane
Locality: South Nowra
Segment Number: Worrigee
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Crocodile Cracking ***Severity:*** 5
(1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	3	10	5	5	Overall Weighted Score
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	
Full Flexible Replacement	218.00	30.00	10.00	10.00	77.5%
In-Situ Stabilisation	52.00	25.00	10.00	10.00	73.3%
Asphalt Resurfacing	29.00	25.00	5.00	10.00	69.6%
Slurry Seal	9.00	10.00	5.00	7.00	44.9%
Rejuvenation Seal	6.00	5.00	5.00	7.00	42.9%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	40.5%
Crack Sealing	13.00	5.00	2.00	2.00	38.0%

Figure 5.11 – Prototype PaveMaint SELECT Solutions: Crocodile Cracking – Quinns Lane, South Nowra

In the ensuing discussion regarding the solutions provided in the assessment of the "Crocodile Cracking" defect, the participant was interested whether the recommended remediation option would have changed significantly had the assessment been carried for the present "Patching Failure" defects instead, and whether or not the decision was appropriate for both options. As such, the system was rerun with the same parameters, except the defect and its severity (shown in Figure 5.12). The recommended treatment provided strong agreement with the previous assessment.

The participant felt that it would beneficial to incorporate multiple defects within the one assessment; however, it was considered beneficial to be able to run two scenarios independent of each other and provide resultant recommendations that can be compared with one another. This was considered by the participant to be a strength of the PaveMaint SELECT program

Date of Assessment: 18/02/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Quinns Lane
Locality:	South Nowra
Segment Number:	Worrigee
Pavement Type:	Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed:	Patching Failure — *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume:	up to 1x10^5 ESA

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	3	10	4	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Full Flexible Replacement	218.00	30.00	10.00	10.00	80.5%
Asphalt Resurfacing	29.00	25.00	5.00	10.00	74.4%
Deep Lift Asphalt	81.00	25.00	7.00	8.00	65.2%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	42.7%

Figure 5.12 – Prototype PaveMaint SELECT Solutions: Patching Failure – Quinns Lane, South Nowra

5.4.2 Case Study: Burelli Street, Wollongong

Burelli Street is a road located in the central business district (CBD) of Wollongong. It consists of a flexible pavement with an asphaltic concrete wearing course. It was suffering from pumping (associated with crocodile cracking) indicating a loss of pavement structure integrity. As such an in-situ stabilisation treatment was selected by the participant to rectify the structural problems with the pavement. A summary of the considerations is provided below and in Section C.4.3.1 of Appendix C.

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Pumping

Treatment Selected: In-Situ Stabilisation

Severity: Poor

Cost Constraint: 1/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

The defect was subsequently modelled in the PaveMaint SELECT DSS which recommended two options "Full Flexible Replacement" and "In Situ Stabilisation", where "Full Flexible Replacement" was recommended as the most suitable treatment option (Figure 5.13). Upon discussion it was thought that the low "Importance" for cost was misrepresentative for the participant's own criteria. Therefore, utilising the in-built "Edit Importance Factors" functionality, the cost importance factor was refined to a value of "2", which resulted in "In Situ Stabilisation" becoming the recommended treatment option (Figure 5.14).

It was also highlighted that the participant would not consider a "Full Flexible Replacement" for their road network and suggested a repair such as "Lean Mix Concrete" would be a more suitable alternative for the treatment of this defect.

Date of Assessment: 15/04/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Burelli Street
Locality: Wollongong
Segment Number: 20
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Pumping *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	1	6	6	10	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Full Flexible Replacement	218.00	30.00	10.00	10.00	97.7%
In-Situ Stabilisation	52.00	25.00	10.00	10.00	97.0%

Figure 5.13 – Prototype PaveMaint SELECT Solutions: Pumping – Burelli Street, Wollongong

Date of Assessment: 15/04/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Burelli Street
Locality: Wollongong
Segment Number: 20
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Pumping *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

Recommended Remediation Option: **In-Situ Stabilisation**

Summary of Results

Importance Factor	2	6	6	10	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
In-Situ Stabilisation	52.00	25.00	10.00	10.00	97.1%
Full Flexible Replacement	218.00	30.00	10.00	10.00	95.5%

Figure 5.14 – Prototype PaveMaint SELECT Solutions: Importance Factor Refinement Pumping – Burelli Street, Wollongong

5.4.3 Case Study: Grey Street, Keiraville

Presented in Section C.4.3.2 of Appendix C, Grey Street in Keiraville is a flexible pavement with an asphaltic concrete wearing course in a suburban area. It was suffering from crocodile cracking with cells of loose pavement surface being dislodged and resulting in potholing. In this instance the participant chose to undertake a lean mix concrete repair which has so far successfully remediated the pavement without further issue. The participant's considerations included the following.

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Crocodile Cracking

Treatment Selected: Lean Mix Concrete

Severity: Unserviceable

Cost Constraint: 1/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

Utilising the PaveMaint SELECT program to evaluate the defect, the DSS recommended "Full Flexible Replacement" as the preferred treatment option. This is not in concurrence with the participant's own decision. In addition, there were a further six treatment options provided in the "Results" worksheet, three of which the participant considered to be likely solutions for their organisation, while the remaining three were not, these are summarised in Table 5.2 below. Of those that were not considered likely choices, the participant concluded that the "Rejuvenation Seal" was not at all an acceptable solution for this defect type and severity. This input will be considered further during system refinement.

Table 5.2 – Participant 3 Consideration of DSS Solutions for Case Study 5.4.3

Treatment Option	**Likely to be Considered by the Organisation?**
Full Flexible	No – consider Lean Mix Concrete instead
In-Situ Stabilisation	Yes
Asphalt Resurfacing	Yes
Hot/Cold Mix Asphalt Patching	Yes
Slurry Seal	No
Rejuvenation Seal	No - remove
Crack Sealing	No

Date of Assessment: 15/04/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Grey Street
Locality:	Keiraville
Segment Number:	10, 20
Pavement Type:	Sealed Flexible - Asphalt Surface Pavement
Defect Assessed:	Crocodile Cracking — *Severity:* 5 [1 = slight >>> 5 = unsatisfactory]
Traffic Volume:	up to 1x10^5 ESA

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	**1**	**10**	**7**	**5**	
Edit Importance Factors	**Cost of Repair ($ / sq.m)**	**Longevity of Repair (years)**	**Time for Repair (Factor)**	**Aesthetic Finish (Factor)**	**Overall Weighted Score**
Full Flexible Replacement	218.00	30.00	10.00	10.00	**78.0%**
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**73.2%**
Asphalt Resurfacing	29.00	20.00	5.00	10.00	**64.5%**
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	**45.1%**
Slurry Seal	9.00	8.00	5.00	7.00	**40.1%**
Rejuvenation Seal	6.00	5.00	5.00	7.00	**38.1%**
Crack Sealing	13.00	3.00	2.00	2.00	**36.2%**

Figure 5.15 – Prototype PaveMaint SELECT Solutions: Crocodile Cracking – Grey Street, Keiraville

5.4.4 Case Study: Lower River Road, Tocumwal

Lower River Road in Tocumwal is an unsealed transit (or collector) road with very low traffic volumes (less than one hundred vehicles per day) but used by a high proportion of heavy vehicles (up to 30%). The dominant defect treated by the participant was soft spots which resulted in a full flexible replacement of that section of pavement. Details of this case are presented below and in Section C.4.4.3 of Appendix C.

Treatment Data:

Road Type:	Flexible Unsealed
Traffic Conditions:	Up to 10^4 ESA
Dominant Defect:	Soft Spots
Treatment Selected:	Full Flexible Replacement
Severity:	Moderate
Cost Constraint:	3/4
Longevity Required:	4/4
Resource Constraints:	1/3
Aesthetic Constraints:	2/3

The defect was modelled in the DSS which provided “In Situ Stabilisation” as the most suitable solution (Figure 5.16) and provided the participant’s own recommendation as the second-highest ranked solution.

The participant questioned the recommendation to use “In-Situ Stabilisation” for unsealed pavements at all. The participant outlined that an “In-Situ Stabilisation” creates a semi-bound pavement, which while improving the structural capacity of the pavement, would result in long term higher operating costs for the organisation. With such low traffic volumes, unsealed pavements are considered cost-effective

assets within the road network, as there are many low cost remediation options available to be selected. By creating a semi-bound pavement, these low cost remediation options will no longer be considered suitable and will result in more expensive maintenance costs. Therefore, "In Situ Stabilisation" should not be considered for any unsealed pavement. This input will be considered during system refinement

Date of Assessment: 22/05/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Lower River Road
Locality: Tocumwal
Segment Number: 2
Pavement Type: Unsealed Flexible Pavement
Defect Assessed: Soft Spots *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Recommended Remediation Option: **In-Situ Stabilisation**

Summary of Results

Importance Factor	6	10	3	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
In-Situ Stabilisation	52.00	15.00	10.00	10.00	79.9%
Full Flexible Replacement	218.00	15.00	10.00	10.00	77.1%
Pavement Nourishment	11.00	2.00	3.00	10.00	62.7%

Figure 5.16 – Prototype PaveMaint SELECT Solutions: Soft Spots – Lower River Road, Tocumwal

5.4.5 Case Study: Browns Road, South Nowra

Presented in Section C.4.5.1 of Appendix C, Browns Road in South Nowra is a suburban road constructed from a flexible pavement with a bituminous spray seal wearing course.

This pavement was suffering from rutting in what was considered an unserviceable condition, in that it was adversely influencing the steering of vehicles whose tyres were being caught in the longitudinal depression. Details of this case study are discussed below.

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Rutting

Treatment Selected: Full Flexible Replacement

Severity: Unserviceable

Cost Constraint: 4/4

Longevity Required: 4/4

Resource Constraints: 1/3

Aesthetic Constraints: 2/3

Evaluating the defect in the PaveMaint SELECT program (Figure 5.17), the most suitable remediation option recommended was "Full Flexible Replacement", which was in agreement with the participant's own decision.

Upon reviewing the other suggested remediation options, the participant indicated that "Asphalt Resurfacing", "Slurry Seal" and "Hot/Cold Mix Asphalt" which were also suggested by the DSS were not considered likely solutions adopted by their organisation, but agreed that "In-Situ Stabilisation" and "Lean Mix Concrete" options were. The participant also noted that a "Deep Lift Asphalt" treatment should also be included as suitable treatment for "Rutting". This inclusion will be discussed further during system refinement.

Date of Assessment: 7/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Browns Road
Locality: South Nowra
Segment Number: 1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Rutting *Severity:* 5
Traffic Volume: up to 1x10^5 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	10	10	5	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Full Flexible Replacement	218.00	30.00	10.00	10.00	64.8%
In-Situ Stabilisation	52.00	25.00	10.00	10.00	63.9%
Lean Mix Concrete	125.00	25.00	10.00	10.00	61.4%
Asphalt Resurfacing	29.00	25.00	5.00	10.00	58.6%
Slurry Seal	9.00	10.00	5.00	7.00	57.1%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	40.3%

Figure 5.17 – Prototype PaveMaint SELECT Solutions: Rutting – Browns Road, South Nowra

5.4.6 Case Study: Terralong Street, Kiama

Terralong Street in Kiama is a flexible pavement constructed with a bituminous spray seal wearing course. It is a major suburban street, parts of which are in the CBD area of Kiama and so aesthetic appeal to the road is of high importance to the organisation and the community. This case study is presented in Section C.4.6.1 of Appendix C and discussed below.

<u>Treatment Data:</u>

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Other – Surface Irregularities

Treatment Selected: Asphalt Resurfacing

Severity: Moderate

Cost Constraint: 2/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

The prototype PaveMaint SELECT program database does not list "Surface Irregularities" as a defect type, so in order to make an assessment in the DSS the participant likened the defect to "Patching Failure" which could be assessed. The evaluation, shown in Figure 5.18, recommended "Asphalt Resurfacing" as the most suitable remediation option. This was in agreement with the participant's own decision making.

While selecting the "Severity" of the defect, the participant commented that the *ALT* descriptions for the degrees of deterioration did not quite match their own expectations. That is, the participant considered the defect severity to be "Moderate" (a value of "3"), however, if the participant was to strictly use the description provided in the *ALT*, they would have chosen a severity value of "2" and therefore thought that the severity would be underestimated.

The participant considered that the cost provided for "Asphalt Resurfacing" is higher than is experienced in their organisation and that it should be in the order of $24 per square metre. Also, the participant deemed that the aesthetic factor shown for "Deep

Lift Asphalt" is lower than they expected and advised that it should be the equivalent of "Asphalt Resurfacing", that is a value of "10".

Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Terralong St
Locality: Kiama
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Patching Failure ***Severity:*** 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	3	10	5	10	Overall Weighted Score
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	
Asphalt Resurfacing	29.00	25.00	5.00	10.00	**88.7%**
Deep Lift Asphalt	81.00	25.00	7.00	8.00	**78.1%**
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	**47.2%**

Figure 5.18 – Prototype PaveMaint SELECT Solutions: Patching Failure – Terralong Street, Kiama

5.4.7 Case Study: Pindaree Road, Peakhurst

Pindaree Road in Peakhurst is an asphaltic concrete surfaced flexible pavement in a metropolitan suburb. This segment of the pavement was suffering from moderate block cracking defects that were treated with crack sealing, with some of the more severe sections requiring deep lift asphalt repairs. However, the participant considered that the dominant repair selection for this defect was crack sealing. The case study is presented below and in Section C.4.7.3 of Appendix C.

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Block Cracking

Treatment Selected: Crack Sealing with Deep Lift Asphalt sections

Severity: Moderate

Cost Constraint: 3/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

The defect was evaluated using the prototype PaveMaint SELECT program which provided "Slurry Seal" as the most suitable remediation option (Figure 5.19). Further, the DSS did not recommend either "Crack Sealing" or "Deep Lift Asphalt" treatment options as alternative selections.

The participant considered that both "Crack Sealing" and "Deep Lift Asphalt" should definitely have been in the consideration of the "Solutions Sheet" and questioned the pruning routine incorporated into the program database. Upon further discussion and review of the "administrator access" database information, an error was found in the formula to prune remediation options listed for the "Block Cracking" defect. It is thought that the correction of this formula will provide solutions that are in better accord with the participant's own decision. This will be evaluated further in the refinement stage of the final PaveMaint SELECT program presented in Section 6.2.

Date of Assessment: 22/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Pindaree Road
Locality: Peakhurst
Segment Number: 1
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Block Cracking ***Severity:*** 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

Recommended Remediation Option: **Slurry Seal**

Summary of Results

Importance Factor	6	10	5	5	
Edit Importance Factors	**Cost of Repair ($ / sq.m)**	**Longevity of Repair (years)**	**Time for Repair (Factor)**	**Aesthetic Finish (Factor)**	**Overall Weighted Score**
Slurry Seal	9.00	8.00	5.00	7.00	**94.4%**
Rejuvenation Seal	6.00	5.00	5.00	7.00	**89.6%**

Figure 5.19 – Prototype PaveMaint SELECT Solutions: Block Cracking – Pindaree Road, Peakhurst

5.5 System Testing Summary

The prototype PaveMaint SELECT decision support system was tested against twenty one case studies from the individual experiences of eight skilled road asset managers and road engineers from various local government organisations in New South Wales, Australia.

Through the field interviews with experienced road asset practitioners and the subsequent case studies exploration there are number of aspects of the prototype identified to provide strong agreement with the real world decisions made by road asset managers and road engineers (and their teams). However, there are a number of areas requiring critical refinement to better reflect the expected outcomes of the field interview participants.

6 SYSTEM VALIDATION AND REFINEMENT

6.1 System Validation Outcomes

Through case study exploration, field interviews and system testing, the experienced road asset managers and engineers who utilised the prototype PaveMaint SELECT program generally considered the decision support system to replicate their own logic, provide good decision making, and be a useful training tool for lesser experienced members of their team. That is, 100% of the researched participants agreed with the system logic and considered the program to be a good learning tool for their asset team. Over 87% of the participants considered that the program replicated good decision making and the remaining 12.5% felt that while they thought the program performed well, more system refinement was warranted before they could be satisfied with its performance.

This outcome was supported when using the prototype DSS to evaluate multiple case studies, which provided recommendations that concurred with 70% of the participants' own selections. Further, in being able to nominate and replicate the constraints that are important to the participants, it was found that in over 75% of the cases, the program provided a range of recommendations that generally aligned with the expert knowledge and decision making of the participants. The remaining 24% of cases have been discussed in Section 5.4 and the data obtained will be utilised to inform the system refinement for the final PaveMaint SELECT program version.

6.1.1 Validation of Prototype Database - Defects and Remediation Options

Case study exploration detailed a number of defects, considered to be either primary or secondary defects affecting the various road networks. Table 6.1 outlines the defects identified and explored through twenty one case studies. The most common defects affecting the researched road networks were "Crocodile Cracking", "Depressions", "Edge Break", "Oxidation", "Patching Failure", "Potholes", "Pumping", "Shoving" and "Surface Irregularities"; while less common defects were "Block Cracking", "Corrugations", "Diagonal Cracking", "Raveling", "Rutting" and "Soft Spots".

Table 6.1 – Common Defects Evaluated through Case Study Exploration

Defect Type	**Number of Cases Considered**
Crocodile Cracking	3
Oxidation	3
Potholes	3
Shoving	3
Other – Surface Irregularities	3
Depressions	2
Edge Break	2
Patching Failure	2
Pumping	2
Block Cracking	1
Corrugations	1
Diagonal Cracking	1
Raveling	1
Rutting	1
Soft Spots	1

Table 6.2 on the other hand outlines the defects discussed in Section 2.2 but not identified in the case studies. This is not to say that those defects are not common in other local government area pavements, and the literature supports the inclusion of these defects in the DSS. However, the robustness in the evaluation of these defects should be met with a degree of caution and should be augmented to reflect organisational constraints and values in future use.

Table 6.2 – Defects not Commonly Identified in Case Study Exploration

Defect Type	**Number of Cases Considered**
Aggregate Polishing	0
Crescent-Shaped Cracking	0
Delamination	0
Erosion Channels	0
Flushing	0
Longitudinal Cracking	0
Loss of Fines	0
Meandering Cracking	0
Stripping	0
Transverse Cracking	0

Table 6.3 provides a summary of all the remediation options selected in the various case studies explored in this study. While almost all were utilised as the primary and sole treatments of the identified defects, in four cases the participants' utilised two remediation options in combination with each other to achieve the outcome they desired. For example, in case study C.4.7.3 the participant opted to treat a "Block Cracking" defect with "Crack Sealing" as the primary remediation option. However, in some sections where the severity was deemed to be worse, a "Deep Lift Asphalt" treatment was utilised. This phenomenon is reinforced in the PaveMaint SELECT "Solutions" sheet, which not only provides a recommendation for the most suitable remediation option but also provides recommendations for other remediation options that didn't necessarily meet the users constraint requirements but may also still be suitable to treat the affected pavement.

Participants highlighted the benefits of being able to review multiple option recommendations and visualise their performance against each of the user constraints. In doing so, this reinforced the notion that the PaveMaint SELECT

program could be considered a useful learning tool for lesser experienced members of their asset teams.

Table 6.3 – Remediation Options Evaluated through Case Study Exploration

Remediation Option Selected	**Number of Cases Selected**
Asphalt Resurface	5
Deep Lift Asphalt	5
Spray Seal	4
In-Situ Stabilisation	3
Crack Sealing	2
Full Flexible Replace	2
Gravel Resheet (otherwise referred to as Pavement Nourishment)	2
Grading	1
Gravel Patch	1
H/C Mix Asphalt Patching	1
Lean Mix Concrete	1
Reshape/Shallow Stabilisation	1
Rejuvenation Seal	0
Ripping	0
Slurry Seal	0

6.1.2 Validation of Prototype Program Interface

All of the participants utilising the prototype PaveMaint SELECT program found it to be intuitive, logical and functional. The sequence of user forms through the data input phase of the program closely emulated the process that the participants themselves follow when evaluating roads within their own networks.

One participant requested the ability to document the pavement's PSI (Pavement Serviceability Index – Section 3.3.2.1) through the data input phase so that it would be captured in the "Results" worksheet.

All the participants agreed with the numbered scoring scales to assess the defect severity and their constraints; however, approximately 60% thought that the wording of the *ALT*'s (Accelerated Learning Tools) associated with the severity and constraints screens required refinement.

For the "Severity" *ALT*'s (Section 4.4.3), each participant had their own organisation's threshold for severity levels and, while some participants agreed with the *ALT* wording, others thought it should be altered. It was for this reason that the Severity *ALT*'s are built in the administrator access "Knowledgebase" worksheets. That is, once the final version of PaveMaint SELECT is completed and released, refinement can be undertaken by each organisation's administrator to easily adjust the Severity *ALT* descriptor to suit their own definition of severity levels.

Participant comments regarding the "Constraints" *ALT*'s were focussed on the "Longevity" and "Resourcing" constraints (Figure 4.16 and Figure 4.17 respectively), and that the descriptors are confusing and counterintuitive to the intended scoring of that particular constraint. The participants felt that the descriptor needed to more clearly define what the scoring number represents. The constraints *ALT*'s will be explored further through the system refinement stage.

Within the "Results" worksheet environment, there were several cases where the participants utilised the evaluation refinement tools to better represent their own decision making criteria. For example, in the Wallaby Hill Road, Jamberoo case study (Section C.4.6.5 of Appendix C) where the participant had elected to undertake

a “Spray Seal” repair of the road, the prototype DSS recommended “Asphalt Resurfacing” as the most suitable remediation option (Figure 6.1). However, upon reviewing the recommended solutions, the participant noticed that the cost to undertake a “Spray Seal” was higher than their own organisation’s costs. Therefore, the participant was able to utilise the unlocked “Costs” cells in the worksheet to update the “Spray Seal” option and refine the assessment which now recommended “Spray Seal” as the most suitable remediation option (Figure 6.2).

Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Wallaby Hill Rd
Locality: Jamberoo
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Oxidation *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	5	6	6	1	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	25.00	5.00	10.00	85.8%
Spray Seal	16.00	15.00	5.00	8.00	79.6%
Slurry Seal	9.00	10.00	5.00	7.00	73.0%
Rejuvenation Seal	6.00	5.00	5.00	7.00	71.1%

Figure 6.1 – Prototype PaveMaint SELECT Solutions: Oxidation – Wallaby Hill Road, Jamberoo

Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Wallaby Hill Rd
Locality: Jamberoo
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Oxidation *Severity:* 4
Traffic Volume: up to 1x10^4 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Spray Seal**

Summary of Results

Importance Factor	5	6	6	1	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Spray Seal	6.00	15.00	5.00	8.00	90.7%
Asphalt Resurfacing	29.00	25.00	5.00	10.00	85.8%
Slurry Seal	9.00	10.00	5.00	7.00	73.0%
Rejuvenation Seal	6.00	5.00	5.00	7.00	71.1%

Figure 6.2 – Prototype PaveMaint SELECT Solutions: (Adjusted Remediation Costs) Oxidation – Wallaby Hill Road, Jamberoo

Another feature of the "Results" worksheet utilised by the participants during the case study exploration is the "Edit Importance Factors" button discussed previously in Section 4.5. Through the Burelli Street, Wollongong case study discussed in Section 5.4.2 (and in Section C.4.3.1 of Appendix C) the participant had selected an "In-Situ Stabilisation" remediation treatment for that road but the prototype DSS recommended an alternate solution (Figure 5.13). Upon review of the Importance Factors presented on the Solutions Sheet, the participant utilised the "Edit Importance Factors" function, refined the importance factor for their cost constraints and updated the sheet which then recommended the same remediation option they had selected themselves (Figure 5.14).

These examples validate the need for minor refinement features within the "Results" phase of the PaveMaint SELECT program, as tools to allow better acceptance of the program outputs and that they are in congruence with real world considerations and solutions.

6.2 System Refinement

Through the case study exploration and field interviews outlined in Sections 5.3, 5.4 and 6.1 (and Appendix C) it was determined that while the prototype PaveMaint SELECT (version 0.1) program was considered to be an effective decision support tool, some refinement was still required to better emulate the road remediation decision making process. In order to effectively develop the final PaveMaint SELECT (version 1.0) decision support system, refinement of the user-interface and Solutions Sheet appearance were necessary, along with modification of the remediation option pruning criteria and selection formulation, various VBA user forms and Accelerated Learning Tools, as well as a number of minor refinements in the data held within the knowledgebase worksheets. The final complete programming code, layout and functionality is presented in Appendix D.

6.2.1 PaveMaint SELECT Refinement: User-Interface Refinements

The "Startup Screen" previously outlined in Section 4.4.1 has been updated to include form control buttons that allow the administrator to access the "KnowledgeBase" worksheets via a password and switch back to the "User-Only" view with greater ease. Illustrated in Figure 6.3, the final "StartUp Screen" presents the user with two options:

1. The "Switch to User-Only View" form control button that performs a macro that hides the knowledgebase worksheets and places password protection over the Excel file and worksheets. This macro executes and functions in the background and, once complete, leaves only the "Startup" and "Results" worksheets visible to the user, as previously shown in Figure 4.21.
2. The "Administrator Access" form control button launches a VBA user form that prompts the user for the administrator password[4] and asks the user to make one of two selections:

[4] the default password for submission of this thesis is "*councils*". This will be changed upon subsequent release for general use

a. "Admin View": If the user has correctly input the administrator password and selects the "Admin View" button, the macro unlocks the workbook and worksheets as well as making the knowledgebase worksheets visible to the user as previously shown in Figure 4.22; or

b. "Change Password": If the user has correctly input the administrator password and selects the "Change Password" button, they will be provided with two subsequent screens where they may first enter, then confirm, the new password they desire which will then be assigned as the workbook and worksheets protection password.

The author believes that the addition of these minor user-interface refinements will make it easier for not only the administrator to maintain the knowledgebase of the decision support system.

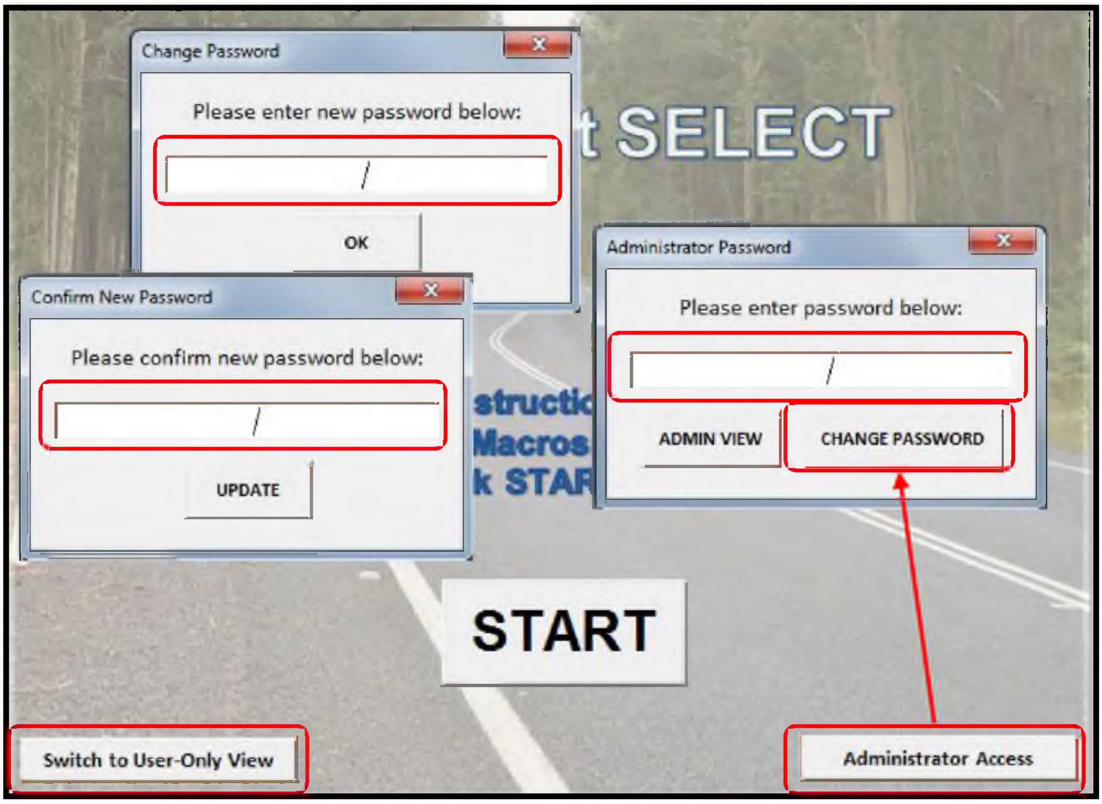


Figure 6.3 – PaveMaint SELECT "Startup Screen" with Administrator Access Tools

6.2.2 PaveMaint SELECT Refinement: Solutions Sheet

The "Solutions Sheet" (presented previously in Figure 4.19) has been reformatted and updated to add better understanding to the solutions recommended, as well as improve functionality.

Figure 6.4 and Figure 6.5 (overleaf) illustrate the appearance of the refined "Solutions Sheet" which now provides a revised header which states "Best Suited Remediation Option", in lieu of the prototype's "Recommended Remediation Option". This revision of language now aims to illustrate to the user that the solution provided is simply a "well suited" option for the constraints provided; however, there are other options recommended that could also be considered appropriate.

Another refinement (of a similar nature) is the inclusion of an identifier heading "Treatment Options" in the margin adjacent to the full list of suitable remediation options, which was included to better inform the user of the purpose of that area in the "Solutions Sheet".

A critical refinement in the functionality of the "Solutions Sheet" is the inclusion of *ALT*'s for both constraint criteria as well as for recommended suitable remediation options. Shown in Figure 6.5, the *ALT*'s to the "Time for Repair" and "Aesthetic Finish" importance factors title cells provide a definition as to the significance of these constraints in the DSS program. While also shown in Figure 6.5 is an example remediation option *ALT* for the "Asphalt Resurfacing" treatment, whose description is adapted from the literature review presented in Section 2.3.2.4.

A functionality improvement to the "Solutions Sheet", shown and highlighted in Figure 6.5, is the inclusion of the "Recalculate Sheet" and "Start New" form control buttons. The "Recalculate Sheet" button executes a macro that sorts and ranks the suitable options list and saves the worksheet. This refinement was necessary to redefine the "Best Suited Remediation Option" should the user adjust any of the factors within the worksheet. The "Start New" form control button simply launches the VBA program to allow the user to begin a new defect assessment without having to switch worksheet tabs.

START NEW

Date of Assessment: 14/10/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Long Road
Locality:	A Town
Segment Number:	S3
Pavement Type:	Sealed Flexible - Asphalt Surface Pavement
Defect Assessed:	Corrugations
Traffic Volume:	up to 1x10^6 ESA

Severity: 4

(1 = slight >>> 5 = unsatisfactory)

Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

Recalculate Sheet

Importance Factor	7	7	3	3	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	15.00	5.00	10.00	**152**
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**106**
Deep Lift Asphalt	81.00	25.00	5.00	10.00	**91**
Lean Mix Concrete	125.00	25.00	10.00	10.00	**44**
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	**21**

TREATMENT OPTIONS

Figure 6.4 – Final PaveMaint SELECT Solutions Sheet (Example: Corrugations with Severity "Poor")

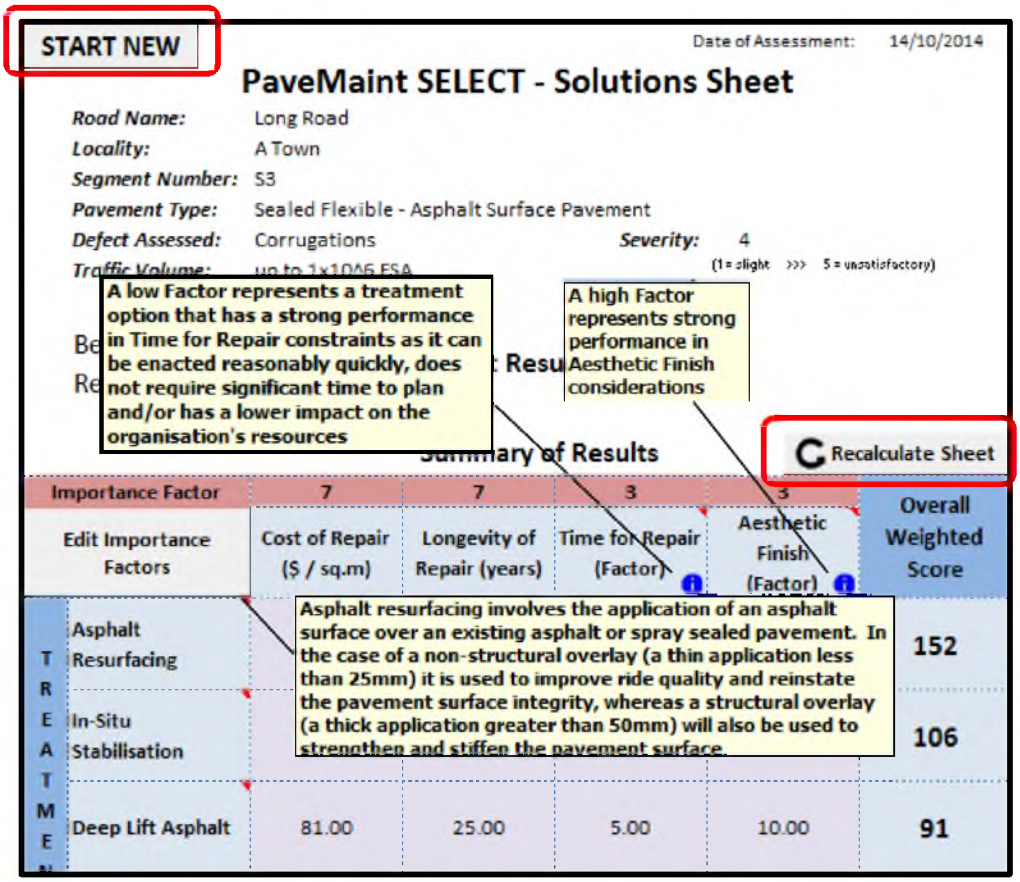


Figure 6.5 – Final PaveMaint SELECT (v1.0) Solutions Sheet *ALT*'s

6.2.3 PaveMaint SELECT Refinement: Overall Weighted Score Calculation

The final refinement to the "Solutions Sheet" is the calculation of the "Overall Weighted Score". The method in which the prototype "Overall Weighted Score" is calculated was discussed with the case study participants so that they may better understand the function of the program.

It was found through the inspection of the prototype solutions produced during the case studies that, despite all other constraints, a primary focus of the participants was the performance of the remediation in regards to the cost and expected longevity of the repair. In what is considered the "Life-Cost" relationship of the remediation options (that is, the expected "Longevity" of a remediation option divided by its "Cost"), the participants believed that when the prototype PaveMaint SELECT did not agree with their own decisions, it was this consideration that was used to justify theirs.

In addition, the "Effectiveness" factor devised by the author as a feature of "system intelligence" (discussed previously in Section 4.5) was also explored with the case study participants, where it was resolved that its aim was not at all to represent the effectiveness of the remediation, but its suitability in remediating the subject defect. For example, in the treatment of "Aggregate Polishing" on an asphaltic concrete surfaced pavement there are two suitable remediation options, "Asphalt Resurfacing" and "Spray Seal". While both should be considered available options, the application of a "Spray Seal" over an asphaltic concrete surface is not as suitable (or appropriate) as "Asphalt Resurfacing", due to texture changes in the pavement that are undesirable. Aimed at scaling the resultant remediation options for the suitability (or compatibility) with the pavement and defect type, a "Suitability Index" is a better accepted and powerful form of "system intelligence" that provides more effective pruning of remediation options, while not eliminating them completely and making the recommended solutions more acceptable to the users.

The original formulation of the prototype "Overall Weighted Score" previously discussed in Section 4.5 and given as Equation 4.1 has been augmented to incorporate the considerations of "Life-Cost", along with the application of a "Suitability Index" along with the previously incorporated "Time" and "Aesthetics" factors. Shown by Equation 6.1, representative figures are provided for the "Asphalt Resurfacing" remediation option presented in Figure 6.4.

$$Score_{Tx} = SI_x \times \left(\frac{(L_x \times L_{Iu})}{(C_{px} \div C_{Iu})}\right) \times \left[\left(\frac{T_{min}}{T_x}\right) T_{Iu} + \left(\frac{A_x}{A_{max}}\right) A_{Iu}\right]$$

Equation 6.1

where:

- *$Score_{Tx}$ is the overall weighted score of remediation option x (Figure 6.4 - $Score_{TAsphalt\ Resurfacing} = 152$);*
- *SI_x is the "Suitability Index" for remediation option x in for each defect being assessed (Figure 6.4 – hidden cell - $SI_{Asphalt\ Resurfacing} = 1.0$);*

- *L_x is the expected longevity (in years) of remediation option x before the repair is expected to deteriorate (Figure 6.4 – $L_{Asphalt\ Resurfacing}$ = 15 years);*
- *L_{Iu} is the user-nominated importance factor for the longevity of the repair in the decision making process (Figure 6.4 – L_{Iu} = 7);*
- *C_{px} is the present day cost (in Australian dollars) of remediation option x (Figure 6.4 – $C_{pAsphalt\ Resurfacing}$ = \$29.00/m^2);*
- *C_{Iu} is the user-nominated importance factor for cost in the decision making process (Figure 6.4 – C_{Iu} = 7);*
- *T_{min} is the minimum time factor (relating to resource capacity available to mobilise a repair) in which the remediation action can be enacted from all the remediation options being assessed (Figure 6.4 – T_{min} = 5);*
- *T_x is the time factor in which the remediation action can be enacted of remediation option x (Figure 6.4 – $T_{Asphalt\ Resurfacing}$ = 5);*
- *T_{Iu} is the user-nominated importance factor for the time to enact the repair in the decision making process (Figure 6.4 – T_{Iu} = 3);*
- *A_x is the factor for the aesthetic appeal of remediation option x (Figure 6.4 – $A_{Asphalt\ Resurfacing}$ = 10);*
- *A_{max} is the maximum factor for aesthetic appeal from all the remediation options being assessed (Figure 6.4 – A_{max} = 10); and*
- *A_{Iu} is the user-nominated importance factor for the aesthetic appeal of the repair in the decision making process (Figure 6.4 – A_{Iu} = 3).*

Revaluating all the previously explored case studies presented in Section 5.4 and Appendix C shows that the final calculation of "Overall Weighted Score" in *PaveMaint SELECT version 1.0* is found to provide scores that now have better disparity between suggested remediation options, but also provides stronger agreement with all the case study scenarios previously evaluated by the prototype DSS. Thus provides greater confidence in the performance of the final decision support system. A full detail of all the case studies revaluated using *PaveMaint SELECT version 1.0* is presented in Appendix E.

6.2.4 PaveMaint SELECT Refinement: Constraints User Forms

As discussed in Section 6.1.2, the *ALT*'s incorporated into the Constraints User Forms, developed to assist in the selection of the user's "Longevity" and "Resourcing" constraints did not align with the expectations of the case study participants.

The "Longevity" constraints (previously outlined in Section 4.4.4) are described to provide an indication of how important the life of the repair is to the user and should the first option button be selected, this would insert a numeric value of "1" into the longevity importance factor cell within the solutions sheet. Similarly should the user select the second, third or fourth option buttons, values of "3", "6" and "10" (respectively) would be inserted into the longevity importance factor cell, where the greater value signifies greater importance.

However, the option button *ALT*'s on the user-form (highlighted in Figure 6.6) provide descriptors that were considered contradictory, somewhat counterintuitive and it was felt that the descriptors should be simpler. It was found that the author's attempt to associate a users' desire for a repair's longevity with the life cycle of the pavement was the source of this confusion. Instead, the participants demonstrated that they understood what the scale was meant to represent, although each person's interpretation varied, and they wanted descriptors that align simply with their intended outcome.

Taking the feedback into account, the refined "Longevity" constraint *ALT*'s are highlighted in Figure 6.7.

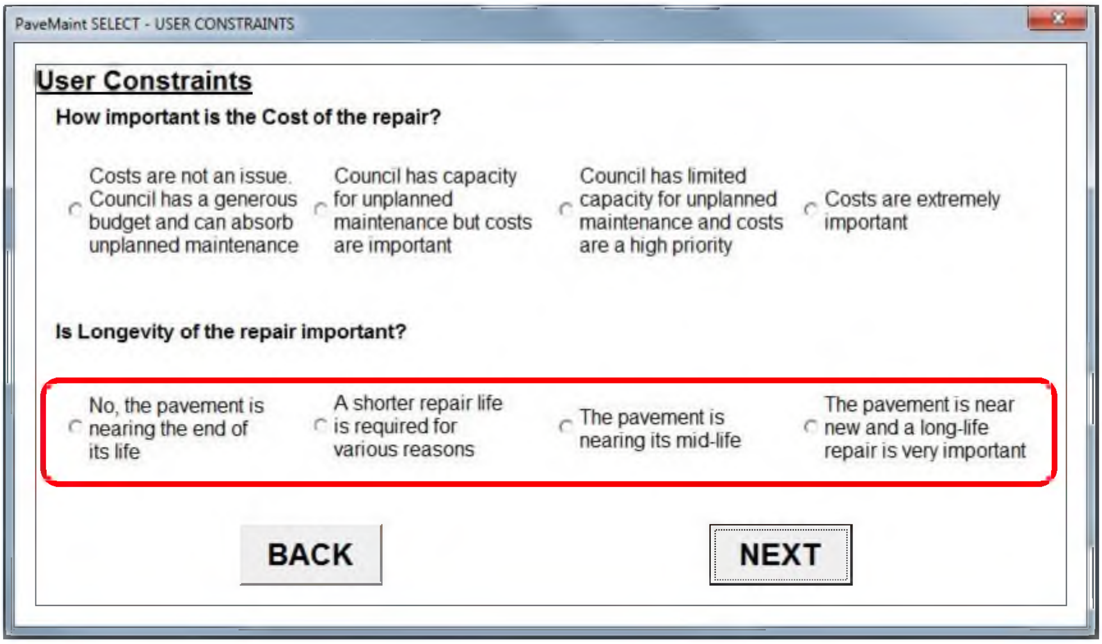


Figure 6.6 – Prototype PaveMaint SELECT User Constraints Selection Screen (1)

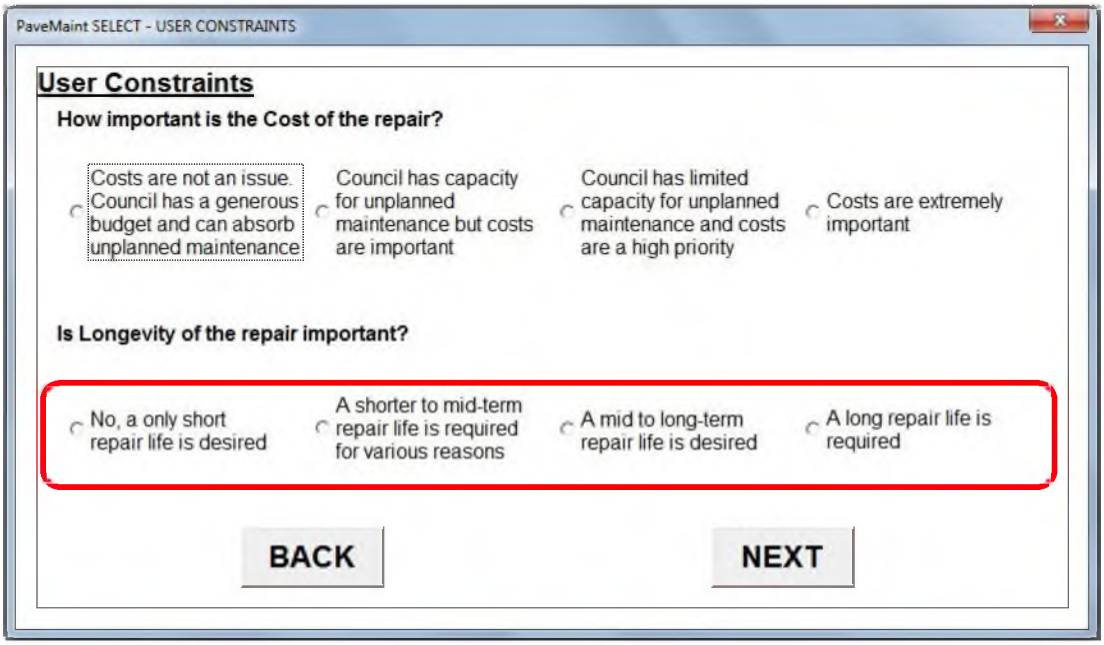


Figure 6.7 – Final PaveMaint SELECT User Constraints Selection Screen (1)

The development of the prototype "Resourcing" constraints *ALT*'s discussed in Section 4.4.4 is intended to represent the organisation's available resources and its readiness (or the "Time" in which they can react) to undertake the selected repair. However, some case study participants found the descriptions ambiguous (highlighted in Figure 6.8) as they did not appear to provide any direct correlation to the importance factors on the "Solutions Sheet".

Accordingly, the *ALT* descriptions have been reviewed by the author (highlighted in Figure 6.9 which illustrates the refined user-form) with the view of clearly defining the link between the organisation's resource constraints with the reactivity, or time, in which they desire for the treatment to be undertaken.

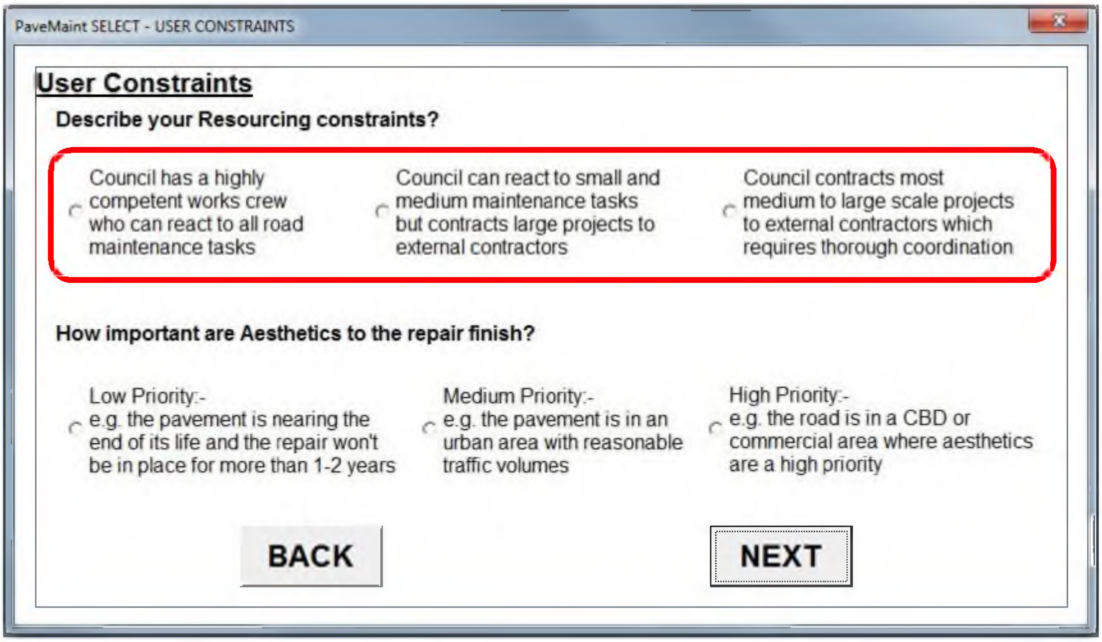


Figure 6.8 – Prototype PaveMaint SELECT User Constraints Selection Screen (2)

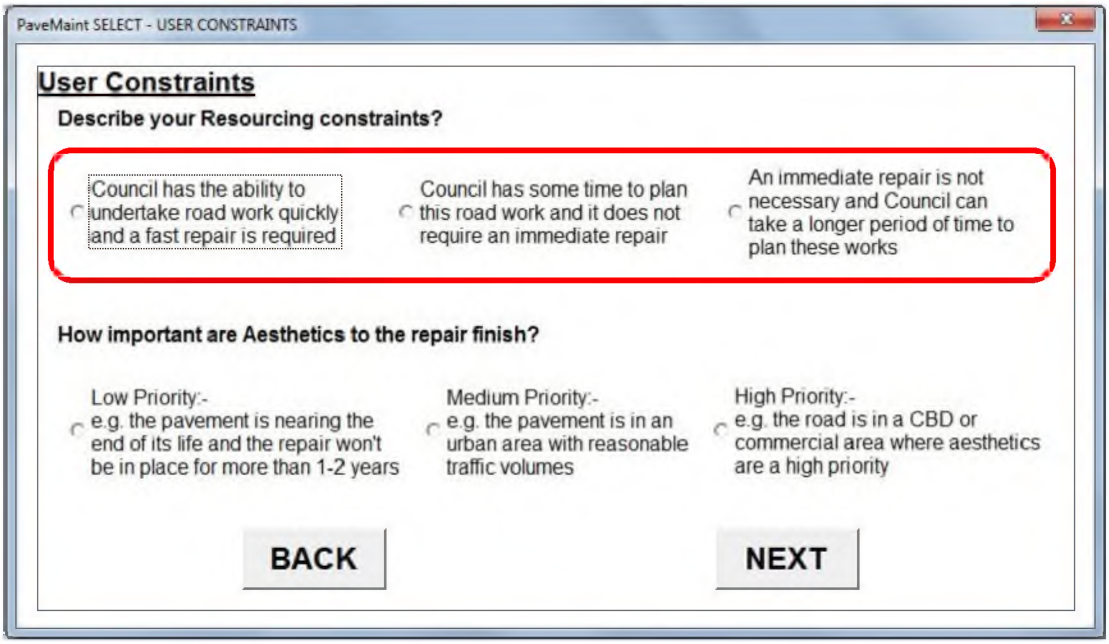


Figure 6.9 – Final PaveMaint SELECT User Constraints Selection Screen (2)

The final aspect for the refinement of the User Constraints forms are values of the Importance Factors promulgated upon the user's selection. It was evident from the discussions with the research participants that despite the organisation's goals for managing its road network, costs inevitably were a highly scrutinised factor and that it was rare for an Importance Factor value of "1" to be accepted by the participant, though a value of "2" was considered the minimum. Therefore the VBA routine was refined to provide a minimum value of "2" in the corresponding cell of the "Solutions Sheet.

Similarly, the Importance Factor values assigned to the "Time" and "Aesthetic" criteria was thought to be too restrictive for what were considered by the participants to be lower valued constraints. In the first instance, the maximum possible score was considered too high and thus providing too much influence on the results. It was therefore decided that it would be more appropriate to reduce the maximum values down to "5" (from "10" in the prototype). Secondly, there were instances when the participant preferred to eliminate the impact of these constraints completely, accordingly the resulting refinement now allows the user to enter a minimum value of "0" (previously "1") for either (or both) the "Time" and "Aesthetic" criteria.

6.2.5 PaveMaint SELECT Refinement: Knowledgebase Refinement

Throughout the exploration of the multiple case studies presented in Appendix C it was found that a number of additions and changes to the various "knowledgebase" worksheets within the prototype PaveMaint SELECT database were necessary to better reflect real world decision making. These include the creation of "Surface Irregularities" and "Loss of Pavement" as new defect types, the creation of "Gravel Patch" as a new remediation option, as well as a number of other minor refinements.

6.2.5.1 Defect: Surface Irregularities – Sealed Flexible Pavements

The inclusion of the new defect type "Surface Irregularities" was deemed necessary after it was highlighted by three separate participants (Participant 2, Participant 6 and Participant 7). "Surface Irregularities" affect both asphaltic concrete surfaced flexible pavements and bituminous spray sealed flexible pavements. It was commonly described by the participants as a surface defect which is considered a

combination of a number of other surface defects such as stripping, raveling, oxidation, minor potholes and patching failures; which in isolation would only be considered to be slight, but when present in large proportions and in combination with one another can lead to significant pavement deterioration. The *ALT* developed for “Surface Irregularities” is provided in Figure 6.10.

Figure 6.10 – *Accelerated Learning Tools* for “Surface Irregularities” Defect

When allowed to develop, the poor surface texture associated with “Surface Irregularities” will cause localised water ponding on the pavement surface which can cause further deterioration of the pavement through water-intrusion into the pavement structure. In addition, the defect will present itself to motorists through poor ride quality and loud tyre noise as a result of pavement roughness, ultimately affecting user satisfaction. The measure of its deterioration was discussed to accord with the severities illustrated in Figure 6.11.

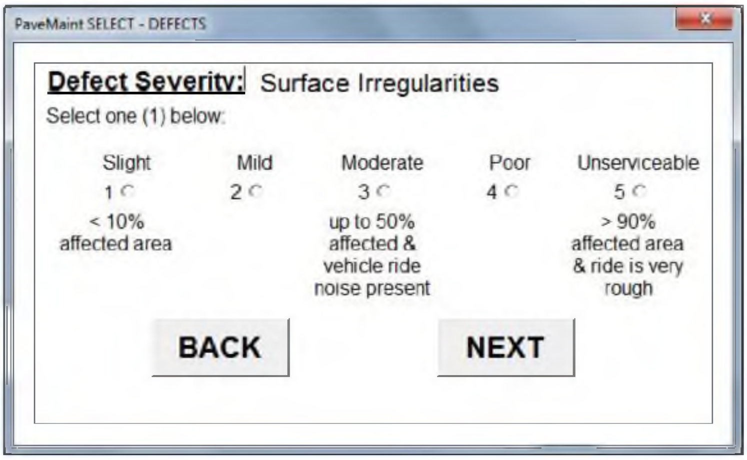


Figure 6.11 – PaveMaint SELECT Defect Severity Selection for Surface Irregularities on Asphaltic Concrete and Bituminous Spray Sealed Surfaces

The participants advised that suitable remediation options for “Surface Irregularities” include: “Asphalt Resurfacing”, “Spray Seal”, “Lean Mix Concrete” and “In-Situ Stabilisation”. It was also discussed that while “Slurry Seal” treatments are not common in New South Wales, it could also be a suitable treatment for this defect.

6.2.5.2 Defect: Loss of Pavement – Unsealed Flexible Pavements

“Loss of Pavement” is a defect outlined by Participant 4, a Road Asset Engineer with an extensive road network predominantly made up of unsealed flexible pavements. Affecting unsealed flexible pavements, “Loss of Pavement” is seen as the progression of “Loss of Fines”, and to some extent “Raveling”, where granular material is lost from the pavement structure, resulting in a more slender pavement and therefore reduces the structural capacity of the road. This input has led to the “Loss of Pavement” defect being included into the final version of PaveMaint SELECT. The ALT developed for “Loss of Pavement” is shown in Figure 6.12.

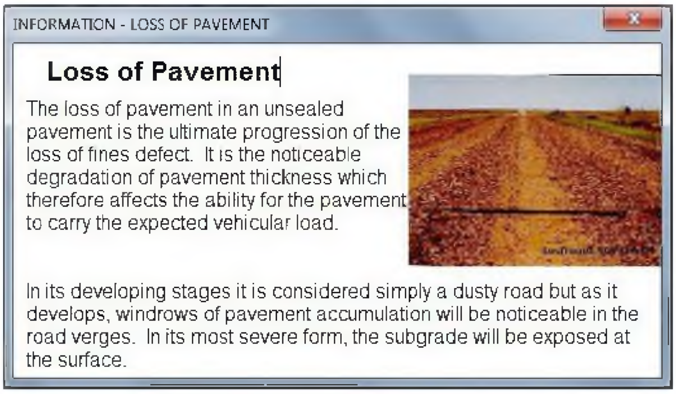


Figure 6.12 – *Accelerated Learning Tools* for “Loss of Pavement” Defect

Being associated with “Loss of Fines”, “Loss of Pavement” in its slightest severity would be considered an excessively dusty road; when allowed to develop, windrows of loose pavement material will be accumulated in the road verges and table drains and the road would become unserviceable when the subgrade is fully exposed at the surface. Its severity thresholds are presented in Figure 6.13.

Due to the nature of the defect, the only treatment options available to remediate “Loss of Pavement” are “Full Flexible Replacement” and “Gravel Resheet”.

Figure 6.13 – PaveMaint SELECT Defect Severity Selection for Loss of Pavement on Unsealed Pavements

A "Gravel Resheet" can be undertaken when the pavement is in a moderate to poor condition and a "Full Flexible Replacement" is common when the pavement is unserviceable. However, on occasions when the pavement is unserviceable but the loose material from the road verges can be won and incorporated back into the pavement, a "Gravel Resheet" may be selected.

6.2.5.3 Remediation Option: Gravel Patch – Unsealed Flexible Pavements

"Gravel Patch" repairs were outlined by Participant 4, a Road Asset Engineer with an extensive road network predominantly made up of unsealed flexible pavements. It was outlined by the participant that a "Gravel Patch" is essentially the unsealed pavement's alternative to "Hot/Cold Mix Asphalt Patch" for sealed pavements, where the small section of failing pavement is removed and replaced with new granular pavement material.

Accordingly, a "Gravel Patch" may now be selected in the treatment of unsealed flexible pavements suffering from "Potholes", "Depressions" and "Soft Spots" defects.

6.2.5.4 Minor Knowledgebase Refinements

Through case study exploration, it was determined a number of minor refinements to the various knowledgebase worksheets were necessary to better reflect the decision making considerations of experienced road asset managers and engineers. These database refinements are summarised in Table 6.4.

