IMPROVING PRODUCTIVITY IN ROAD PAVEMENT MAINTENANCE AND REHABILITATION IN NEW ZEALAND

Masters Thesis

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IMPROVING PRODUCTIVITY IN ROAD PAVEMENT MAINTENANCE AND REHABILITATION IN NEW ZEALAND

A Thesis presented in fulfillment of the requirements for the degree of Master of Construction Management

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ABSTRACT

Improving the productivity of the multi-billion dollar annual investment in the maintenance and rehabilitation of the roading infrastructure could bring about huge cost savings and ensure optimal use of resources and tax payers' money. There is currently little or no research on productivity improvement of the New Zealand roading sector. This study aimed to identify productivity constraints and improvement measures in the road maintenance and rehabilitation (RMR) sector in New Zealand. The study also aimed to provide insights into the RMR process and the criteria that inform strategic decisions for action. Based on a descriptive survey method, qualitative and quantitative data were gathered through pilot interviews and on-line surveys. The investigations were limited to the views of consultants and contractors involved in the New Zealand road pavement maintenance and rehabilitation sector. Content analysis and multi-attribute methods were used in the analysis of the primary data for this research.

Results from the pilot interviews revealed 61 productivity constraint factors. These were aggregated into two main categories: internal and external factors, with an additional eight sub-categories. The five internal factor sub-groups were project finance, workforce, technology/process, project characteristics, and project management/project team characteristics. The three external factor sub-groups were statutory compliance, unforeseen circumstances, and "other" external forces.

Results of the multi-attribute analysis showed that inaccurate estimates, lack of good leadership management capacity, resistance to accept new technologies in road maintenance projects, site location and environmental constraints, and frequency of design changes/change orders/late changes were the most influential internal constraint factors on the level of productivity in the road maintenance and rehabilitation sector in New Zealand. Additionally, the Health and Safety in Employment Act, Resource Management Act, inclement weather, market conditions and the level of competition in the industry for jobs were the most significant factors under the broad category of external constraints.

Recommendations for improving productivity in the New Zealand RMR sector include providing more training courses for the workforce to participate in, in order to improve the level of skills and experience in the work force; having sufficient budget for using new technologies, such as road failure detection systems; using new cost-effective materials with a longer life cycle; providing accurate estimations; applying up-to-date leadership management skills; and improving the quality and accuracy of designs to minimise design errors and late change orders; as well as having adequate planning and regular monitoring of the entire process. It is expected that the application of these recommendations by designers, project managers and contractors could lift efficiency and productivity in the RMR sector and ensure optimal use of resources in the sector, as well as boost the New Zealand economy.

Keywords**:** New Zealand roading industry, productivity, road construction, road pavement maintenance, road pavement rehabilitation.

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STATEMENT OF ORIGINALITY

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(MASTER OF CONSTRUCTION MANAGEMENT) THESIS

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I declare that the above thesis is my own original work. It has not been submitted elsewhere for assessment.

The guidance received from my supervisor is hereby acknowledged. Human Ethics requirement have been complied in accordance with Massey University research requirements.

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Chapter 1. INTRODUCTION

1.1 Overview

This chapter describes the background of this study and also explains why this study is essential in New Zealand; it explains the problems that the research aims to explore and what solutions exist. Furthermore, this chapter explains the scope and limitations of the study and the structure of the report.

1.2 Background

The multibillion dollar annual investments in road rehabilitation and maintenance in New Zealand mean that improvement in the productivity and performance of the roading sector could not only contribute to the social and economic growth of New Zealand, but also optimise delivery of value for the public good. For instance, the New Zealand Treasury (2012) observes that effective infrastructure is important for facilitating economic growth, adding that the Government's objective is for New Zealand's infrastructure to be a means to permanently lift the sustainable growth rate of the economy.

From a focused perspective, the New Zealand Transport Agency (NZTA) (2009) observes that to move people, goods and services efficiently and safely, for a small, sparsely populated country such as New Zealand that is far from world markets, having a robust transport network is vital. Consequently, infrastructure development is one of the New Zealand Government’s key levers for economic growth. The NZTA (2009) argues that because a strain on the nation’s road network could halt economic progress, the New Zealand Government is investing heavily in infrastructure now, to encourage future economic growth. An efficient freight industry with access to cost effective transport is essential to the competitiveness of New Zealand businesses, because around 92% (by weight) of all freight within New Zealand is moved by road (NZTA, 2009). Efficient and effective rehabilitation and maintenance of the New Zealand road network is therefore a crucial underpinning of the strategic and financial health of New Zealand and New Zealand businesses.

Road rehabilitation and maintenance projects often involve challenges and risks, which are quite difficult to ascertain or forecast at the tendering stage. On account of this uncertainty, road projects are usually depend on a cost reimbursement basis, whereby the contractor gets reimbursed for prime costs, together with an allowance for profit, in accordance with a pre-agreed method (Standards New Zealand, 2003). Not having accurate benchmarks for monitoring quality, costs, and schedule at the planning stage, means that efficiency or productivity in road construction is a complex process that requires innovative project leadership (Page, 2010), strict supervision, and accurate contract documentation (Durdyev & Mbachu, 2011) to ensure successful outcomes.

Planning and monitoring performance based on the sound principles of strategic infrastructure asset development and management is therefore a very important issue, especially in relation to road rehabilitation and maintenance. This calls for an evidence-based decision making process that relies on empirical study (Cunningham, 2010). The New Zealand Government, through its National Infrastructure Plan, is keen on investing $7.5 billion in infrastructure asset development and maintenance (National Infrastructure Unit, 2011). Furthermore, the New Zealand Treasury (2012) has highlighted the need for increased productivity and improved management of Crown assets as a means of achieving the Government's objective of leveraging infrastructure investment, to permanently lift the sustainable growth rate of the economy.

Given the importance of strategic road asset management, which is supported by research-led and evidence-based decisions, there is a need to investigate issues around road rehabilitation and maintenance with a view to establishing a framework for improved performance in the planning and monitoring process.

Drawing upon the grounded theory method of qualitative research (Corbin & Strauss, 2008), issues around the rehabilitation and maintenance of road projects were investigated. The investigations involved observation of processes and procedures, as well as an examination of emerging theories or explanations for desired improvement through innovation and improved productivity and performance.

1.3 Research Problem

After an in-depth literature review, I found that several studies had been done on ways of improving productivity in road pavement maintenance; these included Lee, Lee, and Harvey (2006), Lee, Harvey, Ibbs, and St. Martin (2002), Lee and Ibbs (2005), Lee, Lee, and Ibbs (2007), and Dunston, Savage, and Mannering (2000). However, these studies merely provided a list of productivity constraints in the road pavement maintenance sector, without prioritising them to enable optimum disbursement of available resources to address the critical constraints (Talvitie & Sikow, 1992).

Within New Zealand, few, if any, researchers have studied the subject matter of the current research. Only a few articles existed on the improvement of productivity in the field of road maintenance and construction projects, which are the major projects with huge investment outlays in New Zealand.

This research fills an important knowledge gap, by not only updating research on the key productivity constraints that are peculiar to the New Zealand roading sector, but also prioritising these constraints so that available resources could be channeled to address the most critical of these.

1.4 Research Aim and Objectives

The research aimed to explore the road pavement maintenance and rehabilitation process in New Zealand, with special focus on the various constraints to productivity and performance in the process, as well as areas for improvement. Specifically, the research was driven by the following objectives:

1. To investigate the road pavement maintenance and rehabilitation process in the New Zealand roading sector, and the criteria that inform maintenance and rehabilitation decisions.
2. To establish where the key challenges lie and where efficiencies could be improved in the process.

1.5 Importance of the Research Findings

The findings of this study will provide proper guidelines for improving productivity in the road pavement maintenance and rehabilitation sector by providing a list of critical productivity constraints for project managers, asset managers, contractors, and generally all parties who are involved in the New Zealand roading sector. Knowledge of the key constraints and the improvement measures will guide stakeholders in taking action to reduce the cost of projects, and increase efficiency and productivity in maintenance and rehabilitation operations.

1.6 Research Proposition

A proposition was put forward to guide the research in terms of gaining understanding of the nature of the primary data for the research, the research process, and how the data would be analysed. The proposition assumes that the broad categories of internal and external productivity constraint factors identified during the pilot study phase would be confirmed as being relevant by respondents in the second phase questionnaire survey.

1.7 Scope and Limitations

The investigations were limited to the 38 New Zealand companies that were involved in roading maintenance and rehabilitation as identified through online Yellow Pages searches. These companies comprised a range of contractors, consultants, and subcontractors. Companies who were not part of the Yellow Pages database were therefore not included in the study. The study was a snapshot survey conducted during the period October to November 2013. The study is therefore limited in terms of capturing trends in productivity constraints over time.

1.8 Structure of Thesis

The thesis comprises five chapters and appendices as shown in Figure 1 below.

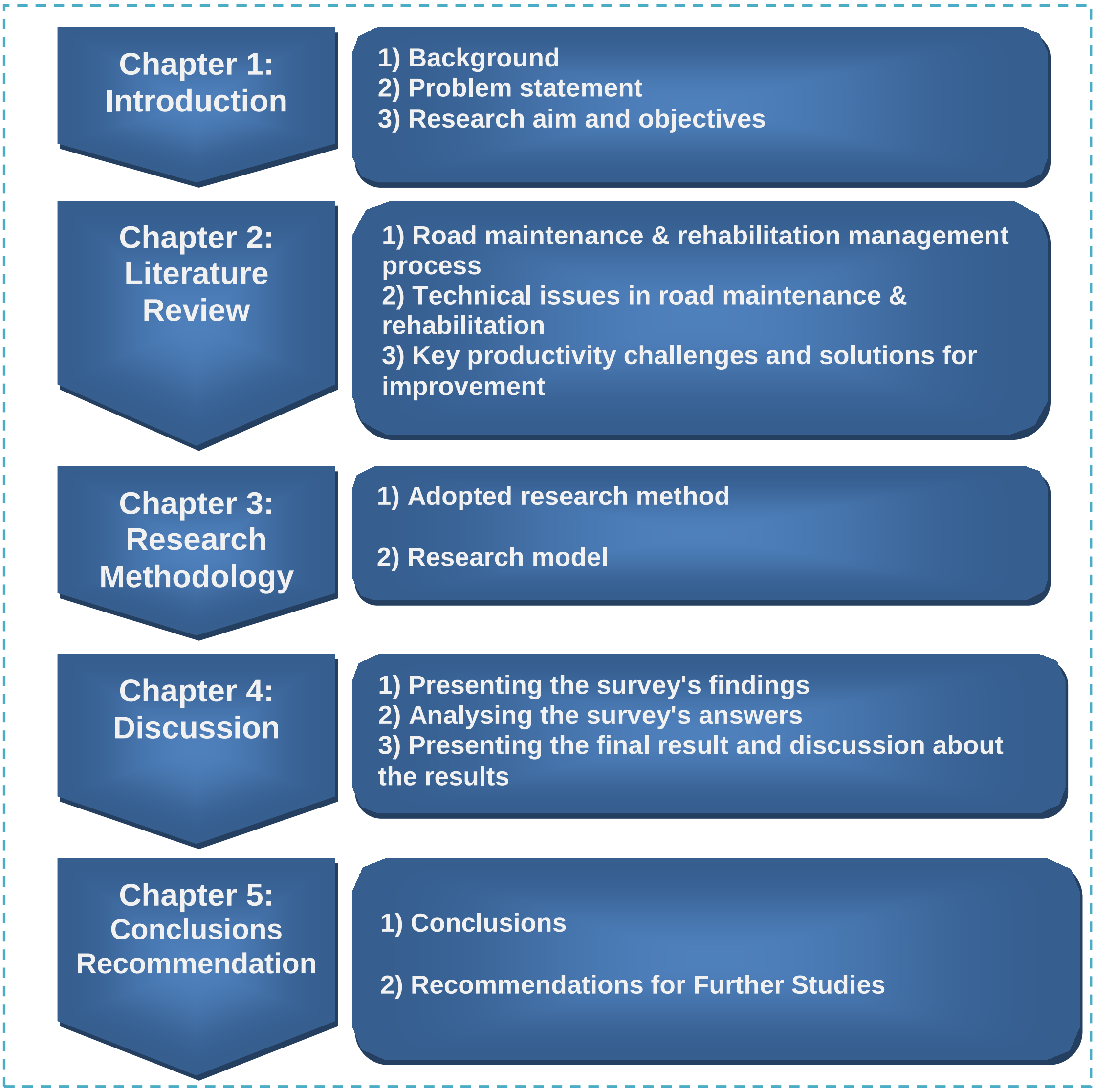


Figure 1: Key structure of report

Chapter one covers the introduction to the research, providing the background, problem statement, objectives, propositions, scope and limitations, and the structure of the final report.

Chapter two is a review of a wide variety of extant literature on the subject of productivity in the field of road maintenance and rehabilitation, in New Zealand and overseas. This chapter helps to fit the study into the context of existing research, which provides the baseline for designing the research, analysing the data and interpreting the results.

Chapter three describes the research methodology, including the method for data gathering, data analysis and compliance with the Massey University ethical requirements.

Chapter four presents the data and a discussion of the results in relation to the research objectives.

Chapter five concludes the research, summarises the main findings, and provides recommendations for further studies.

The report has appendices that include copies of the interview schedules used for the pilot interviews, questionnaires used for the surveys, and the ethical clearance for the research granted by the Massey University Human Ethics Committee (MUHEC).

Chapter 2. LITERATURE REVIEW

2.1 Overview

This chapter aims to provide insights into the road pavement maintenance and rehabilitation process, the key constraints to and the improvement measures for productivity and performance in the process.

It has tried to provide an integrated answer to the objectives, as gathered from the literature. It also aims to link the current study to previous research in this area, as well as to identify gaps in the existing body of knowledge on the topic, and how these could be filled.

In addition, it has tried to provide general information about the road maintenance implementation process in New Zealand, by studying all kinds of road failures and road treatment approaches.

As mentioned previously, the focus of this research is on the key productivity constraints in the New Zealand road maintenance projects. However, In order to gain knowledge about productivity in road maintenance projects, this study has attempted to provide a brief description of all kinds of failures that are common in the New Zealand road network, as well as recommended treatment methods, which have been suggested by the survey participants who were working in this field.

It is clear that improving productivity in road maintenance is not achievable without focusing on three subjects: finding the key constraints of productivity, understanding the common failures and the best and most cost effective treatment methods, and finally using the results of research in real projects to improve productivity.

The following subsections focus on the process of road pavement maintenance management, the technical issues, and the key challenges to productivity in the process.

2.2 Productivity in Context

The term, ‘productivity’ in the context of road pavement maintenance and rehabilitation, lacks adequate research attention and a generally accepted understanding in the road maintenance management (Talvitie & Sikow, 1992).

Productivity in road pavement maintenance is fast becoming a priority issue in almost all developed countries, given the huge amount of investment needed to maintain and rehabilitate aging infrastructure. Lee and Ibbs (2005) reported that a significant portion of road networks in most developed economies, such as the United State of America, have exceeded their 20 year design lives and are seriously deteriorating. Consequently, expensive maintenance is required to mitigate the rapid rate of deterioration and restore the aging infrastructure to useful lives.

Productivity can be explained by different methods for different purposes. From an economist’s perspective, Schreyer (2001) viewed productivity as the ratio of a measure of output to a measure of resource input. In the context of construction, a number of authors (Chan & Chan, 2004; Mbachu, 2008) have seen productivity as the contractor’s ability to deliver the key project objectives in the most cost-effective manner. The principal project objectives in this respect are usually cost, schedule, scope, and quality target achievement. Mbachu and Seadon (2013) identified three key components of productivity at the project level as: ‘e*fficiency’* (i.e. the optimal use of project resources to achieve set targets); ‘e*ffectiveness’ (i.e.* the extent to which the set project objectives were achieved), and ‘sundry measures’ (these are measures of other aspects of performance such as safety, client satisfaction and environmental performance).

In the context of this study, productivity refers to the extent to which the set targets have been achieved on a project. To ensure that the study participants have the same level of understanding of the concept, a question was put to them during the pilot interviews to gauge their level of understanding and to compare this with the concept adopted in the study.

2.3 Road Pavement Maintenance Management Process

2.3.1 Introduction

It is essential to explain the purpose of road maintenance. Robinson, Danielson and Snaith (1998) clearly explained that ”maintenance reduces the rate of pavement deterioration, it lowers the cost of operating vehicles on the road by improving the running surface, and it keeps the road open on a continuous basis"(p.5).

As categorised by Johanns and Craig (2002), pavement maintenance can be divided into three types. First is preventive maintenance, the second type is corrective maintenance, and the third is emergency maintenance. Of these three types of maintenance, preventive maintenance is the most important type. Preventive maintenance is significantly more cost effective and efficiency promoting than costly corrective maintenance or reconstruction. The cost of corrective pavement maintenance that could be reduced through inexpensive early preventive maintenance is significant. The below Figures (2 & 3) show the time and effect of this type of maintenance.

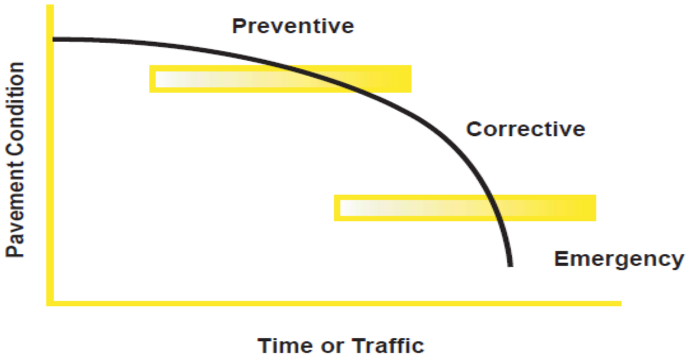


Figure 2 : Categories of pavement maintenance

Source: Johanns and Craig (2002)

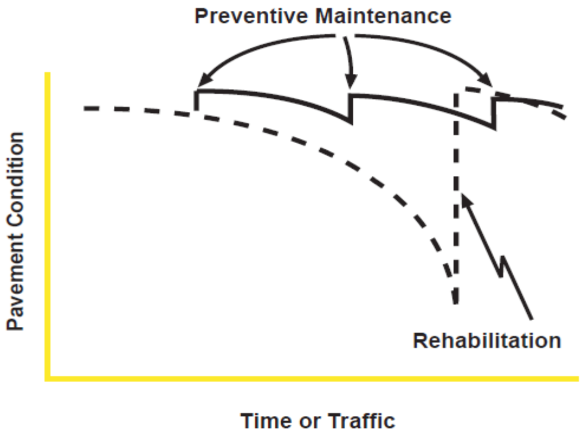


Figure 3: Performance of preventive maintenance treatment

Source: Johanns and Craig (2002)

Johanns and Craig (2002) stated that "planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system without increasing the structural capacity" (p. 5).

As has been mentioned above, for achieving this purpose, an integrated management process is essential. It is assumed that road maintenance management will have more detailed aims. As Robinson et al. (1998) described, these include:

- The use of a systematic approach to decision-making within a consistent and defined framework.
- To assess budget needs and resource requirements.
- To adopt consistent standards for maintenance and for the design of associated works.
- To allocate resources effectively.
- To review policies, standards and the effectiveness of programs on a regular basis.

As Johanns and Craig (2002) stated, even a minimal 20% useful life extension of airfield asphalt pavements could increase efficiency and save the FAA hundreds of millions of dollars a year in additional maintenance and replacement.

An accurate review of international literature on road maintenance management ventures that were used to increase productivity and performance will help the maintenance management tasks that are currently undertaken. The maintenance management tasks include data collection, monitoring strategies, performance strategies and decision making. The review concentrates on:

- International road maintenance management cycle.
- The New Zealand road maintenance management cycle, based on monitoring performance in one of New Zealand's main contractors.
- What methods and technologies are used for collecting data in projects and how the collected data can influence effective and productive decision making systems.
- Classification of factors that have effected productivity and performance, based on the opinion of experienced managers and staff who are working in this field.
- The types of new technologies used for collecting, monitoring, storing and managing data in relation to road failures and road maintenance.

2.3.2 The Pavement Maintenance Management Process

Traditionally, planning and organising maintenance implementation in roading contracting companies has been prepared on a historical basis. Companies, by using information gathered from their completed projects, would specify their new budget for the coming year, with an adjustment for inflation; this has some problems, such as uncertainty, in predicting their budgets. Successful and productive management of any process, in any organisation, is only possible by using up-to-date information.

Robinson et al. (1998) have offered, in their book, a common system that is known as the *management cycle,* with information management situated at the heart of this cycle. The cycle provides a series of well-defined steps for achieving successful decision making. Figure 4, below, shows this cycle.

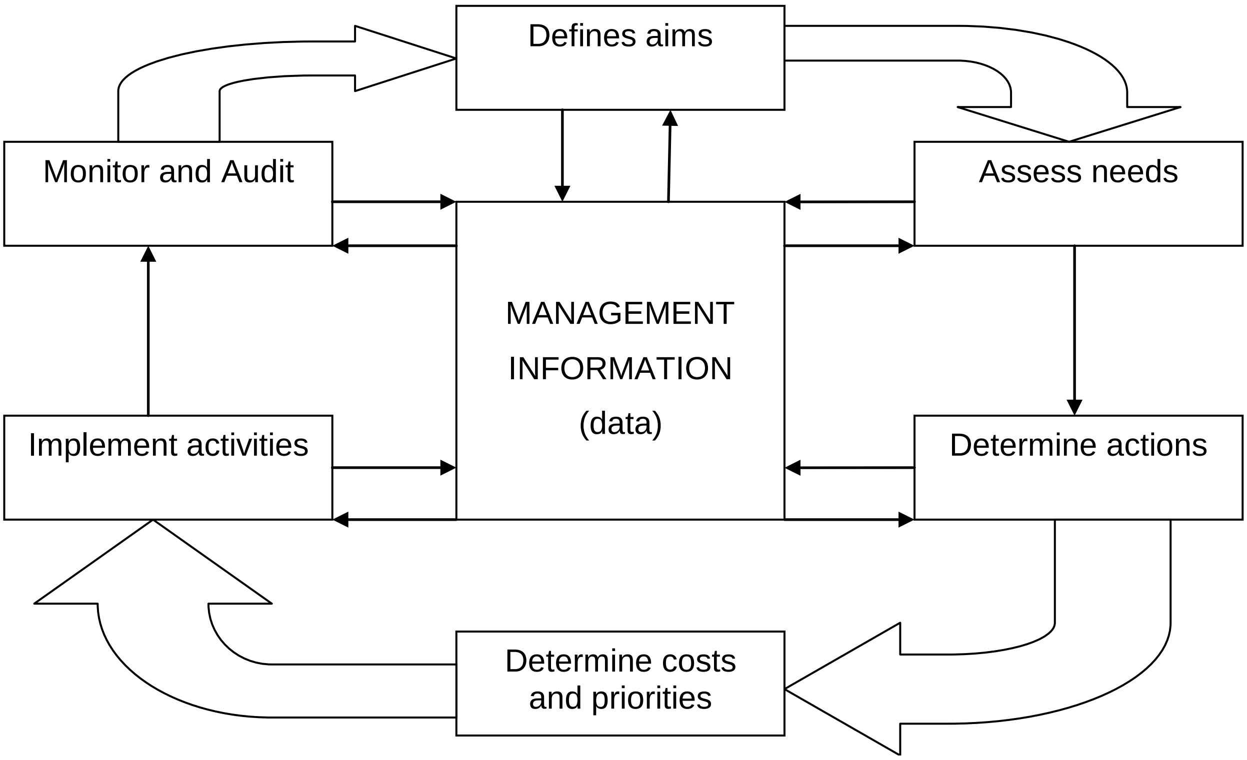


Figure 4: Flowchart of Road Management Cycle

Source: (Robinson, Danielson, & Snaith, 1998)

The pavement maintenance management process could be categorised and described by the following factors (Robinson et al., 1998):

- Management functions
- Project management
- The management cycle
- Cycle within the management functions (a cycle of activities that are undertaken within each of the management functions of planning, programming, preparations and operations).

2.3.3 Management Process

The following processes need to be considered as primary road maintenance management functions. It is obvious that all the following steps have a huge impact on improving productivity in the road maintenance sector.

Planning

The first important function that needs consideration in terms of improving productivity in road maintenance management functions is planning.

Planning involves consideration of a road network system that needs a long term program for regular inspection of the road condition, and for gathering information to make productive maintenance strategies. For strategic level decision making in pavement maintenance management, the condition of the network has to be described by using indicators that summarise the large amount of information obtained from the measurements (Sunitha, Veeraragavan, Srinivasan, & Mathew, 2013).

In order to do the modeling, a forward works program must be created and regularly updated describing maintenance activities and financial forecasts. The pavement performance model evaluations are a significant part of planning, specifically in terms of productive planning.

Planning plays a crucial role in deciding final productivity outcomes in the road pavement maintenance and rehabilitation process.

Programming

The second factor to be considered as a primary road maintenance management function is programming, which is implicated in its development under a limited budget; programming is normally accepted by professional managers. In the case of road maintenance, estimation of maintenance expenditure is one of the main issues that needs to be undertaken through consideration of different types of projects, and different types of treatments and budgets. Also, consideration of productivity is an aspect of programming. It would be ideal if a cost-benefit analysis could be undertaken for determining the economic feasibility of each set of works (Robinson et al., 1998).

Preparation

Preparation is the next stage, which follows design completion, when projects are organised for implementation. At this stage, engineers and technicians who are normally working in a technical department will review and refine designs and work on preparation detail, to make a sufficient, acceptable preparation process. Productivity outcomes are highly dependent on this stage.

Operations

This stage includes all on-going projects' work.

> Decisions about the management of operations are made typically on a daily or weekly basis, including the scheduling of work to be carried out, monitoring in terms of labor, equipment and materials, the recording and evaluation of work completed, and the use of this information for monitoring and control (Robinson et al., 1998, p. 13).

Generally, the process of management starts with planning and finishes with operations. The road maintenance operations start by considering all network conditions, finding subsections where treatments are needed and then specifying the appropriate treatments for the failures. Finally, the quality of the work is checked. Definitely, the main stage that contributes hugely to productivity is the operations stage.

2.4 Data Collection, Methods and Strategies

2.4.1 Storing Data, Analysing Data, Using Data

A proper data collection strategy provides managers with the ability to understand a range of failures, problems and related causes, through making a complete database from which to make sufficient and productive decisions. Therefore, introducing some methods and new technologies for collecting information about road failures was a key point for this research. Providing an objective reference will help managers and decision makers to make appropriate choices.

This stage of management could be called the heart of the management cycle. So it is clear that choosing strategies in terms of data collection and monitoring, will lead to fulfilling the demand for productive results.

All details need to be taken into account at the time of data collection and performance monitoring to achieve national service levels, as detailed below by (Bush, 2011).

- More efficient and reliable infrastructure
- Improved transport safety
- Improved transport access
- Lower environmental impacts
- Improve customer services

The performance of pavement road maintenance, specifically in the field of surfacing maintenance, can be seen as a complicated issue that needs a significant amount of information collected during the usage time. Therefore, it is important to establish a responsive, flexible and advanced strategy for collecting data.

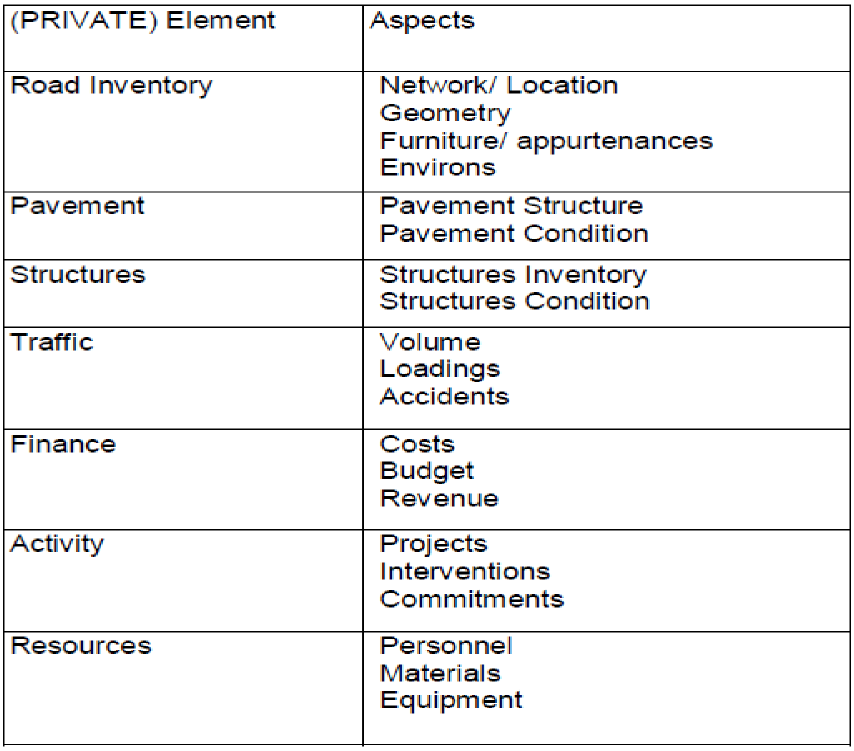
As Robinson et al. (1998) described, managers who are making decisions need appropriate data on such aspects as:

- Determining optimum road condition, and the maintenance strategies and expenditure needed to achieve this

- Determining optimum road condition within actual budget constraints
- Assessing current levels of road and bridge condition
- Determining appropriate level of investment
- Prioritising capital improvements and investments in maintenance
- Simulating the effect of any improvements on the future condition and performance of the road system
- Estimating the cost of improvements
- Controlling on-going expenditures

Table 1 shows factors that are important for making proper decisions.

Table 1: Important factors for making decision



(PRIVATE) Element	Aspects
Road Inventory	Network/ Location Geometry Furniture/ appurtenances Environs
Pavement	Pavement Structure Pavement Condition
Structures	Structures Inventory Structures Condition
Traffic	Volume Loadings Accidents
Finance	Costs Budget Revenue
Activity	Projects Interventions Commitments
Resources	Personnel Materials Equipment

Source: Peterson and Scullion (1990)

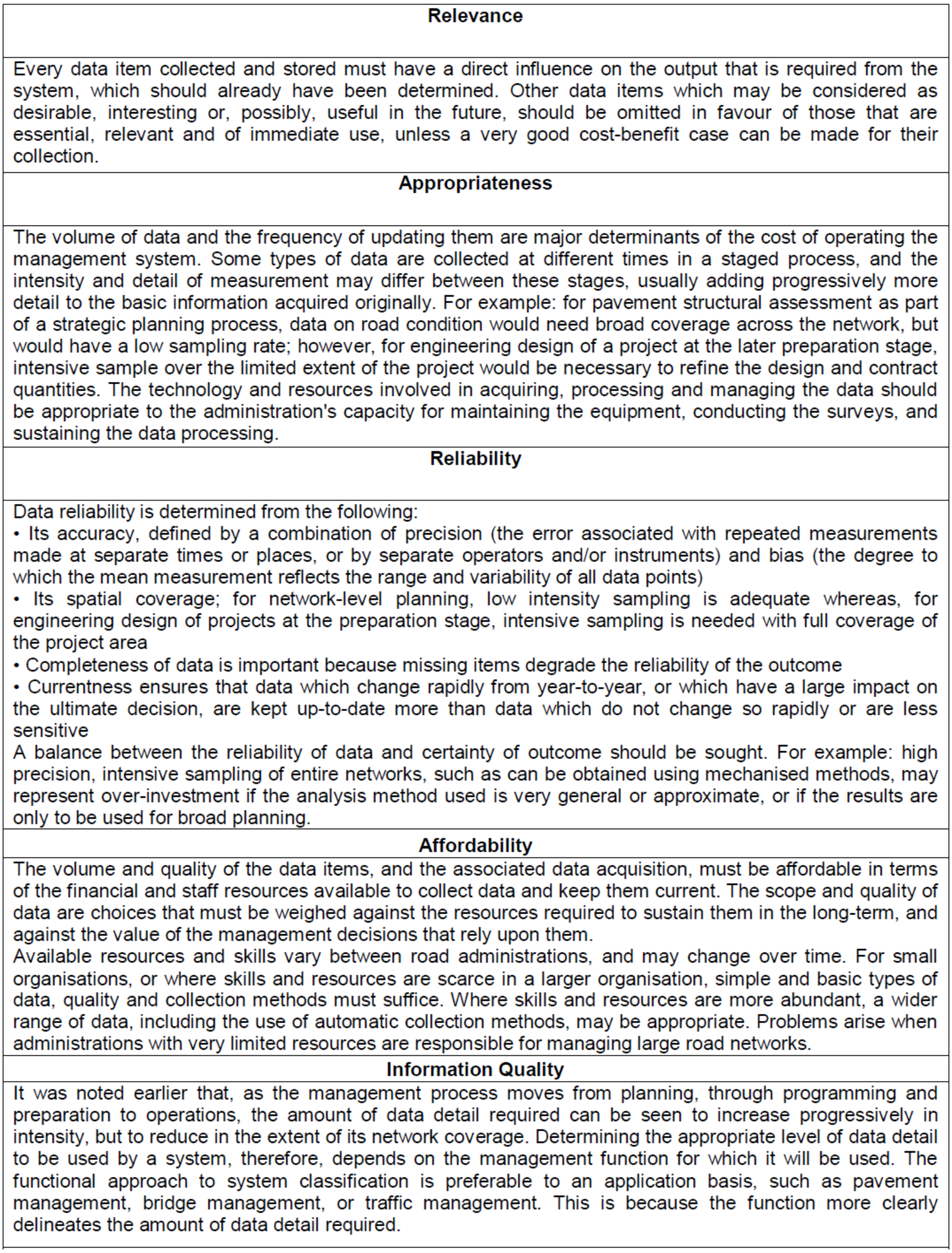
Based on roads hierarchy, providing a periodic database of pavement conditions is the first stage in developing an efficient and productive management system. Roughness, skid resistance, and distress are some types of condition data that should be collected routinely (Sunitha, Veeraragavan, Karthik, & Mathew, 2013).

A guideline prepared by Peterson and Scullion (1990) and published by the World Bank shows the principles for data design to provide a framework for the roads sub-sector. The following criteria should be considered when selecting data items:

- Relevance
- Affordability
- Appropriateness
- Information Quality
- Reliability

Table 2 gives more detail about each of these criteria for selecting data.

Table 2: Explanation about each criterion for selecting data



Relevance
Every data item collected and stored must have a direct influence on the output that is required from the system, which should already have been determined. Other data items which may be considered as desirable, interesting or, possibly, useful in the future, should be omitted in favour of those that are essential, relevant and of immediate use, unless a very good cost-benefit case can be made for their collection.
Appropriateness
The volume of data and the frequency of updating them are major determinants of the cost of operating the management system. Some types of data are collected at different times in a staged process, and the intensity and detail of measurement may differ between these stages, usually adding progressively more detail to the basic information acquired originally. For example: for pavement structural assessment as part of a strategic planning process, data on road condition would need broad coverage across the network, but would have a low sampling rate; however, for engineering design of a project at the later preparation stage, intensive sample over the limited extent of the project would be necessary to refine the design and contract quantities. The technology and resources involved in acquiring, processing and managing the data should be appropriate to the administration's capacity for maintaining the equipment, conducting the surveys, and sustaining the data processing.
Reliability
Data reliability is determined from the following: • Its accuracy, defined by a combination of precision (the error associated with repeated measurements made at separate times or places, or by separate operators and/or instruments) and bias (the degree to which the mean measurement reflects the range and variability of all data points) • Its spatial coverage; for network-level planning, low intensity sampling is adequate whereas, for engineering design of projects at the preparation stage, intensive sampling is needed with full coverage of the project area • Completeness of data is important because missing items degrade the reliability of the outcome • Currentness ensures that data which change rapidly from year-to-year, or which have a large impact on the ultimate decision, are kept up-to-date more than data which do not change so rapidly or are less sensitive A balance between the reliability of data and certainty of outcome should be sought. For example: high precision, intensive sampling of entire networks, such as can be obtained using mechanised methods, may represent over-investment if the analysis method used is very general or approximate, or if the results are only to be used for broad planning.
Affordability
The volume and quality of the data items, and the associated data acquisition, must be affordable in terms of the financial and staff resources available to collect data and keep them current. The scope and quality of data are choices that must be weighed against the resources required to sustain them in the long-term, and against the value of the management decisions that rely upon them. Available resources and skills vary between road administrations, and may change over time. For small organisations, or where skills and resources are scarce in a larger organisation, simple and basic types of data, quality and collection methods must suffice. Where skills and resources are more abundant, a wider range of data, including the use of automatic collection methods, may be appropriate. Problems arise when administrations with very limited resources are responsible for managing large road networks.
Information Quality
It was noted earlier that, as the management process moves from planning, through programming and preparation to operations, the amount of data detail required can be seen to increase progressively in intensity, but to reduce in the extent of its network coverage. Determining the appropriate level of data detail to be used by a system, therefore, depends on the management function for which it will be used. The functional approach to system classification is preferable to an application basis, such as pavement management, bridge management, or traffic management. This is because the function more clearly delineates the amount of data detail required.

Source: Peterson and Scullion (1990)

2.4.2 Strategies for Data Collection in Road Maintenance

Various methods for collecting data are available. Selecting an appropriate method for road networks should be based on the type of road and purpose of data usage.

Options Available

In one approach, high level condition data are collected across the whole network each year. These data are used for planning and programming purposes, and then in those sections that may be likely to undertake any exercise, evolutionary Information will be gathered. Also more detailed data will be collected for those sections that have produced designs, or for those sections that have implementations under process. It is obvious that after collecting new information, the database will be updated, accordingly. This collected data will be used during the annual road inspection or during the execution process of a maintenance project.

In an alternative approach, information about road network conditions will be collected with a cycle of three or five years across part of the network. This information, or current data if available, will be used each year during programming decisions for individual sections of the network. Thus, the network's condition information will be stored to give an estimate of the current condition across the whole network. The information will be stored at the same level of detail, but with a different age.

Other combinations of the above are also used:

- Annual data collection on the primary road network, whereas a cycle of data collection may be used in lower roads in the hierarchy
- Cyclic approach used for the whole network, but with data collected at a lower level of detail
- Cyclic collection methods can be used without projection of condition.

All of the above mentioned strategies have different implications for the level of data detail recorded and stored (Robinson et al., 1998).

Cost-Benefit Analysis

Another important issue regarding choosing a productive strategy for data collection, is to use a cost effective method. For achieving this purpose, ideally, a cost-benefit analysis should be undertaken about the level of data detail to be collected and used. The levels of collected details are different and depend on the results of a cost-benefit analysis, which will also differ for each road administration and are also presumably different, depending on such items as:

- The size and level of development of the network
- Geography
- Topography
- Climate
- Road hierarchy
- Traffic level
- Urban and rural location
- Political or environmental sensitivity of the location on the network or the data item

Nevertheless, the most important key aspect is that the survey strategy adopted, and the amount and level of data that should be gathered, should be subject to rigorous analysis to determine what is cost-effective for its subsequent application (Robinson et al., 1998).

Generally, economic analysis is an essential factor for calculating all project benefits. Also practical limits, which exist in gathering information, should be considered, for example, the amount of time and energy that can or should be spent in gathering information (NZTA, 2010).

2.5 Data Collection in Road Maintenance by Using Non-Destructive Evaluation

To improve productivity in road maintenance, a periodic road inspection that provides accurate and up-to-date information about the road surface conditions, is the most efficient way to maintain high road standards at the lowest price**.** Distress measurement is a crucial factor when evaluating road quality, as cracking is the best indicator of a need for preventive maintenance treatments.

The road sector has started to consider a new approach to road maintenance by adopting a “*preservation culture*”, which consists of immediately protecting structures once they have been constructed or renewed. Based on economic and safety reasons, using manual observation methods are costly and also have problems associated with variability and repeatability resulting in inconsistencies in distress details. Also, these methods of inspection are risky for personnel due to traffic hazards (CSIRO,2011; Gavilan et al., 2011). Therefore, "an automated distress detection system to quantify the quality of road surfaces and assist in prioritizing and planning the maintenance of the road network becomes essential" (Gavilan et al., 2011, p. 9629)

Categorising distress detection methods based on the level of human intervention could be organised in three levels:

- Completely manual
- Semi automated
- Completely automated

Human inspection includes several problems, such as the lack of consistency among operator criteria, which has a huge effect in reducing productivity. Authorities, road owners and scientists have undertaken many efforts to overcome the noted problems in road inspection. Their efforts lead to the first semi automatic system for road inspecting purposes. A semi automatic system uses many different collection technologies for collecting road images, and then passes the images to qualified staff for disaster detection. This system reduced many traffic hazards and increased process speed, but still used manual distress detection, or at least an important level of intervention. It is obvious that using this system is possible with staff well trained in both pavement distress evaluation and in the use of the workstations. Therefore, it is essential to add the cost of having professional staff to use this system, which is a discouraging issue for agencies contemplating use of a semi automated system (NCHRP, 2004; Gavilan et al., 2011).

2.5.1 Review of Crack Detection Systems and Technologies in Different Countries

As Wang and Elliot (1999) indicated in their report, initially available automated technologies for road distress detection were all based on an analog video capturing and storage system. The problem was the low image quality, as well as difficulties in working with computers, as the information had to be digitised to be processed, increasing the cost and complexity of the system.

Since digital systems have appeared, specialist companies in road assessing have preferred to use them. Most of them employ video imaging techniques using either area scan or line scan cameras, with just a few examples of laser-based systems. Area scan methods use a two dimensional array of pixels to cover some of the pavement area, while line scan devices use a single line of sensor pixels to form the image by integrating successive scans. High-quality image collection requires sufficient lighting to overcome shadows and sunlight.

In 1999, the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) was the first entity to develop an automated road crack detection system, RoadCrack (CSIRO, 2011), that was able to identify cracks wider than 1 mm at highway speed. This system has surveyed Australia for several years using line-based digital cameras mounted on a vehicle.

The most widely employed system in the USA is Fugro Roadware’s Automatic Road Analyzer (ARAN) platform (2011). The ARAN system uses area scan cameras with two system configurations, 2 mm resolution with strobe lighting or 1 mm resolution with infrared lighting, to record road images that can be rated either visually or through Roadware’s automated crack detection software (WiseCrax) (Gavilan et al., 2011).

