University of Southern Queensland

Faculty of Engineering and Surveying

Determination of a Strategic Planning Approach for Maintenance Management of a Major Road Network

A dissertation submitted by

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Abstract

Road transport plays a major role in the Australian economy allowing people to travel to work and for the transport of goods to markets. For roads to function effectively they must be maintained to an acceptable level and each road authority spends considerable sums of money each year maintaining their network. However, the funding supplied for maintenance is limited, and optimum expenditure of available funds is therefore paramount.

The objective of this study was to provide a starting point for the New South Wales (NSW) Roads and Maritime Services (RMS) Northern Region to implement a pavement maintenance strategy. In particular, the adoption of key performance indicators, suitability of using road deterioration modelling and investigating the point of rapid deterioration of a pavement were investigated. Currently the Region uses annual site inspections to prioritise maintenance works with no road deterioration modelling used to forecast priorities.

Over the years numerous road deterioration models have been created. However, most of these models have been based on data collected overseas. This study has tested two of the latest road deterioration models created for Australian conditions; the road deterioration for local roads model and the interim network level functional deterioration model. They have been tested to determine their suitability for use on roads in RMS Northern Region. The models have been tested by comparing deterioration predictions of roughness, rut depth and cracking against the last 11 years of road condition data.

From the testing of the models it was found that the interim network level functional deterioration model predicted roughness and rut depths consistent with the measured values for a five year period. The road deterioration for local roads predicted roughness and rut depths consistent with the measured values for the full eleven year period tested. Neither model satisfactorily

predicted cracking. Based on the results it is considered that the models could be used by RMS Northern Region to forecast deterioration of similar roads within the Region. It is also believed that the models could be used by RMS as a whole to predict deterioration of similar roads on the entire network.

In addition the relationship between deflections measured using the traffic speed deflectometer (TSD) and falling weight deflectometer (FWD) were investigated. FWD deflections are used to represent the strength of pavement and sub grade in road deterioration models however the collection of this data is expensive and often hazardous. TSD data is cost effective and safe, but the results are not readily usable in road deterioration modelling at the current time. However the study did find a relationship between TSD and FWD deflections to enable TSD deflections to be used as an input to road deterioration models.

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ABBREVIATIONS

The following abbreviations have been used throughout this text:

AADT Annual Average Daily Traffic

ARRB ARRB Group Ltd. (formerly known as the Australian Road Research Board)

FWD Falling Weight Deflectometer

IRI International Roughness Index

KPI Key Performance Indicator

NSW New South Wales

PMS Pavement Management System

RMS Roads and Maritime Services

RTA Roads and Traffic Authority

SN Structural Number

SNC Modified Structural Number

TMI Thornthwaite Moisture Index

TSD Traffic Speed Deflectometer

1 Introduction

The Australian road network is vital infrastructure that provides access and mobility to industry and communities. Road transport plays a major role in the Australian economy by allowing people to travel to work and for the transport of goods to markets both within Australia and to ports for their export. The volume of traffic and the mass of heavy vehicles is increasing with the amount of freight being moved predicted to double between 2004 and 2020. The movement of this volume of freight and people relies on the road network providing a suitable level of service.

To function effectively roads must be maintained to an acceptable level, with each road authority spending considerable sums of money each year improving and maintaining their road networks. However the funding supplied for maintenance is limited and optimum expenditure of available funds is therefore paramount. In addition, as governments try and reduce spending they are reducing the funds available for maintenance. This places demands on road maintenance engineers to find ways to provide the same level of maintenance with less funds. Therefore to ensure road maintenance funding is spent in the most effective manner, road maintenance engineers require effective strategies to assist them in the decision making process (Hunt & Bunker 2001).

1.1 Roads and Maritime Services

On 1 November 2011 the New South Wales (NSW) Roads and Maritime Services (RMS) was created from the amalgamation of the NSW Roads and Traffic Authority and NSW Maritime. RMS is responsible for the management of 18,028 km of the NSW state highway system. The state highway system consists of the major highways and arterial roads throughout the State. These carry the largest volumes of traffic and the heaviest vehicles. In addition to managing the pavement RMS is responsible for operating and maintaining 3,867 traffic signals, 56,000 km of line marking, 5,130 bridges and 23 tunnels. It can be seen from the above figures that the maintenance of the RMS network is very complex with pavement maintenance only one consideration when funding is allocated.

During the 2010/11 financial year $471.3 million was spent on road pavement maintenance delivery (Roads and Traffic Authority of New South Wales, 2011) including:

- 1.43 million m^2 of asphalt resurfacing (32 percent of the asphalt surfaced network);
- 12 million m^2 of sprayed bitumen resurfacing (9.6 percent of the sealed network); and
- 1.88 million m^2 of road pavement rebuilt (1.01 percent of the total network).