Table 6.4 – Minor Knowledgebase Refinements – PaveMaint SELECT Worksheets

Description of Amendment	**Knowledgebase Worksheet (Appendix D)**	**Case Study (Appendix C)**
Inclusion of "Lean Mix Concrete" remediation option for the treatment of "Pumping"	- "AspKnowledgeBase" - "BitKnowledgeBase"	- Section C.4.3.1
In the treatment of "Crocodile Cracking", remove the remediation option "Rejuvenantion Seal" and include the remediation option "Lean Mix Concrete"	- "AspKnowledgeBase" - "BitKnowledgeBase"	- Section C.4.3.2
Replace the name of the "Pavement Nourishment" remediation option with "Gravel Resheet"	- "UnSeaKnowledgeBase"	- Section C.4.4
Remove the remediation option "Grading" as a selection option in the treatment of "Potholes"	- "UnSeaKnowledgeBase"	- Section C.4.4.1
Remove the remediation option "In-Situ Stabilisation" from the unsealed pavements database	- "AspKnowledgeBase" - "BitKnowledgeBase"	- Section C.4.4.3
Include the remediation option "Deep Lift Asphalt" for the treatment of "Rutting" in sealed flexible pavements	- "AspKnowledgeBase" - "BitKnowledgeBase"	- Section C.4.5.1
Errors in spreadsheet formulas used in the pruning of remediation options to treat all "Cracking" were rectified	- "AspKnowledgeBase" - "BitKnowledgeBase"	- Section C.4.7.3

Table 6.4 – Minor Knowledgebase Refinements – PaveMaint SELECT Worksheets (*continued*)

Description of Amendment	**Knowledgebase Worksheet (Appendix D)**	**Case Study (Appendix C)**
Increase the aesthetic factor for "Deep Lift Asphalt" to a value of "10" as it has the same performance characteristics as "Asphalt Resurfacing"	- "AspKnowledgeBase" - "BitKnowledgeBase"	- Section C.4.6.1
Separation of "Full Flexible Replacement" remediation option from sealed pavements and unsealed pavements. The cost of constructing a sealed flexible pavement ($218/m^2) is much higher than that of a much more slender unsealed ($30/m^2), particularly without a wearing course layer.	- "AspKnowledgeBase" - "BitKnowledgeBase"	- Section C.4.4

6.3 Decision Support System Finalisation: PaveMaint SELECT version 1.0

The prototype PaveMaint SELECT (version 0.1) decision support system (DSS) was tested against twenty one individual case studies across eight experienced, practising road asset managers and road engineers from various local government organisations in New South Wales, Australia. The DSS was thought to be a useful training tool for lesser experienced asset and engineering team members. The prototype DSS was also generally considered to replicate the logic and decision making of the participating individuals, and when tested provided recommendations for over 75%

of the case studies that were congruent with their own decision making considerations.

Upon refinement of the DSS the final iteration of PaveMaint SELECT (version 1.0) is now able to replicate the remediation option decision making of all the case study examples explored. Shown in Appendix E, the *re-run* "Solutions Sheets" provide a list of suitable remediation options that accord with the decision making of all the case studies explored in Section 5.4 (and Section C.4 of Appendix C). These refined solutions provide better confidence in the program's ability to replicate real world situations and decisions made by experienced road asset managers and engineers. It is considered that the final PaveMaint SELECT program will aid the user to better understand the program and refine their own selections as they learn from using the program.

The final programming and functionality of the decision support system is presented in Appendix D, while the program itself can be is located in the Excel file named *PaveMaint SELECT v1.0.xlsm* found in the Compact Disc accompanying this thesis.

7 CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

The need for road asset management and remediation decision support was postulated in Chapter 1 where the question was asked:

"*Can organisational intelligence be used to effectively and efficiently plan for road remediation in combination with established theory?*"

Within Chapters 2 and 3, extensive task profiling was presented surrounding the road asset management phenomenon, from which, a decision support system was developed in Chapter 4 that combined theoretical knowledge with heuristic and procedural knowledge. This decision support system was tested in Chapter 5 through field interviews and case study exploration with experienced road asset managers and road engineers which, in Chapter 6, identified areas for critical system refinement and has led to validation of the program's ability to replicate real world decision making.

7.2 Conclusions

The aim of this study was to develop a decision support system (DSS) for the remediation of flexible road infrastructure in local government. Through an in depth review of the available literature on road pavement deterioration and remediation techniques, combined with an initial case study of a local government organisation, a prototype DSS named *PaveMaint SELECT v0.1* was developed.

During the literature review which formed part of the *Task Profiling* stage of this study, a comprehensive review of flexible road pavements was presented in Chapter 2, that included a detailed assessment of the all the various types of defects known to affect flexible pavements along with a review of the known remediation practices to treat these expected defects. It was shown in the literature that previous research has been traditionally presented in disparate studies that focus on either: quantifying the deterioration mode of one or more specific defect type; or the exploration and refinement of specific remediation techniques in response to one defect mechanism.

The culmination of this critical review resulted in the author's own Table 2.3 which presented a matrix of defects associated with flexible pavements, juxtaposed to their suitable remediation options. Such a matrix was not found in the current available literature. However, following the system testing and refinement undertaken as part of this research, this matrix has now been further refined to better represent current practices and is presented in Table 7.1 overleaf. Key refinements (previously detailed in Section 6.2.5) include the addition of two new pavement defects ("Surface Irregularities" and "Loss of Pavement" in sealed and unsealed flexible pavements respectively); the addition of a "Gravel Patch" remediation option for unsealed flexible pavements; and a number of remediation options that have been either added or removed from selection in the treatment of various defects.

Further considered through the *Task Profiling* stage of this study was the extensive review of road remediation practice both in the literature and at Shoalhaven City Council (SCC), a local government on the south coast of New South Wales in Australia. SCC was the subject council upon which the *PaveMaint SELECT* decision support system was founded. Discussed in Chapter 3 and presented in Appendix C, SCC informed the formulation of the DSS, in particular the method in which SCC organises its road network, its systematic collection of road condition data, the quality evaluation that is undertaken of the roads within the network and the subsequent decisions made by the Road Asset Manager and Road Engineer to undertake works.

It was through this *Task Profiling* exploration that Figure 3.4 was devised by the author (and later refined in Figure 4.1), which identifies the critical process upon which road pavement quality evaluation is undertaken. This quality evaluation process provides the context for the road asset management decision making paradigm, and demonstrates the need for a decision support tool. That is, it was found that road asset decision making is a complex phenomenon that requires the knowledge and ability to balance costs with: the desired performance of the road pavement, organisational constraints and social expectations, a process that was discovered to be much akin to the *engineering design process* previously explored by Lemass (2004) where decision support tools have been successfully applied.

Table 7.1 – Refined Suitability of Available Remediation Actions for Flexible Pavements

Pavement Defect Type	**Suitability of Remediation Options**[5] (√ = Possible Suitable Remediation Solution)														
	Asphalt Resurfacing	Hot/Cold Mix Asphalt Patching	Spray Seal	Slurry Seal	Crack Sealing	Rejuvenation Seal	Full Flexible Pavement Replacement	Deep Lift Asphalt	In-Situ Stabilisation	Lean Mix Concrete	Gravel Resheet*	Grading	Reshaping & Shallow Stabilisation	Ripping	Gravel Patch*
Sealed Flexible Pavements															
Aggregate Polishing	√		√	√											
Block Cracking				√	√	√	√	√	√	√					
Corrugations	√						√	√	√	√					
Crescent-Shaped Cracking		√			√	√									
Crocodile Cracking	√	√		√	√	*	√		√	√*					
Delamination	√	√													
Depressions		√					√		√	√					
Diagonal Cracking	√				√	√	√	√	√						
Edge Break		√													
Flushing	√		√	√											
Longitudinal Cracking	√			√	√	√	√	√	√						

[5] Refer Section 2.2 and Section 2.3

* Table refinement from system testing through field interviews and case studies (refer Chapter 6)

Table 7.1 – Refined Suitability of Available Remediation Actions for Flexible Pavements (*continued*)

Pavement Defect Type	**Suitability of Remediation Options**[6] (√ = Possible Suitable Remediation Solution) Asphalt Resurfacing	Hot/Cold Mix Asphalt Patching	Spray Seal	Slurry Seal	Crack Sealing	Rejuvenation Seal	Full Flexible Pavement Replacement	Deep Lift Asphalt	In-Situ Stabilisation	Lean Mix Concrete	Gravel Resheet*	Grading	Reshaping & Shallow Stabilisation	Ripping	Gravel Patch*
Sealed Flexible Pavements (cont.)															
Meandering Cracks	√				√	√	√			√					
Oxidation	√		√	√		√									
Patching Failure	√	√					√	√							
Potholes		√					√	√	√						
Pumping							√		√	√*					
Raveling	√			√		√									
Rutting	√	√		√			√	√*	√	√					
Shoving		√					√	√	√						
Stripping			√												
Surface Irregularities*	√		√	√					√	√					
Transverse Cracking	√			√	√	√	√	√	√						

[6] Refer Section 2.2 and Section 2.3

* Table refinement from system testing through field interviews and case studies (refer Chapter 6)

Table 7.1 – Refined Suitability of Available Remediation Actions for Flexible Pavements (*continued*)

Pavement Defect Type	**Suitability of Remediation Options**[7] (✓ = Possible Suitable Remediation Solution)														
	Asphalt Resurfacing	Hot/Cold Mix Asphalt Patching	Spray Seal	Slurry Seal	Crack Sealing	Rejuvenation Seal	Full Flexible Pavement Replacement	Deep Lift Asphalt	In-Situ Stabilisation	Lean Mix Concrete	Gravel Resheet*	Grading	Reshaping & Shallow Stabilisation	Ripping	Gravel Patch*
Unsealed Flexible Pavements															
Corrugations									*		✓	✓	✓	✓	
Depressions							✓*		*						✓*
Erosion Channels							✓*		*		✓	✓	✓	✓	
Loss of Fines									*		✓	✓	✓	✓	
Loss of Pavement*							✓*		*		✓				
Potholes							✓*		*		✓	*	✓	✓	✓*
Raveling									*		✓	✓	✓	✓	
Rutting							✓*		*		✓	✓	✓	✓	
Soft Spots							✓*		*		✓				✓*

[7] Refer Section 2.2 and Section 2.3

* Table refinement from system testing through field interviews and case studies (refer Chapter 6)

As suggested in the engineering design process, "expert" road asset managers and engineers are known to have a high-order of decision making skill through heuristics and procedural knowledge that results in road asset decisions that have outcomes with minimal uncertainty. "Junior" or "novice" road asset managers and engineers, on the other hand, apply strong theoretical knowledge but lack the experience and heuristics to complement this knowledge, typically resulting in decision making outcomes with high levels of uncertainty.

Utilising the principle of augmenting theoretical knowledge with heuristics and procedural knowledge, within Chapter 4 the development of the prototype PaveMaint SELECT decision support system (DSS) was developed, which was devised based on the data obtained from the *Task Profiling* stage. The design of the DSS began with Figure 4.2 which was developed by the author from the task profiling stage of the study and was designed to replicate the process upon which decision making considerations are reflected upon by a *typical* road asset manager or engineer. Then building on Table 2.3, which was augmented by initial case study data, two stages of remediation option selection pruning were incorporated into the program along with the inclusion of "Importance Factors" that utilise user and organisational preferences for cost, longevity, time (resource) and aesthetic (social) constraints.

PaveMaint SELECT was programmed using the VBA (Visual Basic for Applications) programming functionality within the Microsoft™ Excel™ (Excel) environment, which is familiar to most (if not all) practising engineers and asset managers. It was during *System Development* of the prototype PaveMaint SELECT program that a comprehensive set of accelerated learning tools (*ALT*'s) were designed and developed to provide learning assistance to the user. The *ALT*'s in PaveMaint SELECT provide a convergence check for experienced road asset managers and engineers and provide an assurance that the program is providing an assessment of conditions that congruent with their own expectations. For junior or novice members of the road asset management team, the *ALT*'s provide the opportunity to learn and improve their own skills and knowledge while using the program, while continuing their capability to contribute to the organisation.

The culmination of the *System Development* stage of this study and the creation of the prototype PaveMaint SELECT program is the remediation option selection formulation, or *Overall Weighted Score*, which was given by Equation 4.1. The calculation of the *Overall Weighted Score* utilises *Importance Factors* adapted from dominant priorities discovered during the task profiling stage and incorporates factors that consider the present *Cost* of the remediation option (augmented by Equation 4.2 for present day value), the expected *Longevity* that repair will bring, the *Aesthetic* finish of the resulting repair and the *Time* to mobilise and execute the repair. Equation 4.1 considers each remediation option's performance against the *Importance Factors*, along with the system's *Effectiveness* factor, and calculates a score determinate on the user-nominated priority for each *Importance Factor*.

The prototype program was tested thoroughly through field interviews with eight experienced local government road asset managers and road engineers who explored a total of twenty-one case studies from their own experiences within their road networks (presented in Chapter 5). During this *System Testing and Refinement* stage of the study it was found that flexible pavements are their most dominant pavement type present in all the local government road networks investigated, with rigid and segmental block pavements rarely being present. Such a finding validates the decision by the author to focus of this study on flexible pavements, as rigid and segmental block pavements only make up a small proportion of the road networks under local government responsibility.

The road asset managers and engineers participating in the study have demonstrated many years of experience and expertise in road asset management and engineering, with the majority possessing over fifteen years of experience in road asset maintenance and management. In addition, the performance of the road networks they control can be generally described as satisfactory or better. The participants' experience and expertise combined with the performance of their own road networks provides greater confidence in the data collected for system testing and refinement. However, with no road networks performing excellently and over 12% considered to be in poor condition, it is also considered that a decision support system such as PaveMaint SELECT for flexible road pavements could be an advantageous tool that

can be implemented to assist local government engineers and asset managers in the managing and planning of their road networks.

During System Testing, it was found that dominant constraints that influence road asset management decision making can be categorised succinctly under the four *Importance Factors* (*Cost*, *Longevity*, *Time* and *Aesthetics*) already incorporated into the prototype DSS. It was found that both *Cost* and *Longevity* were considered primary constraints and should provide the greatest influence into the calculation of the *Overall Weighted Score*, while *Time* and *Aesthetics* were secondary considerations that should have a lesser influence in the calculation. In addition, during the prototype testing, the participants were able to undertake critical "What If" (sensitivity) analyses on the evaluated defects and constraints, which were important in gaining the participant's acceptance for and understanding of the PaveMaint SELECT program.

Following prototype testing, a number of modifications to the prototype PaveMaint SELECT (version 0.1) program were discussed in Chapter 6 as critical refinement for the release of the final PaveMaint SELECT program (version 1.0). Key refinements can be categorised as minor or major refinements; minor refinements include improved flexibility and access for the system administrator via the Startup worksheet, as well as user-only access buttons; along with a number of remediation selection adjustments illustrated in Table 7.1. Major refinements include the creation of one new remediation and two new defect types, but also include the introduction of ALT's within the Solutions Sheet for *Importance Factors* and for all the recommended remediation options. The final major refinement is the revision of the calculation for *Overall Weighted Score* (Equation 6.1) which provides a stronger link to *Cost* and *Longevity* constraints and replaces the lesser understood *Effectiveness* factor with what is considered to be a more robust *Suitability Index*.

Through this system refinement, the PaveMaint SELECT program (presented in its completeness in Appendix D) is now capable of replicating the decision making of all the case studies explored, providing a high degree of confidence in its application

as a decision support tool in the remediation of all flexible road pavements for all practising road asset managers and engineers.

This affirms the assertion postulated at the beginning of this research that:

"*organisational intelligence can be used to effectively and efficiently plan for road remediation in combination with established theory*"

That is, it has been demonstrated that a decision support system can successfully combine experiential, procedural and theoretical knowledge to improve the quality of decision making in the management and maintenance of local government road infrastructure, specifically flexible pavements.

7.2.1 Limitations

The limitations of this study will mainly exist around flexible pavement types, as well as environment and climatic conditions of NSW local government areas.

The primary data collection has been undertaken from the Shoalhaven area, which has only a certain proportion of road pavements in its road network database. While these are a good representation of those found in a typical network, they are by no means a complete representation of all possible road networks in other local government areas. Similarly, with the Shoalhaven being located on the south coast of New South Wales, climatic variation is not significant and certainly not as extreme as other parts of Australia and the world.

However, through field interviews and diverse case studies from multiple New South Wales local government organisations, these limitations can be substantially overcome.

Finally, potential issues associated with group decision making situations and the impact of interdependencies between various factors on decision outcomes have not been considered as they fall outside the scope of this study.

7.3 Recommendations

7.3.1 Implementation of PaveMaint SELECT version 1.0

PaveMaint SELECT version 1.0 is a decision support system developed to assist local government road asset managers, engineers and their teams in their roles to plan, manage and maintain their organisations' road networks in an efficient and consistent manner. Through case study research, *PaveMaint SELECT* has been found to effectively provide recommendations that are consistent with that of a wide variety of local government road asset managers and road engineers.

It is recommended that local government organisations with road networks consisting of flexible pavements consider implementing *PaveMaint SELECT version 1.0* as a tool to not only assist their road asset managers and engineers, but to be utilised as a learning tool for lesser experienced members of their organisation to ensure effective and consistent road asset decision making across their entire road network.

It is recommended that in the implementation of *PaveMaint SELECT* within an organisation, a person (or persons) be assigned as the "System Administrator" of the system and be tasked with the responsibility of reviewing and maintaining the knowledgebase (database) values for the "Cost" of each of the remediation options to ensure they are both current and reflective of the organisation's own constraints. The "System Administrator" may also include additional defects and remediation options (along with the pertinent information required within the knowledgebase worksheets) particular to their own organisation and may also refine the other "Importance Factor" values within the knowledgebase for their own specific requirements. However, this should be done so with extreme caution and in consultation with the system developer (that is, the author).

7.3.2 Anticipated Future Work

The development of *PaveMaint SELECT version 1.0* has seen the creation of a decision support system capable of assisting road asset managers and road engineers in the complex decision making environment of local government roads infrastructure, specifically flexible pavements. There are a number of avenues in

which this decision support system can be further developed to provide broader application in the local government context and beyond.

One such avenue is the further inclusion of other pavement types such as Rigid and Segmental Block pavements. As outlined in the field interview and case study research discussed in Chapter 5 (as well as Appendix C), Rigid and Segmental Block pavements also make up a portion of a number of local government road networks in New South Wales. Further research would facilitate the incorporation of these pavements into a future iteration of the PaveMaint SELECT program and thus provide a complete decision support tool for all local government road networks.

Another future project is the development of this decision support system into a whole-of-road network model capable of evaluating multiple road segments and defects concurrently. This is a feature which was raised during the field interview and case study research, where it was desired to be able to undertake multiple defect and road segment assessments concurrently so as to easily compare the resultant suitable solutions. In the current version of PaveMaint SELECT (version 1.0) this is achieved by a "what-if" analysis, where the user will undertake multiple evaluations of the various scenarios they are required to assess and then make their own comparison of the resultant suitable solutions. A model that is capable of undertaking this function could be quite a beneficial tool, and if it were able to be integrated with the organisation's existing road network database, could save a substantial amount of time and resources for the organisation.

The ultimate progression of the decision support system developed in this research is its adaptation for application to multiple civil infrastructure types (for example drainage, public buildings and other identified typical local government owned asset types), both as individual systems and then ultimately combined into an organisation-wide asset decision support model.

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APPENDIX A

ROAD PAVEMENT ENGINEERING – RIGID AND SEGMENTAL BLOCK PAVEMENTS

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A.1 Introduction

The focus of this current study is to design a decision support system for flexible pavement types. However, other pavement types, namely rigid and segmental block pavements, share similar (as well as disparate) failure mechanisms that lend themselves to some obvious comparisons. It is envisaged that the system developed as part of this study could subsequently be developed into a model for all pavement types in future studies

tool (decision support system or DSS) to assist road asset managers and their staff, conceptualise and develop effective and efficient maintenance engineering decisions, otherwise referred to as 'pavement management'.

It is suggested that an effective pavement management system consists of three basic stages: road network data collection, quality evaluation and decision making (Picado-Santos et al. 2004). While the concepts of quality evaluation and decision making are discussed further in subsequent chapters, this chapter outlines the context in which the pavement management process is bound. In doing so, this chapter presents an overview of road asset types, explores their common issues and discusses documented solutions to those issues.

A.2 Rigid Pavements

Rigid pavements, sometimes referred to as concrete pavements, are distinguished from flexible pavements as they are constructed from a concrete base (Austroads 2009a; Austroads 2012), but otherwise share a similar structure, consisting of a base (albeit concrete), subbase and subgrade as illustrated in Figure A-1 below.

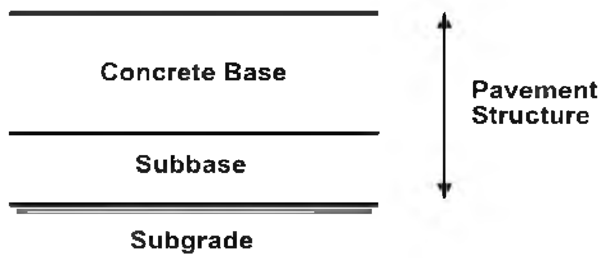

Figure A-1 – Typical Rigid Pavement Structure (Austroads 2009a)

The subgrade and subbase provide the same function in a rigid pavement as discussed for flexible pavements. However, while the subbase in a rigid pavement may be constructed from compacted granular materials, a bound or lean-mix concrete subbase is recommended to resist erosion and pumping at slab joints and edges, provide uniform support, reduce the magnitude of deflection and to assist in shrinkage and swelling control (Austroads 2009a; Austroads 2012).

The base course of a rigid pavement is constructed from principally four types of plain or reinforced concrete, they are plain (jointed unreinforced) concrete pavements (PCP), jointed reinforced concrete pavements (JRCP), continuously reinforced concrete pavements (CRCP) and steel fibre reinforced concrete pavements (SFCP) (Austroads 2012).

Traditionally rigid pavements do not have a wearing surface, rather the surface of the concrete base is treated at the surface to provide a texture to ensure adequate friction or skid resistance is achieved (Austroads 2012). However, there are instances where a thin HMA wearing surface may desired, in these cases they are not essential and the wearing surface provides no structural benefit to the pavement (Austroads 2012).

A.3 Segmental Block Pavements

Segmental block pavements are roads constructed using vitreous clay or high strength concrete pavers (segmental blocks) placed over a base/subbase/subgrade pavement structure, as illustrated in Figure A-2; and the discontinuous nature of the block surfacing allows the structure to behave in a flexible manner (Shackel and Pearson 1991; Giummarra 1995; Austroads 2009b; Fletcher 2009; Soutsos et al. 2011).

With the ability of the segmental blocks to be manufactured in various shapes and sizes, as well as their ability to be arranged in various patterns, they are generally desired for their aesthetic appeal (Giummarra 1995; Austroads 2009b). However, due to the cabin noise that is produced in 'quieter' vehicles (such as cars), these pavements are better suited to areas with low traffic speed or where traffic calming is required, such as intersections and pedestrian crossings (Shackel and Pearson 1991; Giummarra 1995; Austroads 2009b).

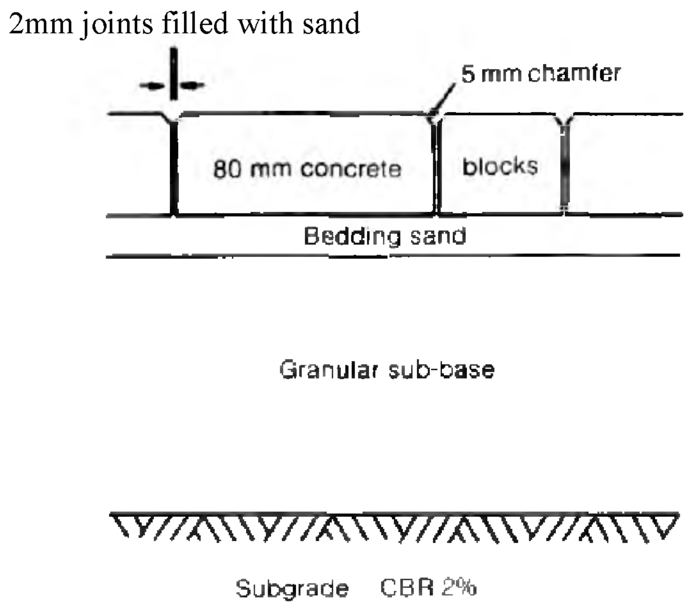

Figure A-2 – Typical Section of Segmental Block Pavement (Barber and Knapton 1979)

A.4 Typical Defect Types

Following on from discussions in Section 2 of this study, discussed herein are some typical defects found in rigid and segmental block pavements. Many share some similarities to those experienced in flexible pavements, however, the mechanisms causing these defects vary for each pavement type.

A.4.1 Surface Texture Deficiencies

A.4.1.1 Aggregate Polishing

Aggregate polishing affects rigid pavements as well as sealed flexible pavements. It has a significant impact on road user safety and skid resistance. As the name suggests, aggregate polishing is the smoothing and rounding of the wearing surface aggregate (Geller 1996; Austroads 2006c; Austroads 2009d; HYD 2009). Sometimes referred to as the loss of surface texture, it is commonly found in the wheel paths of traffic lanes and is distinguished by areas that are relatively smooth compared to surrounding pavement and can sometime feature surfaces that are 'glazed' or 'shiny' (Geller 1996; Ahammed and Tighe 2008; HYD 2009).

This surface defect can be caused by incorrect or inadequate aggregate selection, surface age or higher than expected traffic volume or traffic stresses (Geller 1996; Austroads 2006c; Austroads 2009b; Austroads 2009d; HYD 2009; PavementInteractive 2010; Chen et al. 2011).

A.4.1.2 Raveling

Raveling is the loss of both aggregates and binder from the pavement surface which results in surface disintegration where visibly loose pieces of aggregate sit on the road surface (Austroads 2006c; HYD 2009; Mo et al. 2009; PavementInteractive 2009c). It is considered to be at its worst when those pieces make the surface rough enough to be noticeable to motorists driving on the road (ESB 1998).

Rigid pavements exhibit raveling in similar ways to sealed flexible pavements; though causes are attributed to inadequate curing or overworking of the fresh concrete surface during construction, as well as the use of poor quality concretes or localised cement deficiencies in the concrete mix (HYD 2009).

A.4.1.3 Pumping

Pumping is distinguished by the presence of pavement fines on the surface of the pavement surface. It is not a breakdown of the pavement wearing surface, rather a result of moisture movements within a pavement that cause erosion of the subbase or base course material. It is commonly associated with cracking, where the cyclic loading of traffic movement force the fine particles to migrate upwards towards the surface and the presence of cracking allows these fines to escape the pavement through the surface (Alobaidi and Hoare 1999). It affects all pavements, and is particularly visible in rigid and segmental block pavements through their joints.

A.4.2 Cracking

Cracking is identified as one or more visible discontinuities or fissures radiating along the surface of a pavement. It is considered to be unplanned and uncontrolled and will not necessarily extend through the entire thickness of a pavement (Austroads 2006a; HYD 2009).

A.4.2.1 Block Cracking

Block cracking is a series of interconnected cracks that form quasi-symmetrical polygons (cells) that are square or rectangular in shape, with cell sizes larger than 200-300mm (Austroads 2006a; HYD 2009; PavementInteractive 2009a). Block cracking generally occurs over a large area of pavement and will often affect an entire segment of road (Austroads 2006a; PavementInteractive 2009a).

Block cracking in rigid pavements can be representative of the age of the pavement (fatigue), but may also be caused by the settlement of underlying pavement layers or an inadequate slab thickness (HYD 2009).

A.4.2.2 Diagonal Cracking

Diagonal cracking is unconnected cracking that generally follows an alignment diagonal to the direction of the pavement, it is neither parallel or perpendicular to traffic flow (HYD 2009). While mainly an issue for rigid pavements, flexible pavements with bound pavement layers may also be affected by this cracking type (Austroads 2006a).

Different from corner cracking, these are multidirectional cracks caused by inadequate slab thickness, drying shrinkage, rocking and/or subbase or subgrade movement (Fabre et al. 2003; HYD 2009).

A.4.2.3 Longitudinal Cracking

Longitudinal cracking can be a single isolated crack or a series of cracks that generally follow an alignment that is parallel to the direction of flow of traffic (Austroads 2006a; HYD 2009). While longitudinal cracks are considered to be unidirectional they may also feature shorter cracks which radiate from the main crack in a diagonal or perpendicular direction in what is referred to as 'branching' (Austroads 2006a; HYD 2009).

Longitudinal cracking in rigid pavements is caused from excessive slab widths which result in lateral shrinkage, as well as differential settlement of the base slab (HYD 2009).

A.4.2.4 Transverse Cracking

Transverse cracking will radiate perpendicular to the alignment of traffic flow and can occur singularly or in a series of parallel cracks (Austroads 2006a).

Transverse cracking in rigid pavements can be attributed to inadequate base thickness or subbase preparation, improperly constructed joints and their restraints, from rocking or from shrinkage (HYD 2009).

A.4.2.5 Corner Cracking

Corner cracking affects rigid pavements, where the cracks formed link an edge or longitudinal joint of the pavement with a transverse joint (HYD 2009). This can be explained by excessive differential drying shrinkage, but may also be due top excessive stresses caused from lack of load transfer joints, loss of subbase or subgrade support, improper restraint near the edge of the slab or an ingress of foreign material through joints or cracks (Hiller et al. 2002; HYD 2009). Improper construction can also have a significant impact on corner cracking, where acute corner angles in slabs lead to corner cracking (HYD 2009).

A.4.2.6 Joint Sealant Cracks

Joint sealant defects arise in the form of cracking and/or loss of the joint sealant, which allows the intrusion of foreign material into the pavement structure (HYD 2009).

Rigid Pavements

The occurrence of this type of defect can be attributed adhesive failure at the time of installation, cohesion failure which can be due to age or incorrect installation techniques; or extrusion of the sealant product due again to construction practices where the joint is either overfilled or poorly prepared (HYD 2009; Austroads 2012).

Segmental Block Pavements

This defect is considered to affect a segmental block pavement when any foreign object or material is able to enter the pavement structure, including excessive volumes of water, through the joints between pavement blocks (Geller 1996).

A.4.2.7 Shrinkage Cracks

Shrinkage cracks are found in rigid pavements, they are small cracks radiating along the surface of the concrete base slab in any direction and while they are generally considered surface cracks, given time and stress they have the capability to expand and extend through the pavement structure (HYD 2009; Idiart et al. 2011).

Shrinkage cracking of concrete is a construction related defect, where inadequate curing causes the moisture in the fresh concrete to dry in an inappropriate manner (HYD 2009; Idiart et al. 2011).

A.4.3 Deformation

Deformation is the change in shape and profile of a pavement surface caused by movement or failure of underlying pavement layers or a shear failure of the pavement surface itself (Austroads 2006c).

A.4.3.1 Rutting

Rutting is the vertical deformation of pavement that occurs in the regular wheel paths of a road and is aligned parallel to the flow of traffic (ESB 1998; Austroads 2006c; PavementInteractive 2008b; HYD 2009). Rutting is considered to have a length-to-width ratio of 4:1 and is a measurement of the maximum vertical displacement at any section of the road, where it is considered to be slight when it is less than 12 millimetres deep, moderate when it is less than 25 millimetres deep and considered severe when it is greater than 25 millimetres deep as it will affect the ability of a vehicle to steer with ease (ESB 1998).

For segmental block pavements rutting arises from deformation of any or all of the pavement layers and is due to consolidation or lateral movement of materials due to traffic loads (Geller 1996).

A.4.3.2 Depressions

A depression in pavement is a localised area that has deformed downwards below the original constructed surface level (Austroads 2006c; HYD 2009; PavementInteractive 2009b). Depressions may not necessarily be confined to wheel paths as they may in fact cross several and are particularly noticeable immediately

following rain when they fill with water, creating a safety hazard for vehicles who will experience a loss in skid resistance (HYD 2009; PavementInteractive 2009b).

Depressions of segmental block pavements can be a result of subgrade settlement or improper subbase or bedding construction, such as inadequate block thickness, inadequately graded jointing sand or excessive bedding sand thickness (Geller 1996; ESB 1998; Soutsos et al. 2011).

A.4.3.3 Corrugations

Corrugations are wave-like plastic deformation of the pavement surface, with distortion perpendicular to the direction of traffic flow (PavementInteractive 2006a; Austroads 2009e; HYD 2009). Corrugations are distinguished by regularly and closely spaced undulations, or ripples spaced usually 500 millimetres to 1 metre apart and represent significant deformation of the pavement that can will rapidly to failure (Austroads 2006c; HYD 2009).

Often, corrugations are worsened by drivers who "adapt their travelling velocity so that the vehicle suspension system will obtain the best possible resonance with the already existing road corrugation periodicity, which further increases the amplitude of the corrugation" (Edvardsson 2009).

Corrugations in segmental block pavements are formed under traffic load in combination with the failure of a paving block or the swelling of joints, subgrade or crack material (Geller 1996).

A.4.3.4 Potholes

Potholes are local failures, described as bowl-shaped depressions, where the wearing surface has disintegrated (or displaced) leaving the underlying pavement layers exposed to traffic and weather (Austroads 2006c; PavementInteractive 2007a).

Potholes in segmental block pavements are caused by shifting or dislodged blocks, where the lack of support from surrounding blocks allows further deterioration of the pothole (Geller 1996)

A.4.3.5 Edge Breaks

Edge breaks occur near the shoulder of the pavement (the edge of the road), parallel to the direction of traffic flow (Austroads 2006c). It can result in a reduction of the effective pavement width, loss of ride quality and user safety, the channelling of water leading to erosion of the road shoulder as well as increase the likelihood of lateral water entry into the pavement base (Austroads 2006c).

Edge breaks in segmental block pavements is accelerated under traffic load and caused by moisture in subbase or subgrade layers near the edge of the pavement, or poor edge support at the extremities of the pavement (Geller 1996; Soutsos et al. 2011).

A.4.3.6 Spalling

Spalling, or slab break-up, is described as the disintegration of the concrete pavement surface along transverse cracks or joints, which increases roughness and reduces ride quality and road safety (Zollinger et al. 1994; de Solminihac et al. 2003; HYD 2009).

The affect of spalling reduces the cross-sectional area of the pavement, which in turn decreases the load-transfer efficiency at pavement joints or cracks and leads to higher stresses in the pavement slab. This is illustrated in Figure A-3 which shows that spall development is more likely in a shallow delamination due to higher stresses (Zollinger et al. 1994).

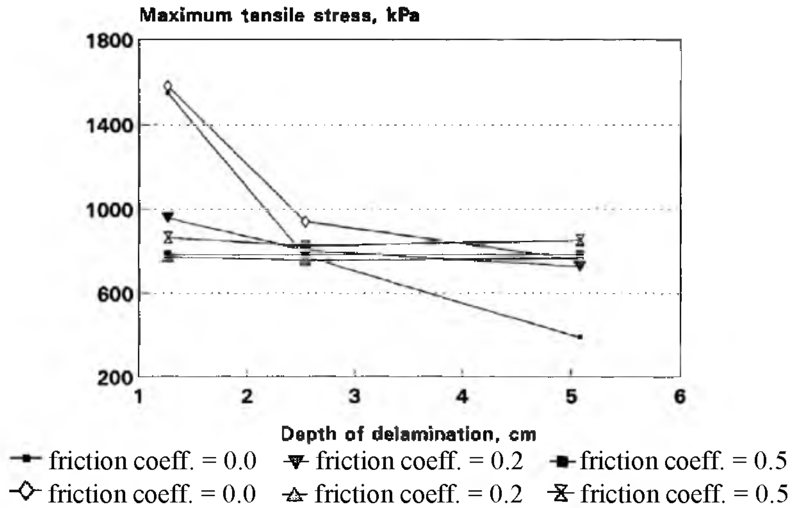

Figure A-3 – Concrete Spalling - Comparison of Maximum Tensile Stress with friction coefficients from a Finite-Element Analysis (Zollinger et al. 1994)

Construction practices have the greatest affect on spalling of concrete pavements, where delaminations occur in the pavement due to differential shrinkage, the concrete spalls develop as the disintegration of this delaminated surface due to traffic load, temperature variation and moisture accumulation on the delaminated interface with the rigid concrete below (Kerr 1994; Zollinger et al. 1994; HYD 2009). This can be exacerbated by the incorrect placement of structures, such as manholes, in the concrete slab, where undesired cracking radiates from the corners of these structures which increase the likelihood of what is termed *box-out spalling* (HYD 2009). Other causes also include infiltration of stones or fine material into the joint or crack or the corrosion of dowels in the joint (HYD 2009).

A.4.3.7 Joint Faulting

Joint faulting is the differential vertical movement of the surface either side of a joint or crack causing a step in the pavement (Geller 1996; de Solminihac et al. 2003; HYD 2009).

Rigid Pavements

Joint or crack width have an impact on joint faulting, where a wider opening provides a lesser load-transfer capacity although this impact diminishes with pavement age and is less significant when the concrete base is constructed with dowels or reinforcement at the joints. Poor subbase or subgrade drainage is also a factor in joint faulting, where pumping results in a reduction of support for the concrete base and differential settlement occurs (de Solminihac et al. 2003; HYD 2009). A summary of the likely causes, and their significance on the occurrence of joint faulting is presented in Figure A-4 below.

Segmental Block Pavements

Faulting in segmental block pavements is the elevation difference between blocks, rather than joints as discussed for rigid pavements. It can be caused from settlement or consolidation of soft subgrades or from pumping of the materials within the pavement structure (Geller 1996).

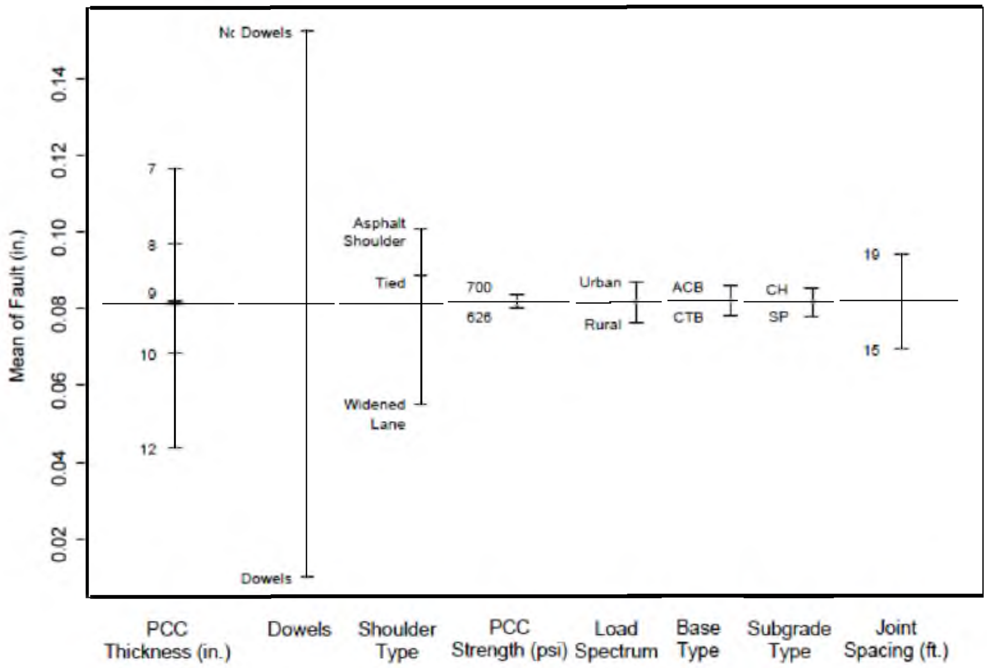

Figure A-4 – Relative effect of variables on faulting (Kannekanti and Harvey 2005)

A.4.3.8 Rocking

Rocking is the dynamic vertical movement of the concrete base slab at a joint or crack under traffic load (HYD 2009). Primarily an issue for plain concrete pavements without dowel restraints at the joints, this dynamic action results pumping of the underlying pavement layers and is caused by lack of support from the subbase or inadequate load transfer through dowels or tie bars at joints (Fabre et al. 2003; HYD 2009).

A.4.3.9 Blow-up

A blow-up is the breaking down and loss of structural integrity of one or many segmental block pavers. It can be caused by inadequate block manufacture, excessive traffic load, mechanical damage from abrasion, potholes or joint sealing defects not treated sufficiently (Geller 1996).

A.4.3.10 Swell

Swell is a defect that affects segmental block pavements; it is the inverse of a depression and is identified by upward bulging of the pavement surface in a long gradual wave typically longer than 3 metres. Causes of this defect can be attributed to frost in the pavement layers or the presence of expansive subgrades (Geller 1996).

A.5 Summary

An exploration of the defect types in flexible, rigid and segmental block pavements show that while defects present themselves in similar ways, the mechanisms that form these defects vary between pavement types. Therefore, for the development of a system such as the one proposed for this study, this warrants the need to separate flexible pavements from other pavement types.

However, it is envisaged that the foundation of this decision support system will lend itself to future development of a road network remediation model, encompassing all pavement types.

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APPENDIX B

DECISION SUPPORT SYSTEM PROGRAM DEVELOPMENT

PAVEMAINT SELECT V0.1 (PROTOTYPE)

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DSS CODE NOTES

* Note: All userforms begin with code that ensures when the user clicks to Close (red cross – at top right of the form) the program is properly stopped and reset – otherwise upon restart userforms will be cached and will affect program functionality

B.1 User form - PaveMaint_Home

B.1.1 Description:

- Home screen to begin the program and introduce its purpose (Figure B.1)

B.1.2 Code Function:

- Upon click of "Begin" button
    - o Clear contents of cells B3:B8 and F7 from the Solutions sheet
    - o Unload any residual data remaining in the User Forms
    - o Reinstate formulas in cells A15:A21, B15:B21, F15:F21, H15:H21, J15:J21 & M15:M21 of the Solutions sheet
    - o Show Road Details userform (No. B.2)

B.1.3 Accelerated Learning Tools:

- Flexible pavements (Figure B.2)

B.1.4 Screen Shots:

Figure B.1 – PaveMaint SELECT "Home" Screen

Figure B.2 – PaveMaint SELECT *Accelerated Learning Tool*: Flexible Pavements

B.2 User form - PaveMaint_RoadDetails

B.2.1 Description:

- Userform with textboxes for user to input road name, locality, description of road section and traffic of road (Figure B.3)

B.2.2 Code Function:

- Upon click of “Next” button:
    - User input is propagated to the “Results” worksheet in the MS Excel spreadsheet (B3, B4, B5 & G3)
    - Date of assessment is propagated to “Results” worksheet in the MS Excel spreadsheet (G1)
    - Warning message box if user has left a text box empty and stop progress to next sheet (Figure B.4)
    - Hide current form and Show Surface Type userform (No. B.3)

B.2.3 Accelerated Learning Tools:

- Traffic Load ESA (Figure B.5)

B.2.4 Screen Shots:

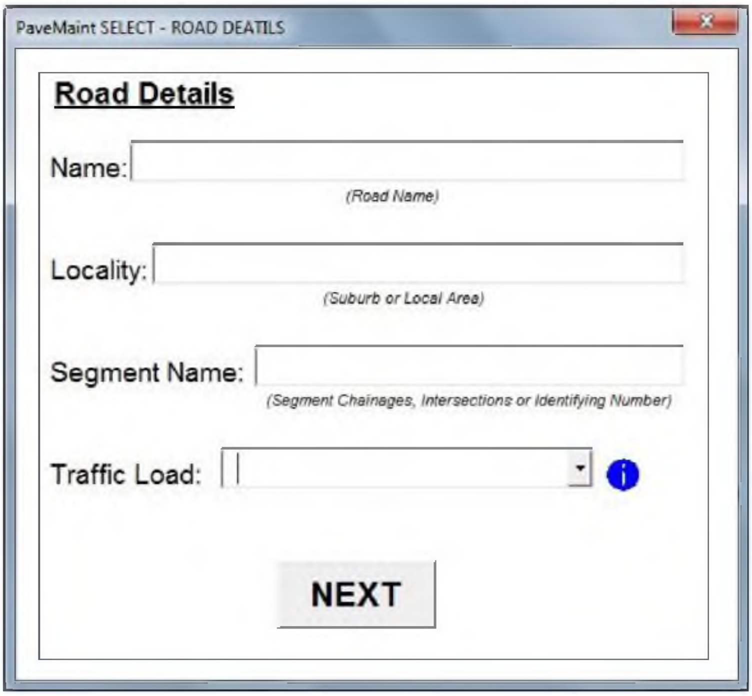


Figure B.3 – PaveMaint SELECT “Road Details” Screen

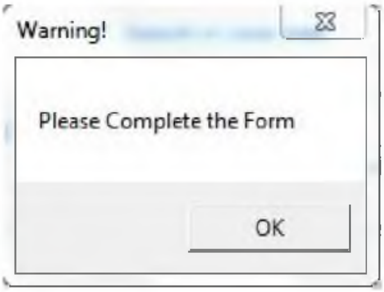


Figure B.4 – PaveMaint SELECT Warning Screen: Incomplete “Road Details” Form

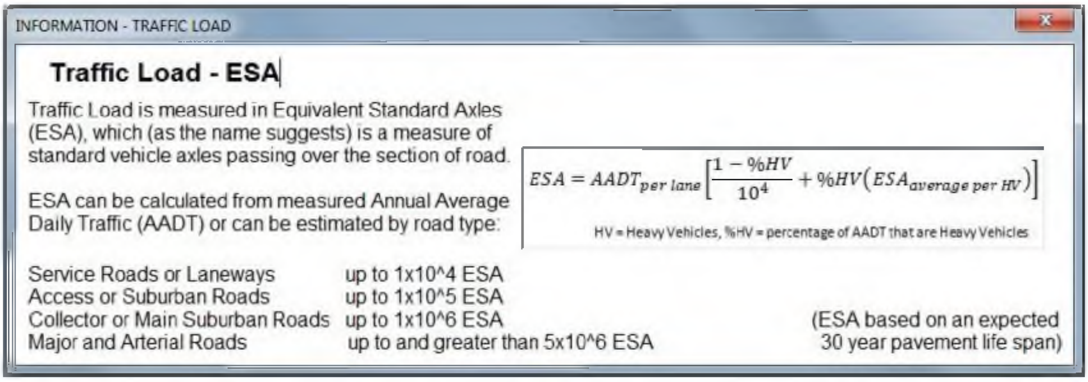


Figure B.5 – PaveMaint SELECT *Accelerated Learning Tool*: “Traffic Load”

B.3 User form - PaveMaint_FlexSurfType

B.3.1 Description:

- Userform with option (or radio) buttons for user to select the surface type of the road being assessed (Asphaltic Concrete, Bituminous Spray Seal or Unsealed Pavement) (Figure B.6)

B.3.2 Code Function:

- Upon click of "Next" button:
    - Turns on the option/radio button and info images on defects1 userform for the appropriate amount of defects for each surface type (uses cells in the knowledgebase worksheets for each of surface types to determine if there is a corresponding defect)
    - Assign the option/radio button labels on defects1 userform – reading from cells in knowledgebase worksheets for each surface type
    - Assign the option/radio button labels on defects2 userform – reading from cells in knowledgebase worksheets for each surface type
    - Propagates the surface type to the "Results" worksheet in the MS Excel spreadsheet (B6) – equation makes cell equal to the equivalent cell in the knowledgebase worksheets
    - Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure B.7)
    - Hide current form and Show Defect Type userform (No. B.4)
- Upon click of "Back" button:
    - Hide Surface Type and Road Details (function does not clear the previous data – the logic is that the user would be going back to simply amend a text field and clearing the data would result in the user needlessly having to fill in all the text boxes again)
    - Show Road Details

B.3.3 Accelerated Learning Tools:

- Asphaltic concrete surfaces (Figure B.8)
- Bituminous spray seal surfaces (Figure B.9)
- Unsealed surfaces (Figure B.10)

B.3.4 Screen Shots:

Figure B.6 – PaveMaint SELECT “Surface Type” Screen

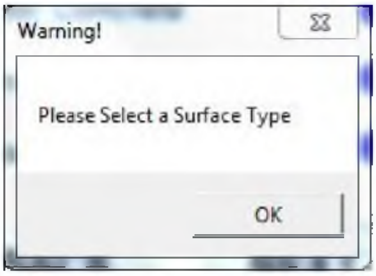


Figure B.7 – PaveMaint SELECT Warning Screen: Incomplete “Surface Type” Form

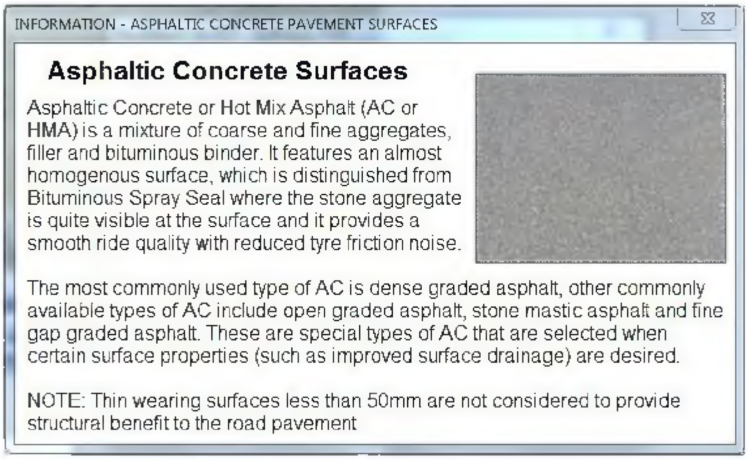


Figure B.8 – PaveMaint SELECT *Accelerated Learning Tool*: “Asphaltic Concrete Surfaces”

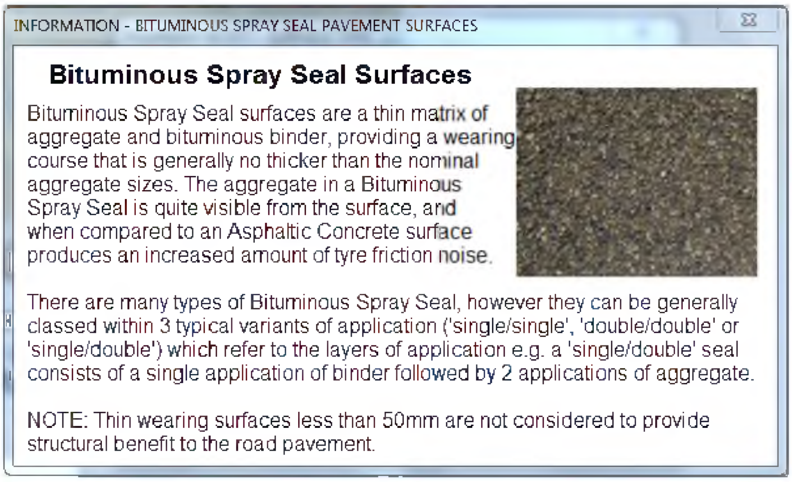


Figure B.9 – PaveMaint SELECT *Accelerated Learning Tool*: “Bituminous Spray Seal Surfaces”

Figure B.10 – PaveMaint SELECT *Accelerated Learning Tool*: “Unsealed Pavements”

B.4 User form - PaveMaint_Defects1

B.4.1 Description:

- Userform with a list of defect types expected for the selected pavement surface type (Figure B.11, Figure B.12 and Figure B.13)

B.4.2 Code Function:

- Upon click of "Next" button:
    - Propagates the defect type to the "Results" worksheet in the MS Excel spreadsheet (B7) – equation makes cell equal to the caption label of the option/radio button selected – will not propagate if cracking is selected, this will be addressed in Cracking Defects userform code
    - Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure B.14)
    - Updates label in Severity userform (No.B.6) to reflect defect chosen (uses caption labels to propagate)
    - Sets Severity options visible or not
    - Sets Severity option/radio button values and accelerated learning tools embedded into the description/label – reading from cells in knowledgebase worksheets for each surface type
    - Hide current form and Show Cracking Defect Type userform (No. B.5) or Show Severity userform (No. B.6) depending on defect chosen
- Upon click of "Back" button:
    - Unload Defects 1 and Defects 2 (clears previous data from the 2 userforms– unloading is necessary for the proper function of the code that makes defects userforms option/radio buttons visible or not visible)
    - Show Surface Type

B.4.3 Accelerated Learning Tools:

- All defect types for all 3 surface types (Table B.1 and Table B.2) – Cracking info button is for cracking generically, specific cracking types are linked to Cracking Defect Type userform (No. B.5)

B.4.4 Screen Shots:

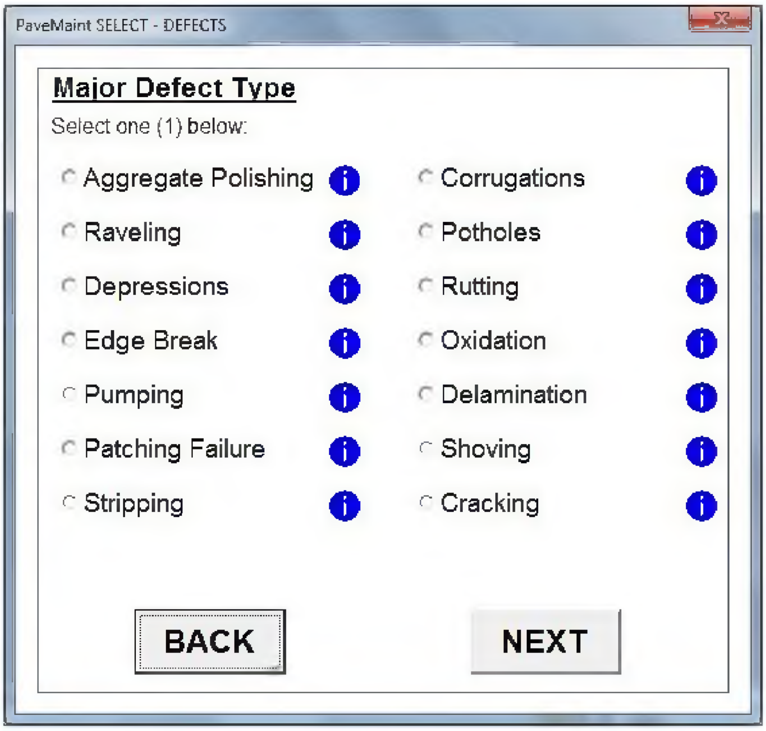


Figure B.11 – PaveMaint SELECT Asphaltic Concrete Surfaced Pavements "Major Defect Type" Screen

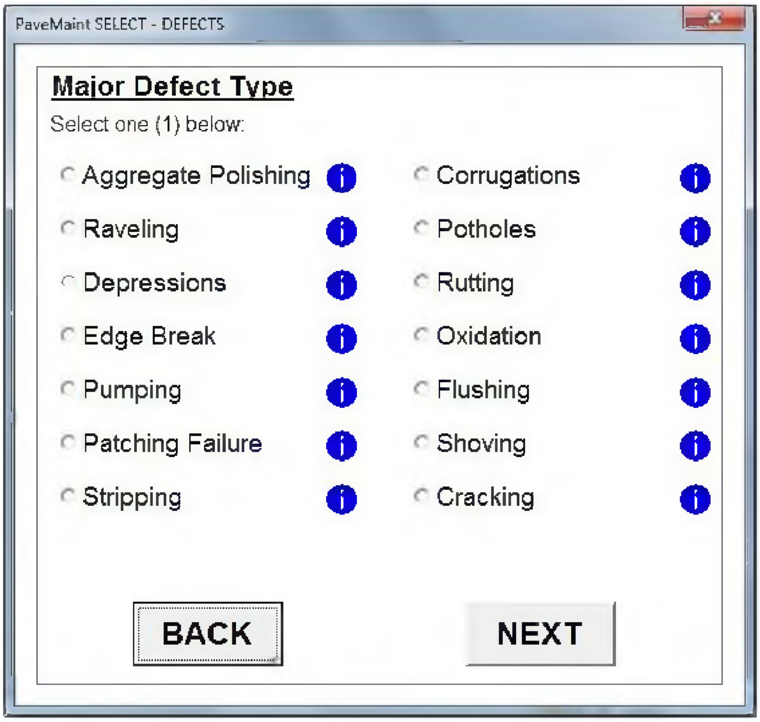


Figure B.12 – PaveMaint SELECT Bituminous Spray Sealed Pavements "Major Defect Type" Screen

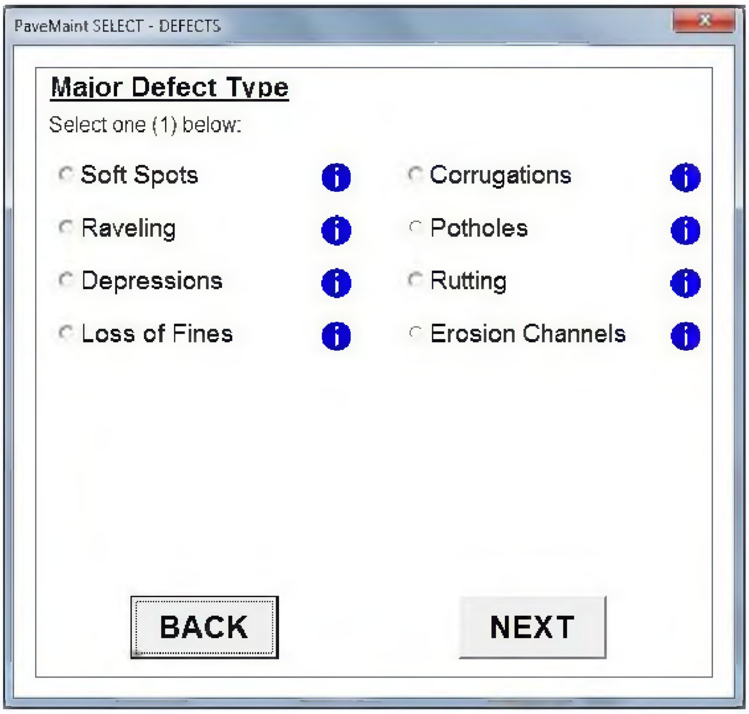


Figure B.13 – PaveMaint SELECT Unsealed Pavements “Major Defect Type” Screen

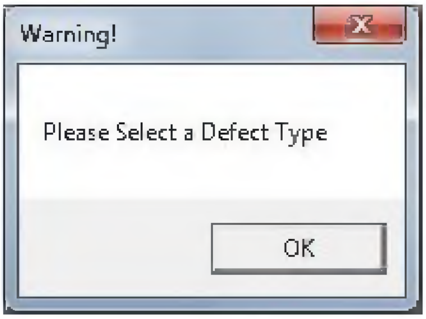


Figure B.14 – PaveMaint SELECT Warning Screen: Incomplete “Defect Type” Form

Table B.1 – *Accelerated Learning Tools* for Defects Associated with Asphaltic Concrete and Bituminous Spray Sealed Pavements - Figure B.11 and Figure B.12

INFORMATION - AGGREGATE POLISHING

Aggregate Polishing

Aggregate Polishing is sometimes referred to as the loss of surface texture. It is commonly found in the wheel paths of traffic lanes and is distinguished by areas that are relatively smooth compared to surrounding pavement where the surface may be described as 'glazed' or 'shiny'.