Some of the ARAN specifications have been listed below (Fugro Roadware, 2011):

- 50% reduction in computing hardware over the previous platform with the same functionality
- Database driven systems
- Robust, fault tolerant systems

- Plug and play system integration
- Microsoft.net platform
- Real-time sub-cm data synchronisation
- Advanced mission management software (on-vehicle and office software for data collection, calibration, and simulation)
- Increased portability of subsystem components
- Global solution with interfaces in several languages
- User friendly operating system to minimise training costs and operator error
- Industry-defining warranty
- Dynamic architecture supporting future upgrades

Also widely employed in the USA, is WayLink's Digital Highway Data Vehicle (DHDV) (WayLink Systems Corporation, 2007), which performs full-lane width distress surveys at speeds of up 100 km/h and uses WayLink's Automated Distress Analyzer (ADA) software for real-time detection. Some of the key features are listed below:

- Full-lane width distress survey of pavements at speeds of up to 60mph (100 km/h) and processes cracking data in real-time with ADA, with laser based imaging sub-system for shadow-free image collection. ADA can also be used offline in office environment.
- Full-lane width Rutting Measurement, using accurate lasers that can detect ruts down to 1-mm depths.
- Longitudinal profiling system to present longitudinal roughness, and calculate International Roughness Index (IRI), Ride Number (RN), and Macrotexture (MT) values, in accordance with the ASTM standards.
- Pavement Right-of-Way imaging system, with multiple high-resolution, digital colour cameras to capture imagary of roadway and roadside structure. Varying camera options are available, including 1080p High-Definition (HD) cameras.
- Positioning System Array consisting of a differential GPS receiver, DMI, and a multi-axis solid-state Gyroscope. User can also select high-precision Inertial Measurement Unit (IMU).

- Multimedia Highway Information System (MHIS), a user-friendly application designed to dynamically display the DHDV-produced data sets in a descriptive, visual, and flexible user interface. The deluxe version of MHIS allows user to manually edit and add various distresses defined through LTPP, MicroPaver, and others.

In Europe, the PAVUE system ("Ramboll, 2011) has operated in the Netherlands and Finland. Ramboll's system can be equipped with either multiple video cameras or line scan cameras for collection of continuous images of the road surface, which are automatically analysed with the Automated Image Evaluation System (AIES) (Gavilan et al., 2011, p. 9631).

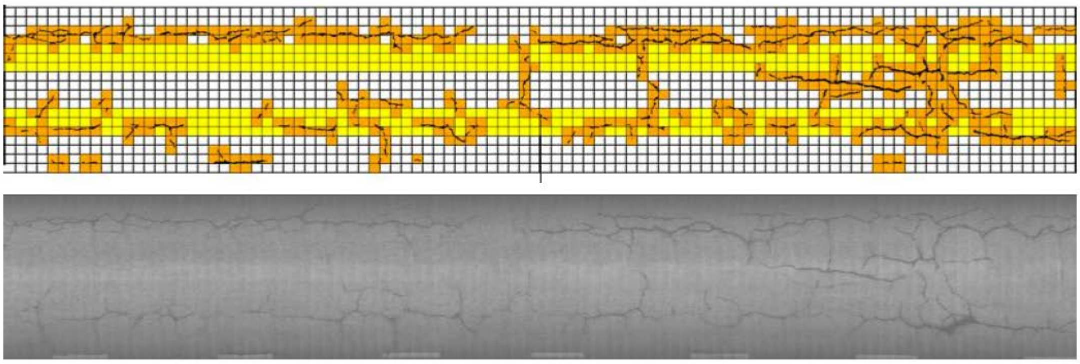


Figure 5 : Picture of Detected Cracks

Source: ("Ramboll Rst Pavue-Crack Recognition System," 2011)

Figure 5 shows some results from the Ramboll system.

It is worth mentioning the Highways Agency Road Research Information System (HARRIS), which is the result of 10 years research carried out by the UK's Transport Research Laboratory (TRL) with the objective of demonstrating the application of state-of-the-art technology in the assessment of road conditions at traffic speed (Transport Research Laboratory, 2013).

″This system has surveyed national and local roads using line scan cameras and 3.5m survey width, providing several objective evaluations about its performance″ (Gavilan et al., 2011, p. 6931).

As mentioned by the TRL (2013), this system has some benefits, such as the capability to carry out surveys over the full range of conditions encountered on the network; the ability to operate at traffic speed, which means no traffic management is required; a reduced need for hazardous and costly visual inspections; and ability to collect high quality forward and downward facing videos of the road surface.

Gavilan et al. (2011) have illustrated another new method for pavement evaluation, the laser test method. This is the most promising and innovative method. An example of a laser-based system is the GIE Laser VISION system (GIE Group, 2009). This system uses four laser sensors and provides 3D measurements giving the system the potential for improved distress measurement. However, it has a weak point which is its low resolution (3 mm by 110 mm), so it is limited to measuring transverse cracking (Rijkswaterstaad,2009).

Recently, a new distress detection system, Mobile 3D Video Mapping (M3DVM), based on a set of 360 degree laser scanners positioned on a van has been presented. However, this new technology needs more development as the operation costs are too high and the location error of points in the imagery is about 5 cm (Gavilan et al., 2011)**.**

It is obvious that comparing commercial systems is not always conceivable. It has been noted in a report by the World Road Association- PIARC, (2003) that the problem arise from the lack of standardised methods to evaluate accuracy and repeatability of distress detection systems.

The below flowchart (Figure 7) shows the global overview of a proposed adaptive road distress detection system that is divided into four main stages: road surface classification, pre-processing, non-crack features detection, and crack detection. The output of the classifier is used to adapt the system parameters (Gavilan et al., 2011).

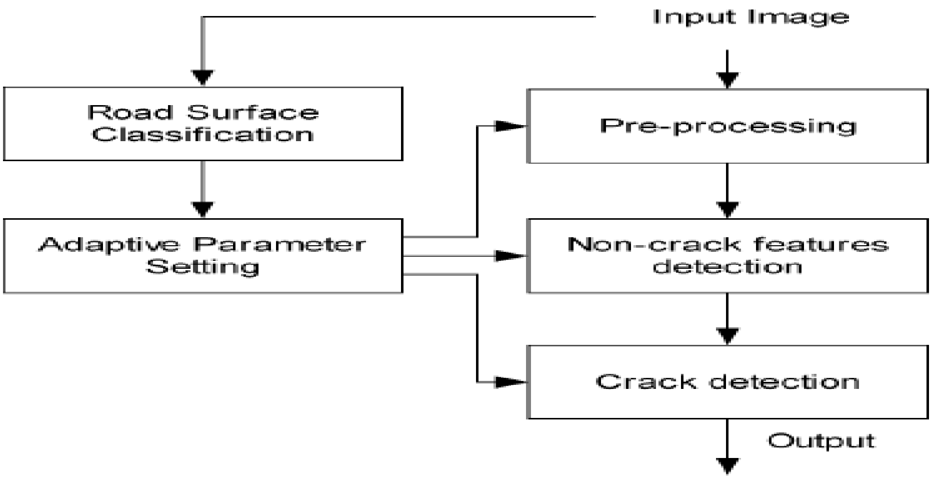


Figure 6: Global overview of a proposed adaptive road distress detection strategy

Resource:Gavilan et al. (2011).

2.5.2 Texture Measurement

Another issue that needs an integrated evaluation before starting any maintenance process is measuring pavement surface texture. This is because this information informs the decision on the type of road maintenance, or rehabilitation process, to be adopted. If the texture measurement is not properly done, then the maintenance or rehabilitation program adopted will have been founded on wrong assumptions. This could impact negatively on productivity through rework or faulty interventions, which ultimately, will lead to high costs and poor road performance.

Road texture provides the ability to drain free water from the road during wet weather, as well as creating friction resistance, which allows interaction between the tyres and road, and assists in the braking and steering of a vehicle (Holloway, 2011).

Doubtless, there is a strong correlation between road friction and accident risk. In rainy weather, the wet pavement accident rate is related to the skid resistance of the pavement, therefore it is important to maintain skid resistance at levels sufficient to prevent high wet-weather accident rates.

Meanwhile, in terms of productivity and In order to characterise the chip seal design and the materials required for the road resurfacing process, the depth of texture measurement of the road surface is a very crucial input (Huang, Gholam Hoseini, Moldovanu, & Devan, 2011).

All professionals in this field agree that the surface texture characteristics can be used to test the skid resistance of a pavement. Several parameters describe texture and by measuring their physical process, or details, regression techniques can be used to relate skid resistance to the chosen texture parameter or process. Two scales of texture are of particular importance: micro texture (small-scale asperities) and macro texture (large-scale asperities) (Wambold, Henry, & Hegmon, 1982).

As Huang et al. (2011) indicated,

> ″Micro texture having deviation amplitudes of 0.5 mm or less and is due mainly to the crystalline surface of the aggregates or the small particles in asphalt, and macro texture in amplitudes less than 50mm from the surface plane, down to micro texture size″ (p.2).

Micro texture is the fine scale texture of individual aggregate particles and macro texture is the projection of wear-resistant coarse aggregates above the pavement surface (Phillips & Kazmierowski, 2010), as displayed in Figure 8.

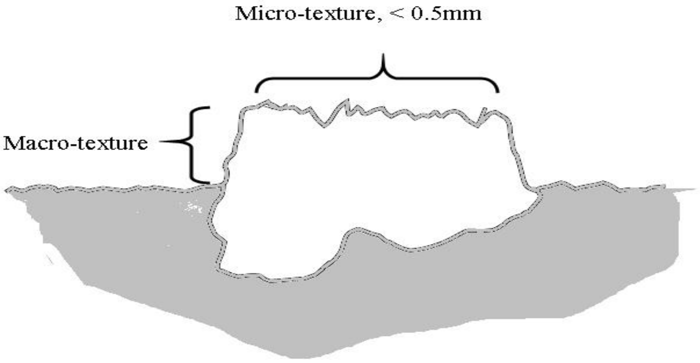


Figure 7: Macro-texture

Source: (Phillips & Kazmierowski, 2010)

Currently contact measurement methods are the most usual and traditional methods for measuring the macro texture. These methods include the outflow meter and sand patch, with the sand patch as the most usual method. The outflow meter estimates the pavement texture indirectly. The outflow meter works based on measuring the time for a fixed volume of water to escape from a measured cylinder with a rubber bottom (Wang, Yan, Huang, Chu, & Abdel-Aty, 2011). An example of an outflow meter is depicted in Figure 9.

Figure 6: Outflow meter

Source: (Klaruw RMS Ltd., 2012)

The sand patch test relies on a given volume of sand, which is spread out on a road surface. The standard procedure is as follows: a fixed volume of sand (45± 0.5 ml) with granulation between 300 and 600 µm is distributed to form a circular patch, the diameter of which is measured. By dividing the volume of sand with the area covered, a value is obtained that represents the average depth of the sand layer, i.e. an average (texture depth) (Huang et al., 2011; Pavestech, 2012). Figure 9 shows a sand patch test being undertaken.

Figure 7: Sand Patch Test

Source: (Pavestech, 2012)

The average texture depth is given by the ration of volume over area of patch to the nearest 0.1 mm, which is called the Sand Patch Texture Depth (SPTD) or Mean Texture Depth (MTD).

SPTD= V/ π÷4D^2

For the standard 45ml volume:

SPTD= 57300/ D^2 (mm)

Sand patch testing is repeated every 50m and is taken for each wheel path and one on the center of two. The value for all readings is averaged, and the value obtained is used in road maintenance design. However, this method of texture testing has some limitations, such as taking a long time to perform. The operation of this test is normally done in moving traffic and with changing climate, so operators are faced with road hazards, and reproducibility of the test is poor (Huang et al., 2011; Pidwerbesky, Waters, Gransberg & Stemprok, 2006). However, to overcome these disadvantages, alternative tactile texture measurements, such as laser sensing and image processing techniques, have been developed.

A new technology for road testing systems, the road testing vehicle SCRIM, was developed by the Transport and Road Research Laboratories to provide a routine method of measuring the resistance to skidding (SFC) of wet roads (Hosking & Woodford, 1976).

> To determine areas of low skid resistance and texture, SCRIM Exception Reports are produced. These report the locations where the SCRIM Friction Coefficient (SFC) is greater than 0.1 SFC below the site investigatory level (which varies depending on site category). The report also highlights sites where Mean Profile Depth (MPD) is less than given threshold levels. A photographic log of each type of deficient site (where either SFC or MPD is below threshold) is part of the exception reporting (Chamberlain, 2005, p. 5).

Another major advancement in non-contact measuring methods for measuring pavement texture is based on laser technology. The Circular Track Meter (CTMeter) is a type of laser based device, which has been widely used in macro texture measurement (Abe, Tamai, Henry, & Wambold, 2001; Henry, 2000; Noyce, Yambo, Chapman, & Bill, 2007; Wang et al., 2011). "The CTMeter has a laser displacement sensor mounted on an arm that rotates on a circumference with a 142 mm radius and measures the texture with a sampling interval of approximately 0.9 mm" (Wang et al., 2011, p.683).

As has been indicated by Flintsch, Huang, and McGhee (2007), Henry (2000), and Wang et al. (2011) the Mean Profile Depth (MPD) obtained by the CTMeter has high correlation with the MTD measured by the sand patch method. However, the CTMeter has some weak points, such as being relatively expensive and time- consuming. The CTMeter is also limited to measuring the static circular track on which the DFT measures the dynamic coefficient of friction. Due to the fixed and relatively large sampling interval, the CTMeter can only measure macro textures with longer wavelengths (Wang et al., 2011). Moreover, another weakness, which has lead to low test efficiency in the field test, was its inability to collect data along a linear wheel path at higher speed (Pidwerbesky et al., 2006).

Therefore, to improve productivity and efficiency, vehicle-mounted laser devices have been developed to measure macro texture along the linear wheel path at highway speeds without interfering with traffic. In comparison with existing methods, the laser based method has several major merits with regards to both hardware and software. Regarding hardware, the proposed device has high resolution in both vertical and horizontal directions. Regarding software, the proposed device contains comprehensive functions required by regular macro texture measuring. Therefore, vehicle-mounted laser devices are regarded as a good method to measure macro texture for pavement management, from a practical perspective (Wang et al., 2011).

Focusing on the above, a best practice approach to texture measurement ensures that the appropriate maintenance or rehabilitation intervention is taken in order to minimise road failure and rework, and to improve productivity and performance in the process.

2.5.3 Falling Weight Deflectometer (FWD)

The quality of compacted soils, including base course and sub base, is the most essential factor in the construction of pavement layers and other earthworks that need assessment. The Falling Weight Deflectometer (FWD) is an important tool for measuring the pavement surface deflection at various distances from a dynamic load (Arnold, Salt, Stevens, Werkmeister, Alabaster & Van Blerk, 2009).

As characterisation of the resilience model (MR) is the most important feature of sub grade soil for designing or evaluation, roading agencies have been provided with nondestructive tests, such as the Falling Weight Deflectometer (Rahim & George, 2002).

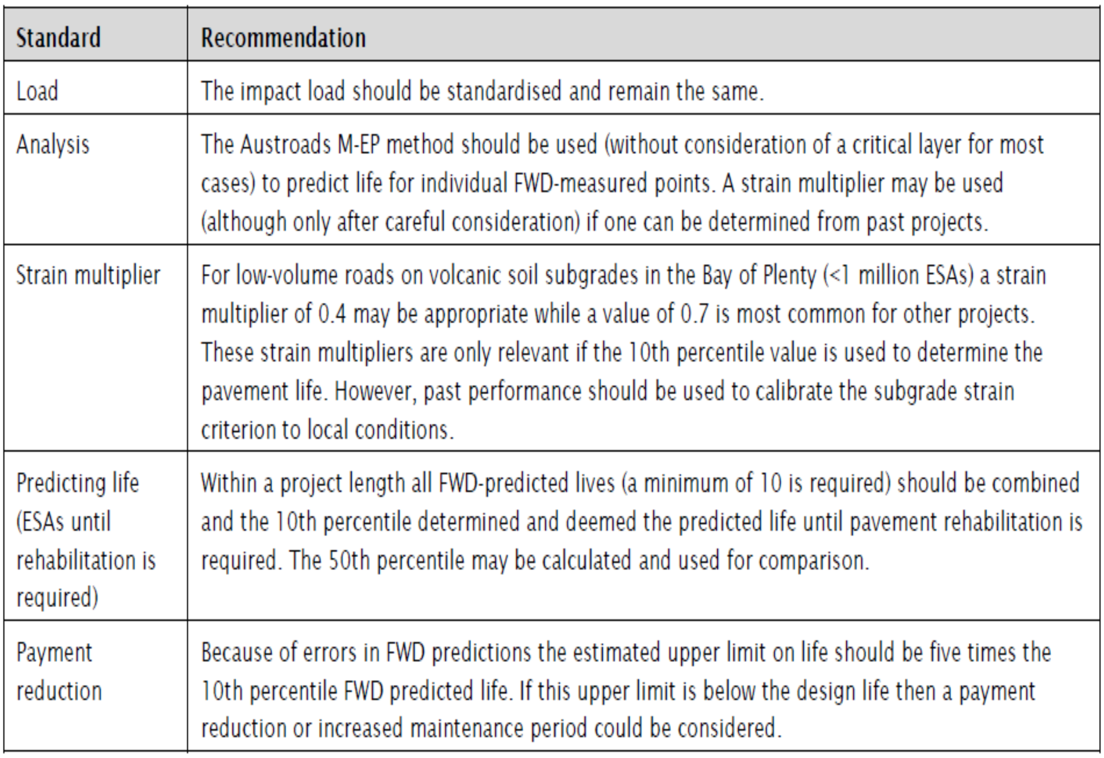
The Falling Weight Deflectometer (FWD), which measures pavement deflections, was assessed for its ability to predict the life of a newly constructed or rehabilitated pavement. By using the FWD test, a wide range of sub grade soil types, (fine- and coarse-grain soils) can be categorised. This test has been designed for conducting directly on the sub grade, before and after preparation, and it is repeated at the same place after the final construction stage (Brown et al., 2002).

Deflection measurement results show that the back-calculated moduli of the prepared subgrade are in good agreement with the laboratory values (Rahim & George, 2002).

Research by Arnold et al. (2009) in conjunction with the NZTA, recommended some methods to analyse the FWD measurements, in order to develop a standard method for predicting pavement life from the FWD.

The following table shows the recommended methods for analysing the FWD measurements, and shows the best time for making decisions about starting a maintenance process. Using this test is one of the best methods to help decision makers make a good decision about starting maintenance or rehabilitation projects. It also has a huge effect on cost and time, which can directly improve efficiency and productivity.

Table 3: Recommended methods for analysing the FWD measurements



Standard	Recommendation
Load	The impact load should be standardised and remain the same.
Analysis	The Austroads M-EP method should be used (without consideration of a critical layer for most cases) to predict life for individual FWD-measured points. A strain multiplier may be used (although only after careful consideration) if one can be determined from past projects.
Strain multiplier	For low-volume roads on volcanic soil subgrades in the Bay of Plenty (<1 million ESAs) a strain multiplier of 0.4 may be appropriate while a value of 0.7 is most common for other projects. These strain multipliers are only relevant if the 10th percentile value is used to determine the pavement life. However, past performance should be used to calibrate the subgrade strain criterion to local conditions.
Predicting life (ESAs until rehabilitation is required)	Within a project length all FWD-predicted lives (a minimum of 10 is required) should be combined and the 10th percentile determined and deemed the predicted life until pavement rehabilitation is required. The 50th percentile may be calculated and used for comparison.
Payment reduction	Because of errors in FWD predictions the estimated upper limit on life should be five times the 10th percentile FWD predicted life. If this upper limit is below the design life then a payment reduction or increased maintenance period could be considered.

Source: Arnold et al. (2009)

The current quality control/quality assurance (QC/QA) methods are based on achieving certain physical properties such as the layer thickness, a target field density, and moisture content. However, achieving a certain density does not guarantee acceptable performance of the compacted highway base layer during its service life (Alshibli, Abu-Farsakh, & Seyman, 2005).

However, as Alshibli et al. (2005) have described, current methods of controlling the quality of compacted soils and bases must be improved, and robust, portable devices capable of giving representative measurements of the properties sought in the design, such as the stiffness/strength of the material, must be introduced.

2.6 Road Condition Rating

Productive decision making is not achievable without assessing routine road maintenance and also providing a database of each road element condition from a visual survey.

The survey needs to be performed by experienced experts who walk over the selected road network and record defects on the survey form. By using RAMM pocket software, the geographic position of each defect will be characterised on the map. Appendices D and E show samples of treatment selection and inspection forms, that are currently in use in the Fulton Hogan maintenance department.

Subsequently, once the survey form has been completed, the survey information will be entered into the road inventory databases of the RAMM contractor software. More information about defect recording and rating purposes follow.

2.7 Classification of Road Failures, Selected Treatment

An investigation into road failures classification and road treatments is essential for exploring all obstacles to improved productivity.

2.7.1 Typical Cross Sections

For a comprehensive understanding of the following definition about road defects and conditions, it will be useful to show a typical cross section of roads (Figures 10 and 11).

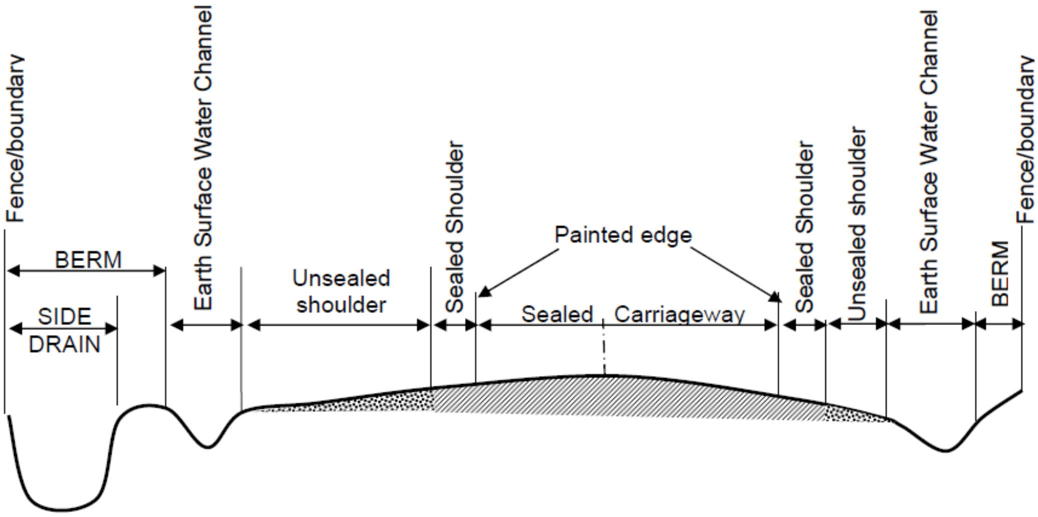


Figure 8: Cross section of rural roads

The unsealed area between the edge of seal and the surface water channel are called as shoulders (Transfund New Zealand, 1997).

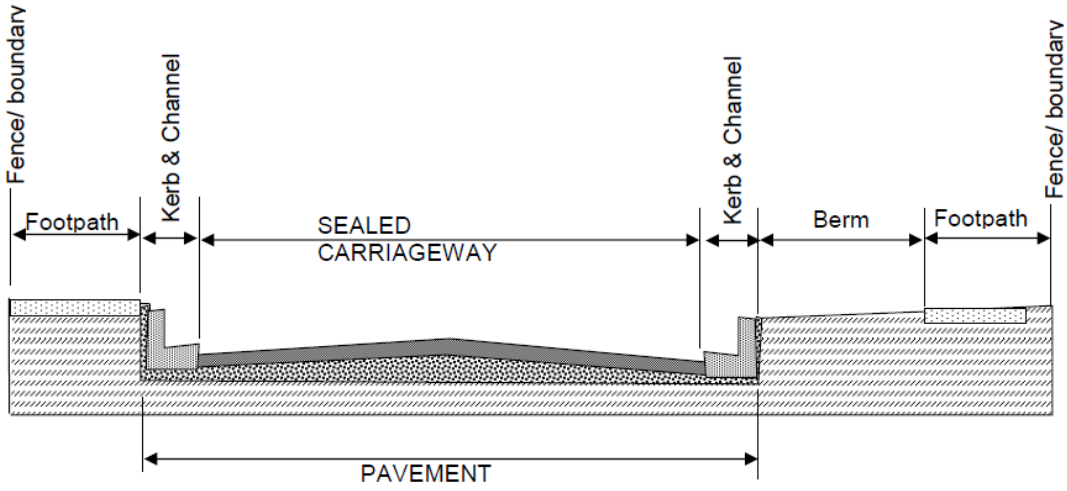


Figure 9: Cross section of urban roads

Source: Transfund New Zealand (1997)

2.7.2 Separating Road Structure for Maintenance Purpose

As has been described in the RAMM manual, for rating purposes the road structure can be divided into the following sections:

1- Surface water channels and shoulders
2- Carriageway

2.7.3 Surface Water Channels (SWCs) and Shoulders

Most pavement failures are caused by water penetrating under the pavement, so one of the most important sections of pavement, which plays a main role in keeping roads safe and flawless, is the drainage system. The Surface Water Channel (SWCs) and shoulders are designed to drain water.

The SWCs can be divided into the following types.

2.7.3.1 Earth Channel or Surfaced Channels.

Types of surfaced channels are:

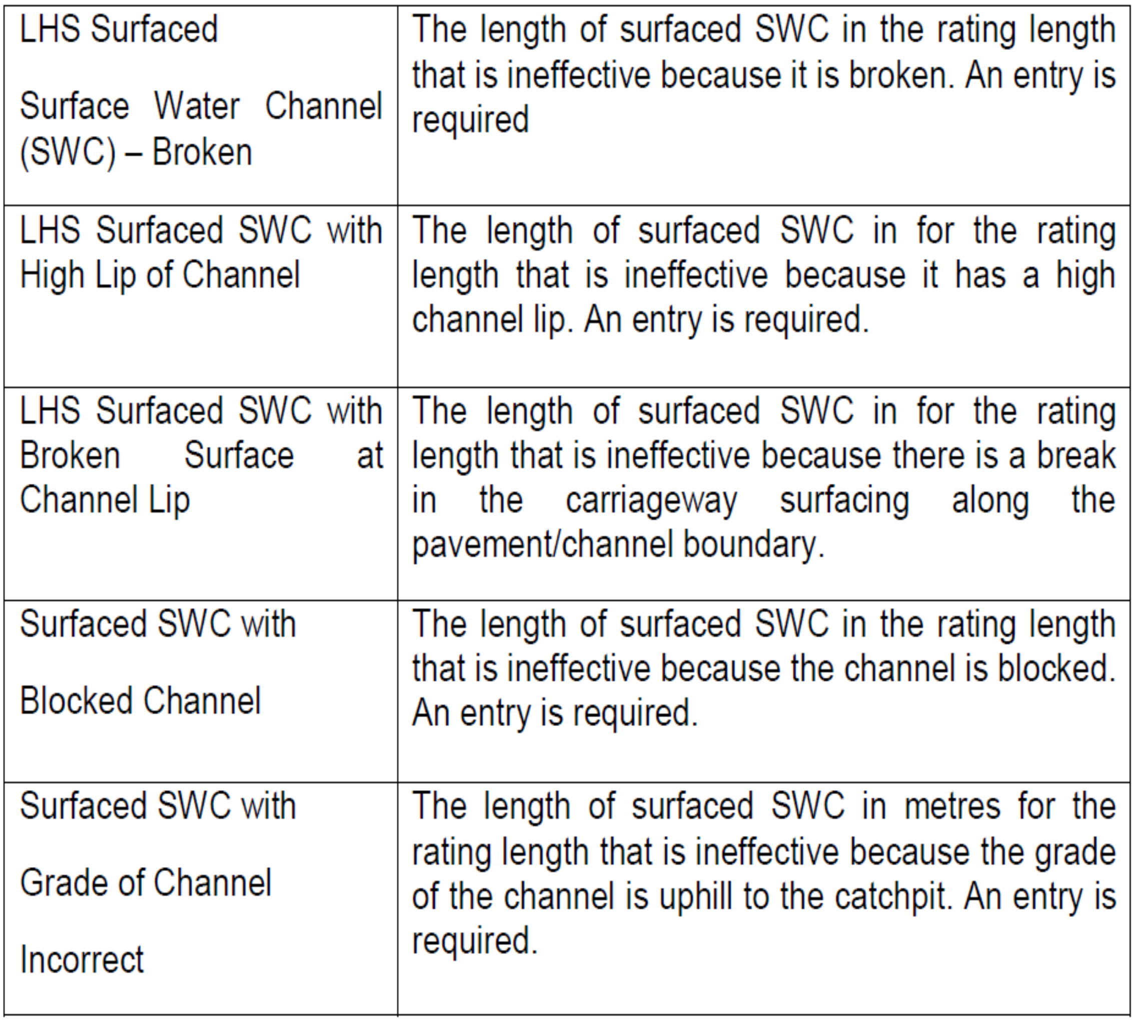
- Kerb and channel
- Concrete dished channel
- Mountable kerb and channel

- Concrete nib kerb (if it is acting as a drainage path)
- Sealed channel
- Asphaltic concrete channel
- Half pipe channels
- Any other constructed channel that has been surfaced

2.7.3.2 Surfaced channels

Table 4 shows the length of defective channels that are unable to gather and transport water from the pavement to the catchpit/sump.

Table 4: Rating of defective channels



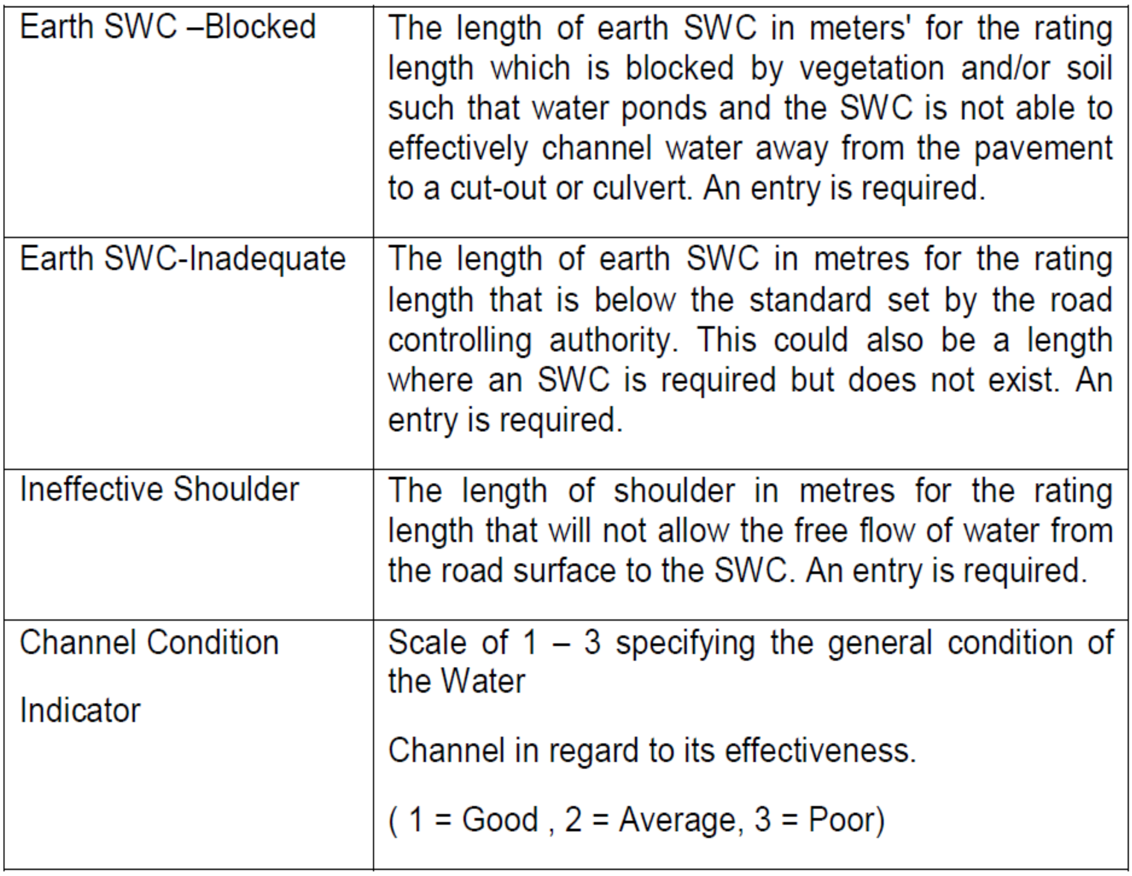
LHS Surfaced Surface Water Channel (SWC) – Broken	The length of surfaced SWC in the rating length that is ineffective because it is broken. An entry is required
LHS Surfaced SWC with High Lip of Channel	The length of surfaced SWC in for the rating length that is ineffective because it has a high channel lip. An entry is required.
LHS Surfaced SWC with Broken Surface at Channel Lip	The length of surfaced SWC in for the rating length that is ineffective because there is a break in the carriageway surfacing along the pavement/channel boundary.
Surfaced SWC with Blocked Channel	The length of surfaced SWC in the rating length that is ineffective because the channel is blocked. An entry is required.
Surfaced SWC with Grade of Channel Incorrect	The length of surfaced SWC in metres for the rating length that is ineffective because the grade of the channel is uphill to the catchpit. An entry is required.

Source: Transfund New Zealand (1997)

2.7.3.3 Earth Surface water Channels

Table 5 shows the length of defective Earth Surface water channels that are unable to gather and transport water from the pavement to the catchpit/sump.

Table 5: Rating of defective Earth Surface Water channels



Earth SWC –Blocked	The length of earth SWC in meters' for the rating length which is blocked by vegetation and/or soil such that water ponds and the SWC is not able to effectively channel water away from the pavement to a cut-out or culvert. An entry is required.
Earth SWC-Inadequate	The length of earth SWC in metres for the rating length that is below the standard set by the road controlling authority. This could also be a length where an SWC is required but does not exist. An entry is required.
Ineffective Shoulder	The length of shoulder in metres for the rating length that will not allow the free flow of water from the road surface to the SWC. An entry is required.
Channel Condition Indicator	Scale of 1 – 3 specifying the general condition of the Water Channel in regard to its effectiveness. (1 = Good , 2 = Average, 3 = Poor)

Source: Transfund New Zealand (1997)

2.7.4 Part one: Description of Surfaced Channel's failures

Broken Channel

Any channel that is badly cracked or broken and will let waters flow steadily to the base and sub-base material is called a broken channel. Inadequate joints between kerbing blocks and separation between two sections of the channel, are also classed as broken channels, as seen in Figure 12.

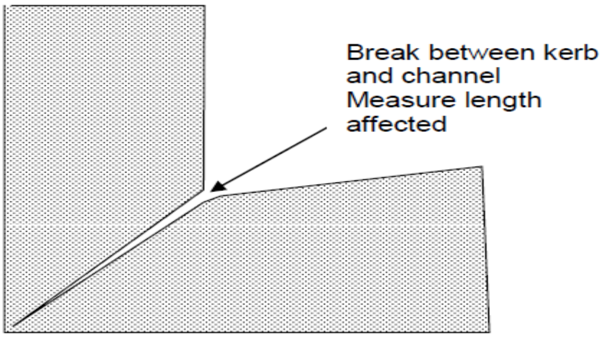


Figure 10: Broken channel

Source: Transfund New Zealand (1997)

The photos below (Figures 13-15) show broken channels, inadequate kerb block joints and separation between the channel and back of the kerb.

Figure 11: Example of a broken channel

Source: Transfund New Zealand (1997)

Figure 12: A badly broken kerb

Source: Transfund New Zealand (1997)

Figure 14 shows an example of a broken kerb and channel that are readily leaking water through to the sub-base of the carriageway.

Figure 13: A broken section of channel adjoining a vehicle crossing

Source: Transfund New Zealand (1997)

Separation between the channel and the kerb up-stand is to be rated as broken.

Figure 14: Single crack in the kerb

Source: Transfund New Zealand (1997)

A single crack >10mm wide at the surface is rated as 1m of broken channel.

High Lip Channel

If the lip of channel is 10mm, (the height of a Bic pen), or more higher than the carriageway surface then the length of kerb affected is recorded. Where there is also broken carriageway surface, this height will have to be estimated from a straight edge placed on the carriageway surface and extended to the channel edge (Transfund New Zealand,1997, p.21).

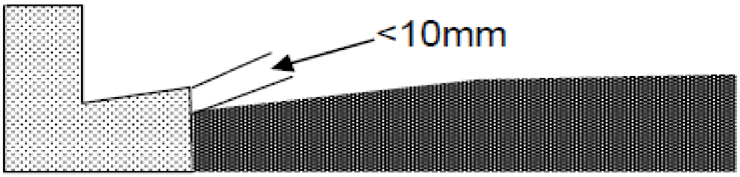


Figure 15: High Lip Channel

Source: Transfund New Zealand (1997)

“Where the carriageway surface is shaped so that it is more than 10mm below the channel lip at a short distance from the line of the channel, then this should also be rated as high lip” (Transfund New Zealand, 1997, p.21).

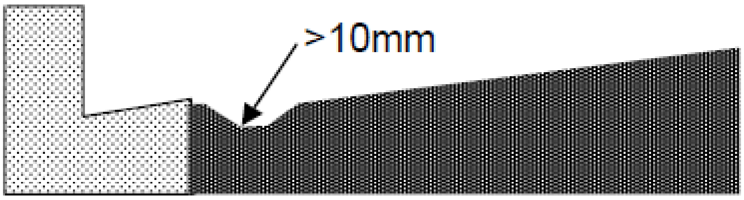


Figure 16: Low lip channel

Source: Transfund New Zealand (1997)

This photo (Figure 19) is a good example of a lip channel above the carriageway surface.

Figure 17: High lip channel

Source: Transfund New Zealand (1997)

Broken Surface at Channel Lip

These kinds of failures happen when the space (more than 10mm) is between the channel and the carriageway. The length of channel that is affected needs to be recorded, as well as the length of kerb where there is structure separation between the kerb and the carriageway, if existent.

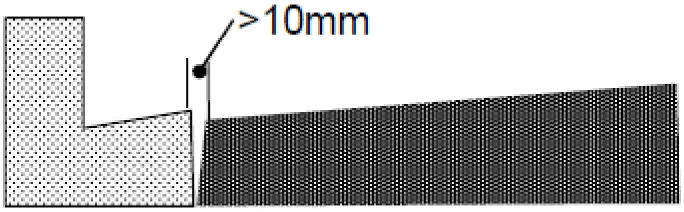


Figure 18: Broken surface at channel lip

Source: Transfund New Zealand (1997)

NOTE: If the defect is the same as in Figure 20, it indicates that the broken surface is the cause of a high lip, and it should be rated as broken surface.

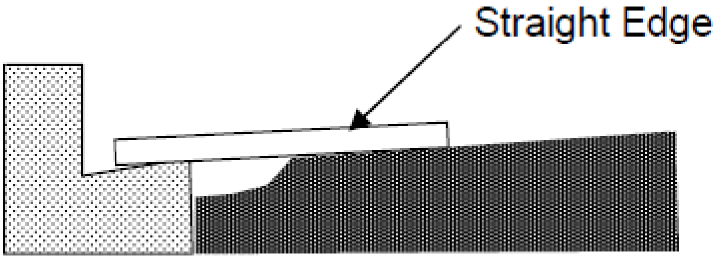


Figure 19: Broken surface at channel lip

Source: Transfund New Zealand (1997)

Figure 20: A break in the carriageway surface alongside the channel

Source: Transfund New Zealand (1997)

Blocked Channel

If weed growth, firm-settle debris or other obstructions block 75% of the channel width and stop water flowing, thereby conducting water onto the carriageway, it is called a blocked channel. The following pictures (Figures 23 and 24) show two examples of a blocked channel.

Figure 21: Kerb and channel blocked by debris and weed growth

Source: Transfund New Zealand (1997)

Figure 22: Kerb and channel blocked

Source: Transfund New Zealand (1997)

In the case of a kerb and channel blocked by a badly maintained plate crossing, the length of the crossing would be recorded as blocked.

Grade of Channel Incorrect

When a specific length of channel does not have sufficient slope and is therefore ineffective, it can cause water to pond onto carriageway surface.

Figure 25 shows an example of an uphill grade kerb and channel**.**

Figure 23: Water ponding in a channel can indicate uphill grade

Source: Transfund New Zealand (1997)

Earth Surface Water Channels

"Earth surface water channels (ESWCs) and shoulders are rated for the whole length not just the inspection length" (Transfund New Zealand, 1997, p.27).

Problems with earth surface water channels can be divided into three sections:

- Blocked shoulder
- Inadequate shoulder
- Ineffective shoulder

Blocked Shoulder

Vegetation, slips, soil, aggregate or general debris may block the ESWC (Figures 26-29). If the channel is not able to transfer water from the pavement to cutoffs/culverts, it will be rated as a blocked channel.

Figure 24: ESWC blocked by a solid mass of vegetation

Source: Transfund New Zealand (1997)

Figure 25: ESWC blocked by weed growth

Source: Transfund New Zealand (1997)

Figure 26: Blocked culvert (blocked ESWC)

Source: Transfund New Zealand (1997)

In Figure 28 the culvert has been blocked; the inlet for the culvert can just be seen and the length of the culvert would be recorded as blocked.

Figure 27: ESWC Blocked by a slip

Source: Transfund New Zealand (1997)

Inadequate Shoulder

If the depth of the adjoining carriageway surface to the invert is less than 300mm (400mm for highways), it will be rated as an inadequate, as depicted in Figure 30.

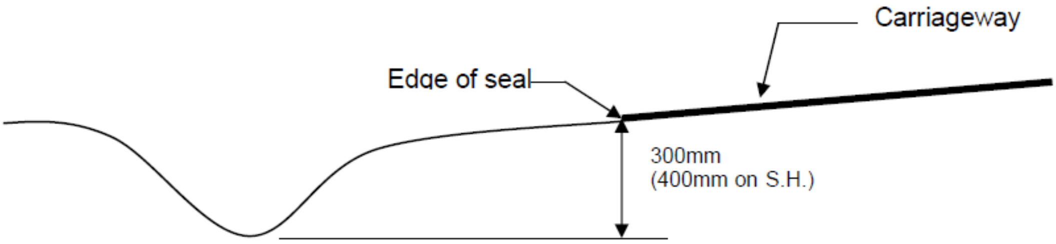


Figure 28: Shoulder cross section

"Where there is no defined ESWC but the ground falls away from the carriageway, the depth is assessed at a point 3m from the edge of seal" (Transfund New Zealand, 1997, p.30)(Figure 31).

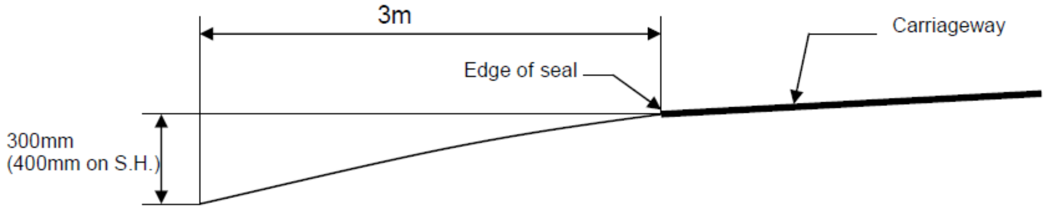


Figure 29: Shoulder cross section

NOTE: one important issue is that the minimum standard for channels may vary due to local conditions, therefore, the consultant should check with the client to establish any local variation (Transfund New Zealand, 1997).