RMS faces considerable challenges in the maintenance of road infrastructure requiring strong risk management, practical planning and robust assessment of the future usage and performance of the road network (Roads and Traffic Authority of New South Wales, 2011). The state highway system is one of the largest asset portfolios in Australia with the current value of road pavements being over $34 billion (Terris, Roberts & Walker 2009). However, over 41 percent of these pavements are over 30 years old. Another challenge faced by RMS is that each year it must fund savings in maintenance without reducing the quantum of work done. In 2010/11 $8.4 million was saved through improved work practices.

1.2 RMS Northern Region

For management purposes RMS has been divided into six regions covering NSW. RMS Northern Region is responsible for the management of the road network in the north east of the state as shown in Figure 1.1.

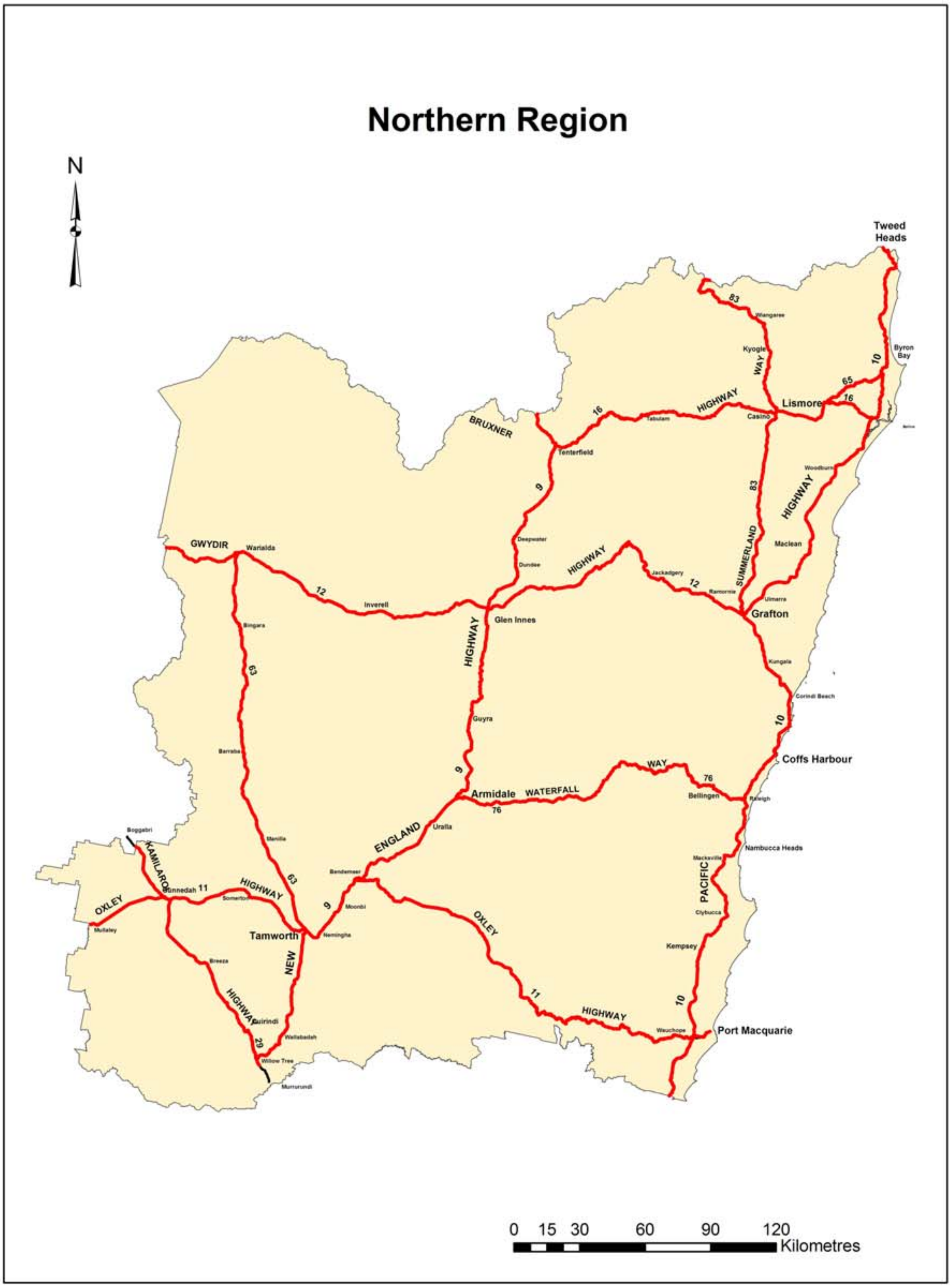

Figure 1.1 Roads and Maritime Services Northern Region road network

RMS Northern Region covers 12.3% of NSW land area and 9% of the population. It is responsible for the management of 2,600 km of roads and pavements, 1150 bridges and over 8000 culverts.