Causes include: incorrect or inadequate aggregate selection, surface age or higher than expected traffic volume or traffic stresses.

INFORMATION - CORRUGATIONS (SEALED PAVEMENTS)

Corrugations

Corrugations are the deformation of the pavement which is setup in wave-like 'ripples' in the pavement surface. They are closely spaced (usually 500mm up to 1m) and are exacerbated by further traffic which can increase the amplitude of the corrugations.

In sealed pavements caused include: inadequate stability in the surface or base courses, excessive moisture in the subgrade, low air voids in pavement layers (particularly surface layers) or steep uphill or downhill gradients exacerbated by braking heavy traffic.

INFORMATION - CRACKING (ASPHALTIC CONCRETE SURFACES)

Cracking

Cracking is one or more visible discontinuities ('fissures' or 'cracks') radiating along the surface of a pavement. It is considered to be unplanned and uncontrolled and will not necessarily extend through the entire thickness of a pavement.

The condition of pavement surfaces is an important guide to the overall condition and future performance of the pavement structure, and the onset of surface cracking has been recognised as an indicator of overall pavement condition.

Pavements with an asphaltic concrete surface suffer from many possible cracking types, including block, crescent-shaped, crocodile, diagonal, longitudinal, meandering and transverse cracking.

INFORMATION - DELAMINATION

Delamination

Delamination is the total removal (or 'peeling off') of large areas of the wearing surface. It is distinguished by a clear delineation between the wearing course and the pavement base course layer below. It 'peels' off the pavement because of a loss of bond between the asphalt or bitumen surface and the base course and results in low shear resistance to traffic stresses.

Delamination can be caused by:

1. Construction deficiencies (inadequately cleaned or tack coated pavement surface prior to placing the asphalt, insufficient thickness and stability during the asphalt placement or arising from patch repairs of failed pavements)
2. In-situ causes (water seepage through the surface which weakens the bond between the layers, failure of a lower layer or as a result of significant damage to the surface from improper usage or traffic loading)

INFORMATION - DEPRESSIONS

Depressions

A depression is a localised area of a pavement surface that has deformed downwards below the original constructed surface level. They are not necessarily confined to wheel paths and are particularly noticeable immediately following rain when they fill with water, creating a safety hazard for vehicles that will experience a loss of skid resistance.

Depressions are generally caused by a volume change in the subgrade or sub-base materials. These volume changes can arise from soft and poorly compacted areas (either during original construction or from recent service trenches), embankment movements, changes in moisture content within pavement materials or the erosion of the underlying pavement layers.

INFORMATION - EDGE BREAKS

Edge Breaks

Edge breaks are the deterioration (fretting) of the edge of the road and is particularly common where the shoulder is unsealed and traffic is prone to traversing the interface of bitumen and shoulder. It is found parallel to the direction of traffic flow and leads to a reduction of the effective pavement width, loss of ride quality and user safety, the channelling of water leading to erosion of the road shoulder as well as increasing the likelihood of lateral water entry into the pavement base.

INFORMATION - FLUSHING

Flushing

Flushing (or 'bleeding') is the partial (or complete) submersion of the surface aggregate into the binder mixture resulting in a slippery surface with poor texture and skid resistance. It is distinguished by a visibly shiny black surface due to the bitumen being almost completely exposed at the surface.

It commonly occurs during hot weather where the bituminous binder fills the aggregate voids and then expands onto the pavement surface. It is not reversible during cold weather and will progressively worsen with time.

Flushing can be caused by excessive binder content on the surface or underlying surfaces, poor mix design, aggregate penetration into underlying low strength pavements, softening of the binder or spillages or accumulation of oil from vehicles.

INFORMATION - OXIDATION

Oxidation

Oxidation is the age hardening of the sealed bitumen surface caused by environmental and atmospheric conditions. It is not easily detected on its own, but often leads to other defects such as cracking, aggregate loss and raveling (among others).

The affects of oxidation leave the pavement more susceptible to moisture intrusion, which leads to further and more severe defects.

INFORMATION - PATCHING FAILURE

Patching Failure

Patching failure is the deterioration of a previous hot or cold mix asphalt patch repair and can be the failure of the patch repair itself or the continued failure of the existing underlying or surrounding pavement material.

Patching failure arises from an improperly constructed repair or a repair that does not completely remediate the entire failing section of road.

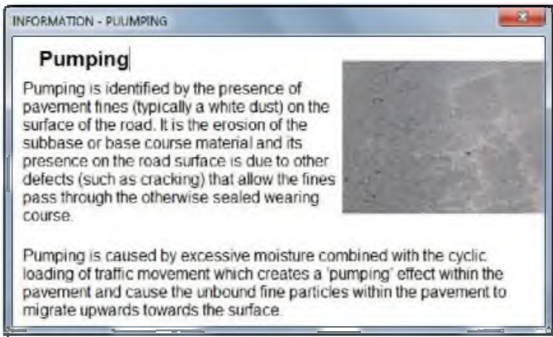
INFORMATION - POTHOLES (SEALED PAVEMENTS)

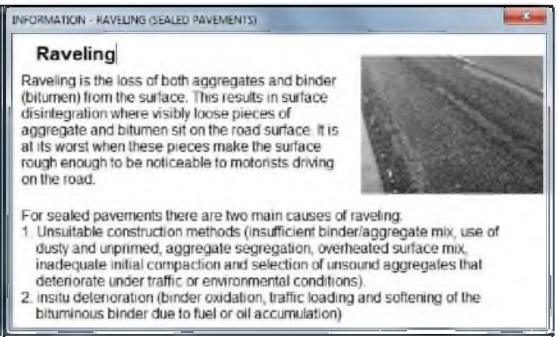
Potholes

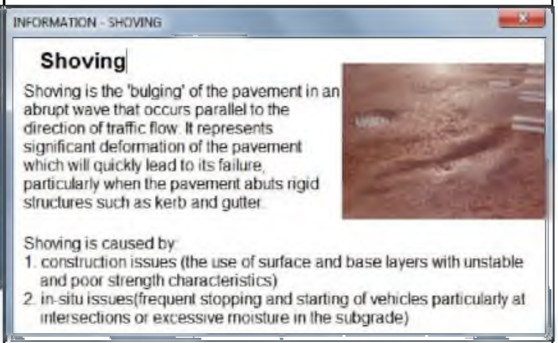
Potholes are local bowl-shaped depressions or failures, where the wearing surface has disintegrated (or displaced) leaving the underlying pavement layers exposed to traffic and weather. They are common in pavements with thin surface layers and are rarely seen in pavements with surfaces greater than 100mm thick.

Potholes in sealed pavements commonly develop as a result of other defects, particularly those that affect the integrity of the pavement surface such as raveling and cracking (particularly crocodile cracking) which allows moisture to enter the pavement and lead to the areas of the surface being dislodged by traffic.

Table B.1 – *Accelerated Learning* Tools for Defects Associated with Asphaltic Concrete and Bituminous Spray Sealed Pavements - Figure B.11 and Figure B.12 (continued)







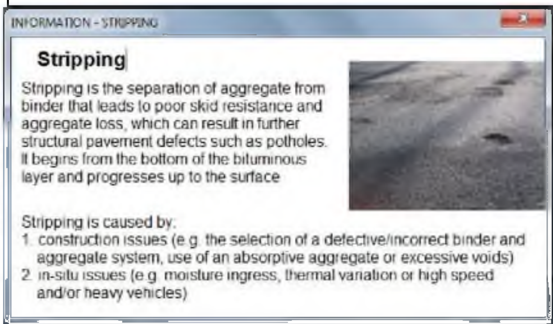


Table B.2 – *Accelerated Learning Tools* for Defects Associated with Unsealed Pavements - Figure B.13

INFORMATION - CORRUGATIONS (UNSEALED PAVEMENTS)

Corrugations

Corrugations are the deformation of the pavement which is setup in wave-like 'ripples' in the pavement surface. They are closely spaced (usually 500mm up to 1m) and are exacerbated by further traffic which can increase the amplitude of the corrugations.

In unsealed pavements corrugations are formed under traffic load where the loose surface is firstly displaced, then arranged in waves set up by vehicle tyre movements. They are common in dry granular pavements with low plasticity and have either limited fines or have lost fines.

INFORMATION - DEPRESSIONS

Depressions

A depression is a localised area of a pavement surface that has deformed downwards below the original constructed surface level. They are not necessarily confined to wheel paths and are particularly noticeable immediately following rain when they fill with water, creating a safety hazard for vehicles that will experience a loss of skid resistance.

Depressions are generally caused by a volume change in the subgrade or sub-base materials. These volume changes can arise from soft and poorly compacted areas (either during original construction or from recent service trenches), embankment movements, changes in moisture content within pavement materials or the erosion of the underlying pavement layers.

INFORMATION - EROSION CHANNELS

Erosion Channels

Erosion channels are common on roads with steep gradients and/or an insufficient crown and are caused by flow of water along or over the road. This results in the loss of pavement material through transportation in high velocity water runoff, primarily during periods of rain.

While they are common on steep gradients which give rise to longitudinal erosion channels, but they may also occur perpendicular to the road alignment, where areas with lower compaction, such as the shoulder, begin the process and progress towards the road pavement or from local depressions that initially hold the water and eventually carves its own drainage path.

INFORMATION - LOSS OF FINES

Loss of Fines

The loss of fines in unsealed pavements is considered the first sign of wearing. It is evident in a road that produces large or excessive plumes of dust in windy conditions or when trafficked and is caused by traffic action and climatic conditions and is the loss of fine particles in road base/surface material.

Note: In addition to road user safety, there are number of health issues surrounding the resulting airborne dust generated from a road suffering a loss of fines.

INFORMATION - POTHOLES (UNSEALED PAVEMENTS)

Potholes

Potholes are local bowl-shaped depressions or failures, where the wearing surface has disintegrated (or displaced) leaving the underlying pavement layers exposed to traffic and weather.

On unsealed pavements, potholes arise from other defects that affect surface integrity and develop into a disintegrating nucleus. Potholes also develop from previous improperly repaired potholes where failure nucleus remains within the pavement and begins to redevelop.

INFORMATION - RAVELING (UNSEALED PAVEMENTS)

Raveling

Raveling is the loss of both aggregates and binder (pavement fines) from the surface. This results in surface disintegration where visibly loose pieces of aggregate and bitumen sit on the road surface. It is at its worst when these pieces make the surface rough enough to be noticeable to motorists driving on the road.

For unsealed pavements, raveling is associated with a loss of fines, since the fines in an unsealed pavement represent the binder of the pavement surface matrix, their loss leads to the exposure of surface aggregate which not only results in a coarse surface with increased noise, roughness and permeability, but increases the likelihood of raveling which decreases skid resistance due to loose aggregates.

INFORMATION - RUTTING (UNSEALED PAVEMENTS)

Rutting

Rutting is vertical deformation that occurs in the regular wheel paths of a road and is also known as 'dry rutting' in unsealed pavements. It is commonly found in areas subject to high stress traffic loading which is common in climbing lanes, and areas with slow heavy traffic.

It is prevalent in dry environments and caused by loss of material from regular or heavy traffic, but can also be due to high moisture content in the subsurface soil or base.

INFORMATION - SOFT SPOTS

Soft Spots

Soft Spots affect unsealed pavements with excessive silt or clay content.

They are localised areas that are reactive to water ingress and combined with aggregate segregation causes the pavement to deform under traffic load.

Soft Spots are almost always formed in combination with other types of defects.

B.5 User form - PaveMaint_Defects2

B.5.1 Description:

- Userform with a list of cracking types expected for the selected pavement surface type (Figure B.16 and Figure B.17)

B.5.2 Code Function:

- Upon click of “Next” button:
  - Propagates the cracking defect type to the “Results” worksheet in the MS Excel spreadsheet (B7) – equation makes cell equal to the caption label of the option/radio button selected
  - Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure B.15)
  - Updates label in Severity userform (No. B.6) to reflect defect chosen (uses caption labels to propagate)
  - Sets Severity options visible or not
  - Sets Severity option/radio button values and accelerated learning tools embedded into the description/label – reading from cells in knowledgebase worksheets for each surface type
  - Hide current form and Show Severity userform (No. B.6)
- Upon click of “Back” button:
  - Hide Cracking Defects
  - Show Defect Types

B.5.3 Accelerated Learning Tools:

- Cracking info for all expected cracking types for the selected pavement surface

B.5.4 Screen Shots:

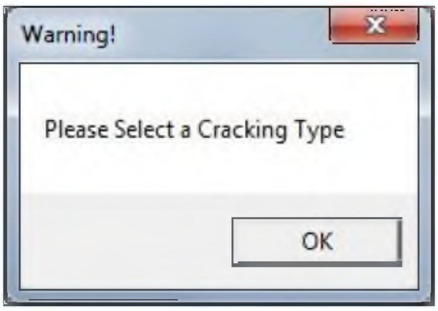


Figure B.15 – PaveMaint SELECT Warning Screen: Incomplete “Cracking Type” Form

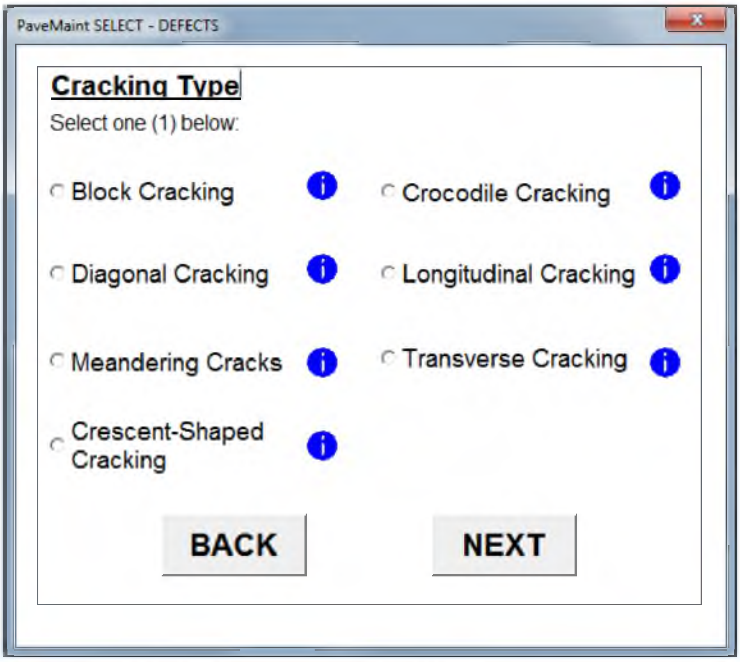


Figure B.16 – PaveMaint SELECT Asphaltic Concrete Surfaced Pavements "Cracking Type" Screen

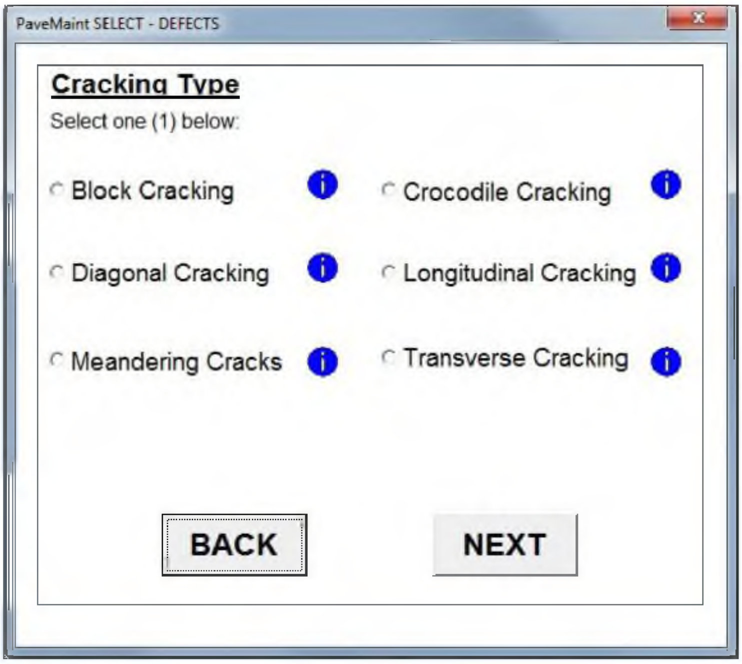


Figure B.17 – PaveMaint SELECT Bituminous Spray Sealed Pavements "Cracking Type" Screen

Table B.3 – *Accelerated Learning Tools* for Defects Associated with Cracking of Asphaltic Concrete and Bituminous Spray Sealed Pavements - Figure B.16 and Figure B.17

INFORMATION - BLOCK CRACKING

Block Cracking

Block cracking is a series of cracks that form almost symmetrical polygons (or "cells") that are square/rectangular in shape and larger than 200-300mm. It generally affects a large area of pavement and will often affect an entire segment of road.

Causes of Block Cracking include: the hardening and shrinkage of the bituminous surface; fatigue in an aged and brittle wearing course; reflection from joints or discontinuities associated with an underlying bound base, subbase or subgrade layer; or the loss of subbase or subgrade support.

INFORMATION - CROCODILE CRACKING

Crocodile Cracking

Crocodile cracking is a series of interconnected cracks that form irregular shaped cells that are smaller than 300mm in nominal diameter and resembles the pattern of crocodile (or alligator) skin, and is sometimes referred to as "alligator" or "polygon" cracking or "crazing".

Crocodile cracking regularly occurs in wheel paths and is mainly caused by traffic loading causes the propogation of other cracking defects such as block cracking. It can also be caused by other issues such as the saturation of underlying pavement layers; fatigue (ageing and brittleness of bituminous wearing course); or inadequate pavement thickness or compaction.

INFORMATION - DIAGONAL CRACKING

Diagonal Cracking

Diagonal cracking is unconnected cracking that generally follows an alignment diagonal to the direction of the pavement, it is neither parallel or perpendicular to traffic flow.

Causes of diagonal cracking include reflection from joints or discontinuities associated with an underlying bound base, subbase or subgrade layer; differential settlement from adjacent embankments, cuttings or structures; tree roots; or disturbance from underground service installation.

INFORMATION - LONGITUDINAL CRACKING

Longitudinal Cracking

Longitudinal cracking can be a single isolated crack or a series of cracks that generally follow an alignment that is parallel to the direction of flow of traffic. While longitudinal cracks are considered to be unidirectional they may also feature shorter 'branching' cracks which radiate from the main crack.

Causes may include reflection from joints or discontinuities associated with an underlying pavement layer; bitumen hardening; early developing slips (for roads located on slopes); or poor work practices such as poorly constructed asphalt surfacing joint and reflection from joints where pavement widening works have been undertaken.

INFORMATION - MEANDERING CRACKS

Meandering Cracks

Meandering cracks are unconnected, singularly discontinuities that, as the name suggests, follow an undefined and multidirectional alignment.

Causes include: weakening of pavement due to saturation; shrinkage of pavement subgrade due to tree roots; reflected shrinkage cracks from bound base and subbase materials; or disturbance from underground service installation.

INFORMATION - TRANSVERSE CRACKING

Transverse Cracking

Transverse cracking will radiate perpendicular to the alignment of traffic flow and can occur singularly or in a series of parallel cracks.

Transverse cracking can be caused by a construction joint or shrinkage in asphalt surfacing; reflection from joints or discontinuities associated with an underlying pavement layer; differential settlement occurring at a cut/fill plane on an embankment; or movement in underlying pavement.

INFORMATION - CRESCENT-SHAPED CRACKING

Crescent-Shaped Cracking

Crescent-shaped (or slippage) cracking is named according to its appearance, this cracking type is evident by its half-moon, or curve, shaped alignment, which may occur as a singular crack or in a group of concentric cracks.

Crescent-shaped cracking is representative of shear movements in pavement surfaces and is commonly associated with shoving an asphalt pavement surface. Causes may be due to poor construction techniques such as dragging by paver when laying asphalt at low temperatures, or inadequate bond between asphalt wearing course and pavement base course due to dust, dirt, oil or the absence of a tack coat; due to excessive shear forces due to braking and acceleration movements; or due underlying pavement layers with low densities and stiffness.

Note:

Crescent-Shaped Cracking is not associated with Bituminous Spray Sealed pavements.

B.6 User form - PaveMaint_Severity

B.6.1 Description:

- Userform where the severity of the defect is identified (Figure B.18 to Figure B.40)

B.6.2 Code Function:

- Upon click of "Next" button:
  - o Propagates a value between 1-5 to the "Results" worksheet in the MS Excel spreadsheet (J7)
  - o Propagates the full list of suitable remediation options to the "Results" worksheet in the MS Excel spreadsheet (A15:A21) based on the Defect, Surface Type and Severity chosen
  - o Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure B.41)
  - o Hide current form and Show User Constraints (1) userform (No. B.7)
- Upon click of "Back" button:
  - o Hide and Unload Severity
  - o Show Defect Types or Cracking Defect Types (depending on defect previously chosen)

B.6.3 Accelerated Learning Tools:

- Incorporated into radio options which are descriptive and lead user to giving informed answers

B.6.4 Screen Shots:

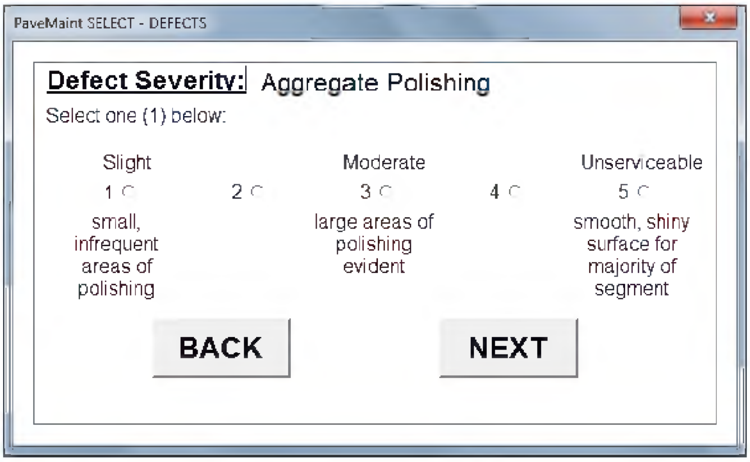


Figure B.18 – PaveMaint SELECT Defect Severity Selection for Aggregate Polishing of Asphaltic Concrete and Bituminous Spray Sealed Surfaces

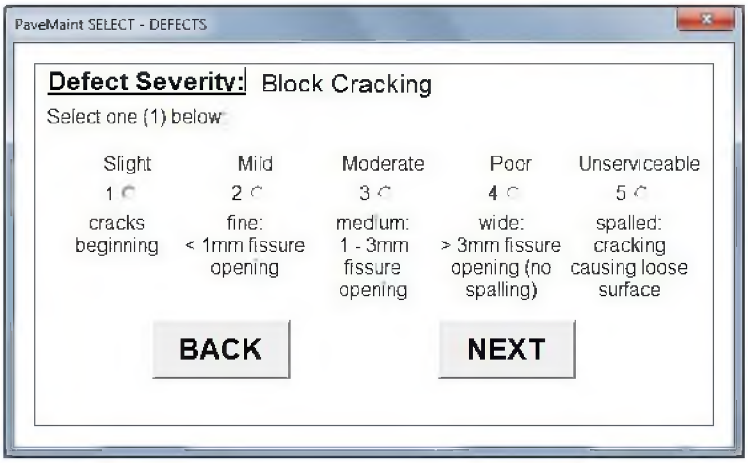


Figure B.19 – PaveMaint SELECT Defect Severity Selection for All Types of Cracking in Asphaltic Concrete and Bituminous Spray Sealed Pavements

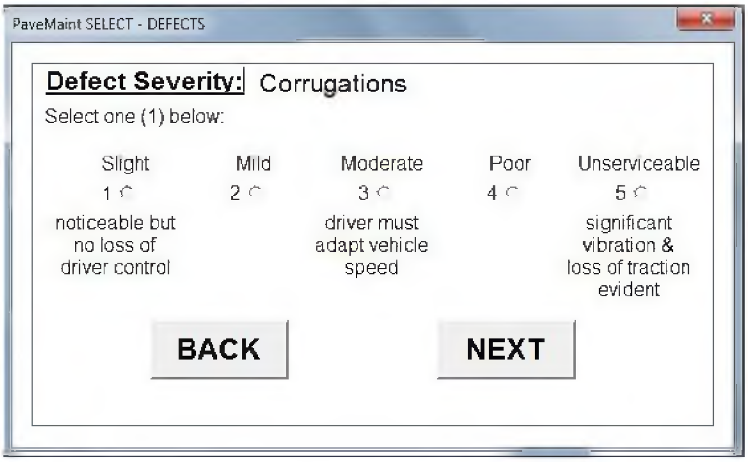


Figure B.20 – PaveMaint SELECT Defect Severity Selection for Corrugations in Asphaltic Concrete and Bituminous Spray Sealed Pavements

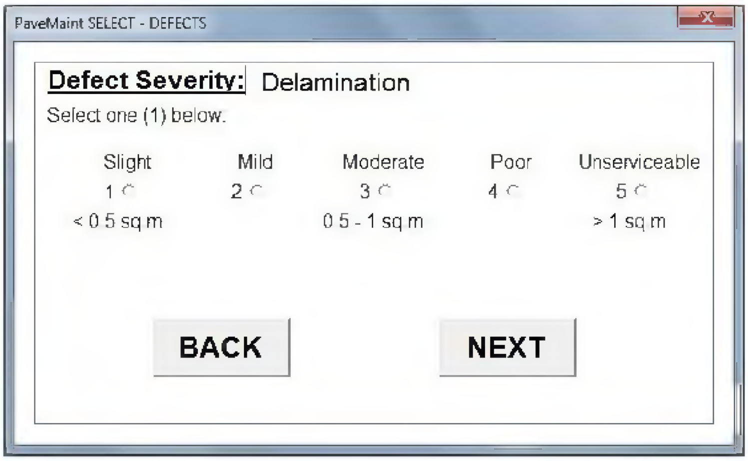


Figure B.21 – PaveMaint SELECT Defect Severity Selection for Delamination of Asphaltic Concrete Surfaces

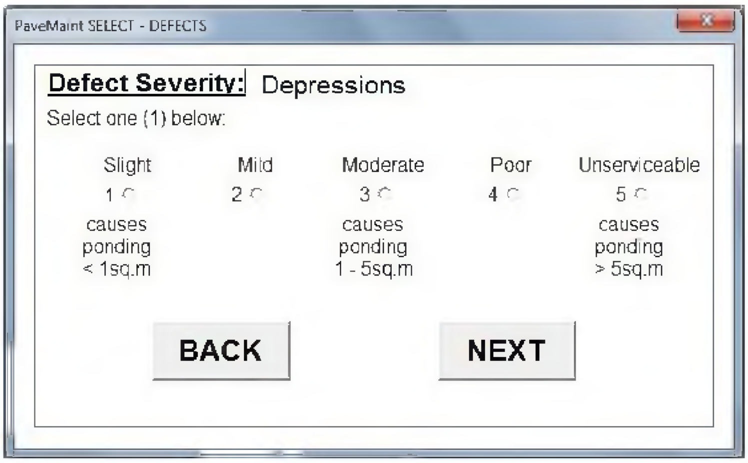


Figure B.22 – PaveMaint SELECT Defect Severity Selection for Depressions on Asphaltic Concrete and Bituminous Spray Sealed Pavements

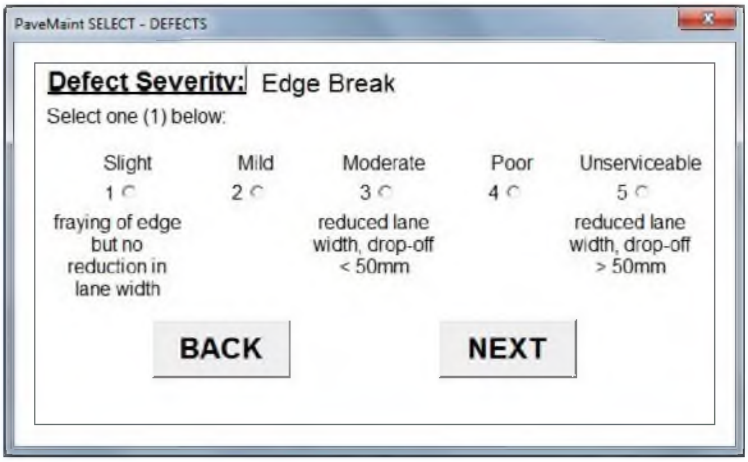


Figure B.23 – PaveMaint SELECT Defect Severity Selection for Edge Breaks along Asphaltic Concrete and Bituminous Spray Sealed Pavements

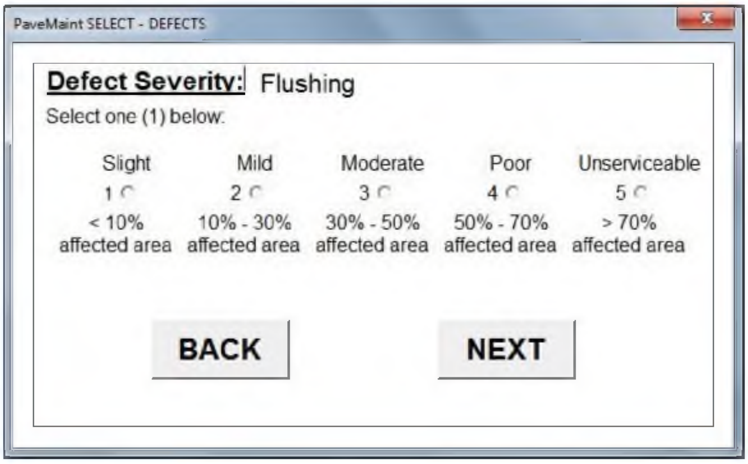


Figure B.24 – PaveMaint SELECT Defect Severity Selection for Flushing of Bituminous Spray Sealed Surfaces

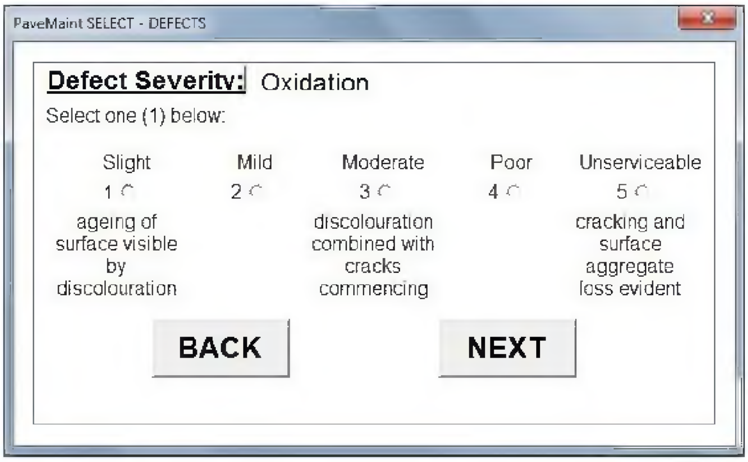


Figure B.25 – PaveMaint SELECT Defect Severity Selection for Oxidation of Asphaltic Concrete and Bituminous Spray Sealed Surfaces

Figure B.26 – PaveMaint SELECT Defect Severity Selection for Patching Failure on Asphaltic Concrete and Bituminous Spray Sealed Pavements

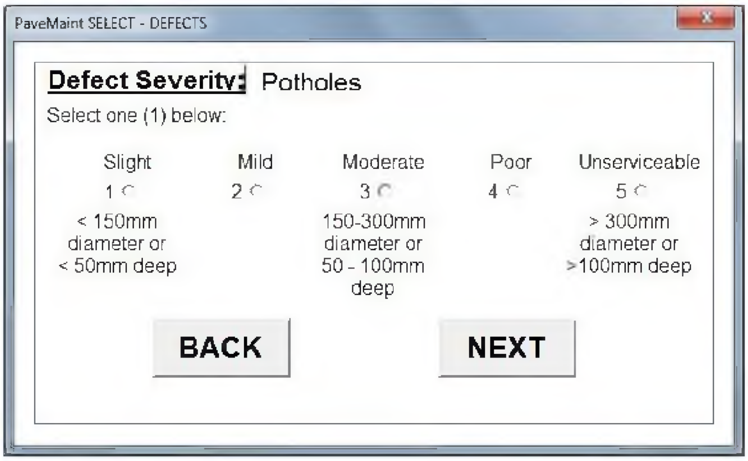


Figure B.27 – PaveMaint SELECT Defect Severity Selection for Potholes in Asphaltic Concrete and Bituminous Spray Sealed Pavements

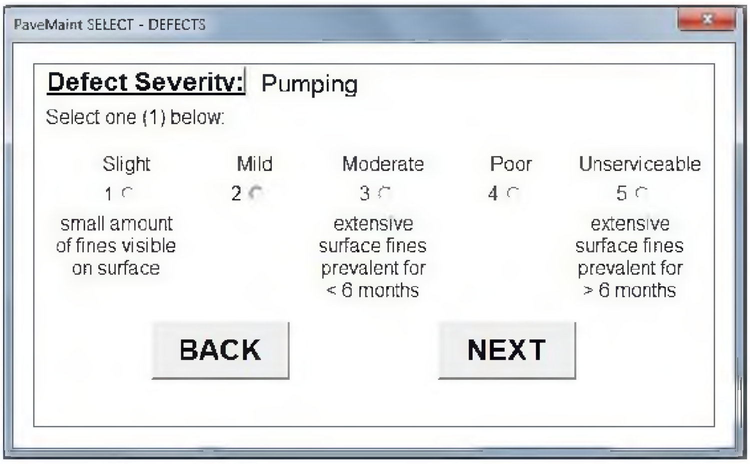


Figure B.28 – PaveMaint SELECT Defect Severity Selection for Pumping of Asphaltic Concrete and Bituminous Spray Sealed Pavements

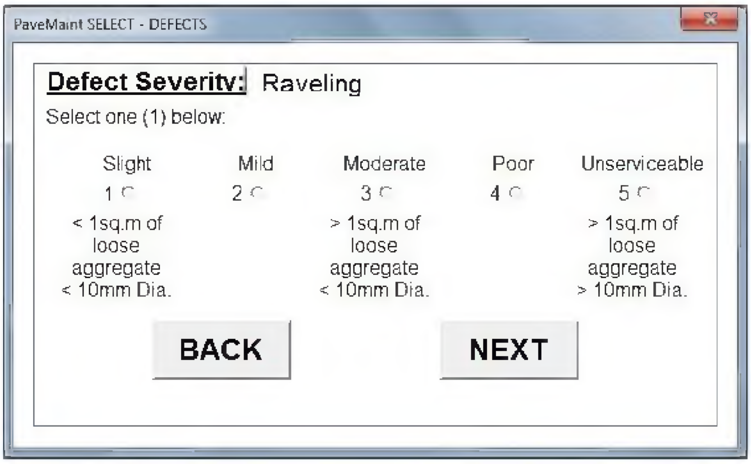


Figure B.29 – PaveMaint SELECT Defect Severity Selection for Raveling of Asphaltic Concrete and Bituminous Spray Sealed Surfaces

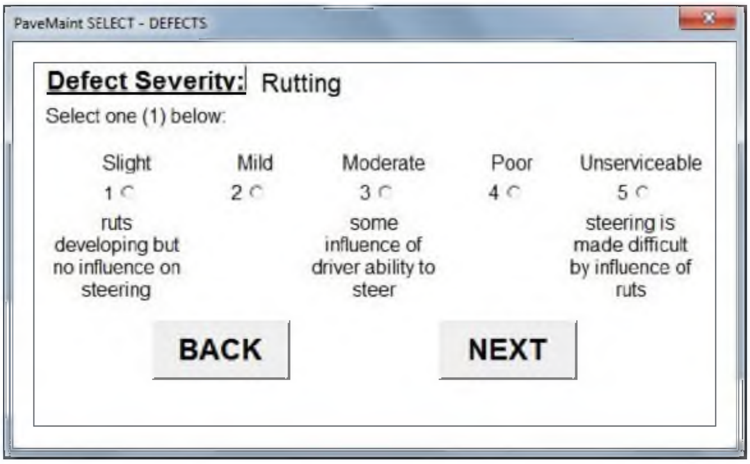


Figure B.30 – PaveMaint SELECT Defect Severity Selection for Rutting of Asphaltic Concrete and Bituminous Spray Sealed Pavements

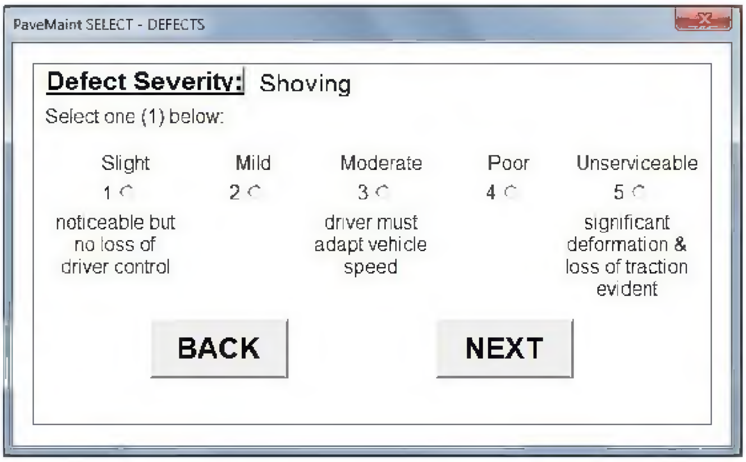


Figure B.31 – PaveMaint SELECT Defect Severity Selection for Shoving on Asphaltic Concrete and Bituminous Spray Sealed Pavements

Figure B.32 – PaveMaint SELECT Defect Severity Selection for Stripping on Asphaltic Concrete and Bituminous Spray Sealed Surfaces

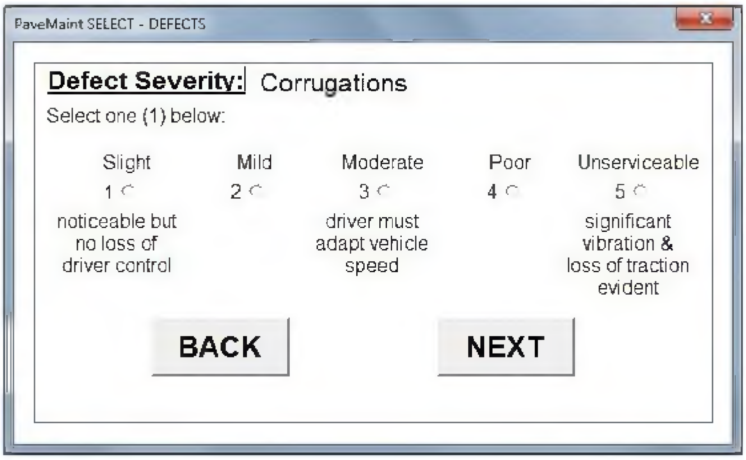


Figure B.33 – PaveMaint SELECT Defect Severity Selection for Corrugations on Unsealed Pavements

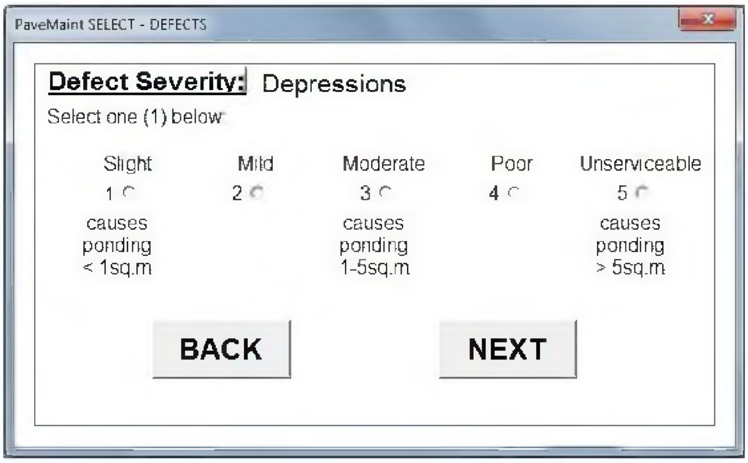


Figure B.34 – PaveMaint SELECT Defect Severity Selection for Depressions on Unsealed Pavements

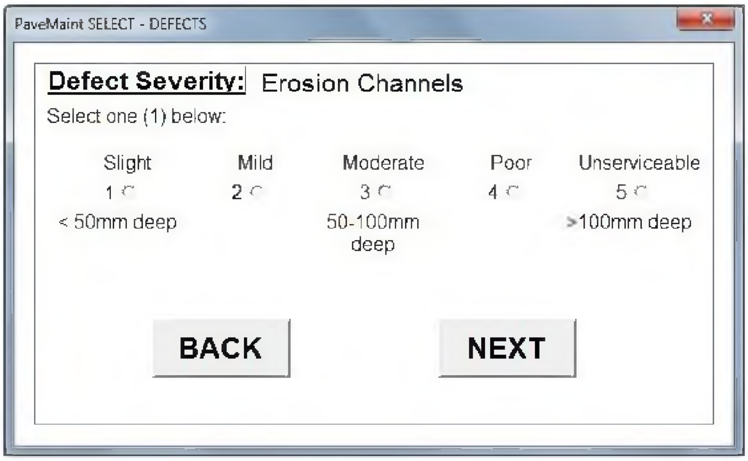


Figure B.35 – PaveMaint SELECT Defect Severity Selection for Erosion Channels on Unsealed Pavements

Figure B.36 – PaveMaint SELECT Defect Severity Selection for Loss of Fines on Unsealed Pavements

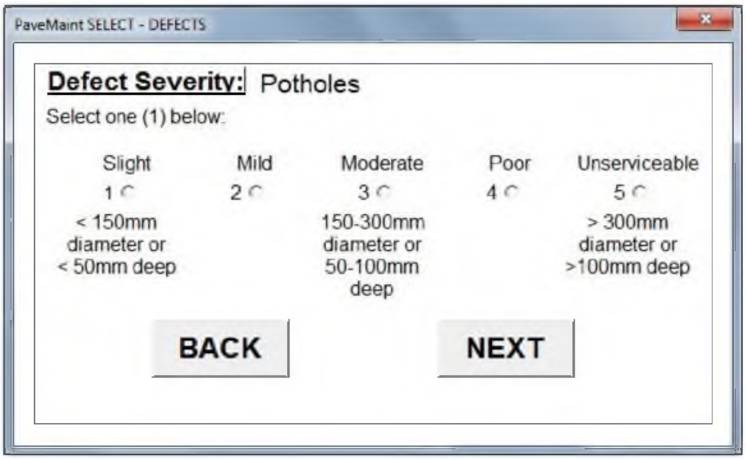


Figure B.37 – PaveMaint SELECT Defect Severity Selection for Potholes in Unsealed Pavements

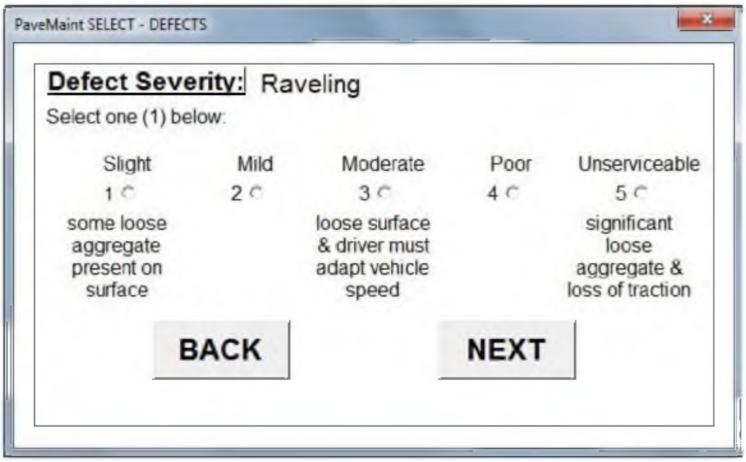


Figure B.38 – PaveMaint SELECT Defect Severity Selection for Raveling of Unsealed Pavements

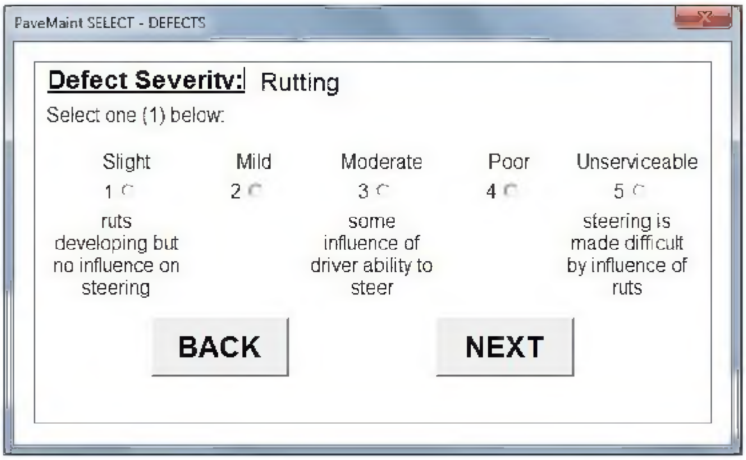


Figure B.39 – PaveMaint SELECT Defect Severity Selection for Rutting on Unsealed Pavements

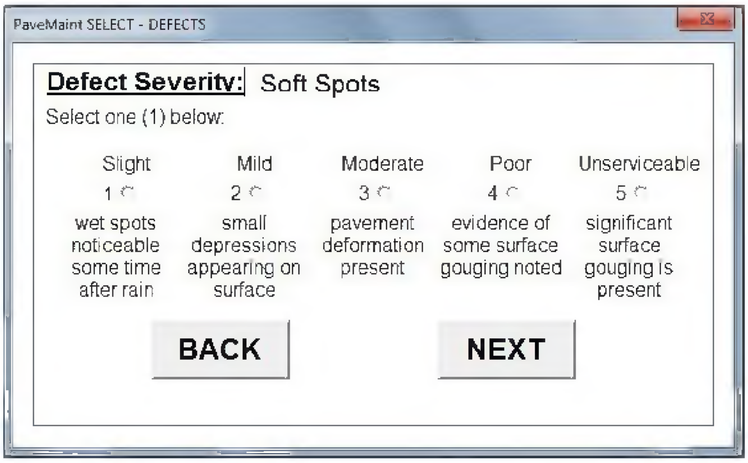


Figure B.40 – PaveMaint SELECT Defect Severity Selection for Soft Spots on Unsealed Pavements

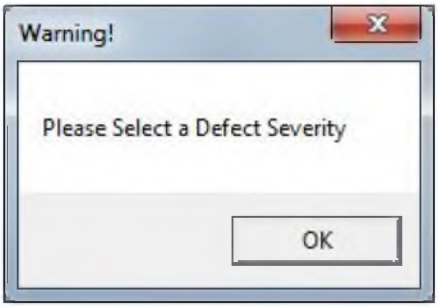


Figure B.41 – PaveMaint SELECT Warning Screen: Incomplete "Defect Severity" Form

B.7 User form - PaveMaint_Constrain1

B.7.1 Description:

- Userform where user nominates the importance of Cost and repair Longevity (Figure B.45)

B.7.2 Code Function:

- Upon click of “Next” button:
    - o Propagates a predetermined value between 1-10 to the “Results” worksheet in the MS Excel spreadsheet (B13 [Cost] & F13 [Longevity])
    - o Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure B.42 to Figure B.44)
    - o Hide current form and Show Constrain2 userform (No. B.8)
- Upon click of “Back” button:
    - o Hide and Unload Constrain1
    - o Show Severity

B.7.3 Accelerated Learning Tools:

- Incorporated into radio options which are descriptive and lead user to giving informed answers

B.7.4 Screen Shots:

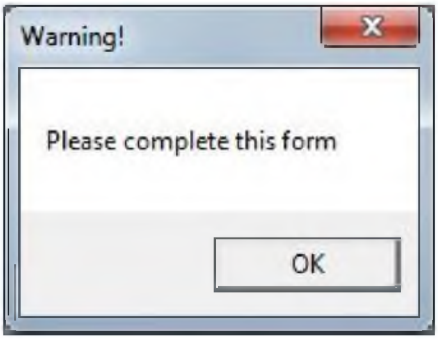


Figure B.42 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (1) Form (No Selection)

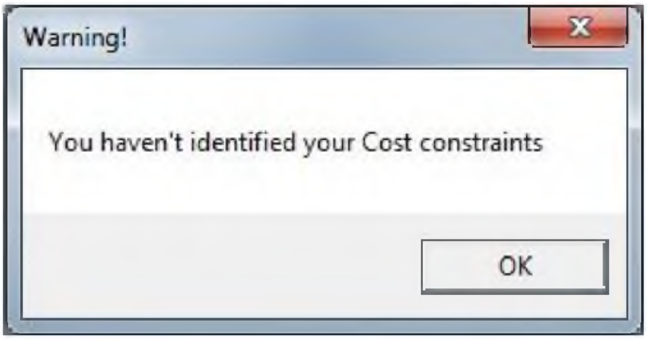


Figure B.43 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (1) Form (No Cost Constraint Selected)

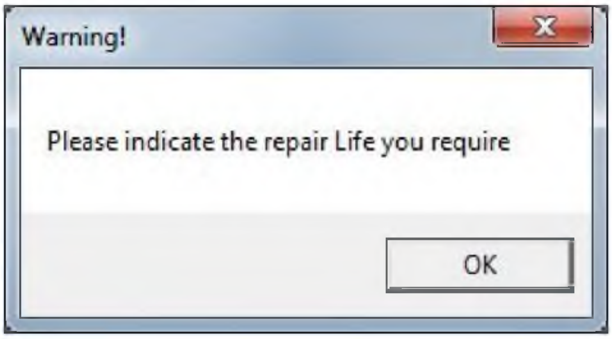


Figure B.44 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (1) Form (No Longevity Constraint Selected)

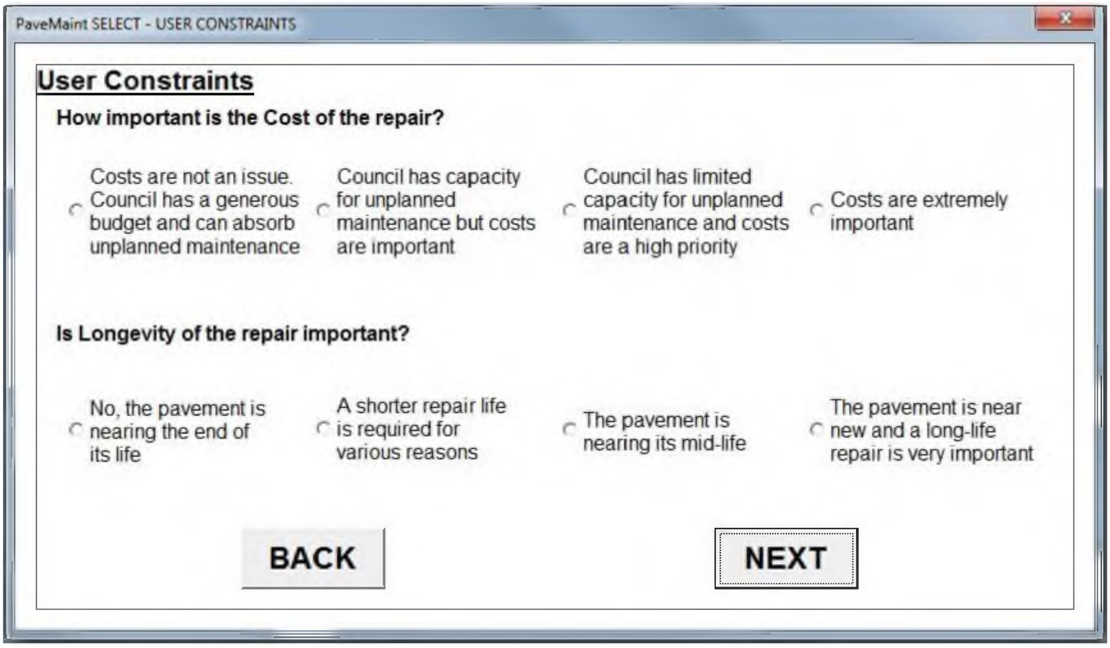


Figure B.45 – PaveMaint SELECT User Constraints (1) Selection Screen

B.8 User form - PaveMaint_Constrain2

B.8.1 Description:

- Userform where user nominates the importance of repair Time and Aesthetics (Figure B.49)

B.8.2 Code Function:

- Upon click of “Next” button:
  - Propagates a value between 1-10 to the “Results” worksheet in the MS Excel spreadsheet (H13 [Time] & J13 [Aesthetic])
  - Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure B.46 to Figure B.48)
  - Hide current form and Show Program End userform (No.9)
- Upon click of “Back” button:
  - Hide and Unload Constrain2
  - Show Severity

B.8.3 Accelerated Learning Tools:

- Incorporated into radio options which are descriptive and lead user to giving informed answers

B.8.4 Screen Shots:

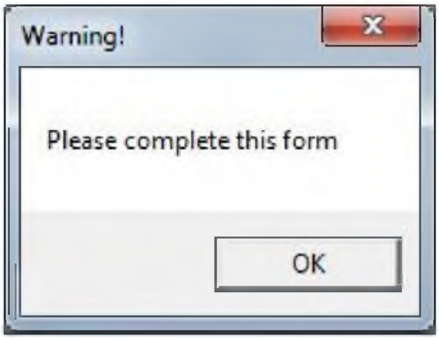


Figure B.46 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (2) Form (No Selection)

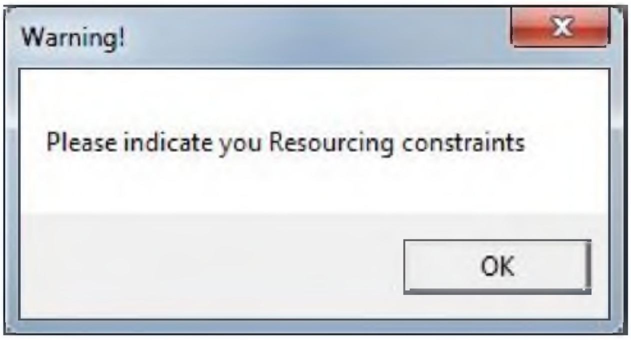


Figure B.47 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (2) Form (No Resource Constraint Selected)

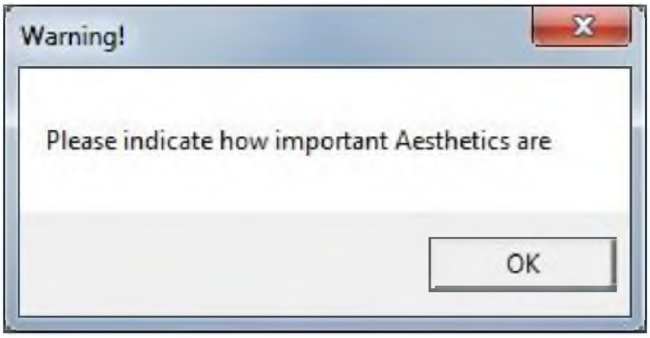


Figure B.48 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (2) Form (No Aesthetics Constraints Selected)

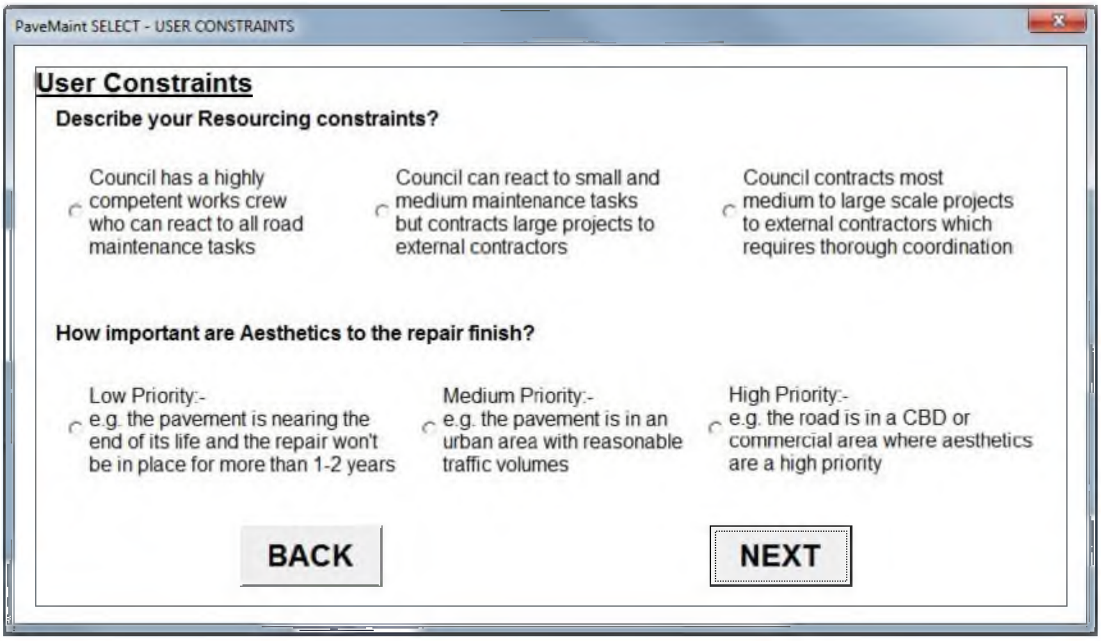


Figure B.49 – PaveMaint SELECT User Constraints (2) Selection Screen

B.9 User form - PaveMaint_End

B.9.1 Description:

- Userform informing that the program is finished and provides the user a chance to make any changes to their selections before progressing to the Solutions Sheet

B.9.2 Code Function:

- Upon click of "View Results" button:
  - o Performs a sorting function over the Solutions Sheet in the spreadsheet for the calculated results and weightings
  - o Performs a "Save As" operation for the workbook
  - o Hide current form and redirect user to spreadsheet with the Solutions Sheet shown
- Upon click of "Make Changes" button:
  - o Hide and Unload End
  - o Show Constrain2