Figure 30: An inadequate ESWC

Source: Transfund New Zealand (1997)

Figure 31: Inadequate ESWC

Source: Transfund New Zealand (1997)

Figure 33 shows inadequate ESWC because of the depth of the channel. The weed growth would slow water down but would not cause it to pond.

Figure 32: Inadequate ESWC

Source: Transfund New Zealand (1997)

Figure 34 depicts a case where an ESWC does not exist. It is rated as inadequate as there is not 300mm of ground fall 3m out from the edge of the carriageway.

Ineffective Shoulder

If any obstruction prevents water flowing freely from the carriageway to cutoffs/culvert, the length of shoulder will be rated as an ineffective shoulder.

OR: Any obstruction (e.g. windrow) that would cause ponding of water to a depth of> 50mm:

- Between the carriageway and the surface water channel
- Within 2m of the carriageway surface where there is no formed surface water channel and the ground falls away from the carriageway.

Typically high shoulders with edge rutting would be rated as ineffective shoulders. Low shoulders that do not impact on the flow of water should not be rated (Transfund New Zealand, 1997).

Figure 33: Ineffective shoulder due to deep tyre track

Source: Transfund New Zealand (1997)

If, for any reason, the shoulder was too much higher than the carriageway surface and it does not let water flow away from the carriageway, it will be rated as an ineffective shoulder. Another problem, illustrated in Figure 36, is an ineffective shoulder due to deep tyres tracks.

Figure 34: Shoulder is ineffective due to the wheel rut along the edge of the carriageway

Source: Transfund New Zealand (1997)

Figure 35: Ineffective shoulder due to the high area between the carriageway and the ESWC

Source: Transfund New Zealand (1997)

2.7.5 Alternative Drainage Rating

As the RAMM instruction manual described, based on the existing method, there are some problems with rating the drainage:

*"*Disproportionate amount of time rating ESWC's compared to carriageway faults, variations in local requirements, Importance of the results to the treatment selection process" (Transfund New Zealand, 1997, p. 1).

Therefore, based on the discretion of the client, the RAMM instruction manual has introduced some alternative ways for rating as follows:

Combined Rating

> To better balance the effort in rating ESWC drainage with the use of data in the treatment selection process, the three defect types (ineffective shoulder, blocked SWC, and inadequate SWC) may be amalgamated

> into a single rating as inadequate drainage (Transfund New Zealand, 1997, p.37).

However, the first option (recorded as three separate defects) is still available, but it should be considered that recording the length of inadequate drainage is by length in metres.

Selective Rating

Based on one of the following reasons, the client has the option of designating a certain area that should not to be rated.

- Ground is free draining
- Sub-soil drainage is present
- An embankment situation
- Super elevation on curves

Figure 38 demonstrates a logic flow for the selective rating method.

ESWC RATING FLOW DIAGRAM

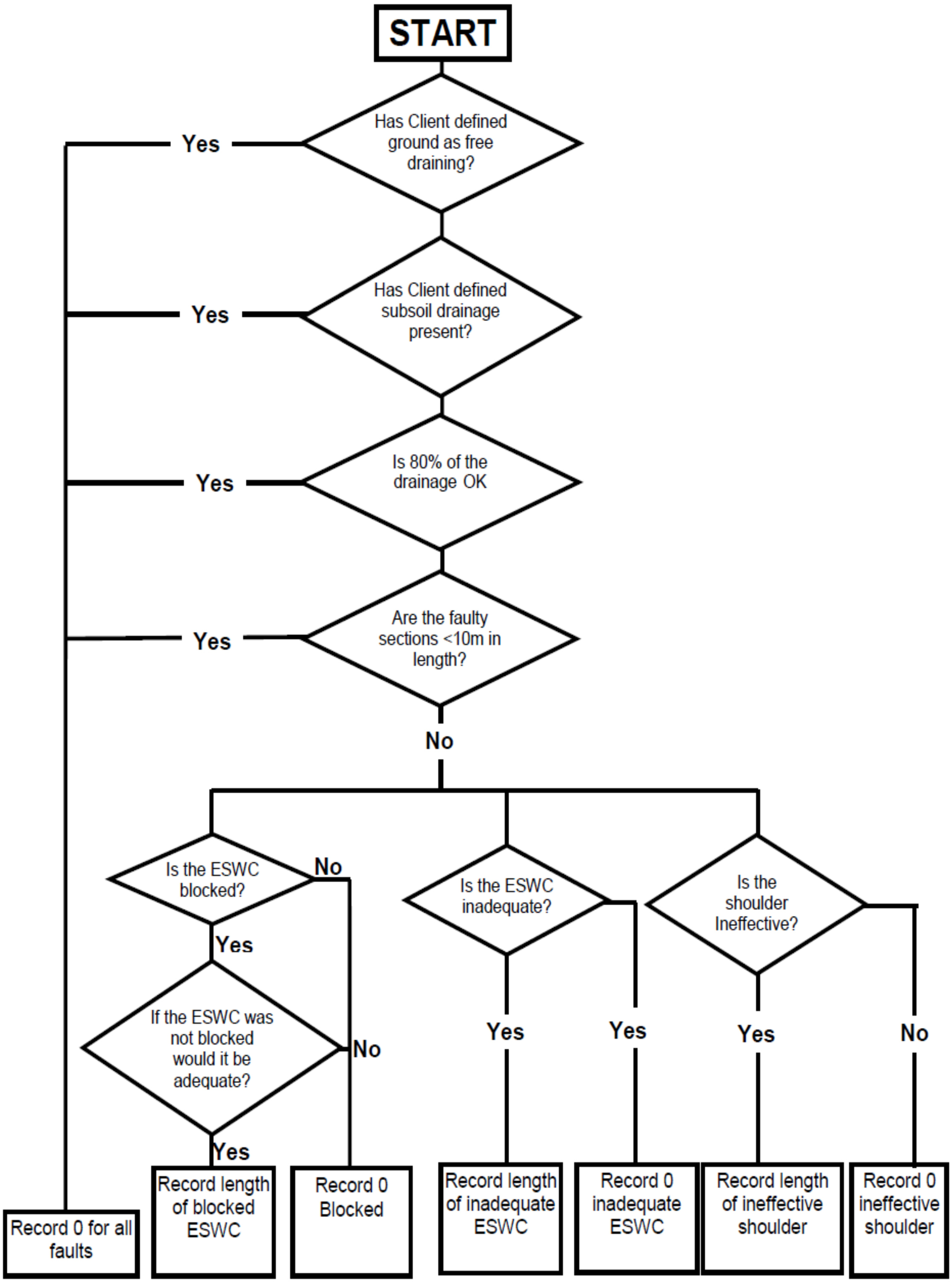


Figure 36: Flowchart of ESWC rating method

Source: Transfund New Zealand (1997)

ESWC Condition Severity Indicator

To illustrate the general intensity of failures on the ESWCs, this system of rating allocates a number on a scale of 1 to 3.

This scale has been described in the RAMM instruction manual, therefore, it is essential to exactly follow these instructions.

1- Indicates low severity of faults as typified by ESWCs that comply with the conditions in the flow chart above.

I.e. 80% of the ESWCs in the treatment length show no faults and faulty areas are less than 10m long

Or

- Subsoil drainage is present
- The ground is free draining
- The client has specified that ESWCs are not required for this TL.

2 -Indicates that the ESWC faults exceed the levels above. (Longer than 10m in length and Over 20% of the total length of channel is faulty. But there are no obvious water related faults on the carriageway or evidence of flooding or ponding on the carriageway, or shoulder.

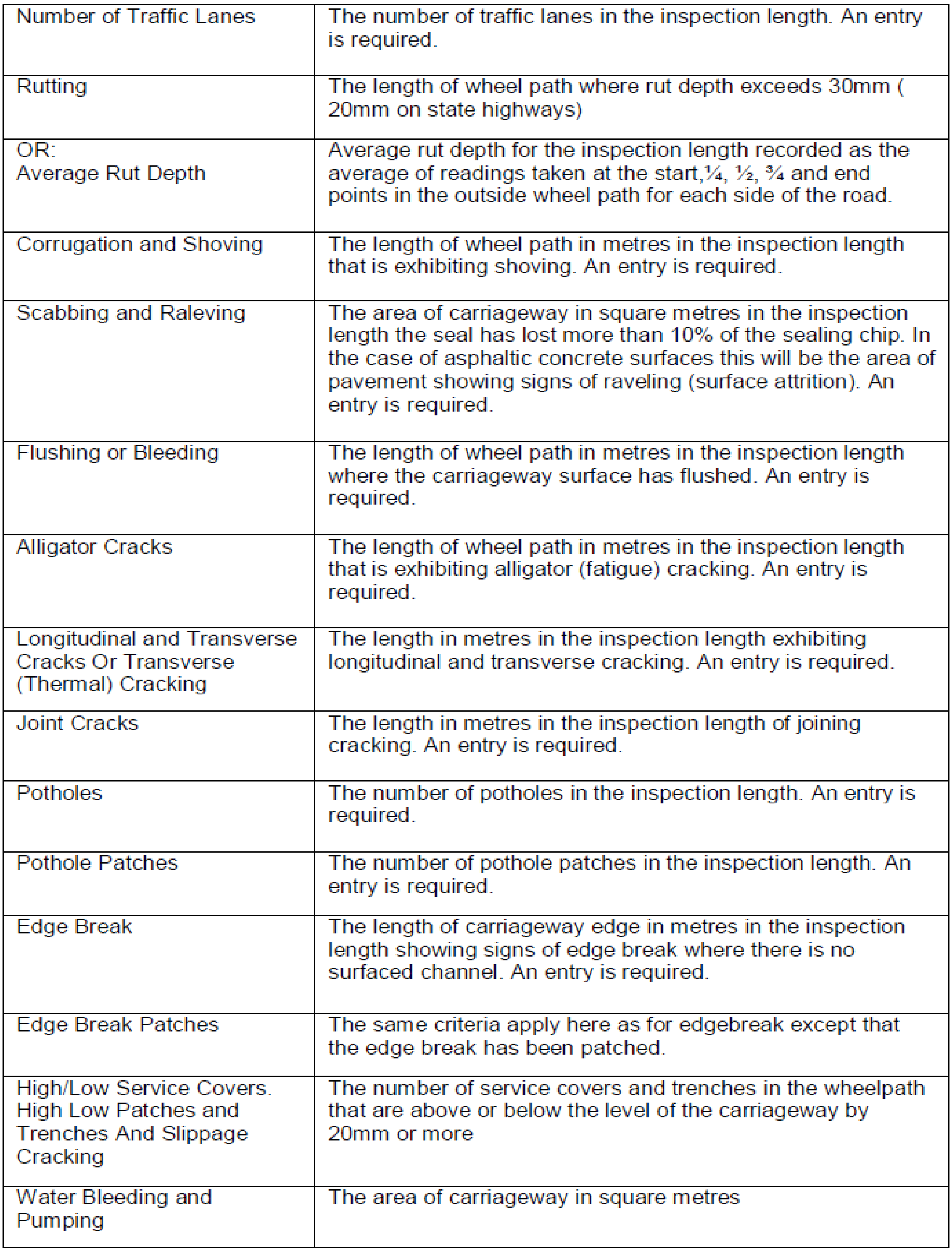
3-Indicates that the ESWC faults exceed the levels of level 1 and the following conditions also exist

- Boggy or rough water damaged shoulder
- Evidence of water ponding on the shoulder or carriageway
- Water related faults on the carriageway adjacent to areas of faulty ESWC. (Transfund New Zealand, 1997, p.39).

2.7.6 Part two: Description of Carriageway Failures

The carriageway is the main area of road that is rated only within the defined inspection length. Table 6 briefly describes all kind of pavement failures and the methods of rating.

Table 6: Pavement failures and the rating methods



Number of Traffic Lanes	The number of traffic lanes in the inspection length. An entry is required.
Rutting	The length of wheel path where rut depth exceeds 30mm (20mm on state highways)
OR: Average Rut Depth	Average rut depth for the inspection length recorded as the average of readings taken at the start,¼, ½, ¾ and end points in the outside wheel path for each side of the road.
Corrugation and Shoving	The length of wheel path in metres in the inspection length that is exhibiting shoving. An entry is required.
Scabbing and Raleving	The area of carriageway in square metres in the inspection length the seal has lost more than 10% of the sealing chip. In the case of asphaltic concrete surfaces this will be the area of pavement showing signs of raveling (surface attrition). An entry is required.
Flushing or Bleeding	The length of wheel path in metres in the inspection length where the carriageway surface has flushed. An entry is required.
Alligator Cracks	The length of wheel path in metres in the inspection length that is exhibiting alligator (fatigue) cracking. An entry is required.
Longitudinal and Transverse Cracks Or Transverse (Thermal) Cracking	The length in metres in the inspection length exhibiting longitudinal and transverse cracking. An entry is required.
Joint Cracks	The length in metres in the inspection length of joining cracking. An entry is required.
Potholes	The number of potholes in the inspection length. An entry is required.
Pothole Patches	The number of pothole patches in the inspection length. An entry is required.
Edge Break	The length of carriageway edge in metres in the inspection length showing signs of edge break where there is no surfaced channel. An entry is required.
Edge Break Patches	The same criteria apply here as for edgebreak except that the edge break has been patched.
High/Low Service Covers. High Low Patches and Trenches And Slippage Cracking	The number of service covers and trenches in the wheelpath that are above or below the level of the carriageway by 20mm or more
Water Bleeding and Pumping	The area of carriageway in square metres

Sources: Pavement Interactive (2009), Transfund New Zealand (1997)

2.7.7 Carriageway Rating

The main section of the rating process is rating the carriageway, since many different defects may occur on the road surface. Differentiation between defects is one of the more difficult phases in road pavement maintenance. However, the following explanations illustrate the differences between defects, and techniques required to observe these defects, helping this process to be more recognisable.

A classification of all types of carriageway surface failures, possible causes and repair types to illustrate the results of this comprehensive research, follows.

Rutting (Wheel tracking)

Figure 37: Shallow rutting

Source: Pavement Interactive (2009)

There are two basic kinds of pavement rutting or permanent deformation that have been a long term problem for pavement, particularly for hot-mix asphalt (HMA) or flexible pavement:

1. Mix rutting
2. Sub-grade rutting.

> Mix rutting occurs when the sub-grade does not rut yet the pavement surface exhibits wheel-path depressions as a result of compaction/mix design problems. Sub-grade rutting occurs when the sub-grade exhibits wheel-path depressions due to loading. In this case, the pavement

settles into the sub-grade ruts causing surface depressions in the wheel-path (Pavement Interactive, 2009, p.8).

Safety Concern

In rainy weather the ruts fill with water, which can cause vehicle hydroplaning. Another dangerous problem is that the ruts tend to pull cars towards the rut's path (Pavement Interactive, 2009; Fulton Hogan, 2006).

Possible Causes of rutting failure

The following are possible causes of rutting failure of the road pavement**:**

- Inadequate compaction of sub-grade during the construction process.
- Inadequate compaction of base-course during the construction process.
- Consolidation of base-course or sub-base due to excessive moisture content.
- Base-course layer too thin and sub-grade deforms under the traffic. Sub-grade rutting (e.g., as a result of inadequate pavement structure)
- Traffic volumes in excess of the design causing base course to break down
- Inappropriate mix design or manufacture (e.g., excessively high asphalt content, excessive mineral filler, insufficient amount of angular aggregate particles)
- Narrow ruts are generally a sign that rutting has occurred in the top layer of the pavement.
- Wide ruts are generally a sign that the rutting has occurred through the entire depth of the pavement (Fulton Hogan, 2006; Pavement Interactive, 2009).

Also, Fang, Haddock, White, and Hand (2004) stated that ″improper design, poor materials or construction quality, poor drainage conditions, and/or any combination of these factors may result in an inadequately designed layer″ (p.51).

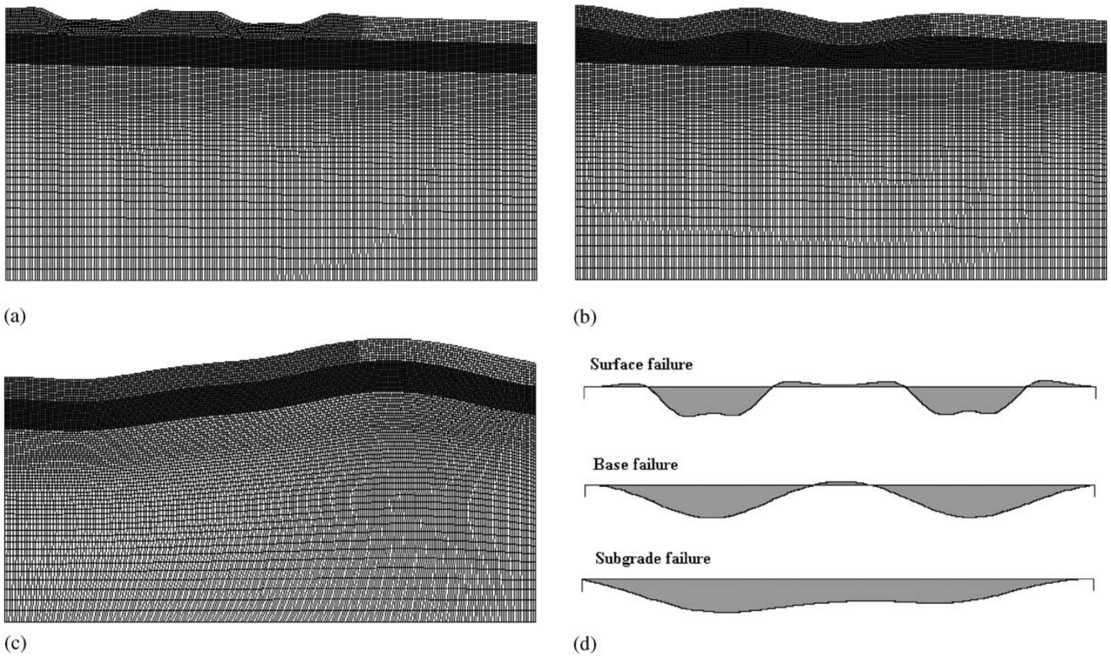


Figure 38: Finite element analysis results (FEA)

Source: (Fang et al., 2004)

Figure 40 illustrates finite element analysis results (FEA) of different pavement layer failures: (a) surface failure; (b) base failure; (c) subgrade failure; and (d) surface profiles.

The Best Repair Strategy

> A heavily rutted pavement should be investigated to determine the root cause of failure (e.g. insufficient compaction, sub-grade rutting, poor mix design or studded tire wear). Slight ruts (< 1/3 inch deep) can generally be left untreated. Pavement with deeper ruts should be leveled and overlaid. (Pavement Interactive, 2009, p. 1).

Some common repair strategies have been offered in Fulton Hogan's Sealed Pavement Maintenance Manual (2006). These are:

- For minor rutting, fill the ruts with rut-fill slurry and follow up with a chip seal.
- Add makeup metal to the rut and then stabilise, re-lay and compact, followed with chip seal.

- For serious ruts, a full investigation should be carried out to work out what has caused the rutting. This will most likely involve using a laboratory and a pavement designer.

Generally large ruts will re-occur in a short time unless a full depth overlay is carried out.

Rating Type

It is clear that the first step for deciding which kind of treatment should be used is an accurate rating. There are two options for rating the ruts.

- **Option1: (Exceeding 30mm)**

When the depth of wheel path exceeds 30mm and is measured under a 2m long straight edge, rutting tends to funnel down and up over a length of failure road. It is important to mention that only the length of rutting that has 30mm depth or more will be recorded (Transfund New Zealand, 1997).

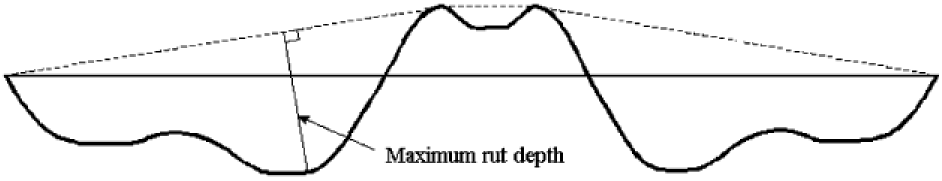


Figure 39: Definition of maximum rut depth of a transverse surface profile

Source: (Fang et al., 2003, p. 50)

- **Option 2: (Mean rut depth)**

As described in the RAMM instruction manual, the mean rut depth is calculated by measuring 10 times, using a two metre long straight edge (Figure 43). In the outside wheel path in each direction, at the start, 1/4, 1/2/ 3/4, and end points in the inspection length (see Table 7). By using these 10 readings, the inspector can calculate the mean depth (Transfund New Zealand, 1997).

Table 7: An example of rutting measurement

Ruth Depth	Start	1/4	1/2	3/4	End	Total
Left Wheel Path	12	10	15	30	13	80
Right Wheel Path	10	0	0	10	0	20
					Total	100
					Mean	10

Source: (Transfund New Zealand, 1997)

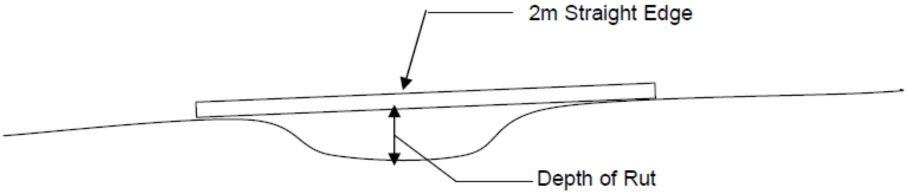


Figure 40: Rutting measurement method

Source: (Transfund New Zealand, 1997)

Based on the two options outlined above, Fang et al. (2004) have described how the types of treatment are different. When rutting is limited to the surface layer, it is a pavement failure, and when rutting is observed in both the surface and base layer, it will be called a base failure, unless it is observed in the sub grade layer, so that the failure refers to the deepest layer of the supporting rutted surface. Therefore, "the layers above the damaged layer need to be replaced and the failed layer needs to be rehabilitated to prevent the relapse of the rutting in a short period of time after rehabilitation" (Fang et al., 2004, p. 50).

Also, it will be useful to mention the results of Simpson, Daleiden, and Hadley (1995) who hypothesised that "the area under the transverse surface profile could be used to predict the source of rutting from within the pavement structure"(p,45)..They classified 128 transverse surface profiles into four main categories representing the source of rutting failures. Table 8 presents these four categories, which are:

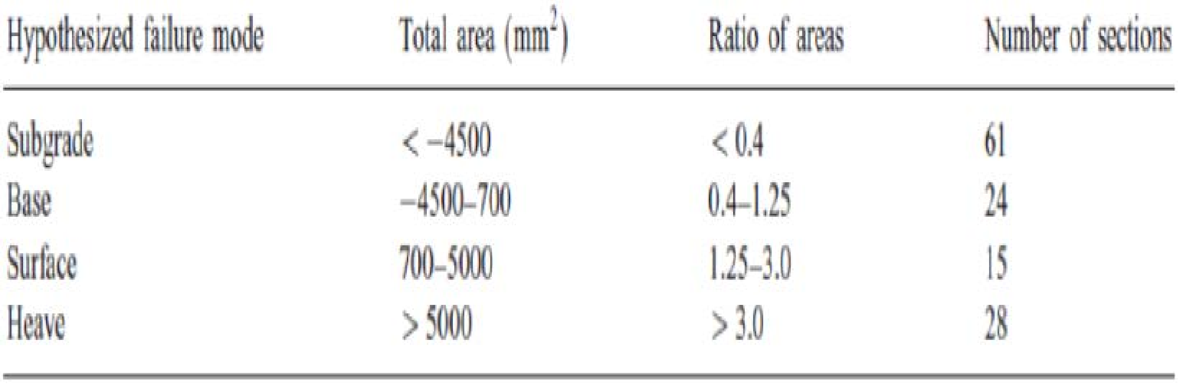
1) Surface failure

2) Base failure

3) Sub grade failure

4) Sub grade heave

Table 8: Rutting origin sorting criteria



Hypothesized failure mode	Total area (mm^2)	Ratio of areas	Number of sections
Subgrade	< −4500	< 0.4	61
Base	−4500–700	0.4–1.25	24
Surface	700–5000	1.25–3.0	15
Heave	> 5000	> 3.0	28

Source: Simpson et al. (1995)

In addition, Fung et al. (2004) illustrated the shape of the transverse surface profiles, Figure 43, but they indicated that "sub grade heave could not coexist with rutting because the sub grade would be weakened by the heavy, and an increase rutting rate would result in a sub-grade failure“ (p. 3).

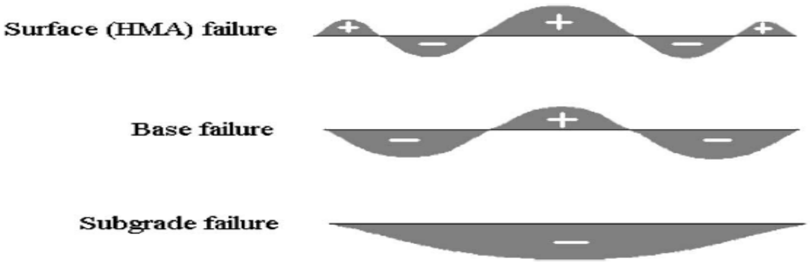


Figure 41: Shape of transverse surface profiles

Appendix G and Table 9 show a sample of rated rutting failure over almost three years in the Waitakere region, which is one of Fulton Hogan's maintenance projects.

Table 9: Sample of rated rutting failure during 3 years at Waitakere region

	May '09	Jun '09	Jul '09	Aug '09	Sep '09	Oct '09	Nov '09	Dec '09	Jan '10	Feb '10	Mar '10	Apr '10	May '10	Jun '10	Jul '10	Aug '10	Sep '10	Oct '10	Nov '10	Dec '10	Jan '11	Feb '11	Mar '11	Apr '11	May '11	Jun '11	Jul '11	Aug '11	Sep '11	Oct '11	Nov '11	Dec '11	Jan '12	Feb '12	Mar '12	Apr '12	May '12	Jun '12	Jul '12	Aug '12	Sep '12	Oct '12	Nov '12	Dec '12	Jan '13	Feb '13	Mar '13
■ 1 REGIONAL ARTERIAL		162	167	152	147	147	147	147	147	144	144	144	156	144	138	98	98	98	98	98	98	82	82	82	84	32	32	34	49	34	34	39	39	39	45	45	45	46	39	39	39	39	39	37	37	37	37
■ 2 DISTRICT ARTERIAL		392	407	440	400	392	372	380	395	411	380	365	348	445	457	457	454	462	499	327	333	255	197	205	197	177	161	173	314	332	375	354	354	280	287	298	296	252	288	326	323	308	308	278	270	269	269
■ 3 DISTRICT ART-SCENIC		6	6	6	6	6	6	6	6	12	12	12	12	12	12	12	6	6	6	106	106	106	6	6	6	16	16	16	26	26	26	29	33	38	38	40	40	40	50	50	56	56	50	50	40	40	35
■ 4 COLLECTOR-DISTRICT		329	329	317	332	329	279	278	294	298	305	313	340	314	306	553	553	559	553	553	543	543	527	271	291	291	231	253	523	526	540	543	497	498	500	514	520	581	619	599	595	595	585	577	571	577	570
■ 5_1 MASSEY		69		31		27		27		27		32		32		10		10		10		10		7		4		29		42		33		37		39		20		41		33		33		32	
■ 5_2 HENDERSON	78		72		69		69		36		26		28		28		28		21		21		21		33		33		147		146		116		116		99		104		98		110		120		125
■ 5_3 NEW LYNN	64		109		107		104		132		169		134		132		132		121		118		118		117		120		127		126		122		116		111		44		39		47		49		46
■ 5_4 WAITAKERE		337		247		243		232		248		262		295		291		321		322		226		268		270		292		344		372		447		558		653		676		676		682		707	
■ 5_Total LOCAL	142	548	587	459	454	446	443	432	427	443	470	489	456	489	487	461	461	491	473	474	471	375	375	414	425	424	427	474	595	660	658	677	643	722	716	829	807	883	821	865	854	846	866	872	884	908	910

Source: Fulton Hogan's Monthly report, prepared by ONSITE DEVELOPMENT LTD. 30 April 2013.

The Best Repair Strategy

A professional investigation is necessary to categorise the level of rutting. Slight ruts (<1/3 inch deep) can generally be left untreated, but for deeper ruts the following process has been offered (Pavement Interactive, 2009).

As described in Fulton Hogan's Sealed Pavement Maintenance (2006) report, repairs to the minor rutting involving filling the ruts with a rut-fill slurry and following up with a chip seal (for chip-seal paved roads). Alternatively, the makeup metal could be added to the rut and subsequently stabilized, re-laid and compacted. It could then be finished with the chip seal.

For serious ruts, a full investigation should be carried out to determine the actual cause of the rutting. A decision could then be made about the proper type of treatment. "Generally, the large ruts will re-occur in a short time unless a full depth overlay is carried out" (P.18).

Shoving and Heaving (Bulging of the road surface)

One of the main reasons for shoving is displaced material. Shoving occurs when materials are displaced to form a bulge or heave alongside a depressed area, see Figures 44 and 45. The length in metres is recorded (Transfund New Zealand, 1997).

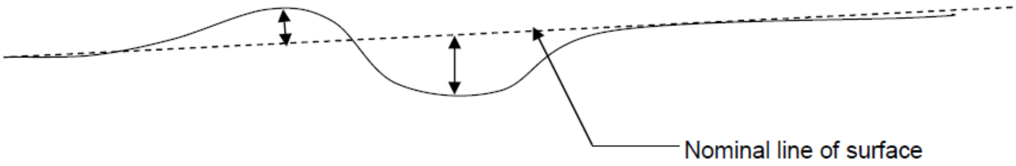


Figure 42: Sample of shoving

> A form of plastic movement typified by ripples (corrugation) or an abrupt wave (shoving) across the pavement surface. The distortion is perpendicular to the traffic direction. Usually occurs at points where traffic starts and stops (corrugation) or areas where HMA abuts a rigid object (shoving) (Pavement Interactive, 2009).

Figure 43: Shoving

Source: (Pavement Interactive, 2009)

Possible Causes

As has been explained in Fulton Hogan's (2006) manual there are some possible causes for shoving failures.

1- The fist problem is when water penetrates under the road surface through a crack, under the pumping action of the vehicles, the seal and other materials will move.

2- Another cause is when there is no shoulder support for the material, or the shoulder is too steep or too narrow, and vehicles force the material out towards the edge of shoulder.

3- The base-course fails and the material breaks down and is squeezed out sideways and then lifts up.

4- Compaction has been carried out against a soft base.

Figure 44: A large shoved area

Source: (Transfund New Zealand, 1997, p. 42)

It is not essential to record additional faults such as cracking, potholes and patches within the shoved area.

Figure 45: An abrupt shove near a service cover

Source: (Pavement Interactive, 2009)

The Best Repair Strategy

Determining the causes of heavily corrugated or shoved pavement is essential for choosing repair strategies. "The repair strategies generally fall into one or two categories: Small, localized areas of corrugation or shoving. Remove the distorted pavement and patch. Large corrugated or shoved areas indicative of general HMA failure. Remove the damaged pavement and overlay" (Pavement Interactive, 2009).

In addition, the following repairing categorisation could be used for choosing the best strategy. These steps have been indicated in Fulton Hogan's (2006) manual. The first three steps are in relation to a shoved area that is caused by corrugation. The first and best action is to level out the corrugations and stabilise the pavement. Then, surface with a minimum of 35mm stone mastic asphalt (SMA), porous asphalt, or dense graded mix where the texture is deemed not to be a problem. An alternative is to carry out a minor leveling over the corrugations, then overlay with 35mm SMA, porous asphalt, or dense graded asphalt.

Straight road corrugations use the minor level repair method using an asphalt paving machine with the screed wound down. Fill in the corrugations and leave mix alone if specification allows. Otherwise, seal after six months trafficking to allow diluents to get out of the asphalt.

The second four types of repair are in relation to other kinds of shoving. If the base course has good stone size in the failed area, then stabilise the area with a stabilising agent suitable for the material and traffic loadings. If there is no shoulder support, the engineer should be advised and shoulder repair should also be carried out. If the shoving is very severe due to the base course breaking down under stress, then a dig out should be considered to add base strength. There may be an overlay required if there is insufficient strength in the pavement to cope with the forces applied by the traffic.

Cracks

Cracks happen when the pavement is too old and the surface (seal or asphalt) does not have enough flexibility under the action of heavy traffic. Different types of cracks appear in the three major pavement structures: rigid, semi-rigid or flexible structures. Cracks may range between 2mm to 30mm and may different vary in length. One of the most important impacts of cracks is that they leak water into the pavement. Fulton Hogan's manual (2006) has mentioned six causes for cracking and water leaking, in this case, into the asphalt.

1- Weakness of applying tack coat before laying the final mix (tack coat too small or no tack coat).
2- Age of surface. Old surfaces always start cracking because of fatigue.
3- Insufficient mix temperature before applying and also inadequate cohesion between two sections of the applied mixture.
4- Applying a new base course in old trenches.
5- Some cracks happen due to settlement of the underlying pavement.
6- Use of ground beside the road surface, causing movement of the road surface and then cracking.

Figure 48 shows examples of some of the most common crack types.

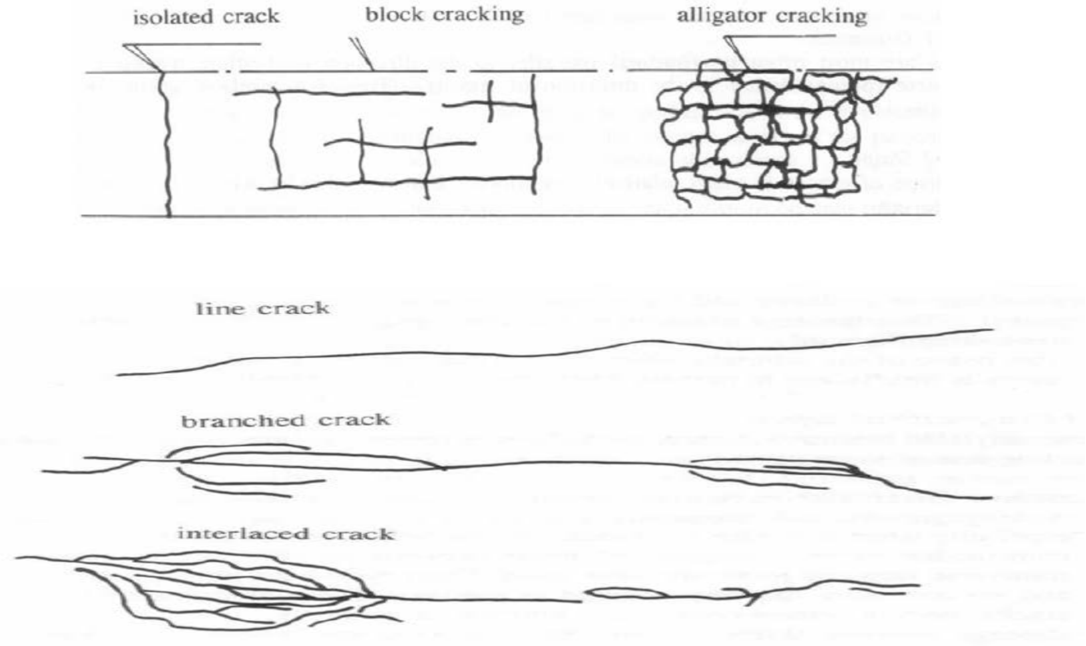


Figure 46: Example of some of the most common crack types

Source: (Francken, 2005)

A precise classification for crack failures on asphalt pavement, which has a huge influence on productivity, was undertaken by Siddique and Hoque (2005), as summarised below:

1- Fatigue or alligator cracks
2- Block cracking
3- Reflection cracks
4- Edge cracks
5- Edge joint cracks
6- Lane joint cracks
7- Shrinkage cracks
8- Slippage cracks
9- Widening cracks

Moreover, some possible causes of cracks are listed below:

- Lack of strong sub-grade, which will cause shoving, then cracks occur on the surface under the action of vehicles.
- Poor seal that allows water to seep through the pavement and then it will be caused for shoved base course.
- Using a huge amount of inessential cement for stabilisation of weak sub grade, which then causes block cracks on the surface.
- Some cracks and shoving happen on the surface of a bend area because of weak pavement surface.
- Asphalt oxidisation, which is caused by age of surface, will cause block cracks.

In addition, some different kinds of cracks have been described subsequently.

Alligator Cracks (Fatigue Cracks)

When a series of interconnected cracks happen on the road pavement, it is called an "alligator crack" (Figure 51). This kind of surface distress is caused by fatigue failure.

Fatigue failure occurs under repeated traffic loading.

> As the number and magnitude of loads becomes too great, longitudinal cracks begin to form (usually in the wheel paths). After repeated loading, these longitudinal cracks connect forming many-sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile ("Pavement Interactive, 2009, p. 2).

Also, "Alligator cracking is commonly called chicken wire cracking as it has the appearance of chicken wire mesh″ (Transfund New Zealand, 1997, p. 43).

The most common method for rating alligator cracks is by visual observation. They will be more obvious when the water start to penetrate into the cracks, so it is easiest to observe after light rain and also in colder seasons. However, it is difficult to observe fine cracks on a wet surface and bright sunshine, and is easier to observe in shadow and dry weather, as demonstrated in Figures 49 and 50.

> Flushing, rutting, and alligator cracking are usually found in the wheel paths shown by traffic wear on the carriageway surface. Sometimes vehicles traffic the pavement outside the normal wheel paths such as in bus bays, sealed shoulders etc. If any of the above faults are found outside the wheel paths, they should be recorded. The total recorded however, may not exceed the number of wheel paths x length of inspection section″ (Transfund New Zealand, 1997, p. 43).

Figure 47: Observing fine cracks in the sunshine

Figure 48: Observing fine cracks in shadow

Source: (Transfund New Zealand, 1997)

Figure 49: Sample of Alligators Cracks

Source: Pavement Interactive (2009)

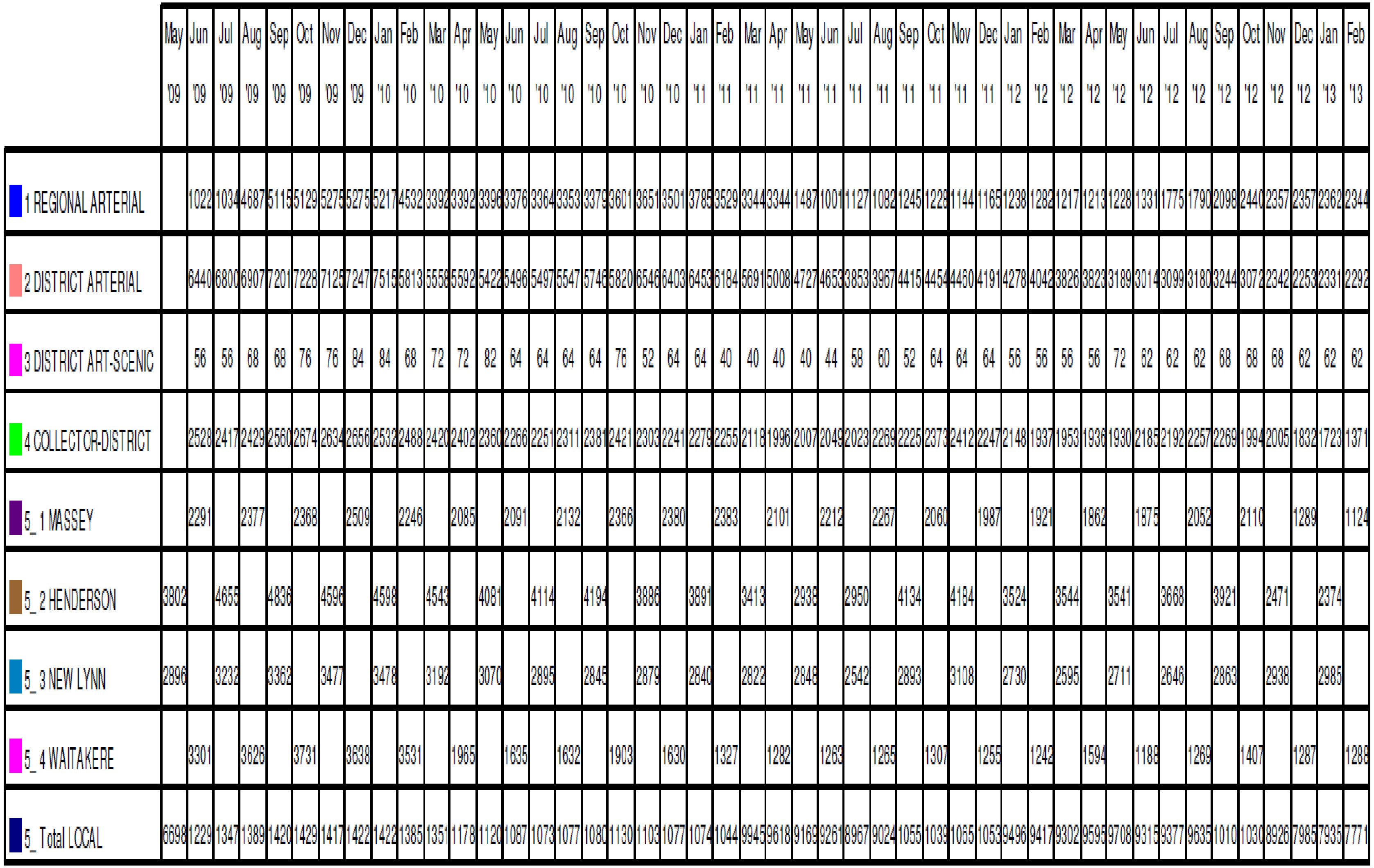
Possible Causes for Alligator Cracks

The main cause for alligator cracking is inadequate structural support. As described above, cracks can be caused that water leak to the base and sub grade and finally lead to pothole damage if not treated. Based on Transfund New Zealand's (1997) RAMM manual, some possible and common causes for alligator cracking are listed below:

- Decrease in pavement load supporting characteristics.
- Probably the most common reason is a loss of base, sub-base or sub-grade support from poor drainage. Water under a pavement will generally cause the underlying materials to become weak.
- Stripping on the bottom of the HMA layer. The stripped depth contributes little to pavement strength so the effective HMA thickness decreases.
- Increase in loading (i.e., the pavement is being loaded more heavily than anticipated in design)

- Inadequate structural design (i.e., the pavement was designed too thin for the anticipated loads)
- Poor construction (i.e., inadequate compaction)"

Appendix H and Table 10 show a history of road faults, specifically alligator cracks.