1.3 Problem Statement

While RMS Northern Region is responsible for the maintenance of 2,600 km of pavement it does not have a documented strategic maintenance plan to guide the development and implementation of the pavement maintenance program. Northern Region considers its current pavement maintenance activities to be effective. There is some uncertainty as to whether the optimum pavement maintenance program is developed and delivered each year.

The current methodology for programming pavement maintenance is a combination of using road condition data and physical site inspections. Programming of maintenance activities is based on a numerical prioritisation based on road condition data. This prioritisation is reviewed when undertaking the site inspections resulting in a candidate list of works for a highway. Periodic maintenance is considered in isolation of rehabilitation projects. The resulting program is generally based on a worst segment first system where the segment most in need of maintenance is treated first. It has been shown in many studies that a worst first strategy does not produce an optimal pavement maintenance program. Therefore the Region needs a pavement maintenance strategy that produces a program of work that delivers the greatest amount of benefits within the funding allocated.

2 Literature Review – Asset Management Background

2.1 Introduction

A major component of the research project is the literature review. The review is used to obtain information relevant to the objectives of the project. The review is to ensure that the project does not repeat research already undertaken and reported. The focus of the literature review is on road pavement maintenance strategies and management including performance indicators, network monitoring, road deterioration models and decision support systems.

2.2 Infrastructure Asset Management

Infrastructure is vital to the national economy due to it delivering essential services, driving economic growth and linked to quality of life (Too, Betts & Kumar 2006). An asset is a physical component of a facility which has a value and enables a service to be provided (Association of Local Government Engineering New Zealand & Institute of Public Works Engineering Australia 2006). To provide these benefits these infrastructure assets must be managed and maintained effectively. Asset management is a tool used to effectively manage and maintain these infrastructure assets. “Maintenance is the work carried out on a construction to maintain its efficiency or quality” (Standards Australia 2002).

The goal of infrastructure asset management is to provide a required level of service in the most cost effective manner through the management of assets for present and future customers (Association of Local Government Engineering New Zealand & Institute of Public Works Engineering Australia 2006). Infrastructure asset management is a “systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practices and economic rationale, and providing tools to facilitate a more organised and flexible approach to decision making to achieve the public's expectations" (Organisation for Economic Cooperation and Development 2001a). Asset management is undertaken within the framework of organizational policies and budget constraints (Austroads 2009a).

An asset management system adopts all the processes, tools, data and policies necessary to achieve the goal of effectively managing assets (Organisation for Economic Cooperation and Development 2001a). These systems generally concentrate on assets after they are constructed with the focus on the maintenance, operation and replacement phases of the asset life cycle (Association of Local Government Engineering New Zealand & Institute of Public Works Engineering Australia 2006). They provide the framework for an administration to make the best informed decisions about the use of available resources, its capital operation and maintenance program (Organisation for Economic Cooperation and Development 2001a). It should be noted that an asset management system is only a tool to help decision makers, with expertise still required when making the final decisions.

An asset management system generally (Association of Local Government Engineering New Zealand & Institute of Public Works Engineering Australia, 2006 & Organisation for Economic Cooperation and Development 2001a):

- Includes inventory data for the asset and condition measures.
- Includes a performance prediction capability.
- Includes all relevant components in life cycle cost analyses.
- Reports relevant information about the asset including monitoring the performance of the asset.

An asset management plan is a plan developed for the management of infrastructure assets that combines multidisciplinary management techniques over the lifecycle of the asset in the most cost effective manner to provide a specified level of service (Association of Local Government Engineering New Zealand & Institute of Public Works Engineering Australia 2006).

Benefits of asset management include (Association of Local Government Engineering New Zealand & Institute of Public Works Engineering Australia, 2006):

- More sustainable decisions due to improved decision making based on considering all the alternatives.
- Improved financial efficiency by prioritisation or optimisation of decisions with decision making based on costs and benefits of alternatives.
- Improved risk management by assessing the probability and consequences of asset failure.