B.9.3 Accelerated Learning Tools:

- Nil

B.9.4 Screen Shots:

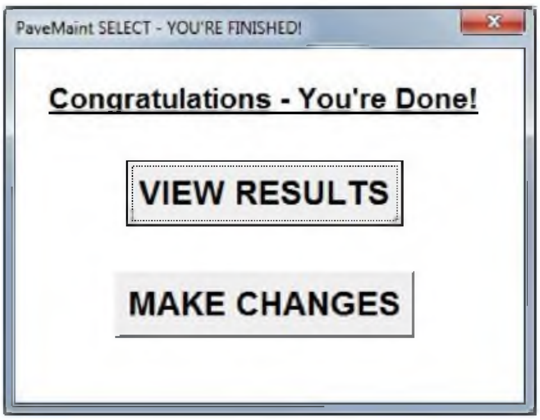


Figure B.50 – PaveMaint SELECT End of Program / View or Edit Results Screen

B.10 Worksheet - PaveMaint SELECT "StartUp"

B.10.1 Description:

- Sheet 1 of the PaveMaint SELECT spreadsheet file
- Provides a simple introduction screen and a "form control" button to launch the VBA program
- Sheet can be viewed and accessed by both the user and the administrator

B.10.2 Cells and Functionality

- Upon click of the "START" form control button, executes the "PaveMaintSelect" macro

B.10.3 Accelerated Learning Tools:

- Nil

B.10.4 Screen Shots:

Figure B.51 – PaveMaint SELECT "StartUp" Worksheet

B.11 Worksheet - PaveMaint SELECT "Results"

B.11.1 Description:

- Sheet 2 of the PaveMaint SELECT spreadsheet file
- Presents a data-sheet of all the information input through the VBA screens
- Presents a list of possible remediation options and scores against how they meet the user's nominated priorities
- Provides a recommendation of the most suitable remediation option based on the priorities nominated by the user
- Sheet size: Columns "A:S"; Rows "1:23"
- Sheet can be viewed and accessed by both the user and the administrator

B.11.2 Cells and Functionality

- All cells in the sheet are locked (cannot be edited) to preserve functionality with the exception of "B3:B5", "B15:B21", "F15:F21", "H15:H21" and "J15:J21"
- Columns "C:E", "G", "I", "K", "L" and "N:S" are hidden and locked and are not to be edited by the administrator
- Cells "J1", "A2:M2", "A3:A10", "J8:M8", "A12:M12", "A13", "M13:M14" and "B14:J14" provide headings for the columns of information stored below or adjacent to them
- Cell "M1" displays the date when the VBA macro program was run; that is, when the defect assessment is undertaken
- Cells "B3:B8" and "J7" displays the information input by the user in the first 6 VBA user forms (see B.1 to B.6 earlier)
- Cells "B13", "F13", "H13" and "J13" display a numeric representation of the user constraints selections from the VBA user forms (see B.7 and B.8) earlier
- Cell "A14" displays a form control button labelled "Edit Importance Factors" that allows the user to adjust the relative weighting of user constraints. Upon click:
    - o Provides a user screen with 4 text boxes to allow user to numerically enter the weight of the constraint between 1 and 10 (see Figure B.54)
    - o Upon click of "View Results"
        - ▪ If user has input numbers outside the range of 1 to 10, a warning screen is displayed (see Figure B.55)
        - ▪ Cells "B13", "F13", "H13" and "J13" are updated with the refined constraint weightings
        - ▪ Performs a sorting function over the Solutions Sheet in the spreadsheet for the calculated results and weightings
        - ▪ Performs a save operation for the workbook
        - ▪ Hide current form and redirect user to spreadsheet with the Solutions Sheet shown

- Cells “B15:B21”, “D15:21”, “F15:F21”, “H15:H21” and “J15:J21” display each of the individual remediation option’s performance against each of user constraints, using the typical Equation B.1 (shown for cell “B15”) to reference both the corresponding row in column “A” and the corresponding hidden cell in column “C”, “G”, “I” and “K” respectively

$$= IF(\$A15 = \text{""}, \text{""}, C15)$$

Equation B.1

- Cells “M15:21” display the overall percentage score for each remediation option using the typical equation, Equation B.2 (shown for cell “M15”) that references the corresponding hidden cells in column “L”. Cells are formatted to show percentage

$$= IF(ISERROR(L15) = TRUE, 0, L15)$$

Equation B.2

- Cells “C15:21”, “E15:21”, “G15:21”, “I15:21” and “K15:21” contain lookup formulas (Equation B.3 provides the typical equation, shown for cell “C15”) to reference the relative data from the respective knowledgebase worksheets (see sections B.15, B.12 and B.13)

$$= \left(\begin{array}{c} IF(\$B\$6 = AsphKnowledgeBase!\,\$B\$1, \\ VLOOKUP(\$A15, AsphKnowledgeBase!\,\$B\$34{:}\,\$L\$45,3, FALSE), \\ IF(\$B\$6 = BitKnowledgeBase!\,\$B\$1, \\ VLOOKUP(\$A15, BitKnowledgeBase!\,\$B\$34{:}\,\$L\$45,3, FALSE), \\ IF(\$B\$6 = UnSeaKnowledgeBase!\,\$B\$1, \\ VLOOKUP(\$A15, UnSeaKnowledgeBase!\,\$B\$34{:}\,\$L\$45,3, FALSE), \\ \text{"}ERROR\text{"}))) \end{array} \right)$$

Equation B.3

- Cells “L15:21” normalise each remediation option’s performance against the user constraints against the optimum performing value which is then multiplied by the importance factor for each constraint. Equation B.4 provides the typical equation, shown for cell “L15”

$$
= \left(\begin{array}{c} \left(\left(\frac{MIN(\$B\$15:\$B\$21)}{B15} \right) \$B\$13 \right) + \\ \left(\left(\frac{D15}{MAX(\$D\$15:\$D\$21)} \right) \$D\$13 \right) + \\ \left(\left(\frac{F15}{MAX(\$F\$15:\$F\$21)} \right) \$F\$13 \right) + \\ \left(\left(\frac{MIN(\$H\$15:\$H\$21)}{H15} \right) \$H\$13 \right) + \\ \left(\left(\frac{J15}{MAX(\$J\$15:\$J\$21)} \right) \$J\$13 \right) \end{array} \right) \div SUM(\$B\$13:\$J\$13)
$$

Equation B.4

- Cells “O15:21” provide a rank for each of the remediation option overall scores from cells “M15:21” using Equation B.5 which shows the typical equation (shown for cell “O15”)

$$
= RANK(M15, \$M\$15:\$M\$21,0)
$$

Equation B.5

- Cells “P15:21” provide a rank against the highest priority importance criteria (given in cells “B13”, “F13”, “H13” and “J13”) for the remediation option criteria scores from cell range “B15:J21” using Equation B.6 which shows the typical equation (shown for cell “P15”)

$$
= \left(\begin{array}{c} IF(\$B\$13 = MAX(\$B\$13, \$F\$13, \$H\$13, \$J\$13), \\ \left(RANK.EQ(B15, \$B\$15:\$B\$21,1)\right), \\ IF(\$F\$13 = MAX(\$B\$13, \$F\$13, \$H\$13, \$J\$13), \\ RANK.EQ(F15, \$F\$15:\$F\$21,0), \\ IF(\$H\$13 = MAX(\$B\$13, \$F\$13, \$H\$13, \$J\$13), \\ RANK.EQ(H15, \$H\$15:\$H\$21,1), \\ RANK.EQ(J15, \$J\$15:\$J\$21,0)))) \end{array} \right)
$$

Equation B.6

- Cells “Q15:21” sum the rank of the corresponding cells in column “O” and “P” if column “O” returns a value of 1, otherwise gives a value of 11 to 17 respectively from row “15:17” using Equation B.7 which shows the typical equation (shown for cell “Q15”)

$$= IF(O15 = 1, SUM(O15{:}P15), 11)$$

Equation B.7

- Cells “R15:21” provide a rank for each of the results from cells “Q15:21” using Equation B.8 which shows the typical equation (shown for cell “R15”)

$$= ROUNDDOWN\left((RANK.EQ(Q15, \$Q\$15{:}\,\$Q\$21,1)), 1\right)$$

Equation B.8

- Cells “S15:21” display (duplicate) the text of the remediation options shown in the corresponding rows of column “A”
- Cell “F10” displays the highest ranked remediation option (or if none shown, displays text “No Action - Monitor Defect”) formulated in accordance with Equation B.9

$$= \left(\begin{array}{l} IF(A15 = \text{""}, \text{"}No\ Action\ -\ Monitor\ Defect\text{"}, \\ \quad IF(R15 = 1, S15, IF(R16 = 1, S16, \\ \quad IF(R17 = 1, S17, IF(R18 = 1, S18, \\ \quad IF(R19 = 1, S19, IF(R20 = 1, S20, \\ \quad IF(R21 = 1, S21, \text{"}ERROR\text{"}))))))) \end{array} \right)$$

Equation B.9

B.11.3 Accelerated Learning Tools:

- Nil

B.11.4 Screen Shots:

Date of Assessment: 13/09/2014

PaveMaint SELECT - Solutions Sheet

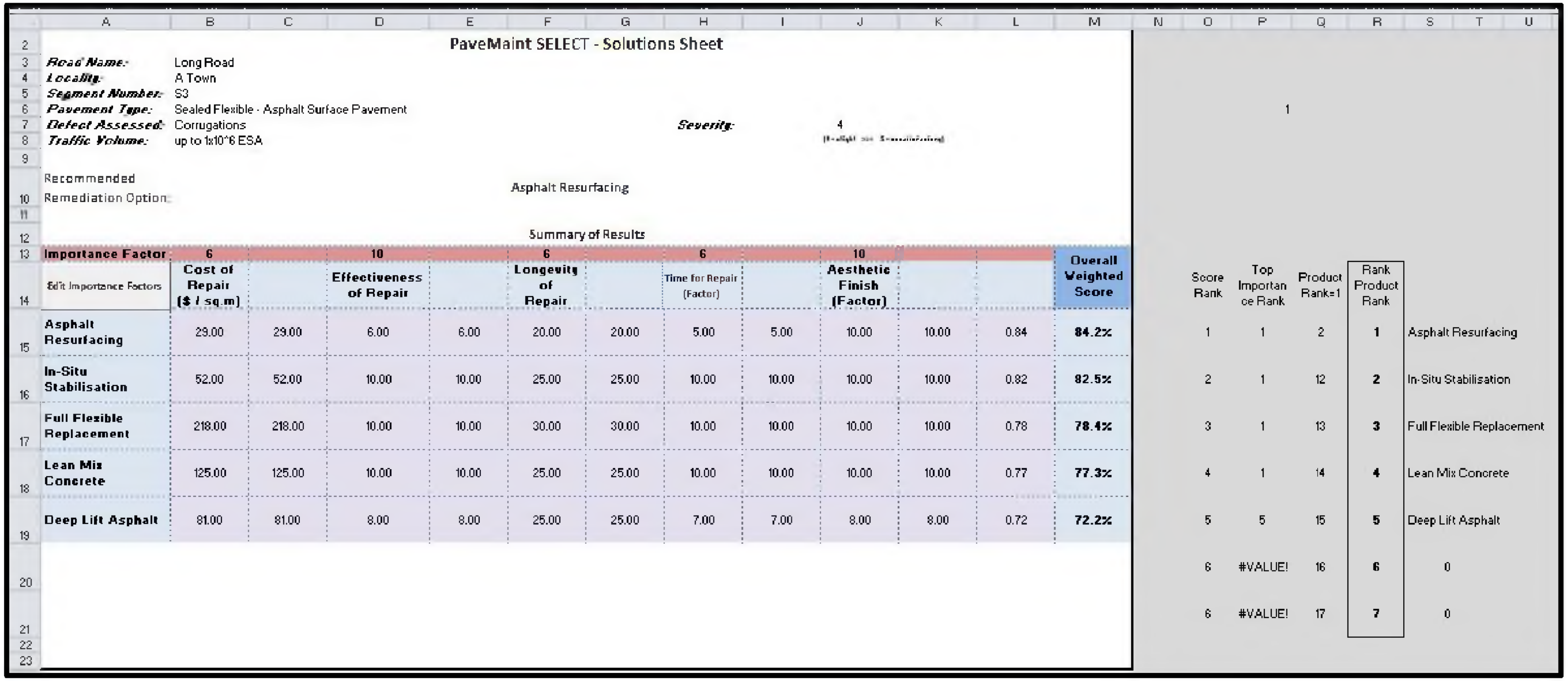
Road Name: Long Road
Locality: A Town
Segment Number: S3
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Corrugations *Severity:* 4
Traffic Volume: up to 1x10^6 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	6	6	6	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	20.00	5.00	10.00	81.8%
In-Situ Stabilisation	52.00	25.00	10.00	10.00	79.8%
Full Flexible Replacement	218.00	30.00	10.00	10.00	75.1%
Lean Mix Concrete	125.00	25.00	10.00	10.00	73.9%
Deep Lift Asphalt	81.00	25.00	7.00	8.00	71.0%

Figure B.52 – PaveMaint SELECT “Results” Worksheet User Access View



PaveMaint SELECT - Solutions Sheet

Road Name: Long Road
Locality: A Town
Segment Number: S3
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Corrugations ***Severity:*** 4
Traffic Volume: up to 1x10^6 ESA

Recommended Remediation Option: Asphalt Resurfacing

Summary of Results

Importance Factor	6		10		6		6		10				Score Rank	Top Importance Rank	Product Rank=1	Rank Product Rank	
Edit Importance Factors	Cost of Repair ($ / sq.m)		Effectiveness of Repair		Longevity of Repair		Time for Repair (Factor)		Aesthetic Finish (Factor)			Overall Weighted Score					
Asphalt Resurfacing	29.00	29.00	6.00	6.00	20.00	20.00	5.00	5.00	10.00	10.00	0.84	84.2%	1	1	2	1	Asphalt Resurfacing
In-Situ Stabilisation	52.00	52.00	10.00	10.00	25.00	25.00	10.00	10.00	10.00	10.00	0.82	82.5%	2	1	12	2	In-Situ Stabilisation
Full Flexible Replacement	218.00	218.00	10.00	10.00	30.00	30.00	10.00	10.00	10.00	10.00	0.78	78.4%	3	1	13	3	Full Flexible Replacement
Lean Mix Concrete	125.00	125.00	10.00	10.00	25.00	25.00	10.00	10.00	10.00	10.00	0.77	77.3%	4	1	14	4	Lean Mix Concrete
Deep Lift Asphalt	81.00	81.00	8.00	8.00	25.00	25.00	7.00	7.00	8.00	8.00	0.72	72.2%	5	5	15	5	Deep Lift Asphalt
													6	#VALUE!	16	6	0
													6	#VALUE!	17	7	0

Figure B.53 – PaveMaint SELECT "Results" Worksheet Administrator Access View

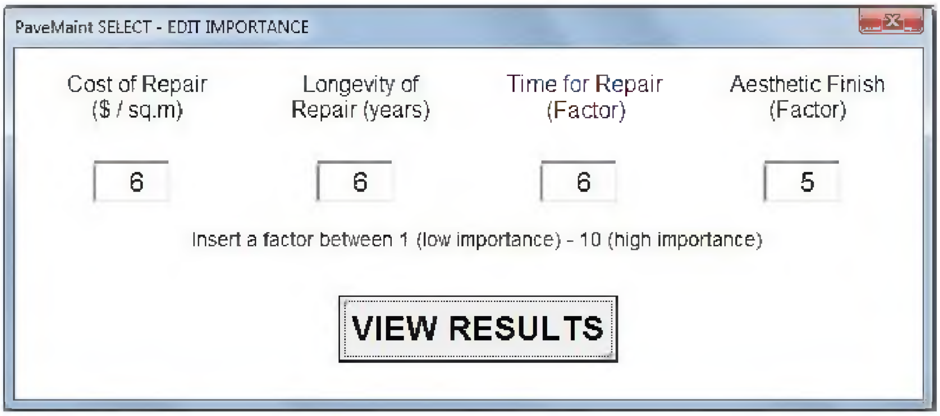


Figure B.54 – PaveMaint SELECT "Results" Worksheet – "Edit Importance Factors" User Form

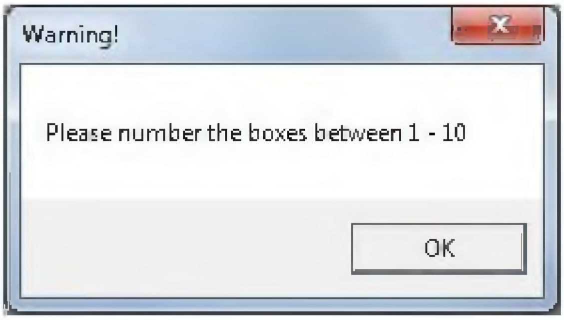


Figure B.55 – PaveMaint SELECT Warning Screen: "Edit Importance Factors" Invalid Numerical Value Input

B.12 Worksheet - PaveMaint SELECT "AsphKnowledgeBase"

B.12.1 Description:

- Sheet 3 of the PaveMaint SELECT spreadsheet file
- Holds information for asphaltic concrete surfaced pavements only
- Contains a list of all the possible defect types, a description of the defect severities, references the list of the possible remediation options (from the "RemedyKnowledgeBase" worksheet") applicable for that pavement type only and provides scoring and weighting for all user constraint fields
- Sheet size: Columns "A:AB"; Rows "1:55"
- Sheet is hidden from users of the program. The organisation's administrator can unprotect the spreadsheet and unhide the worksheet to be able to access it

B.12.2 Cells and Functionality

- Rows "2:3", "21", "31:32", "46" and "55" as well as column "M" are empty cells formatted grey to provide a table break and clear visual delineation of the data presented
- Rows "1", "4", "22", "33" and "47" are heading rows and are used by other cells in lookup functions
- Cells "A5:A20" and "A23:30" display reference numbers for the individual defect types. The numbers provide a visual unique identity for the administrator but do not serve a function in the program
- Cells in columns "C", "E", "G", "I" and "K" between rows "5:20" and "23:30" provide numeric representations of the 5 severity levels
- Cells in columns "D", "F", "H", "J" and "L" between rows "5:20" and "23:30" provide descriptions of what the severity level means for each defect type
- Cells "B34:B43" display the possible remediation options available for the pavement type
- Cells in columns "O", "Q", "S", "U", "W", "Y" and "AA" between rows "5:20" and "23:30" display the suitable remediation options for the corresponding defect type.
    - o The cells contain a conditional formula that displays a blank cell for severities less than a value of 2 (that is, considered slight) unless the user has nominated aesthetics to be of high importance (greater than a value of 8). Equation B.10 provides an example for the "Asphalt Resurfacing" remediation option in the treatment of "Aggregate Polishing"

$$= IF\left(Results!\,\$J\$13 > 8, B34, IF(Results!\,\$J\$7 < 2, "", B34)\right)$$

Equation B.10

- Cells “O29”, “Q6”, “Q8”, “Q16”, “S9”, “S15”, “U6”, “U8”, “U9”, “U10”, “U16”, “U23”, “U25”, “U27”, “W6”, “W10”, “W23”, ‘W25”, “W26”, “W27”, “W28”, “Y10”, “Y23”, “Y24”, “Y25”, “Y26”, “Y28”, “AA23”, “AA24”, “AA26” and “AA28” display remediation options that require more substantial disturbance to the existing pavement and therefore the severity value in Equation B.10 is 4 (instead of 2) as it is not considered that such a significant repair would be undertaken unless the pavement is in poor or unserviceable condition.
- Cells “Q23”, “Q25”, “Q27”, “Q29”, “S26”, “S28” and “U24” represent the “Crack Sealing” remediation option which is considered to have poor performance for aesthetics and is therefore pruned from selection if aesthetic importance is high (greater than a value of 8). The formula for this option is given in Equation B.11 for the example of the treatment of “Block Cracking”

$$= IF\left(Results!\,\$J\$7 < 2, "", IF(Results!\,\$J\$13 > 8, "", B38)\right)$$

Equation B.11

- Cells in columns “N”, “P”, “R”, “T”, “V”, “X” and “Z” between rows “5:20” and “23:30” display a factor representing the effectiveness of the respective remediation option in providing a repair to the respective defect type
- Cells “D34:D45” display the adjusted cost for each remediation option, referencing the “RemedyKnowledgeBase” worksheet (see B.15 above) using the formula outlined in Equation B.12 for the example of Asphalt Resurfacing

$$= VLOOKUP(B34, RemedyKnowledgeBase!\,\$B\$4{:}\,\$D\$23, 3, FALSE)$$

Equation B.12

- Cells “H34:H45” display the anticipated longevity for each remediation option in years
- Cells “J34:J45” display a factor between 1 to 10 representing the time taken to mobilise plant, equipment and materials to undertake the repair for each remediation option. A factor of 1 represents a fast repair while a factor of 10 requires a large amount of time to plan the repair
- Cells “L34:L45” display a factor between 1 to 10 representing the aesthetic appearance of each completed remediation option. A factor of 10 represents high aesthetic appeal, while a factor of 1 represents a low aesthetic appeal
- Cell “B48” identifies what defect is being assessed via the lookup function shown in Equation B.13 referencing the “Results” worksheet

$$= IF(B1 = Results!\,\$B\$6, VLOOKUP(Results!\,B7, B5{:}B30, 1, FALSE), 0)$$

Equation B.13

- Cells “D48:D54” display the remediation options available to treat the defect displayed in cell “B48” via a lookup function referencing the cells in columns “O”, “Q”, “S”, “U”, “W”, “Y” and “AA” between rows “5:20” and “23:30” via the example lookup function shown in Equation B.14

$$= IF\begin{pmatrix} VLOOKUP(\$B\$48, \$B\$5:\$AB\$30,14, FALSE) = 0, "", \\ VLOOKUP(\$B\$48, \$B\$5:\$AB\$30,14, FALSE) \end{pmatrix}$$

Equation B.14

- Cells “E48:E54” display the factor of effectiveness of the remediation options to treat the defect displayed in cell “B48” via a lookup function referencing the cells in columns “N”, “P”, “R”, “T”, “V”, “X” and “Z” between rows “5:20” and “23:30” via the example lookup function shown in Equation B.15

$$= IF\begin{pmatrix} VLOOKUP(\$B\$48, \$B\$5:\$AB\$30,13, FALSE) = 0, "", \\ VLOOKUP(\$B\$48, \$B\$5:\$AB\$30,13, FALSE) \end{pmatrix}$$

Equation B.15

B.12.3 Screen Shots:

Sealed Flexible - Asphalt Surface Pavement

Asphalt Surface	*Severities*				
1 Aggregate Polishing	1 small, infrequent areas of polishing commencing	2	3 large areas of polishing evident	4	5 smooth, shiny surface for majority of segment
2 Corrugations	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant vibration & loss of traction evident
3 Raveling	1 < 1sq.m of loose aggregate < 10mm Dia	2	3 > 1sq.m of loose aggregate < 10mm Dia	4	5 > 1sq.m of loose aggregate > 10mm Dia
4 Potholes	1 < 150mm diameter or < 50mm deep	2	3 150-300mm diameter or 50 - 100mm deep	4	5 > 300 mm diameter or >100mm deep
5 Depressions	1 causes ponding < 1sq.m	2	3 causes ponding 1 - 5sq.m	4	5 causes ponding > 5sq.m
6 Rutting	1 ruts developing but no influence on steering	2	3 some influence of driver ability to steer	4	5 steering is made difficult by influence of ruts
7 Edge Break	1 fraying of edge but no reduction in lane width	2	3 reduced lane width, drop-off < 50mm	4	5 reduced lane width, drop-off > 50mm
8 Oxidation	1 ageing of surface visible by discolouration only	2	3 discolouration combined with cracks commencing	4	5 cracking and surface aggregate loss evident
9 Pumping	1 small amount of fines visible on surface	2	3 extensive surface fines prevalent for < 6 months	4	5 extensive surface fines prevalent for > 6 months
10 Delamination	1 < 0.5 sq.m	2	3 0.5 - 1 sq.m	4	5 > 1 sq.m
11 Patching Failure	1 < 25mm drop off	2	3 25 - 50mm drop off	4	5 > 50mm drop off
12 Shoving	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant deformation & loss of traction evident
13 Stripping	1 < 10% affected area	2 10% - 30% affected area	3 30% - 50% affected area	4 50%- 70% affected area	5 > 70% affected area
14 Cracking	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5

	Cracking					
14.1	Block Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.2	Crocodile Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.3	Diagonal Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.4	Longitudinal Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.5	Meandering Cracks	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.6	Transverse Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.7	Crescent-Shaped Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.8		1	2	3	4	5

Remediation Options	Cost of Repair ($ / sq.m) x 3.5% CPI from year 2013	Effectiveness of Repair	Longevity of Repair (years) (max. years)	Speed of Repair (Factor) (> = longest time to repair /10)	Aesthetic Finish(Factor) (> = greater aesthetics /10)
Asphalt Resurfacing	29.00		20	5	10
Hot/Cold Mix Asphalt Patching	26.00		2	1	2
Spray Seal	16.00		10	5	8
Slurry Seal	9.00		8	5	7
Crack Sealing	13.00		3	2	2
Rejuvenation Seal	6.00		5	5	7
Full Flexible Replacement	218.00		30	10	10
Deep Lift Asphalt	81.00		25	7	8
In-Situ Stabilisation	52.00		25	10	10
Lean Mix Concrete	125.00		25	10	10
	#N/A				
	#N/A				

Transpose Effectiveness	*Transpose Effectiveness*	
Corrugations	Asphalt Resurfacing	6
	Full Flexible Replacement	10
	Deep Lift Asphalt	8
	In-Situ Stabilisation	10
	Lean Mix Concrete	10

Figure B.56 – PaveMaint SELECT “AsphKnowledgeBase” Worksheet (Columns “A:L”)

Remediation Options and their Effectiveness (>= more effective /10)

10 Asphalt Resurfacing	10 Spray Seal	7 Slurry Seal				
6 Asphalt Resurfacing	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation	10 Lean Mix Concrete		
10 Asphalt Resurfacing	8 Slurry Seal	6 Rejuvenation Seal	Spray Seal			
5 Hot/Cold Mix Asphalt Patching	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation			
8 Hot/Cold Mix Asphalt Patching	10 Full Flexible Replacement	10 In-Situ Stabilisation	10 Lean Mix Concrete			
6 Asphalt Resurfacing	6 Hot/Cold Mix Asphalt Patching	5 Slurry Seal	10 Full Flexible Replacement	10 In-Situ Stabilisation	10 Lean Mix Concrete	
8 Hot/Cold Mix Asphalt Patching						
10 Asphalt Resurfacing	10 Spray Seal	8 Slurry Seal	7 Rejuvenation Seal			
10 Full Flexible Replacement	10 In-Situ Stabilisation					
10 Asphalt Resurfacing	7 Spray Seal					
7 Asphalt Resurfacing	5 Hot/Cold Mix Asphalt Patching	10 Full Flexible Replacement	7 Deep Lift Asphalt			
6 Hot/Cold Mix Asphalt Patching	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation			
10 Asphalt Resurfacing	10 Spray Seal					
5 Slurry Seal	7	5 Rejuvenation Seal	10 Full Flexible Replacement	10 Deep Lift Asphalt	10 In-Situ Stabilisation	10 Lean Mix Concrete
8 Asphalt Resurfacing	6 Hot/Cold Mix Asphalt Patching	5 Slurry Seal	6	5 Rejuvenation Seal	10 Full Flexible Replacement	10 In-Situ Stabilisation
8 Asphalt Resurfacing	7	5 Rejuvenation Seal	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation	
8 Asphalt Resurfacing	6 Slurry Seal	7	6 Rejuvenation Seal	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation
8 Asphalt Resurfacing	7	6 Rejuvenation Seal	10 Full Flexible Replacement	10 Lean Mix Concrete		
8 Asphalt Resurfacing	6 Slurry Seal	7	6 Rejuvenation Seal	10 Full Flexible Replacement	9 Deep Lift Asphalt	10 In-Situ Stabilisation
7 Hot/Cold Mix Asphalt Patching	5	7 Rejuvenation Seal				

Figure B.57 – PaveMaint SELECT “AsphKnowledgeBase” Worksheet (Columns “M:AB”)

B.13 Worksheet - PaveMaint SELECT "BitKnowledgeBase"

B.13.1 Description:

- Sheet 4 of the PaveMaint SELECT spreadsheet file
- Holds information for bituminous spray sealed pavements only
- Contains a list of all the possible defect types, a description of the defect severities, references the list of the possible remediation options (from the "RemedyKnowledgeBase" worksheet") applicable for that pavement type only and provides scoring and weighting for all user constraint fields
- Sheet size: Columns "A:AB"; Rows "1:55"
- Sheet is hidden from users of the program. The organisation's administrator can unprotect the spreadsheet and unhide the worksheet to be able to access it

B.13.2 Cells and Functionality

- Rows "2:3", "21", "31:32", "46" and "55" as well as column "M" are empty cells formatted grey to provide a table break and clear visual delineation of the data presented
- Rows "1", "4", "22", "33" and "47" are heading rows and are used by other cells in lookup functions
- Cells "A5:A20" and "A23:30" display reference numbers for the individual defect types. The numbers provide a visual unique identity for the administrator but do not serve a function in the program
- Cells in columns "C", "E", "G", "I" and "K" between rows "5:20" and "23:30" provide numeric representations of the 5 severity levels
- Cells in columns "D", "F", "H", "J" and "L" between rows "5:20" and "23:30" provide descriptions of what the severity level means for each defect type
- Cells "B34:B43" display the possible remediation options available for the pavement type
- Cells in columns "O", "Q", "S", "U", "W", "Y" and "AA" between rows "5:20" and "23:30" display the suitable remediation options for the corresponding defect type.
    - o The cells contain a conditional formula (Equation B.10) that displays a blank cell for severities less than a value of 2 (that is, considered slight) unless the user has nominated aesthetics to be of high importance (greater than a value of 8).
    - o Cells "O5:7", "O10", "O12", "O14:15", "O24:28", "Q6", "Q8", "Q16", "S9", "S15", "U6", "U8", "U9", "U10", "U16", "U23", "U25", "U27", "W6", "W10", "W23", "W25", "W26", "W27", "W28", "Y10", "Y23", "Y24", "Y25", "Y26", "Y28", "AA23", "AA24", "AA26" and "AA28" display remediation options that require more substantial disturbance to the existing pavement and therefore the severity value in Equation B.10 is 4 (instead of 2) as it is

not considered that such a significant repair would be undertaken unless the pavement is in poor or unserviceable condition.

- Cells "Q23", "Q25", "Q27", "S26", "S28" and "U24" represent the "Crack Sealing" remediation option which is considered to have poor performance for aesthetics and is therefore pruned from selection if aesthetic importance is high (greater than a value of 8). The formula for this option is given in Equation B.11

- Cells in columns "N", "P", "R", "T", "V", "X" and "Z" between rows "5:20" and "23:30" display a factor representing the effectiveness of the respective remediation option in providing a repair to the respective defect type
- Cells "D34:D45" display the adjusted cost for each remediation option, referencing the "RemedyKnowledgeBase" worksheet (see B.15 above) using the formula outlined in Equation B.12 for the example of Asphalt Resurfacing
- Cells "H34:H45" display the anticipated longevity for each remediation option in years
- Cells "J34:J45" display a factor between 1 to 10 representing the time taken to mobilise plant, equipment and materials to undertake the repair for each remediation option. A factor of 1 represents a fast repair while a factor of 10 requires a large amount of time to plan the repair
- Cells "L34:L45" display a factor between 1 to 10 representing the aesthetic appearance of each completed remediation option. A factor of 10 represents high aesthetic appeal, while a factor of 1 represents a low aesthetic appeal
- Cell "B48" identifies what defect is being assessed via the lookup function shown in Equation B.13 referencing the "Results" worksheet
- Cells "D48:D54" display the remediation options available to treat the defect displayed in cell "B48" via a lookup function referencing the cells in columns "O", "Q", "S", "U", "W", "Y" and "AA" between rows "5:20" and "23:30" via the example lookup function shown in Equation B.14
- Cells "E48:E54" display the factor of effectiveness of the remediation options to treat the defect displayed in cell "B48" via a lookup function referencing the cells in columns "N", "P", "R", "T", "V", "X" and "Z" between rows "5:20" and "23:30" via the example lookup function shown in Equation B.15

B.13.3 Screen Shots:

Sealed Flexible - Bituminous Spray Seal Surface Pavement

Bituminous Spray Seal Surface	*Severities*				
1 Aggregate Polishing	1 small, infrequent areas of polishing commencing	2	3 large areas of polishing evident	4	5 smooth, shiny surface for majority of segment
2 Corrugations	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant vibration & loss of traction evident
3 Raveling	1 < 1sq.m of loose aggregate < 10mm Dia.	2	3 > 1sq.m of loose aggregate < 10mm Dia.	4	5 > 1sq.m of loose aggregate > 10mm Dia.
4 Potholes	1 < 150mm diameter or < 50mm deep	2	3 150-300mm diameter or 50-100mm deep	4	5 > 300mm diameter or >100mm deep
5 Depressions	1 causes ponding < 1sq.m	2	3 causes ponding 1-5sq.m	4	5 causes ponding > 5sq.m
6 Rutting	1 ruts developing but no influence on steering	2	3 some influence of driver ability to steer	4	5 steering is made difficult by influence of ruts
7 Edge Break	1 fraying of edge but no reduction in lane width	2	3 reduced lane width, drop off < 50mm	4	5 reduced lane width, drop off > 50mm
8 Oxidation	1 ageing of surface visible by discolouration only	2	3 discolouration combined with cracks commencing	4	5 cracking and surface aggregate loss evident
9 Pumping	1 small amount of fines visible on surface	2	3 extensive surface fines prevalent for < 6 months	4	5 extensive surface fines prevalent for > 6 months
10 Flushing	1 < 10% affected area	2 10% - 30% affected area	3 30% - 50% affected area	4 50% - 70% affected area	5 > 70% affected area
11 Patching Failure	1 < 25mm drop off	2	3 25 - 50mm drop off	4	5 > 50mm drop off
12 Shoving	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant deformation & loss of traction evidem
13 Stripping	1 < 10% affected area	2 10% - 30% affected area	3 30% - 50% affected area	4 50% - 70% affected area	5 > 70% affected area
14 Cracking	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5

Cracking

14.1	Block Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.2	Crocodile Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.3	Diagonal Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.4	Longitudinal Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.5	Meandering Cracks	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.6	Transverse Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.7		1	2	3	4	5
14.8		1	2	3	4	5

Remediation Options	*Cost of Repair ($ / sq.m) x 3.5% CPI from year 2013*	Effectiveness of Repair	Longevity of Repair (years) (max. years)	Speed of Repair (Factor) (> = longest time to repair /10)	Aesthetic Finish (Factor) (> = greater aesthetics /10)
Asphalt Resurfacing	29.00		25	5	10
Hot/Cold Mix Asphalt Patching	26.00		2	1	2
Spray Seal	16.00		15	5	8
Slurry Seal	9.00		10	5	7
Crack Sealing	13.00		5	2	2
Rejuvenation Seal	6.00		5	5	7
Full Flexible Replacement	210.00		30	10	10
Deep Lift Asphalt	81.00		25	7	8
In-Situ Stabilisation	52.00		25	10	10
Lean Mix Concrete	125.00		25	10	10
	#N/A				
	#N/A				

Transpose Effectiveness	*Transpose Effectiveness*	
Corrugations	Asphalt Resurfacing	6
	Full Flexible Replacement	10
	Deep Lift Asphalt	8
	In-Situ Stabilisation	10
	Lean Mix Concrete	10

Figure B.58 – PaveMaint SELECT “BitKnowledgeBase” Worksheet (Columns “A:L”)

Remediation Options and their Effectiveness (> = more effective /10)

10 Asphalt Resurfacing	10 Spray Seal	7 Slurry Seal				
6 Asphalt Resurfacing	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation	10 Lean Mix Concrete		
10 Asphalt Resurfacing	8 Slurry Seal	6 Rejuvenation Seal	7 Spray Seal			
5 Hot/Cold Mix Asphalt Patching	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation			
8 Hot/Cold Mix Asphalt Patching	10 Full Flexible Replacement	10 In-Situ Stabilisation	10 Lean Mix Concrete			
6 Asphalt Resurfacing	6 Hot/Cold Mix Asphalt Patching	5 Slurry Seal	10 Full Flexible Replacement	10 In-Situ Stabilisation	10 Lean Mix Concrete	
8 Hot/Cold Mix Asphalt Patching						
10 Asphalt Resurfacing	10 Spray Seal	8 Slurry Seal	7 Rejuvenation Seal			
10 Full Flexible Replacement	10 In-Situ Stabilisation					
10 Asphalt Resurfacing	8 Spray Seal	8 Slurry Seal				
7 Asphalt Resurfacing	5 Hot/Cold Mix Asphalt Patching	10 Full Flexible Replacement	7 Deep Lift Asphalt			
6 Hot/Cold Mix Asphalt Patching	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation			
10 Asphalt Resurfacing	10 Spray Seal					
5 Slurry Seal	7	5 Rejuvenation Seal	10 Full Flexible Replacement	10 Deep Lift Asphalt	10 In-Situ Stabilisation	10 Lean Mix Concrete
8 Asphalt Resurfacing	6 Hot/Cold Mix Asphalt Patching	5 Slurry Seal	6	5 Rejuvenation Seal	10 Full Flexible Replacement	10 In-Situ Stabilisation
8 Asphalt Resurfacing	7	5 Rejuvenation Seal	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation	
8 Asphalt Resurfacing	6 Slurry Seal	7	6 Rejuvenation Seal	10 Full Flexible Replacement	8 Deep Lift Asphalt	10 In-Situ Stabilisation
8 Asphalt Resurfacing	7	6 Rejuvenation Seal	10 Full Flexible Replacement	10 Lean Mix Concrete		
8 Asphalt Resurfacing	6 Slurry Seal	7	6 Rejuvenation Seal	10 Full Flexible Replacement	9 Deep Lift Asphalt	10 In-Situ Stabilisation

Figure B.59 – PaveMaint SELECT “BitKnowledgeBase” Worksheet (Columns “M:AB”)

B.14 Worksheet - PaveMaint SELECT "UnSeaKnowledgeBase"

B.14.1 Description:

- Sheet 5 of the PaveMaint SELECT spreadsheet file
- Holds information for unsealed pavements only
- Contains a list of all the possible defect types, a description of the defect severities, references the list of the possible remediation options (from the "RemedyKnowledgeBase" worksheet") applicable for that pavement type only and provides scoring and weighting for all user constraint fields
- Sheet size: Columns "A:AB"; Rows "1:55"
- Sheet is hidden from users of the program. The organisation's administrator can unprotect the spreadsheet and unhide the worksheet to be able to access it

B.14.2 Cells and Functionality

- Rows "2:3", "21", "31:32", "46" and "55" as well as column "M" are empty cells formatted grey to provide a table break and clear visual delineation of the data presented
- Rows "1", "4", "22", "33" and "47" are heading rows and are used by other cells in lookup functions
- Cells "A5:A20" display reference numbers for the individual defect types. The numbers provide a visual unique identity for the administrator but do not serve a function in the program
- Cells in columns "C", "E", "G", "I" and "K" between rows "5:20" provide numeric representations of the 5 severity levels
- Cells in columns "D", "F", "H", "J" and "L" between rows "5:20" provide descriptions of what the severity level means for each defect type
- Cells "B34:B43" display the possible remediation options available for the pavement type
- Cells in columns "O", "Q", "S", "U", "W", "Y" and "AA" between rows "5:20" display the suitable remediation options for the corresponding defect type.
    - o The cells contain a conditional formula (Equation B.10) that displays a blank cell for severities less than a value of 2 (that is, considered slight) unless the user has nominated aesthetics to be of high importance (greater than a value of 8).
    - o Cells "O9", "Q5", "Q9", "S5", "S6", "S7", "S8", "S10", "S11", "S12" "W8", "W10", "W12", "Y8" and "Y10" display remediation options that require more substantial disturbance to the existing pavement and therefore the severity value in Equation B.10 is 4 (instead of 2) as it is not considered that such a significant repair would be undertaken unless the pavement is in poor or unserviceable condition.
- Cells in columns "N", "P", "R", "T", "V", "X" and "Z" between rows "5:20" display a factor representing the effectiveness of the respective remediation option in providing a repair to the respective defect type

- Cells “D34:D45” display the adjusted cost for each remediation option, referencing the “RemedyKnowledgeBase” worksheet (see B.15 above) using the formula outlined in Equation B.12 for the example of Asphalt Resurfacing
- Cells “H34:H45” display the anticipated longevity for each remediation option in years
- Cells “J34:J45” display a factor between 1 to 10 representing the time taken to mobilise plant, equipment and materials to undertake the repair for each remediation option. A factor of 1 represents a fast repair while a factor of 10 requires a large amount of time to plan the repair
- Cells “L34:L45” display a factor between 1 to 10 representing the aesthetic appearance of each completed remediation option. A factor of 10 represents high aesthetic appeal, while a factor of 1 represents a low aesthetic appeal
- Cell “B48” identifies what defect is being assessed via the lookup function shown in Equation B.13 referencing the “Results” worksheet
- Cells “D48:D54” display the remediation options available to treat the defect displayed in cell “B48” via a lookup function referencing the cells in columns “O”, “Q”, “S”, “U”, “W”, “Y” and “AA” between rows “5:20” via the example lookup function shown in Equation B.14
- Cells “E48:E54” display the factor of effectiveness of the remediation options to treat the defect displayed in cell “B48” via a lookup function referencing the cells in columns “N”, “P”, “R”, “T”, “V”, “X” and “Z” between rows “5:20” via the example lookup function shown in Equation B.15

B.14.3 Screen Shots:

Unsealed Flexible Pavement

Unsealed	*Severities*				
1 Soft Spots	1 wet spots noticeable some time after rain	2 small depressions appearing on surface	3 pavement deformation present	4 evidence of some surface gouging noted	5 significant surface gouging is present
2 Corrugations	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant vibration & loss of traction evident
3 Raveling	1 some loose aggregate present on surface	2	3 loose surface & driver must adapt vehicle speed	4	5 significant loose aggregate & loss of traction
4 Potholes	1 < 150mm diameter or < 50mm deep	2	3 150-300mm diameter or 50-100mm deep	4	5 > 300mm diameter or >100mm deep
5 Depressions	1 causes ponding < 1sq.m	2	3 causes ponding 1-5sq.m	4	5 causes ponding > 5sq.m
6 Rutting	1 ruts developing but no influence on steering	2	3 some influence of driver ability to steer	4	5 steering is made difficult by influence of ruts
7 Loss of Fines	1 dusty road under traffic	2	3 dusty road with reduced visibility in traffic	4	5 plumes of dust present with wind & traffic
8 Erosion Channels	1 < 50mm deep	2	3 50-100mm deep	4	5 >100mm deep
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5

Not Used

Remediation Options	Cost of Repair ($ / sq.m) x 3.5% CPI from year 2013	Effectiveness of Repair	Longevity of Repair (years) (max. years)	Speed of Repair (Factor) (> = longest time to repair)	Aesthetic Finish (Factor) (> = greater aesthetics)
Pavement Nourishment	11.00		2	3	10
Grading	2.00		1	1	10
Reshaping & Shallow Stabilisation	6.00		5	3	10
Ripping	4.00		1	1	10
Full Flexible Replacement	218.00		15	10	10
In-Situ Stabilisation	52.00		15	10	10
	#N/A				
	#N/A				
	#N/A				
	#N/A				
	#N/A				
	#N/A				

Transpose Effectiveness	*Transpose Effectiveness*	
Corrugations	Pavement Nourishment	7
	Grading	7
	Reshaping & Shallow Stabilisation	6
	Ripping	8

Figure B.60 – PaveMaint SELECT "UnSeaKnowledgeBase" Worksheet (Columns "A:L")

Remediation Options and their Effectiveness					
6 Pavement Nourishment	10 Full Flexible Replacement	10 In-Situ Stabilisation			
7 Pavement Nourishment	7 Grading	6 Reshaping & Shallow Stabilisation	8 Ripping		
8 Pavement Nourishment	7 Grading	9 Reshaping & Shallow Stabilisation	8 Ripping		
6 Pavement Nourishment	7 Grading	6 Reshaping & Shallow Stabilisation	7 Ripping	10 Full Flexible Replacement	10 In-Situ Stabilisation
10 Full Flexible Replacement	10 In-Situ Stabilisation				
7 Pavement Nourishment	8 Grading	8 Reshaping & Shallow Stabilisation	8 Ripping	10 Full Flexible Replacement	10 In-Situ Stabilisation
6 Pavement Nourishment	7 Grading	8 Reshaping & Shallow Stabilisation	8 Ripping		
7 Pavement Nourishment	8 Grading	8 Reshaping & Shallow Stabilisation	8 Ripping	10 Full Flexible Replacement	
1					
1					
1					
1					
1					
1					
1					
1					

Figure B.61 – PaveMaint SELECT "UnSeaKnowledgeBase" Worksheet (Columns "M:AB")

B.15 Worksheet - PaveMaint SELECT "RemedyKnowledgeBase"

B.15.1 Description:

- Sheet 6 of the PaveMaint SELECT spreadsheet file
- Contains a list of all the available remediation options for all the flexible pavement types, along with their costs
- Sheet size: Columns "A:E"; Rows "1:23"
- Sheet is hidden from users of the program. The organisation's administrator can unprotect the spreadsheet and unhide the worksheet to be able to access it

B.15.2 Cells and Functionality

- Cell "C2" contains the manually updated date upon which the administrator last updated the costs of the remediation options
- Cells "B2", "D2" and "B3:D3" provide headings for the columns of information stored below or adjacent to them
- Cells "B4:B17" display the list of all the remediation options (in text format), while cells "B18:B23" provide blank cells that the administrator may be able to add additional remediation options
- Cells "C4:C17" display the manually updated costs of each of the remediation options. The worksheet is prefilled with cost information researched by the author
- Cell "E2" provides a percentage cost growth factor set to a default value of 3.5%
- Cells "D4:D17" contain a formula whose function to provide an estimated update to the remediation costs on a yearly basis, should the administrator elect not to manually update the knowledgebase regularly. The equation for cell "D4" (which is representative of all the cells "D4:D17") is given as Equation B.16 below:

$$= [\![C4 \times (1 + \$E\$2)]\!]\char`^((ROUNDDOWN(((YEAR(Results!\,\$M\$1) - YEAR(\$C\$2)) \times 12 + (MONTH(Results!\,\$M\$1) - MONTH(C\$C2))) \div 12, -0.5)\ )$$

Equation B.16

B.15.3 Accelerated Learning Tools:

- Cell "C2" has a comment dialogue box attributed to it providing instructions to the administrator on what information is required in this cell
- Cells "C4:C17" contain comment fields in each cell providing the reference where the information was obtained through the author's research
- Cell "E2" has a comment dialogue box attributed to it providing instructions to the administrator that they can adjust the cost growth factor manually as required

B.15.4 Screen Shots:

	A	B	C	D	E
1					
2		Date updated	1/01/2013	CPI from 2013	3.5%
3		*Remediation Options*	$/sqm	Adjusted Current Year $/sqm	
4		Asphalt Resurfacing	$ 28.00	$29.00	
5		Hot/Cold Mix Asphalt Patching	$ 24.95	$26.00	
6		Spray Seal	$ 15.00	$16.00	
7		Slurry Seal	$ 8.00	$9.00	
8		Crack Sealing	$ 11.65	$13.00	
9		Rejuvenation Seal	$ 5.00	$6.00	
10		Full Flexible Replacement	$ 210.00	$218.00	
11		Deep Lift Asphalt	$ 78.00	$81.00	
12		In-Situ Stabilisation	$ 50.00	$52.00	
13		Lean Mix Concrete	$ 120.00	$125.00	
14		Pavement Nourishment	$ 10.00	$11.00	
15		Grading	$ 1.30	$2.00	
16		Reshaping & Shallow Stabilisation	$ 5.00	$6.00	
17		Ripping	$ 3.00	$4.00	
18					
19					
20					
21					
22					
23					

Figure B.62 – PaveMaint SELECT "RemedyKnowledgeBase" Worksheet

APPENDIX C

FIELD INTERVIEWS AND CASE STUDIES: EXPLORATION OF ROAD REMEDIATION AND ASSET MANAGEMENT DECISION MAKING IN LOCAL GOVERNMENT

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C.1 Field Interview Participant Coding

As discussed in Section 5.2, participants who have taken part in this study were advised in their Participant Information Sheet (Figure C.1, Figure C.2 and Figure C.3 overleaf) that their contributions would be coded in a manner that meant they could not be personally identified (for ethical concerns). Accordingly, it was necessary to code the participants to enable clear reference to individual responses and cases without personally identifying that participant.

The initial case study participants discussed in Chapter 3 and their personal communications referenced in the body text as "Manager, SCC Roads Asset" (Manager 2011) and "Manager, SCC Maintenance" (Manager 2012) are known as Participant 0.1 and Participant 0.2 (or P0.1 and P0.2) respectively. As these participants were critical for the "Task Profiling" stage of the study and were employees of the "host organisation", the interviews were mostly unstructured and the joint results are outlined in the discussion presented in Section C.3.

The participants recruited for the purpose of the "System Testing and Refinement" stage of the study were sought after the PaveMaint SELECT prototype was developed. These participants are coded numerically with random integers between one and eight starting with Participant 1 (or P1) through to Participant 8 (P8) and the data relating to these participants is discussed in summary form in Chapter 5.

While the individual participants are coded such that their names cannot be identified, references to localities explored during the PaveMaint SELECT testing examples have remained uncoded. While doing so does provide a degree of identification through identifying the local government area and therefore the organisation in which the information was obtained, the author believes that since all the participants outlined that their organisations work in a road asset management/maintenance team, the individual from within that team will still not be readily identified, therefore maintaining the participant's anonymity.

Shoalhaven City Council

University of Wollongong

PARTICPANT INFORMATION SHEET

Decision Support System for the Remediation of Flexible Road Pavements in Local Government

PURPOSE OF THE RESEARCH

This is an opportunity to participate in a research study conducted by the following researchers (investigators) at the University of Wollongong. The purpose of this study is to develop a decision support system to assist local government road asset managers and road maintenance decision makers via a software tool designed to provide decision making and prioritisation justification and learning.

INVESTIGATORS

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lteh@uow.edu.au   blemass@uow.edu.au

METHODS AND DEMANDS ON PARTICIPANTS

Information and feedback will be collected from experienced local government road asset managers and engineers as well as road maintenance engineers and senior technical maintenance staff to refine and validate the decision support software tool.

The interview questions will focus around specific cases of road management and maintenance from within your own experience and are designed to determine what decisions were made and what informed this decision making process.

Before participating in the interview, you are required to complete and sign the attached participant consent form.

Figure C.1 – Participant Information Sheet (page 1 of 2)

POSSIBLE RISKS, INCONVENIENCES AND DISCOMFORTS

Your involvement in the field study is voluntary and you may choose not to respond to any questions. You are also able to discontinue participating in the study at any stage and withdraw your data. Withdrawal from this study will not affect any relationship you have with your employer or the University of Wollongong. Apart from the time spent on participating in the study, we can foresee no significant risks for you. Any information obtained in connection with this study and will be coded such that you will not be able to be identified and will remain confidential and be disclosed only with your permission except as required by law. Interviews will be audio recorded for the purposes of assisting with writing up transcripts. Once transcripts are written up, the audio recordings will be securely destroyed.
Councils will only receive feedback based on total aggregated data at the completion of this research. The results of this study, in aggregate form, may be presented, discussed and published in appropriate academic forums and journals for the purpose of contributing to the advancement of knowledge. In any publication, information attributed to an individual will be provided in such a way that you cannot be individually identified.

The information collected as part of this study is related to your work experiences in the area of road asset maintenance and management. It is highly unlikely that the questions asked will cause you any distress. However, you are able to stop at any time and are not obliged to continue with the interview. If you do become distressed and would like to talk to someone not involved in the research project, please contact Lifeline on 13 11 14.

FUNDING AND BENEFITS OF THE RESEARCH

Once developed, the decision support system (software tool) will serve as an accelerated learning tool for junior or novice road asset team members, but will also serve as a checking (or justification) tool between the engineer's intuition and technical knowledge with a structured systematic assessment that converges on one or two feasible solutions.

ETHICS REVIEW AND COMPLAINTS

This study has been reviewed by the Human Research Ethics Committee of the University of Wollongong. If you have any issues regarding the study, you can contact Matthew Apolo, Lip Teh or Brett Lemass using the above contact details. If you have any concerns or complaints regarding the way this research is or has been conducted, you can contact the University of Wollongong Ethics Officers (phone: 02 4221 4457 or email: rso-ethics@uow.edu.au).

Thank you for your interest and time taken to consider this study.

Figure C.2 – Participant Information Sheet (page 2 of 2)

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University of Wollongong

PARTICPANT CONSENT FORM

RESEARCH TITLE: **Decision Support System for the Remediation of Flexible Road Pavements in Local Government**]

I have received a copy of the Participant Information Sheet for the research study titled **Decision Support System for the Remediation of Ageing Roads Infrastructure in Local Government** and discussed it with **Matthew Apolo** who is conducting the research as part of both the University of Wollongong's Local Government Consortium and for his degree of Master of Engineering Research, supervised by Dr Lip Teh and Dr Brett Lemass of the UOW's Faculty of Engineering.

i understand that my participation in this research is voluntary, I am free to refuse to participate and I am free to withdraw from the research at any time. My refusal to participate or withdrawal of consent will not affect my relationship with my employer or the University of Wollongong.

I understand that the data collected from my participation will be used primarily for a Masters thesis and agree to have my interview audio recorded by the researcher/s.

i understand there are minimal potential risks and burdens associated with this research, and that I can discuss any concerns regarding the research and my participation with Matthew Apolo (0421 824 243) or the other contacts listed in the Participant Information Sheet. Alternatively, if I have any concerns or complaints regarding the way the research is being conducted I can contact the Ethics Officer of the Human Research Ethics Committee in the University of Wollongong's Office of Research on 4221 3386 or via email rso-ethics@uow.edu.au.

By signing below I am indicating my consent to participate in the survey and respond to the questionnaire related to local government road asset management and maintenance practices.

....

Name (please print)

....

Signed

....

Date

Figure C.3 – Participant Consent Form

C.2 Initial Case Study: Participant 0.1 and Participant 0.2

There are approximately 2500 kilometres of roads within the Shoalhaven City Council (SCC) local government area with 2100 kilometres of these owned and/or controlled by SCC and the remaining roads are owned and controlled by state or federal governments.

SCC employs many resources to maintain and manage its roads network in order to meet its legal and community obligations. The manner in which this is done can be defined by two separate systems; risk-based (or reactionary) management and strategic (or whole-of life) management. These are discussed below.

C.2.1 Risk-Based Management

SCC undertakes risk-based, or reactionary, management of its roads network which is undertaken on a defect-incidental basis. The process and procedure that this system follows is driven by SCC's Roads Risk Management policies, which stem from a legal requirement to provide safe infrastructure to the public.

The responsible group for the implementation of this system is the City Services and Operations Group[1], which utilises an action-request based database named Merit™ to manage the implementation of maintenance interventions on SCC's roads.

The two methods in which SCC obtains information and data on its roads' condition are:

- Routine: SCC's Roads Inspector is required to inspect the roads network for defects on a regular basis as listed in Table C.1 below.
- Incidental: SCC receives complaints and/or requests from residents, road users and the general public for current issues and defects on its roads. This also includes staff within SCC.

For sealed roads, the routine inspections are carried out in accordance with Table C.1 which is intrinsically linked to the traffic load and speed environment of the road.

[1] At the time of collating this research (post-2013) the functional group has been restructured and is now called the "Assets and Works" group

Table C.1 – Inspection Intervals (Sealed Roads)

Road Hierarchy Category	Hazard/Risk Identification Inspection Interval	Distribution of Inspections
Sealed Arterial	Monthly	12 in any 12 month period
Sealed Collector	6 Monthly	2 in any 12 month period
Sealed Local	12 Monthly	1 in any 12 month period

Table C.2 lists a series of common defect types and severities for sealed roads which have been predetermined by a risk based assessment. Any defects that meet (or exceed) this severity will require maintenance intervention and an action request or "Merit" is raised.

Table C.2 – Defect Intervention Thresholds (Sealed Roads)

Hazard Code	Hazard Description	Recording Level
1200	Pot holes and Edge Breaks	150mm in diameter or 150mm from design edge of seal both at least 50mm deep
1240	Surface Irregularity	40mm above Design level of road
1250	Edge drop-off	50mm below Design level of road
1280	Spilled or Loose Material	Any granular material deeper than 10mm And 1 sq metre in area

Within the general capabilities of SCC's Works and Services maintenance resources, defect interventions are limited to cold-mix asphalt pot-hole filling, road resealing (including corrective seals/courses), edge-break rectification and hot-mix asphalt heavy patching less than 50m^2 in area. More comprehensive intervention activities, such as stabilisation of the granular pavement and/or subgrade material as well as road reconstruction (base and/or subbase replacement) and heavy patching greater than 50m^2 in area are referred back to the elected Council to consider as a dedicated project requiring a project-specific budget allocation. Other actions such as crack sealing are generally not undertaken on SCC roads.

SCC's risk management procedure for sealed roads outlines the required response times for rectifying a defect once it is identified (Table C.3). While the timely repair of defects is important for maintaining road user safety, it is equally critical for preserving structural integrity of the pavement and ultimately its longevity.

Table C.3 – Minimum Required Defect Repair Periods (Sealed Roads)

	Risk/Hazard Type			
Road Type	Pot Holes	Edge Drop Off	Surface Irregularity (Shoving)	Spilled Materials
Sealed Arterial Roads	10 calendar days	30 calendar days	60 calendar days	10 calendar days
Sealed Collector Roads	30 calendar days	60 calendar days	180 calendar days	10 calendar days
Sealed Local Roads	60 calendar days	180 calendar days	360 calendar days	10 calendar days

Similarly for unsealed roads (which represent approximately 20% of SCC's roads network), routine inspections are required in accordance with SCC's Risk Management Procedure for Unsealed Roads shown in Table C.4 below.