	May '09	Jun '09	Jul '09	Aug '09	Sep '09	Oct '09	Nov '09	Dec '09	Jan '10	Feb '10	Mar '10	Apr '10	May '10	Jun '10	Jul '10	Aug '10	Sep '10	Oct '10	Nov '10	Dec '10	Jan '11	Feb '11	Mar '11	Apr '11	May '11	Jun '11	Jul '11	Aug '11	Sep '11	Oct '11	Nov '11	Dec '11	Jan '12	Feb '12	Mar '12	Apr '12	May '12	Jun '12	Jul '12	Aug '12	Sep '12	Oct '12	Nov '12	Dec '12	Jan '13	Feb '13
■ 1 REGIONAL ARTERIAL		1022	1034	4687	5115	5129	5275	5275	5217	4532	3392	3392	3396	3376	3364	3353	3379	3601	3651	3501	3785	3529	3344	3344	1487	1001	1127	1082	1245	1228	1144	1165	1238	1282	1217	1213	1228	1331	1775	1790	2098	2440	2357	2357	2362	2344
■ 2 DISTRICT ARTERIAL		6440	6800	6907	7201	7228	7125	7247	7515	5813	5558	5592	5422	5496	5497	5547	5746	5820	6546	6403	6453	6184	5691	5008	4727	4653	3853	3967	4415	4454	4460	4191	4278	4042	3826	3823	3189	3014	3099	3180	3244	3072	2342	2253	2331	2292
■ 3 DISTRICT ART-SCENIC		56	56	68	68	76	76	84	84	68	72	72	82	64	64	64	64	76	52	64	64	40	40	40	40	44	58	60	52	64	64	64	56	56	56	56	72	62	62	62	68	68	68	62	62	62
■ 4 COLLECTOR-DISTRICT		2528	2417	2429	2560	2674	2634	2656	2532	2488	2420	2402	2360	2266	2251	2311	2381	2421	2303	2241	2279	2255	2118	1996	2007	2049	2023	2269	2225	2373	2412	2247	2148	1937	1953	1936	1930	2185	2192	2257	2269	1994	2005	1832	1723	1371
■ 5_1 MASSEY		2291		2377		2368		2509		2246		2085		2091		2132		2366		2380		2383		2101		2212		2267		2060		1987		1921		1862		1875		2052		2110		1289		1124
■ 5_2 HENDERSON	3802		4655		4836		4596		4598		4543		4081		4114		4194		3886		3891		3413		2938		2950		4134		4184		3524		3544		3541		3668		3921		2471		2374	
■ 5_3 NEW LYNN	2896		3232		3362		3477		3478		3192		3070		2895		2845		2879		2840		2822		2848		2542		2893		3108		2730		2595		2711		2646		2863		2938		2985	
■ 5_4 WAITAKERE		3301		3626		3731		3638		3531		1965		1635		1632		1903		1630		1327		1282		1263		1265		1307		1255		1242		1594		1188		1269		1407		1287		1288
■ 5_Total LOCAL	6698	1229	1347	1389	1420	1429	1417	1422	1422	1385	1351	1178	1120	1087	1073	1077	1080	1130	1103	1077	1074	1044	9945	9618	9169	9261	8967	9024	1055	1039	1065	1053	9496	9417	9302	9595	9708	9315	9377	9635	1010	1030	8926	7985	7935	7771

Table 10: Sample of rated alligator failures over almost 3 years in the Waitakere region

Source: Fulton Hogan's Monthly report, prepared by ONSITE DEVELOPMENT LTD. 30 April 2013.

Longitudinal and Transverse Cracks (Not Joint Cracks)

These kinds of cracks include longitudinal, or parallel, and transverse cracks along and across carriageways (see Figures 52 - 54). They are usually a type of fatigue cracking and also cause similar problems to the other types of cracks described above.

Furthermore, these kind of surface failures also happen on another kind of pavement, for example, concrete pavement, as was indicated in investigations by Jia-liang and Qing-hua (2012). Replacement of the sub grade caused longitudinal cracks on the newly rehabbed joint concrete pavement, more so than rubblisation and break-and-seat, in a project investigated by them. Non uniform compaction of the replaced sub grade, attributable to diversity of replacing materials, inappropriate moisture, and some construction problems, caused plastic deformation, which caused longitudinal cracks.

Figure 50: Straight longitudinal and transverse cracks

Source: (Pavement Interaction, 2009)

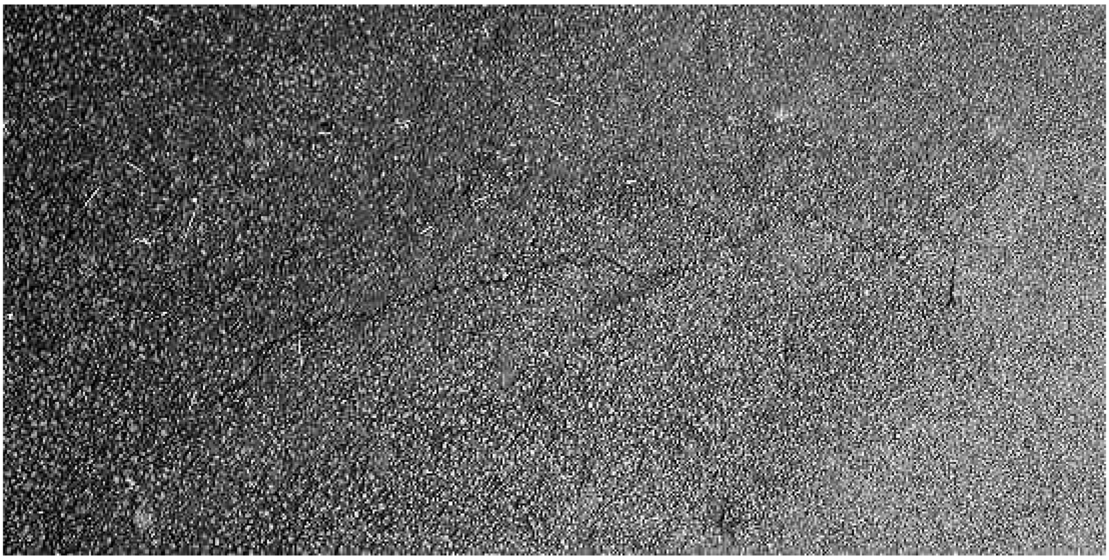


Figure 51: A small irregular longitudinal and transverse crack

Figure 52: Straight longitudinal and transverse cracks

Source: (Transfund New Zealand, 1997)

Possible Causes for Longitudinal Craks

The findings of the investigations by Jia-liang and Qing-hua (2012) indicated that sub grade replacement caused more longitudinal cracks on the newly rehabbed JCP than rubblisation and break-and-seat because it seemed to have caused plastic deformation and non-uniform compaction of the replaced subgrade, attributable to diversity of replacing materials, variances in moisture content of replacing materials, and some problems related to construction. The plastic deformation and non-uniform compaction, in turn, led to uneven settlement of the replaced subgrade and then voids underneath new surface slabs. Also they found that heavy truck traffic was one of the major factors causing longitudinal and transverse (L&T) cracks.

Joint Cracks

Joint cracks almost always happen after repairing the surface of the carriageway. They can be caused by a number of issues, which are:

- Construction joints in asphaltic concrete pavement
- Construction joints in concrete pavements
- Joints between concrete and asphalt pavements

(Transfund New Zealand, 1997)

The joint crack will be rated as a L&T crack if it occurs in a continued surface and if it is a visible joint between two different surfaces; the total length of the crack will be recorded for rating purposes.

Figure 53: Joints along service trenches

Source: (Pavement Interactive, 2009)

Figure 54: Saw cuts that have not been sealed also rate as joints

Source: (Pavement Interactive, 2009)

Figure 55: Joint crack at the edge of a repair

Source: (Pavement Interactive, 2009)

Figure 56: Joint cracking around a patch

Source: (Pavement Interactive, 2009)

Selecting the Best Repair Strategy

Generally, for any kind of crack, an investigation determining the root cause of failure is essential. The offered process for finding the root cause is, digging out a pit or coring the pavement to determine the pavement's structural makeup, as well as determining whether or not subsurface moisture is a contributing factor.

Based on these kind of cracks, some different types of repair strategies have been offered by Fulton Hogan's (2006) manual on sealed pavement maintenance. These are:

If the fault is due to soft sub grade then the pavement design should be checked. A short term repair would be to stabilise the pavement to maintain safety.

If the pavement has cracked and shoved badly a dig will need to be carried out and potential stabilisation of the sub-base prior to adding new base course.

Block cracking due to over cementing will require stabilisation of the sub-base, potentially followed by stabilising the block cracked surface.

For oxidized asphalt, mill the asphalt and re-compact the base.

The Best Repair Strategy

The first strategy for repairing pavement cracks is crack filling. A crack filling repair is a repair to an asphalt mix or a sealed pavement that has cracked due to stress and that crack has travelled across the asphalt or seal on the road.

Cracks can be 2mm to 30mm wide and several metres long. Three different ways for crack repairing are:

1- Emulsion and sand (for cracks up to 5mm wide).
2- Emulsion, sand and cover the crack with a crack seal bandage (for cracks 6mm to 15mm wide).
3- Hot polymer modified binder (for cracks 16mm to 30mm wide) (Fulton Hogan, 2006).

An investigation is essential to figure out the root cause of a fatigue cracked pavement. The following steps need to be implemented.

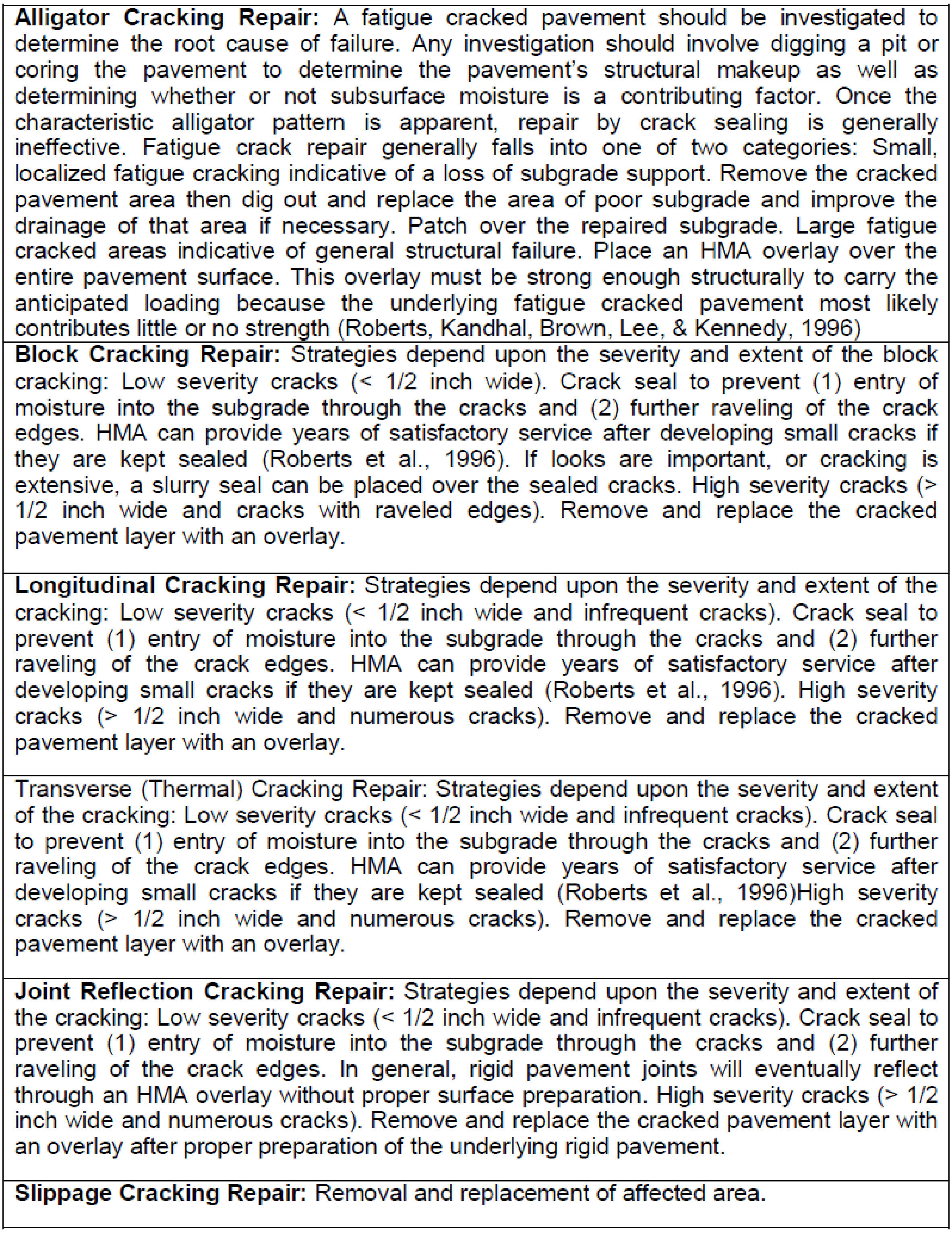
The fault is due to soft sub grade: the pavement design should be checked. A short term repair would be to stabilise the pavement to maintain safety. If the pavement has cracked and shoved badly, it will most likely need a dig-out and perhaps stabilising of the sub-base prior to adding new base-course.

Block cracking due to over cementing will require stabilising of the sub-base. Then look at perhaps stabilising the sub-base prior to adding new base-course.

Oxidized pavement needs to be milled and then the base re-compacted and then followed up with new pavement surface. Meanwhile it is worth mentioning, for low-volume roads, the fog seal is preventive maintenance for this kind of failure and is used to restore or rejuvenate a HMA surface. In some cases it is possible to postpone the need for a BST or non-structural overlay for a maximum of two years.

More detail can be found in Table 11.

Table 11: Brief description of all kinds of cracks repair strategies



Alligator Cracking Repair: A fatigue cracked pavement should be investigated to determine the root cause of failure. Any investigation should involve digging a pit or coring the pavement to determine the pavement's structural makeup as well as determining whether or not subsurface moisture is a contributing factor. Once the characteristic alligator pattern is apparent, repair by crack sealing is generally ineffective. Fatigue crack repair generally falls into one of two categories: Small, localized fatigue cracking indicative of a loss of subgrade support. Remove the cracked pavement area then dig out and replace the area of poor subgrade and improve the drainage of that area if necessary. Patch over the repaired subgrade. Large fatigue cracked areas indicative of general structural failure. Place an HMA overlay over the entire pavement surface. This overlay must be strong enough structurally to carry the anticipated loading because the underlying fatigue cracked pavement most likely contributes little or no strength (Roberts, Kandhal, Brown, Lee, & Kennedy, 1996)
Block Cracking Repair: Strategies depend upon the severity and extent of the block cracking: Low severity cracks (< 1/2 inch wide). Crack seal to prevent (1) entry of moisture into the subgrade through the cracks and (2) further raveling of the crack edges. HMA can provide years of satisfactory service after developing small cracks if they are kept sealed (Roberts et al., 1996). If looks are important, or cracking is extensive, a slurry seal can be placed over the sealed cracks. High severity cracks (> 1/2 inch wide and cracks with raveled edges). Remove and replace the cracked pavement layer with an overlay.
Longitudinal Cracking Repair: Strategies depend upon the severity and extent of the cracking: Low severity cracks (< 1/2 inch wide and infrequent cracks). Crack seal to prevent (1) entry of moisture into the subgrade through the cracks and (2) further raveling of the crack edges. HMA can provide years of satisfactory service after developing small cracks if they are kept sealed (Roberts et al., 1996). High severity cracks (> 1/2 inch wide and numerous cracks). Remove and replace the cracked pavement layer with an overlay.
Transverse (Thermal) Cracking Repair: Strategies depend upon the severity and extent of the cracking: Low severity cracks (< 1/2 inch wide and infrequent cracks). Crack seal to prevent (1) entry of moisture into the subgrade through the cracks and (2) further raveling of the crack edges. HMA can provide years of satisfactory service after developing small cracks if they are kept sealed (Roberts et al., 1996)High severity cracks (> 1/2 inch wide and numerous cracks). Remove and replace the cracked pavement layer with an overlay.
Joint Reflection Cracking Repair: Strategies depend upon the severity and extent of the cracking: Low severity cracks (< 1/2 inch wide and infrequent cracks). Crack seal to prevent (1) entry of moisture into the subgrade through the cracks and (2) further raveling of the crack edges. In general, rigid pavement joints will eventually reflect through an HMA overlay without proper surface preparation. High severity cracks (> 1/2 inch wide and numerous cracks). Remove and replace the cracked pavement layer with an overlay after proper preparation of the underlying rigid pavement.
Slippage Cracking Repair: Removal and replacement of affected area.

Sources: Pavement Interactive, (2009); Roberts, Kandhal, Brown, Lee, & Kennedy (1996)

Pothole

Potholes have been introduced in one article, as follows:

> Small, bowl-shaped depressions in the pavement surface that penetrate all the way through the HMA layer down to the base course. They generally have sharp edges and vertical sides near the top of the hole. Potholes are most likely to occur on roads with thin HMA surfaces (1 to 2 inches) and seldom occur on roads with 4 inch or deeper HMA surfaces. (Roberts et al., 1996)

Figure 57: Pothole

Source: (Pavement Interactive, 2009)

Potholes range in size from 50mm across up to 1 metre across. Depth can vary from 50mm up to 200mm deep in extreme cases. However, the break must have a maximum dimension of 70mm or more to be rated as a hole, as illustrated in Figure 60.

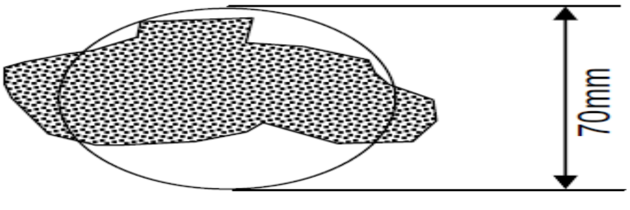


Figure 58: Pothole size

Source: (Transfund New Zealand, 1997)

In addition, the rating for potholes is a count of quantity, however, sometimes a pothole is rated as a pothole patch, where it is less than 0.5m2 in area (Transfund New Zealand, 1997).

Another definition for a pothole provided by Transit New Zealand (1993) is:

> ...where surface attrition has occurred over an area exceeding 70 mm in diameter but not exceeding $1m^2$ in area and the base course aggregate is exposed, or where the defect exceeds 50 mm in depth in structural asphaltic concrete. A pothole shall also be where surface attrition has occurred over an area exceeding 70 mm diameter and the underlying pavement is exposed. This does not include scabbing and stripping on a chip seal (p. 1).

Appendix I and Table 12 show a range of rated potholes for a specific area. It is obvious from these figures that in some roads, with specific usage, the count of potholes that have occured are different.

	May '09	Jun '09	Jul '09	Aug '09	Sep '09	Oct '09	Nov '09	Dec '09	Jan '10	Feb '10	Mar '10	Apr '10	May '10	Jun '10	Jul '10	Aug '10	Sep '10	Oct '10	Nov '10	Dec '10	Jan '11	Feb '11	Mar '11	Apr '11	May '11	Jun '11	Jul '11	Aug '11	Sep '11	Oct '11	Nov '11	Dec '11	Jan '12	Feb '12	Mar '12	Apr '12	May '12	Jun '12	Jul '12	Aug '12	Sep '12	Oct '12	Nov '12	Dec '12	Jan '13	Feb '13	Mar '13	Apr '13
🟦 1 REGIONAL ARTERIAL		7	7	9	2	3	2		1					3	2	2	6	2	1	3																	1	1	1	2		1						
🟥 2 DISTRICT ARTERIAL		22	22	21	7	20	12	13	11	6	26	5	5	9	18	30	30	19	2	5	4				7	6	9	6	6	6		4		1		1		1	6	3	2	2	2		1	2	1	1
🟪 3 DISTRICT ART-SCENIC		2	2	1									1																																			
🟩 4 COLLECTOR-DISTRICT		28	10	12	24	22	19	11		1	2	6	15	13	32	22	19	38	5	13	8	1	3		9	13	32	8	7	3	3	7	1	2	3	6	1	8	6	13	8	1	2					
🟪 5_ 1 MASSEY		11		18		24		11		8		4		2		12		17		14		6		1		9		7		14		3		3		3		3		11		6		6		4		6
🟫 5_ 2 HENDERSON	20		33		45		18		9		30		20		27		45		16		21		9		5		10		14		7		12		4		6		11		9		9		14		2	
🟦 5_ 3 NEW LYNN	13		14		8		15		10		15		8		10		12		13		10		3		7		13		8		5		6		4		7		4		12		3		3		5	
🟪 5_ 4 WAITAKERE		33		43		42		33		5		8		12		18		30		22		5		9		22		18		14		19		11		19		8		22		18		6		2		5
🟦 5_ Total LOCAL	33	77	91	108	114	119	99	77	63	32	58	57	40	42	51	67	87	104	76	65	67	42	23	22	22	43	54	48	47	50	40	34	40	32	22	30	35	24	26	48	54	45	36	24	29	23	13	18

Table 12: Sample of rated potholes failure during 3 years at Waitakere region

Source: Fulton Hogan's Monthly report, prepared by ONSITE DEVELOPMENT LTD. 30 April 2013.

Possible Causes for Potholes

The main cause for potholes is fatigue cracking. Generally, a pothole is the final result of fatigue cracking if the appropriate treatment has not taken place (for HMA surfaces).

When pressure from car tyres pushes the water into the pavement surface, it causes it to blow out the surface aggregates, causing potholes. Therefore, in wet weather potholes grow very rapidly.

Another cause for potholes, which occurs more on sealed surfaces, is flushed bitumen. "The bitumen stuck on the tyres pulls the road surface apart" (Fulton Hogan, 2006, p. 104).

Furthermore, as described in Fulton Hogan's (2006) manual, spillage of all kinds of fuel on the sealed surface will destroy the seal waterproofing specification and also, a blocked nuzzle on the bitumen sprayer will have a considerable impact on situating insufficient waterproofed surface.

Safety Concern

An untreated pothole might cause serious vehicular damage or a crash for crossing cars. Infiltration will also happen on the surface by potholes.

Figure 59: A pothole caused by fatigue cracking

Source: (Transfund New Zealand, 1997)

Figure 60: Potholes in Smithfield Ave, Paremoremo

Source: Fulton Hogan's Monthly report, prepared by ONSITE DEVELOPMENT LTD. 30 April 2013.The Best Repair Strategy

The repair processes start with preparation of the repair area, which includes excavation, trimming the sides of excavations and removing distressed or loose materials. The excavation of the damaged area shall be carried out in such a manner that the integrity of adjacent sections of pavement are not disturbed.

The next step is backfilling the damaged area. The backfilling process depends on the kind of pavement. In granular pavement, for less than 100 mm deep, to ensure bond with the surrounding pavement material, a light tack-coat of emulsion shall be applied to all surfaces in contact with premix material, then should be filled with premix material. A thorough compaction is essential to make a uniform density that does not move under the action of ordinary road traffic.

In granular pavement, when the depth of repair is more than 100 mm deep, backfilling to a level of 50mm below the finished level may be done with base course of nominal maximum size not greater than 0.4 times the layer depth. The remaining 50mm shall be constructed in accordance with the previous pavement design.

In structural asphaltic concrete pavements, the contractor shall select the repair method most appropriate to correct the defect. The following issues should be considered:

> Ragged edges shall not be permitted. Where the defect extends below the depth of the asphaltic concrete, all distressed unbound granular material shall be removed and the base of excavation compacted to provide a firm foundation for replacement materials. Base course aggregate confirming to the requirements of TNZ M4 specification shall be used to reinstate the repair to the underside of the asphaltic concrete. Repair material used above the underside of the structural asphaltic concrete shall conform to the requirement of TNZ M10 specifications.
>
> ...The finished running surface of the repair... shall be waterproof... (and) shall match the general profile of the adjacent surface have no sharp ridges and shall be such that it does not allow water to pond nor is higher

than the adjacent pavement by more than 10 mm when measured by a 2 m straightedge(Transit New Zealand, 1993, p. 3).

Edge Break

Edge break failures appear at the edge of a road's surface. This failure occurs where there is no supporting drainage system, such as surface water channels, or the existing drainage system does not work.

Figure 61: Slight edge break

Figure 62: Moderate edge break

Source: (Transfund New Zealand, 1997)

Figure 63: Edge break

As has been described in Transfund New Zealand's RAMM manual (1997):

> Edge break will be rated if the seal width is reduced by 100mm or more from the nominal edge of seal. The length recorded shall be measured from the start of the taper leading up to the 100mm+ edge break to the point where the broken edge rejoins the line of the nominal seal edge as shown in the diagram and photo below (p. 53).

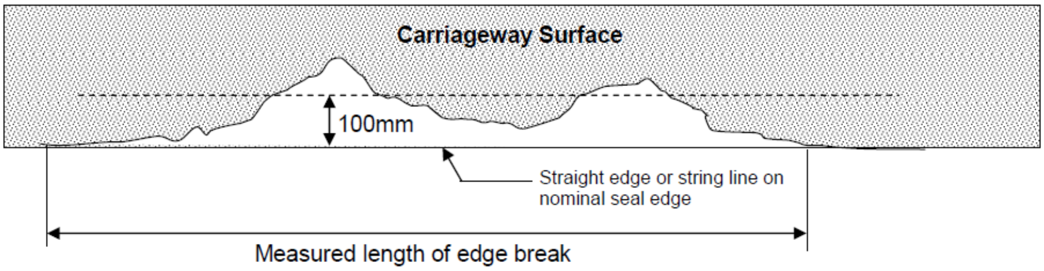


Figure 64: Edge break measurement

Possible Causes for Edge Break

Generally, edge breaks occur due to pressure of vehicle tyres on the edge of sealed or HMA pavements. The pressure is caused by reasons such as:

- Vehicle driving over the edge
- Road is too narrow for two passing cars, therefore, the second car passes close to edge of pavement.
- The support ground has been washed by heavy rain because of lack of vegetation.

The Best Repair Strategy

The edge break repairs need to be carried out to stop the sealed pavement from fretting away and becoming a safety hazard for the travelling public.

As has been indicated by Fulton Hogan’s (2006) manual, for minor edge breaks, normal repair is to use the standard edge break repair methodology. Major edge breaks may require the edge break to be first filled with base course to within 50mm of the top of pavement.

However, in all cases it is essential to check the real cause of an edge break and try and fix the original problem first, then repair the edge break. This may mean that the inside of the curve requires sealing so that vehicles no longer travel over the edge seal.

Ravelling or Scabbing

When chipseal or asphaltic concrete pavement aggregates are separated from a carriageway's surface, it is called scabbing for chipseal or raveling for asphaltic concrete.

The rating process for chipseal and asphalt surface is the same. The pavement will be rated as a scabbed or raveled area when it has lost more than 10% of its surface aggregates. The scale for this rating is in square metres.

Figure 65: A chipseal with greater than 10% chip loss in large areas

Source: (Transfund New Zealand, 1997)

Possible Causes for Ravelling or Scabbing

Some possible causes exist, which are a little different between chipseal, asphalt and other kinds of pavements. Some common reasons for raveling on asphaltic surfaces are as follows.

The first reason is age of the surface. For example for asphalt, age causes asphalt binder oxidation. When the binder gets older, the oxygen reacts with its constituent molecules resulting in a stiffer, and therefore, more viscose material, so it is more likely for the aggregate to separate from the pavement as they are pulled away by traffic. This reason has also been illustrated by Holleran, Wieringa, and Tailby (2006):

> The main mechanisms of aging of bitumen are oxidation and the loss of volatiles. When bitumen ages it becomes higher in viscosity (stiffer) and the composition changes noticeably. These changes can lead to

> brittleness and loss of adhesion, especially in the presence of water (Oxidation products are acidic and can be hydrolyzed) (p. 1).

Dusty aggregate is another problem, because dust does not allow a strong stickiness between the asphalt's binder and the aggregate. Aggregate segregation: if fine aggregate does not exist in the aggregate gradation, the asphalt binder is unable to bind big particles together.

Inadequate compaction: inadequate compaction will cause inadequate cohesion within pavement materials. Inadequate compaction might also cause rutting on the pavement surface, because if the initial compaction has not been sufficient, compaction may be done by car tyre pressure, which means rutting will happen.

Moreover, *"*mechanical dislodging by certain types of traffic (studded tires, snow plow blades or tracked vehicles) *might cause rutting on the pavement"* (Pavement Interactive, 2009, p. 8).

Safety Concern

The raveling or scabbing causes the aggregate to become loose on the pavement. Also water ponding in raveled sections may result in vehicles hydroplaning and finally, loss of skid resistance.

The Best Repair Strategy

Selecting the best repair strategy is up to determining the root cause of failure. Generally two categories exist for repairing raveled pavement.

The first is for small, localised areas of raveling. Remove the raveled pavement and patch. If the pavement is still structurally sound, the raveling can be fixed with a fog seal or slurry seal. Secondly, large raveled areas are indicative of general HMA failure. Remove the damaged pavement and overlay (Mamlouk & Zaniewski, 1998; Pavement Interactive, 2009).

Flushing (Bleeding)

Where the bitumen or binder comes up and covers the surface of the aggregate on the road, it is called flushing or bleeding. The specifications of a flushed area are generally a flossy and smooth appearance, as well as lack of surface texture and skid resistance when wet.

The rating method for flushing is in metres, where the surface is affected by flushing.

Possible Causes for Flushing (Bleeding)

The possible causes have been described by Pavement Interactive (2009). Bleeding occurs when asphalt binder fills the aggregate voids during hot weather or traffic compaction, and then expands onto the pavement surface. Since bleeding is not reversible during cold weather or periods of low loading, asphalt binder will accumulate on the pavement surface over time. Flushing often results in surface irregularities (Brewer, 2007)

Likely causes are:

- Excessive asphalt binder in the HMA (either due to a poor mix design or manufacturing problems).
- Excessive application of asphalt binder during BST application.
- Low HMA air void content (e.g., not enough void space for the asphalt to occupy), likely a mix design problem.

In the case of chip seal, Ball and Patrick (2005) described that: "there is a maximum compaction level for any particular multilayer chip seal with a corresponding void content; if the total binder content is greater than this, then flushing will eventually occur" (p. 9).

Figure 66: Carriageway with extensive flushing on the wheelpath's surface

Source: (Transfund New Zealand, 1997)

The Best Repair Strategy

The following measures may improve or decrease the flushing but cannot repair an underlying problem. Therefore, the best choice is to find and repair the underlying problem that initially caused the flushing.

For a minor bleeding correction coarse sand can usually be applied to blot up the excess asphalt binder.

Major bleeding can be corrected by cutting off excess asphalt with a motor grader or removing it with a heater planer and then replacing a new layer by overlying the area with a seal coat or hot planet mix having a suitable asphalt content, or planing the area. If the resulting surface is excessively rough, resurfacing may be necessary (Brewer, 2007; Pavement Interactive, 2009).

High and Low Service Covers and Trenches

Service covers that are too high or too low cause vibrations that may annoy nearby landowners and cause discomfort to the travelling public. They can also be a safety hazard (Fulton Hogan, 2006).

For the purpose of rating service covers (hydrants, manholes, etc), the number of service trenches that are lower or higher than the carriageway surface need to be recorded. Figure 69 shows an example of this failure.

Figure 67: High service cover

Source: (Transfund New Zealand, 1997)

The Best Repair Strategy

The repair process starts by finding all out of specification service covers and preparing a schedule for starting repairs. The stages are:

- Cut around it with a concrete saw to create a straight edge and tidy appearance.
- Dig out materials where a riser/ adjusting ring will be placed.
- Compact around the outside of the pipe.
- Reseat cover to level and profile
- Backfill with basecourse
- Reinstate surfacing
- Apply road marking
- Use temporary traffic management

2.7.8 Treatment Application

The process of treatment starts with defining initial treatment lengths by finding the widest surfaces within each road split in:

- ADT

- Number of lanes
- Pavement type
- Pavement use
- Urban/Rural flag

It is important to split the treatment length to the same subsections.

2.7.9 Preparing Reseal List

It is clear that when preparing a reseal list, one of the most important issues in terms of sufficiency and productivity, is to have a good knowledge of all kinds of failures and offered treatments. Investigation of successful companies in the field of road maintenance and rehabilitation processes showed that almost all of them have achieved this issue by preparing a database. This allows the expert to access a huge resource of monitored, implemented projects and also use previous experiences to provide a productive method of project implementation. In addition, developing and recording appropriate pavement maintenance solutions, particularly, for the project area network, is the most important issue, because the offered solutions vary depending on a number of factors such as:

- "Traffic Loading- particularly the percentage of heavy vehicle traffic.
- Climate
- Drainage systems
- Season
- Geology
- Terrain
- Other Local Characteristics" (Fulton Hogan, 2006, p. 13).

To generate a database, it is important to mention all kinds of road failures and treatment performances. It would be useful to categorise maintenance implementation in four main sections:

- Edge break repair
- Pothole repairs
- Crack filling repair
- Heavy duty pavement maintenance

One of the main causes for pavement failure, which needs heavy duty pavement maintenance, is water entering the pavement layers; therefore, effective drainage is the first step for preventing future failures and also for repairing current defects. Figures 70 and 71show a positive drainage system that has been used for repairing damage caused by water leaking.

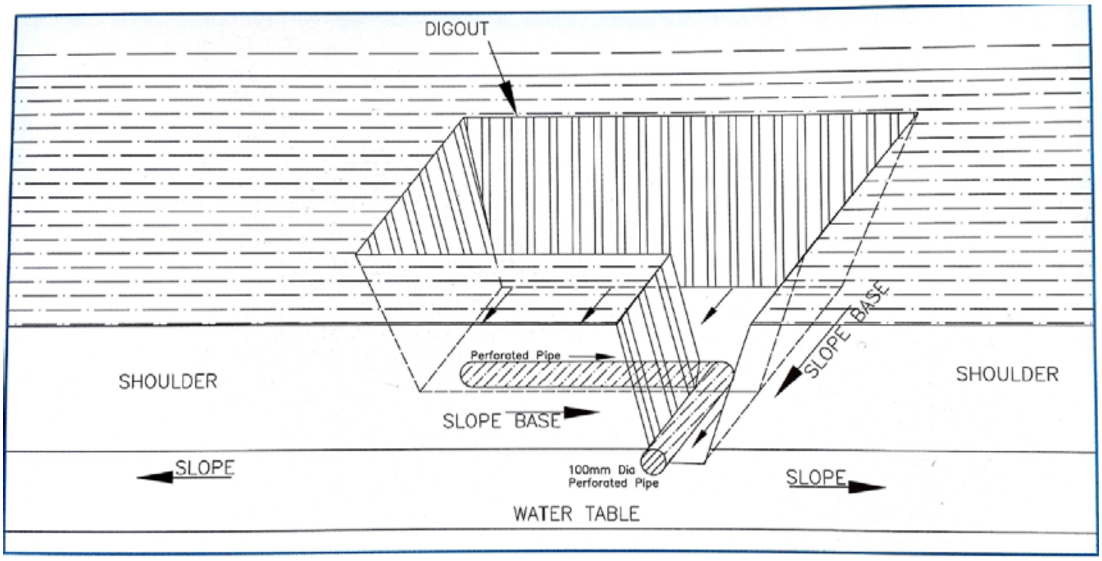


Figure 68: Positive drainage, 3D diagram

Source: (Fulton Hogan, 2006)

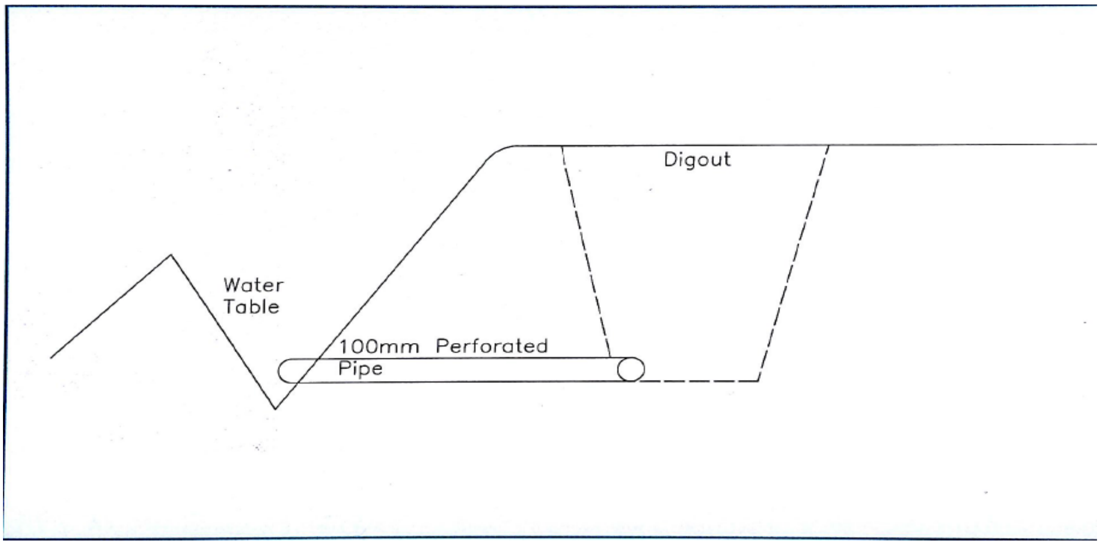


Figure 69: Positive drainage, cross-section

Source: (Fulton Hogan, 2006)

2.8 An Introduction of RAMM Software

Road owners, contractors, and consultants in New Zealand have been using RAMM software for storing data and decision making. RAMM has been used by all parties that are involved in New Zealand's roading sector, and it has been the benchmark for road asset management software in New Zealand for over 25 years. It is now used in Australia. The capability of transferring information between RAMM Contractor and RAMM databases enables both the contractor and the network owner to have productive contract management (Mackenzie, 2011).

The most important subsection of this software, in relation to road maintenance management, is RAMM Contractor. RAMM Contractor is highly operational software with the following functions, which makes it effective software for improving productivity in road maintenance and rehabilitation management. RAMM Contractor provides productive and sufficient management for road maintenance and rehabilitation projects by facilitating the following processes (Mackenzie, 2011):

- Job management
- Monthly works program
- Monthly claiming
- Contract history
- Reporting and analysis
- Staff contract permissions

2.9 Introducing RAMM Pocket Software

The best definition for RAMM Pocket has been written by Mackenzie (2011):

> Pocket RAMM is the module of the suite of products which enables a user to run RAMM on a notebook, laptop, tablet or PDA, and to perform Contract, Inventory and Claim management while mobile, in the field. Virtually all of the everyday maintenance ability of RAMM Contractor is present in Pocket RAMM (p. 21).

2.10 Model of Productivity Constraints in a Road Maintenance Project

To improve productivity in the road maintenance and rehabilitation process, the key constraints need to be identified so the available resources can be directed at eliminating, mitigating or transferring the risks involved.

Some studies have been conducted in the past to identify productivity constraints, or ways of improving productivity in the roading sector. For instance, Gill and Zuccollo (2012) argue that the first step to improving productivity is to have a common national performance framework/ benchmark. Other measures include the following:

- Having common data protocols
- Having agreed common standards on levels of service
- Improved data infrastructure to enhance data input and user access
- Focus upon measuring the effectiveness of road maintenance interventions
- Learning through communities of practice
- Enhancing the capability of people to work in a different way
- Support by leadership, engagement, focus and commitment.

In the specific aspects of urban pavement maintenance and rehabilitation, Lee and Ibbs (2005) argued that one key constraint to productivity and performance was heavy traffic. Therefore, integrating pavement materials, design, construction logistics and minimising the maintenance impact on traffic flow are clearly essential. Lee and Ibb’s (2005) findings also indicate that for high volume urban freeways, exploring the most economical rehabilitation strategies is essential. These could be accomplished through the following approaches:

- The pavement should have a service life of at least 30 years. To achieve this goal, thinner structural sections, materials and curing times should be reduced to shorten construction time without sacrificing quality and performance.
- Construction schedules should be fast and should focus on minimising traffic delay impact without sacrificing construction productivity.

- Traffic delays resulting from construction closures should be minimised.

Lee et al. (2007) further reported that nighttime productivity was affected by traffic volume, type of work, material delivery, lighting, supervision, communication, and worker morale.

Furthermore, Dunston et al. (2000) compared production rates achieved during a project using full weekend closure with those documented for a similar project using nighttime closures. They observed that higher average shift production rates were achieved using a full weekend closure strategy that allowed a longer period of uninterrupted work. The works of Lee et al. (2007) and Dunston et al. (2000) showed that traffic volume was one of the most important constraints against productivity, beside other factors.

One constraint that has a huge impact on productivity during nighttime rehabilitation or maintenance is lighting. "Surprisingly little research has been done on the subject of lighting for nighttime construction. Having determined lighting to be one of the most important elements of nighttime construction" (Dunston et al., 2000, p. 8).

From a different perspective, Talvitie and Sikow (1992) investigated the role of proper equipment for road pavement maintenance on productivity. They argued that efficient, high-capacity machines would be idle in small projects, whereas many small machines would be in each other’s way for small project, and would also be too slow for big scale projects. The second issue around machine capability is the ability and skill of the machine operators.

Another obstacle against productivity is major resource constraints that are limiting the production capabilities of urban pavement rehabilitation (Lee et al., 2002).

From a design perspective, Ball and Patrick (2005) found that in New Zealand, roads surfaced with chip seal fell below expected lifespan. Approximately 30% of state highway chip seal surfaces failed through flushing before they reached half their expected lifetimes, and some 5700 km (50%) showed significantly reduced seal lifetimes because of flushing. Flushing was also a major cause of seal failure in urban areas.

To address this constraint, refining the designed plans through the use of new materials is a cost effective option for achieving productivity. For example a new product such as GSB-88 Sealer/Binder pavement preservation can control corrosion and sustainment of road pavement (Cline, 2009).

Generally, New Zealand focused investigations could provide new insights on the constraints that impact the capacity and productivity of road maintenance and rehabilitation, and could provide alternative strategies and processes for pavement maintenance. This research therefore, focused on addressing factors that have influenced road maintenance productivity based on the point of view of experienced people who are working in this field.

As a starting point for the investigation, the following model of broad internal and external productivity constraints, which were found in the literature, will be used and subsequently modified with the empirical data from the pilot interviews and quantitative surveys.