Table C.4 – Inspection Intervals (Unsealed Roads)

Road Hierarchy Category	Hazard/Risk Identification Inspection Interval	Distribution of Inspections
Collector	6 Monthly	2 in any 12 month period
Local	12 Monthly	1 in any 12 month period

Common defect types identified and their minimum reporting thresholds are also listed in below:

Table C.5 – Defect Intervention Thresholds (Unsealed Roads)

Hazard Code	Hazard Description	Recording Level
1400	Pot holes	300mm in diameter and deeper than 75mm
1430	Slippery Surface	No gravel or gravel with excessive fine particles
1450	Corrugations	30mm high and more than 10 metres In length along the centreline
1480	Loose Material	50 mm deep in windrows or Objects over 75mm
1490	Scour/Rock Outcrop	50mm in height or depth
1591	Tree Obstruction	Overhanging onto road past edge of formation

Maintenance interventions for unsealed roads have been identified in SCC's Unsealed Roads Asset Management Plan. These include:

- Routine Grading: reshaping and compacting existing gravel pavement; allowance included for minor gravel importing.
- Gravel Resheeting: undertaken when existing gravel pavement has worn away and requires replenishment (typically placing of 100mm depth of pavement).
- Emergency and Other: during periods of storms, interim actions may be required to correct large scours, correct drainage or other actions to make the roads safe. This can include hand placing of gravel to scours.
- Sacrificial Seal Program: undertaken as a maintenance activity to supplement the annual Gravel Resheeting Program. An annual allowance is made to place a single coat seal to selected roads that are due for Gravel Resheeting. Selected roads must meet certain criteria as detailed later in the Plan.
- Low Cost Seal: sealing of short sections of urban roads where existing alignment, width and drainage is satisfactory. Annual Program reported to the elected Council for adoption. The Strategy was adopted by SCC and commenced in 1999/2000 to accelerate the road sealing program in a cost effective manner.
- Road Sealing Strategy (Urban and Rural): a three year program adopted by Council as part of the annual Management Plan and Budget process. Generally applies to roads requiring widening/realignment and of higher traffic volumes and higher standard pavement design.

The planned execution of these maintenance activities are required to be undertaken in the timeframes outlined in Table C.6.

Table C.6 – Minimum Required Defect Repair Periods (Unsealed Roads)

Road Hierarchy Category	Pot Holes	Slippery Surface	Corrugations	Loose Material	Scour/Rock Outcrop
Collector	6 months	6 months	6 months	6 months	6 months
Local	One year	One year	One year	One year	One year

C.2.2 Strategic Management

The strategic management of SCC's roads is undertaken at a network or 'macro' level. It is a condition based system that looks at the sum of the individual defects and severities on a road pavement to manage its overall performance.

SCC's Strategic Planning and Infrastructure Group[2] is responsible for implementing this system and does this by implementing the asset management database software Conquest™. It is the complete (or near complete) database of all of SCC's assets (buildings, footpaths, drainage and roads among others) and their details which are linked via a Geographic Information System (GIS).

Roads are defined by segments, each approximately 500m in length, measured in reference to road chainages. Characteristically, lengths of road within each individual segment will be of the same age and will be constructed with the same pavement types, thicknesses and materials. An individual road could be many kilometres in length and local conditions can result in some sections of a road deteriorating at different rates to other sections of road. Therefore, undertaking maintenance and rehabilitation interventions over the entire length of the road can be costly and sometimes unnecessary. The purpose of segments is to break the roads network into manageable pieces and by planning and coordinating interventions at a segment level allows SCC's road asset manager to more efficiently implement SCC's limited budget over the whole of the roads network for their entire life-cycle.

SCC's Roads Assets Inspector undertakes inspections of the road network with a minimum requirement of reporting on 100% of the network annually. Each defect is recorded into Conquest™ with its severity scored between 1 (excellent) and 5 (unsatisfactory). Table C.7 outlines the four predetermined categories of defects that are listed in Conquest™, which are weighted based on their known ability to affect overall pavement life and performance of SCC roads.

[2] At the time of collating this research (post-2013) the functional group has been restructured and is now part of the "Assets and Works" group

Table C.7 – Conquest™ Defects Weighting

Defect Type	Weighting
Cracking	2
Patching (m^2/m of road)	3
Binder/Stone loss	1
Rutting/Deformation	2
Total	**8**

A road segment is then given an average condition score for its condition, which is given as:

$$ACS = \sum \frac{(S_i W_i)}{W_T}$$

Equation C.1

where:

ACS is the Average condition Score, which is comparable to PSI (the pavement serviceability index);

S_i is the severity score of individual recorded defects;

W_i is the weighting of the individual defect type given by Table C.7; and

W_T is the sum of the defect weightings, which Table C.7 shows will be a constant value of 8

Using the average condition score, SCC's road asset manager is then able to make engineering decisions, based on heuristics, for that particular segment and prioritised according to their ACS - high, mid or low:

High (ACS >75) – geotechnical investigation will be undertaken and probable road reconstruction will be required

Mid (ACS 25-75) – significant maintenance determined on case by case assessment which may result in either resealing, heavy patching or further monitoring and investigation

Low (ACS <25) – no action, monitor condition

At SCC the road segments are again broken down further by road chainage, so that maintenance and rehabilitation interventions are carried out only over those sections of road showing the worst symptoms of disrepair or failure. By undertaking interventions over selected chainages within a segment the asset manager is then able to again spread short-term limited budgetary resources over the whole of the roads network.

C.2.3 Significance of the Initial Case Study

This initial case study of Shoalhaven City Council, in combination with the literature review presented in Chapters 2 and 3, have formed the basis for the development of the prototype PaveMaint SELECT program. By understanding the constraints and issues that experienced practitioners and their organisations face have shaped the logic, format and pruning data captured within the programed prototype decision support system structure.

C.3 Field Interviews: Participant Knowledgebase

Road asset managers and engineers involved in the "System Testing and Refinement" stage of this study participated in semi-structured interviews initially exploring the predefined questions provided in Figure C.4 to Figure C.6 (inclusive), followed by an examination of real examples from their own roads networks utilising the prototype PaveMaint SELECT questionnaire discussed in Section C.4.

For ease of interpretation, participant input from the initial questionnaire are tabulated in Table C.8 to Table C.21 (inclusive). The subsequent "System Testing" of the prototype PaveMaint SELECT program undertaken with each individual participant as case studies, is presented in Section C.4.

University of Wollongong

Shoalhaven City Council

Road Remediation in Local Government – Field Interview Questionnaire

1. Which of the following describes your position in your organisation?

☐ Asset Manager ☐ Asset Officer/Inspector ☐ Roads/ Maintenance Engineer ☐ Maintenance Officer ☐ Maintenance Crew Leading Hand

☐ Other (please describe) ______________________________

2. How many years experience do you have in road maintenance/management? (including developmental years in similar, lower hierarchical or construction roles that you believe have helped shaped your knowledge on road asset management)

☐ <10 ☐ 10-15 ☐ 15-20 ☐ 25-30 ☐ >30

3. What pavement types make up your organisation's road network? (number the boxes by percentage of overall road network make up – 1 = most common, 5 = least common, 0 = not present in network)

☐ Sealed Flexible ☐ Unsealed Flexible ☐ Rigid ☐ Segmental Block (Pavers)

☐ Other (please describe) ______________________________

4. Of the pavement types you listed above as the two most common, what percentage would one and two represent?

☐ % -No. 1 ☐ % - No. 2

5. How would you rate the current condition of your road network overall?

☐ Excellent ☐ Good ☐ Satisfactory ☐ Unsatisfactory ☐ Poor ☐ Failing

6. Rate the influence the following factors have on road maintenance decisions in your organisation? (1 = most important, 7 = least important)

☐ Minimise Cost ☐ Maximise User Satisfaction ☐ Maximise Present Day Performance ☐ Minimise Resource Usage

☐ Maximise Asset Life ☐ Political / Reactionary ☐ Other (please describe) ______________________________

Figure C.4 – Participant Preliminary Questionnaire (page 1 of 3)

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Road Remediation in Local Government – Field Interview Questionnaire (cont.)

7. Select the statement that best describes your organisation's road asset team

- ☐ The road asset team is highly experienced and individuals make road management and maintenance decisions independently and effectively
- ☐ The road asset team is comprised of both senior and junior members, where only senior members are given the opportunity to make asset maintenance and management decisions
- ☐ Senior and junior members of the road asset team make decisions collaboratively
- ☐ I am the only person who makes road asset decisions in my organisation

8. Select the statement that best describes road network decision making in your organisation

- ☐ Using asset inspections and the network database the road asset team are able to prioritise maintenance works strategically; balancing technical, budgetary and social (road user) constraints without being required to react to external or internal pressures
- ☐ The road asset team has the capacity to plan strategic maintenance, however works are often reprioritised by some external or internal pressures
- ☐ Strategic maintenance planning is desirable when possible, however the budget available means that nearly all road maintenance is completely reactionary and only the worst sections of road are repaired
- ☐ Road maintenance planning is not a priority for my organisation and the road asset team are only required to undertake road repairs when Council has been requested to do so

9. Do you agree with the general terminology of "Road Remediation? Select the option below that you would use to refer to both the temporary and permanent rectification of road defects

☐ Road Remediation ☐ Road Repair ☐ Road Maintenance ☐ Road Management ☐ Road Restoration

☐ Other (please describe) ________________________________

Figure C.5 – Participant Preliminary Questionnaire (page 2 of 3)

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Shoalhaven City Council

Road Remediation in Local Government – Field Interview Questionnaire (cont.)

10. Using the DSS "PaveMaint SELECT" - do you agree with its logic? How do you feel it could be improved?

☐ Yes ☐ No

11. Using the DSS "PaveMaint SELECT" – does the application replicate what you consider to be good decisions? How do you feel it could be improved?

☐ Yes ☐ No

12. Do you think "PaveMaint SELECT" could be a useful training tool for less experienced members of your asset team? Please provide comment

☐ Yes ☐ No

Figure C.6 – Participant Preliminary Questionnaire (page 3 of 3)

Table C.8 – Initial Interview Questionnaire Responses, Question 1

Q1	**Which of the following describes your position in your organisation?**								
Total	**Position Description**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
62.5%	Asset Manager			Y	Y	Y	Y	Y	
12.5%	Asset Officer/Inspector								Y
25.0%	Roads/ Maintenance Engineer	Y	Y						

Table C.9 – Initial Interview Questionnaire Responses, Question 2

Q2	**How many years' experience do you have in road maintenance/management? (including developmental years in similar, lower hierarchical or construction roles that you believe have helped shaped your knowledge on road asset management)**								
Total	**Years**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
12.5%	< 10					Y			
12.5%	10-15	Y							
25.0%	15-20			Y					Y
37.5%	25-30		Y				Y	Y	
12.5%	> 30				Y				

Table C.10 – Initial Interview Questionnaire Responses, Question 3

Q3	**What pavement types make up your organisation's road network? (number the boxes by percentage of overall road network make up – 1 = most common, 5 = least common, 0 = not present in network)**							
Pavement Type	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
Sealed Flexible	1	1	1	2	1	1	1	1
Unsealed Flexible	2	2	N/A	1	2	2	N/A	N/A
Rigid	4	4	2	N/A	N/A	N/A	2	2
Segmental Block	3	3	N/A	N/A	N/A	N/A	N/A	N/A

Table C.11 – Aggregation of the Ranked Most Common Pavement Types in Road Network from Table C.10 (1 = Most Common, 4 = Least Common)

Pavement Type	**1**	**2**	**3**	**4**
Sealed Flexible	87.5%	12.5%	0.0%	0.0%
Unsealed Flexible	12.5%	50.0%	0.0%	0.0%
Rigid	0%	37.5%	0.0%	25.0%
Segmental Block	0%	0.0%	25.0%	0.0%

Table C.12 – Initial Interview Questionnaire Responses, Question 4

Q4	**Of the pavement types you listed above as the two most common, what percentage would one and two represent?** (Refer Table C.10)							
Percentage of Road Network	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
Most Common Pavement Type	90%	90%	95%	75%	85%	99%	98%	98%
2nd Most Common Pavement Type	10%	9%	5%	25%	15%	1%	2%	2%

Table C.13 – Initial Interview Questionnaire Responses, Question 5

Q5	**How would you rate the current condition of your road network overall?**								
Total	**Condition**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
0.0%	Excellent								
62.5%	Good			Y	Y		Y	Y	Y
25.0%	Satisfactory	Y				Y			
0.0%	Unsatisfactory								
12.5%	Poor		Y						
0.0%	Failing								

Table C.14 – Initial Interview Questionnaire Responses, Question 6

Q6	Rate the influence the following factors have on road maintenance decisions in your organisation? (1 = most important, 7 = least important)							
Constraint Description	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
Minimise Cost	1	3	2	3	1	4	2	2
Maximise User Satisfaction	5	6	4	4	6	3	4	4
Maximise Present Day Performance	6	4	5	5	2	2	3	3
Minimise Resource Usage	3	5	3	6	4	5	6	6
Maximise Asset Life	2	1	1	2	3	1	1	1
Political / Reactionary	4	2	6	7	5	0	5	5
Other Safety	0	0	0	1	0	0	0	0

Table C.15 – Aggregation of the Ranked Most Influential Constraint from Table C.14 (1 = Highest, 7 = Lowest)

Constraint Description	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Minimise Cost	25%	37.5%	25.0%	12.5%	0.0%	0.0%	0%
Maximise User Satisfaction	0%	0.0%	12.5%	50.0%	12.5%	25.0%	0%
Maximise Present Day Performance	0%	25.0%	25.0%	12.5%	25.0%	12.5%	0%
Minimise Resource Usage	0%	0.0%	25.0%	12.5%	25.0%	37.5%	0%
Maximise Asset Life	62.5%	25.0%	12.5%	0.0%	0.0%	0.0%	0%
Political / Reactionary	0%	12.5%	0.0%	12.5%	37.5%	12.5%	13%
Other Safety	12.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0%

Table C.16 – Initial Interview Questionnaire Responses, Question 7

Q7	**Select the statement that best describes your organisation's road asset team**							
Total	**Statement:**							
(a) 37.5%	The road asset team is highly experienced and individuals make road management and maintenance decisions independently and effectively							
(b) 25.0%	The road asset team is comprised of both senior and junior members, where only senior members are given the opportunity to make asset maintenance and management decisions							
(c) 37.5%	Senior and junior members of the road asset team make decisions collaboratively							
(d) 0.0%	I am the only person who makes road asset decisions in my organisation							
Participant Responses	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
	(b)	(b)	(a)	(a)	(c)	(a)	(c)	(c)

Table C.17 – Initial Interview Questionnaire Responses, Question 8

Q8	**Select the statement that best describes road network decision making in your organisation**							
Total	**Statement:**							
(a) 25.0%	Using asset inspections and the network database the road asset team are able to prioritise maintenance works strategically; balancing technical, budgetary and social constraints without being required to react to external or internal pressures							
(b) 62.5%	The road asset team has the capacity to plan strategic maintenance, however works are often reprioritised by some external or internal pressures							
(c) 12.5%	Strategic maintenance planning is desirable when possible, however the budget available means that nearly all road maintenance is completely reactionary and only the worst sections of road are repaired							
(d) 0.0%	Road maintenance planning is not a priority for my organisation and the road asset team are only required to undertake road repairs when Council has been requested to do so							
Participant Responses	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
	(c)	(b)	(a)	(b)	(a)	(b)	(b)	(b)

Table C.18 – Initial Interview Questionnaire Responses, Question 9

Q9	**Do you agree with the general terminology of "Road Remediation? Select the option below that you would use to refer to both the temporary and permanent rectification of road defects**								
Total	**Name**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
25.0%	Road Remediation	Y	Y						
12.5%	Road Repair					Y			
50.0%	Road Maintenance				Y		Y	Y	Y
0.0%	Road Management								
0.0%	Road Restoration								
12.5%	Other: Road Works			Y					

Table C.19 – Initial Interview Questionnaire Responses, Question 10

Q10	**Using the DSS "PaveMaint SELECT" - do you agree with its logic? How do you feel it could be improved?**
Total	**Response**
100%	Yes
0%	No

Table C.20 – Initial Interview Questionnaire Responses, Question 11

Q11	**Using the DSS "PaveMaint SELECT" – does the application replicate what you consider to be good decisions? How do you feel it could be improved?**								
Total	**Response**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
87.5%	Yes	Y		Y	Y	Y	Y	Y	Y
12.5%	No		Y						

Table C.21 – Initial Interview Questionnaire Responses, Question 12

Q12	**Do you think "PaveMaint SELECT" could be a useful training tool for less experienced members of your asset team? Please provide comment**
Total	**Response**
100%	Yes
0%	No

C.4 Case Studies: System Testing and Refinement

Through System Testing and Refinement investigations, participants were asked to discuss real examples of remediation projects that recently occurred or that are about to be undertaken. Utilising the predetermined data sheets provided in Figure C.7 and Figure C.8 (overleaf) that are designed to replicate the prototype PaveMaint SELECT data screens, the participant discussed the road environment, the dominant defect to be considered, the ultimate selection of the remediation treatment type and the constraints that led to that decision being made.

Concurrently through that exploration, they would physically use the prototype PaveMaint SELECT program and compare their decisions with the results for the DSS and provide commentary on aspects that appear to work well and also suggest potential improvements they felt necessary.

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INTERVIEW PROFORMA - REMEDIATION OPTIONS EXPLORATION

Participant: ____________________ **Date:** ____________________

Road Type: Sealed ☐ Unsealed ☐

Traffic Conditions: ____________________

Defect: (tick one)

Aggregate Polishing ☐	Block Crack ☐	Corrugations ☐	Crescent Crack ☐
Crocodile Crack ☐	Delamination ☐	Depressions ☐	Diagonal Crack ☐
Edge Break ☐	Flushing ☐	Longit. Crack ☐	Meander. Crack ☐
Oxidation ☐	Patch Failure ☐	Potholes ☐	Pumping ☐
Raveling ☐	Rutting ☐	Shoving ☐	Stripping ☐
Transverse Crack ☐	Erosion Chnls ☐	Loss of Fines ☐	Soft Spots ☐

Other: ☐ ____________________

Repair: (tick one)

Asphalt Resurface ☐	H/C Mix Patch ☐	Spray Seal ☐	Slurry Seal ☐
Crack Seal ☐	Rejuv. Seal ☐	Full Replace ☐	DeepLift Asphalt ☐
In-Situ Stabilise ☐	LeanMix Conc. ☐	Pave Nourish ☐	Grading ☐
Reshape/Shallow Stabilisation ☐			Ripping ☐

Other: ☐ ____________________

Figure C.7 – Participant Remediation Exploration Questionnaire (page 1 of 2)

Shoalhaven City Council

University of Wollongong

INTERVIEW PROFORMA - REMEDIATION OPTIONS EXPLORATION

Constraints:

Defect Severity:

Slight	Mild	Moderate	Poor	Unserviceable
1 ○	2 ○	3 ○	4 ○	5 ○

How important is the Cost of the repair?

- ○ Costs are not an issue. Council has a generous budget and can absorb unplanned maintenance
- ○ Council has capacity for unplanned maintenance but costs are important
- ○ Council has limited capacity for unplanned maintenance and costs are a high priority
- ○ Costs are extremely important

Is Longevity of the repair important?

- ○ No, the pavement is nearing the end of its life
- ○ A shorter repair life is required for various reasons
- ○ The pavement is nearing its mid-life
- ○ The pavement is near new and a long-life repair is very important

Describe your Resourcing constraints?

- ○ Council has a highly competent works crew who can react to all road maintenance tasks
- ○ Council can react to small and medium maintenance tasks but contracts large projects to external contractors
- ○ Council contracts most medium to large scale projects to external contractors which requires thorough coordination

How important are Aesthetics to the repair finish?

- ○ Low Priority:- e.g. the pavement is nearing the end of its life and the repair won't be in place for more than 1-2 years
- ○ Medium Priority:- e.g. the pavement is in an urban area with reasonable traffic volumes
- ○ High Priority:- e.g. the road is in a CBD or commercial area where aesthetics are a high priority

Figure C.8 – Participant Remediation Exploration Questionnaire (page 2 of 2)

C.4.1 Participant 1

Participant 1 (P1) is a Roads Engineer responsible for the maintenance and reconstruction of their organisation's roads. P1 is provided a brief to undertake rectification works for a specific segment of road without any stipulation as to the type of remediation treatment required.

P1 considers "In-Situ Stabilisation" to be more of a construction technique when rehabilitating and renewing a road but wouldn't use it as a remediation or "minor" maintenance treatment. Furthermore, it was considered that term "Stabilisation" could or should include other forms of other than the cement or lime additive type, such as geotechnical materials and grids.

P1 also highlighted that they commonly treat more than one defect and it is usually a combination of or two or three defects within the one failing segment of road.

C.4.1.1 Case Study: Quinns Lane, South Nowra

Treatment Data:

Road Type:	Flexible Bituminous Spray Seal
Traffic Conditions:	Up to 10^5 ESA
Dominant Defect:	Crocodile Cracking
Treatment Selected:	Full Flexible Replacement
Severity:	Poor to Unserviceable
Cost Constraint:	2/4
Longevity Required:	4/4
Resource Constraints:	1/3
Aesthetic Constraints:	2/3

The participant indicated that there were at least two defects present “Crocodile Cracking” and “Patching Failure” (shown in Figure C.9, Figure C.10 and Figure C.11) but considered the former to be the dominant defect requiring treatment. “Crocodile Cracking” was modelled in the DSS (Figure C.13) which provided a recommendation to undertake “Full Flexible Replacement” as the treatment type. This was in agreement with the participant’s own selection and an image of the completed works is shown in Figure C.12.

Figure C.9 – Quinns Lane before Treatment Demonstrating Failed Crocodile Cracking with Patching Failure in a Poor to Unserviceable Condition

Figure C.10 – Quinns Lane before Treatment Demonstrating Failed Crocodile Cracking with Patching in a Poor to Unserviceable Condition

Figure C.11 – Quinns Lane before Treatment Demonstrating Crocodile Cracking in a Poor Condition

Figure C.12 – Quinns Lane following Full Flexible Replacement Treatment

Date of Assessment: 18/02/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Quinns Lane
Locality: South Nowra
Segment Number: Worrigee
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Crocodile Cracking ***Severity:*** 5
Traffic Volume: up to 1x10^5 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	3	10	5	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Full Flexible Replacement	218.00	30.00	10.00	10.00	**77.5%**
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**73.3%**
Asphalt Resurfacing	29.00	25.00	5.00	10.00	**69.6%**
Slurry Seal	9.00	10.00	5.00	7.00	**44.9%**
Rejuvenation Seal	6.00	5.00	5.00	7.00	**42.9%**
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	**40.5%**
Crack Sealing	13.00	5.00	2.00	2.00	**38.0%**

Figure C.13 – Prototype PaveMaint SELECT Results: Crocodile Cracking – Quinns Lane, South Nowra

Date of Assessment: 18/02/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Quinns Lane
Locality: South Nowra
Segment Number: Worrigee
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Patching Failure ***Severity:*** 4
(1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	3	10	4	5	
Edit Importance Factors	**Cost of Repair ($ / sq.m)**	**Longevity of Repair (years)**	**Time for Repair (Factor)**	**Aesthetic Finish (Factor)**	**Overall Weighted Score**
Full Flexible Replacement	218.00	30.00	10.00	10.00	**80.5%**
Asphalt Resurfacing	29.00	25.00	5.00	10.00	**74.4%**
Deep Lift Asphalt	81.00	25.00	7.00	8.00	**65.2%**
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	**42.7%**

Figure C.14 – Prototype PaveMaint SELECT Results: Patching Failure – Quinns Lane, South Nowra

C.4.2 Participant 2

Participant 2 (P2) is a Roads Maintenance Engineer responsible for the maintenance of their organisation's roads.

In utilising the prototype PaveMaint SELECT software the following comments and notes were made:

- Cracking – considers that the width of the fissure opening is not of significant importance, rather makes assessment of whether the pavement surface is intact. In stipulating fissure width, suggested only 5mm and 30mm would be necessary measures.

- Would consider the addition of the defect type "Surface Irregularities" which describes a surface that has a combination of patch repair deterioration; non-descript slight deformation of the pavement and surface layer deterioration.
- Incorporation of a prompt to ensure the user has adequately checked their organisation's database to determine whether the defect has already been raised and whether any work has already been scheduled.
- Suggested to incorporate a comments field where the user could note whether the defect was identified through routine inspection or otherwise.
- Resource usage was an important constraint
- First input screen would like to also see speed environment as a category and augment traffic load to display vehicles per day instead of equivalent standard axles.
- Quantification of severity by user description of length and size and use this severity to make an assessment of the organisation's risk exposure.
- Costs could be better represented if it factored savings through economies of scale. That is, for any given treatment option it would be expected there would be a higher cost for smaller areas and lower costs for larger treatment areas.
- More consideration of road environment. For example, where kerb and gutter is present an overlay is often less desirable due to surface level differences that result in that such a treatment.
- Described a "Patch Repair as typically 250-300mm gravel with an asphalt "cap".

C.4.2.1 Case Study: Terara Road, Terara

Treatment Data:

Road Type:	Flexible Bituminous Spray Sealed
Traffic Conditions:	Medium to Heavy
Dominant Defect:	Other – Surface Irregularities
Treatment Selected:	Spray Seal
Severity:	Moderate
Cost Constraint:	3/4
Longevity Required:	2/4
Resource Constraints:	2/3
Aesthetic Constraints:	2/3

The defect was modelled in the DSS as "Depressions" in lieu of a "Surface Irregularities" defect being considered in the system (Figure C.15). Unsurprisingly, the results are not at all representative of the treatment option considerations identified by the participant. It was considered that treatment types for this defect would be primarily a "Spray Seal" treatment, although an "Asphalt Resurface" may be considered but is not considered as flexible and fit-for-purpose as a "Spray Seal" treatment.

Date of Assessment: 17/03/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Terara Road
Locality: Terara
Segment Number: Ferry Lane
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Depressions *Severity:* 3 (1= slight ››› 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Recommended Remediation Option: **Hot/Cold Mix Asphalt Patching**

Summary of Results

Importance Factor	6	3	5	5	Overall Weighted Score
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	69.7%
Full Flexible Replacement	218.00	30.00	10.00	10.00	66.3%

Figure C.15 – Prototype PaveMaint SELECT Results: Depressions (as Surface Irregularities) – Terara Road, Terara

C.4.2.2 Case Study: Supply Street, Nowra

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Light

Dominant Defect: Shoving

Treatment Selected: Full Flexible Replacement

Severity: Poor

Cost Constraint: 3/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

The defect was modelled in the DSS which produced “In-Situ Stabilisation” as the recommended remediation option (Figure C.16). The participant did not consider that an “In-Situ Stabilisation” treatment was appropriate for this situation due to resourcing constraints and that a long-life repair was desired. In addition, the on-staff workforce was quite proficient at traditional road construction practices and therefore a “Full Flexible Replacement” treatment was ultimately selected and was the second highest ranked solution.

The participant noted that if they were seeking to undertake a short-term repair, options such as “Deep Lift Asphalt” or “Reshaping/Shallow Stabilisation” might have been considered.

Date of Assessment: 17/03/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Supply Street
Locality: Nowra
Segment Number: 1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Shoving *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Recommended Remediation Option: **In-Situ Stabilisation**

Summary of Results

Importance Factor	6	6	6	10	Overall Weighted Score
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	
In-Situ Stabilisation	52.00	25.00	10.00	10.00	75.3%
Full Flexible Replacement	218.00	30.00	10.00	10.00	71.9%
Deep Lift Asphalt	81.00	25.00	7.00	8.00	62.6%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	53.7%

Figure C.16 – Prototype PaveMaint SELECT Results: Shoving – Supply Street, Nowra

C.4.2.3 Case Study: Greenwell Point Road, Pyree

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Medium

Dominant Defect: Edge Break

Treatment Selected: Patch (with some Grading)

Severity: Poor

Cost Constraint: 3/4

Longevity Required: 2/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

The defect was modelled in the DSS which produced "Patching" as the recommended (and only) treatment option, which was in agreement with the participant's own selection.

Date of Assessment: 17/03/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Greenwell Point Road
Locality: Pyree
Segment Number: Pyree Lane
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Edge Break *Severity:* 4
Traffic Volume: up to 1x10^5 ESA (1= slight >>> 5= unsatisfactory)

Recommended Remediation Option: **Hot/Cold Mix Asphalt Patching**

Summary of Results

Importance Factor	6	3	6	5	Overall Weighted Score
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	100.0%

Figure C.17 – Prototype PaveMaint SELECT Results: Edge Break – Greenwell Point Road, Pyree

C.4.3 Participant 3

Participant 3 (P3) is a Road Asset Manager responsible for the management and planning of maintenance of their organisation's roads network.

The organisation considers itself quite adept at road works and has a strong understanding of its network's local characteristics. Over the participant's (and the organisation's) experience with their road network, they have condensed their repair and reconstruction methodologies into the following seven treatment types:

1. Lean Mix Concrete – 100mm thick subbase from 7MPa lean mix concrete with 100mm thick asphaltic concrete base course/wearing surface.
2. In-Situ Stabilisation – 250mm (or greater) cement stabilised base course with a 14/7mm spray seal.
3. Deep Lift Asphalt – 100mm thick asphaltic concrete base course/wearing surface.
4. No-Fines Concrete – Subsurface drainage overlain with no-fines concrete to improve pavement drainage.
5. Asphaltic Concrete Resurfacing.
6. Bituminous Spray Seal – 7mm single coat seal.
7. High Friction Seal – proprietary polymerised high stress seal for areas such as cul-de-sac's and car parks with significant tensile stresses due to turning manoeuvres.

The road network contains a number of slag-cement based pavements, which the participant considered "higher than normal" for other council areas due to an abundance of by-product slag produced in their local area. These pavements behave in a similar manner to stabilised (or semi-bound) pavements and the participant highlighted that cracking and deformation defects are the largest proportion of the defects treated by the organisation.

In utilising the prototype PaveMaint SELECT software the following comments and notes were made:

- PSI would be an appropriate input to enter into the "Road Details" user form.

- A good input for the DSS could pavement depth or subgrade parameters as this will assist in pruning unsuitable options.
- In Central Business District (CBD) areas, the participant would not undertake "Stabilisation" or "Spray Seal" treatments because of amenity and dust issues during the construction of the works as well as the time required to undertake the works.
- The participant considered "Lean Mix Concrete" treatments to be the most effective repair with the greatest longevity.
- Percentage of pavement affected will influence the selection of a treatment option.
- The questions pertaining to longevity ("Constraints 1" user form) are confusing and require refinement.

Specifically regarding defects within the system, the participant noted the following:

- "Aggregate Polishing", "Edge Breaks", "Flushing", "Rutting", "Erosion Channels", "Corrugations", "Shoving" and "Loss of Fines" are defects that are rarely found in the participants road network and are therefore not applicable to that organisation.
- The participant did not differentiate between the various types of "Cracking" and were all considered to be the same.
- "Oxidation" and "Raveling" were considered to be the same defect and are referred to as "Surface Texture"; likewise "Potholes" and "Delamination" are also considered to be the same defect.
- "Pumping" is closely linked with "Crocodile Cracking", that is "Pumping" is considered more of a degree of deterioration of "Crocodile Cracking" and is not treated as a standalone defect.
- Considers the most important and common defects in their road network are "Depressions" and "Crocodile Cracking".

The following comments were noted about the remediation options in the system:

- Their road network did not have any unsealed roads, therefore the repairs associated with those pavement types were not undertake by the organisation,

which include “Reshaping and Shallow Stabilisation”, “Pavement Nourishment”, “Grading” and “Ripping”.

- “Full Flexible Replacement”, “Slurry Seal”, “Rejuvenation Seal” and “Cold Mix Asphalt” treatments are not undertaken by the organisation. It was noted that value of a “Rejuvenation Seal” is quite poor and that it is considered more cost-effective to simply undertake a “Spray Seal”.
- “Crack Sealing” is rarely undertaken on its own due to poor aesthetic performance, but may be utilised as a pre-treatment in combination with other surface treatments.

C.4.3.1 Case Study: Burelli Street, Wollongong

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Pumping

Treatment Selected: In-Situ Stabilisation

Severity: Poor

Cost Constraint: 1/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

The defect was modelled in the DSS which recommended two options “Full Flexible Replacement” and “In Situ Stabilisation”, where “Full Flexible Replacement” was recommended as the most suitable treatment option (Figure C.18). Upon discussion it was thought that the low “Importance” for cost was misrepresentative, which was then refined by the participant to a value of 2, which then resulted in “In Situ Stabilisation” becoming the recommended treatment option (Figure C.19).

It was also highlighted that the participant would not consider a “Full Flexible Replacement” for their road network and suggested a repair such as “Lean Mix Concrete” would be a more suitable option.

Date of Assessment: 15/04/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Burelli Street
Locality:	Wollongong
Segment Number:	20
Pavement Type:	Sealed Flexible - Asphalt Surface Pavement
Defect Assessed:	Pumping
Traffic Volume:	up to 1x10^6 ESA

Severity: 4 (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	1	6	6	10	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Full Flexible Replacement	218.00	30.00	10.00	10.00	**97.7%**
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**97.0%**

Figure C.18 – Prototype PaveMaint SELECT Results: Pumping – Burelli Street, Wollongong

Date of Assessment: 15/04/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Burelli Street
Locality:	Wollongong
Segment Number:	20
Pavement Type:	Sealed Flexible - Asphalt Surface Pavement
Defect Assessed:	Pumping
Traffic Volume:	up to 1x10^6 ESA

Severity: 4 (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **In-Situ Stabilisation**

Summary of Results

Importance Factor	2	6	6	10	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**97.1%**
Full Flexible Replacement	218.00	30.00	10.00	10.00	**95.5%**

Figure C.19 – Prototype PaveMaint SELECT Results: Importance Factor Refinement Pumping – Burelli Street, Wollongong

C.4.3.2 Case Study: Grey Street, Keiraville

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Crocodile Cracking

Treatment Selected: Lean Mix Concrete

Severity: Unserviceable

Cost Constraint: 1/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

The DSS modelled the defect, recommending "Full Flexible Replacement" as the preferred treatment option which was not in accordance with the participant's own decision. In addition, there were a further six treatment options provided in the "Results" sheet, three of which the participant considered to be acceptable solutions, while the remaining three were not, these are summarised in Table C.22 below.

Table C.22 – Participant 3 Consideration of DSS Results for Case Study C.4.3.2

Treatment Option	**Acceptable Solution?**
Full Flexible	No – consider Lean Mix Concrete instead
In-Situ Stabilisation	Yes
Asphalt Resurfacing	Yes
Hot/Cold Mix Asphalt Patching	Yes
Slurry Seal	No
Rejuvenation Seal	No
Crack Sealing	No

Date of Assessment: 15/04/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Grey Street
Locality: Keiraville
Segment Number: 10, 20
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Crocodile Cracking ***Severity:*** 5
(1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	1	10	7	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Full Flexible Replacement	218.00	30.00	10.00	10.00	**78.0%**
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**73.2%**
Asphalt Resurfacing	29.00	20.00	5.00	10.00	**64.5%**
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	**45.1%**
Slurry Seal	9.00	8.00	5.00	7.00	**40.1%**
Rejuvenation Seal	6.00	5.00	5.00	7.00	**38.1%**
Crack Sealing	13.00	3.00	2.00	2.00	**36.2%**

Figure C.20 – Prototype PaveMaint SELECT Results: Crocodile Cracking – Grey Street, Keiraville

C.4.3.3 Case Study: Simpson Place, Wollongong

<u>Treatment Data:</u>

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Oxidation

Treatment Selected: Asphalt Resurfacing

Severity: Poor

Cost Constraint: 1/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

Figure C.21 shows that when the defect was modelled in the DSS, it recommended "Asphalt Resurfacing" as the most suitable remediation option, which is in agreement with selection of the participant. Upon reviewing the other recommended options, the participant outlined that they would not consider "Slurry Seal" as a treatment option in this instance; however, it was discussed that a significant reason for this is that in NSW there are currently no suppliers offering this treatment and it has "gone out of fashion".

Date of Assessment: 15/04/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Simpson Place		
Locality:	Wollongong		
Segment Number:	10		
Pavement Type:	Sealed Flexible - Asphalt Surface Pavement		
Defect Assessed:	Oxidation	*Severity:*	4
Traffic Volume:	up to 1x10^4 ESA		(1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	1	10	6	10	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	20.00	5.00	10.00	97.9%
Spray Seal	16.00	10.00	5.00	8.00	79.4%
Slurry Seal	9.00	8.00	5.00	7.00	69.4%
Rejuvenation Seal	6.00	5.00	5.00	7.00	63.5%

Figure C.21 – Prototype PaveMaint SELECT Results: Oxidation – Simpson Place, Wollongong

C.4.4 Participant 4

Participant 4 (P4) is an Asset Manager responsible for the management and planning of maintenance of their organisation’s assets, including the roads network.

A large proportion of P4’s road network consists of unsealed flexible pavements with very low traffic loads in the order of approximately 100 vehicles per day and a large proportion of heavy vehicles (up to 30%). With such low traffic loads, the unsealed road component of the network is commonly constructed from a slender pavement of typically 100 millimetre thickness using natural gravels that contain a higher plasticity that wouldn’t necessarily be suitable in a sealed pavement but for an unsealed pavement allow for better binding of the pavement materials.

It was discovered that what is referenced as “Pavement Nourishment” through literature review is referred to by this participant as “Gravel Resheet”. It was discussed that particularly with unsealed pavements, intervention at moderate

severities is undertaken and that the organisation undertakes a regular "Gravel Resheet" program under its capital works expenditure, prioritised on a yearly basis with an expected performance life anywhere between five years up to twenty-five years.

The participant explored a number of examples from Lower River Road, Tocumwal (a major unsealed road in the organisation's road network) and while using the prototype PaveMaint SELECT, the participant made the following notes:

- Despite the low traffic load on the unsealed pavements in this organisation's road network, many are classified as "Collector" roads and therefore the *ALT* for the "Traffic Load" field in the "Road Details" user-form could be misleading to a lesser experienced user.
- In the case of unsealed pavements, aesthetics have a relatively high importance; such that a pavement that the community believes looks bad, is quite often in poor condition. Therefore, aesthetics go hand-in-hand with functionality and performance.
- The defect "Raveling" would not be considered by this organisation, but would be closely associated with "Loss of Pavement" which should be added to the defects list.
- The participant indicated that the majority of their work utilises a combination of "Ripping" with "Pavement Nourishment" (thereby mixing the existing pavement material with imported pavement materials) followed by "Grading" to reshape the surface. However, this was discussed further and it was decided that this is almost certainly the description associated with the work methodology of a "Gravel Resheet", albeit a thinner profile adaptation of that treatment, and therefore considered to be the same thing.
- In addition to the "Gravel Resheet" option, the organisation also undertakes "Gravel Patch" repairs which are considered to be the unsealed pavement's equivalent to the "Hot/Cold Mix Asphalt Patching" undertaken on sealed pavements, and used in the treatment of "Potholes" and "Soft Spots".
- "Reshape/Shallow Stabilisation" is not a remediation option undertaken by the organisation.

C.4.4.1 Case Study: Lower River Road, Tocumwal

Treatment Data:

Road Type: Flexible Unsealed

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Potholes

Treatment Selected: Gravel Patch

Severity: Moderate

Cost Constraint: 3/4

Longevity Required: 4/4

Resource Constraints: 1/3

Aesthetic Constraints: 2/3

The defect was modelled in the DSS (Figure C.22) which recommended "Grading" as the most suitable treatment option. At this point the system does not contain the remediation option of "Gravel Patch"; however it was thought by the participant that from the remediation options listed, "Pavement Nourishment" would have been a more suitable selection and that "Grading" on its own was not a suitable solution for "Potholes".

Date of Assessment: 22/05/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Lower River Road
Locality: Tocumwal
Segment Number: 1
Pavement Type: Unsealed Flexible Pavement
Defect Assessed: Potholes *Severity:* 3
(1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Recommended Remediation Option: **Grading**

Summary of Results

Importance Factor	6	10	3	5	Overall Weighted Score
Edit Importance Factors	**Cost of Repair ($ / sq.m)**	**Longevity of Repair (years)**	**Time for Repair (Factor)**	**Aesthetic Finish (Factor)**	
Grading	2.00	1.00	1.00	10.00	85.3%
Ripping	4.00	1.00	1.00	10.00	76.5%
Pavement Nourishment	11.00	2.00	3.00	10.00	75.5%

Figure C.22 – Prototype PaveMaint SELECT Results: Potholes – Lower River Road, Tocumwal

C.4.4.2 Case Study: Lower River Road, Tocumwal

Treatment Data:

Road Type: Flexible Unsealed

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Other – Loss of Pavement

Treatment Selected: Gravel Resheet

Severity: Moderate

Cost Constraint: 3/4

Longevity Required: 4/4

Resource Constraints: 1/3

Aesthetic Constraints: 2/3

The defect was modelled in the DSS as "Raveling" in lieu of a "Loss of Pavement" defect being considered in the system (Figure C.23). With consideration that "Gravel Resheet" is otherwise referred to as "Pavement Nourishment" in the prototype DSS, so generally the participant indicated that the resultant solutions presented were generally in concurrence with their own experience, with the exception that "Pavement Nourishment" would have been the preferred option.

Date of Assessment: 22/05/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Lower River Road
Locality: Tocumwal
Segment Number: 5
Pavement Type: Unsealed Flexible Pavement
Defect Assessed: Raveling *Severity:* 3
Traffic Volume: up to 1x10^4 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Grading**

Summary of Results

Importance Factor	6	10	3	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Grading	2.00	1.00	1.00	10.00	81.6%
Pavement Nourishment	11.00	2.00	3.00	10.00	79.7%
Ripping	4.00	1.00	1.00	10.00	76.5%

Figure C.23 – Prototype PaveMaint SELECT Results: Raveling (as Loss of Pavement) – Lower River Road, Tocumwal

C.4.4.3 Case Study: Lower River Road, Tocumwal

<u>Treatment Data:</u>

Road Type: Flexible Unsealed

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Soft Spots

Treatment Selected: Full Flexible Replacement

Severity: Moderate

Cost Constraint: 3/4

Longevity Required: 4/4

Resource Constraints: 1/3

Aesthetic Constraints: 2/3

The defect was modelled in the DSS which provided "In Situ Stabilisation" as the most suitable solution (Figure C.24). The participant questioned the recommendation to use "In-Situ Stabilisation" at all for unsealed pavements as it was thought that this treatment changes the pavement characteristic which would affect the cost-effectiveness of this pavement type in the road network. That is, unsealed pavements are considered cost-effective because their relative cost of maintenance is quite low compared to treatments required for sealed pavements. An "In-Situ Stabilisation" treatment would create a semi-bound pavement that would render any subsequent repair options for unsealed pavements unsuitable.

Date of Assessment: 22/05/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Lower River Road
Locality: Tocumwal
Segment Number: 2
Pavement Type: Unsealed Flexible Pavement
Defect Assessed: Soft Spots — *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Recommended Remediation Option: **In-Situ Stabilisation**

Summary of Results

Importance Factor	6	10	3	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
In-Situ Stabilisation	52.00	15.00	10.00	10.00	**79.9%**
Full Flexible Replacement	218.00	15.00	10.00	10.00	**77.1%**
Pavement Nourishment	11.00	2.00	3.00	10.00	**62.7%**

Figure C.24 – Prototype PaveMaint SELECT Results: Soft Spots – Lower River Road, Tocumwal

C.4.5 Participant 5

Participant 5 (P5) is a Road Asset Manager responsible for the management and planning of the road maintenance of their organisation's roads network.

The participant considered the prototype DSS especially important for their own use, as the organisation is currently investigating the implementation of a pavement management system (PMS) and would consider PaveMaint SELECT one tool in a range of tools that could be available to their organisation.

Upon using the prototype DSS the participant made the following comments:

- The "Results" sheet should also display the PSI for that segment of road, as further justification as to their decision to undertake works

- The “Overall Weighted Scores” are quite close and it would be better to see more variance in those values.
- The Importance Factors for “Speed” and “Aesthetics” seemed to be quite high. While they are important and will assist with options pruning, they have a large impact on the results, when it is “Cost” and “Longevity” that are the most important constraints to the organisation.

C.4.5.1 Case Study: Browns Road, South Nowra

<u>Treatment Data:</u>

Road Type:	Flexible Bituminous Spray Sealed
Traffic Conditions:	Up to 10^5 ESA
Dominant Defect:	Rutting
Treatment Selected:	Full Flexible Replacement
Severity:	Unserviceable
Cost Constraint:	4/4
Longevity Required:	4/4
Resource Constraints:	1/3
Aesthetic Constraints:	2/3

The defect was modelled in the DSS (Figure C.25) which provided “Full Flexible Replacement” as the suitable solution, which was in agreement with the participant’s own decision.

The participant indicated that the treatment options “Asphalt Resurfacing”, “Slurry Seal” and “Hot/Cold Mix Asphalt” that were also suggested by the DSS were not considered acceptable solutions, while the suggested “In-Situ Stabilisation” and “Lean Mix Concrete” options were. The participant also noted that a “Deep Lift Asphalt” treatment would have also been suitable in the treatment of “Rutting”.

Date of Assessment: 7/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Browns Road
Locality: South Nowra
Segment Number: 1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Rutting *Severity:* 5
Traffic Volume: up to 1x10^5 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	10	10	5	5	
Edit Importance Factors	**Cost of Repair ($ / sq.m)**	**Longevity of Repair (years)**	**Time for Repair (Factor)**	**Aesthetic Finish (Factor)**	**Overall Weighted Score**
Full Flexible Replacement	218.00	30.00	10.00	10.00	**64.8%**
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**63.9%**
Lean Mix Concrete	125.00	25.00	10.00	10.00	**61.4%**
Asphalt Resurfacing	29.00	25.00	5.00	10.00	**58.6%**
Slurry Seal	9.00	10.00	5.00	7.00	**57.1%**
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	**40.3%**

Figure C.25 – Prototype PaveMaint SELECT Results: Rutting – Browns Road, South Nowra

C.4.5.2 Case Study: Church Street, Milton

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Crocodile Cracking

Treatment Selected: Full Flexible Replacement

Severity: Unserviceable

Cost Constraint: 4/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

The defect was modelled in the DSS which agreed with the participant's own decision of "Full Flexible Replacement" as the most suitable remediation option Figure C.26.

Table C.23 outlines the participant's acceptance of the remediation options suggested in the "Results" sheet but also stated that a "Spray Seal" would also have been an acceptable remediation option that they would have considered in this instance.

Table C.23 – Participant 5 Consideration of DSS Results for Case Study C.4.5.2

Treatment Option	Acceptable Solution?
Full Flexible	Yes
In-Situ Stabilisation	Yes
Asphalt Resurfacing	Yes
Rejuvenation Seal	No
Slurry Seal	No
Crack Sealing	No
Hot/Cold Mix Asphalt Patching	No

Date of Assessment: 7/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Church Street
Locality: Milton
Segment Number: 1 & 2
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Crocodile Cracking *Severity:* 5
Traffic Volume: up to 1x10^6 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Full Flexible Replacement**

Summary of Results

Importance Factor	10	10	5	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Full Flexible Replacement	218.00	30.00	10.00	10.00	64.4%
In-Situ Stabilisation	52.00	25.00	10.00	10.00	62.5%
Asphalt Resurfacing	29.00	25.00	5.00	10.00	61.0%
Rejuvenation Seal	6.00	5.00	5.00	7.00	52.9%
Slurry Seal	9.00	10.00	5.00	7.00	48.8%
Crack Sealing	13.00	5.00	2.00	2.00	39.5%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	37.4%

Figure C.26 – Prototype PaveMaint SELECT Results: Crocodile Cracking – Church Street, Milton

C.4.6 Participant 6

Participant 6 (P6) is a Road Asset Manager responsible for the management and planning of the road maintenance of their organisation's roads network.

The participant considers the organisation to be in a strong financial situation that allows for early intervention of defects but, as such, is also in the midst of a program (nearing completion) to seal all the unsealed roads in their road network. Therefore the road network is made up almost exclusively sealed flexible pavements.

C.4.6.1 Case Study: Terralong Street, Kiama

<u>Treatment Data:</u>

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Other – Surface Irregularities

Treatment Selected: Asphalt Resurfacing

Severity: Moderate

Cost Constraint: 2/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

The defect was modelled in the DSS as "Patching Failure" in lieu of "Surface Irregularities" (Figure C.27) which recommends the most suitable remediation option as "Asphalt Resurfacing" and is concurrence with the participant's own decision making.

The participant suggested that the cost of "Asphalt Resurfacing" is in the order of $24 per square metre, and that the aesthetic factor for "Deep Lift Asphalt" is low and that it should be the equivalent of "Asphalt Resurfacing", that is a value of 10.

In addition, the participant commented that the severity description didn't quite match their own expectations and if they were to use the *ALT*'s description they would have chosen a value of 2.

Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Terralong St
Locality: Kiama
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Patching Failure *Severity:* 3
Traffic Volume: up to 1x10^6 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	3	10	5	10	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	25.00	5.00	10.00	88.7%
Deep Lift Asphalt	81.00	25.00	7.00	8.00	78.1%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	47.2%

Figure C.27 – Prototype PaveMaint SELECT Results: Patching Failure – Terralong Street, Kiama

C.4.6.2 Case Study: Havilah Place, Kiama

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Rutting

Treatment Selected: Asphalt Resurfacing

Severity: Moderate

Cost Constraint: 2/4

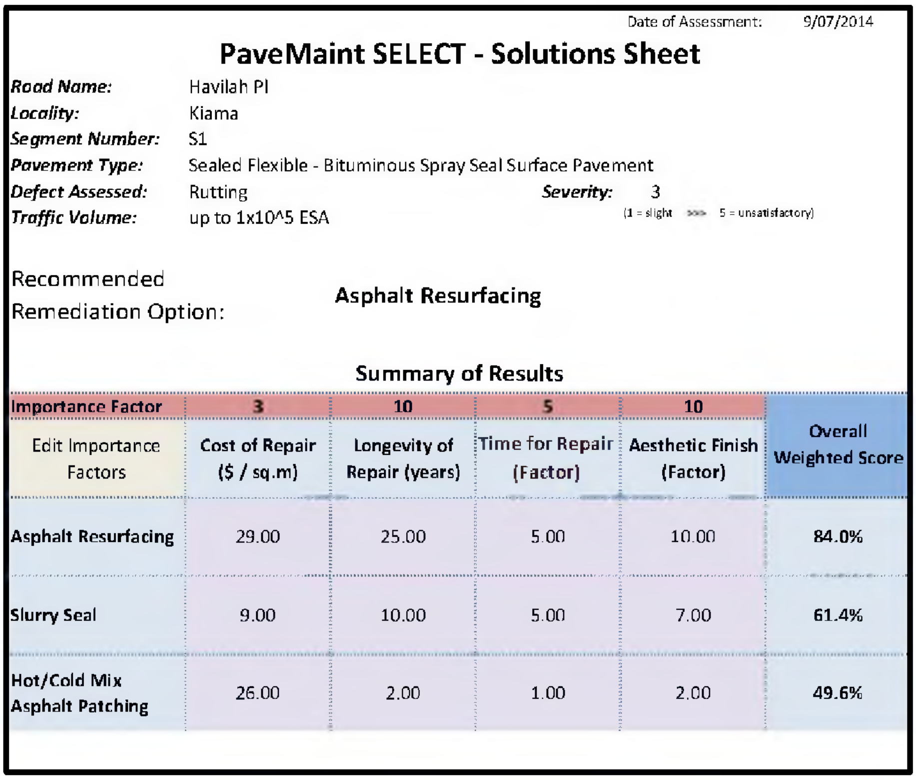
Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

The defect was modelled in the DSS (Figure C.28) which recommended the same solution as most suitable as the participant.

From the other recommended solutions, the participant commented that a “Slurry Seal” would not be considered for this defect and that “Deep Lift Asphalt” should be included instead.



Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Havilah Pl
Locality: Kiama
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Rutting *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	3	10	5	10	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	25.00	5.00	10.00	84.0%
Slurry Seal	9.00	10.00	5.00	7.00	61.4%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	49.6%

Figure C.28 – Prototype PaveMaint SELECT Results: Patching Failure – Havilah Place, Kiama

C.4.6.3 Case Study: Foxground Road, Foxground

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Other – Surface Irregularities

Treatment Selected: In-Situ Stabilisation

Severity: Moderate

Cost Constraint: 2/4

Longevity Required: 2/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

The participant indicated that the deterioration of the pavement was due to excessive and failing pothole and patching repairs combined with "Edge Break" defects. The defect was modelled in the DSS as "Patching Failure" in lieu of "Surface Irregularities" in the system (Figure C.29), however the desired "In-Situ Stabilisation" treatment was not a recommendation of the DSS.

In order to test the system's sensitivity to the chosen defect, the DSS was run again instead with "Edge Break" as the selected defect (Figure C.30). However, again the recommended remediation options did not align with the participant's own considerations.

It was discussed that due to the low severity (moderate), options such as "In-Situ Stabilisation" and "Full Flexible Replacement" are pruned from selection and that the participant's unique budgetary/financial circumstances have resulted in participant choices that are not 'ordinary' for most other councils in NSW.

Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Foxground Rd
Locality: Foxground
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Patching Failure *Severity:* 3
Traffic Volume: up to 1x10^4 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	3	3	5	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	25.00	5.00	10.00	83.4%
Deep Lift Asphalt	81.00	25.00	7.00	8.00	71.8%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	63.0%

Figure C.29 – Prototype PaveMaint SELECT Results: Patching Failure – Foxground Road, Foxground

Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Foxground Rd
Locality: Foxground
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Edge Break *Severity:* 4
Traffic Volume: up to 1x10^4 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Hot/Cold Mix Asphalt Patching**

Summary of Results

Importance Factor	3	10	6	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	100.0%

Figure C.30 – Prototype PaveMaint SELECT Results: Edge Break – Foxground Road, Foxground

C.4.6.4 Case Study: Oxely Avenue, Kiama

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Crocodile Cracking

Treatment Selected: Asphalt Resurfacing

Severity: Moderate

Cost Constraint: 2/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

The defect was modelled in the DSS (Figure C.31) which concurred with the participant's own selection, but considered that the addition of "Deep Lift Asphalt" should have also been suggested in the recommended options.

Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Oxely Ave
Locality:	Kiama
Segment Number:	S2
Pavement Type:	Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed:	Crocodile Cracking — *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume:	up to 1x10^5 ESA

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	3	10	5	10	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	25.00	5.00	10.00	83.2%
Slurry Seal	9.00	10.00	5.00	7.00	53.3%
Rejuvenation Seal	6.00	5.00	5.00	7.00	50.7%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	42.1%

Figure C.31 – Prototype PaveMaint SELECT Results: Crocodile Cracking – Oxely Avenue, Kiama

C.4.6.5 Case Study: Wallaby Hill Road, Jamberoo

<u>Treatment Data:</u>

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Oxidation

Treatment Selected: Spray Seal

Severity: Poor

Cost Constraint: 2/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 1/3

The defect was modelled in the DSS which recommended "Asphalt Resurfacing" as the most suitable remediation option (Figure C.32). However, the participant identified that the cost of "Spray Seal" was higher than the organisation's known costs. Therefore, the cost was adjusted down to $6 per square metre and the "Results" sheet was updated which resulted in the recommendation being changed to the participant's preferred "Spray Seal" (Figure C.33).

Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Wallaby Hill Rd
Locality: Jamberoo
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Oxidation ***Severity:*** 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	5	6	6	1	Overall Weighted Score
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	
Asphalt Resurfacing	29.00	25.00	5.00	10.00	85.8%
Spray Seal	16.00	15.00	5.00	8.00	79.6%
Slurry Seal	9.00	10.00	5.00	7.00	73.0%
Rejuvenation Seal	6.00	5.00	5.00	7.00	71.1%

Figure C.32 – Prototype PaveMaint SELECT Results: Oxidation – Wallaby Hill Road, Jamberoo

Date of Assessment: 9/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Wallaby Hill Rd
Locality: Jamberoo
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Oxidation *Severity:* 4
Traffic Volume: up to 1x10^4 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Spray Seal**

Summary of Results

Importance Factor	5	6	6	1	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Spray Seal	6.00	15.00	5.00	8.00	90.7%
Asphalt Resurfacing	29.00	25.00	5.00	10.00	85.8%
Slurry Seal	9.00	10.00	5.00	7.00	73.0%
Rejuvenation Seal	6.00	5.00	5.00	7.00	71.1%

Figure C.33 – Prototype PaveMaint SELECT Results: (Adjusted Remediation Costs) Oxidation – Wallaby Hill Road, Jamberoo

C.4.7 Participant 7

Participant 7 (P7) is a Road Asset Manager responsible for the management and planning of the road maintenance of their organisation's roads network.

The participant's organisation is a metropolitan council who have a high proportion (98%) of asphaltic concrete surfaced flexible pavements. They do not have any unsealed pavements nor do they have any bituminous spray sealed pavements in their road network as they are considered uncharacteristic for the urban area, and so the remaining proportion (2%) are rigid pavements. In the case of bituminous spray sealed pavements, it was considered that these surfaces generate a higher amount of tyre noise caused by vehicle passage, which is an important consideration for metropolitan and densely populated urban areas, which therefore leads to the selection of asphalt surfaced pavements (which are quieter) in these areas.

The participant's organisation once ran a Pavement Management System (PMS) but no longer does. Data is collected through the Maintenance Engineer who reviews the roads in their network and programs work based on the immediacy of the condition, along with residents' complaints. Periodically the organisation will engage consultants to undertake a vehicle survey (equipped with sensors that capture electronically the condition of the pavement) in order to capture a whole of network snapshot for the roads network.