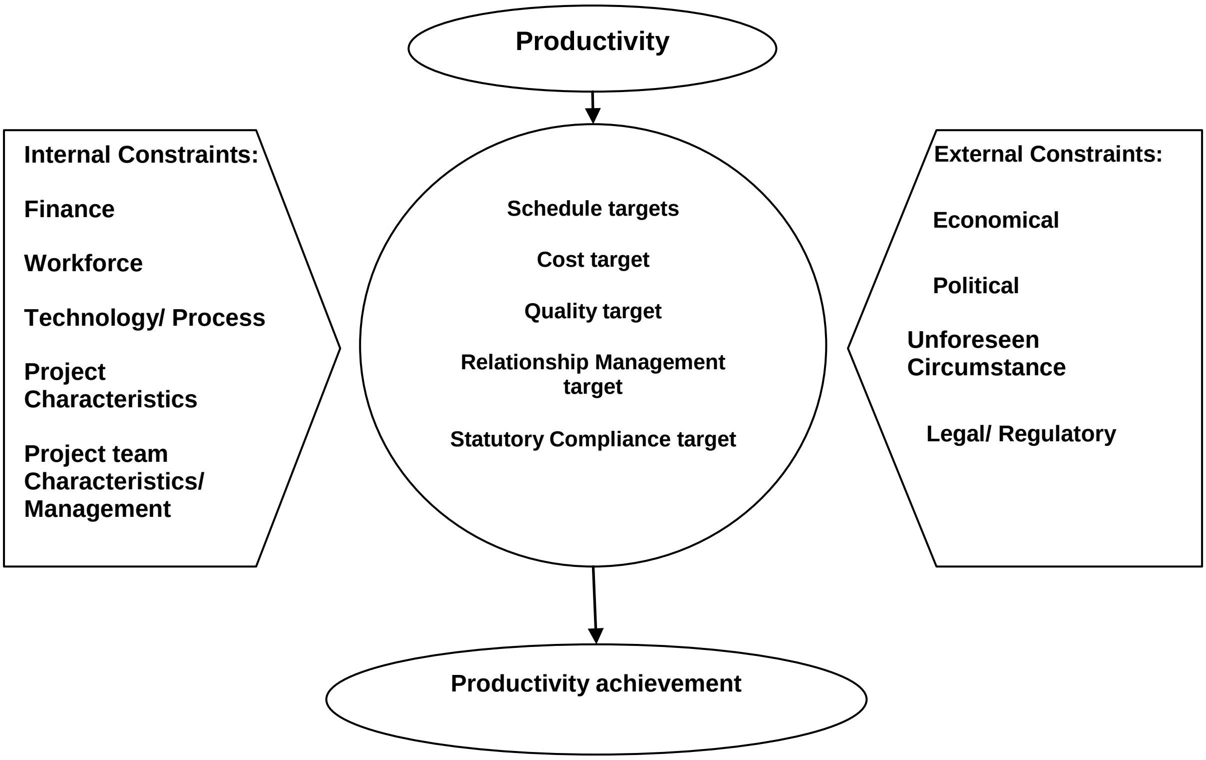


Figure 70: Holistic model of productivity constraints

The above model (Figure 72) has provided insights into the key criteria for productivity measurements and the anticipated principal external and internal constraints. The relevance of the identified constraints to the New Zealand roading sector were explored in the qualitative and quantitative surveys.

2.11 Summary of the Review of Literature and Knowledge Gap

This chapter has provided insights into the road pavement maintenance and rehabilitation process, the key constraints to, and the improvement measures for productivity and performance in the process.

The chapter aimed to provide answers to the research objectives as gathered from the literature. It also aimed to link the current study to previous research in this area, as well as identify the gaps in the existing body of knowledge on the topic, and how these could be filled.

In addition, it has tried to provide general information about the road maintenance implementation process in New Zealand by exploring different road pavement failure mechanisms and treatment approaches.

Overall, it was found that information on the road maintenance and rehabilitation process, the key constraints to, and the improvement measures for productivity and performance in the process, relate to overseas countries. Little or no research has been carried out to gain insights into the peculiarities of the issues as relating to the New Zealand roading sector. Through case study and questionnaire surveys, this study aimed to contribute to filling the identified knowledge gap by exploring specifics about the New Zealand road pavement maintenance and rehabilitation process, and productivity constraints and improvement measures.

Chapter 3. RESEARCH METHODOLOGY

3.1 Overview

This section aims to introduce the research methodology that has been used in this study. It presents the steps followed in the implementation of the research, from concept phase to completed phase. Figure 73 shows these steps in a flowchart. This chapter also provides information about data gathering and methods for analysing the data. The research program shows the schedule for the tasks that provided a baseline for the monitoring process. Compliance with ethical requirements for the research is also highlighted.

3.2 Research Design

The research adopted a mixed method involving a first stage of qualitative data gathering through pilot interviews and a second stage of data gathering through a questionnaire survey. The first stage qualitative data gathering was based on grounded theory. As recommended by Corbin and Strauss (2008), grounded theory helps researchers to drive a general, abstract theory of a process, action, or interaction, grounded in the views of participants in a study. Therefore, this framework was adopted to provide guidance about all facets of the research. Information gathered from the interviews and the literature was used to design an open-ended questionnaire for gathering quantitative data. The aim the open-ended survey was to give survey participants the opportunity to provide further constructs over and above those established during the qualitative survey, or to make further comments about issues of interest.

3.3 Qualitative Survey

To identify where productivity constraints arise in the roading maintenance sector in New Zealand, nine pilot interviews were scheduled. The target population was chosen from those of Fulton Hogan's managers who occupied various managerial roles within the maintenance sector. As much as possible, the managers were chosen based on their background experience of working with other organisations, such as the NZTA or other consultants. This helped to gather points of view of other parties involved in road maintenance. The Interview questions were designed to be open ended, allowing the participants to share their experiences in connection with the questions asked. The constructs generated during the pilot interviews were used to design the questionnaire for the quantitative survey.

3.4 Quantitative Survey

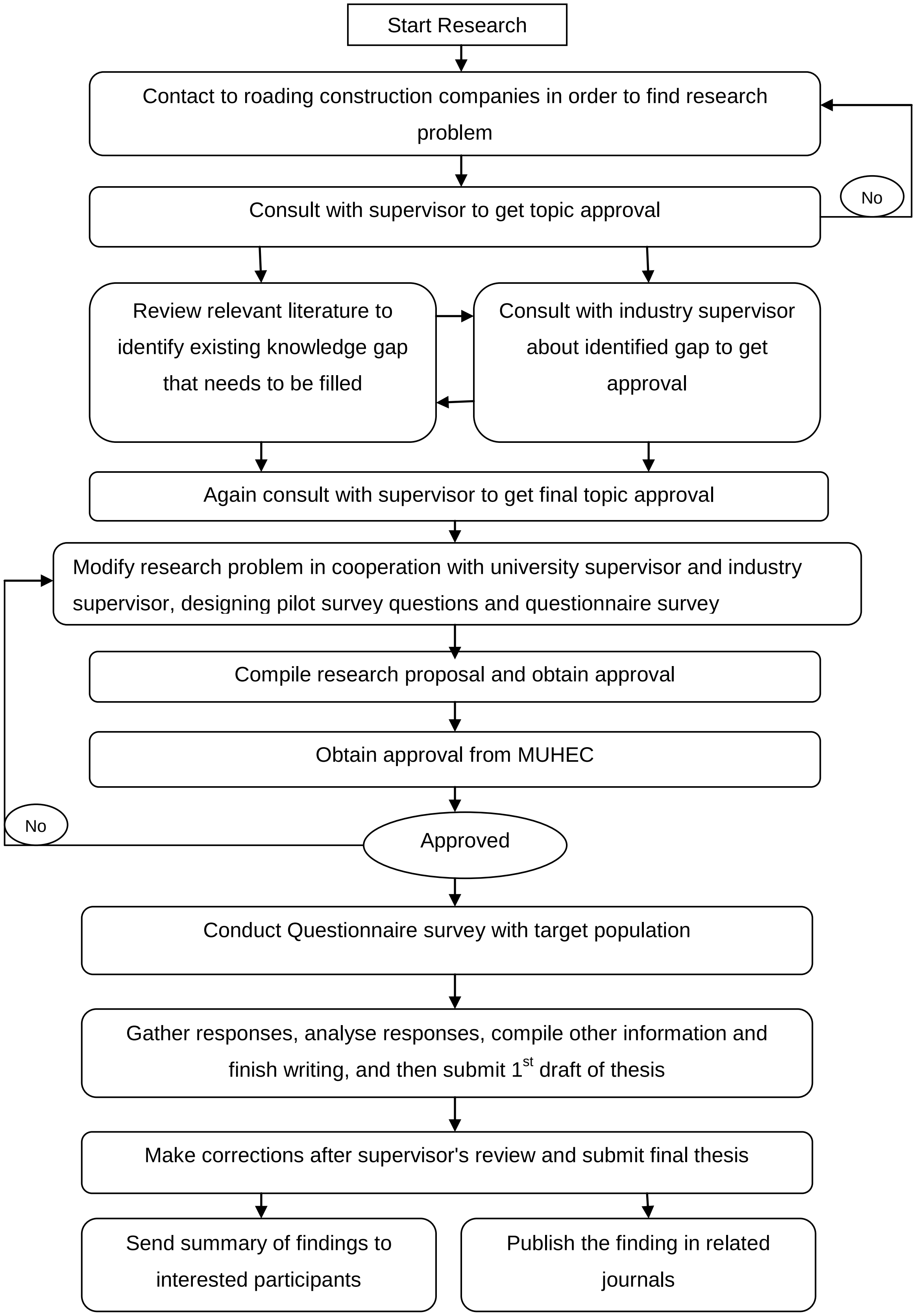
The questionnaire survey was hosted on the SurveyMonkey server- a web-based survey platform. The survey participants were invited to respond to the online survey through links in the emails sent to them.

The questionnaire was designed based on two broad categories of constraints: internal constraints and external constraints. The external and internal constraints included some sub-constraints. Respondents were asked to rate the relative levels of impact of the identified constraints on a 5-point Likert scale (Maurer & Pierce, 1998). This allowed the participants to rate, based on their experiences in the road maintenance sector in New Zealand.

3.5 Flowchart of the Research

Figure 73 shows the process followed in carrying out this research. This consisted of 15 inter-related steps. Identifying the research problem was the first step. This was followed by another 14 steps and finally finishes with publishing the findings and sending a summary of the research findings to participants, in keeping with the pledge made to them as a reward for participating.

Figure 71: Flowchart of the process of the research project from conception to completion



3.6 Target Population

Selecting a target population of participants for this research comprised two stages. The first stage was finding a target population of companies that were involved in roading maintenance contracts in New Zealand. The second phase involved finding managers or staff with highly professional backgrounds who were working in the selected companies.

3.7 Sampling Frame for the Study

In the absence of a database or organisation for the target population, an online search through the Yellow Pages was adopted to establish the sampling frame for the study. The search phrases comprised “road pavement maintenance”, “road pavement rehabilitation”, “road contractors”, “highway contractors”, “highway consultants”, “road construction companies in New Zealand”, “roading consultants in New Zealand” and similar search phrases. In total, the 38 consulting and contracting firms that came up as being involved in road pavement maintenance and rehabilitation in New Zealand formed the sampling frame for the study.

Due to the limited number of subjects in the sampling frame, a census survey was carried out by inviting all of them to participate in the survey. This ensured that each subject had an equal opportunity of participating in the survey.

3.8 Data Analysis

The multi-attribute analysis method was recommended by a number of studies (Durdyev, 2011; Mbachu & Nkado, 2006), as the appropriate method for analysing responses from respondents who rated attributes of various dimensions in a questionnaire survey based on the Likert rating scale.

Mean rating point (MRP)

The aim of the multi-attribute analysis was to compute the mean rating point (MRP), which could be taken as the representative rating point for a group of respondents rating the variables under a particular subset (Mbachu & Nkado, 2006). This was particularly important for understanding the group's consensual rating, since the respondents associated different rating points to the variables based on their perceptions of the relative importance or relative weights of the variables. Mbachu and Nkado (2006) provided an expression for computing the mean rating point (MRP) as shown in Equation 1.

$$\mathrm{MRj} = \sum_{\mathbf{K=1}}^{\mathbf{5}} \left(\mathbf{R_{pjk}} * \%\mathbf{R_{jK}}\right) \qquad (1)$$

Where MRj= Mean Rating for constraint factor *j*, =Rating Point k(ranging from 1-5), and = Percentage Response to rating point *k*, for constraint factor *j.*

Relativity index (RI)

Further to the mean rating point, Mbachu and Seadon (2013) and Mbachu and Nkado (2006) provide the relativity Index (RI) for evaluating the relative contributions of a set of subcomponents to the component level outcome. This was computed as a unit of the sum of mean ratings (MRs) of the subcomponents within a set of variables. Equation 2 is an expression of the RI.

$$RI_j = \frac{MR_j}{\sum_{j=1}^{N} MR_J} \qquad (2)$$

Where: R_j = Relativity index for the j^{th} subcomponent in a set. This could also be expressed as a percentage. MR_j = Mean rating for the *jth* subcomponent computed using Equation 1.

Rating scale

Mbachu and Nkado (2006) argued that the 5-point Likert rating was the most appropriate rating scale for survey responses, adding that a fewer point rating scale would fail to properly discriminate the priority levels of the subcomponents, while a larger rating scale would be too cumbersome for respondents. In addition, they (2006) argued that a 5-point or less rating scale does not need re-scaling from an ordinal to an interval scale using Correspondence Analysis for the purpose of performing mathematical computations on the ratings. Mbachu and Nkado (2006) provided the rescaled version of the ordinal rating points into 5 band interval rating, as shown in Table 13, for use in interpreting the results of the multi attribute mean rating analysis, and the prioritisation of the analysed variables in a subset. The table shows that any variable that receives a mean rating point below 2.60 out of the 5-point maximum should be considered as insignificant.

Table13: Rescaling 5-point ordinal Likert scale to 5 band interval rating for interpreting multi-attribute analysis outcome

Ordinal 5-point rating		Rescaled Interval rating band		
Rating point	Nominal interpretation	Min	Max	Significant level
5	Very high	4.20	5.00	Significant
4	High	3.40	4.19	
3	Moderate	2.60	3.39	
2	Low	1.80	2.59	Insignificant
1	Very low	1.00	1.79	

[Interval rating band: 'Very high' (4.20 – 5); 'High' (3.40 – 4.19); 'Moderate/ average' (2.60 – 3.39); 'Low' (1.80 – 2.59); 'Very low' (1.00 – 1.79)]

3.9 Research Model

The research investigation process started with finding the key constraints in the New Zealand road maintenance sector through an in depth review of literature. The identified constraints were categorised into internal constraints and external constraints. Furthermore, the internal constraints comprised 44 sub-factors, while the external constraints comprised 17 sub- factors. Figure 75 (in the following chapter) shows all the factors and sub-factors.

In order to evaluate and analyse the level of impact of each sub-factor on road maintenance productivity, a Likert rating was used. This helped to identify the relative levels of impact of the constraints as the basis for their ranking.

3.10 Research Schedule

The scheduled timeframe for the execution of the different stages of the research is shown in appendix C.

As illustrated, the forecast for the final completion of the study was around late February, 2014.

3.11 Ethical Clearance for the Research

Based on the requirements and policy of Massey University, before obtaining research data, permission to undertake the research was applied for. The application was made and approval given by Massey University's Human Ethics Committee (MUHEC). Appendix B presents the Low Risk Notification approved for the study.

Chapter 4: DATA PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

4.1 Overview

The objectives of this study were in two parts. The first part looked at the process of road maintenance and rehabilitation process in the New Zealand roading sector.

The second part aimed to establish where the key challenges lay and where efficiencies could be improved in the process of road pavement maintenance. The second part was addressed through a two stage primary data gathering process that comprised pilot interviews and questionnaire surveys as explained in the Methodology chapter.

The aim of this chapter is to present and analyse the data obtained from the pilot study and questionnaire surveys. The following subsections therefore present the analysed primary data and discussion of the results in relation to the research objectives.

4.2 Pilot Interview Results

Pilot interviews were conducted with a convenience sample of 9 interviewees, as explained in the Methodology chapter. The interviewees comprised two design and project management consultants, four contractors, one client and two subcontractors. As stated in the Methodology chapter, the aim of the pilot interviews was to establish the key constraints that have an effect on productivity in road maintenance and rehabilitation. Constructs generated at the pilot interviews were used to design the questionnaire for the second stage quantitative survey.

4.3 Interviewees' Understanding of the Concept of Productivity

The interviewees' understanding of the concept of productivity in the road maintenance and rehabilitation sector was first assessed by asking them to freely define the concept, in line with their everyday usage in practice. Content and thematic analysis was used to analyse the recurring themes in the interviewees' feedback. Generally, the following components of the concept were mentioned, or alluded to, by the interviewees in their definitions:

- Speed of construction
- Achievement of cost target/ budget
- Quality of construction; compliance with specifications
- Waste minimisation
- Optimum resource utilisation
- Minimisation of idle times
- Efficiency
- Client satisfaction
- Safety in construction

The above constructs constitute the concept of productivity as defined in the literature review, namely, a measure of the extent to which the set targets have been achieved on a project; the targets being cost, time and quality. The constructs such as client satisfaction and safety also constitute Mbachu and Seadon's (2013) 'sundry' measures of productivity. Surprisingly, there was no mention of environmental impact or sustainability as a component of productivity, despite global concerns about these aspects. Perhaps, the reason behind this gap would be worthy of investigations in further research.

4.4 Road Maintenance and Rehabilitation Process

The first objective of the study was to investigate the road pavement maintenance and rehabilitation process in the New Zealand roading sector, and the criteria that inform the maintenance and rehabilitation decisions. During the investigations, while undertaking a case study with Fulton Hogan, a 12-step process was found. The details are summarised in Figure 75 and explained in the following subsections.

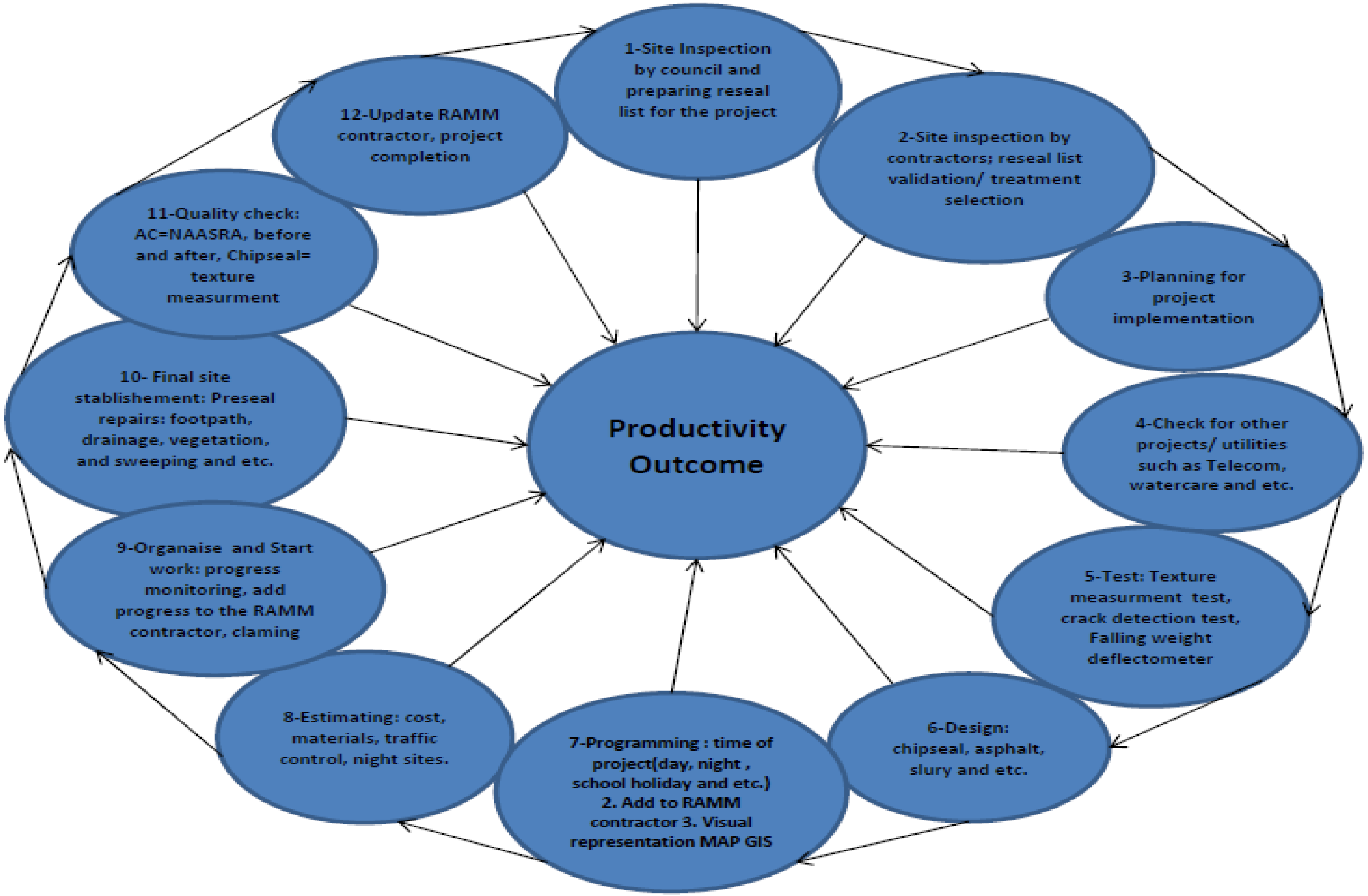


Figure 72: Road pavement maintenance and rehabilitation process in New Zealand

Step 1: Inspection by Road Controlling Authority

The first step in the road pavement maintenance and rehabilitation process is a field inspection by the Road Controlling Authority in conjunction with the NZTA. The aim of the inspection is to identify the condition of the road pavement and formulate the appropriate Maintenance Intervention Strategy (MIS). The MIS is a statement that describes the types of normal maintenance activities that are appropriate given the planned future capital works and renewal goals. The key objective is to communicate the normal maintenance intent to contractors selected for the works execution. The inspections are informed by the Forward Work Programme (FWP) of the NZTA. The FWP records the predicted maintenance treatments required for each road section treatment length. The program indicates the year in which treatment is planned and the key reason for the design to establish a particular treatment at any point in time (Transit New Zealand, 2000). The outcome of the inspections is a list of up-coming maintenance or rehabilitation that will be needed in each road section. Contractors will use the list as a starting point for the next action step.

Step 2: Inspection by the contractors

Depending on the procurement system in place and the way responsibilities are allocated, the second step is the site inspection by contractors. The aim at this stage is to evaluate and validate the maintenance and rehabilitation list proposed by the council. List evaluation gives contractors the opportunity to have detailed planning and designing as described in the following steps.

Step 3: Planning for project implementations

Obviously, planning plays a crucial role in improving final productivity outcomes in the road pavement maintenance and rehabilitation process (Wambold et al., 1982).

Planning for a maintenance or rehabilitation project will be provided based on the outcome of the evaluation of the council’s list by the contractors. The planning involves a consideration of the road network system, which needs a long term program for regular inspection of the road condition and for gathering information to make productive maintenance strategies. The level of accuracy of the evaluation and planning exercises can guarantee or mar the success of project implementations, achievement of acceptable results, and the level of productivity and performance on the job.

Step 4: Check for underground utilities and other upcoming projects

The next stage is to locate and re-direct any underground utilities within the sections mapped for rehabilitation. The programs of other infrastructure service providers, such as Watercare, Transpower or Telecom, need to be checked to avoid potential conflict, delay and disruption during the proposed maintenance and rehabilitation period in a given area.

Step 5: Tests

This step is essential for providing data and information for appropriate and cost effective designs and project implementation. The most important tests include texture measurement, crack detections and the falling weight test. Based on the results of these tests, a decision will be made on whether to maintain or rehabilitate the failed road section, and what sort of maintenance or rehabilitation is needed. A complete review of the various tests is provided in Chapter 3.

Step 6: Design and specifications

The sixth stage is the design and specifications that underpin the quality assurance for the road pavement maintenance and rehabilitation project. At this stage the contractor provides designs, plans and specifications based on the evaluated list, test results and other influential issues, such as road hierarchy, and the kind of and reason for the road section failures. The designs, plans and specifications detail the kind of treatment and appropriate materials, plant, equipment and workmanship to be used in a maintenance or rehabilitation work, to meet the quality standards specified for the road section in accordance with New Zealand regulations, as stated in the NZTA'S State Highway Asset Management Manual (SHAMM). The design stage has a huge effect on productivity because it sets the stage for the implementation process. Wrong design assumptions or uneconomic designs could constrain productivity outcomes.

Step 7: Programming and scheduling

At this stage, all road maintenance and rehabilitation works being handled by the contractor need to be properly planned for, and scheduled together, to provide performance measurement benchmarks, ensure optimum use of available resources, and to integrate the works of other subcontractors. Modeling is often required, which provides a forward works program for the contracting organisation. This must be created and regularly updated, describing maintenance activities and financial forecasts. The model of pavement performance evaluations is a significant part of productive planning. Road Asset and Maintenance Management (RAMM) is the main software used in New Zealand for undertaking planning and modeling work. The integrative software is used by all parties, such as the council, consultants, contractors and subcontractors, involved in a project.

Step 8: Cost and quantity estimation

Following the completion of the design, specification and planning processes, a cost and quantity estimation is undertaken. This stage has a very important influence on productivity outcomes, as it sets the budget or cost plan, for the proposed maintenance or rehabilitation work. If not properly done, it will lose its potential as a benchmark for cost performance and the cost target may not be realised. The quantity estimation and costing is done by the quantity surveying department of each contracting company. It involves a thorough estimation of the direct costs of materials, labour and plant, and the indirect costs of project overheads, an appropriate contingency provision for risks, and the contractors' profit margin for the job. The accuracy of this step helps to increase productivity and minimise wastage of materials, money and resources.

Step 9: Project organisation, implementation and monitoring

This step marks the commencement of the project implementation. First, the organisation required for the project execution is set up, involving the recruitment and procurement of the appropriate workforce, materials and equipment for the job. The project plan would have specified the sequence of the work, the responsibility allocation and the expected completion time for the set milestones, and for the overall project. The scale of the organisation and the reporting framework that is needed depends on the size and complexity of the job, as determined by the nature of the failures to be addressed in the project.

The next issue, which is quite important at this stage for measuring productivity and performance in the project, is progress and performance monitoring. Monitoring is aimed at detecting any significant deviations from the project plan, the immediate and remote causes and the necessary intervention measures to bring the project on track. Proper monitoring will ensure that the project is completed on target, within budget and to the desired quality level. The plans may be revisited to align with real life constraints experienced during the implementation stage.

Step 10: Pre-seal repairs and preparations

After the pavement design, the next stage starts by preparing the site for the proposed maintenance. Preparation includes evaluation of the integrity of the footpath condition, checking drainage, vegetation, signage, clearing detritus, and sweeping the ground.

Also at this stage, contractors will submit claims for works duly completed. Interim payments will be made for approved works that comply with the contract terms and conditions and the specified quality standards.

Step 11: Final quality checks

Final quality check comes after project completion. Different tests are used for the quality checks based on the specified characteristics of the repaired pavement. The regular test for asphalt in New Zealand is the NAASRA Roughness Count, which is routinely implemented during and after project completion. Essentially, the test provides a good objective measure of the surface characteristics of the completed road pavement in terms of the ride quality experienced by a passenger car occupant (McLean & Ramsay, 1996). Another test is texture measurement, which is used for measuring the texture quality of the applied chip seal.

Step 12: Update RAMM Contractor/ Project completion

The final stage involves updating the maintenance data maintained in RAMM Contractor for the completed road pavements. Once a project is finished, asset managers update all information about a project by importing new information into the RAMM software. This stage is also essential, with a huge impact on decision making for up-coming projects. The information informs the planned and preventative road pavement maintenance/ rehabilitation program for the future.

4.5 Constraints to Productivity in the Road Maintenance and Rehabilitation Process

The interviewees' feedback on the constraints to productivity in the road pavement maintenance and rehabilitation process were analysed, using content analysis, as described in the Methodology chapter. Results show that the constraints could be categorised into internal and external groupings as follows:

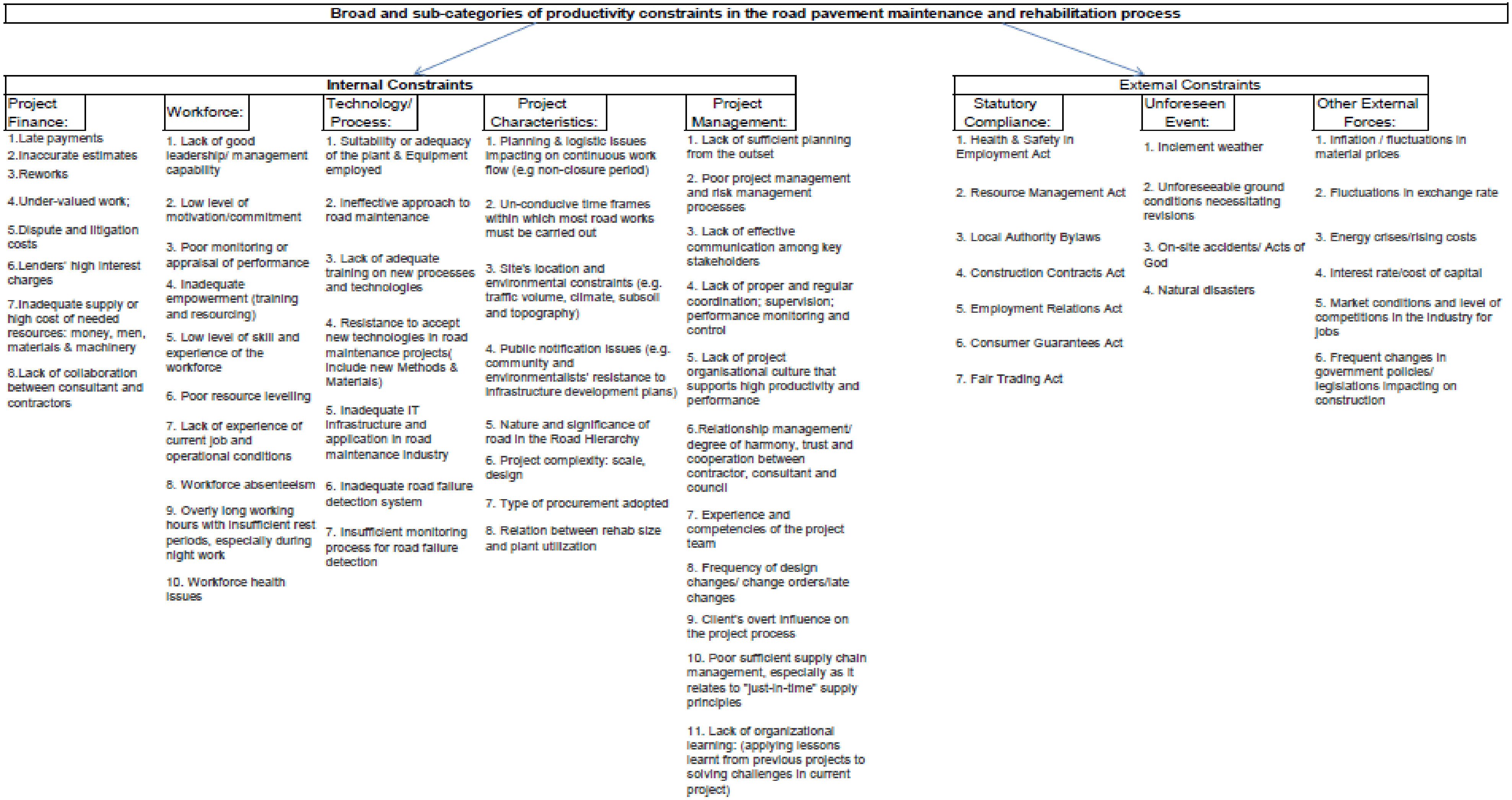
Internal constraints

- Project finance
- Workforce
- Technology and process
- Project characteristics
- Project management

External constraints

- Statutory/ regulatory compliance
- Unforeseen events
- Other factors

The subcomponents of the above broad categories are modeled in Figure 75.



Broad and sub-categories of productivity constraints in the road pavement maintenance and rehabilitation process

Internal Constraints

Project Finance:
1.Late payments
2.Inaccurate estimates
3.Reworks
4.Under-valued work;
5.Dispute and litigation costs
6.Lenders' high interest charges
7.Inadequate supply or high cost of needed resources: money, men, materials & machinery
8.Lack of collaboration between consultant and contractors

Workforce:
1. Lack of good leadership/ management capability
2. Low level of motivation/commitment
3. Poor monitoring or appraisal of performance
4. Inadequate empowerment (training and resourcing)
5. Low level of skill and experience of the workforce
6. Poor resource levelling
7. Lack of experience of current job and operational conditions
8. Workforce absenteeism
9. Overly long working hours with insufficient rest periods, especially during night work
10. Workforce health issues

Technology/ Process:
1. Suitability or adequacy of the plant & Equipment employed
2. Ineffective approach to road maintenance
3. Lack of adequate training on new processes and technologies
4. Resistance to accept new technologies in road maintenance projects(Include new Methods & Materials)
5. Inadequate IT infrastructure and application in road maintenance industry
6. Inadequate road failure detection system
7. Insufficient monitoring process for road failure detection

Project Characteristics:
1. Planning & logistic issues impacting on continuous work flow (e.g non-closure period)
2. Un-conducive time frames within which most road works must be carried out
3. Site's location and environmental constraints (e.g. traffic volume, climate, subsoil and topography)
4. Public notification issues (e.g. community and environmentalists' resistance to infrastructure development plans)
5. Nature and significance of road in the Road Hierarchy
6. Project complexity: scale, design
7. Type of procurement adopted
8. Relation between rehab size and plant utilization

Project Management:
1. Lack of sufficient planning from the outset
2. Poor project management and risk management processes
3. Lack of effective communication among key stakeholders
4. Lack of proper and regular coordination; supervision; performance monitoring and control
5. Lack of project organisational culture that supports high productivity and performance
6.Relationship management/ degree of harmony, trust and cooperation between contractor, consultant and council
7. Experience and competencies of the project team
8. Frequency of design changes/ change orders/late changes
9. Client's overt influence on the project process
10. Poor sufficient supply chain management, especially as it relates to "just-in-time" supply principles
11. Lack of organizational learning: (applying lessons learnt from previous projects to solving challenges in current project)

External Constraints

Statutory Compliance:
1. Health & Safety in Employment Act
2. Resource Management Act
3. Local Authority Bylaws
4. Construction Contracts Act
5. Employment Relations Act
6. Consumer Guarantees Act
7. Fair Trading Act

Unforeseen Event:
1. Inclement weather
2. Unforeseeable ground conditions necessitating revisions
3. On-site accidents/ Acts of God
4. Natural disasters

Other External Forces:
1. Inflation / fluctuations in material prices
2. Fluctuations in exchange rate
3. Energy crises/rising costs
4. Interest rate/cost of capital
5. Market conditions and level of competitions in the industry for jobs
6. Frequent changes in government policies/ legislations impacting on construction

Figure 73: Broad and sub-categories of productivity constraints in the road pavement maintenance and rehabilitation process

4.6 Questionnaire Survey

The recurring constraint factors identified during the pilot interviews were incorporated into the questionnaire so they could be rated for relevance and relative levels of impact in the second stage quantitative surveys. The questionnaire was pre-tested for relevance and clarity before being administered to the survey participants, as described in the Methodology section. The following subsections provide details about the survey responses and discussion in relation to the research objectives.

4.6.1 Survey Responses

In total, 38 New Zealand companies were found to be involved in road maintenance and rehabilitation work through online search engines, such as the Yellow Pages and Google. These companies comprised contractors, consultants and subcontractors. After identifying the companies, a list of potential respondents who were working in the identified companies in related roles was compiled. Through these compilations, a target sampling frame of 205 respondents was established for the research. Invitation letters were forwarded to the respondents via email and phone calls. Following reminders, 40 responses were received by the cut-off date. This represented a 20% effective response rate.

4.6.2 Demographic Profile of Respondents

Frequent Role of the Respondents in the Project Team

Figure 76 shows the demographic profiles of the survey participants in terms of their role as members of the project team. From this figure, it can be seen that the majority (75%) of respondents were contractors, with the smallest group being subcontractors (2.8%), and clients (2.8%). The results of this research could therefore be highly influenced by the opinions of contractors. The greater proportion of contractors was a positive outcome, given that they have an important role in any field of construction projects (Mbachu & Nkado, 2007).

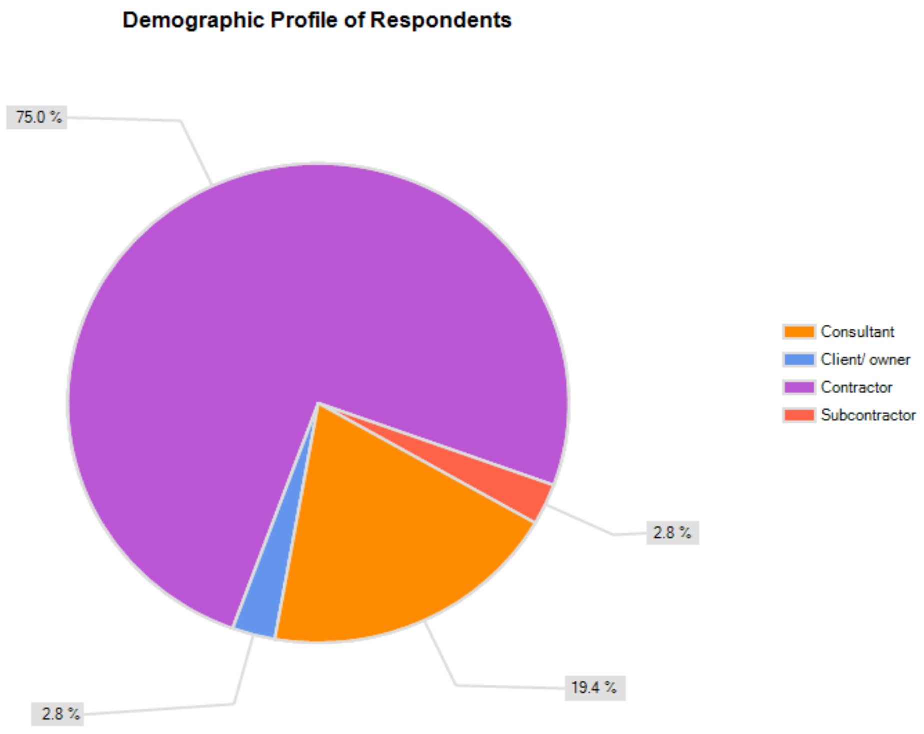


Figure 74: Frequent role of respondents in project team

Length of Experience of the Respondents in above Capacity

Figure 77 presents the length of experience of the respondents in their key roles as project team members. As shown, the majority (67.5%) of the participants have at least 10 years experience in the roading sector in New Zealand. This depth of experience adds to the quality of the feedback.

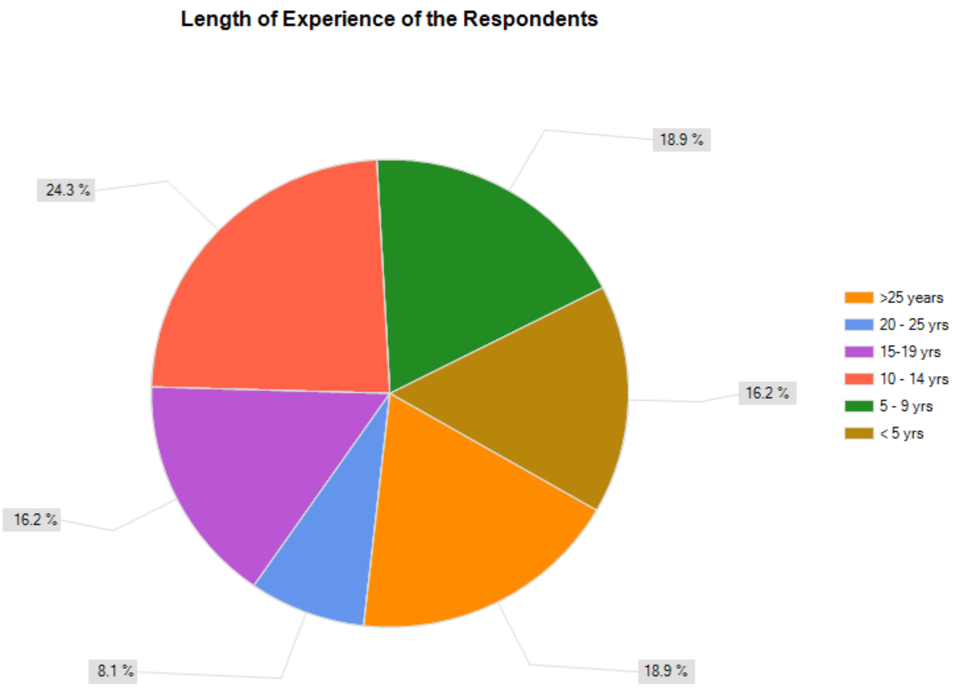


Figure 75: Respondents' length of experience as project team role players

4.6.3 Status of the Respondents in their Organisations

Figure 78 presents each survey participant's role in their organisation, and shows that a majority (62.5%) belonged to the Manager/ Associate Director category. As would be expected, the General Foreman/ Section Head and the Director/ Executive Director categories comprised the smallest groups, with 9.4% and 3.1%, respectively.

Implications for research

In total, all the respondents occupied leadership or senior positions in their respective organisations. It is, therefore, expected that the feedback from those who make strategic decisions about road pavement maintenance and rehabilitations would be of high quality, and so add to the reliability of the study findings and conclusions.

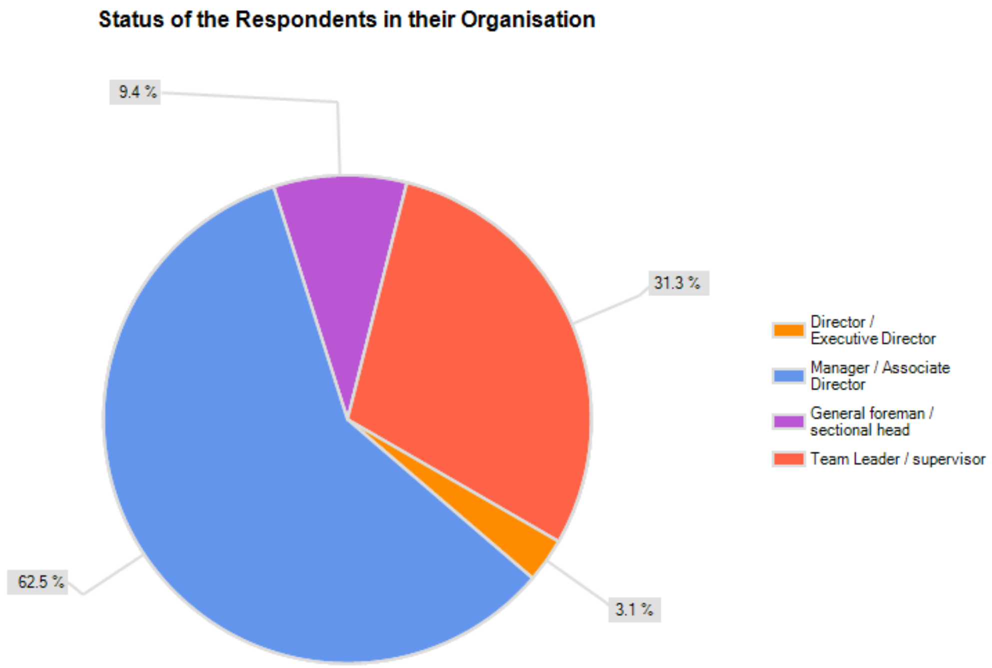


Figure 76: Respondents' status in their organisation

4.7 Prioritising the Productivity Constraint Factors

The 61 factors identified during the pilot interviews were rated for their relative levels of impact during the questionnaire survey. The following subsections present the prioritisation of the sub-factors under the eight broad categories of Project Finance, Workforce, Technology/ Process, Project Characteristics, Project Management/Project Team Characteristics, Statutory Compliance, Unforeseen Circumstances and Other External Forces.

4.7.1 Project Finance Related Constraint Factors

Out of the eight factors identified under the project finance related category, five were rated as being influential to the productivity of the road pavement maintenance and rehabilitation process in New Zealand. Table 14 presents the analysed sub-factors and their relative levels of influence. The table shows that the most influential factors under the project finance category were inaccurate estimates and the lack of collaboration between consultants and contractors.

These sub-factors achieved mean rating points of 3.67 and 3.53, respectively. The finding of inaccurate estimate as a major productivity constraint factor was consistent with similar findings by Wang and Horner (2007) that an accurate cost estimate is essential for major road maintenance at the early stage of design. In addition, Vassallo and Izquierdo (2002) concur by arguing that tackling financial constraints arising from inaccurate estimates is a significant way to improve productivity in the construction industry. Also Nijkamp and Ubbels (1998) found that inaccurate estimate could have a critical influence on the whole project and may even lead to planning failures.

The next most influential factor rated by respondents was a lack of collaboration between consultant and contractors. This finding is important because road pavement maintenance and rehabilitation is a complex process that is greatly influenced by the relationship among various actors involved in execution of the maintenance tasks. The relationship factor becomes more critical when outsourcing maintenance tasks. To minimise the problem of lack of collaboration between consultant and contractors, the most important success factor was found to be creating mutual “goodwill trust” between partners (Olsson & Espling, 2004).

Table 14: Analysis of the Project Finance constraint factors

Levels of impact on productivity and performance

	Very low	Low	Moderate	High	Very High	No Idea	*Rating Average	Level of Impact	Rating Count	
1.Inaccurate estimates;	2.60%	15.40%	17.90%	30.80%	25.60%	7.70%	3.67	High	39	Significant
2. Lack of collaboration between consultant and contractors.	2.60%	10.30%	41.00%	20.50%	23.10%	2.60%	3.53	High	39	
3. Inadequate supply or high cost of needed resources: money, men, materials & machinery;	2.60%	12.80%	38.50%	25.60%	12.80%	7.70%	3.36	Moderate	39	
4. Reworks;	12.80%	7.70%	30.80%	23.10%	20.50%	5.10%	3.32	Moderate	39	
5. Under-valued work;	7.70%	17.90%	33.30%	23.10%	7.70%	10.30%	3.06	Moderate	39	
6. Late payments;	15.40%	33.30%	25.60%	10.30%	2.60%	12.80%	2.44	Low	39	Insignificant
7. Dispute and litigation costs;	23.10%	35.90%	12.80%	12.80%	0.00%	15.40%	2.18	Low	39	
8. Lenders' high interest charges;	20.50%	35.90%	15.40%	2.60%	0.00%	25.60%	2.00	Low	39	

**Rating average = mean rating (see Equation 3.1): ‘Very high’ (4.20 – 5); ‘High’ (3.40 – 4.19); ‘Moderate/ average’ (2.60 – 3.39); ‘Low’ (1.80 – 2.59); ‘Very low’ (1.00 – 1.79)*

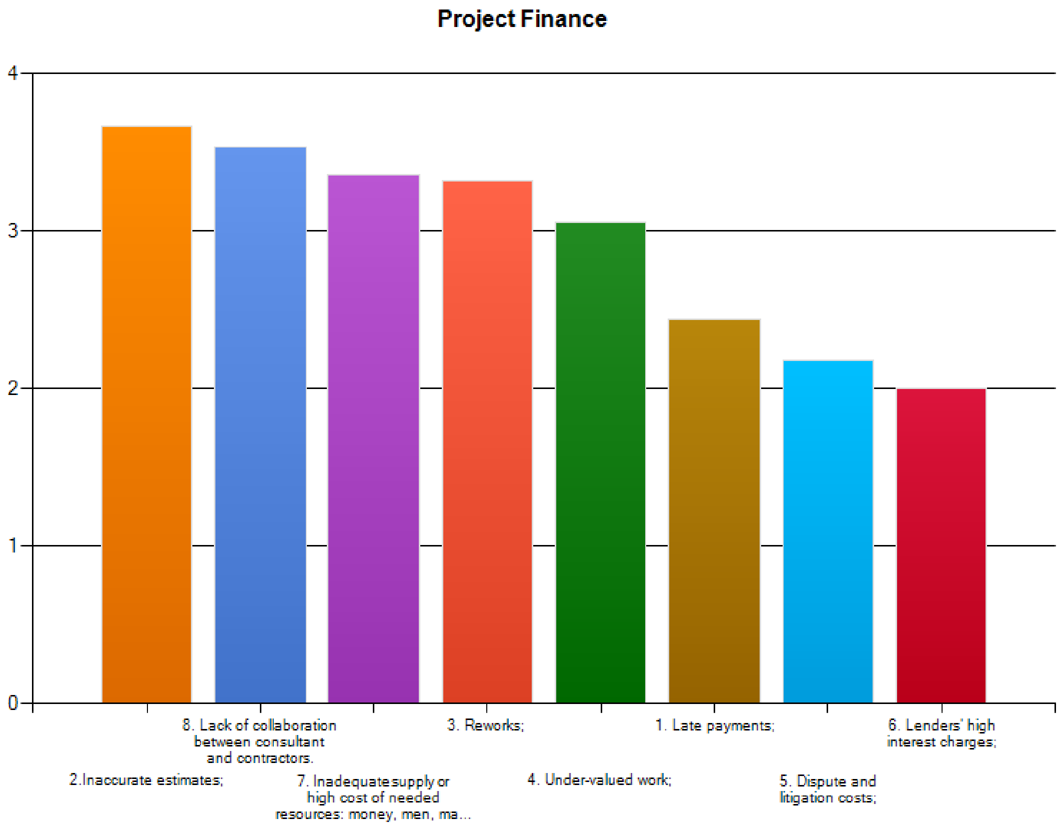


Figure 77: Importance of each factor under category of Project Finance

Further project finance related factors

Respondents were asked to advise on additional factors under the project finance category in the text box sections of the open-ended questionnaire. The respondents' feedback is listed as follows.

1. Insufficient funds or budget for proper road maintenance and rehabilitation due to issues such as the "gas tax" not bringing in enough revenue. [*Perhaps, concerns such as this would have informed the recent Cabinet's agreement to repeal regional fuel tax and introduce a compensating increase in fuel exercise duty and an equivalent increase in road user charges. The Office of the Minister of Transport (2013) states that these changes will increase the total income from road users as well as improve the fund allocations to the National Land Transport Fund for state highway construction and road maintenance*].

2. Financial risks introduced by fluctuating workloads and lack of forward planning: steady workload to the market is required throughout the year. At the moment, most work comes out for tender all at once in July - September due to new budgets. Then more work comes out in May/June and must be spent in winter. This leads to capacity issues and uncertainties, which has serious financial implications.
3. Insufficient budget to undertake preventative maintenance works for early interventions. This causes backlog of preventative maintenance works and further deterioration of the failures to more expensive intervention costs at a delayed stage.
4. Inaccurate estimates arising from client's inaccurate project information and preference to lowest tender: often tenderers are required to tender in competition for work using inaccurate information provided in the tender documents and conditions. Tenderers are not given sufficient time to verify the accuracy of the background information and are constrained to price the associated risks well for fear of losing the contract in an era of lowest tender. The result is serious financial cash flow problems and low margins that constrain the contractors' productivity and performance.

4.7.2 Workforce Related Factors

The level of impact of the sub-factors under the workforce category on productivity in road maintenance was analysed in Table 15 and summarised in Figure 80 for better visual appreciation. The table shows that eight out of the identified 10 sub-factors had moderate to high impact on the productivity and performance of road maintenance and rehabilitation projects in New Zealand. The most influential factor was found to be lack of good leadership/ management capability on the part of the project management team. Müller and Turner (2010) concur with this finding by confirming that the project manager's leadership style and the project manager's leadership capability impact significantly on a project's success.

They also found that motivation is an important factor of a project's success and productivity. Their research findings indicated that motivation is the second most influential factor.

The next influential factor was found to be low level of motivation/ commitment of the workforce. The value of this factor as a potential productivity influencer was documented in the work of Tohidi (2011) on the effect of motivation on productivity. Tohidi (2011) argues that having an effective reward system can improve the level of motivation because motivation has a huge effect on increasing productivity during a project's implementation.

Low level of skill and experience of the work force was analysed as the third effective factor on productivity of road maintenance projects. This finding aligns with the findings of earlier studies - Mason, O'Leary, and Vecchi (2012), Durdyev (2011),Mojahed and Aghazadeh (2008), and Alinaitwe, Mwakali, and Hansson (2007), who similarly concluded that the level of skill and experience of the work force have significant influence on productivity.

Table 15: Factors ranked under Work Force Group

Levels of impact on productivity and performance

	Very Low	Low	Moderate	High	Very High	No Idea	Rating Average	Level of Impact	Rating Count	
1. Lack of good leadership/ management capability	2.60%	15.40%	30.80%	28.20%	20.50%	2.60%	3.50	High	39	Significant
2. Low level of motivation/commitment	2.60%	21.10%	39.50%	23.70%	10.50%	2.60%	3.19	Moderate	38	
3. Low level of skill and experience of the workforce	5.10%	25.60%	28.20%	23.10%	15.40%	2.60%	3.18	Moderate	39	
4. Poor monitoring or appraisal of performance	7.70%	20.50%	28.20%	30.80%	10.30%	2.60%	3.16	Moderate	39	
5. Overly long working hours with insufficient rest periods, especially during night work	5.10%	23.10%	38.50%	23.10%	5.10%	5.10%	3.00	Moderate	39	
6. Inadequate empowerment (training and resourcing)	7.90%	23.70%	36.80%	23.70%	5.30%	2.60%	2.95	Moderate	38	
7. Poor resource leveling	7.90%	26.30%	26.30%	34.20%	0.00%	5.30%	2.92	Moderate	38	
8. Lack of experience of current job and operational conditions	7.70%	33.30%	30.80%	20.50%	5.10%	2.60%	2.82	Moderate	39	
9.Workforce health issues	12.80%	43.60%	30.80%	10.30%	0.00%	2.60%	2.39	Low	39	Insignificant
10. Workforce absenteeism	15.40%	48.70%	25.60%	5.10%	2.60%	2.60%	2.29	Low	39	

**Rating average = mean rating (see Equation 3.1): ‘Very high’ (4.20 – 5); ‘High’ (3.40 – 4.19); ‘Moderate/ average’ (2.60 – 3.39); ‘Low’ (1.80 – 2.59); ‘Very low’ (1.00 – 1.79)*

Further workforce related factors

Respondents were asked to advise on additional factors under the workforce related category. Only one respondent provided feedback as follows:

- Not enough jobs for the upcoming workforce
- Individuals working longer or entering retirement later

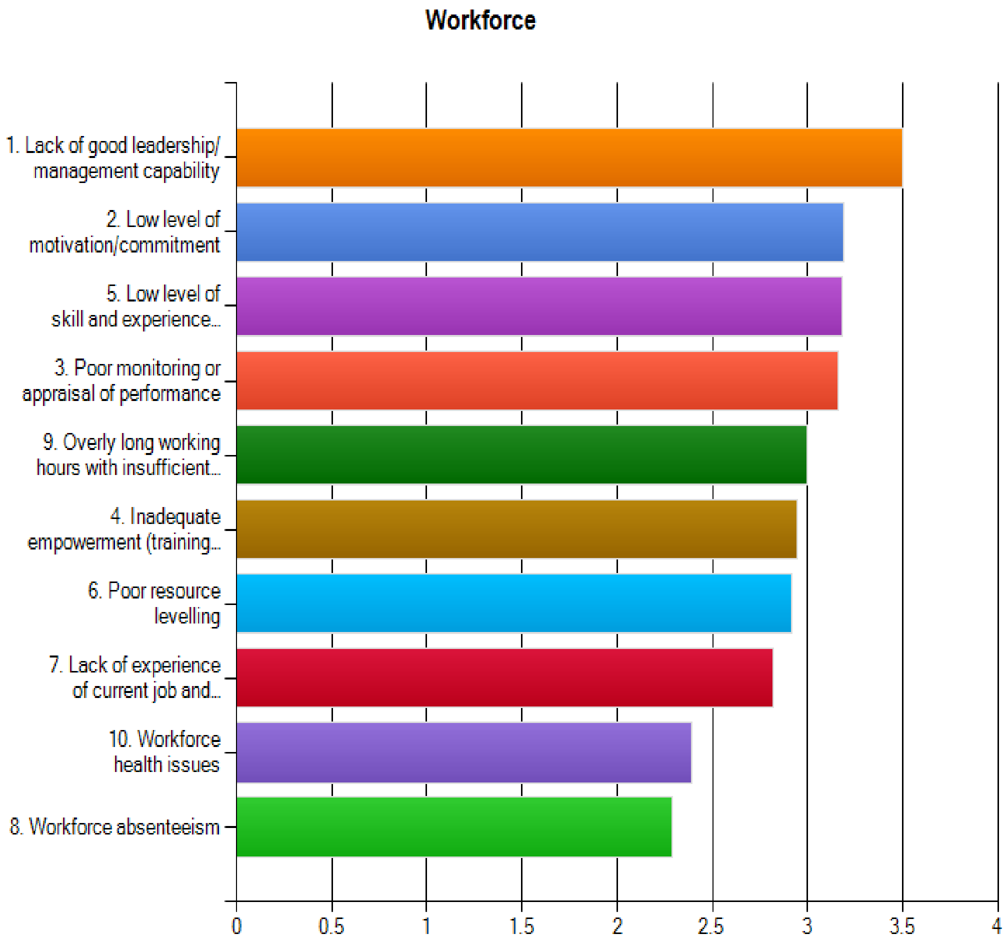


Figure 78: The level of impact of each factor under Work Force group

4.7.3 Technology/Process Related Factors

The analysis of the sub-factors under the technology/process related broad category of roading maintenance productivity constraints is presented in Table 16 and Figure 81. The table shows that all the seven subfactors identified during the pilot interviews were rated as having a significant influence on the productivity and performance outcomes in the road maintenance and rehabilitation projects.

Table 16: Analysis of the sub-factors under the technology/process

Levels of impact on productivity and performance

	Very Low	Low	Moderate	High	Very High	No idea	*Rating Average	Level of Impact	Rating Count	
1. Resistance to accept new technologies in road maintenance projects(include new Methods & Materials)	2.60%	30.80%	33.30%	23.10%	10.30%	0.00%	3.08	Moderate	39	Significant
2. ineffective approach to road maintenance	7.70%	28.20%	33.30%	17.90%	12.80%	0.00%	3.00	Moderate	39	
3. Lack of adequate training on new processes and technologies	2.60%	33.30%	35.90%	20.50%	5.10%	2.60%	2.92	Moderate	39	
4. Inadequate road failure detection system	2.60%	39.50%	34.20%	15.80%	5.30%	2.60%	2.81	Moderate	38	
5. Inadequate IT infrastructure and application in road maintenance industry	2.60%	35.90%	41.00%	15.40%	2.60%	2.60%	2.79	Moderate	39	
6. Suitability or adequacy of the plant & Equipment employed	7.70%	35.90%	33.30%	12.80%	7.70%	2.60%	2.76	Moderate	39	
7. Insufficient monitoring process for road failure detection	5.10%	33.30%	46.20%	7.70%	5.10%	2.60%	2.74	Moderate	39	

*Rating average = mean rating (see Equation 3.1): ‘Very high’ (4.20 – 5); ‘High’ (3.40 – 4.19); ‘Moderate/ *average’ (2.60 – 3.39); ‘Low’ (1.80 – 2.59); ‘Very low’ (1.00 – 1.79)*

The survey respondents’ feedback shows that resistance to accepting new technologies, materials and methods in road maintenance projects is the most important factor that has a significant impact on productivity and performance in road maintenance projects. This result is consistent with the findings of Mukhopadhyay et al. (1997) and Peansupap and Walker (2005) who argued that using new technologies, such as ITC, could enhance the effectiveness of many construction processes at each project phase. Peansupap and Walker (2005) maintained that change resistance often hinges on the lack of understanding of how to actually implement a new technology into a construction organisation, and the training costs and time required to bring workers up to speed on the use of the new technology. Furthermore, Björk 1999, 2003) and Gambatese and Hallowell (2011) found that implementing new technologies can improve integration as well as enhance productivity and service delivery in construction projects.

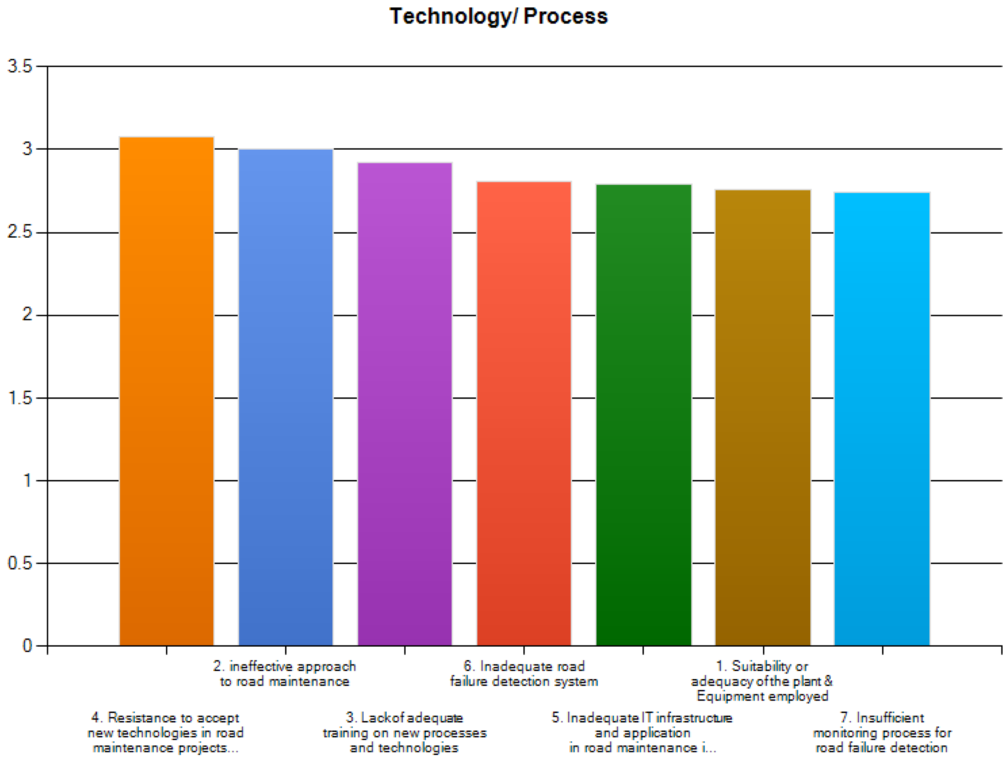


Figure 79: The level of impact of each factor under technology/ process broad category

Further technology/ process related constraint factors

Respondents of the surveys freely supplied the following additional factors under the technology/ process broad category:

1- Lack of funds to purchase new technologies
2- Consultants / clients requiring the use of preferred technology known to them i.e. RAMM, which is a great tool but not implementing it correctly or not understanding its use themselves. This could be quite frustrating to the contractor and could impact on work progress and productivity due to the large amount of data processing required.

4.7.4 Project Characteristics Related Factors

The analysis of the sub-factors under the project characteristics related broad category is presented in Table 17. Figure 82 summarises the factors for better visual appreciation. The table shows that all eight subfactors identified during the pilot interviews were rated as having a significant influence on the productivity and performance outcomes in road maintenance and rehabilitation projects.

Table 17: Analysis of the sub-factors under the project characteristics

	Levels of impact on productivity and performance									
	Very Low	Low	Moderate	High	Very High	No Idea	*Rating Average	Level of Impact	Rating Count	
1. Site's location and environmental constraints (e.g. traffic volume, climate, subsoil and topography)	0.00%	7.70%	30.80%	43.60%	15.40%	2.60%	3.68	High	39	Significant
2. Planning & logistic issues impacting on continuous work flow (e.g non-closure period)	0.00%	21.10%	26.30%	28.90%	18.40%	5.30%	3.47	High	38	
3. Un-conducive time frames within which most road works must be carried out	0.00%	20.50%	23.10%	41.00%	12.80%	2.60%	3.47	High	39	
4. Public notification issues (e.g. community and environmentalists' resistance to infrastructure development plans)	5.10%	15.40%	35.90%	28.20%	10.30%	5.10%	3.24	Moderate	39	
5. Type of procurement adopted	0.00%	32.40%	35.10%	13.50%	16.20%	2.70%	3.14	Moderate	37	
6. Project complexity: scale, design	0.00%	26.30%	36.80%	26.30%	5.30%	5.30%	3.11	Moderate	38	
7. Relation between rehab size and plant utilization	2.60%	23.70%	39.50%	15.80%	10.50%	7.90%	3.09	Moderate	38	
8. Nature and significance of road in the Road Hierarchy	5.30%	23.70%	44.70%	21.10%	0.00%	5.30%	2.86	Moderate	38	

**Rating average = mean rating (see Equation 3.1): 'Very high' (4.20 – 5); 'High' (3.40 – 4.19); 'Moderate/ average' (2.60 – 3.39); 'Low' (1.80 – 2.59); 'Very low' (1.00 – 1.79)*

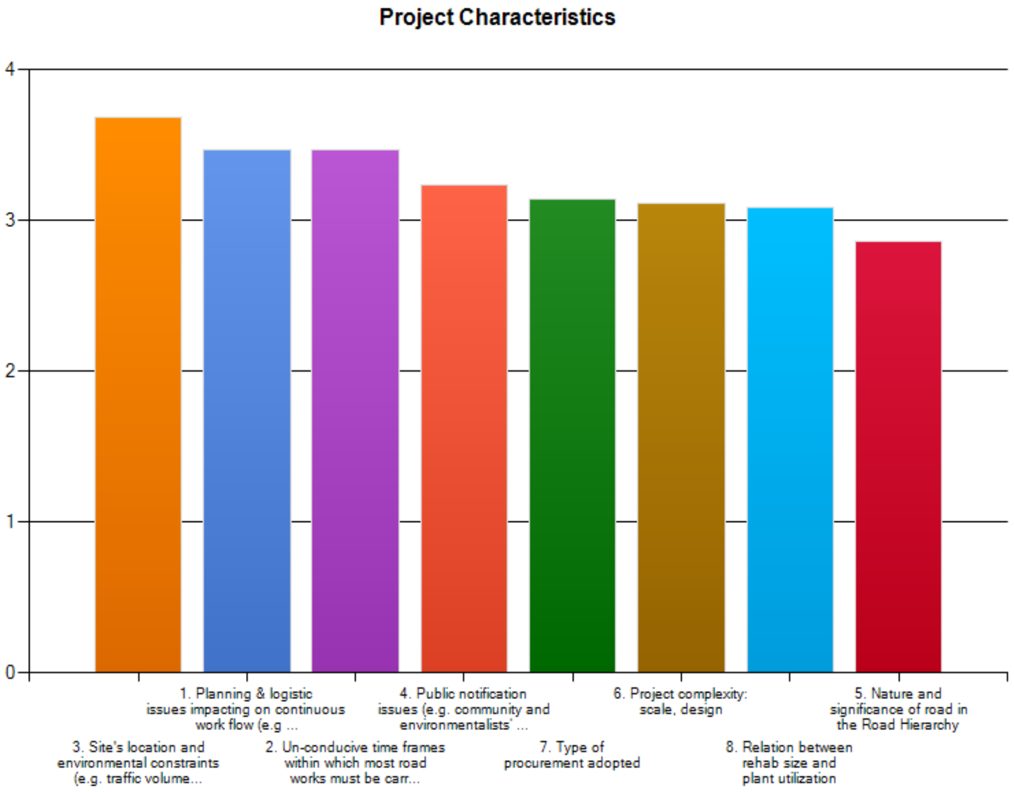


Figure 80: The impact of project characteristics factors

The most influential factor in this subgroup was found to be issues relating to site location and environmental constraints, such as traffic volume, climate, subsoil and topography. This result is consistence with the findings of Perrier, Langevin, and Campbell (2006), who confirmed that influences such as site location and subsoil conditions impact significantly on productivity and efficiency of road maintenance. The next important factor relates to planning and logistics issues that impact on the continuity of the workflow. As indicated by Mobley (2002) and also Wang, Chu, and Wu (2007), one third of all maintenance costs are wastes arising from unnecessary or improper maintenance activities, and which could be associated with improper planning and logistics issues. In addition Lee et al. (2006) submitted that "the contractor’s production rates varied considerably depending upon the construction logistics, material delivery and hauling methods, lane-closure tactics, and/or pavement designs being implemented" (p. 798).

Further project characteristics related constraint factors

Respondents to the survey freely supplied the following additional factors under the project characteristics broad category.

1- Jobs are in small bits that result in high cost per square metre and overheads.
2- Timing and availability of road closures is an issue: if we had full closures we could complete a whole lot more work.

4.7.5 Project Management/ Project Team Characteristics Related Factors

The sub-factors under the project management/ project team characteristics group of constraint factors were analysed in Table 18. For better visual appreciation, the sub-factors were summarised in Figure 84. The table shows that all 11 sub-factors identified during the pilot interviews were rated as having a moderate to highly significant influence on the productivity and performance outcomes in road maintenance and rehabilitation projects.

The table shows that the most influential factor on productivity in road maintenance relates to frequent design changes, change orders or late changes at critical stages of the implementation process. This result corroborates with earlier studies (Assaf and Al-Hejji (2006); Makulsawatudom, Emsley, and Sinthawanarong (2004); Alinaitwe et al. (2007); and Kadir, Lee, Jaafar, Sapuan, and Ali (2005)), which equally concluded that late change orders significantly constrain productivity in the road maintenance process. This is usually due to the delay to works while waiting for revised project information, or wastages involved in correcting the completed work sections to meet the revision requirements.

The second most influential constraint stemmed from lack of sufficient planning from the outset. To elaborate this point, one of the respondents hinted that poor planning at the onset had an adverse impact on contractor productivity during the implementation stage. Lack of adequate time for robust planning and poor risk analysis could contribute to poor planning, which in turn sets unreliable baselines for benchmarking performance at the implementation stage (Mbachu & Nkado, 2006).

Further Project Management/ Project Team Characteristics related constraint factors

The following are additional factors advised by the respondents in the text box sections of the open-ended questionnaire:

1. Inaccurate measurement/ monitoring of progress: Some respondents alluded to the fact that if completed works were not measured correctly in relation to the work progress, the progress report would be inaccurate in terms of productivity and performance outcomes during interim valuation stages. [*It should be noted that progress monitoring issues have been covered under the seventh factor captioned 'lack of proper and regular coordination, supervision, and performance monitoring*'].
2. Sharing of cost savings: Incentives should be provided to motivate project stakeholders explore ways of reducing costs in the project. In addition, the achieved cost savings should be shared as bonuses in accordance with the extent of cost savings achieved by each stakeholder.
3. Avoiding unnecessary or duplicated processes: proper coordination should be in place to allocate responsibilities to minimise or eliminate overlaps and duplication of efforts.
4. Promote innovation: Stakeholders should be encouraged to explore innovative ways of delivering value without being constrained by contractual provisions, regulations and red-tapes; "*We are good in this country at regulating but not good at cutting through the red tape and getting on quickly with the job*". "*Over regulation/ legislations stifle creativity, innovation and value delivery*". Value engineering, lean construction and last planner methodologies could be explored to improve innovation and value delivery.

5. Learning organisation: Efforts should be made to debrief on projects with a view to articulating the lessons learned and innovations achieved for improving the management and outcomes of future projects. “*We are often too process-driven and pay little attention to how our efforts contribute to the final outcomes or the bigger picture. We often resort to covering our tracks in case things go wrong*”. [It should be noted that the respondents’ feedback largely amplifies the fifth constraint factor entitled, ‘Lack of organisational learning: applying lessons learnt from previous projects to solving challenges in current project’].
6. Encourage partnership and win-win outcomes: “*The regulators should be in partnership with the providers and get onboard and work as teams, guiding each other along the way rather than waiting for mistakes to be made and pass the buck”. “We are too heavy on top management and design resources and not enough spent on the doing, interactions and teamwork part of the project*".

Table 18: Factors ranked under project management/ project characteristics

Levels of impact on productivity and performance										
	Very Low	Low	Moderate	High	Very High	No idea	*Rating Average	Level of Impact	Rating Count	
1. Frequency of design changes/ change orders/late changes	5.10%	2.60%	28.20%	30.80%	28.20%	5.10%	3.78	High	39	Significant
2. Lack of sufficient planning from the outset	5.10%	20.50%	12.80%	35.90%	23.10%	2.60%	3.53	High	39	
3. Lack of effective communication among key stakeholders	0.00%	25.60%	30.80%	25.60%	15.40%	2.60%	3.32	Moderate	39	
4.Relationship management/ degree of harmony, trust and cooperation between contractor, consultant and council	2.60%	17.90%	38.50%	25.60%	10.30%	5.10%	3.24	Moderate	39	
5. Lack of organizational learning: (applying lessons learnt from previous projects to solving challenges in current project)	5.10%	23.10%	35.90%	15.40%	17.90%	2.60%	3.18	Moderate	39	
6. Client's overt influence on the project process	0.00%	20.50%	43.60%	28.20%	2.60%	5.10%	3.14	Moderate	39	
7. Lack of proper and regular coordination; supervision; performance monitoring and control	5.10%	28.20%	23.10%	33.30%	7.70%	2.60%	3.11	Moderate	39	
8. Experience and competencies of the project team	5.30%	18.40%	39.50%	28.90%	5.30%	2.60%	3.11	Moderate	38	
9. Lack of project organisational culture that supports high productivity and performance	7.70%	28.20%	20.50%	23.10%	15.40%	5.10%	3.11	Moderate	39	
10. Poor project management and risk management processes	7.70%	28.20%	20.50%	30.80%	10.30%	2.60%	3.08	Moderate	39	
11. Poor sufficient supply chain management, especially as it relates to "just-in-time" supply principles	5.30%	28.90%	28.90%	31.60%	2.60%	2.60%	2.97	Moderate	38	

*Rating average = mean rating (see Equation 3.1): ‘Very high’ (4.20 – 5); ‘High’ (3.40 – 4.19); ‘Moderate/ average’ (2.60 – 3.39); ‘Low’ (1.80 – 2.59); ‘Very low’ (1.00 – 1.79)

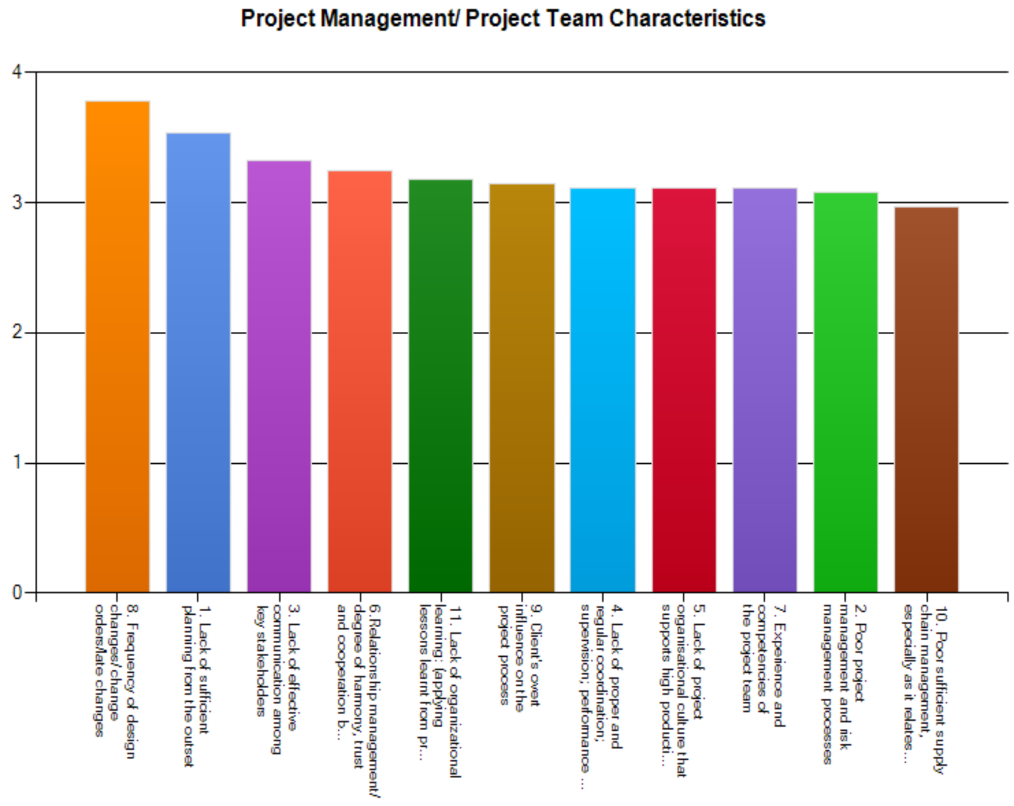


Figure 81: Relative levels of influence of the sub-factors under the broad category of project management/ project team characteristics

4.7.6 Statutory Compliance Related Factors

Table 19 presents the analysis of factors relating to the statutory compliance group. Results show that the Health & Safety in Employment Act and Resource Management Act were rated as the two most influential sub-factors within the statutory compliance category. A study by Durdyev (2011) also found statutory compliance as a key constraint issue (to labour productivity) in the New Zealand building and construction industry. In addition McShane (1996) reported that there were high compliance costs to businesses associated with the Resource Management Act, with a dampening effect on productivity in the construction industry.

Table 19: Ranked factors under the category of statutory compliance

Levels of impact on productivity and performance

	Very Low	Low	Moderate	High	Very High	No idea	Rating Average	Level of Impact	Rating Count	
1. Health & Safety in Employment Act	5.30 %	26.30%	18.40%	23.70%	18.40%	7.90%	3.26	Moderate	38	Significant
2. Resource Management Act	5.30 %	23.70%	23.70%	15.80%	21.10%	10.50%	3.26	Moderate	38	
3. Local Authority Bylaws	7.90 %	23.70%	39.50%	18.40%	0.00%	10.50%	2.76	Moderate	38	
4. Construction Contracts Act	10.50 %	26.30%	34.20%	13.20%	2.60%	13.20%	2.67	Moderate	38	
5. Employment Relations Act	7.90 %	31.60%	42.10%	5.30%	2.60%	10.50%	2.59	Low	38	Insignificant
6. Consumer Guarantees Act	10.50 %	39.50%	23.70%	2.60%	5.30%	18.40%	2.42	Low	38	
7. Fair Trading Act	13.20 %	34.20%	26.30%	5.30%	2.60%	18.40%	2.39	Low	38	

**Rating average = mean rating (see Equation 3.1): 'Very high' (4.20 – 5); 'High' (3.40 – 4.19); 'Moderate/ average' (2.60 – 3.39); 'Low' (1.80 – 2.59); 'Very low' (1.00 – 1.79)*

Figure 84 provides a summary of the key influential factors under the statutory compliance group.

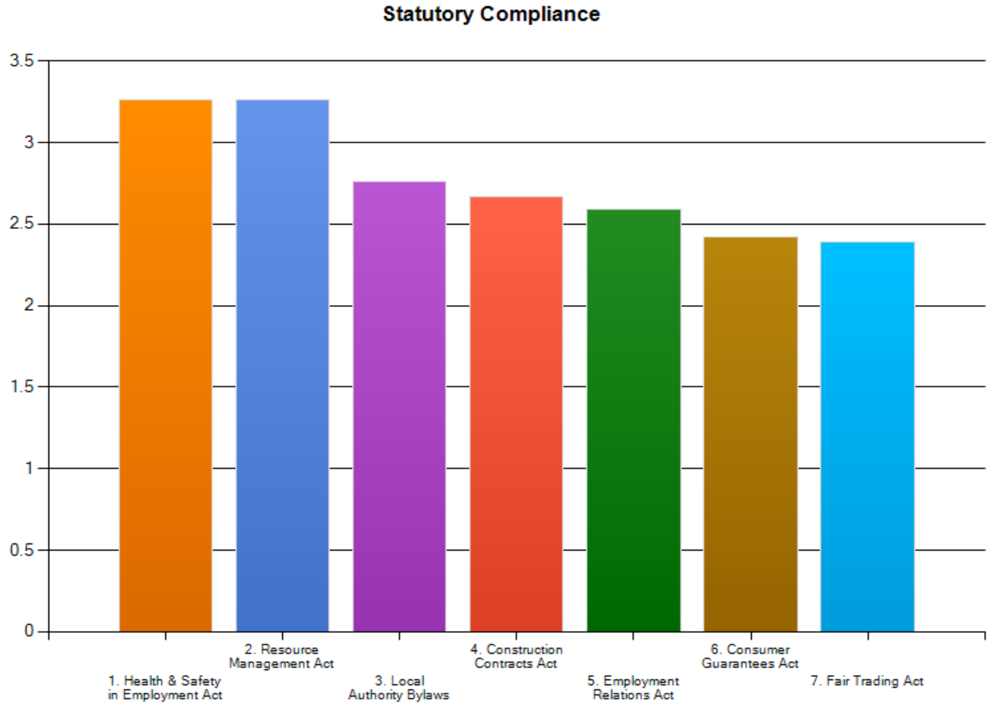


Figure 82: Importance of each factor under the category of statutory compliance

4.7.7 Unforeseen Events Related Factors

Analysis in Table 20 shows that inclement weather was perceived as the most influential sub-factor under unforeseen events, with high impact on productivity in road maintenance projects. Similar findings have been made in a number of studies, such as Alinaitwe et al. (2007), Makulsawatudom et al. (2004), Kazaz, Manisali, and Ulubeyli (2008) and Kadir et al. (2005). These studies confirmed the pervasiveness of inclement weather as a key constraint factor to productivity and performance in the construction industry.

Further factors related to unforeseen events

The following are additional factors advised by the respondents in the text box sections of the open-ended questionnaire:

1. Heavy rain and flooding can be detrimental to work continuity and could significantly slow down progress. Some respondents hinted that this could be avoided with good pre-planning, proper risk analysis and contingency planning, and earlier program starts.
2. Risk sharing: unforeseen circumstances are an issue, due to the difficulty in accurately forecasting them or the high costs associated with properly budgeting for them. The increased costs caused by bona fide delays should be shared among the project stakeholders in relation to the risks they bear. This will help to minimise conflict over genuinely unforeseen delays.

Table 20: Factors ranked under unforeseen events

Levels of impact on productivity and performance

	Very Low	Low	Moderate	High	Very High	No Idea	Rating Average	Level of Impact	Rating Count	
1.Inclement weather	2.70%	5.40%	16.20%	37.80%	35.10%	2.70%	4.00	High	37	**Significant**
2.Unforeseeable ground conditions necessitating revisions	2.70%	10.80%	35.10%	32.40%	16.20%	2.70%	3.50	High	37	
3. On-site accidents/ Acts of God	19.40%	30.60%	30.60%	13.90%	2.80%	2.80%	2.49	Low	36	**Insignificant**
4. Natural disasters	32.40%	32.40%	21.6% (8)	8.10%	2.70%	2.70%	2.14	Low	37	

**Rating average = mean rating (see Equation 3.1): 'Very high' (4.20 – 5); 'High' (3.40 – 4.19); 'Moderate/ average' (2.60 – 3.39); 'Low' (1.80 – 2.59); 'Very low' (1.00 – 1.79)*

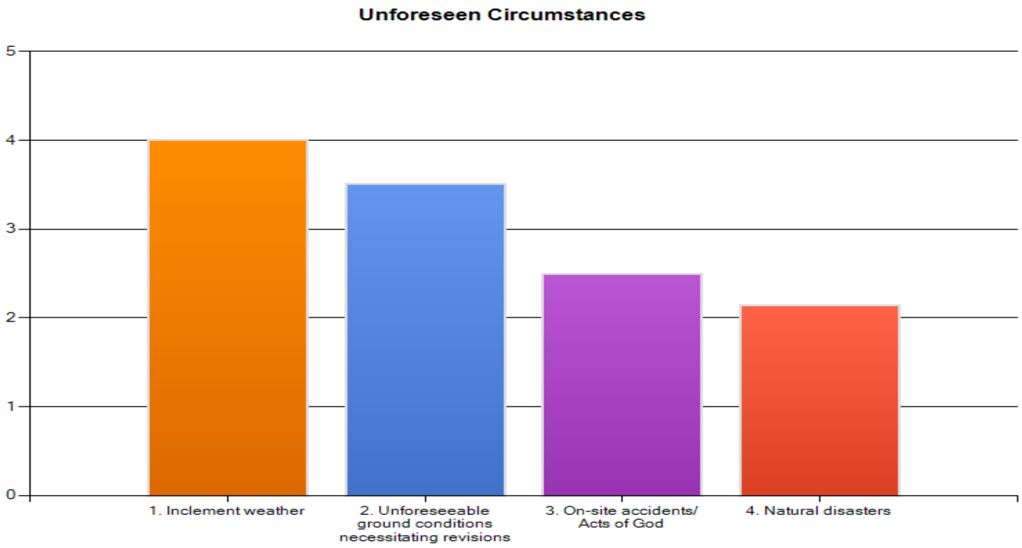


Figure 83: shows the importance of each factor under category of unforeseen circumstances

The next most influential factor under the category of unforeseen circumstances relates to unforeseeable ground conditions. To minimise the risk associated with this subfactor, Baynes (2010) suggested that a systematic assessment of the nature and sources of various hazards must be used to identify and differentiate the types of geotechnical risks during implementation of a project, in line with their risk profiles and the required contingency provisions.