The participant is highly aware that their organisation's budgetary constraints change with every financial year, based on the number of capital projects planned and other strains. Therefore, they will often devise a larger program of resheets and overlays in favour of structural repairs as a way to provide better coverage for the network. However, conversely, when the budget is quite healthy the participant will elect to take early intervention on defects and will favour more complete structural repairs.

In utilising the prototype PaveMaint SELECT software the following comments and notes were made:

- The *ALT*'s for describing severity and all constraints needed refinement. For example, severity for both "Oxidation" and "Raveling" should be:
    - Slight – up to 10% of the pavement affected
    - Moderate – up to 20% of the pavement affected
    - Poor – greater than 50% of the pavement affected
    - Unserviceable is not a condition associated with these defect types and should not be considered as such.
- Likewise, "Cracking" defects should be presented in terms of percentage affecting pavement, not fissure width
- Consider the inclusion of "Surface Irregularities" as a defect.
- Would like the opportunity to test more than one defect at a time.
- Did not completely understand the in which the "Resource" constraint plays in the DSS.

- While the cost of the “Deep Lift Asphalt” remediation is approximately correct, it doesn’t seem to incorporate the associated cost of the final asphalt wearing course and is therefore lower what would be expected.
- The participant questioned some of the results, in that while it may be technically correct to undertake some of recommended options, the participant would consider the expected longevity against the cost of the option. It was discussed the role of the system’s “Effectiveness’ rating plays in the treatment options evaluation and the participant considered that a cost-life ratio might be a better application.

C.4.7.1 Case Study: Dora Street, Hurstville

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Crocodile Cracking

Treatment Selected: Crack Sealing

Severity: Moderate

Cost Constraint: 2/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

The assessment was undertaken on a decision which the participant considered poor. Undertaken a number of years previous (and before their own tenure), “Crack Sealing” over such an extensive area of “Crocodile Cracking” provided a particularly unideal outcome with significantly poor aesthetic appearance. In fact, the repair is so pronounced that is can be seen from satellite/aerial images of the area (Figure C.34).

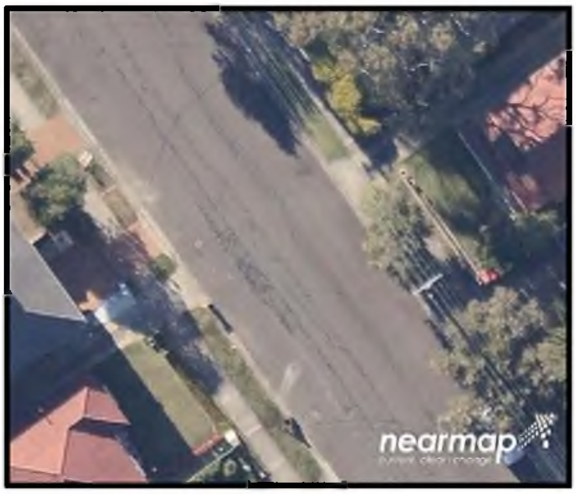


Figure C.34 – Satellite Imagery of Crack Sealing Repair of Dora Street, Hurstville (NearMap 2014)

The defect was modelled in the DSS (Figure C.35) which recommended "Asphalt Resurfacing" as the most suitable remediation option, but also did not suggest "Crack Sealing" as an option at all. The participant agreed with this outcome and would choose the same option given the chance today.

Date of Assessment: 22/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Dora Street
Locality: Hurstville
Segment Number: A
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Crocodile Cracking *Severity:* 3
(1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	3	3	5	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	20.00	5.00	10.00	75.5%
Rejuvenation Seal	6.00	5.00	5.00	7.00	55.8%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	55.7%
Slurry Seal	9.00	8.00	5.00	7.00	53.7%

Figure C.35 – Prototype PaveMaint SELECT Results: Crocodile Cracking – Dora Street, Hurstville

C.4.7.2 Case Study: Warrawee Place, Beverly Hills

<u>Treatment Data:</u>

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Other – Surface Irregularities

Treatment Selected: Deep Lift Asphalt

Severity: Poor

Cost Constraint: 4/4

Longevity Required: 3/4

Resource Constraints: 3/3

Aesthetic Constraints: 3/3

The defect was modelled in the DSS as "Potholes" in lieu of a "Surface Irregularities" defect yet being incorporated into the system (Figure C.36). Despite this, the resultant recommended remediation option was in concurrence with that selected by the participant.

Date of Assessment: 22/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Warrawee PL
Locality:	Beverly Hills
Segment Number:	full
Pavement Type:	Sealed Flexible - Asphalt Surface Pavement
Defect Assessed:	Potholes — *Severity:* 4
Traffic Volume:	up to 1x10^5 ESA — (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Deep Lift Asphalt**

Summary of Results

Importance Factor	10	5	10	8	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Deep Lift Asphalt	81.00	25.00	2.00	10.00	66.0%
In-Situ Stabilisation	52.00	25.00	10.00	10.00	65.5%
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	62.6%
Full Flexible Replacement	218.00	30.00	10.00	10.00	58.6%

Figure C.36 – Prototype PaveMaint SELECT Results: Raveling – Warrawee Place, Beverly Hills

C.4.7.3 Case Study: Pindaree Road, Peakhurst

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Block Cracking

Treatment Selected: Crack Sealing with Deep Lift Asphalt sections

Severity: Moderate

Cost Constraint: 3/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

The defect was modelled in the DSS (Figure C.37) but did not recommend either "Crack Sealing" or "Deep Lift Asphalt" treatment options. It was considered that the pruning constraints in the system required refinement as there were no obvious reasons as to why these selections were not recommended by the DSS and should have been.

Date of Assessment: 22/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Pindaree Road
Locality: Peakhurst
Segment Number: 1
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Block Cracking ***Severity:*** 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

Recommended Remediation Option: **Slurry Seal**

Summary of Results

Importance Factor	6	10	5	5	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Slurry Seal	9.00	8.00	5.00	7.00	94.4%
Rejuvenation Seal	6.00	5.00	5.00	7.00	89.6%

Figure C.37 – Prototype PaveMaint SELECT Results: Block Cracking – Pindaree Road, Peakhurst

C.4.8 Participant 8

Participant 8 (P8) is an Asset Officer that assists the organisation's Road Asset Manager in managing and planning for their road network.

The participant believes that while their department makes the decision to undertake road works, the ultimate decision as to the scope and type of work is not determined until a geotechnical investigation has been undertaken.

C.4.8.1 Case Study: Lockundy Lane, Hurstville

<u>Treatment Data:</u>

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Raveling

Treatment Selected: Asphalt Resurfacing

Severity: Poor

Cost Constraint: 2/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 1/3

The defect was modelled in the DSS (Figure C.38) which resulted in the same remediation option selected by the participant.

Date of Assessment: 22/07/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Lockundy Lane
Locality: Hurstville
Segment Number: Full
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Raveling ***Severity:*** 4
Traffic Volume: up to 1x10^4 ESA (1 = slight >>> 5 = unsatisfactory)

Recommended Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	3	6	6	1	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	20.00	5.00	10.00	90.8%
Slurry Seal	9.00	8.00	5.00	7.00	73.5%
Rejuvenation Seal	6.00	5.00	5.00	7.00	66.2%
Spray Seal	16.00	10.00	5.00	8.00	53.6%

Figure C.38 – Prototype PaveMaint SELECT Results: Raveling – Lockundy Lane, Hurstville

APPENDIX D

DECISION SUPPORT SYSTEM PROGRAM DEVELOPMENT

PAVEMAINT SELECT V1.0 (FINAL RELEASE VERSION)

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DSS CODE NOTES

* Note: All userforms begin with code that ensures when the user clicks to Close (red cross – at top right of the form) the program is properly stopped and reset – otherwise upon restart userforms will be cached and will affect program functionality

D.1 User form - PaveMaint_Home

D.1.1 Description:

- Home screen to begin the program and introduce its purpose (Figure D.1)

D.1.2 Code Function:

- Upon click of "Begin" button
  - o Clear contents of cells C3:C8, K7, C13, G13, I13 and K13 from the Solutions Sheet
  - o Unload any residual data remaining in the User Forms
  - o Reinstate formulas in cells B15:B21, C15:C21, G15:G21, I15:I21, K15:K21 & N15:N21 of the Solutions Sheet
  - o Show Road Details userform (No. D.2)

D.1.3 Accelerated Learning Tools:

- Flexible pavements (Figure D.2)

D.1.4 Screen Shots:

Figure D.1 – PaveMaint SELECT "Home" Screen

Figure D.2 – PaveMaint SELECT *Accelerated Learning Tool*: Flexible Pavements

D.2 User form - PaveMaint_RoadDetails

D.2.1 Description:

- Userform with textboxes for user to input road name, locality, description of road section and traffic of road (Figure D.3)

D.2.2 Code Function:

- Upon click of “Next” button:
  - User input is propagated to the “Results” worksheet in the MS Excel spreadsheet (C3, C4, C5 & H3)
  - Date of assessment is propagated to “Results” worksheet in the MS Excel spreadsheet (N1)
  - Warning message box if user has left a text box empty and stop progress to next sheet (Figure D.4)
  - Hide current form and Show Surface Type userform (No. D.3)

D.2.3 Accelerated Learning Tools:

- Traffic Load ESA (Figure D.5)

D.2.4 Screen Shots:

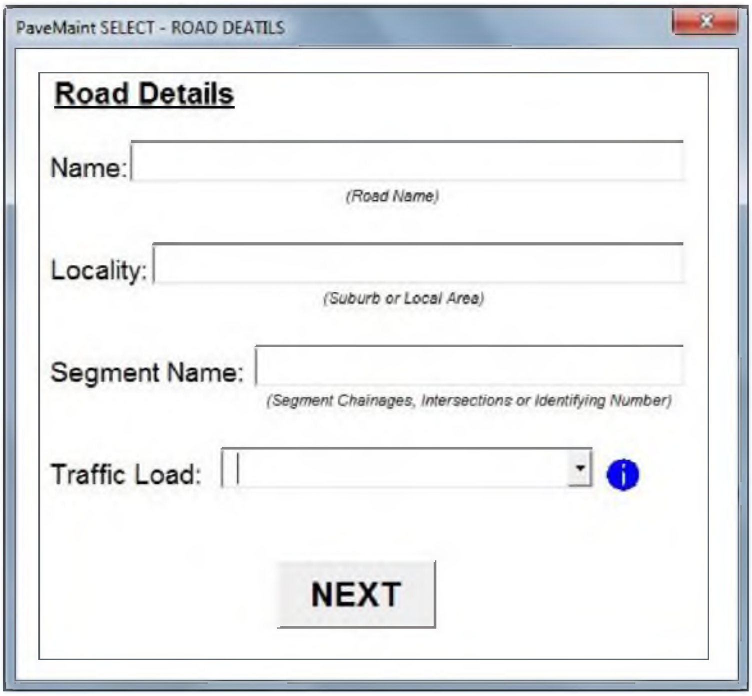


Figure D.3 – PaveMaint SELECT "Road Details" Screen

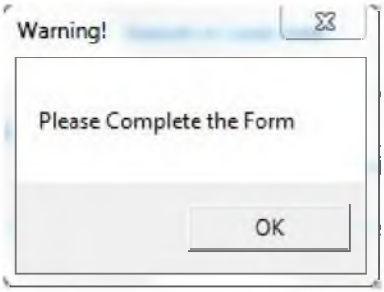


Figure D.4 – PaveMaint SELECT Warning Screen: Incomplete "Road Details" Form

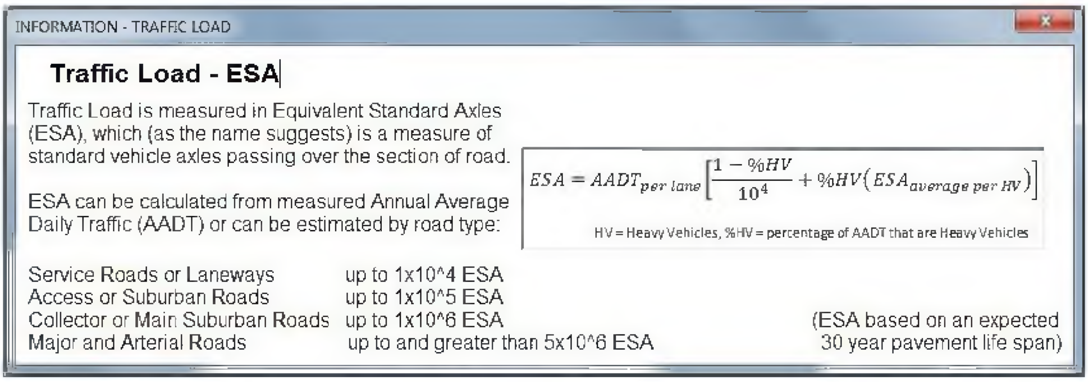


Figure D.5 – PaveMaint SELECT *Accelerated Learning Tool*: "Traffic Load"

D.3 User form - PaveMaint_FlexSurfType

D.3.1 Description:

- Userform with option (or radio) buttons for user to select the surface type of the road being assessed (Asphaltic Concrete, Bituminous Spray Seal or Unsealed Pavement) (Figure D.6)

D.3.2 Code Function:

- Upon click of “Next” button:
  - Turns on the option/radio button and info images on defects1 userform for the appropriate amount of defects for each surface type (uses cells in the knowledgebase worksheets for each of surface types to determine if there is a corresponding defect)
  - Assign the option/radio button labels on defects1 userform – reading from cells in knowledgebase worksheets for each surface type
  - Assign the option/radio button labels on defects2 userform – reading from cells in knowledgebase worksheets for each surface type
  - Propagates the surface type to the “Results” worksheet in the MS Excel spreadsheet (C6) – equation makes cell equal to the equivalent cell in the knowledgebase worksheets
  - Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure D.7)
  - Hide current form and Show Defect Type userform (No. D.4)
- Upon click of “Back” button:
  - Hide Surface Type and Road Details (function does not clear the previous data – the logic is that the user would be going back to simply amend a text field and clearing the data would result in the user needlessly having to fill in all the text boxes again)
  - Show Road Details

D.3.3 Accelerated Learning Tools:

- Asphaltic concrete surfaces (Figure D.8)
- Bituminous spray seal surfaces (Figure D.9)
- Unsealed surfaces (Figure D.10)

D.3.4 Screen Shots:

Figure D.6 – PaveMaint SELECT "Surface Type" Screen

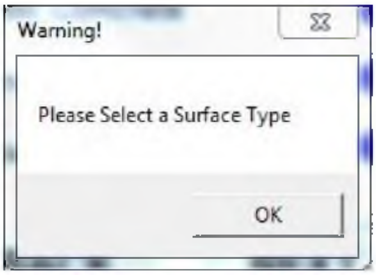


Figure D.7 – PaveMaint SELECT Warning Screen: Incomplete "Surface Type" Form

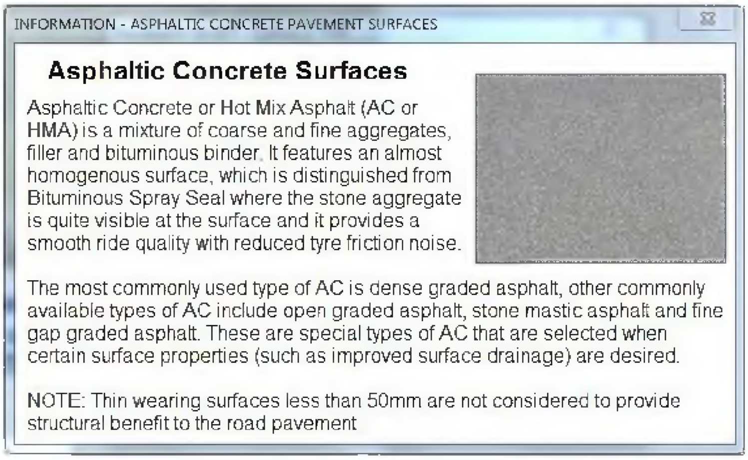


Figure D.8 – PaveMaint SELECT *Accelerated Learning Tool*: "Asphaltic Concrete Surfaces"

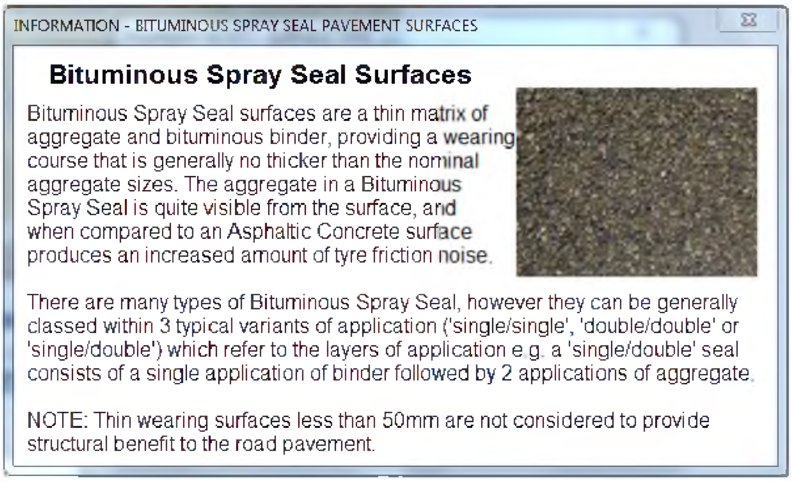


Figure D.9 – PaveMaint SELECT *Accelerated Learning Tool*: “Bituminous Spray Seal Surfaces”

Figure D.10 – PaveMaint SELECT *Accelerated Learning Tool*: “Unsealed Pavements”

D.4 User form - PaveMaint_Defects1

D.4.1 Description:

- Userform with a list of defect types expected for the selected pavement surface type (Figure D.11, Figure D.12 and Figure D.13)

D.4.2 Code Function:

- Upon click of "Next" button:
    - Propagates the defect type to the "Results" worksheet in the MS Excel spreadsheet (C7) – equation makes cell equal to the caption label of the option/radio button selected – will not propagate if cracking is selected, this will be addressed in Cracking Defects userform code
    - Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure D.14)
    - Updates label in Severity userform (No.D.6) to reflect defect chosen (uses caption labels to propagate)
    - Sets Severity options visible or not
    - Sets Severity option/radio button values and accelerated learning tools embedded into the description/label – reading from cells in knowledgebase worksheets for each surface type
    - Hide current form and Show Cracking Defect Type userform (No. D.5) or Show Severity userform (No. D.6) depending on defect chosen
- Upon click of "Back" button:
    - Unload Defects 1 and Defects 2 (clears previous data from the 2 userforms– unloading is necessary for the proper function of the code that makes defects userforms option/radio buttons visible or not visible)
    - Show Surface Type

D.4.3 Accelerated Learning Tools:

- All defect types for all 3 surface types (Table D.1 and Table D.2) – Cracking info button is for cracking generically, specific cracking types are linked to Cracking Defect Type userform (No. D.5)

D.4.4 Screen Shots:

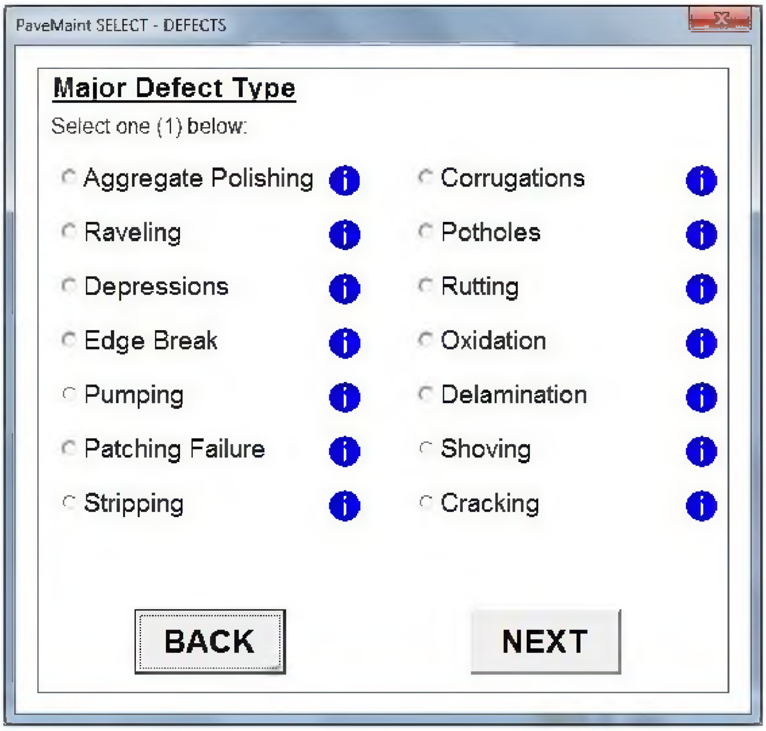


Figure D.11 – PaveMaint SELECT Asphaltic Concrete Surfaced Pavements "Major Defect Type" Screen

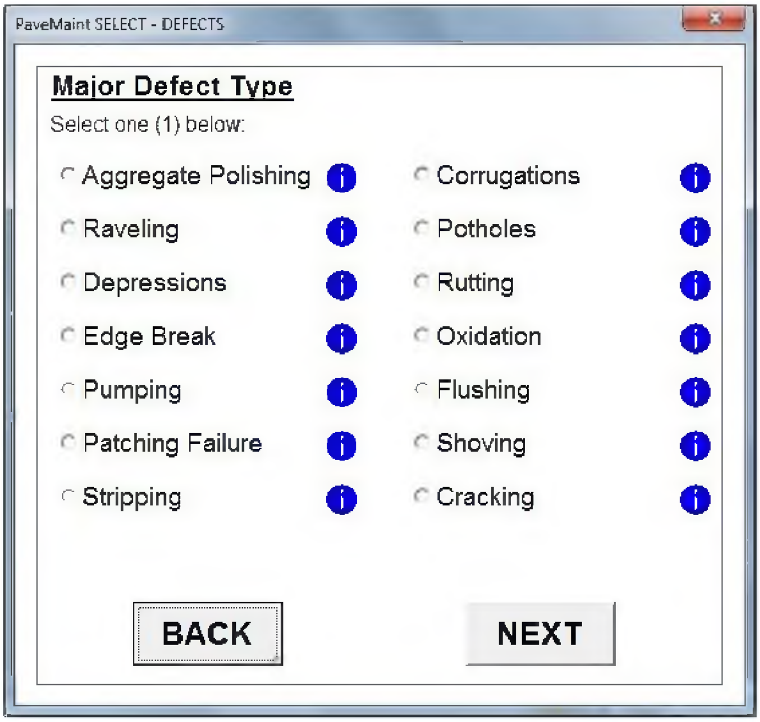


Figure D.12 – PaveMaint SELECT Bituminous Spray Sealed Pavements "Major Defect Type" Screen

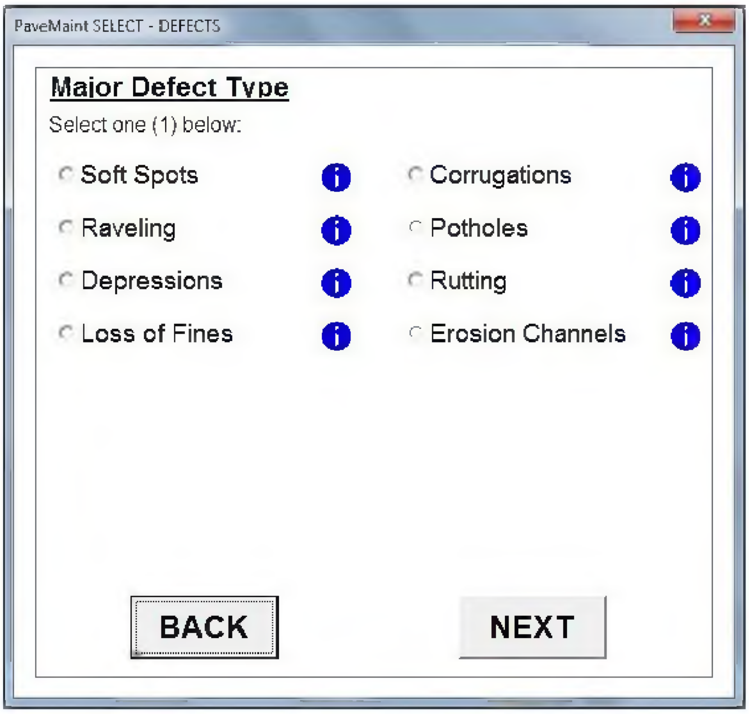


Figure D.13 – PaveMaint SELECT Unsealed Pavements "Major Defect Type" Screen

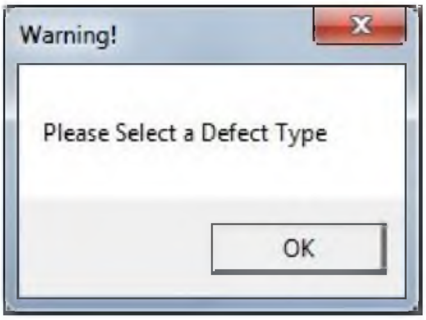


Figure D.14 – PaveMaint SELECT Warning Screen: Incomplete "Defect Type" Form

Table D.1 – *Accelerated Learning Tools* for Defects Associated with Asphaltic Concrete and Bituminous Spray Sealed Pavements - Figure D.11 and Figure D.12

INFORMATION - AGGREGATE POLISHING **Aggregate Polishing**  Aggregate Polishing is sometimes referred to as the loss of surface texture. It is commonly found in the wheel paths of traffic lanes and is distinguished by areas that are relatively smooth compared to surrounding pavement where the surface may be described as 'glazed' or 'shiny'. Causes include: incorrect or inadequate aggregate selection, surface age or higher than expected traffic volume or traffic stresses	INFORMATION - CORRUGATIONS (SEALED PAVEMENTS) **Corrugations**  Corrugations are the deformation of the pavement which is setup in wave-like 'ripples' in the pavement surface. They are closely spaced (usually 500mm up to 1m) and are exacerbated by further traffic which can increase the amplitude of the corrugations. In sealed pavements caused include: inadequate stability in the surface or base courses, excessive moisture in the subgrade, low air voids in pavement layers (particularly surface layers) or steep uphill or downhill gradients exacerbated by braking heavy traffic
INFORMATION - CRACKING (ASPHALTIC CONCRETE SURFACES) **Cracking** Cracking is one or more visible discontinuities ('fissures' or 'cracks') radiating along the surface of a pavement. It is considered to be unplanned and uncontrolled and will not necessarily extend through the entire thickness of a pavement. The condition of pavement surfaces is an important guide to the overall condition and future performance of the pavement structure, and the onset of surface cracking has been recognised as an indicator of overall pavement condition. Pavements with an asphaltic concrete surface suffer from many possible cracking types, including block, crescent-shaped, crocodile, diagonal, longitudinal, meandering and transverse cracking.	INFORMATION - DELAMINATION **Delamination**  Delamination is the total removal (or 'peeling off') of large areas of the wearing surface. It is distinguished by a clear delineation between the wearing course and the pavement base course layer below. It 'peels' off the pavement because of a loss of bond between the asphalt or bitumen surface and the base course and results in low shear resistance to traffic stresses. Delamination can be caused by: 1. Construction deficiencies (inadequately cleaned or tack coated pavement surface prior to placing the asphalt, insufficient thickness and stability during the asphalt placement or arising from patch repairs of failed pavements) 2. In-situ causes (water seepage through the surface which weakens the bond between the layers, failure of a lower layer or as a result of significant damage to the surface from improper usage or traffic loading)
INFORMATION - DEPRESSIONS **Depressions**  A depression is a localised area of a pavement surface that has deformed downwards below the original constructed surface level. They are not necessarily confined to wheel paths and are particularly noticeable immediately following rain when they fill with water, creating a safety hazard for vehicles that will experience a loss of skid resistance. Depressions are generally caused by a volume change in the subgrade or sub-base materials. These volume changes can arise from soft and poorly compacted areas (either during original construction or from recent service trenches), embankment movements, changes in moisture content within pavement materials or the erosion of the underlying pavement layers.	INFORMATION - EDGE BREAKS **Edge Breaks**  Edge breaks are the deterioration (fretting) of the edge of the road and is particularly common where the shoulder is unsealed and traffic is prone to traversing the interface of bitumen and shoulder. It is found parallel to the direction of traffic flow and leads to a reduction of the effective pavement width, loss of ride quality and user safety, the channelling of water leading to erosion of the road shoulder as well as increasing the likelihood of lateral water entry into the pavement base.
INFORMATION - FLUSHING **Flushing**  Flushing (or 'bleeding') is the partial (or complete) submersion of the surface aggregate into the binder mixture resulting in a slippery surface with poor texture and skid resistance. It is distinguished by a visibly shiny black surface due to the bitumen being almost completely exposed at the surface. It commonly occurs during hot weather where the bituminous binder fills the aggregate voids and then expands onto the pavement surface. It is not reversible during cold weather and will progressively worsen with time. Flushing can be caused by excessive binder content on the surface or underlying surfaces, poor mix design, aggregate penetration into underlying low strength pavements, softening of the binder or spillages or accumulation of oil from vehicles.	INFORMATION - OXIDATION **Oxidation**  Oxidation is the age hardening of the sealed bitumen surface caused by environmental and atmospheric conditions. It is not easily detected on its own, but often leads to other defects such as cracking, aggregate loss and raveling (among others). The affects of oxidation leave the pavement more susceptible to moisture intrusion, which leads to further and more severe defects.
INFORMATION - PATCHING FAILURE **Patching Failure**  Patching failure is the deterioration of a previous hot or cold mix asphalt patch repair and can be the failure of the patch repair itself or the continued failure of the existing underlying or surrounding pavement material. Patching failure arises from an improperly constructed repair or a repair that does not completely remediate the entire failing section of road.	INFORMATION - POTHOLES (SEALED PAVEMENTS) **Potholes**  Potholes are local bowl-shaped depressions or failures, where the wearing surface has disintegrated (or displaced) leaving the underlying pavement layers exposed to traffic and weather. They are common in pavements with thin surface layers and are rarely seen in pavements with surfaces greater than 100mm thick. Potholes in sealed pavements commonly develop as a result of other defects, particularly those that affect the integrity of the pavement surface such as raveling and cracking (particularly crocodile cracking) which allows moisture to enter the pavement and lead to the areas of the surface being dislodged by traffic.

Table D.1 – *Accelerated Learning* Tools for Defects Associated with Asphaltic Concrete and Bituminous Spray Sealed Pavements - Figure D.11 and Figure D.12 (continued)

INFORMATION - PUUMPING **Pumping**  Pumping is identified by the presence of pavement fines (typically a white dust) on the surface of the road. It is the erosion of the subbase or base course material and its presence on the road surface is due to other defects (such as cracking) that allow the fines pass through the otherwise sealed wearing course. Pumping is caused by excessive moisture combined with the cyclic loading of traffic movement which creates a 'pumping' effect within the pavement and cause the unbound fine particles within the pavement to migrate upwards towards the surface.	INFORMATION - RAVELING (SEALED PAVEMENTS) **Raveling**  Raveling is the loss of both aggregates and binder (bitumen) from the surface. This results in surface disintegration where visibly loose pieces of aggregate and bitumen sit on the road surface. It is at its worst when these pieces make the surface rough enough to be noticeable to motorists driving on the road. For sealed pavements there are two main causes of raveling: 1. Unsuitable construction methods (insufficient binder/aggregate mix, use of dusty and unprimed, aggregate segregation, overheated surface mix, inadequate initial compaction and selection of unsound aggregates that deteriorate under traffic or environmental conditions). 2. insitu deterioration (binder oxidation, traffic loading and softening of the bituminous binder due to fuel or oil accumulation)
INFORMATION - RUTTING (SEALED PAVEMENTS) **Rutting**  Rutting is vertical deformation that occurs in the regular wheel paths of a road. It is commonly found in areas subject to high stress traffic loading which is common in climbing lanes, roundabouts and at intersections with slow heavy traffic. Rutting in sealed pavements is caused by: 1. In-situ deterioration (e.g. settlement of underlying pavement layers, plastic deformation of the bituminous surface and structural failure of the subgrade), or 2. Construction deficiencies (e.g. poor density of any or all pavement layers or from an inappropriate asphalt mix in HMA pavements)	INFORMATION - SHOVING **Shoving**  Shoving is the 'bulging' of the pavement in an abrupt wave that occurs parallel to the direction of traffic flow. It represents significant deformation of the pavement which will quickly lead to its failure, particularly when the pavement abuts rigid structures such as kerb and gutter. Shoving is caused by: 1. construction issues (the use of surface and base layers with unstable and poor strength characteristics) 2. in-situ issues(frequent stopping and starting of vehicles particularly at intersections or excessive moisture in the subgrade)
INFORMATION - STRIPPING **Stripping**  Stripping is the separation of aggregate from binder that leads to poor skid resistance and aggregate loss, which can result in further structural pavement defects such as potholes. It begins from the bottom of the bituminous layer and progresses up to the surface. Stripping is caused by: 1. construction issues (e.g. the selection of a defective/incorrect binder and aggregate system, use of an absorptive aggregate or excessive voids) 2. in-situ issues (e.g. moisture ingress, thermal variation or high speed and/or heavy vehicles)	INFORMATION - SURFACE IRREGULARITIES **Surface Irregularities**  Surface Irregularities is a combination of a number of surface defects such as stripping, raveling, oxidation, minor potholes and patching failures who in isolation can only be considered to be slight, but when present in large proportions and in combination with one another can cause significant pavement deterioration. When allowed to develop this defect will result in poor ride quality resulting in loud tyre noise caused by pavement roughness and ultimately affects user satisfaction with the road

Table D.2 – *Accelerated Learning Tools* for Defects Associated with Unsealed Pavements - Figure D.13

INFORMATION - CORRUGATIONS (UNSEALED PAVEMENTS)

Corrugations

Corrugations are the deformation of the pavement which is setup in wave-like 'ripples' in the pavement surface. They are closely spaced (usually 500mm up to 1m) and are exacerbated by further traffic which can increase the amplitude of the corrugations.

In unsealed pavements corrugations are formed under traffic load where the loose surface is firstly displaced, then arranged in waves set up by vehicle tyre movements. They are common in dry granular pavements with low plasticity and have either limited fines or have lost fines.

INFORMATION - DEPRESSIONS

Depressions

A depression is a localised area of a pavement surface that has deformed downwards below the original constructed surface level. They are not necessarily confined to wheel paths and are particularly noticeable immediately following rain when they fill with water, creating a safety hazard for vehicles that will experience a loss of skid resistance.

Depressions are generally caused by a volume change in the subgrade or sub-base materials. These volume changes can arise from soft and poorly compacted areas (either during original construction or from recent service trenches), embankment movements, changes in moisture content within pavement materials or the erosion of the underlying pavement layers.

INFORMATION - EROSION CHANNELS

Erosion Channels

Erosion channels are common on roads with steep gradients and/or an insufficient crown and are caused by flow of water along or over the road. This results in the loss of pavement material through transportation in high velocity water runoff, primarily during periods of rain.

While they are common on steep gradients which give rise to longitudinal erosion channels, but they may also occur perpendicular to the road alignment, where areas with lower compaction, such as the shoulder, begin the process and progress towards the road pavement or from local depressions that initially hold the water and eventually carves its own drainage path.

INFORMATION - LOSS OF FINES

Loss of Fines

The loss of fines in unsealed pavements is considered the first sign of wearing. It is evident in a road that produces large or excessive plumes of dust in windy conditions or when trafficked and is caused by traffic action and climatic conditions and is the loss of fine particles in road base/surface material.

Note: In addition to road user safety, there are number of health issues surrounding the resulting airborne dust generated from a road suffering a loss of fines.

INFORMATION - LOSS OF PAVEMENT

Loss of Pavement

The loss of pavement in an unsealed pavement is the ultimate progression of the loss of fines defect. It is the noticeable degradation of pavement thickness which therefore affects the ability for the pavement to carry the expected vehicular load.

In its developing stages it is considered simply a dusty road but as it develops, windrows of pavement accumulation will be noticeable in the road verges. In its most severe form, the subgrade will be exposed at the surface.

INFORMATION - POTHOLES (UNSEALED PAVEMENTS)

Potholes

Potholes are local bowl-shaped depressions or failures, where the wearing surface has disintegrated (or displaced) leaving the underlying pavement layers exposed to traffic and weather.

On unsealed pavements, potholes arise from other defects that affect surface integrity and develop into a disintegrating nucleus. Potholes also develop from previous improperly repaired potholes where failure nucleus remains within the pavement and begins to redevelop.

INFORMATION - RAVELING (UNSEALED PAVEMENTS)

Raveling

Raveling is the loss of both aggregates and binder (pavement fines) from the surface. This results in surface disintegration where visibly loose pieces of aggregate and bitumen sit on the road surface. It is at its worst when these pieces make the surface rough enough to be noticeable to motorists driving on the road.

For unsealed pavements, raveling is associated with a loss of fines, since the fines in an unsealed pavement represent the binder of the pavement surface matrix, their loss leads to the exposure of surface aggregate which not only results in a coarse surface with increased noise, roughness and permeability, but increases the likelihood of raveling which decreases skid resistance due to loose aggregates.

INFORMATION - RUTTING (UNSEALED PAVEMENTS)

Rutting

Rutting is vertical deformation that occurs in the regular wheel paths of a road and is also known as 'dry rutting' in unsealed pavements. It is commonly found in areas subject to high stress traffic loading which is common in climbing lanes, and areas with slow heavy traffic.

It is prevalent in dry environments and caused by loss of material from regular or heavy traffic, but can also be due to high moisture content in the subsurface soil or base.

INFORMATION - SOFT SPOTS

Soft Spots

Soft Spots affect unsealed pavements with excessive silt or clay content.

They are localised areas that are reactive to water ingress and combined with aggregate segregation causes the pavement to deform under traffic load.

Soft Spots are almost always formed in combination with other types of defects.

D.5 User form - PaveMaint_Defects2

D.5.1 Description:

- Userform with a list of cracking types expected for the selected pavement surface type (Figure D.16 and Figure D.17)

D.5.2 Code Function:

- Upon click of "Next" button:
  - Propagates the cracking defect type to the "Results" worksheet in the MS Excel spreadsheet (C7) – equation makes cell equal to the caption label of the option/radio button selected
  - Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure D.15)
  - Updates label in Severity userform (No. D.6) to reflect defect chosen (uses caption labels to propagate)
  - Sets Severity options visible or not
  - Sets Severity option/radio button values and accelerated learning tools embedded into the description/label – reading from cells in knowledgebase worksheets for each surface type
  - Hide current form and Show Severity userform (No. D.6)
- Upon click of "Back" button:
  - Hide Cracking Defects
  - Show Defect Types

D.5.3 Accelerated Learning Tools:

- Cracking info for all expected cracking types for the selected pavement surface

D.5.4 Screen Shots:

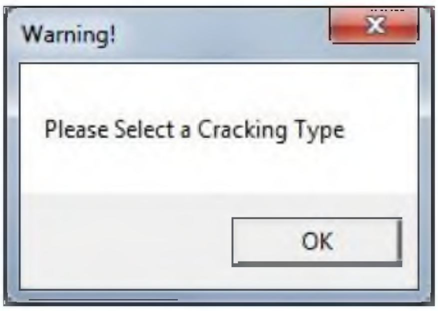


Figure D.15 – PaveMaint SELECT Warning Screen: Incomplete "Cracking Type" Form

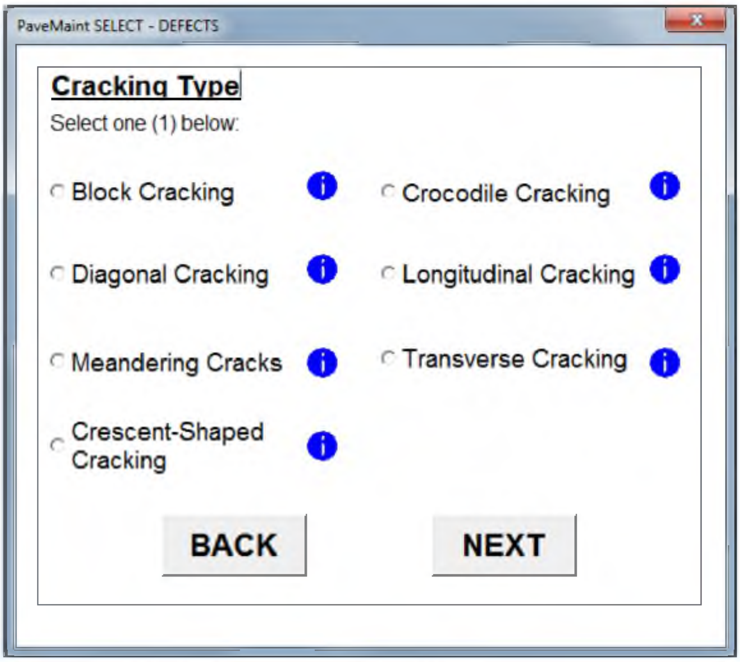


Figure D.16 – PaveMaint SELECT Asphaltic Concrete Surfaced Pavements "Cracking Type" Screen

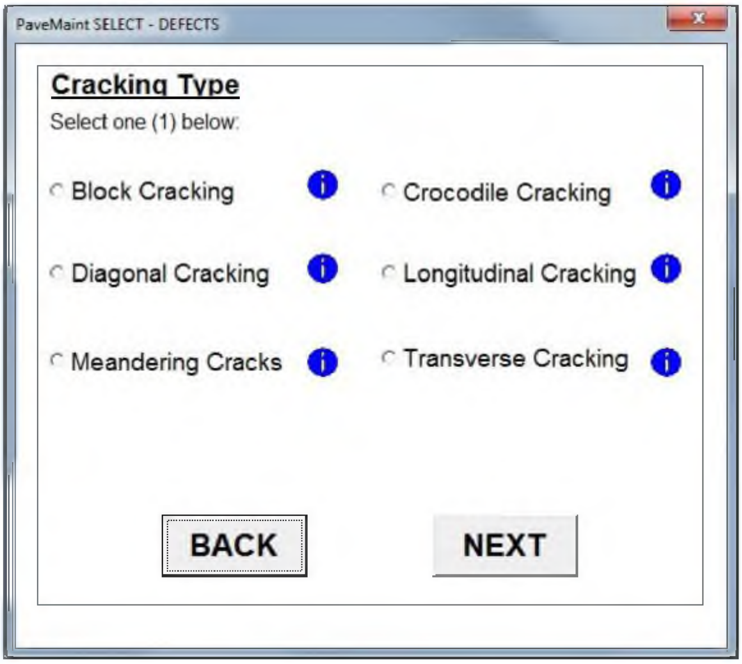


Figure D.17 – PaveMaint SELECT Bituminous Spray Sealed Pavements "Cracking Type" Screen

Table D.3 – *Accelerated Learning Tools* for Defects Associated with Cracking of Asphaltic Concrete and Bituminous Spray Sealed Pavements - Figure D.16 and Figure D.17

INFORMATION - BLOCK CRACKING

Block Cracking

Block cracking is a series of cracks that form almost symmetrical polygons (or "cells") that are square/rectangular in shape and larger than 200-300mm. It generally affects a large area of pavement and will often affect an entire segment of road.

Causes of Block Cracking include: the hardening and shrinkage of the bituminous surface; fatigue in an aged and brittle wearing course; reflection from joints or discontinuities associated with an underlying bound base, subbase or subgrade layer; or the loss of subbase or subgrade support.

INFORMATION - CROCODILE CRACKING

Crocodile Cracking

Crocodile cracking is a series of interconnected cracks that form irregular shaped cells that are smaller than 300mm in nominal diameter and resembles the pattern of crocodile (or alligator) skin, and is sometimes referred to as "alligator" or "polygon" cracking or "crazing".

Crocodile cracking regularly occurs in wheel paths and is mainly caused by traffic loading causes the propogation of other cracking defects such as block cracking. It can also be caused by other issues such as the saturation of underlying pavement layers; fatigue (ageing and brittleness of bituminous wearing course); or inadequate pavement thickness or compaction.

INFORMATION - DIAGONAL CRACKING

Diagonal Cracking

Diagonal cracking is unconnected cracking that generally follows an alignment diagonal to the direction of the pavement, it is neither parallel or perpendicular to traffic flow.

Causes of diagonal cracking include reflection from joints or discontinuities associated with an underlying bound base, subbase or subgrade layer; differential settlement from adjacent embankments, cuttings or structures; tree roots; or disturbance from underground service installation.

INFORMATION - LONGITUDINAL CRACKING

Longitudinal Cracking

Longitudinal cracking can be a single isolated crack or a series of cracks that generally follow an alignment that is parallel to the direction of flow of traffic. While longitudinal cracks are considered to be unidirectional they may also feature shorter 'branching' cracks which radiate from the main crack.

Causes may include reflection from joints or discontinuities associated with an underlying pavement layer; bitumen hardening; early developing slips (for roads located on slopes); or poor work practices such as poorly constructed asphalt surfacing joint and reflection from joints where pavement widening works have been undertaken.

INFORMATION - MEANDERING CRACKS

Meandering Cracks

Meandering cracks are unconnected, singularly discontinuities that, as the name suggests, follow an undefined and multidirectional alignment.

Causes include: weakening of pavement due to saturation; shrinkage of pavement subgrade due to tree roots; reflected shrinkage cracks from bound base and subbase materials; or disturbance from underground service installation.

INFORMATION - TRANSVERSE CRACKING

Transverse Cracking

Transverse cracking will radiate perpendicular to the alignment of traffic flow and can occur singularly or in a series of parallel cracks.

Transverse cracking can be caused by a construction joint or shrinkage in asphalt surfacing; reflection from joints or discontinuities associated with an underlying pavement layer; differential settlement occurring at a cut/fill plane on an embankment; or movement in underlying pavement.

INFORMATION - CRESCENT-SHAPED CRACKING

Crescent-Shaped Cracking

Crescent-shaped (or slippage) cracking is named according to its appearance, this cracking type is evident by its half-moon, or curve, shaped alignment, which may occur as a singular crack or in a group of concentric cracks.

Crescent-shaped cracking is representative of shear movements in pavement surfaces and is commonly associated with shoving an asphalt pavement surface. Causes may be due to poor construction techniques such as dragging by paver when laying asphalt at low temperatures, or inadequate bond between asphalt wearing course and pavement base course due to dust, dirt, oil or the absence of a tack coat; due to excessive shear forces due to braking and acceleration movements; or due underlying pavement layers with low densities and stiffness.

Note:

Crescent-Shaped Cracking is not associated with Bituminous Spray Sealed pavements.

D.6 User form - PaveMaint_Severity

D.6.1 Description:

- Userform where the severity of the defect is identified (Figure D.18 to Figure D.42)

D.6.2 Code Function:

- Upon click of "Next" button:
  - o Propagates a value between 1-5 to the "Results" worksheet in the MS Excel spreadsheet (K7)
  - o Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure D.43)
  - o Hide current form and Show User Constraints (1) userform (No. D.7)
- Upon click of "Back" button:
  - o Hide and Unload Severity
  - o Show Defect Types or Cracking Defect Types (depending on defect previously chosen)

D.6.3 Accelerated Learning Tools:

- Incorporated into radio options which are descriptive and lead user to giving informed answers

D.6.4 Screen Shots:

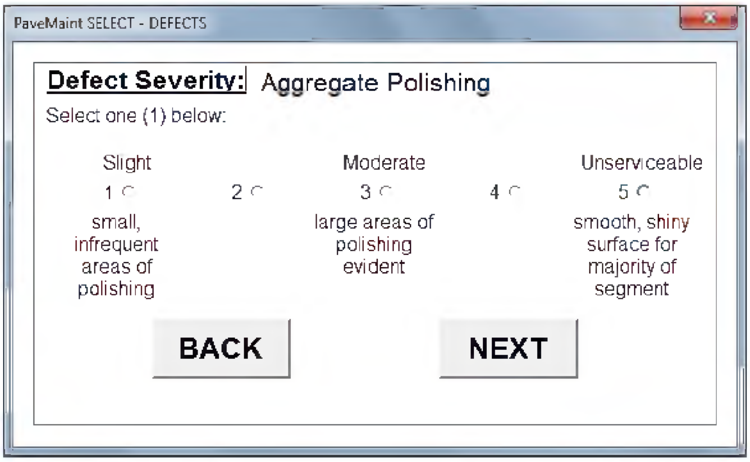


Figure D.18 – PaveMaint SELECT Defect Severity Selection for Aggregate Polishing of Asphaltic Concrete and Bituminous Spray Sealed Surfaces

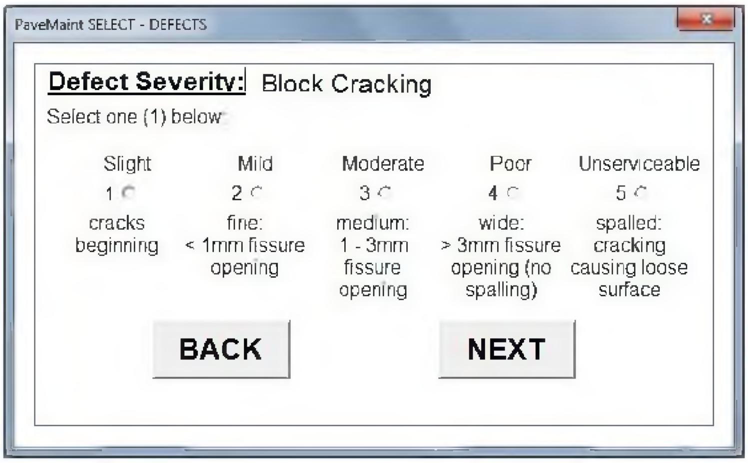


Figure D.19 – PaveMaint SELECT Defect Severity Selection for All Types of Cracking in Asphaltic Concrete and Bituminous Spray Sealed Pavements

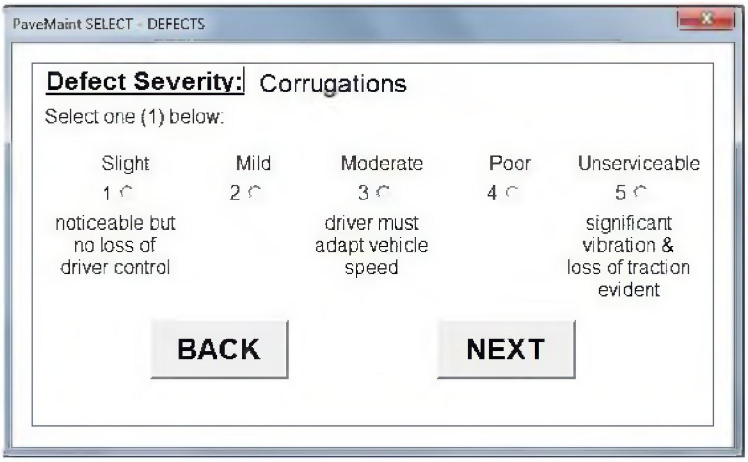


Figure D.20 – PaveMaint SELECT Defect Severity Selection for Corrugations in Asphaltic Concrete and Bituminous Spray Sealed Pavements

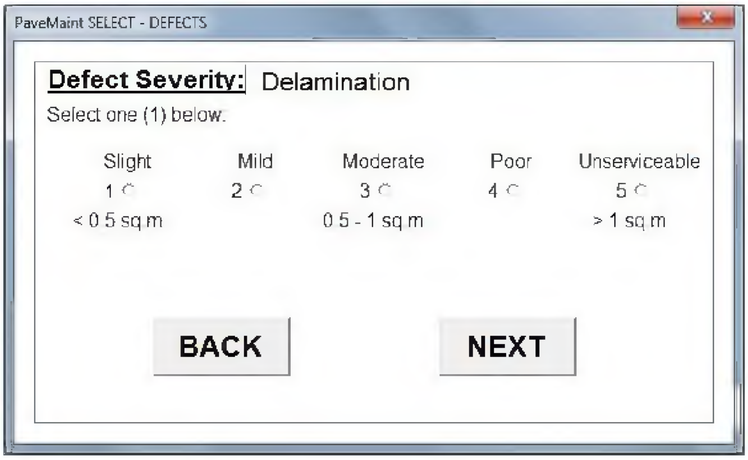


Figure D.21 – PaveMaint SELECT Defect Severity Selection for Delamination of Asphaltic Concrete Surfaces

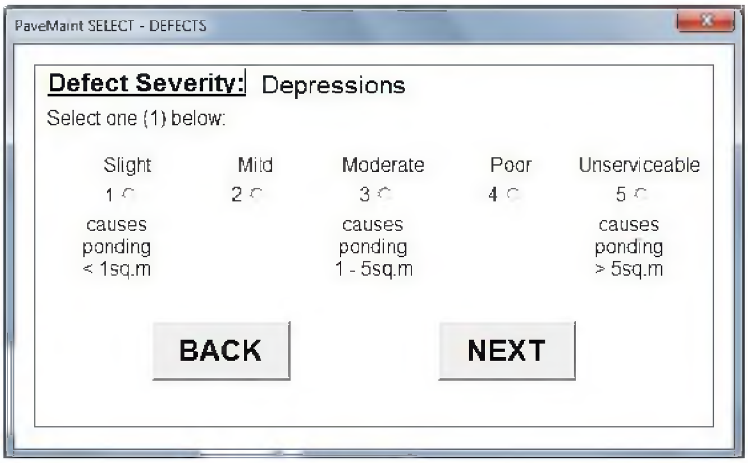


Figure D.22 – PaveMaint SELECT Defect Severity Selection for Depressions on Asphaltic Concrete and Bituminous Spray Sealed Pavements

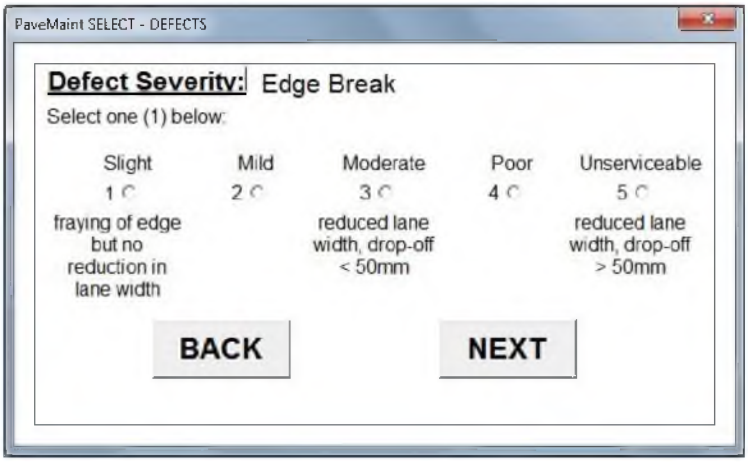


Figure D.23 – PaveMaint SELECT Defect Severity Selection for Edge Breaks along Asphaltic Concrete and Bituminous Spray Sealed Pavements

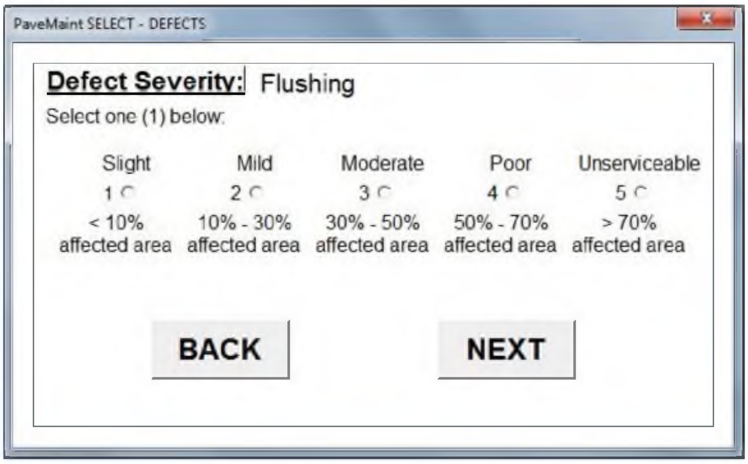


Figure D.24 – PaveMaint SELECT Defect Severity Selection for Flushing of Bituminous Spray Sealed Surfaces

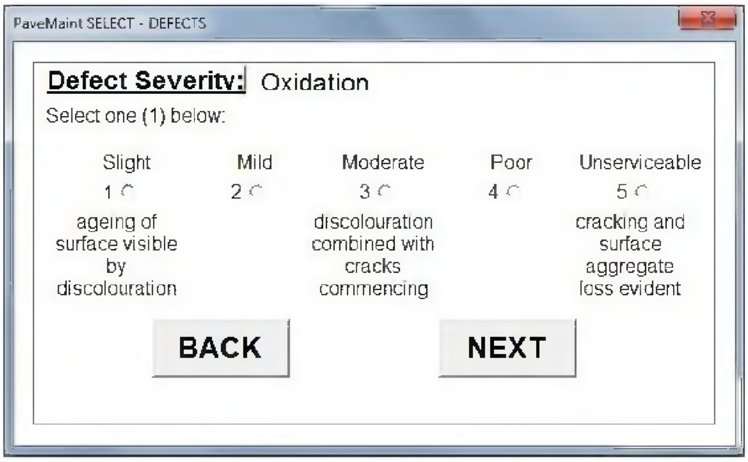


Figure D.25 – PaveMaint SELECT Defect Severity Selection for Oxidation of Asphaltic Concrete and Bituminous Spray Sealed Surfaces

Figure D.26 – PaveMaint SELECT Defect Severity Selection for Patching Failure on Asphaltic Concrete and Bituminous Spray Sealed Pavements

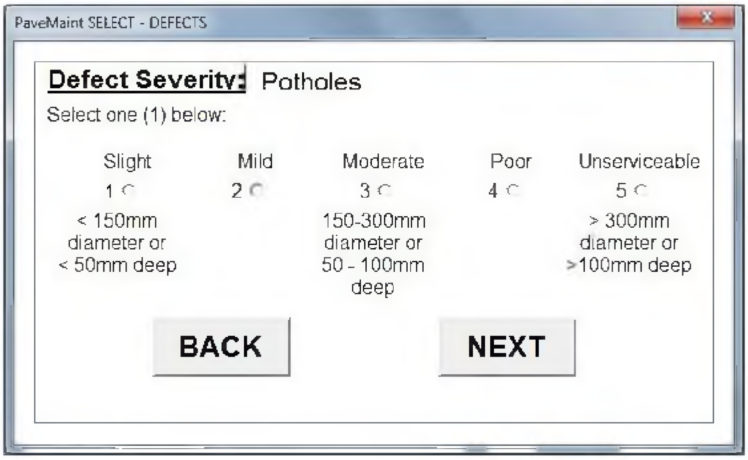


Figure D.27 – PaveMaint SELECT Defect Severity Selection for Potholes in Asphaltic Concrete and Bituminous Spray Sealed Pavements

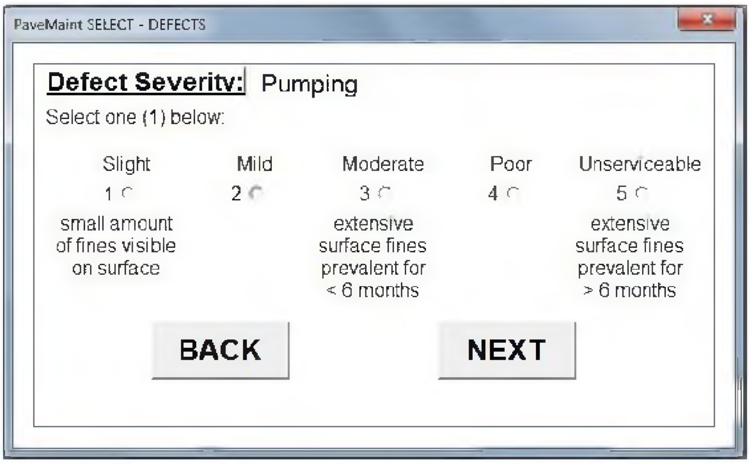


Figure D.28 – PaveMaint SELECT Defect Severity Selection for Pumping of Asphaltic Concrete and Bituminous Spray Sealed Pavements

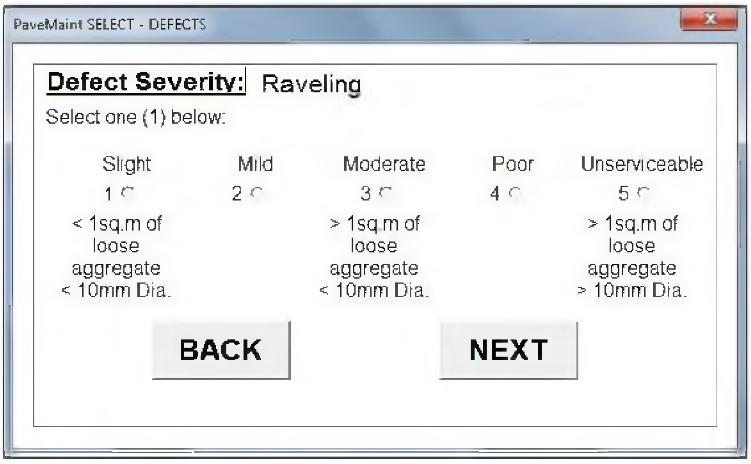


Figure D.29 – PaveMaint SELECT Defect Severity Selection for Raveling of Asphaltic Concrete and Bituminous Spray Sealed Surfaces

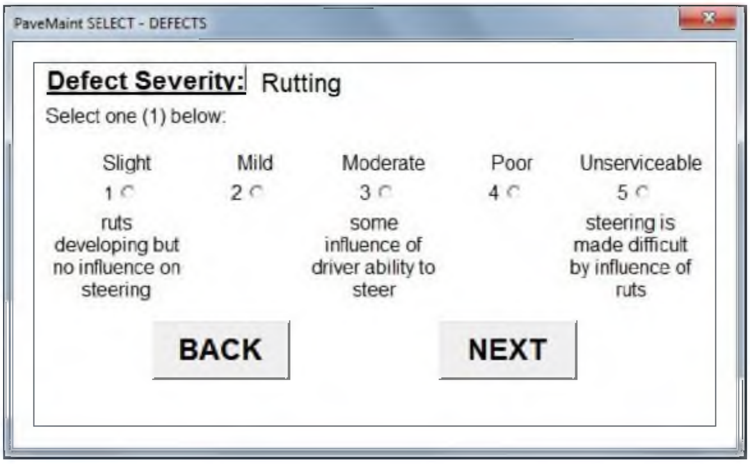


Figure D.30 – PaveMaint SELECT Defect Severity Selection for Rutting of Asphaltic Concrete and Bituminous Spray Sealed Pavements

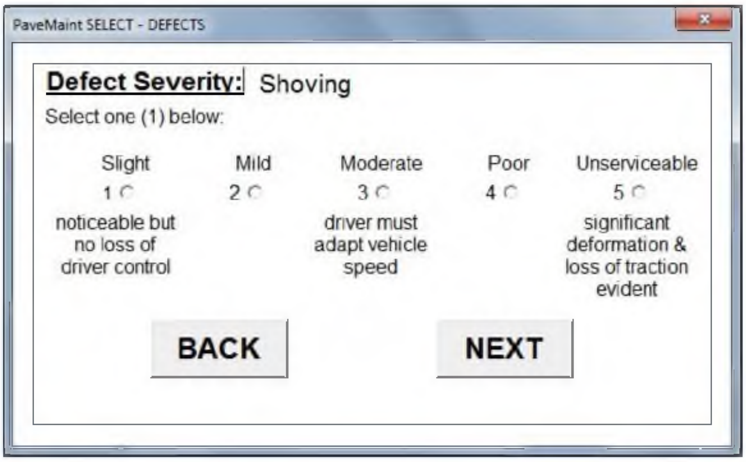


Figure D.31 – PaveMaint SELECT Defect Severity Selection for Shoving on Asphaltic Concrete and Bituminous Spray Sealed Pavements

Figure D.32 – PaveMaint SELECT Defect Severity Selection for Stripping on Asphaltic Concrete and Bituminous Spray Sealed Surfaces

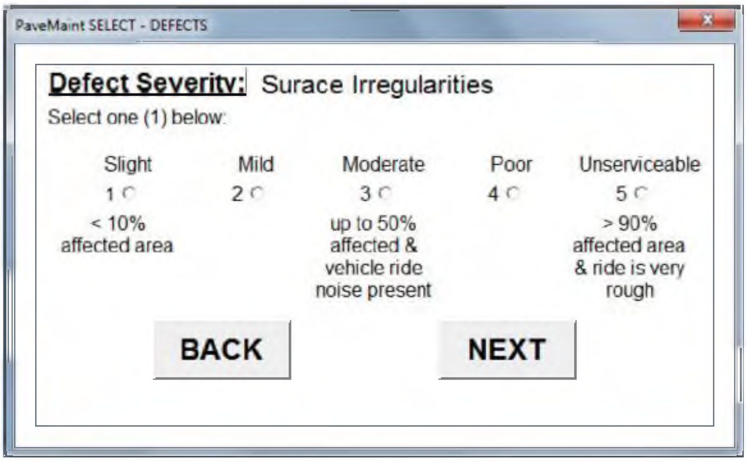


Figure D.33 – PaveMaint SELECT Defect Severity Selection for Surface Irregularities on Asphaltic Concrete and Bituminous Spray Sealed Surfaces

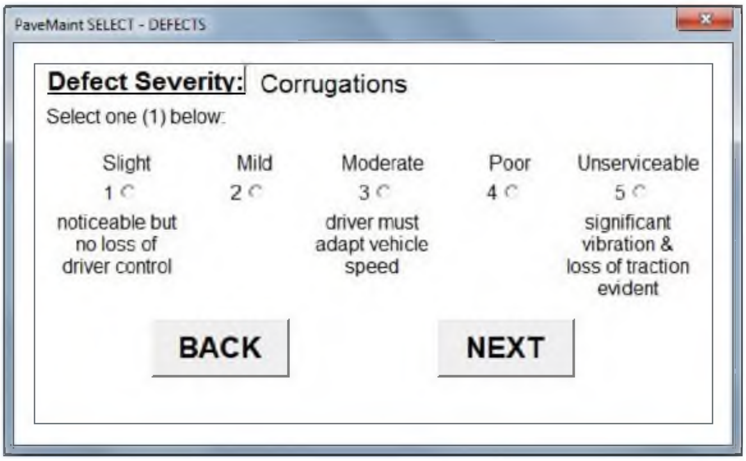


Figure D.34 – PaveMaint SELECT Defect Severity Selection for Corrugations on Unsealed Pavements

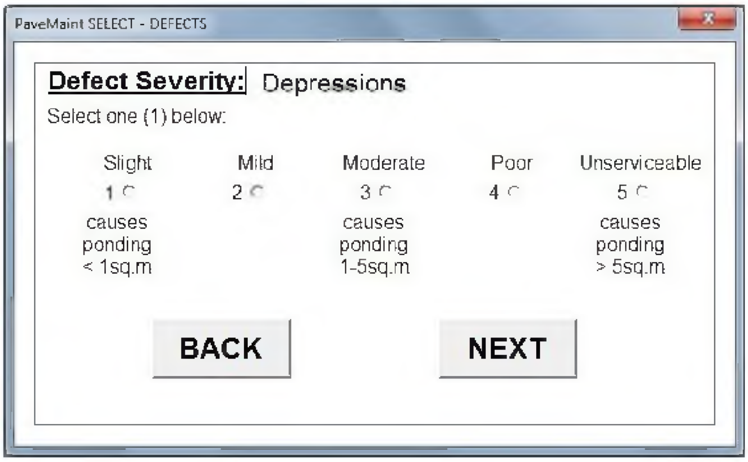


Figure D.35 – PaveMaint SELECT Defect Severity Selection for Depressions on Unsealed Pavements

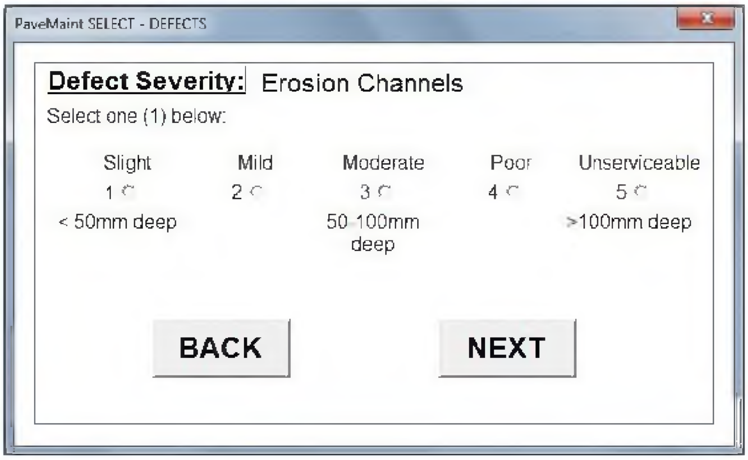


Figure D.36 – PaveMaint SELECT Defect Severity Selection for Erosion Channels on Unsealed Pavements

Figure D.37 – PaveMaint SELECT Defect Severity Selection for Loss of Fines on Unsealed Pavements

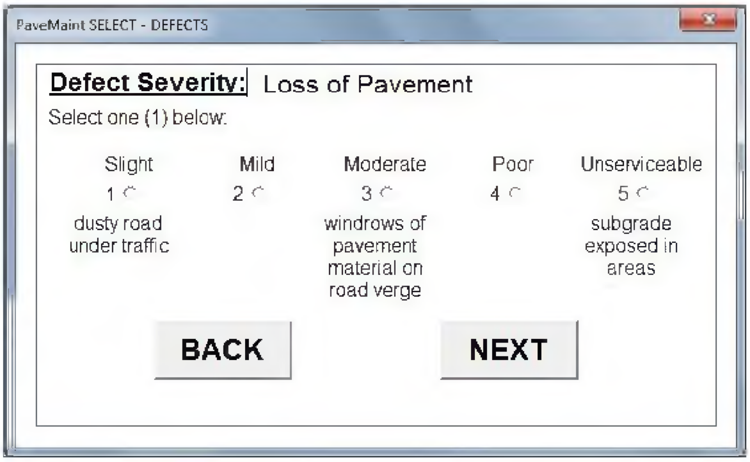


Figure D.38 – PaveMaint SELECT Defect Severity Selection for Loss of Pavement on Unsealed Pavements

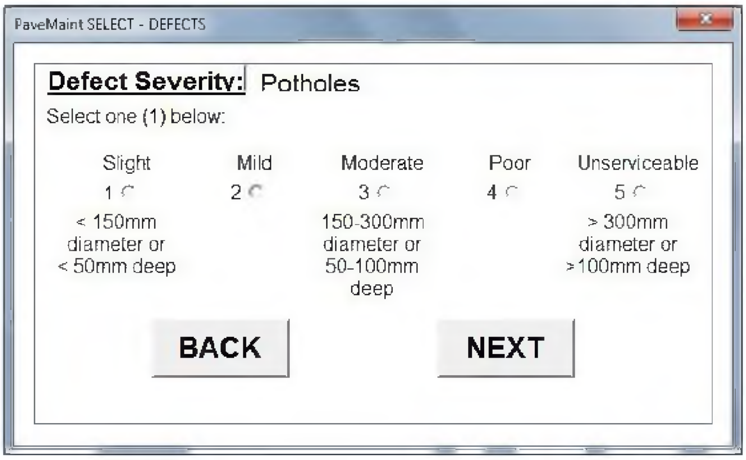


Figure D.39 – PaveMaint SELECT Defect Severity Selection for Potholes in Unsealed Pavements

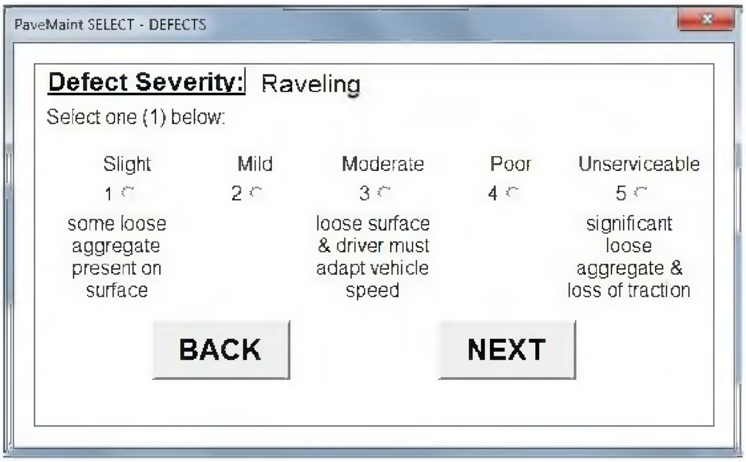


Figure D.40 – PaveMaint SELECT Defect Severity Selection for Raveling of Unsealed Pavements

Figure D.41 – PaveMaint SELECT Defect Severity Selection for Rutting on Unsealed Pavements

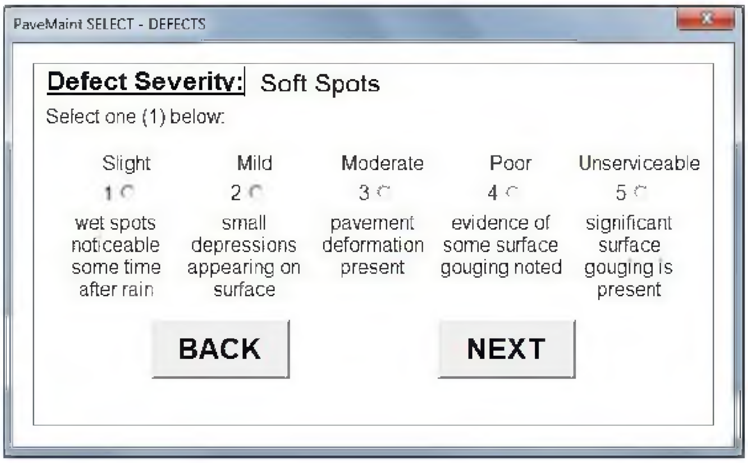


Figure D.42 – PaveMaint SELECT Defect Severity Selection for Soft Spots on Unsealed Pavements

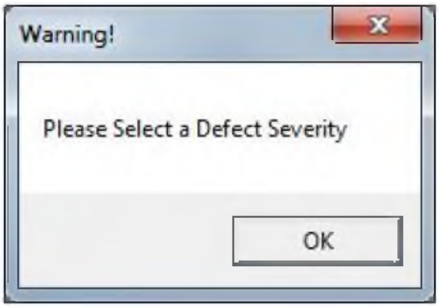


Figure D.43 – PaveMaint SELECT Warning Screen: Incomplete "Defect Severity" Form

D.7 User form - PaveMaint_Constrain1

D.7.1 Description:

- Userform where user nominates the importance of Cost and repair Longevity (Figure D.47)

D.7.2 Code Function:

- Upon click of "Next" button:
  - Propagates a predetermined value between 1-10 to the "Results" worksheet in the MS Excel spreadsheet (C13 [Cost] & G13 [Longevity])
  - Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure D.44 to Figure D.46)
  - Hide current form and Show Constrain2 userform (No. D.8)
- Upon click of "Back" button:
  - Hide and Unload Constrain1
  - Show Severity

D.7.3 Accelerated Learning Tools:

- Incorporated into radio options which are descriptive and lead user to giving informed answers

D.7.4 Screen Shots:

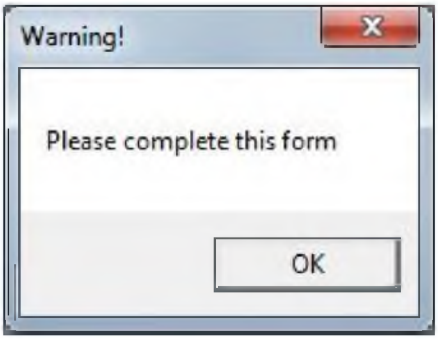


Figure D.44 – PaveMaint SELECT Warning Screen: Incomplete "User Constraints" (1) Form (No Selection)

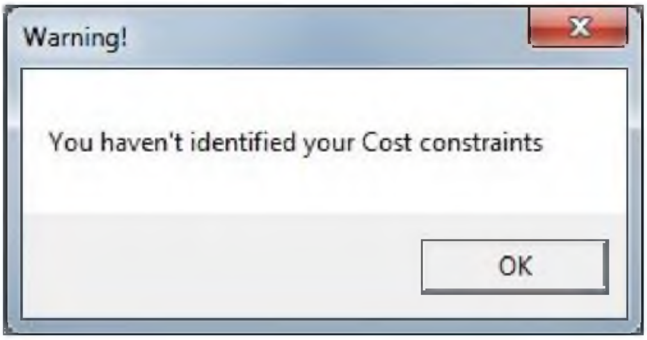


Figure D.45 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (1) Form (No Cost Constraint Selected)

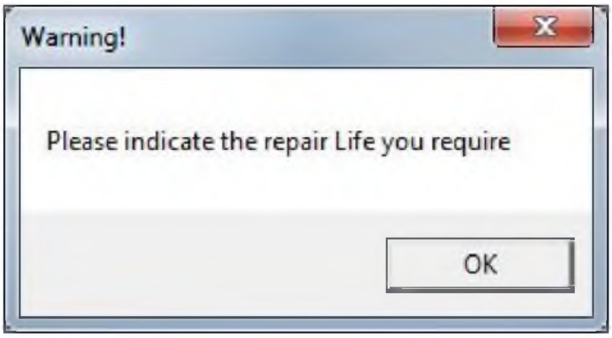


Figure D.46 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (1) Form (No Longevity Constraint Selected)

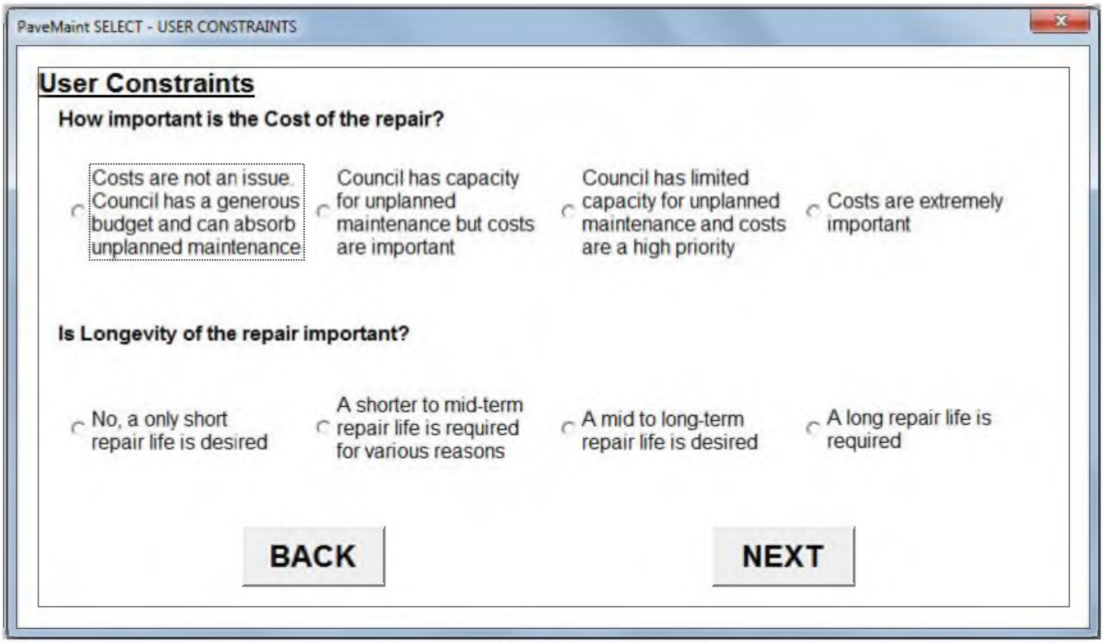


Figure D.47 – PaveMaint SELECT User Constraints (1) Selection Screen

D.8 User form - PaveMaint_Constrain2

D.8.1 Description:

- Userform where user nominates the importance of repair Time and Aesthetics (Figure D.51)

D.8.2 Code Function:

- Upon click of "Next" button:
  - Propagates a value between 1-10 to the "Results" worksheet in the MS Excel spreadsheet (I13 [Time] & K13 [Aesthetic])
  - Warning message box if no option/radio button has been selected and stop progress to next sheet (Figure D.48 to Figure D.50)
  - Hide current form and Show Program End userform (No.9)
- Upon click of "Back" button:
  - Hide and Unload Constrain2
  - Show Severity

D.8.3 Accelerated Learning Tools:

- Incorporated into radio options which are descriptive and lead user to giving informed answers

D.8.4 Screen Shots:

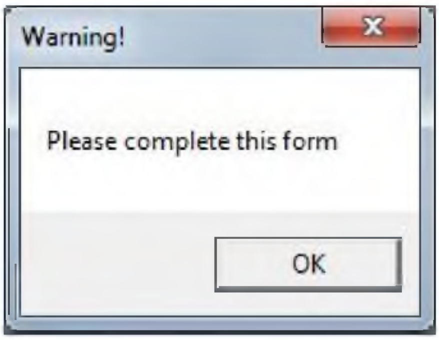


Figure D.48 – PaveMaint SELECT Warning Screen: Incomplete "User Constraints" (2) Form (No Selection)

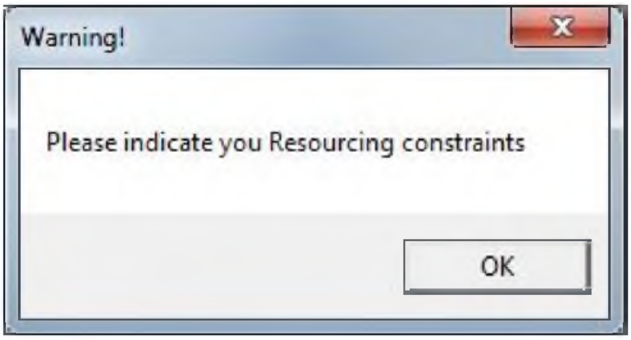


Figure D.49 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (2) Form (No Resource Constraint Selected)

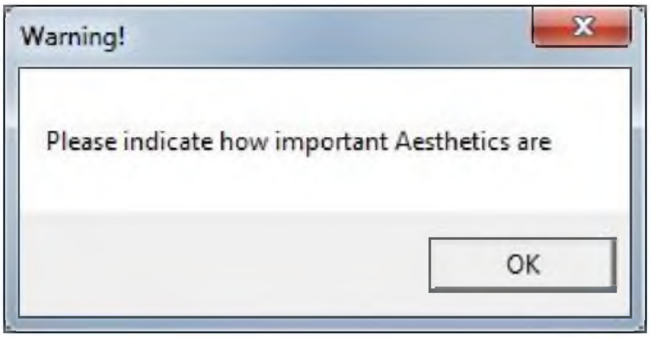


Figure D.50 – PaveMaint SELECT Warning Screen: Incomplete “User Constraints” (2) Form (No Aesthetics Constraints Selected)

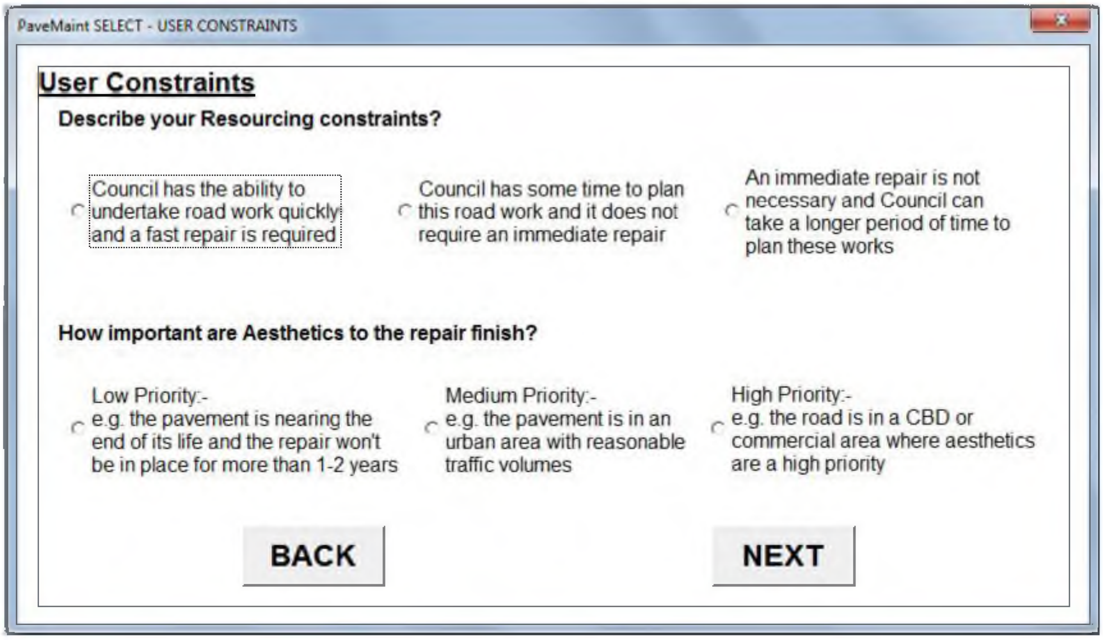


Figure D.51 – PaveMaint SELECT User Constraints (2) Selection Screen

D.9 User form - PaveMaint_End

D.9.1 Description:

- Userform informing that the program is finished and provides the user a chance to make any changes to their selections before progressing to the Solutions Sheet

D.9.2 Code Function:

- Upon click of “View Results” button:
  - o Performs a sorting function over the Solutions Sheet in the spreadsheet for the calculated results and weightings
  - o Performs a “Save As” operation for the workbook
  - o Hide current form and redirect user to spreadsheet with the Solutions Sheet shown
- Upon click of “Make Changes” button:
  - o Hide and Unload End
  - o Show Constrain2

D.9.3 Accelerated Learning Tools:

- Nil

D.9.4 Screen Shots:

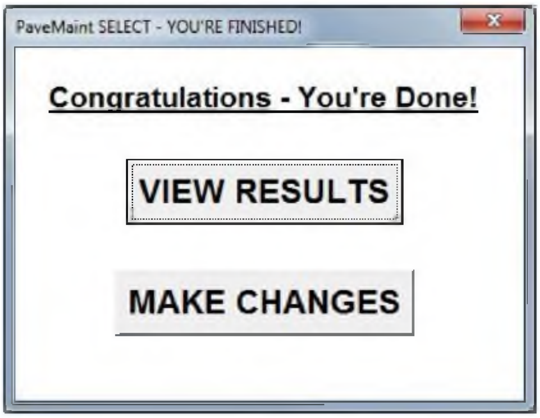


Figure D.52 – PaveMaint SELECT End of Program / View or Edit Results Screen

D.10 Worksheet - PaveMaint SELECT "StartUp"

D.10.1 Description:

- Sheet 1 of the PaveMaint SELECT spreadsheet file
- Provides a simple introduction screen and a "form control" button to launch the VBA program
- "Form control" buttons to switch between "administrator access" and "user-only" views of the program
- Sheet can be viewed and accessed by both the user and the administrator

D.10.2 Cells and Functionality

- Upon click of the "START" form control button, executes the "PaveMaintSelect" macro
- Cell "Z500" is a hidden and locked cell containing the program's default password "councils" which is used to protect worksheets 1 and 2, as well as the entire workbook
- Upon click of the "Administrator Access" form control button, executes the "PassAdminAccess" macro and form prompting for the administrator password
    - o Within the "PassAdminAccess" form, if the administrator inputs the correct password and click the "ADMIN VIEW" button, the workbook becomes unprotected and the "knowledgebase" worksheets become unhidden
    - o Within the "PassAdminAccess" form, if the administrator inputs the correct password and click the "CHANGE PASSWORD" button, the "Pass_Update" form is presented where a new password is entered and by clicking "OK" on that form, the administrator is presented with the "Pass_UpdateConfirm" form to verify the new password
- Upon click of the "Switch to User-Only View" form control button, executes the macro to hide the "Knowledgebase" worksheets and reinstate password protection for worksheets 1 and 2 and the entire workbook

D.10.3 Accelerated Learning Tools:

- Nil

D.10.4 Screen Shots:

Figure D.53 – PaveMaint SELECT “StartUp” Worksheet

Figure D.54 – PaveMaint SELECT “PassAdminAccess” form

Figure D.55 – PaveMaint SELECT “PassAdminAccess” Message Box “Incorrect Password”

Figure D.56 – PaveMaint SELECT “PassUpdate” form

Figure D.57 – PaveMaint SELECT “PassUpdateConfirn” form

Figure D.58 – PaveMaint SELECT “PassUpdateConfirm” Message Box “Successfully Updated Password”

Figure D.59 – PaveMaint SELECT “PassUpdateConfirn” Message Box “Password Mismatch”

D.11 Worksheet - PaveMaint SELECT "Results"

D.11.1 Description:

- Sheet 2 of the PaveMaint SELECT spreadsheet file
- Presents a data-sheet of all the information input through the VBA screens
- Presents a list of possible remediation options and scores against how they meet the user's nominated priorities
- Provides a recommendation of the most suitable remediation option based on the priorities nominated by the user
- Sheet size: Columns "A:S"; Rows "1:23"
- Sheet can be viewed and accessed by both the user and the administrator

D.11.2 Cells and Functionality

- All cells in the sheet are locked (cannot be edited) to preserve functionality with the exception of "C3:C5", "C15:C21", "G15:G21", "I15:I21" and "K15:K21"
- Columns "D:F", "H", "J", "L", "M" and "O:T" are hidden and locked and are not to be edited by the administrator
- Cells "K1", "B2:N2", "B3:B10", "K8:N8", "B12:N12", "B13", "N13:N14" and "C14:K14" provide headings for the columns of information stored below or adjacent to them
- Cell "N1" displays the date when the VBA macro program was run; that is, when the defect assessment is undertaken
- Cells "C3:C8" and "K7" displays the information input by the user in the first 6 VBA user forms (see D.1 to D.6 earlier)
- Cells "C13", "G13", "I13" and "K13" display a numeric representation of the user constraints selections from the VBA user forms (see D.7 and D.8) earlier
- Cells "A14:B14" display a form control button labelled "Edit Importance Factors" that allows the user to adjust the relative weighting of user constraints. Upon click:
  - Provides a user screen with 4 text boxes to allow user to numerically enter the weight of the constraint between 0 and 10 (see Figure D.62)
  - Upon click of "View Results"
    - If user has input numbers outside the range of 1 to 10, a warning screen is displayed (see Figure D.63)
    - Cells "C13", "G13", "I13" and "K13" are updated with the refined constraint weightings
    - Performs a sorting function over the Solutions Sheet in the spreadsheet for the calculated results and weightings
    - Performs a save operation for the workbook
    - Hide current form and redirect user to spreadsheet with the Solutions Sheet shown
- Cells "B15:B21" are locked cells that display each of the recommended remediation options for the selected defect and pavement type by referencing each of the "Knowledgebase" worksheets using the typical Equation D.1.

$$= IF\left(\begin{matrix} \$C\$6 = AsphKnowledgeBase!\,\$B\$1, AsphKnowledgeBase!\,\$D\$48, \\ IF\left(\begin{matrix} \$C\$6 = BitKnowledgeBase!\,\$B\$1, BitKnowledgeBase!\,\$D\$48, \\ UnSeaKnowledgeBase!\,\$D\$48 \end{matrix}\right)\end{matrix}\right)$$

Equation D.1

- Cells "C15:C21", "G15:G21", "I15:I21" and "K15:K21" display each of the individual remediation option's performance against each of user constraints, using the typical Equation D.2 (shown for cell "C15") to reference both the corresponding row in column "B" and the corresponding hidden cell in column "D", "H", "J" and "L" respectively

$$= IF(\$B15 = "", "", D15)$$

Equation D.2

- Cells "E15:E21" are a calculation of the corresponding remediation option's life-cost ratio using the typical Equation D.3 to reference the respective cells in columns "C" and "G"

$$= IF(OR(ISERROR(D15) = TRUE, D15 = "ERROR"), "", (G15/C15))$$

Equation D.3

- Cells "N15:N21" display the overall score for each remediation option using the typical equation, Equation D.4 (shown for cell "N15") that references the corresponding hidden cells in column "M". Cells are formatted to show percentage

$$= IF\big(ISERROR(M15) = TRUE, 0, (M15 \times 100)\big)$$

Equation D.4

- Cells "D15:D21", "H15:H21", "J15:J21" and "L15:L21" contain lookup formulas (Equation D.5 provides the typical equation, shown for cell "D15") to reference the relative data from the respective knowledgebase worksheets (see sections D.15, D.12 and D.13)

$$= \left(\begin{matrix} IF(\$C\$6 = AsphKnowledgeBase!\,\$B\$1, \\ VLOOKUP(\$B15, AsphKnowledgeBase!\,\$B\$34{:}\,\$L\$45,3, FALSE), \\ IF(\$C\$6 = BitKnowledgeBase!\,\$B\$1, \\ VLOOKUP(\$B15, BitKnowledgeBase!\,\$B\$34{:}\,\$L\$45,3, FALSE), \\ IF(\$C\$6 = UnSeaKnowledgeBase!\,\$B\$1, \\ VLOOKUP(\$B15, UnSeaKnowledgeBase!\,\$B\$34{:}\,\$L\$45,3, FALSE), \\ "ERROR"))) \end{matrix}\right)$$

Equation D.5

- Cells "M15:M21" normalise each remediation option's performance against the user constraints against the optimum performing value which is then multiplied by the importance factor for each constraint. Equation D.6 provides the typical equation, shown for cell "M15"

$$= E15 \times \begin{pmatrix} \left(\left(\frac{MIN(\$C\$15:\$C\$21)}{C15}\right)\$C\$13\right) + \\ \left(\left(\frac{G15}{MAX(\$G\$15:\$G\$21)}\right)\$G\$13\right) + \\ \left(\left(\frac{MIN(\$I\$15:\$I\$21)}{I15}\right)\$I\$13\right) + \\ \left(\left(\frac{K15}{MAX(\$K\$15:\$K\$21)}\right)\$K\$13\right) \end{pmatrix} \div SUM(\$C\$13:\$K\$13)$$

Equation D.6

- Cells "P15:P21" provide a rank for each of the remediation option overall scores from cells "N15:N21" using Equation D.7 which shows the typical equation (shown for cell "P15")

$$= RANK(N15, \$N\$15:\$N\$21,0)$$

Equation D.7

- Cells "Q15:Q21" provide a rank against the highest priority importance criteria (given in cells "C13", "G13", "I13" and "K13") for the remediation option criteria scores from cell range "C15:K21" using Equation D.8 which shows the typical equation (shown for cell "Q15")

$$= \begin{pmatrix} IF(\$C\$13 = MAX(\$C\$13, \$G\$13, \$I\$13, \$K\$13), \\ (RANK.EQ(C15, \$C\$15:\$C\$21,1)), \\ IF(\$G\$13 = MAX(\$C\$13, \$G\$13, \$I\$13, \$K\$13), \\ RANK.EQ(G15, \$G\$15:\$G\$21,0), \\ IF(\$I\$13 = MAX(\$C\$13, \$G\$13, \$I\$13, \$K\$13), \\ RANK.EQ(I15, \$I\$15:\$I\$21,1), \\ RANK.EQ(K15, \$K\$15:\$K\$21,0)))) \end{pmatrix}$$

Equation D.8

- Cells “R15:R21” sum the rank of the corresponding cells in column “P” and “Q” if column “P” returns a value of 1, otherwise gives a value of 11 to 17 respectively from row “15:17” using Equation D.9 which shows the typical equation (shown for cell “R15”)

$$= IF(P15 = 1, SUM(P15{:}\,Q15), 11)$$

Equation D.9

- Cells “S15:S21” provide a rank for each of the results from cells “R15:R21” using Equation D.10 which shows the typical equation (shown for cell “S15”)

$$= ROUNDDOWN\left((RANK.EQ(R15, \$R\$15{:}\,\$R\$21{,}1)), 1\right)$$

Equation D.10

- Cells “T15:T21” display (duplicate) the text of the remediation options shown in the corresponding rows of column “B”
- Cell “G10” displays the highest ranked remediation option (or if none shown, displays text “No Action - Monitor Defect”) formulated in accordance with Equation D.11

$$= \begin{pmatrix} IF(B15 = "", "No\ Action\ -\ Monitor\ Defect", \\ IF(S15 = 1, T15, IF(S16 = 1, T16, \\ IF(S17 = 1, T17, IF(S18 = 1, T18, \\ IF(S19 = 1, T19, IF(S20 = 1, T20, \\ IF(S21 = 1, T21, "ERROR")))))))) \end{pmatrix}$$

Equation D.11

D.11.3 Accelerated Learning Tools:

- Nil

D.11.4 Screen Shots:

START NEW

Date of Assessment: 14/10/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Long Road
Locality: A Town
Segment Number: 53
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Corrugations *Severity:* 4
(1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

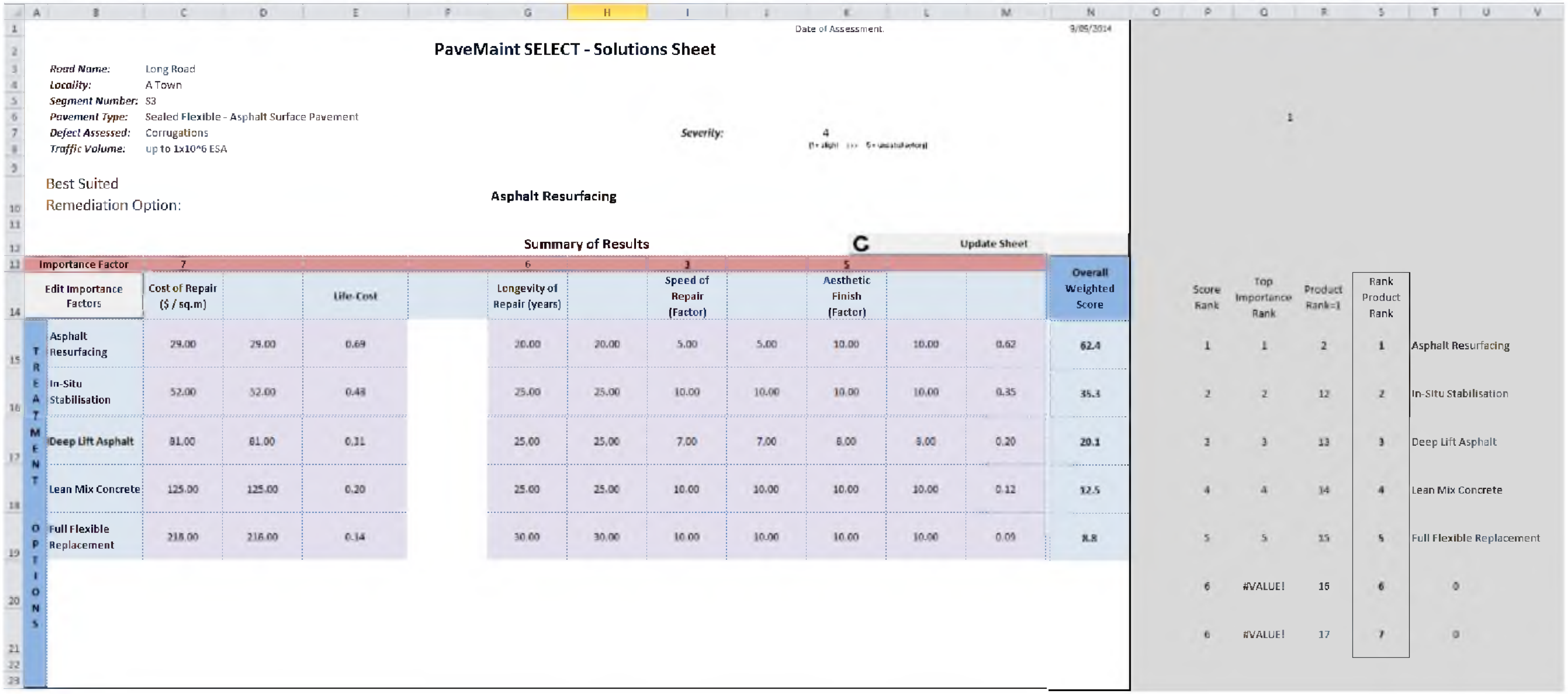
Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

Recalculate Sheet

Importance Factor	7	7	3	3	
Edit Importance Factors	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Time for Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
TREATMENT OPTIONS					
Asphalt Resurfacing	29.00	15.00	5.00	10.00	**152**
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**106**
Deep Lift Asphalt	81.00	25.00	5.00	10.00	**91**
Lean Mix Concrete	125.00	25.00	10.00	10.00	**44**
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	**21**

Figure D.60 – PaveMaint SELECT “Results” Worksheet User Access View



Date of Assessment: 9/05/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Long Road
Locality: A Town
Segment Number: S3
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Corrugations
Traffic Volume: up to 1x10^6 ESA

Severity: 4

Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

Update Sheet

Importance Factor	7				6		3		5			
Edit Importance Factors	Cost of Repair ($ / sq.m)		Life Cost		Longevity of Repair (years)		Speed of Repair (Factor)		Aesthetic Finish (Factor)			Overall Weighted Score
Asphalt Resurfacing	29.00	29.00	0.69		20.00	20.00	5.00	5.00	10.00	10.00	0.62	62.4
In-Situ Stabilisation	52.00	52.00	0.48		25.00	25.00	10.00	10.00	10.00	10.00	0.35	35.3
Deep Lift Asphalt	81.00	81.00	0.31		25.00	25.00	7.00	7.00	8.00	8.00	0.20	20.1
Lean Mix Concrete	125.00	125.00	0.20		25.00	25.00	10.00	10.00	10.00	10.00	0.12	12.5
Full Flexible Replacement	218.00	218.00	0.14		30.00	30.00	10.00	10.00	10.00	10.00	0.09	8.8

TREATMENT OPTIONS

Score Rank	Top Importance Rank	Product Rank=1	Rank Product Rank	
1	1	2	1	Asphalt Resurfacing
2	2	12	2	In-Situ Stabilisation
3	3	13	3	Deep Lift Asphalt
4	4	14	4	Lean Mix Concrete
5	5	15	5	Full Flexible Replacement
6	#VALUE!	16	6	0
6	#VALUE!	17	7	0

Figure D.61 – PaveMaint SELECT "Results" Worksheet Administrator Access View

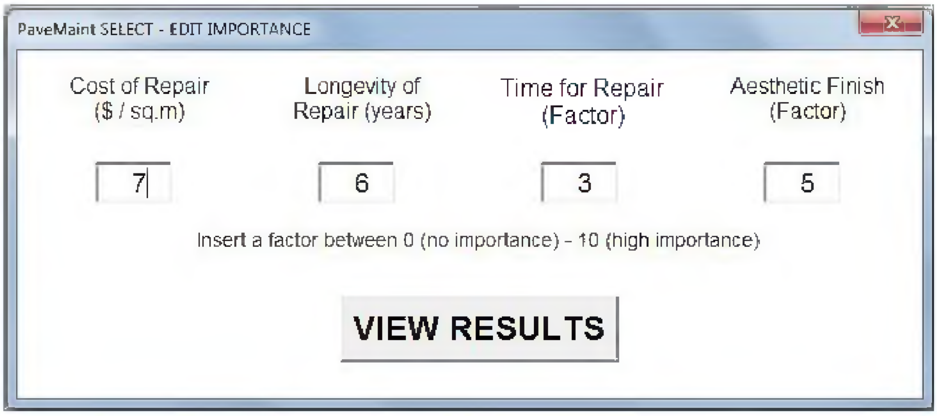


Figure D.62 – PaveMaint SELECT “Results” Worksheet – “Edit Importance Factors” User Form

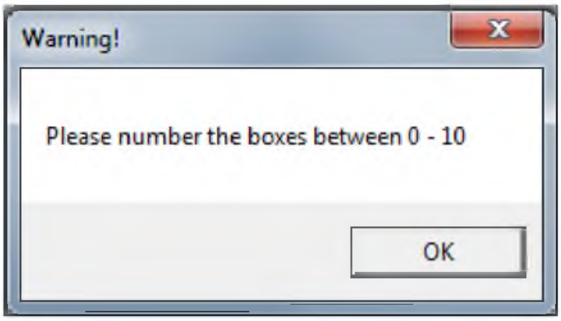


Figure D.63 – PaveMaint SELECT Warning Screen: “Edit Importance Factors” Invalid Numerical Value Input

D.12 Worksheet - PaveMaint SELECT "AsphKnowledgeBase"

D.12.1 Description:

- Sheet 3 of the PaveMaint SELECT spreadsheet file
- Holds information for asphaltic concrete surfaced pavements only
- Contains a list of all the possible defect types, a description of the defect severities, references the list of the possible remediation options (from the "RemedyKnowledgeBase" worksheet") applicable for that pavement type only and provides scoring and weighting for all user constraint fields
- Sheet size: Columns "A:AB"; Rows "1:55"
- Sheet is hidden from users of the program. The organisation's administrator can unprotect the spreadsheet and unhide the worksheet to be able to access it

D.12.2 Cells and Functionality

- Rows "2:3", "21", "31:32", "46" and "55" as well as column "M" are empty cells formatted grey to provide a table break and clear visual delineation of the data presented
- Rows "1", "4", "22", "33" and "47" are heading rows and are used by other cells in lookup functions
- Cells "A5:A20" and "A23:30" display reference numbers for the individual defect types. The numbers provide a visual unique identity for the administrator but do not serve a function in the program
- Cells in columns "C", "E", "G", "I" and "K" between rows "5:20" and "23:30" provide numeric representations of the 5 severity levels
- Cells in columns "D", "F", "H", "J" and "L" between rows "5:20" and "23:30" provide descriptions of what the severity level means for each defect type
- Cells "B34:B43" display the possible remediation options available for the pavement type
- Cells in columns "O", "Q", "S", "U", "W", "Y" and "AA" between rows "5:20" and "23:30" display the suitable remediation options for the corresponding defect type.
  - The cells contain a conditional formula that displays a blank cell for severities less than a value of 2 (that is, considered slight) unless the user has nominated aesthetics to be of high importance (greater than a value of 8). Equation D.12 provides an example for the "Asphalt Resurfacing" remediation option in the treatment of "Aggregate Polishing"

$$= IF(Results!\$J\$13 > 4, B34, IF(Results!\$J\$7 < 2, "", B34))$$

Equation D.12

  - Cells "O8", "O9", "O16", "O23", "Q7", "Q15", "Q24", "Q26", "Q28","S5", "S7", "S10", "S12", "S14", "S18", "S23:S25", "S27", "U12", "U26" and "U28" contain an augmentation of Equation D.12

that prunes options will low longevity when longevity is rated as a high importance factor. Equation D.13 provides an example for the "Slurry Seal" remediation option in the treatment of "Raveling"

$$= IF\left(IF\left(\begin{array}{c} Results!\,\$G\$13 > 6,, \\ Results!\,\$J\$13 > 4, B34, \\ IF(Results!\,\$J\$7 < 2, "", B34) \end{array}\right)\right)$$

Equation D.13

- Cells "O29", "Q6", "Q8", "Q16", "S9", "S15", "U6", "U8", "U9", "U10", "U16", "U23", "U25", "U27", "W6", "W10", "W23", 'W25", "W26", "W27", "W28", "Y10", "Y23", "Y24", "Y25", "Y26", "Y28", "AA23", "AA24", "AA26" and "AA28" display remediation options that require more substantial disturbance to the existing pavement and therefore the severity value in Equation D.12 is 4 (instead of 2) as it is not considered that such a significant repair would be undertaken unless the pavement is in poor or unserviceable condition.
- Cells "Q23", "Q25", "Q27", "Q29", "S26", "S28" and "U24" represent the "Crack Sealing" remediation option which is considered to have poor performance for aesthetics and is therefore pruned from selection if aesthetic importance is high (greater than a value of 8). The formula for this option is given in Equation D.14 for the example of the treatment of "Block Cracking"

$$= IF\big(Results!\,\$J\$7 < 2, "", IF(Results!\,\$J\$13 > 4, "", B38)\big)$$

Equation D.14

- Cells in columns "N", "P", "R", "T", "V", "X" and "Z" between rows "5:20" and "23:30" display a factor representing the effectiveness of the respective remediation option in providing a repair to the respective defect type
- Cells "D34:D45" display the adjusted cost for each remediation option, referencing the "RemedyKnowledgeBase" worksheet (see D.15 above) using the formula outlined in Equation D.15 for the example of Asphalt Resurfacing

$$= VLOOKUP(B34, RemedyKnowledgeBase!\,\$B\$4{:}\,\$D\$23,3, FALSE)$$

Equation D.15

- Cells "H34:H45" display the anticipated longevity for each remediation option in years
- Cells "J34:J45" display a factor between 1 to 10 representing the time taken to mobilise plant, equipment and materials to undertake the repair for each

remediation option. A factor of 1 represents a fast repair while a factor of 10 requires a large amount of time to plan the repair

- Cells "L34:L45" display a factor between 1 to 10 representing the aesthetic appearance of each completed remediation option. A factor of 10 represents high aesthetic appeal, while a factor of 1 represents a low aesthetic appeal
- Cell "B48" identifies what defect is being assessed via the lookup function shown in Equation D.16 referencing the "Results" worksheet

$$= IF(B1 = Results!\$C\$6, VLOOKUP(Results!C7, B5{:}B30,1, FALSE), 0)$$

Equation D.16

- Cells "D48:D54" display the remediation options available to treat the defect displayed in cell "B48" via a lookup function referencing the cells in columns "O", "Q", "S", "U", "W", "Y" and "AA" between rows "5:20" and "23:30" via the example lookup function shown in Equation D.17

$$= IF\begin{pmatrix} VLOOKUP(\$B\$48, \$B\$5{:}\$AB\$30,14, FALSE) = 0, "", \\ VLOOKUP(\$B\$48, \$B\$5{:}\$AB\$30,14, FALSE) \end{pmatrix}$$

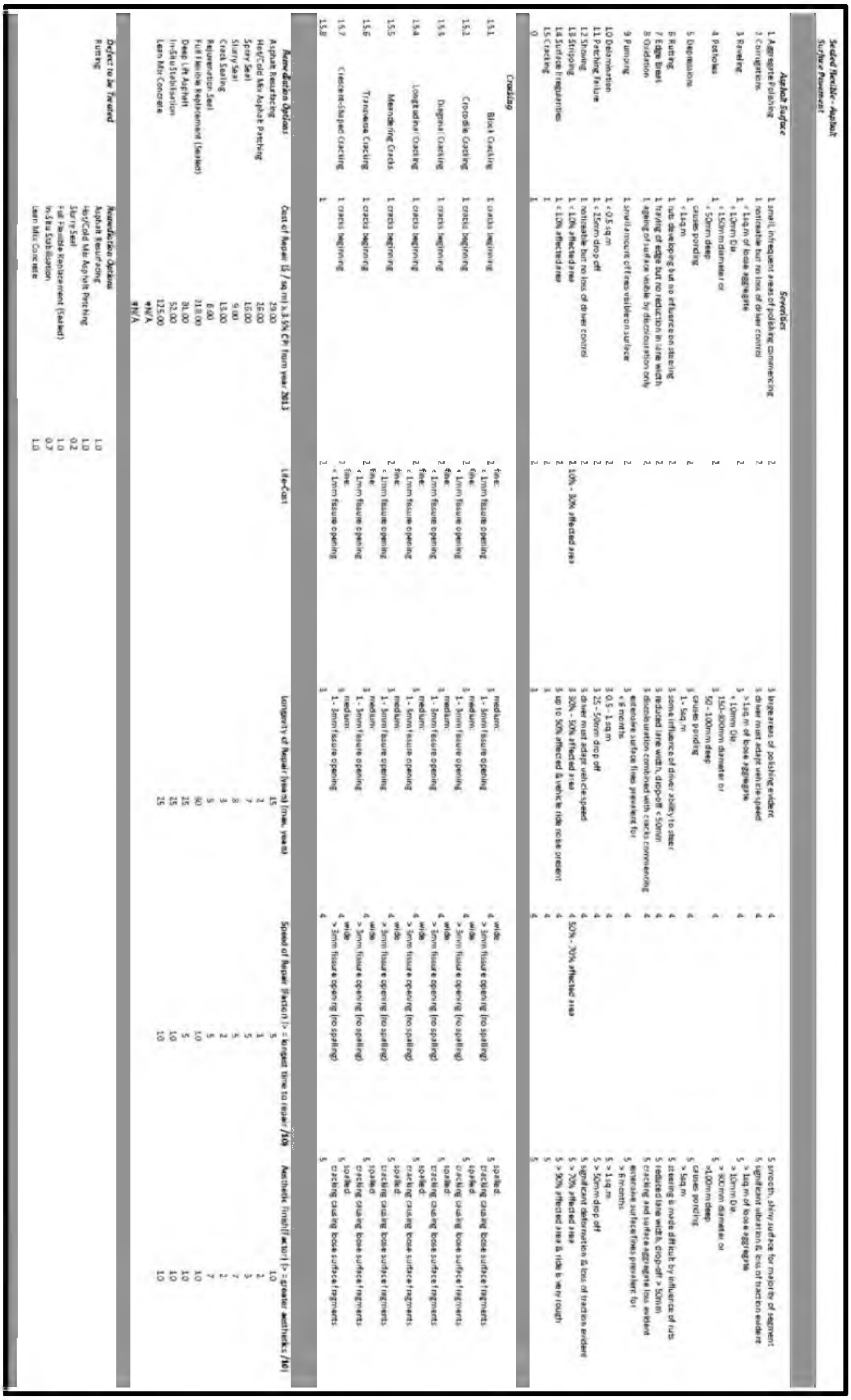
Equation D.17

- Cells "E48:E54" display the factor of effectiveness of the remediation options to treat the defect displayed in cell "B48" via a lookup function referencing the cells in columns "N", "P", "R", "T", "V", "X" and "Z" between rows "5:20" and "23:30" via the example lookup function shown in Equation D.18

$$= IF\begin{pmatrix} VLOOKUP(\$B\$48, \$B\$5{:}\$AB\$30,13, FALSE) = 0, "", \\ VLOOKUP(\$B\$48, \$B\$5{:}\$AB\$30,13, FALSE) \end{pmatrix}$$

Equation D.18

D.12.3 Screen Shots:



Sealed flexible - Asphalt
Surface Pavement

Asphalt Surface	*Severities*				
1 Aggregate Polishing	1 small, infrequent areas of polishing commencing	2	3 large areas of polishing evident	4	5 smooth, shiny surface for majority of segment
2 Corrugations	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant vibration & loss of traction evident
3 Raveling	1 < 1sq.m of loose aggregate < 10mm Dia.	2	3 > 1sq.m of loose aggregate < 10mm Dia.	4	5 > 1sq.m of loose aggregate > 10mm Dia.
4 Potholes	1 < 150mm diameter or < 50mm deep	2	3 150-300mm diameter or 50 - 100mm deep	4	5 > 300mm diameter or >100mm deep
5 Depressions	1 causes ponding < 1sq.m	2	3 causes ponding 1 - 5sq.m	4	5 causes ponding > 5sq.m
6 Rutting	1 ruts developing but no influence on steering	2	3 some influence of driver ability to steer	4	5 steering is made difficult by influence of ruts
7 Edge Break	1 fraying of edge but no reduction in lane width	2	3 reduced lane width, drop-off < 50mm	4	5 reduced lane width, drop-off > 50mm
8 Oxidation	1 ageing of surface visible by discolouration only	2	3 discolouration combined with cracks commencing	4	5 cracking and surface aggregate loss evident
9 Pumping	1 small amount of fines visible on surface	2	3 extensive surface fines prevalent for < 6 months	4	5 extensive surface fines prevalent for > 6 months
10 Delamination	1 < 0.5 sq.m	2	3 0.5 - 1 sq.m	4	5 > 1 sq.m
11 Patching Failure	1 < 25mm drop off	2	3 25 - 50mm drop off	4	5 > 50mm drop off
12 Shoving	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant deformation & loss of traction evident
13 Stripping	1 < 10% affected area	2 10% - 30% affected area	3 30% - 50% affected area	4 50% - 70% affected area	5 > 70% affected area
14 Surface Irregularities	1 < 10% affected area	2	3 up to 50% affected & vehicle ride noise present	4	5 > 90% affected area & ride is very rough
15 Cracking	1	2	3	4	5
0	1	2	3	4	5