4.7.8 Other External Forces

Table 21 presents an analysis of the sub-factors under the wider external forces broad category. Figure 86 presents a more visual segregation of the factors in accordance with their relative levels of influence.

Table 21: Ranked factors under the wider external forces broad category.

	Levels of impact on productivity and performance									
	Very Low	Low	Moderate	High	Very High	No Idea	*Rating Average	Level of Impact	Rating Count	
1. Market conditions and level of competitions in the industry for jobs	7.70%	17.90%	33.30%	30.80 %	7.70%	2.60%	3.13	Moderate	39	Significant
2. Inflation / fluctuations in material prices	17.90%	28.20%	28.20%	17.90 %	5.10%	2.60%	2.63	Moderate	39	
3. Energy crises/rising costs	15.40%	43.60%	25.60%	7.70%	5.10%	2.60%	2.42	Low	39	Insignificant
4. Frequent changes in government policies/ legislations impacting on construction	21.10%	42.10%	15.80%	13.20 %	5.30%	2.60%	2.38	Low	38	
5. Interest rate/cost of capital	18.40%	39.50%	31.60%	0.00%	5.30%	5.30%	2.31	Low	38	
6. Fluctuations in exchange rate	23.70%	42.10%	21.10%	7.90%	2.60%	2.60%	2.22	Low	38	

**Rating average = mean rating (see Equation 3.1): 'Very high' (4.20 – 5); 'High' (3.40 – 4.19); 'Moderate/ average' (2.60 – 3.39); 'Low' (1.80 – 2.59); 'Very low' (1.00 – 1.79)*

The table shows that only two out of six sub-factors were perceived as being significant, with a 'moderate' level of influence. Constraints relating to market conditions and the level of competition in the industry were the most influential in this group. Some of the respondents hinted, in the open-ended section of the questionnaire, that stiff job competition in the market and clients' inclinations to the lowest tender price drive up costs and claims, and drive down quality and profit margins. Though it might appear that this is good for clients in the initial stages, it is not so in the long run. This development is not helpful to consultants and contractors due to the associated cash flow risks and low margins on the job.

Conclusions of a number of studies, such as Aw, Chung, and Roberts (2000); Bernard, Eaton, Jenson, and Kortum (2000) and Porter (2000) are consistent with the findings of this survey. The authors found that market conditions were an important factor for all kinds of trades and industries, as it dictates how the industry stakeholders operate, compete and interact, and has a profound influence on expected outcomes, including productivity and performance.

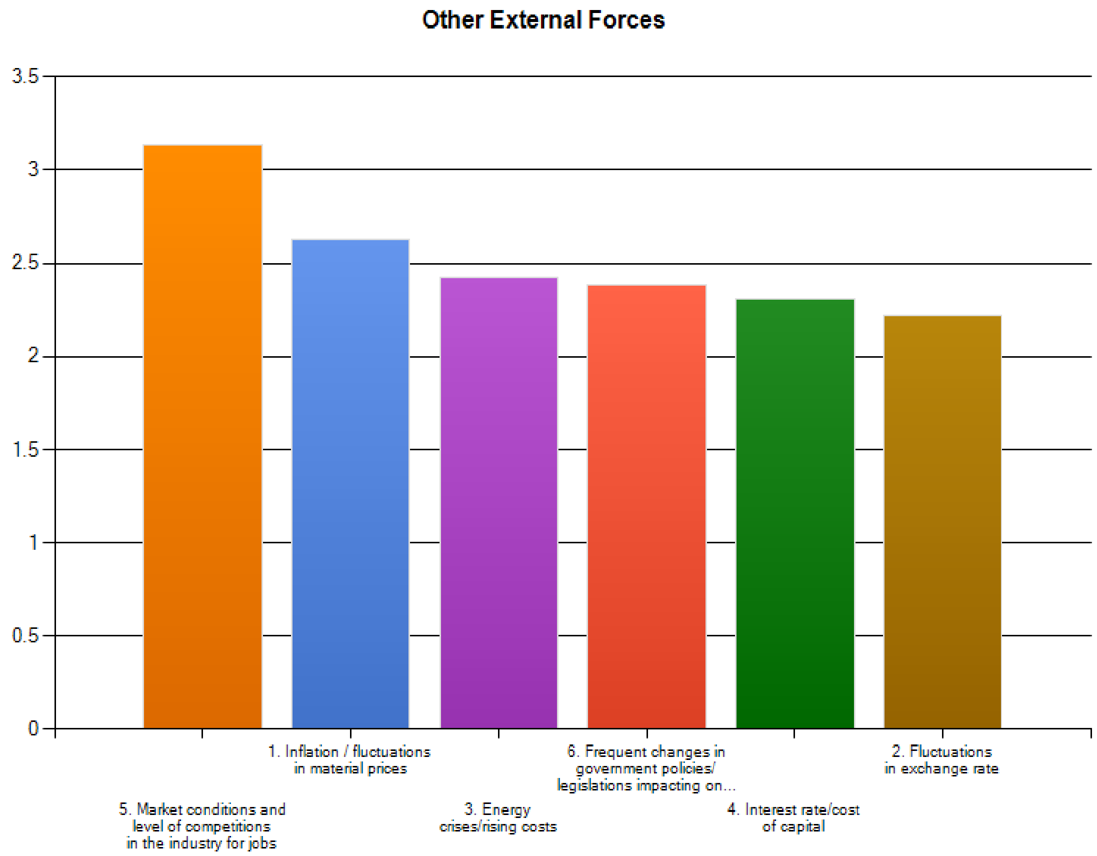


Figure 84: The importance of each factor under the category of other external forces

4.7.9 Relative Levels of Impact of the Broad Constraints Categories

The relative levels of impact of the broad constraints categories were analysed in Table 22 so as to provide a basis for prioritisation.

Table 22: The level of impact of productivity constraints under the broad categories of internal and external

Levels of impact on productivity and performance

	Very Low	Low	Moderate	High	Very High	Rating Average	Level of Impact	Rating Count	
1. Workforce	2.60%	10.50%	36.80%	39.50%	10.50%	3.45	High	38	Significant
2. Project management/ project team characteristics	0.00%	10.80%	54.10%	27.00%	8.10%	3.32	Moderate	37	
3. Project characteristics	0.00%	15.80%	44.70%	36.80%	2.60%	3.26	Moderate	38	
4. Project finance	7.90%	26.30%	34.20%	23.70%	7.90%	2.97	Moderate	38	
5. Technology/process	2.60%	26.30%	47.40%	21.10%	2.60%	2.95	Moderate	38	
6. Unforeseen events	2.70%	40.50%	32.40%	16.20%	8.10%	2.86	Moderate	37	
7. Statutory compliance	15.80%	21.10%	31.60%	28.90%	2.60%	2.82	Moderate	38	
8. Other external forces (economic, political, industry, etc)	24.30%	35.10%	27.00%	8.10%	5.40%	2.35	Low	37	Insignificant

**Rating average = mean rating (see Equation 3.1): 'Very high' (4.20 – 5); 'High' (3.40 – 4.19); 'Moderate/ average' (2.60 – 3.39); 'Low' (1.80 – 2.59); 'Very low' (1.00 – 1.79)*

The table shows that seven out of the eight identified factors under the broad categories of road maintenance productivity constraints were ranked as moderate to high influencers. The most influential constraint category relates to workforce issues. It should be noted that the most influential sub-factors under the workforce category comprise lack of good leadership/ management capability, low level of motivation/commitment, and low level of skill and experience of the workforce. Workforce related issues, as one of the most influential set of factors constraining productivity and performance in the construction industry (of New Zealand), was also reported by Fabling and Grimes (2010). The significance of workforce related issues was found by Mbachu and Nkado (2006) based on the conclusion that all other factors of production – materials, money, machinery and method – can be effectively controlled, but it is difficult to control the workforce, owing to the complexity of its characteristics and behavior; without proper control of the workforce, all other efforts could be sub-optimal in terms of delivering expected results. Only good leadership can bring about the best outcomes in workforce outputs. In addition, Durdyev and Mbachu (2011) found workforce related issues a key underpinning of labour productivity in the New Zealand building and construction industry.

Project finance issues constituted the second most influential broad constraint category. This finding supports that of Chan and Kumaraswamy (1997), that project finance related issues could underpin and drive other constraint factors. This would be understandable, given that cash flow is the lifeblood of the building industry (Mbachu, 2008).

Relative levels of contributions of broad categories to productivity outcomes

Using the Relativity Index (Equation 2) highlighted in the Methodology chapter, the relative levels of contribution of the broad constraint categories were analysed to reveal where the greatest opportunities for improvements lie. Figure 87 summarises the results of the relative levels of contributions of the broad categories on productivity and performance outcomes in the New Zealand road pavement maintenance and rehabilitation projects, with workforce related issues contributing over 14% of the outcomes.

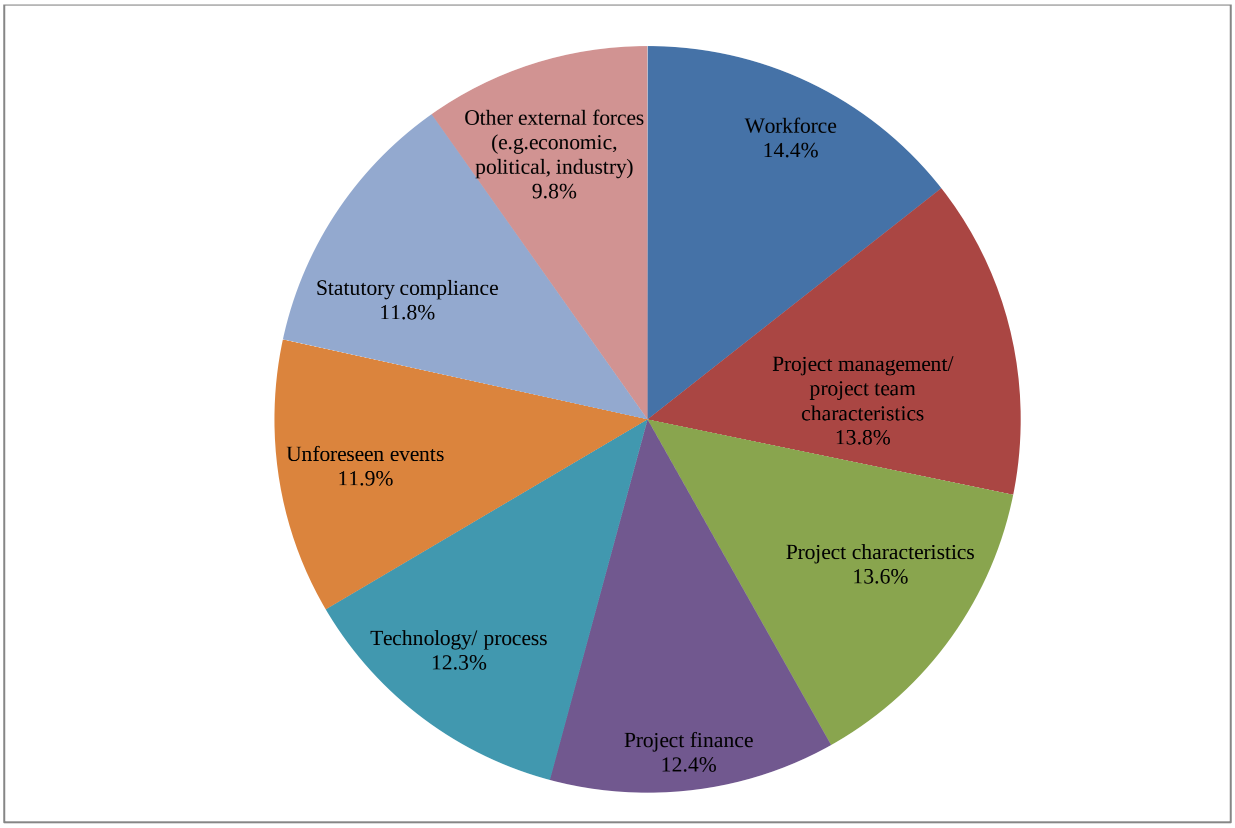


Figure 85: Broad categories of productivity constraint factors in the road pavement maintenance and rehabilitation process showing their key components

4.8 Recommendations for Improving Productivity in Road Maintenance and Rehabilitation Projects

Results of the relative levels of contributions of the broad categories to the productivity and performance outcomes in New Zealand road pavement maintenance and rehabilitation projects (Figure 87) reveal where the greatest opportunities for productivity and performance improvement lie in the process: i.e. with the broad category offering the highest contribution to productivity outcomes. Figure 87 shows that workforce related issues have the highest contribution (over 14%) to productivity outcomes. Recommendations for improving productivity in road pavement maintenance and rehabilitation projects could therefore be made along the lines of addressing the identified influential sub-factors under the priority broad categories as follows.

Recommendations addressing the key sub-factors related to workforce issues

From Table 15, recommendations for improving workforce related issues could be as follows.

1. Improving leadership and management skills by regular training courses for enhancing management skills which includes technical skills, managerial skills, financial skills, IT skills, legal skills, communication skills and general skills, such as marketing, understanding the organisation and chairing meetings. These are essential skills for having successful, productive leaders and managers (Edum-Fotwe & McCaffer, 2000).
2. Improve motivation of the workforce by providing appropriate incentives such as rewards, bonuses, worker involvement in key decision making processes and career development plans (Khan, 1993).

Recommendations addressing the key sub-factors related to project management/ project team characteristics

From Table 15, recommendations for improving project management/ project team characteristic related issues could be as follows:

1- Apply sufficient consideration in design stage to avoid delays in project caused by changing designs or late order changes.

2- Providing better and sufficient planning and scheduling from the outset to have non-stop processes during a maintenance or rehabilitation project, also to avoid cost overrun and disputes (Assaf & Al-Hejji, 2006).

Recommendations addressing the key sub-factors related to project characteristics

From Table 15, recommendations for improving project characteristic related issues could be as follows:

1- Have a precise investigation from the planning phase to reduce site location and environmental constraints.

2- Predictive advanced planning & logistic issues impacting on continuous work flow (Lee, Ibbs, Harvey, & Roesler, 2000).

Recommendations addressing the key sub-factors related to project finance

From Table 15, recommendations for improving project finance related issues could be as follows:

1- Avoiding inaccurate estimates at the early stage of design by providing a proper estimation regime (Vassallo & Izquierdo, 2002).
2- To minimise the problem of lack of collaboration between consultant and contractors, the most important success factor would be creating mutual “goodwill trust” between partners (Olsson & Espling, 2004).

Recommendations addressing key sub-factors related to technology/process

From Table 15, recommendations for improving technology/process related issues could be as follows:

1- Providing sufficient training and time to bring workers up to speed on the use of new technology and also to give them a better understanding of ways of using a new technology. This could be lead to minimising resistance of accepting new technologies (Peansupap & Walker, 2005).

Recommendations addressing key sub-factors related to unforeseen events

From Table 15, recommendations for improving unforeseen event related issues could be as follows:

1- The effect of unforeseen events could be minimised with good pre-planning, proper risk analysis and contingency planning, and earlier program starts (start a project in the proper season).
2- Systematic assessment of the nature and sources of various hazards must be used to identify and differentiate the types of geotechnical risks

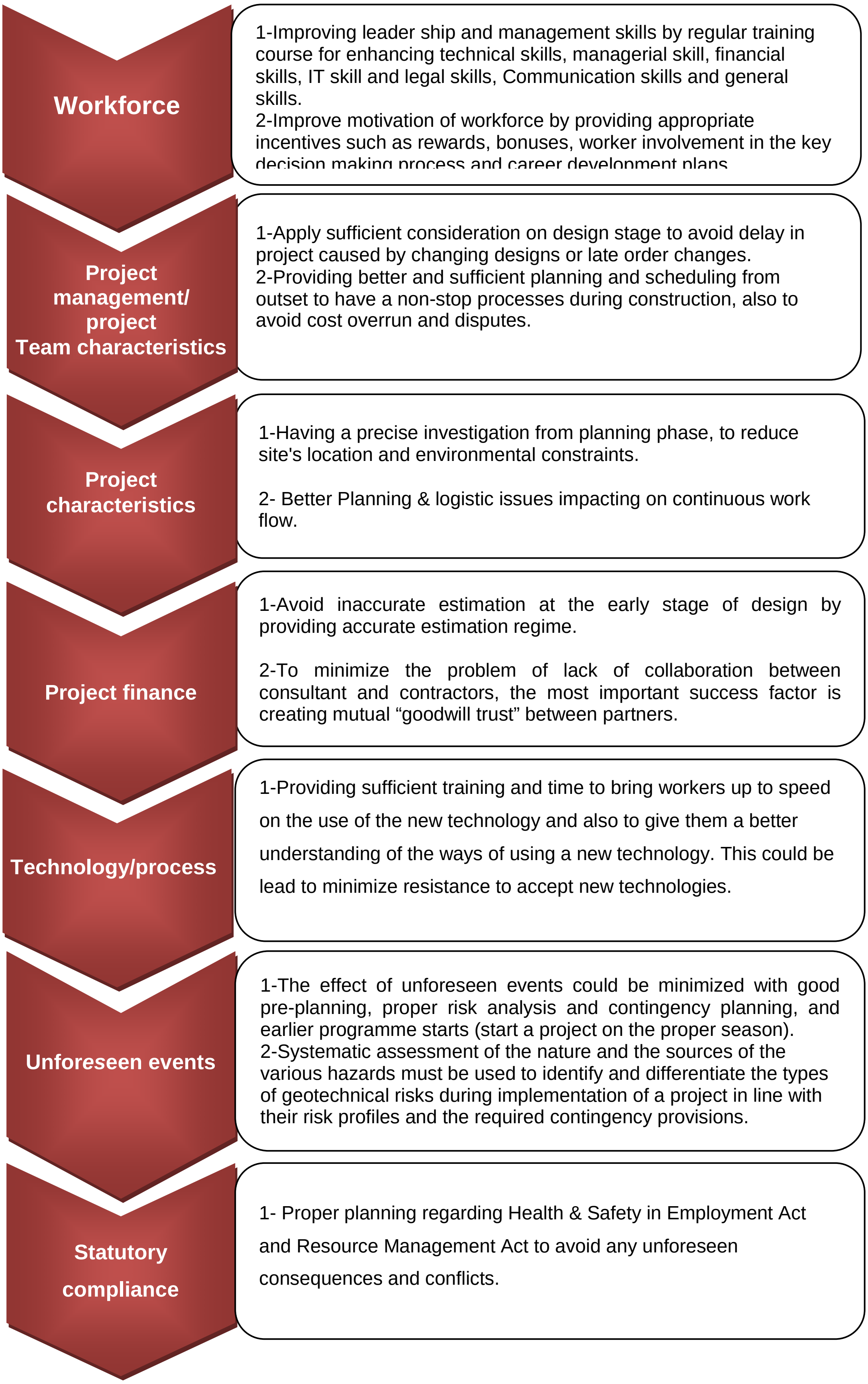
during implementation of a project, in line with their risk profiles and required contingency provisions (Baynes, 2010) .

Recommendations addressing key sub-factors related to statutory compliance

From Table 15, recommendations for improving statutory compliance related issues could be as follows:

1- Proper planning regarding H&S and resource management Act to avoid any unforeseen consequences and conflicts.

Figure 88 highlights recommendations for improving productivity along the lines of addressing the identified influential sub-factors under the priority broad categories.



Workforce

1-Improving leader ship and management skills by regular training course for enhancing technical skills, managerial skill, financial skills, IT skill and legal skills, Communication skills and general skills.
2-Improve motivation of workforce by providing appropriate incentives such as rewards, bonuses, worker involvement in the key decision making process and career development plans

Project management/ project Team characteristics

1-Apply sufficient consideration on design stage to avoid delay in project caused by changing designs or late order changes.
2-Providing better and sufficient planning and scheduling from outset to have a non-stop processes during construction, also to avoid cost overrun and disputes.

Project characteristics

1-Having a precise investigation from planning phase, to reduce site's location and environmental constraints.

2- Better Planning & logistic issues impacting on continuous work flow.

Project finance

1-Avoid inaccurate estimation at the early stage of design by providing accurate estimation regime.

2-To minimize the problem of lack of collaboration between consultant and contractors, the most important success factor is creating mutual "goodwill trust" between partners.

Technology/process

1-Providing sufficient training and time to bring workers up to speed on the use of the new technology and also to give them a better understanding of the ways of using a new technology. This could be lead to minimize resistance to accept new technologies.

Unforeseen events

1-The effect of unforeseen events could be minimized with good pre-planning, proper risk analysis and contingency planning, and earlier programme starts (start a project on the proper season).
2-Systematic assessment of the nature and the sources of the various hazards must be used to identify and differentiate the types of geotechnical risks during implementation of a project in line with their risk profiles and the required contingency provisions.

Statutory compliance

1- Proper planning regarding Health & Safety in Employment Act and Resource Management Act to avoid any unforeseen consequences and conflicts.

Figure 86: Recommendation for improving productivity in road maintenance and rehabilitation projects in New Zealand

Chapter 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research aimed at identifying productivity constraints in road maintenance and rehabilitation projects. Detailed investigation of management and project implementation processes was undertaken, and the priority influential constraints to productivity were explored through a survey of clients, consultants and contractors in the road maintenance and rehabilitation sector.

Results of the investigations and analysis into the road pavement maintenance and rehabilitation process revealed a 12 step approach that commences with the road surface inspection by the Council, validation of the Council's repair list by the contractors, project planning, preliminary tests, design, programming and scheduling, and estimation, through to project organisation, pre-seal repair, final quality checks and information update on the RAMM Contractor software at the completion stage. Productivity constraints lie in the various steps and build up to create the final productivity outcome in any given project. A framework for addressing constraint factors and for improving overall productivity and performance in the road pavement maintenance and rehabilitation process was provided to guide clients, consultants and contractors involved in the road pavement management sector.

Results of the analysis of the productivity constraint factors show seven broad categories, the most influential being workforce related issues. This was found to contribute 14.4% of the productivity outcomes in road pavement maintenance and rehabilitation projects. Other broad categories in diminishing order of influence comprise project management/project team characteristics, project characteristics, project finance, technology/process, unforeseen events and statutory compliance. Surprisingly, the external forces comprising economic, political and industry related sub-factors were not found to be significantly influential.

Under the broad category of workforce related factors, eight out of the 10 sub-factors identified during the pilot survey were analysed as being significant. The most significant sub-factor in this category was found to be lack of good leadership/management capability. Other significant sub-factors in diminishing order of influence comprise low level of motivation/commitment, low level of skill and experience of the workforce, poor monitoring or appraisal of performance, overly long working hours with insufficient rest periods, especially during night work, Inadequate empowerment (training and resourcing), poor resource leveling and lack of experience in current job and operational conditions.

The survey respondents provided additional sub-factors under each broad category, as well as comments on innovative ways of addressing the sub-factors with a view to improving productivity outcomes in relation to the broad constraint categories.

Based on the survey results, the following recommendations were put forward for improving productivity in the New Zealand road maintenance and rehabilitation industry.

- Improving leadership and management skills by regular training courses for enhancing management skills.
- Improving motivation of the workforce by providing appropriate incentives, such as rewards, bonuses, worker involvement in key decision making processes and career development plans.
- Applying sufficient consideration in design stage to avoid delay in the project caused by changing designs or late order changes.
- Providing better and more sufficient planning and scheduling from the outset to have a non-stop process during construction and to avoid cost overrun and disputes.
- Having a precise investigation from the planning phase to reduce site location and environmental constraints.
- Better planning of logistical issues impacting on continuous work flow (the effect of unforeseen events could be minimised with good pre-planning).

- Proper risk analysis and contingency planning, and earlier program starts (start a project on the proper season).
- Systematic assessment of the nature and sources of various hazards must be used to identify and differentiate the types of geotechnical risks during implementation of a project in line with their risk profiles and the required contingency provisions.
- Providing sufficient training and time to bring workers up to speed on the use of new technologies (to give them a better understanding of the ways of using a new technology).
- Avoiding inaccurate estimations at the early stage of design by providing an accurate estimation regime.
- Minimizing the problem of lack of collaboration between consultant and contractors. The most important success factor is creating mutual “goodwill trust” between partners.

Altogether, by considering the identified priority productivity constraints on road maintenance and rehabilitation projects and trying to tackle them, remarkable productive and efficient results are achievable.

5.2 Recommendations for Further Studies

This study focused on exploring productivity constraints in road maintenance and rehabilitation. However, there are many other issues that need further investigation to explore other influencing factors on improving productivity in this field.

During this study it was found that there was a lack of investigation on applying new technologies. New technologies, such as new road failure detection systems can improve productivity though setting up more preventive maintenance in New Zealand.

Furthermore, some other problems were found during this study, such as lack of a formal measurement regime applying to road maintenance for measuring performance and productivity in the road maintenance sector. Gill and Zuccollo (2012) also found the same issue*:*

> The first problem is that there is no cycle of performance measurement. Rather there is an open loop with limited direct and indirect feedback from the monitoring and measurement subsystem to the design of programmes and policies. This lack of a closed loop is impeding performance improvements being identified and implemented. The lack of measurement of the effectiveness of interventions, such as pavement treatments, inhibits learning and the development of asset management expertise (p. 1).

Therefore, this field could be another subject for future investigation.

Further investigations should also be focused on the effect of using new products and materials that give a longer life cycle to the road pavement, such as emulsified sealer/binder (GSB-88) on improving productivity in road maintenance and rehabilitation projects.

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APPENDICES:

APPENDIX A: DOCUMENTS USED IN PLANNING AND CONDUCTING THE PILOT SURVEYS AND QUESTIONNAIRE SURVEYS

APPENDIX B: APPROVAL FOR MUHEC LOW RISK NOTIFICATION

APPENDIX C: RESEARCH PROGRAMME

APPENDIX D: SAMPLE FORM IS FOR THE TREATMENT SELECTION

APPENDIX E: SAMPLE OF ROAD'S FAILURES SURVEY FORM

APPENDIX F: SAMPLE OF RATED RUTTING FAILURE DURING ALMOST 3 YEARS AT WITAKERE REGION

APPENDIX G: SAMPLE OF RATED ALLIGATPORS FAILURE DURING ALMOST 3 YEARS AT WITAKERE REGION

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APPENDIX A: DOCUMENTS USED IN PLANNING AND CONDUCTING THE PILOT SURVEYS AND QUESTIONNAIRE SURVEYS

A1: Covering letter for the pilot Interviews

A2: Participant consent form- Individual

A2: Sample copy of the pilot Interview questions

A3: Covering letter for the questionnaire survey

A4: Sample copy of the questionnaire

APPENDIX A1: Covering letter for the pilot Interviews

School of Engineering & Advanced Technology
Private Bag 120 904, North Shore City 0745
Auckland, New Zealand
Tel: +64 9 414 0800 extn 41544 Fax: +64 9 443 9774

Dear Sir/Madam

Survey Topic: **Improving Productivity in Road Pavement Maintenance and Rehabilitation in New Zealand**

My name is Saeed Karimian, a Master's research student of the School of Engineering and Advanced Technology, Massey University, New Zealand. My research is entitled, "**Improving Productivity in Road Pavement Maintenance and Rehabilitation in New Zealand** ".

The aim of this study is to investigate the level of impact and frequencies of occurrence of the key productivity constraints as well as establishing innovative ways of improving productivity in the road maintenance industry. The outcomes of the study are expected to guide efficiency planning, monitoring and performance, to improve productivity in the New Zealand future road projects.

The questions below will be asked to industry operatives who are involved in road pavement rehabilitation and maintenance projects. You have been selected to participate in the research survey based on your related experience in the field of road maintenance.

Participation in this research is voluntary and you are under no obligation to accept this invitation. However, feedback from representatives of reputable organizations or experts, such as you, will help to achieve the objectives of the study. I would therefore be grateful if you could grant me your time for this purpose. I assure you that your responses will be treated with strictest confidentiality and will be used solely for the purpose of this research.

I will highly appreciate your time and help for making this research a success. If you have any queries or want to have access to a summary of the project findings when it is concluded, please contact me through my contact details:

Saeed Haji Karimian
School of Engineering & Advanced Technology
Private Bag 102 904, North Shore City 0745

Auckland, New Zealand
Cell: +64 22 089 1217
Fax: +64 9 443 9774
Email: saeedhajikarimian@gmail.com

You may wish to contact my supervisors:

Dr. Jasper Mbachu
Senior Lecturer and coordinator, Construction Programs
School of Engineering & Advanced Technology
Private Bag 102 904, North Shore City 0745
Auckland, New Zealand
Tell: +64 9 414 0800 extn 41543
Fax: +64 9 4439774
Email: J.I.Mbachu@massey.ac.nz

Kacha Vuletich
Resurfacing Manager at Fulton Hogan
Waitakere City Council Road Maintenance Contract
40 Flexman Place
PO Box 305, Silverdale, 0944, New Zealand
Phone +64 9 427 0447 Ext 9327
kacha.vuletich@fultonhogan.com

Saeed Haji Karimian (Researcher)

Yours faithfully

APPENDIX A2: Participant consent form- Individual

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

School of Engineering & Advanced Technology
Private Bag 120 904, North Shore City 0745
Auckland, New Zealand
Tel: +64 9 414 0800 extn 41544 Fax: +64 9 443 9774

Improving Productivity in Road Pavement Maintenance and Rehabilitation in New Zealand

PARTICIPANT CONSENT FORM- INDIVIDUAL

I have read the information sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: **Date:**

Full Name:

APPENDIX A2: Sample copy of the pilot Interview questions

QUESTIONS:

1- What aspects of the road pavement maintenance work are you involved in?

Repairing patches within the network

2- How would you define productivity in the context of road pavement maintenance and rehabilitation?

Patches are small and time consuming, rehab work has larger areas where plant can be utilized better

Based on your experiences, how do you think performance could be improved in your section of the road rehabilitation and maintenance process?

a) Larger areas to ensure we don't revisit the same area of the network regularly

b) Do all work in the area so we don't go back for a few years

c) Using new products so we can recycle the same road latter down the track

d) Think outside the square when it comes to rehab and Maintenance.

3- What is your current position within your company?

Divisional Manager

4- How many years of work experience have you had in your current position?

Six years

5- Do you have further comments on the issues around productivity in the road pavement rehabilitation and maintenance projects and how these could be improved?

Thank you for your time. Your inputs to this study are greatly appreciated. If you would like to have summary of the key findings of the study, you may advise your contact address for sending you the feedback.

C/O: _Bob Wilson ______________________

Fax: _______________________

Email: ___bob .wilson@fultonhogan.com____________________

Disclaimer: This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher named above is responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher, please contact Professor John O'Neill, Director (research Ethics), telephone 06 350 5249, e-mail humanethics@massey.ac.nz

APPENDIX A3: Sample of covering letter for the questionnaire survey

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

School of Engineering & Advanced Technology
Private Bag 120 904, North Shore City 0745
Auckland, New Zealand
Tel: +64 9 414 0800 extn 41544 Fax: +64 9 443 9774

Improving Productivity in Road Pavement Maintenance and Rehabilitation in New Zealand

Dear Daniel

We are conducting a research survey which looks at how productivity and performance could be improved in the road pavement rehabilitation and maintenance operations in New Zealand.

Based on an online search engine or through personal referral, you have been selected to participate in the survey as one of the key service providers in the New Zealand roading sector. We'll appreciate 15 -20 minutes of your time in responding to the survey online at:

https://www.surveymonkey.com/s/Improving-Productivity-in-Road-Pavement-Rehabilitation-and-Maintenance-in-New-Zealand.

We'll also appreciate it if you could forward the link to your colleagues or associates who are involved in the road pavement rehabilitation and maintenance services.

All responses to the survey will be treated in confidence and used solely for research purposes without linking the responses to individuals or firms.

By participating in the survey, you'll be contributing to the advancement of research in New Zealand and the improvement of productivity and performance of the roading sector.

Please feel free to contact us if you require more information or you would like to request for the research result.

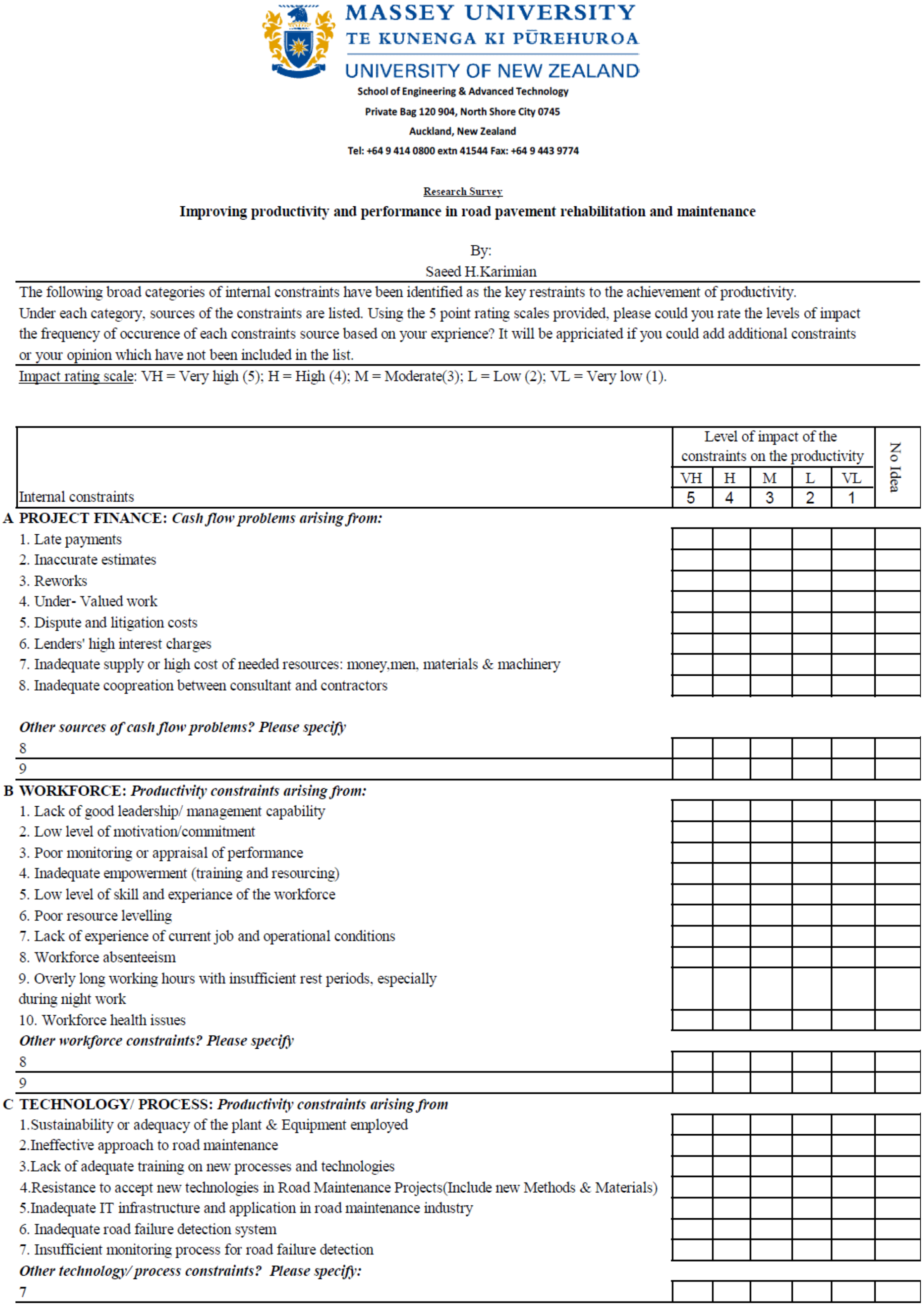
Many thanks in advance for your anticipated participation and useful feedback.

Regards,

Saeed Karimian(Researcher)
School of Engineering and Advanced Technology,
Massey University

Kacha Vuletich (Industry Supervisor)
Resurfacing & Asset Manager
Fulton Hogan Limited.

APPENDIX A4: Sample copy of the questionnaire



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Research Survey

Improving productivity and performance in road pavement rehabilitation and maintenance

By:
Saeed H.Karimian

The following broad categories of internal constraints have been identified as the key restraints to the achievement of productivity. Under each category, sources of the constraints are listed. Using the 5 point rating scales provided, please could you rate the levels of impact the frequency of occurence of each constraints source based on your exprience? It will be appriciated if you could add additional constraints or your opinion which have not been included in the list.

Impact rating scale: VH = Very high (5); H = High (4); M = Moderate(3); L = Low (2); VL = Very low (1).

Internal constraints	Level of impact of the constraints on the productivity VH 5	 H 4	 M 3	 L 2	 VL 1	No Idea
A **PROJECT FINANCE:** ***Cash flow problems arising from:***						
1. Late payments						
2. Inaccurate estimates						
3. Reworks						
4. Under- Valued work						
5. Dispute and litigation costs						
6. Lenders' high interest charges						
7. Inadequate supply or high cost of needed resources: money,men, materials & machinery						
8. Inadequate coopreation between consultant and contractors						
Other sources of cash flow problems? Please specify						
8						
9						
B **WORKFORCE:** ***Productivity constraints arising from:***						
1. Lack of good leadership/ management capability						
2. Low level of motivation/commitment						
3. Poor monitoring or appraisal of performance						
4. Inadequate empowerment (training and resourcing)						
5. Low level of skill and experiance of the workforce						
6. Poor resource levelling						
7. Lack of experience of current job and operational conditions						
8. Workforce absenteeism						
9. Overly long working hours with insufficient rest periods, especially during night work						
10. Workforce health issues						
Other workforce constraints? Please specify						
8						
9						
C **TECHNOLOGY/ PROCESS:** ***Productivity constraints arising from***						
1.Sustainability or adequacy of the plant & Equipment employed						
2.Ineffective approach to road maintenance						
3.Lack of adequate training on new processes and technologies						
4.Resistance to accept new technologies in Road Maintenance Projects(Include new Methods & Materials)						
5.Inadequate IT infrastructure and application in road maintenance industry						
6. Inadequate road failure detection system						
7. Insufficient monitoring process for road failure detection						
Other technology/ process constraints? Please specify:						
7						

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Research Survey

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By:
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The following broad categories of internal constraints have been identified as the key restraints to the achievement of productivity. Under each category, sources of the constraints are listed. Using the 5 point rating scales provided, please could you rate the levels of impact the frequency of occurence of each constraints source based on your exprience? It will be appriciated if you could add additional constraints or your opinion which have not been included in the list.

Impact rating scale: VH = Very high (5); H = High (4); M = Moderate(3); L = Low (2); VL = Very low (1).

	Level of impact of the constraints on the productivity					No Idea
	VH	H	M	L	VL	
Internal constraints	5	4	3	2	1	
D PROJECT CHARACRERISTICS: ***Productivity constraints arising from:***						
1.Planning & logistic issues impacting on continuous work flow (e.g non-closure period)						
2. Un-conducive time frames within which most road works must be carried out						
3.Site's location and environmental constraints (e.g. traffic volume, climate, subsoil and topography)						
4.Public notification issues (e.g. community and environmentalists' resistance to infrastructure development plans)						
5. Nature and significance of road in the Road Hierarchy						
6. Project complexity: scale, design						
7. Type of procurement adopted						
8. Relation between rehab size and plant utilization						
Other project characteristic constraints? Please specify						
5						
9						
E PROJECT MANAGEMENT/ PROJECT TEAM CHARACTERISTIC						
Productivity constraints arising from:						
1. Lack of sufficient planning from the outset						
2. Poor project management and risk management processes						
3. Lack of effective communication among key stakeholders						
4. Lack of proper and regular coordination; supervision; performance monitoring and control						
5. Lack of project organisational culture that supports high productivity and performance						
6.Relationship management/ degree of harmony, trust and cooperation between contractor, consultant and council						
7. Experience and competencies of the project team						
8. Frequency of design changes/ change orders/late changes						
9. Client's overt influence on the project process						
10. Poor sufficient supply chain management, especially as it relates to "just-in-time" supply principles						
11. Lack of organizational learning: (applying lessons learnt from previous projects to solving challenges in current project)						
Other project management constraints? Please specify						
8						
9						

2. The following broad categories of external constraints have been identified as the key restraints to the achievement of productivity. Under each category, sources of the constraint are listed. Using the 5-point rating scales as before, pleased could you rate the levels of impact and the frequency of occurence of each constraint source based on your exprience? It will be appreciated if you could add other constraints which have not been included in the list.

	Level of impact of the constraints on the productivity					No Idea
	VH	H	M	L	VL	
External constraints	5	4	3	2	1	
A STATUTORY COMPLIANCE: ***Productivity impediment arising from compliance with:***						
1. Health & Safety in Employment Act						
2. Resource Management Act						
3. Local Authority Bylaws						
4.Construction Contracts Act						
5. Employment Relations Act						
6. Consumer Guarantees Act						
7. Fair Trading Act						
Other compliance issues? Please specify:						
10						
11						
B UNFORSEEN EVENTS: ***Productivity impediments arising from unforseen events:***						
1. Inclement weather						
2. Unforeseeable ground conditions necessitating revisions						
3. On-site accidents/ Acts of God						
4. Natural disasters						
Other unforseen events issues? Please specify						
5						
6						

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Research Survey

Improving productivity and performance in road pavement rehabilitation and maintenance

By:
Saeed H.Karimian

The following broad categories of external constraints have been identified as the key restraints to the achievement of productivity. Under each category, sources of the constraints are listed. Using the 5 point rating scales provided, please could you rate the levels of impact the frequency of occurence of each constraints source based on your exprience? It will be appriciated if you could add additional constraints or your opinion which have not been included in the list.

Impact rating scale: VH = Very high (5); H = High (4); M = Moderate(3); L = Low (2); VL = Very low (1).

External constraints	Level of impact of the constraints on the productivity					No Idea
	VH	H	M	L	VL	
	5	4	3	2	1	
C **OTHER EXTERNAL FORCES:** ***Productivity constraints arising from misellaneous including:***						
1. Inflation/ fluctuations in material prices						
2. Fluctuations in Exchange rate						
3. Energy crises/ costs						
4. Intrest rate/ cost of capital						
5. Market conditions and level of competitions in the industry for jobs						
6. Frequent changes in government policies/ legislations impacting on construction						
Other constraints from miscellaneous sources? Please specify						
9						

3. For the broad categories of internal and external constraints mentioned before, how would you rate their relative levels of impact on the achievement of on-site productivity as well as their occurrence frequencies? Five- point rating scales have been provided as before.

Broad categories of internal and external constraints	Level of impact of the					No Idea
	VH	H	M	L	VL	
	5	4	3	2	1	
1. Project finance						
2. Workforce						
3. Technology/ process						
4. Project charactiristics						
5. Statutory compliance						
6. Unforseen events						
7. Project management/ project team characteristics						
8. Other External forces (economic, political, industry, etc)						

4. If there is one piece of advice you can give to improve productivity in the New Zealand Road Maintenance industry, what would that be? (You are welcome to supply more than one piece of advice, if you choose to!)

SECTION II: DEMOGRAPHIC BACKGROUND

1. Kindly indicate only one of the following as your most frequent role as a member of the project team:

Consultant ☐ Contractor ☐
Client/ owner ☐ Subcontractor ☐
Other (please specify): ☐

2. Kindly indicate how long have you been working in the industry in the above capacity?

More than 25 years ☐ 10-14 years ☐
20-25 years ☐ 5-9 years ☐
15-19 years ☐ lower than 5 years ☐

3. Kindly indicate your status in the organization

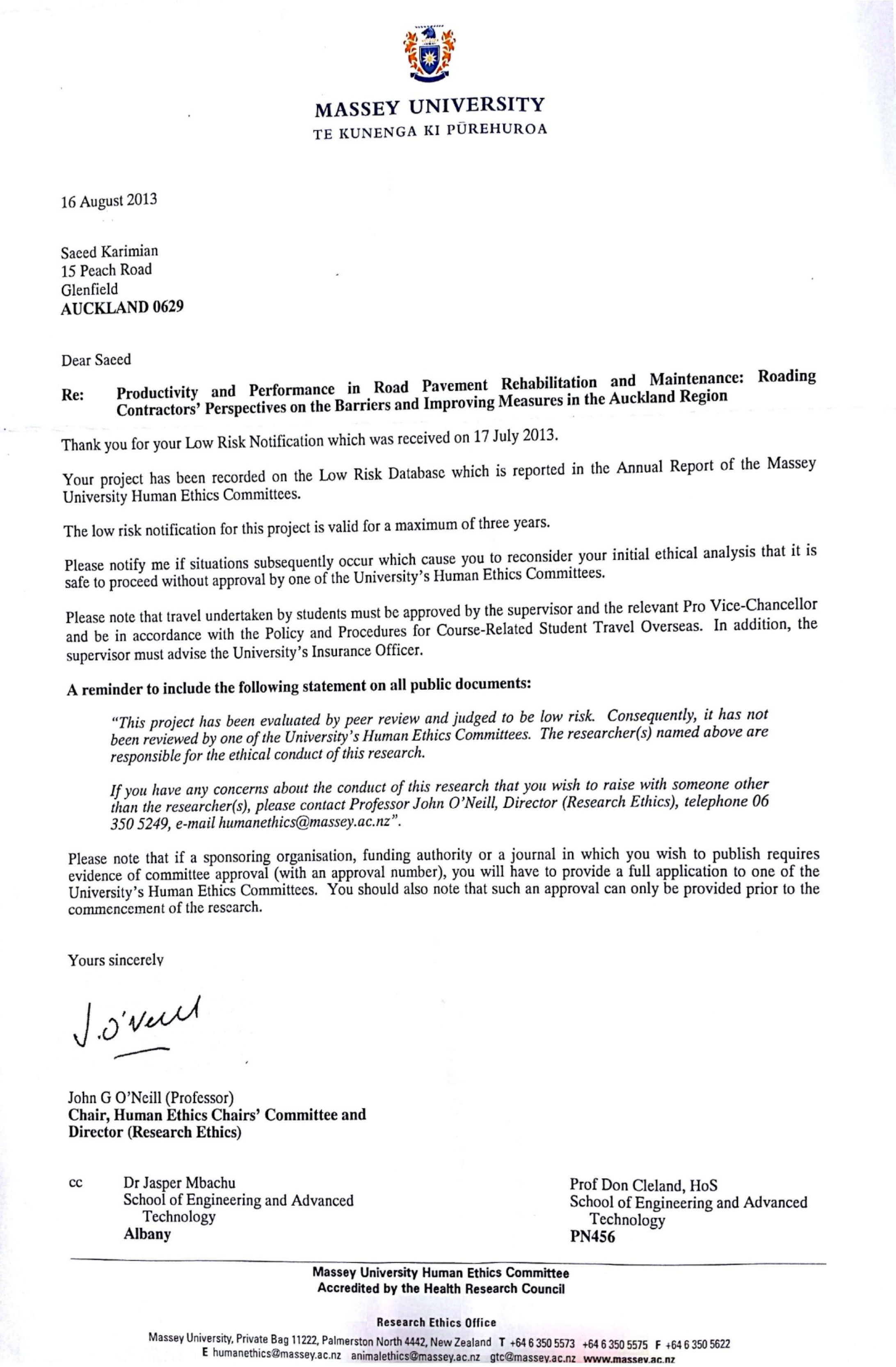
Director/ Executive Director ☐ General forman/ Section head ☐
Manager/ Associate Director ☐ Team Leader/ Supervisor ☐
Other (please specify): ☐

APPENDIX B: APPROVAL FOR MUHEC LOW RISK NOTIFICATION

B1: Letter of Approval for MUHEC Low Risk Notification

B2: Screening Questionnaire to Determine the Approval Procedure

APPENDIX B1: Letter of Approval for MUHEC Low Risk Notification



MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA

16 August 2013

Saeed Karimian
15 Peach Road
Glenfield
AUCKLAND 0629

Dear Saeed

Re: Productivity and Performance in Road Pavement Rehabilitation and Maintenance: Roading Contractors' Perspectives on the Barriers and Improving Measures in the Auckland Region

Thank you for your Low Risk Notification which was received on 17 July 2013.

Your project has been recorded on the Low Risk Database which is reported in the Annual Report of the Massey University Human Ethics Committees.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis that it is safe to proceed without approval by one of the University's Human Ethics Committees.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

A reminder to include the following statement on all public documents:

> *"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.*
>
> *If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director (Research Ethics), telephone 06 350 5249, e-mail humanethics@massey.ac.nz".*

Please note that if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to provide a full application to one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

J.O'Neill

John G O'Neill (Professor)
Chair, Human Ethics Chairs' Committee and
Director (Research Ethics)

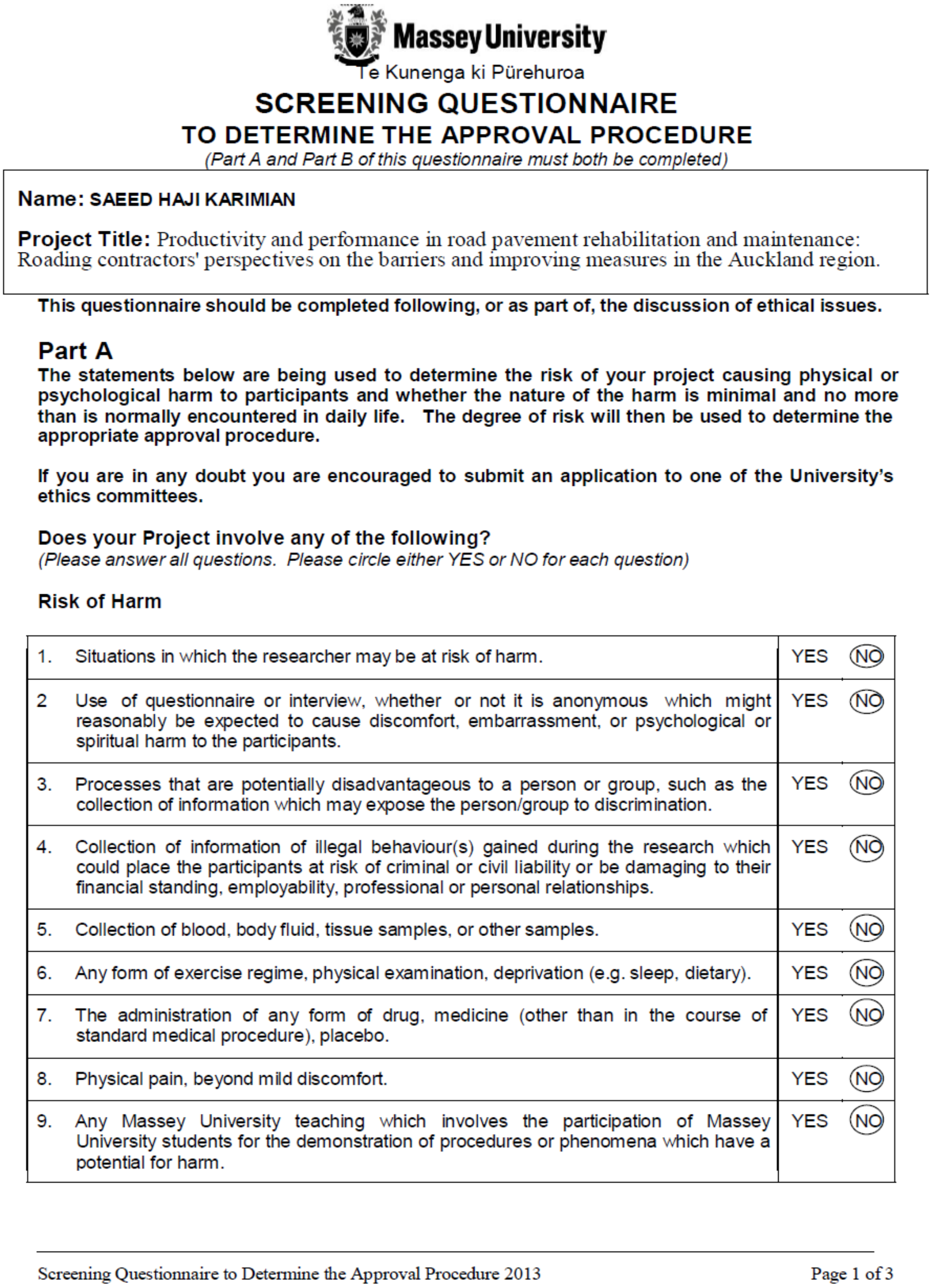
cc Dr Jasper Mbachu
School of Engineering and Advanced Technology
Albany

Prof Don Cleland, HoS
School of Engineering and Advanced Technology
PN456

Massey University Human Ethics Committee
Accredited by the Health Research Council

Research Ethics Office
Massey University, Private Bag 11222, Palmerston North 4442, New Zealand **T** +64 6 350 5573 +64 6 350 5575 **F** +64 6 350 5622
E humanethics@massey.ac.nz animalethics@massey.ac.nz gtc@massey.ac.nz **www.massey.ac.nz**

APPENDIX B2: Screening Questionnaire to Determine the Approval Procedure



Massey University
Te Kunenga ki Pūrehuroa

SCREENING QUESTIONNAIRE
TO DETERMINE THE APPROVAL PROCEDURE

(Part A and Part B of this questionnaire must both be completed)

Name: SAEED HAJI KARIMIAN

Project Title: Productivity and performance in road pavement rehabilitation and maintenance: Roading contractors' perspectives on the barriers and improving measures in the Auckland region.

This questionnaire should be completed following, or as part of, the discussion of ethical issues.

Part A

The statements below are being used to determine the risk of your project causing physical or psychological harm to participants and whether the nature of the harm is minimal and no more than is normally encountered in daily life. The degree of risk will then be used to determine the appropriate approval procedure.

If you are in any doubt you are encouraged to submit an application to one of the University's ethics committees.

Does your Project involve any of the following?
(Please answer all questions. Please circle either YES or NO for each question)

Risk of Harm

1.	Situations in which the researcher may be at risk of harm.	YES [✓ NO]
2	Use of questionnaire or interview, whether or not it is anonymous which might reasonably be expected to cause discomfort, embarrassment, or psychological or spiritual harm to the participants.	YES [✓ NO]
3.	Processes that are potentially disadvantageous to a person or group, such as the collection of information which may expose the person/group to discrimination.	YES [✓ NO]
4.	Collection of information of illegal behaviour(s) gained during the research which could place the participants at risk of criminal or civil liability or be damaging to their financial standing, employability, professional or personal relationships.	YES [✓ NO]
5.	Collection of blood, body fluid, tissue samples, or other samples.	YES [✓ NO]
6.	Any form of exercise regime, physical examination, deprivation (e.g. sleep, dietary).	YES [✓ NO]
7.	The administration of any form of drug, medicine (other than in the course of standard medical procedure), placebo.	YES [✓ NO]
8.	Physical pain, beyond mild discomfort.	YES [✓ NO]
9.	Any Massey University teaching which involves the participation of Massey University students for the demonstration of procedures or phenomena which have a potential for harm.	YES [✓ NO]

Screening Questionnaire to Determine the Approval Procedure 2013 Page 1 of 3

Informed and Voluntary Consent

10. Participants whose identity is known to the researcher giving oral consent rather than written consent (if participants are anonymous you may answer No).	YES [✓ NO]
11. Participants who are unable to give informed consent.	YES [✓ NO]
12. Research on your own students/pupils.	YES [✓ NO]
13. The participation of children (seven (7) years old or younger).	YES [✓ NO]
14. The participation of children under sixteen (16) years old where active parental consent is not being sought.	YES [✓ NO]
15. Participants who are in a dependent situation, such as those who are under custodial care, or residents of a hospital, nursing home or prison or patients highly dependent on medical care.	YES [✓ NO]
16. Participants who are vulnerable.	YES [✓ NO]
17. The use of previously collected identifiable personal information or research data for which there was no explicit consent for this research.	YES [✓ NO]
18. The use of previously collected biological samples for which there was no explicit consent for this research.	YES [✓ NO]

Privacy/Confidentiality Issue

19. Any evaluation of organisational services or practices where information of a personal nature may be collected and where participants or the organisation may be identified.	YES [✓ NO]

Deception

20. Deception of the participants, including concealment and covert observations.	YES [✓ NO]

Conflict of Interest

21. Conflict of interest situation for the researcher (e.g. is the researcher also the lecturer/teacher/treatment-provider/colleague or employer of the research participants or is there any other power relationship between the researcher and research participants?)	YES [✓ NO]

Compensation to Participants

22. Payments or other financial inducements (other than reasonable reimbursement of travel expenses or time) to participants.	YES [✓ NO]

Procedural

23. A requirement by an outside organisation (e.g. a funding organisation or a journal in which you wish to publish) for Massey University Human Ethics Committee approval.	YES [✓ NO]

Part B

FOR PROPOSED HEALTH AND DISABILITY RESEARCH ONLY

Not all health and disability research requires review by a Health and Disability Ethics Committee (HDEC).

Your study is likely to require HDEC review if it involves:

- **human participants recruited in their capacity as:**
    - **consumers of health or disability support services; or**
    - **relatives or caregivers of such consumers; or**
    - **volunteers in clinical trials; or**
- **human tissue; or**
- **health information.**

In order to establish whether or not HDEC review is required: (i) read the Massey University Digest of the HDEC Scope of Review standard operating procedure; (ii) work through the 'Does your study require HDEC review?' flowchart; and (iii) answer Question 24 below.

If you are still unsure whether your project requires HDEC approval, please email the Ministry of Health for advice (hdecs@moh.govt.nz) and keep a copy of the response for your records.

24. Is HDEC review required for this study?	YES [✓ NO]

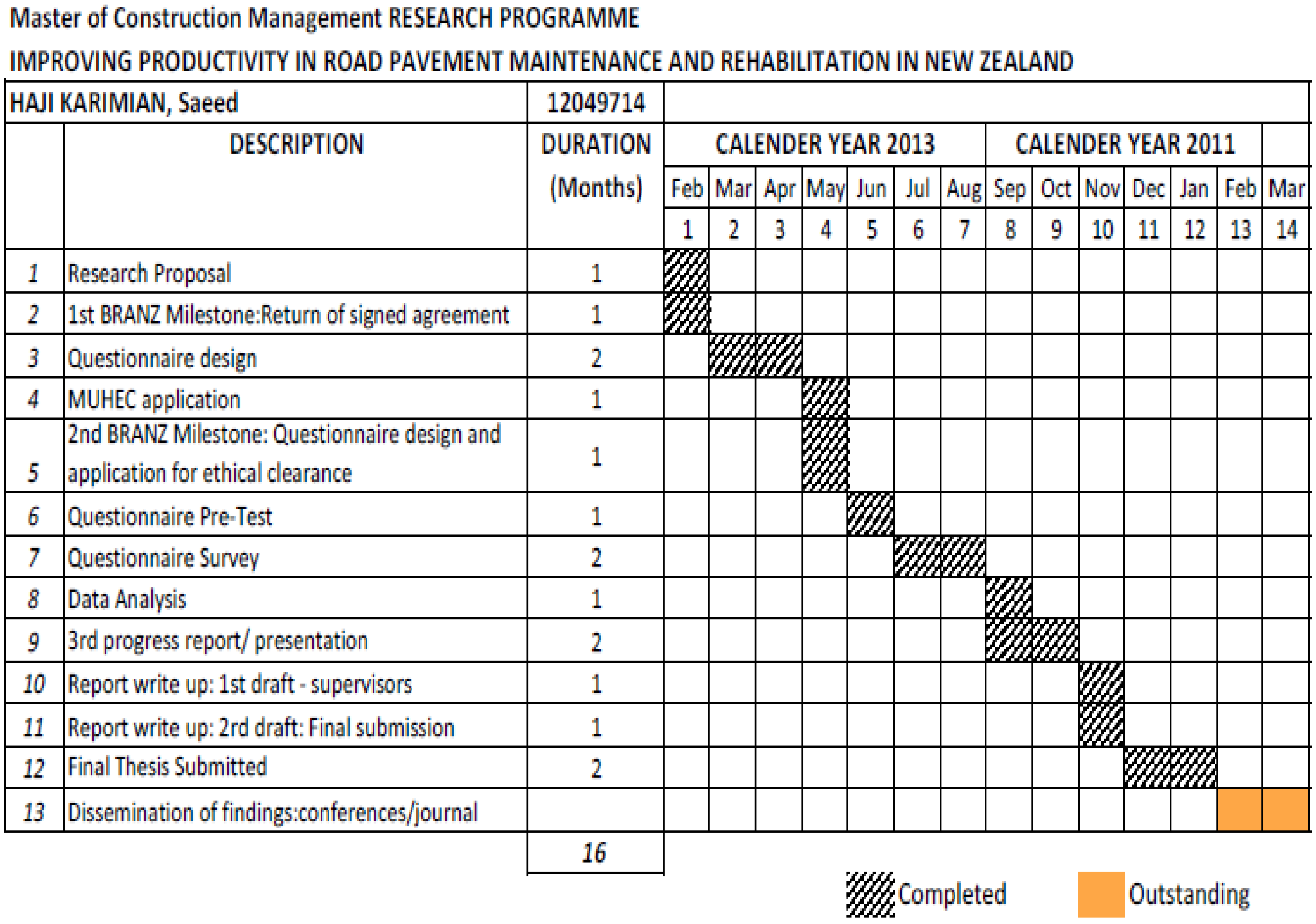
Select the appropriate procedure to be used (choose one option):

If you answer **YES** to any of the questions 1 to 23 (Part A) and **NO** to Q24 in Part B	If you answer **YES** to question 24 (Part B)	If you answer **NO** to all of the questions in Parts A and B*
↓	↓	↓
Prepare an application using the **MUHEC Application Pack**	**Prepare an application using the** **Health & Disability Ethics Committee Application Form**	**Prepare a** **Low Risk Notification** ** Note- researchers who are new to the University, new to research with human participants or for whom Committee approval is desirable are welcome to send in a full MUHEC application, even if the Screening Questionnaire questions have all been answered "no".*
↓		↓

GO BACK TO APPROVAL PROCEDURES, STEP 4, AND DOWNLOAD THE INFORMATION REQUIRED.

http://www.massey.ac.nz/massey/research/research-ethics/human-ethics/approval.cfm

APPENDIX C: RESEARCH PROGRAMME



Master of Construction Management RESEARCH PROGRAMME

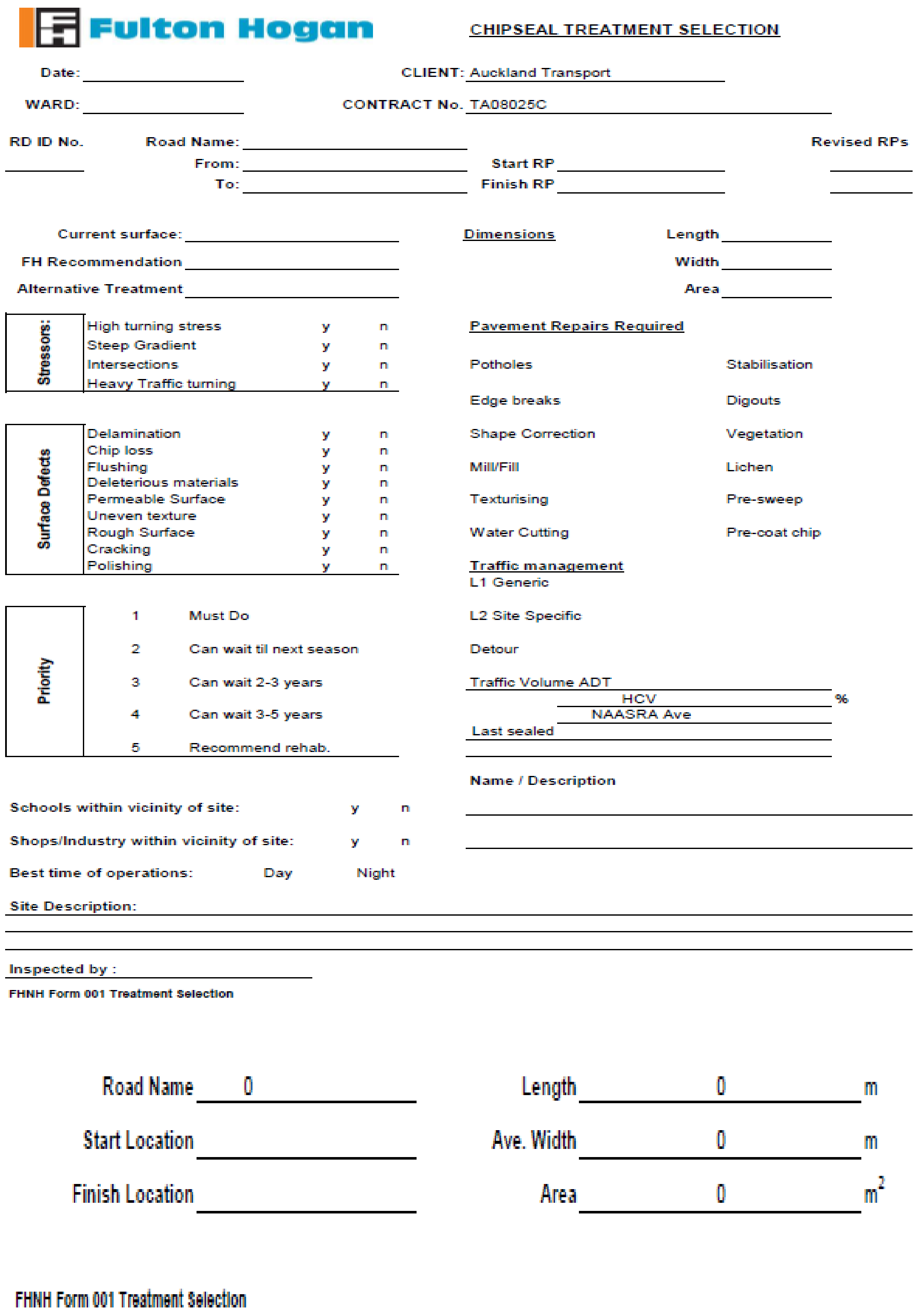
IMPROVING PRODUCTIVITY IN ROAD PAVEMENT MAINTENANCE AND REHABILITATION IN NEW ZEALAND

HAJI KARIMIAN, Saeed		12049714														
	DESCRIPTION	DURATION (Months)	CALENDER YEAR 2013							CALENDER YEAR 2011						
			Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Research Proposal	1	▨													
2	1st BRANZ Milestone:Return of signed agreement	1	▨													
3	Questionnaire design	2		▨	▨											
4	MUHEC application	1				▨										
5	2nd BRANZ Milestone: Questionnaire design and application for ethical clearance	1				▨										
6	Questionnaire Pre-Test	1					▨									
7	Questionnaire Survey	2						▨	▨							
8	Data Analysis	1								▨						
9	3rd progress report/ presentation	2								▨	▨					
10	Report write up: 1st draft - supervisors	1										▨				
11	Report write up: 2rd draft: Final submission	1										▨				
12	Final Thesis Submitted	2											▨	▨		
13	Dissemination of findings:conferences/journal														🟧	🟧
		16														

▨ Completed 🟧 Outstanding

APPENDIX D: SAMPLE FORM IS FOR THE TREATMENT SELECTION.

(Courtesy of Fulton Hogan)



Fulton Hogan

CHIPSEAL TREATMENT SELECTION

Date: ____________________

CLIENT: Auckland Transport

WARD: ____________________

CONTRACT No. TA08025C

RD ID No. ____________

Road Name: ____________________

From: ____________________

To: ____________________

Start RP ____________________

Finish RP ____________________

Revised RPs ____________ ____________

Current surface: ____________________

FH Recommendation ____________________

Alternative Treatment ____________________

Dimensions

Length ____________

Width ____________

Area ____________

Stressors:	High turning stress	y	n
	Steep Gradient	y	n
	Intersections	y	n
	Heavy Traffic turning	y	n

Surface Defects	Delamination	y	n
	Chip loss	y	n
	Flushing	y	n
	Deleterious materials	y	n
	Permeable Surface	y	n
	Uneven texture	y	n
	Rough Surface	y	n
	Cracking	y	n
	Polishing	y	n

Priority	1	Must Do
	2	Can wait til next season
	3	Can wait 2-3 years
	4	Can wait 3-5 years
	5	Recommend rehab.

Pavement Repairs Required

Potholes	Stabilisation
Edge breaks	Digouts
Shape Correction	Vegetation
Mill/Fill	Lichen
Texturising	Pre-sweep
Water Cutting	Pre-coat chip

Traffic management

L1 Generic

L2 Site Specific

Detour

Traffic Volume ADT ____________________

HCV ____________________ %

NAASRA Ave ____________________

Last sealed ____________________

Name / Description

____

____

Schools within vicinity of site: y n

Shops/Industry within vicinity of site: y n

Best time of operations: Day Night

Site Description: ____________________

Inspected by : ____________________

FHNH Form 001 Treatment Selection

Road Name 0

Start Location ____________________

Finish Location ____________________

Length 0 m

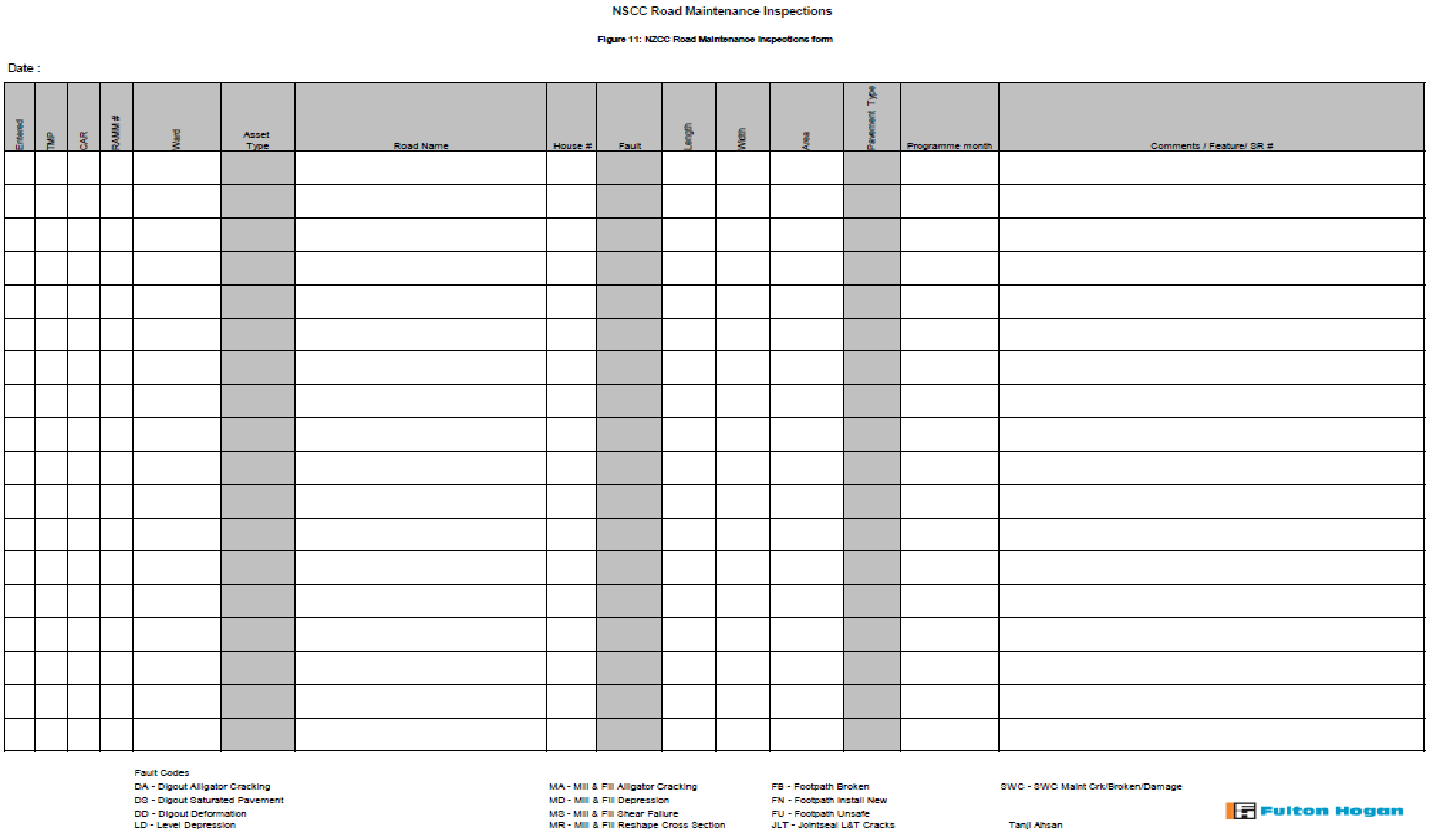
Ave. Width 0 m

Area 0 m2

FHNH Form 001 Treatment Selection

APPENDIX E: SAMPLE OF ROAD'S FAILURES SURVEY FORM

(Courtesy of Fulton Hogan)



NSCC Road Maintenance Inspections

Figure 11: NZCC Road Maintenance Inspections form

Date :

Entered	TMP	CAR	RAMM #	Ward	Asset Type	Road Name	House #	Fault	Length	Width	Area	Pavement Type	Programme month	Comments / Feature/ SR #

Fault Codes

DA - Digout Alligator Cracking
DS - Digout Saturated Pavement
DD - Digout Deformation
LD - Level Depression

MA - Mill & Fill Alligator Cracking
MD - Mill & Fill Depression
MS - Mill & Fill Shear Failure
MR - Mill & Fill Reshape Cross Section

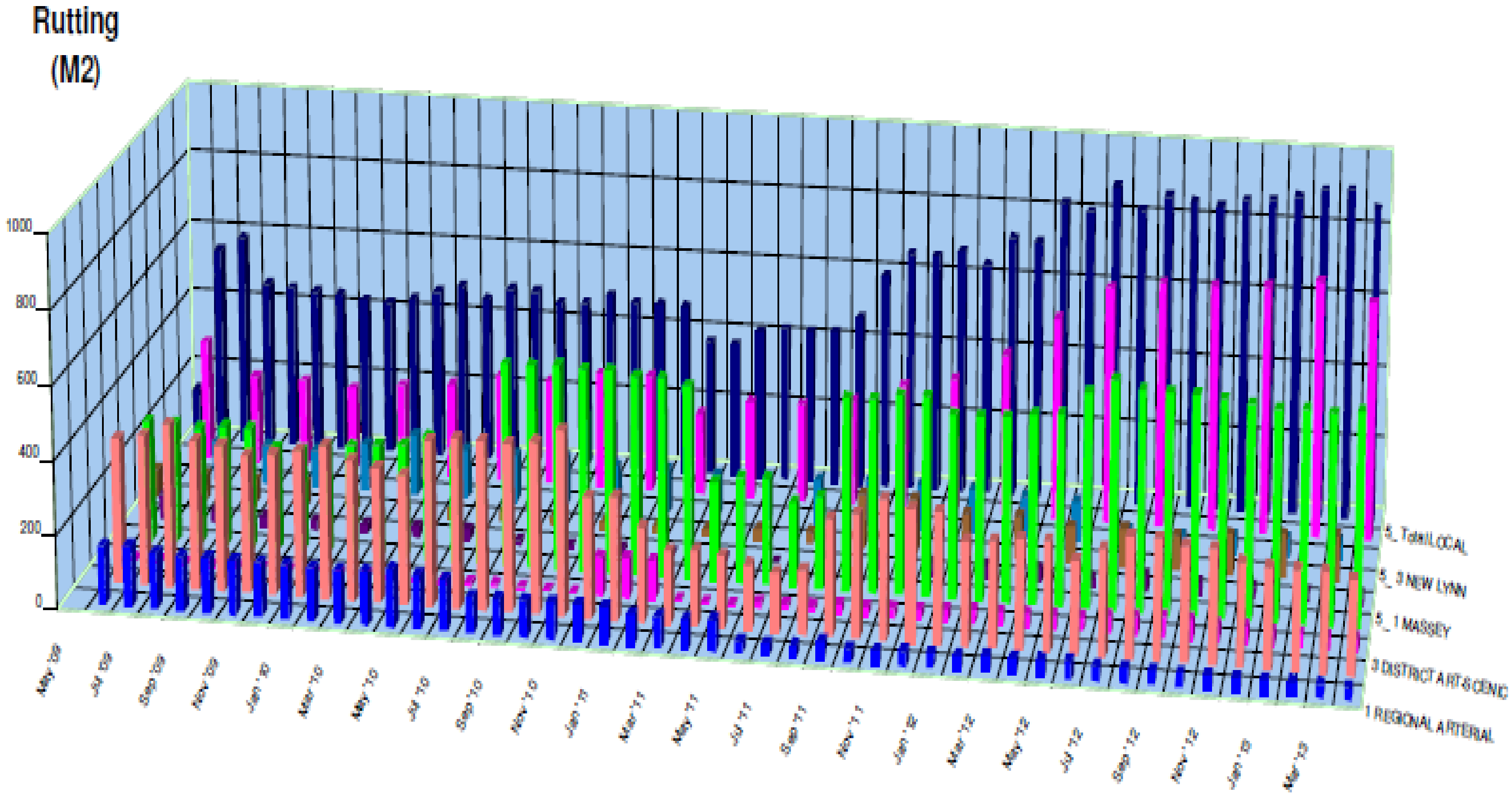
FB - Footpath Broken
FN - Footpath Install New
FU - Footpath Unsafe
JLT - Jointseal L&T Cracks

SWC - SWC Maint Crk/Broken/Damage

Tanji Ahsan

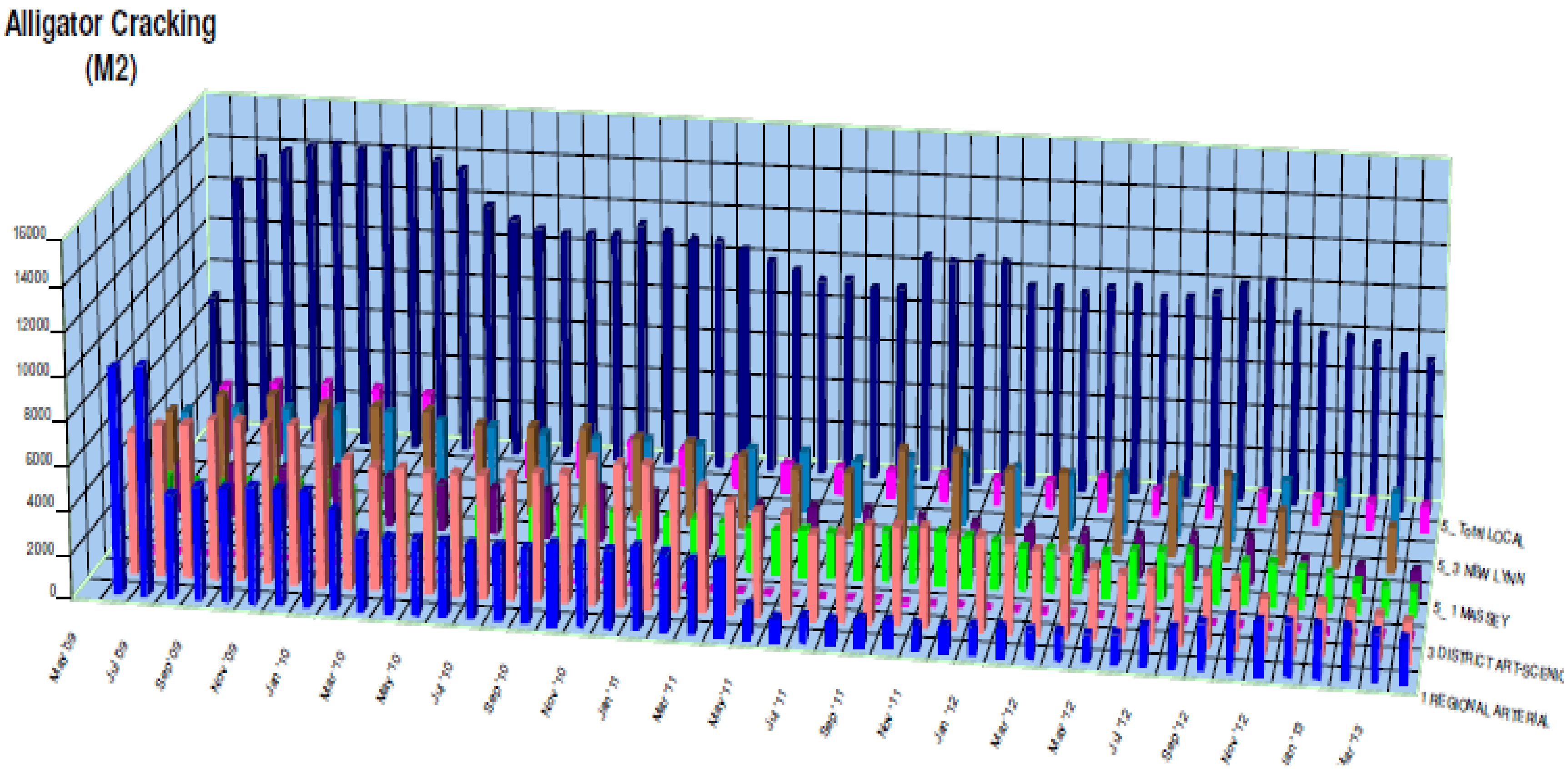
Fulton Hogan

APPENDIX F: SAMPLE OF RATED RUTTING FAILURES DURING ALMOST 3 YEARS AT WITAKERE REGION



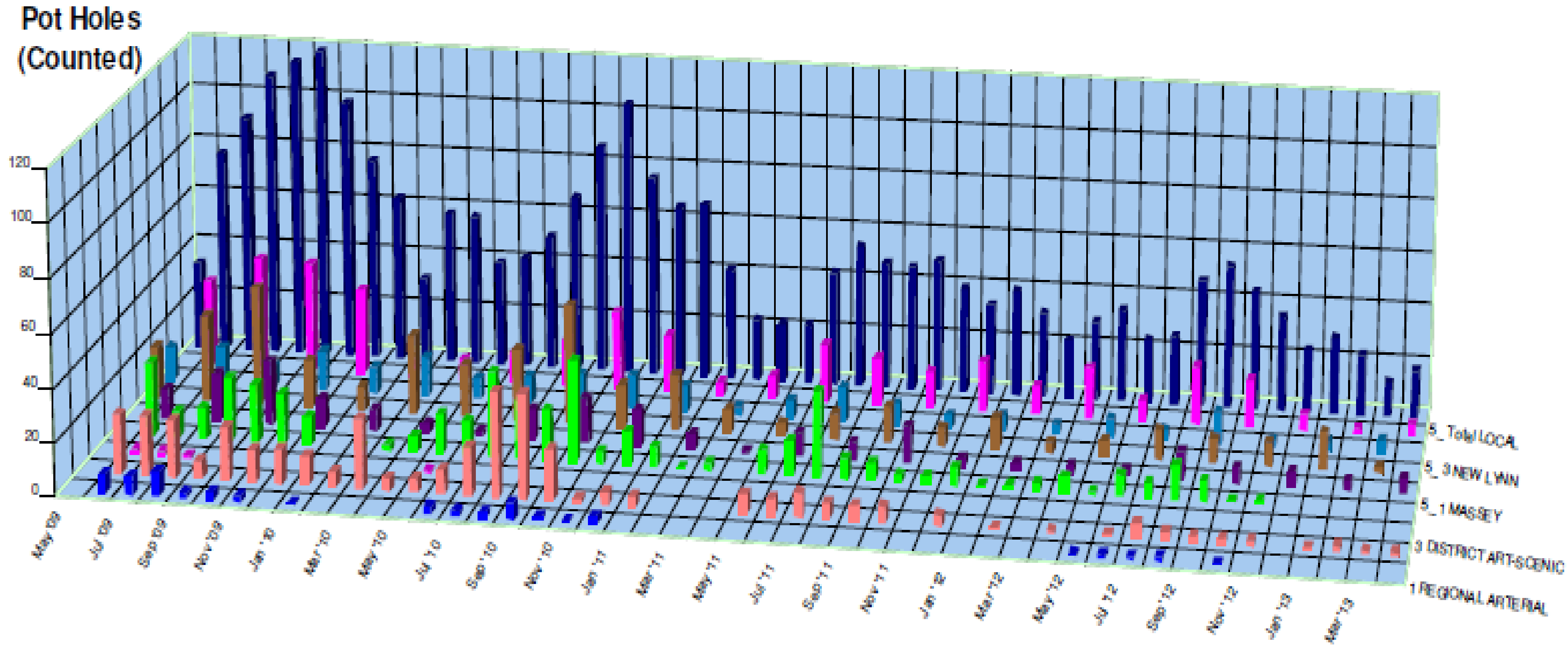
Source: Fulton Hogan's Monthly report, prepared by ONSITE DEVELOPMENT LTD. 30 April 2013.

APPENDIX G: SAMPLE OF RATED ALLIGATOR FAILURES DURING ALMOST 3 YEARS AT WITAKERE REGION



Source: Fulton Hogan's Monthly report, prepared by ONSITE DEVELOPMENT LTD. 30 April 2013.

APPENDIX H: SAMPLE OF RATED POTHOLE FAILURES DURING ALMOST 3 YEARS AT WITAKERE REGION



Source: Fulton Hogan's Monthly report, prepared by ONSITE DEVELOPMENT LTD. 30 April 2013