Cracking

15.1	Block Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
15.2	Crocodile Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
15.3	Diagonal Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
15.4	Longitudinal Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
15.5	Meandering Cracks	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
15.6	Transverse Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
15.7	Crescent-Shaped Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
15.8		1	2	3	4	5

Remediation Options	Cost of Repair ($ / sq.m) x 3.5% CPI from year 2013	Life-Cost	Longevity of Repair (years) (max. years)	Speed of Repair (Factor) (> = longest time to repair /10)	Aesthetic Finish(Factor) (> = greater aesthetics /10)
Asphalt Resurfacing	29.00		15	5	10
Hot/Cold Mix Asphalt Patching	26.00		2	1	2
Spray Seal	16.00		7	5	3
Slurry Seal	9.00		8	5	7
Crack Sealing	13.00		3	2	2
Rejuvenation Seal	6.00		5	5	7
Full Flexible Replacement (Sealed)	318.00		50	10	10
Deep Lift Asphalt	81.00		25	5	10
In-Situ Stabilisation	52.00		25	10	10
Lean Mix Concrete	125.00		25	10	10
	#N/A				
	#N/A				

Defect to be Treated	*Remediation Options*	
Rutting	Asphalt Resurfacing	1.0
	Hot/Cold Mix Asphalt Patching	1.0
	Slurry Seal	0.2
	Full Flexible Replacement (Sealed)	1.0
	In-Situ Stabilisation	0.7
	Lean Mix Concrete	1.0

Figure D.64 – PaveMaint SELECT "AsphKnowledgeBase" Worksheet (Columns "A:L")

Suitability Index of Remediation Options (0.1 > 1.0)						
1.0 Asphalt Resurfacing	0.5 Spray Seal	0.2 Slurry Seal				
1.0 Asphalt Resurfacing	0.7 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation	1.0 Lean Mix Concrete		
1.0 Asphalt Resurfacing	0.2 Slurry Seal	0.8 Rejuvenation Seal	0.7 Spray Seal			
1.0 Hot/Cold Mix Asphalt Patching	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	In-Situ Stabilisation			
1.0 Hot/Cold Mix Asphalt Patching	1.0 Full Flexible Replacement (Sealed)	0.7 In-Situ Stabilisation	1.0 Lean Mix Concrete			
1.0 Asphalt Resurfacing	1.0 Hot/Cold Mix Asphalt Patching	0.2 Slurry Seal	1.0 Full Flexible Replacement (Sealed)	0.7 In-Situ Stabilisation	1.0 Lean Mix Concrete	
1.0 Hot/Cold Mix Asphalt Patching						
1.0 Asphalt Resurfacing	0.7 Spray Seal	0.2 Slurry Seal	0.8 Rejuvenation Seal			
1.0 Full Flexible Replacement (Sealed)	0.7 In-Situ Stabilisation	1.0 Lean Mix Concrete				
1.0 Asphalt Resurfacing	0.7 Spray Seal					
1.0 Asphalt Resurfacing	1.0 Hot/Cold Mix Asphalt Patching	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt			
1.0 Hot/Cold Mix Asphalt Patching	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation			
1.0 Asphalt Resurfacing	0.7 Spray Seal					
1.0 Asphalt Resurfacing	0.7 Spray Seal	0.2 Slurry Seal	1.0 Lean Mix Concrete	0.7 In-Situ Stabilisation	1.0 Deep Lift Asphalt	
0.2 Slurry Seal	1.0	0.8 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation	1.0 Lean Mix Concrete
0.5 Asphalt Resurfacing	1.0 Hot/Cold Mix Asphalt Patching	0.2 Slurry Seal	1.0	1.0 Lean Mix Concrete	1.0 Full Flexible Replacement (Sealed)	0.7 In-Situ Stabilisation
0.9 Asphalt Resurfacing	1.0	0.8 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation	
0.9 Asphalt Resurfacing	0.2 Slurry Seal	1.0	0.8 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation
0.8 Asphalt Resurfacing	1.0	0.8 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Lean Mix Concrete		
0.5 Asphalt Resurfacing	0.2 Slurry Seal	1.0	0.8 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation
1.0 Hot/Cold Mix Asphalt Patching	1.0	0.8 Rejuvenation Seal				

Figure D.65 – PaveMaint SELECT “AsphKnowledgeBase” Worksheet (Columns “M:AB”)

D.13 Worksheet - PaveMaint SELECT "BitKnowledgeBase"

D.13.1 Description:

- Sheet 4 of the PaveMaint SELECT spreadsheet file
- Holds information for bituminous spray sealed pavements only
- Contains a list of all the possible defect types, a description of the defect severities, references the list of the possible remediation options (from the "RemedyKnowledgeBase" worksheet") applicable for that pavement type only and provides scoring and weighting for all user constraint fields
- Sheet size: Columns "A:AB"; Rows "1:55"
- Sheet is hidden from users of the program. The organisation's administrator can unprotect the spreadsheet and unhide the worksheet to be able to access it

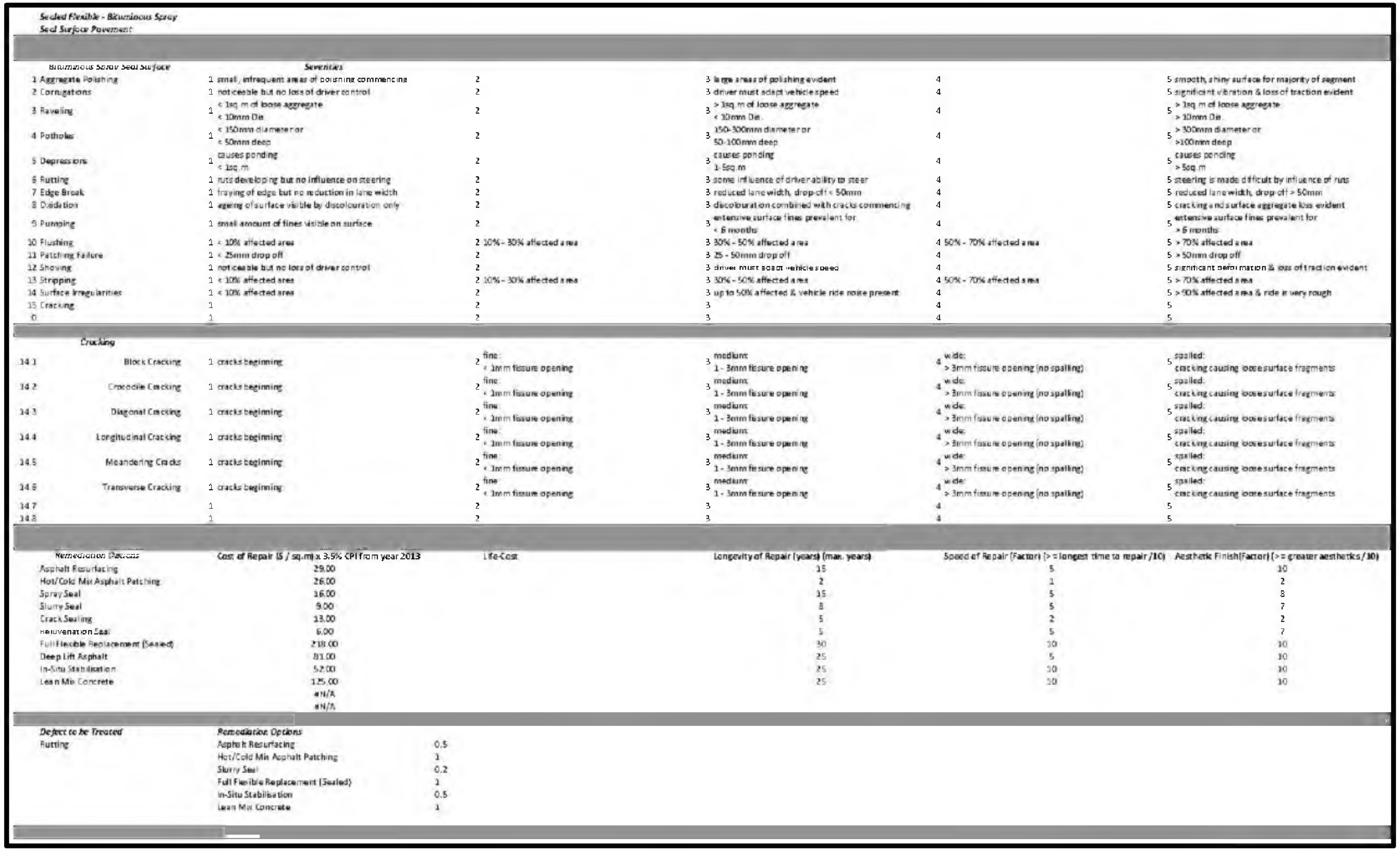
D.13.2 Cells and Functionality

- Rows "2:3", "21", "31:32", "46" and "55" as well as column "M" are empty cells formatted grey to provide a table break and clear visual delineation of the data presented
- Rows "1", "4", "22", "33" and "47" are heading rows and are used by other cells in lookup functions
- Cells "A5:A20" and "A23:30" display reference numbers for the individual defect types. The numbers provide a visual unique identity for the administrator but do not serve a function in the program
- Cells in columns "C", "E", "G", "I" and "K" between rows "5:20" and "23:30" provide numeric representations of the 5 severity levels
- Cells in columns "D", "F", "H", "J" and "L" between rows "5:20" and "23:30" provide descriptions of what the severity level means for each defect type
- Cells "B34:B43" display the possible remediation options available for the pavement type
- Cells in columns "O", "Q", "S", "U", "W", "Y" and "AA" between rows "5:20" and "23:30" display the suitable remediation options for the corresponding defect type.
    - The cells contain a conditional formula (Equation D.12) that displays a blank cell for severities less than a value of 2 (that is, considered slight) unless the user has nominated aesthetics to be of high importance (greater than a value of 8).
    - Cells "O5:7", "O10", "O12", "O14:15", "O24:28", "Q6", "Q8", "Q16", "S9", "S15", "U6", "U8", "U9", "U10", "U16", "U23", "U25", "U27", "W6", "W10", "W23", "W25", "W26", "W27", "W28", "Y10", "Y23", "Y24", "Y25", "Y26", "Y28", "AA23", "AA24", "AA26" and "AA28" display remediation options that require more substantial disturbance to the existing pavement and therefore the severity value in Equation D.12 is 4 (instead of 2) as it is not considered that such a significant repair would be undertaken unless the pavement is in poor or unserviceable condition.

- Cells “O8”, “O9”, “O16”, “O23”, “Q7”, “Q15”, “Q24”, “Q26”, “Q28”,”S5”, “S7”, “S10”, “S12”, “S14”, “S18”, “S23:S25”, “S27”, “U12”, “U26” and “U28” contain an augmentation of Equation D.12 that prunes options will low longevity when longevity is rated as a high importance factor. Equation D.13 provides an example for the “Slurry Seal” remediation option in the treatment of “Raveling”
- Cells “Q23”, “Q25”, “Q27”, “S26”, “S28” and “U24” represent the “Crack Sealing” remediation option which is considered to have poor performance for aesthetics and is therefore pruned from selection if aesthetic importance is high (greater than a value of 8). The formula for this option is given in Equation D.14

- Cells in columns “N”, “P”, “R”, “T”, “V”, “X” and “Z” between rows “5:20” and “23:30” display a factor representing the effectiveness of the respective remediation option in providing a repair to the respective defect type
- Cells “D34:D45” display the adjusted cost for each remediation option, referencing the “RemedyKnowledgeBase” worksheet (see D.15 above) using the formula outlined in Equation D.15 for the example of Asphalt Resurfacing
- Cells “H34:H45” display the anticipated longevity for each remediation option in years
- Cells “J34:J45” display a factor between 1 to 10 representing the time taken to mobilise plant, equipment and materials to undertake the repair for each remediation option. A factor of 1 represents a fast repair while a factor of 10 requires a large amount of time to plan the repair
- Cells “L34:L45” display a factor between 1 to 10 representing the aesthetic appearance of each completed remediation option. A factor of 10 represents high aesthetic appeal, while a factor of 1 represents a low aesthetic appeal
- Cell “B48” identifies what defect is being assessed via the lookup function shown in Equation D.16 referencing the “Results” worksheet
- Cells “D48:D54” display the remediation options available to treat the defect displayed in cell “B48” via a lookup function referencing the cells in columns “O”, “Q”, “S”, “U”, “W”, “Y” and “AA” between rows “5:20” and “23:30” via the example lookup function shown in Equation D.17
- Cells “E48:E54” display the factor of effectiveness of the remediation options to treat the defect displayed in cell “B48” via a lookup function referencing the cells in columns “N”, “P”, “R”, “T”, “V”, “X” and “Z” between rows “5:20” and “23:30” via the example lookup function shown in Equation D.18

D.13.3 Screen Shots:



Sealed Flexible - Bituminous Spray
Seal Surface Pavement

Bituminous Spray Seal Surface	*Severities*				
1 Aggregate Polishing	1 small, infrequent areas of polishing commencing	2	3 large areas of polishing evident	4	5 smooth, shiny surface for majority of segment
2 Corrugations	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant vibration & loss of traction evident
3 Raveling	1 < 1sq.m of loose aggregate < 10mm Dia.	2	3 > 1sq.m of loose aggregate < 10mm Dia.	4	5 > 1sq.m of loose aggregate > 10mm Dia.
4 Potholes	1 < 150mm diameter or < 50mm deep	2	3 150-300mm diameter or 50-100mm deep	4	5 > 300mm diameter or >100mm deep
5 Depressions	1 causes ponding < 1sq.m	2	3 causes ponding 1-5sq.m	4	5 causes ponding > 5sq.m
6 Rutting	1 ruts developing but no influence on steering	2	3 some influence of driver ability to steer	4	5 steering is made difficult by influence of ruts
7 Edge Break	1 fraying of edge but no reduction in lane width	2	3 reduced lane width, drop-off < 50mm	4	5 reduced lane width, drop-off > 50mm
8 Oxidation	1 ageing of surface visible by discolouration only	2	3 discolouration combined with cracks commencing	4	5 cracking and surface aggregate loss evident
9 Pumping	1 small amount of fines visible on surface	2	3 extensive surface fines prevalent for < 6 months	4	5 extensive surface fines prevalent for > 6 months
10 Flushing	1 < 10% affected area	2 10% - 30% affected area	3 30% - 50% affected area	4 50% - 70% affected area	5 > 70% affected area
11 Patching Failure	1 < 25mm drop off	2	3 25 - 50mm drop off	4	5 > 50mm drop off
12 Shoving	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant deformation & loss of traction evident
13 Stripping	1 < 10% affected area	2 10% - 30% affected area	3 30% - 50% affected area	4 50% - 70% affected area	5 > 70% affected area
14 Surface Irregularities	1 < 10% affected area	2	3 up to 50% affected & vehicle ride noise present	4	5 > 90% affected area & ride is very rough
15 Cracking	1	2	3	4	5
0	1	2	3	4	5

Cracking						
14.1	Block Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.2	Crocodile Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.3	Diagonal Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.4	Longitudinal Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.5	Meandering Cracks	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.6	Transverse Cracking	1 cracks beginning	2 fine: < 1mm fissure opening	3 medium: 1 - 3mm fissure opening	4 wide: > 3mm fissure opening (no spalling)	5 spalled: cracking causing loose surface fragments
14.7		1	2	3	4	5
14.8		1	2	3	4	5

Remediation Options	Cost of Repair ($ / sq.m) x 3.5% CPI from year 2013	Life-Cost	Longevity of Repair (years) (max. years)	Speed of Repair (Factor) (>=longest time to repair/10)	Aesthetic Finish(Factor) (>=greater aesthetics/10)
Asphalt Resurfacing	29.00		15	5	10
Hot/Cold Mix Asphalt Patching	26.00		2	1	2
Spray Seal	16.00		15	5	8
Slurry Seal	9.00		8	5	7
Crack Sealing	13.00		5	2	2
Rejuvenation Seal	6.00		5	5	7
Full Flexible Replacement (Sealed)	218.00		30	10	10
Deep Lift Asphalt	81.00		25	5	10
In-Situ Stabilisation	52.00		25	10	10
Lean Mix Concrete	125.00		25	10	10
	#N/A				
	#N/A				

Defect to be Treated	*Remediation Options*	
Rutting	Asphalt Resurfacing	0.5
	Hot/Cold Mix Asphalt Patching	1
	Slurry Seal	0.2
	Full Flexible Replacement (Sealed)	1
	In-Situ Stabilisation	0.5
	Lean Mix Concrete	1

Figure D.66 – PaveMaint SELECT “BitKnowledgeBase” Worksheet (Columns “A:L”)

Suitability Index of Remediation Options (0.1 > 1.0)

0.5 Asphalt Resurfacing	1.0 Spray Seal	0.2 Slurry Seal				
0.5 Asphalt Resurfacing	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation	1.0 Lean Mix Concrete		
0.5 Asphalt Resurfacing	0.2 Slurry Seal	0.8 Rejuvenation Seal	1.0 Spray Seal			
1.0 Hot/Cold Mix Asphalt Patching	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation			
1.0 Hot/Cold Mix Asphalt Patching	1.0 Full Flexible Replacement (Sealed)	1.0 In-Situ Stabilisation	1.0 Lean Mix Concrete			
0.5 Asphalt Resurfacing	1.0 Hot/Cold Mix Asphalt Patching	0.2 Slurry Seal	1.0 Full Flexible Replacement (Sealed)	0.5 In-Situ Stabilisation	1.0 Lean Mix Concrete	
1.0 Hot/Cold Mix Asphalt Patching						
0.5 Asphalt Resurfacing	1.0 Spray Seal	0.2 Slurry Seal	0.8 Rejuvenation Seal			
1.0 Full Flexible Replacement (Sealed)	0.7 In-Situ Stabilisation	1.0 Lean Mix Concrete				
0.5 Asphalt Resurfacing	1.0 Spray Seal	0.2 Slurry Seal				
0.7 Asphalt Resurfacing	1.0 Hot/Cold Mix Asphalt Patching	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt			
1.0 Hot/Cold Mix Asphalt Patching	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation			
0.5 Asphalt Resurfacing	1.0 Spray Seal					
0.6 Asphalt Resurfacing	0.4 Spray Seal	0.2 Slurry Seal	1.0 Lean Mix Concrete	0.7 In-Situ Stabilisation		

0.2 Slurry Seal	1.0	0.8 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation	1.0 Lean Mix Concrete
0.6 Asphalt Resurfacing	1.0 Hot/Cold Mix Asphalt Patching	0.2 Slurry Seal	1.0	1.0 Lean Mix Concrete	1.0 Full Flexible Replacement (Sealed)	0.7 In-Situ Stabilisation
0.7 Asphalt Resurfacing	1.0	0.2 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation	
0.7 Asphalt Resurfacing	0.2 Slurry Seal	1.0	0.8 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation
0.7 Asphalt Resurfacing	1.0	0.8 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Lean Mix Concrete		
0.4 Asphalt Resurfacing	0.2 Slurry Seal	1.0	0.8 Rejuvenation Seal	1.0 Full Flexible Replacement (Sealed)	1.0 Deep Lift Asphalt	0.7 In-Situ Stabilisation

Figure D.67 – PaveMaint SELECT “BitKnowledgeBase” Worksheet (Columns “M:AB”)

D.14 Worksheet - PaveMaint SELECT "UnSeaKnowledgeBase"

D.14.1 Description:

- Sheet 5 of the PaveMaint SELECT spreadsheet file
- Holds information for unsealed pavements only
- Contains a list of all the possible defect types, a description of the defect severities, references the list of the possible remediation options (from the "RemedyKnowledgeBase" worksheet") applicable for that pavement type only and provides scoring and weighting for all user constraint fields
- Sheet size: Columns "A:AB"; Rows "1:55"
- Sheet is hidden from users of the program. The organisation's administrator can unprotect the spreadsheet and unhide the worksheet to be able to access it

D.14.2 Cells and Functionality

- Rows "2:3", "21", "31:32", "46" and "55" as well as column "M" are empty cells formatted grey to provide a table break and clear visual delineation of the data presented
- Rows "1", "4", "22", "33" and "47" are heading rows and are used by other cells in lookup functions
- Cells "A5:A20" display reference numbers for the individual defect types. The numbers provide a visual unique identity for the administrator but do not serve a function in the program
- Cells in columns "C", "E", "G", "I" and "K" between rows "5:20" provide numeric representations of the 5 severity levels
- Cells in columns "D", "F", "H", "J" and "L" between rows "5:20" provide descriptions of what the severity level means for each defect type
- Cells "B34:B43" display the possible remediation options available for the pavement type
- Cells in columns "O", "Q", "S", "U", "W", "Y" and "AA" between rows "5:20" display the suitable remediation options for the corresponding defect type.
  - o The cells contain a conditional formula (Equation D.12) that displays a blank cell for severities less than a value of 2 (that is, considered slight) unless the user has nominated aesthetics to be of high importance (greater than a value of 8).
  - o Cells "O9", "Q5", "Q9", "S5", "S6", "S7", "S8", "S10", "S11", "S12" "W8", "W10", "W12", "Y8" and "Y10" display remediation options that require more substantial disturbance to the existing pavement and therefore the severity value in Equation D.12 is 4 (instead of 2) as it is not considered that such a significant repair would be undertaken unless the pavement is in poor or unserviceable condition.
- Cells in columns "N", "P", "R", "T", "V", "X" and "Z" between rows "5:20" display a factor representing the effectiveness of the respective remediation option in providing a repair to the respective defect type
- Cells "D34:D45" display the adjusted cost for each remediation option, referencing the "RemedyKnowledgeBase" worksheet (see D.15 above) using

the formula outlined in Equation D.15 for the example of Asphalt Resurfacing

- Cells “H34:H45” display the anticipated longevity for each remediation option in years
- Cells “J34:J45” display a factor between 1 to 10 representing the time taken to mobilise plant, equipment and materials to undertake the repair for each remediation option. A factor of 1 represents a fast repair while a factor of 10 requires a large amount of time to plan the repair
- Cells “L34:L45” display a factor between 1 to 10 representing the aesthetic appearance of each completed remediation option. A factor of 10 represents high aesthetic appeal, while a factor of 1 represents a low aesthetic appeal
- Cell “B48” identifies what defect is being assessed via the lookup function shown in Equation D.16 referencing the “Results” worksheet
- Cells “D48:D54” display the remediation options available to treat the defect displayed in cell “B48” via a lookup function referencing the cells in columns “O”, “Q”, “S”, “U”, “W”, “Y” and “AA” between rows “5:20” via the example lookup function shown in Equation D.17
- Cells “E48:E54” display the factor of effectiveness of the remediation options to treat the defect displayed in cell “B48” via a lookup function referencing the cells in columns “N”, “P”, “R”, “T”, “V”, “X” and “Z” between rows “5:20” via the example lookup function shown in Equation D.18

D.14.3 Screen Shots:

Unsealed Flexible Pavement

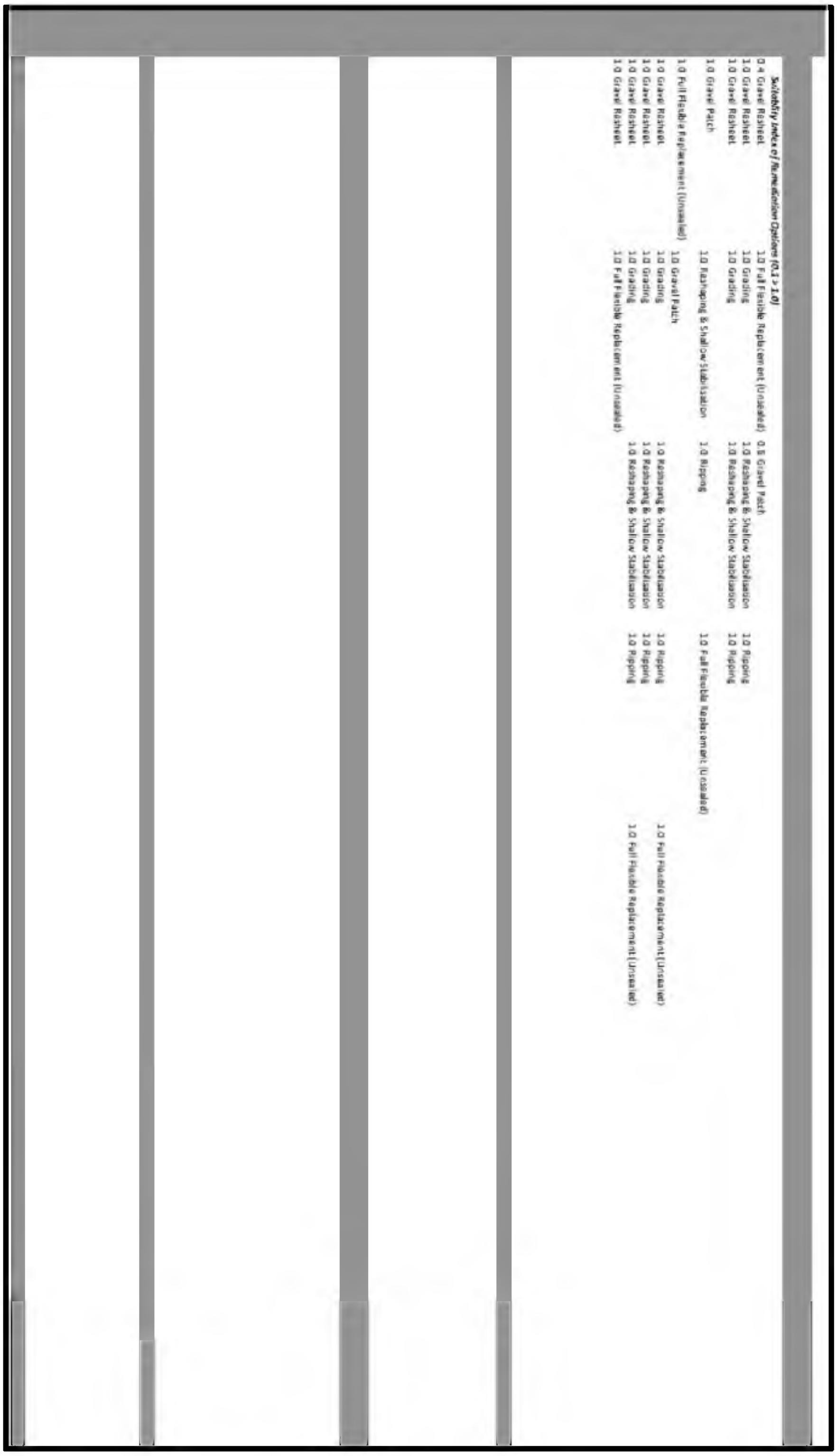
Unsealed	*Severities*				
1 Soft Spots	1 wet spots noticeable some time after rain	2 small depressions appearing on surface	3 pavement deformation present	4 evidence of some surface gouging noted	5 significant surface gouging is present
2 Corrugations	1 noticeable but no loss of driver control	2	3 driver must adapt vehicle speed	4	5 significant vibration & loss of traction evident
3 Raveling	1 some loose aggregate present on surface	2	3 loose surface & driver must adapt vehicle speed	4	5 significant loose aggregate & loss of traction
4 Potholes	1 < 150mm diameter or < 50mm deep	2	3 150-300mm diameter or 50-100mm deep	4	5 > 300 mm diameter or >100mm deep
5 Depressions	1 causes ponding < 1sq.m	2	3 causes ponding 1-5sq.m	4	5 causes ponding > 5sq.m
6 Rutting	1 ruts developing but no influence on steering	2	3 some influence of driver ability to steer	4	5 steering is made difficult by influence of ruts
7 Loss of Fines	1 dusty road under traffic	2	3 dusty road with reduced visibility in traffic	4	5 plumes of dust present with wind & traffic
8 Erosion Channels	1 < 50mm deep	2	3 50-100mm deep	4	5 >100mm deep
9 Loss of Pavement	1 dusty road under traffic	2	3 windrows of pavement material on road verge	4	5 subgrade exposed in areas
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5

Not Used

Remediation Options	Cost of Repair ($ / sq.m) x 3.5% CPI from year 2013	Life-Cost	Longevity of Repair (years) (max. years)	Speed of Repair (Factor) (> = longest time to repair)	Aesthetic Finish(Factor) (> = greater aesthetics)
Gravel Resheet	11.00		7	3	10
Grading	2.00		1	1	10
Reshaping & Shallow Stabilisation	6.00		5	3	10
Ripping	4.00		1	1	10
Full Flexible Replacement (Unsealed)	30.00		15	10	10
Gravel Patch	9.00		5	10	10
	#N/A				
	#N/A				
	#N/A				
	#N/A				
	#N/A				
	#N/A				

Defect to be Treated	*Remediation Options*	
Soft Spots	Gravel Resheet	0.4
	Full Flexible Replacement (Unsealed)	1
	Gravel Patch	0.6

Figure D.68 – PaveMaint SELECT “UnSeaKnowledgeBase” Worksheet (Columns “A:L”)



Suitablity Index of Remediation Options (0.1 > 1.0)				
0.4 Gravel Resheet	1.0 Full Flexible Replacement (Unsealed)	0.5 Gravel Patch		
1.0 Gravel Resheet	1.0 Grading	1.0 Reshaping & Shallow Stabilisation	1.0 Ripping	
1.0 Gravel Resheet	1.0 Grading	1.0 Reshaping & Shallow Stabilisation	1.0 Ripping	
1.0 Gravel Patch	1.0 Reshaping & Shallow Stabilisation	1.0 Ripping	1.0 Full Flexible Replacement (Unsealed)	
1.0 Full Flexible Replacement (Unsealed)	1.0 Gravel Patch			
1.0 Gravel Resheet	1.0 Grading	1.0 Reshaping & Shallow Stabilisation	1.0 Ripping	1.0 Full Flexible Replacement (Unsealed)
1.0 Gravel Resheet	1.0 Grading	1.0 Reshaping & Shallow Stabilisation	1.0 Ripping	
1.0 Gravel Resheet	1.0 Grading	1.0 Reshaping & Shallow Stabilisation	1.0 Ripping	1.0 Full Flexible Replacement (Unsealed)
1.0 Gravel Resheet	1.0 Full Flexible Replacement (Unsealed)			

Figure D.69 – PaveMaint SELECT “UnSeaKnowledgeBase” Worksheet
(Columns “M:AB”)

D.15 Worksheet - PaveMaint SELECT "RemedyKnowledgeBase"

D.15.1 Description:

- Sheet 6 of the PaveMaint SELECT spreadsheet file
- Contains a list of all the available remediation options for all the flexible pavement types, along with their costs
- Sheet size: Columns "A:E"; Rows "1:23"
- Sheet is hidden from users of the program. The organisation's administrator can unprotect the spreadsheet and unhide the worksheet to be able to access it

D.15.2 Cells and Functionality

- Cell "C2" contains the manually updated date upon which the administrator last updated the costs of the remediation options
- Cells "B2", "D2" and "B3:D3" provide headings for the columns of information stored below or adjacent to them
- Cells "B4:B18" display the list of all the remediation options (in text format), while cells "B19:B23" provide blank cells that the administrator may be able to add additional remediation options
- Cells "C4:C18" display the manually updated costs of each of the remediation options. The worksheet is prefilled with cost information researched by the author
- Cell "E2" provides a percentage cost growth factor set to a default value of 3.5%
- Cells "D4:D18" contain a formula whose function to provide an estimated update to the remediation costs on a yearly basis, should the administrator elect not to manually update the knowledgebase regularly. The equation for cell "D4" (which is representative of all the cells "D4:D18") is given as Equation D.19 below:

$$= [\![C4 \times (1 + \$E\$2)]\!]\hat{}((ROUNDDOWN(((YEAR(Results!\,\$M\$1) - YEAR(\$C\$2)) \times 12 + (MONTH(Results!\,\$M\$1) - MONTH(C\$C2))) \div 12, -0.5)\ )$$

Equation D.19

D.15.3 Accelerated Learning Tools:

- Cell "C2" has a comment dialogue box attributed to it providing instructions to the administrator on what information is required in this cell
- Cells "C4:C18" contain comment fields in each cell providing the reference where the information was obtained through the author's research
- Cell "E2" has a comment dialogue box attributed to it providing instructions to the administrator that they can adjust the cost growth factor manually as required
- Column "E" provides ALT descriptions for each remediation option (which are referenced by the Results worksheet)

D.15.4 Screen Shots:

	A	B	C	D	E
1					
2		Date updated	1/01/2013	CPI from 2013	3.5%
3		*Remediation Options*	$/sqm	Adjusted Current Year $/sqm	
4		Asphalt Resurfacing	$ 28.00	$29.00	
5		Hot/Cold Mix Asphalt Patching	$ 24.95	$26.00	
6		Spray Seal	$ 15.00	$16.00	
7		Slurry Seal	$ 8.00	$9.00	
8		Crack Sealing	$ 11.65	$13.00	
9		Rejuvenation Seal	$ 5.00	$6.00	
10		Full Flexible Replacement	$ 210.00	$218.00	
11		Deep Lift Asphalt	$ 78.00	$81.00	
12		In-Situ Stabilisation	$ 50.00	$52.00	
13		Lean Mix Concrete	$ 120.00	$125.00	
14		Gravel Resheet	$ 10.00	$11.00	
15		Grading	$ 1.30	$2.00	
16		Reshaping & Shallow Stabilisation	$ 5.00	$6.00	
17		Ripping	$ 3.00	$4.00	
18		Gravel Patch	$ 8.00	$9.00	
19					
20					
21					
22					
23					

Figure D.70 – PaveMaint SELECT “RemedyKnowledgeBase” Worksheet
(Columns “A:E”)

3.5%

Accelerated Learning Tool

Asphalt resurfacing involves the application of an asphalt surface over an existing asphalt or spray sealed pavement. In the case of a non-structural overlay (a th
Patching is a local repair which is the replacement of a failed section of a sealed flexible pavement to its full depth with either hot or cold mix asphalt to reinstat
The use of a spray seal treatment is a suitable remediation method for all sealed flexible pavements, restoring the waterproof membrane as well as replenishing
A slurry surface is the application of bituminous mixture containing cementitious binder, sands, filler and graded aggregate (to a maximum 7mm stone size), whi
Crack sealing involves either placing a bituminous sealant over a crack or filling a crack with bitumen emulsion to improve waterproofing. Crack sealing is most e
Rejuvenation seals are a form of spray seal designed to replace lost oils and soften aged and cracked bitumen or asphalt. Rejuvenation seals are considered bene
A full flexible pavement replacement is the removal of the affected pavement to its full depth and replacement with suitable flexible pavement materials and inc
A deep lift asphalt repair involves the placement of a thick asphalt layer over an existing pavement or subgrade. It differs significantly from an asphalt resurfacin
An in-situ stabilisation treatment is the recycling of the existing failing pavement material (including its subgrade) which is stiffened with a cementitious admixtu
A lean mix concrete treatment is the replacement of one of the existing pavement layers (usually the subbase) with low strength concrete, typically 5MPa. Its pri
A gravel resheet is broadly the importation of further pavement materials to top-up or improve the integrity of a road pavement.
Grading is considered an important maintenance activity for unsealed flexible pavements and particularly beneficial at improving the smoothness of the surface.
Reshaping involves the shallow scarification of the road surface, which allows the pavement surface aggregates and fines to be blended back to a desirable gradi
Ripping involves scarifying an unsealed pavement to penetrate the surface to a depth up to 150mm, where the surface is then shaped with the grader blade and
Gravel patching is a local repair which is the replacement of a failed section of unsealed flexible pavement to its full depth with similar granular mateerial to rein
A full flexible pavement replacement is the removal of the affected pavement to its full depth and replacement with suitable flexible pavement materials.

Figure D.71 – PaveMaint SELECT "RemedyKnowledgeBase" Worksheet (Columns "E:AR")

APPENDIX E

FINAL SYSTEM TESTING: CASE STUDIES RE-EVALUATION

PAVEMAINT SELECT VERSION 1.0

E.1 Case Study: C4.1.1

<u>Treatment Data:</u>

Road Type:	Flexible Bituminous Spray Seal
Traffic Conditions:	Up to 10^5 ESA
Dominant Defect:	Crocodile Cracking
Treatment Selected:	Full Flexible Replacement
Severity:	Poor to Unserviceable
Cost Constraint:	2/4
Longevity Required:	4/4
Resource Constraints:	1/3
Aesthetic Constraints:	2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Quinns Lane
Locality:	South Nowra
Segment Number:	Worrigee
Pavement Type:	Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed:	Crocodile Cracking — ***Severity:*** 5 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume:	up to 1x10^5 ESA

Best Suited Remediation Option: **In-Situ Stabilisation**

Summary of Results

TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Importance Factor	4	10	4	3	
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**73**
Lean Mix Concrete	125.00	25.00	10.00	10.00	**30**
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	**21**
Asphalt Resurfacing	29.00	15.00	5.00	10.00	**19**
Crack Sealing	13.00	5.00	2.00	2.00	**7**

Figure E.1 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.1.1 (Crocodile Cracking Defect)

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Quinns Lane
Locality: South Nowra
Segment Number: Worrigee
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Patching Failure ***Severity:*** 4
Traffic Volume: up to 1x10^5 ESA (1 = slight >>> 5 = unsatisfactory)

Best Suited Remediation Option: **Deep Lift Asphalt**

Summary of Results

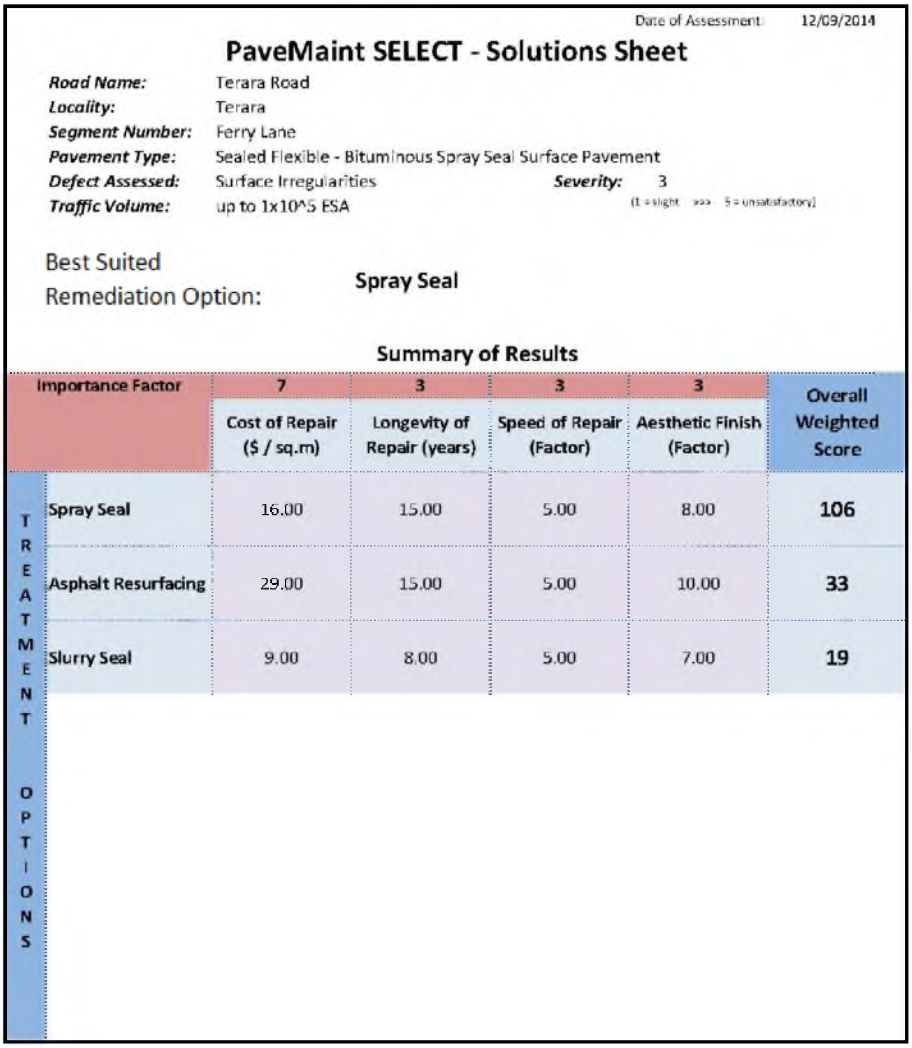
Importance Factor	4	10	3	3	Overall Weighted Score
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
Deep Lift Asphalt	81.00	25.00	5.00	10.00	**74**
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	**25**
Asphalt Resurfacing	29.00	15.00	5.00	10.00	**25**

Figure E.2 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.1.1 (“What-If” Analysis – Patching Failure Defect)

E.2 Case Study: C.4.2.1

<u>Treatment Data:</u>

Road Type:	Flexible Bituminous Spray Sealed
Traffic Conditions:	Medium to Heavy
Dominant Defect:	Other – Surface Irregularities
Treatment Selected:	Spray Seal
Severity:	Moderate
Cost Constraint:	3/4
Longevity Required:	2/4
Resource Constraints:	2/3
Aesthetic Constraints:	2/3



Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Terara Road
Locality: Terara
Segment Number: Ferry Lane
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Surface Irregularities *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Best Suited Remediation Option: **Spray Seal**

Summary of Results

Importance Factor	7	3	3	3	Overall Weighted Score
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
Spray Seal	16.00	15.00	5.00	8.00	106
Asphalt Resurfacing	29.00	15.00	5.00	10.00	33
Slurry Seal	9.00	8.00	5.00	7.00	19

Figure E.3 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.2.1

E.3 Case Study: C.4.2.2

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Light

Dominant Defect: Shoving

Treatment Selected: Full Flexible Replacement

Severity: Poor

Cost Constraint: 3/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Supply Street
Locality: Nowra
Segment Number: 1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Shoving *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Best Suited Remediation Option: **In-Situ Stabilisation**

Summary of Results

Importance Factor	6	6	2	5	Overall Weighted Score
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**63**
Deep Lift Asphalt	81.00	25.00	5.00	10.00	**60**
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	**26**
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	**8**

Figure E.4 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.2.2

E.4 Case Study: C.4.2.3

<u>Treatment Data:</u>

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Medium

Dominant Defect: Edge Break

Treatment Selected: Patch (with some Grading)

Severity: Poor

Cost Constraint: 3/4

Longevity Required: 2/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Greenwell Point Road
Locality: Pyree
Segment Number: Pyree Lane
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Edge Break *Severity:* 4
Traffic Volume: up to 1x10^5 ESA (1 = slight >>> 5 = unsatisfactory)

Best Suited Remediation Option: **Hot/Cold Mix Asphalt Patching**

Summary of Results

Importance Factor	7	3	3	3	Overall Weighted Score
	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
TREATMENT OPTIONS: Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	10

Figure E.5 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.2.3

E.5 Case Study: C.4.3.1

<u>Treatment Data:</u>

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Pumping

Treatment Selected: In-Situ Stabilisation

Severity: Poor

Cost Constraint: 1/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Burelli Street
Locality: Wollongong
Segment Number: 20
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Pumping *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

Best Suited Remediation Option: **In-Situ Stabilisation**

Summary of Results

Importance Factor	2	7	3	5	
	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
TREATMENT OPTIONS					
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**38**
Lean Mix Concrete	125.00	25.00	10.00	10.00	**22**
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	**15**

Figure E.6 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.3.1

E.6 Case Study: C.4.3.2

<u>Treatment Data:</u>

Road Type:	Flexible Asphaltic Concrete Surface
Traffic Conditions:	Up to 10^5 ESA
Dominant Defect:	Crocodile Cracking
Treatment Selected:	Lean Mix Concrete
Severity:	Unserviceable
Cost Constraint:	1/4
Longevity Required:	4/4
Resource Constraints:	2/3
Aesthetic Constraints:	2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Grey Street
Locality: Keiraville
Segment Number: 10, 20
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Crocodile Cracking *Severity:* 5 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Best Suited Remediation Option: **In-Situ Stabilisation**

Summary of Results

Importance Factor	2	10	4	3	
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
In-Situ Stabilisation	52.00	25.00	10.00	10.00	37
Asphalt Resurfacing	29.00	15.00	5.00	10.00	24
Lean Mix Concrete	125.00	25.00	10.00	10.00	15
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	10
Crack Sealing	13.00	3.00	2.00	2.00	2

Figure E.7 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.3.2

E.7 Case Study: C.4.3.3

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Oxidation

Treatment Selected: Asphalt Resurfacing

Severity: Poor

Cost Constraint: 1/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Simpson Place
Locality: Wollongong
Segment Number: 10
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Oxidation *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	2	10	3	5	
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	15.00	5.00	10.00	83
Spray Seal	16.00	7.00	5.00	3.00	28

Figure E.8 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.3.3

E.8 Case Study: C.4.4.1

Treatment Data:

Road Type:	Flexible Unsealed
Traffic Conditions:	Up to 10^4 ESA
Dominant Defect:	Potholes
Treatment Selected:	Gravel Patch
Severity:	Moderate
Cost Constraint:	3/4
Longevity Required:	4/4
Resource Constraints:	1/3
Aesthetic Constraints:	2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Lower River Road
Locality: Tocumwal
Segment Number: 1
Pavement Type: Unsealed Flexible Pavement
Defect Assessed: Potholes *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Best Suited Remediation Option: **Gravel Patch**

Summary of Results

Importance Factor	7	10	2	3	Overall Weighted Score
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
Gravel Patch	9.00	5.00	10.00	10.00	**124**
Ripping	4.00	1.00	1.00	10.00	**88**

Figure E.9 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.4.1

E.9 Case Study: C.4.4.2

Treatment Data:

Road Type: Flexible Unsealed

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Other – Loss of Pavement

Treatment Selected: Gravel Resheet

Severity: Moderate

Cost Constraint: 3/4

Longevity Required: 4/4

Resource Constraints: 1/3

Aesthetic Constraints: 2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Lower River Road
Locality: Tocumwal
Segment Number: 5
Pavement Type: Unsealed Flexible Pavement
Defect Assessed: Loss of Pavement — *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Best Suited Remediation Option: **Gravel Resheet**

Summary of Results

Importance Factor	7	10	2	3	
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Gravel Resheet	11.00	7.00	3.00	10.00	**223**
Full Flexible Replacement (Unsealed)	30.00	15.00	10.00	10.00	**126**

Figure E.10 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.4.2

E.10 Case Study: C.4.4.3

<u>Treatment Data:</u>

Road Type:	Flexible Unsealed
Traffic Conditions:	Up to 10^4 ESA
Dominant Defect:	Soft Spots
Treatment Selected:	Full Flexible Replacement
Severity:	Moderate
Cost Constraint:	3/4
Longevity Required:	4/4
Resource Constraints:	1/3
Aesthetic Constraints:	2/3

Date of Assessment 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Lower River Road
Locality: Tocumwal
Segment Number: 2
Pavement Type: Unsealed Flexible Pavement
Defect Assessed: Soft Spots *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Best Suited Remediation Option: **Full Flexible Replacement (Unsealed)**

Summary of Results

Importance Factor	7	10	2	3	Overall Weighted Score
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
Full Flexible Replacement (Unsealed)	30.00	15.00	10.00	10.00	**126**
Gravel Resheet	11.00	7.00	3.00	10.00	**89**
Gravel Patch	9.00	5.00	10.00	10.00	**84**

Figure E.11 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.4.3

E.11 Case Study: C.4.5.1

<u>Treatment Data:</u>

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Rutting

Treatment Selected: Full Flexible Replacement

Severity: Unserviceable

Cost Constraint: 4/4

Longevity Required: 4/4

Resource Constraints: 1/3

Aesthetic Constraints: 2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Browns Road
Locality: South Nowra
Segment Number: 1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Rutting *Severity:* 5 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Best Suited Remediation Option: **Lean Mix Concrete**

Summary of Results

Importance Factor	10	10	4	3	
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Lean Mix Concrete	125.00	25.00	10.00	10.00	100
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	69
In-Situ Stabilisation	52.00	25.00	10.00	10.00	48
Asphalt Resurfacing	29.00	15.00	5.00	10.00	36

Figure E.12 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.5.1

E.12 Case Study: C.4.5.2

<u>Treatment Data:</u>

Road Type:	Flexible Bituminous Spray Sealed
Traffic Conditions:	Up to 10^6 ESA
Dominant Defect:	Crocodile Cracking
Treatment Selected:	Full Flexible Replacement
Severity:	Unserviceable
Cost Constraint:	4/4
Longevity Required:	4/4
Resource Constraints:	2/3
Aesthetic Constraints:	2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Church Street
Locality: Milton
Segment Number: 1 & 2
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Crocodile Cracking *Severity:* 5
Traffic Volume: up to 1x10^6 ESA (1 = slight >>> 5 = unsatisfactory)

Best Suited Remediation Option: **In-Situ Stabilisation**

Summary of Results

Importance Factor	10	10	4	3	
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**183**
Lean Mix Concrete	125.00	25.00	10.00	10.00	**76**
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	**52**
Asphalt Resurfacing	29.00	15.00	5.00	10.00	**48**
Crack Sealing	13.00	5.00	2.00	2.00	**18**

Figure E.13 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.5.2

E.13 Case Study: C.4.6.1

Treatment Data:

Road Type:	Flexible Bituminous Spray Sealed
Traffic Conditions:	Up to 10^6 ESA
Dominant Defect:	Other – Surface Irregularities
Treatment Selected:	Asphalt Resurfacing
Severity:	Moderate
Cost Constraint:	2/4
Longevity Required:	4/4
Resource Constraints:	2/3
Aesthetic Constraints:	3/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Terralong Street
Locality: Kiama
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Patching Failure *Severity:* 3
Traffic Volume: up to 1x10^6 ESA (1 = slight >>> 5 = unsatisfactory)

Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	4	10	3	5	Overall Weighted Score
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
Asphalt Resurfacing	29.00	15.00	5.00	10.00	116
Deep Lift Asphalt	81.00	25.00	5.00	10.00	99
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	36

Figure E.14 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.6.1

E.14 Case Study: C.4.6.2

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Rutting

Treatment Selected: Asphalt Resurfacing

Severity: Moderate

Cost Constraint: 2/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 3/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Havilah Place
Locality: Kiama
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Rutting *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	4	10	3	5	
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	15.00	5.00	10.00	83
In-Situ Stabilisation	52.00	25.00	10.00	10.00	63
Lean Mix Concrete	125.00	25.00	10.00	10.00	52
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	36

Figure E.15 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.6.2

E.15 Case Study: C.4.6.3

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Other – Surface Irregularities

Treatment Selected: In-Situ Stabilisation

Severity: Moderate

Cost Constraint: 2/4

Longevity Required: 2/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Foxground Road
Locality: Foxground
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Surface Irregularities ***Severity:*** 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Best Suited Remediation Option: **In-Situ Stabilisation**

Summary of Results

TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Importance Factor	4	3	3	3	
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**26**
Spray Seal	16.00	15.00	5.00	8.00	**24**
Asphalt Resurfacing	29.00	15.00	5.00	10.00	**22**
Slurry Seal	9.00	8.00	5.00	7.00	**11**
Lean Mix Concrete	125.00	25.00	10.00	10.00	**11**

Figure E.16 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.6.3

E.16 Case Study: C.4.6.4

Treatment Data:

Road Type: Flexible Bituminous Spray Sealed

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Crocodile Cracking

Treatment Selected: Asphalt Resurfacing

Severity: Moderate

Cost Constraint: 2/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Oxley Avenue
Locality: Kiama
Segment Number: S2
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Crocodile Cracking *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	4	10	3	5	Overall Weighted Score
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
Asphalt Resurfacing	29.00	15.00	5.00	10.00	99
In-Situ Stabilisation	52.00	25.00	10.00	10.00	88
Lean Mix Concrete	125.00	25.00	10.00	10.00	52
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	36

Figure E.17 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.6.4

E.17 Case Study: C.4.6.5

Treatment Data:

Road Type:	Flexible Bituminous Spray Sealed
Traffic Conditions:	Up to 10^4 ESA
Dominant Defect:	Oxidation
Treatment Selected:	Spray Seal
Severity:	Poor
Cost Constraint:	2/4
Longevity Required:	3/4
Resource Constraints:	2/3
Aesthetic Constraints:	1/3

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PaveMaint SELECT - Solutions Sheet

Road Name: Wallaby Hill Road
Locality: Jamberoo
Segment Number: S1
Pavement Type: Sealed Flexible - Bituminous Spray Seal Surface Pavement
Defect Assessed: Oxidation *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Best Suited Remediation Option: **Spray Seal**

Summary of Results

Importance Factor	4	7	3	1	Overall Weighted Score
	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
TREATMENT OPTIONS					
Spray Seal	16.00	15.00	5.00	8.00	**100**
Asphalt Resurfacing	29.00	15.00	5.00	10.00	**29**

Figure E.18 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.6.5

E.18 Case Study: C.4.7.1

<u>Treatment Data:</u>

Road Type:	Flexible Asphaltic Concrete Surface
Traffic Conditions:	Up to 10^6 ESA
Dominant Defect:	Crocodile Cracking
Treatment Selected:	Crack Sealing
Severity:	Moderate
Cost Constraint:	2/4
Longevity Required:	3/4
Resource Constraints:	2/3
Aesthetic Constraints:	2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Dora Street
Locality: Hurstville
Segment Number: A
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Crocodile Cracking *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Importance Factor	4	3	3	3	
Asphalt Resurfacing	29.00	15.00	5.00	10.00	11
Lean Mix Concrete	125.00	25.00	10.00	10.00	8
Crack Sealing	13.00	3.00	2.00	2.00	6
Slurry Seal	9.00	8.00	5.00	7.00	6
Hot/Cold Mix Asphalt Patching	26.00	2.00	1.00	2.00	3

Figure E.19 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.7.1

Case Study: C.4.7.2

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^5 ESA

Dominant Defect: Other – Surface Irregularities

Treatment Selected: Deep Lift Asphalt

Severity: Poor

Cost Constraint: 4/4

Longevity Required: 3/4

Resource Constraints: 3/3

Aesthetic Constraints: 3/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Warrawee Place
Locality: Beverly Hills
Segment Number: Full
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Surace Irregularities *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

Importance Factor	10	7	4	3	
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Asphalt Resurfacing	29.00	15.00	5.00	10.00	**253**
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**168**
Deep Lift Asphalt	81.00	25.00	5.00	10.00	**151**
Spray Seal	16.00	7.00	5.00	3.00	**105**
Lean Mix Concrete	125.00	25.00	10.00	10.00	**70**

Figure E.20 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.7.2 (Surface Irregularities Defect)

Date of Assessment 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Warrawee Place
Locality: Beverly Hills
Segment Number: Full
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Potholes ***Severity:*** 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^5 ESA

Best Suited Remediation Option: **Deep Lift Asphalt**

Summary of Results

Importance Factor	10	7	4	5	
TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Deep Lift Asphalt	81.00	25.00	5.00	10.00	**194**
In-Situ Stabilisation	52.00	25.00	10.00	10.00	**165**
Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	**67**

Figure E.21 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.7.2 (Potholes Defect)

E.19 Case Study: C.4.7.3

<u>Treatment Data:</u>

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^6 ESA

Dominant Defect: Block Cracking

Treatment Selected: Crack Sealing with Deep Lift Asphalt sections

Severity: Moderate

Cost Constraint: 3/4

Longevity Required: 4/4

Resource Constraints: 2/3

Aesthetic Constraints: 2/3

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name: Pindaree Road
Locality: Peakhurst
Segment Number: 1
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Block Cracking *Severity:* 3 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^6 ESA

Best Suited Remediation Option: **Crack Sealing**

Summary of Results

Importance Factor	7	10	3	3	
	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
TREATMENT OPTIONS: Crack Sealing	13.00	3.00	2.00	2.00	10

Figure E.22 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.7.3 (Moderate Defect Severity)

Date of Assessment: 12/09/2014

PaveMaint SELECT - Solutions Sheet

Road Name:	Pindaree Road
Locality:	Peakhurst
Segment Number:	1
Pavement Type:	Sealed Flexible - Asphalt Surface Pavement
Defect Assessed:	Block Cracking — ***Severity:*** 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume:	up to 1x10^6 ESA

Best Suited Remediation Option: **In-Situ Stabilisation**

Summary of Results

	Importance Factor	7	10	3	3	Overall Weighted Score
		Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	
TREATMENT OPTIONS	**In-Situ Stabilisation**	52.00	25.00	10.00	10.00	**121**
	Deep Lift Asphalt	81.00	25.00	5.00	10.00	**91**
	Lean Mix Concrete	125.00	25.00	10.00	10.00	**50**
	Full Flexible Replacement (Sealed)	218.00	30.00	10.00	10.00	**35**
	Crack Sealing	13.00	3.00	2.00	2.00	**6**

Figure E.23 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.7.3 (Poor Defect Severity)

E.20 Case Study: C.4.8.1

Treatment Data:

Road Type: Flexible Asphaltic Concrete Surface

Traffic Conditions: Up to 10^4 ESA

Dominant Defect: Raveling

Treatment Selected: Asphalt Resurfacing

Severity: Poor

Cost Constraint: 2/4

Longevity Required: 3/4

Resource Constraints: 2/3

Aesthetic Constraints: 1/3

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PaveMaint SELECT - Solutions Sheet

Road Name: Lockundy Lane
Locality: Hurstville
Segment Number: Full
Pavement Type: Sealed Flexible - Asphalt Surface Pavement
Defect Assessed: Raveling *Severity:* 4 (1 = slight >>> 5 = unsatisfactory)
Traffic Volume: up to 1x10^4 ESA

Best Suited Remediation Option: **Asphalt Resurfacing**

Summary of Results

TREATMENT OPTIONS	Cost of Repair ($ / sq.m)	Longevity of Repair (years)	Speed of Repair (Factor)	Aesthetic Finish (Factor)	Overall Weighted Score
Importance Factor	4	7	3	1	
Asphalt Resurfacing	29.00	15.00	5.00	10.00	**58**
Spray Seal	16.00	7.00	5.00	3.00	**28**

Figure E.24 – *PaveMaint SELECT v1.0* Re-Evaluation of Case Study C.4.8.1