2.3 Road Asset Management

Road asset management is a specific type of asset management responsible for the provision and management of road infrastructure to meet the needs of current and future customers (Transport Scotland 2007). Effective road asset management is based on using sound engineering, economic, business and environmental principles (Austroads 2009a). Road asset management is not just the responsibility of providing and maintaining road infrastructure, it is also responsible for the operation of the asset to facilitate the effective delivery of community benefits. While road asset management is focused on the physical asset it needs to take place in support of the total land transport objectives which in turn aim to meet the transport needs of the community (Austroads 2009a).

Physical assets that require management include the road in terms of access and capacity management, pavement, bridges, traffic control devices and drainage structures. Road asset management has issues that specifically relate to roads. These include:

- The fact that the asset is highly visible means that any defects are visible to all users travelling past the defect.
- Poor maintenance can lead to a loss of life.

- The environment causes the asset to deteriorate even if it is not used. The environmental causes this deterioration due to ultraviolet radiation from the sun causing bitumen to become brittle and from water penetrating the pavement damaging its structure.
- Poor quality roads affect the mobility of most people in regional areas as road transport is often the only mode of transport available.
- Maintenance activities are also highly visible to the road user and can cause the user delays.

2.4 Asset management strategies

Asset management strategies are critical for the effective operation and maintenance of physical assets. The role of the strategy is to guide the asset owner in the management of the asset (New South Wales Treasury 2006). Asset strategies provide detail (New South Wales Treasury 2006 and Austroads 2009a):

- On how the asset will provide services for the users.
- On asset related risks which may impact on services.
- On asset performance levels required to achieve a particular level of service.
- Provides a suitable range of interventions that maximise effectiveness and reduce long term costs.
- Provides guidance for capital investment and maintenance of assets.

Austroads (Austroads 2009b) has proposed separate but integrated strategies to undertake the asset management task. These strategies focus on road system performance, capital investment, infrastructure preservation and road use (Austroads 2009b). The infrastructure preservation strategy is applicable to pavement management strategies.

2.5 Asset management of pavements

The focus of this research project is on the management of road pavement assets and in particular pavements constructed on granular bases with a thin bituminous wearing surface. The pavement is one of the most valuable assets in a road authority's inventory. The pavement is a critical component of the road network with its condition impacting on the effectiveness of the road in terms of cost and travel efficiency.

Pavements are assets that are subject to deterioration caused by vehicular traffic and the environment. Pavements deteriorate with time; however time is not the primary cause of the deterioration. In order to repair and slow pavement deterioration, maintenance of the pavement is required.

2.6 Life cycle of pavements

One common approach to asset management is the life cycle approach. This is an asset management concept that takes into consideration the whole of life of the asset. The whole of life of an asset comprises the following cycles (Victoria Department of Treasury and Finance 2000):

- The planning and determination of asset requirements to meet the needs of the organisation or community in the case of public assets.
- The acquisition of assets. This phase of the asset lifecycle is the procurement of an asset. In the case of road pavements this would be the construction of the pavement.
- Operation and maintenance. This involves the management and use of the asset and includes its maintenance.
- Disposal of an asset that is under performing or that has reached the end of its service life.

Integral to the asset lifecycle model is lifecycle costing. Lifecycle cost or whole of life cost analysis is a means of analysing the total cost of an asset including the cost of its design, acquisition, construction, operation, maintenance and disposal (Bureau of Infrastructure, Transport and Regional Economics 1990). User costs may also be included in a lifecycle cost analysis. It allows the comparison of competing alternatives by considering the whole of life costs for all alternatives rather than just the initial capital cost of construction.

While a pavement passes through the complete lifecycle model, pavement management and pavement preservation focus on the operation and maintenance phase of a pavement's life. Most pavements have been designed and built with the goal of minimising their whole of life costs. Pavement preservation is directed at maintaining the life of the pavement after it is constructed and keeping it from its end of life for as long as possible with the minimum of cost. These maintenance activities should be scheduled until repair costs exceed the benefits derived from such activities. A whole of life cost for maintenance strategies may also be undertaken to determine the most effective maintenance strategy.

The life of a pavement after its construction is illustrated in Figure 2.1 (Austroads 2009a). Figure 2.1 shows that the pavement starts deteriorating with age as soon as it is constructed. The dashed line shows the increased deterioration due to little or no maintenance. It also shows that when periodic or major maintenance is undertaken the condition is raised or improved. When the pavement reaches the end of its life it would be rebuilt with the figure resetting back to the beginning. Another interesting interpretation of the deterioration of a pavement is that of Cossens (2010) as shown in Figure 2.2 which shows the deterioration as a rough line with the roughness caused by routine maintenance. The roughness is actually the small improvements in condition to the pavement due to routine maintenance activities.

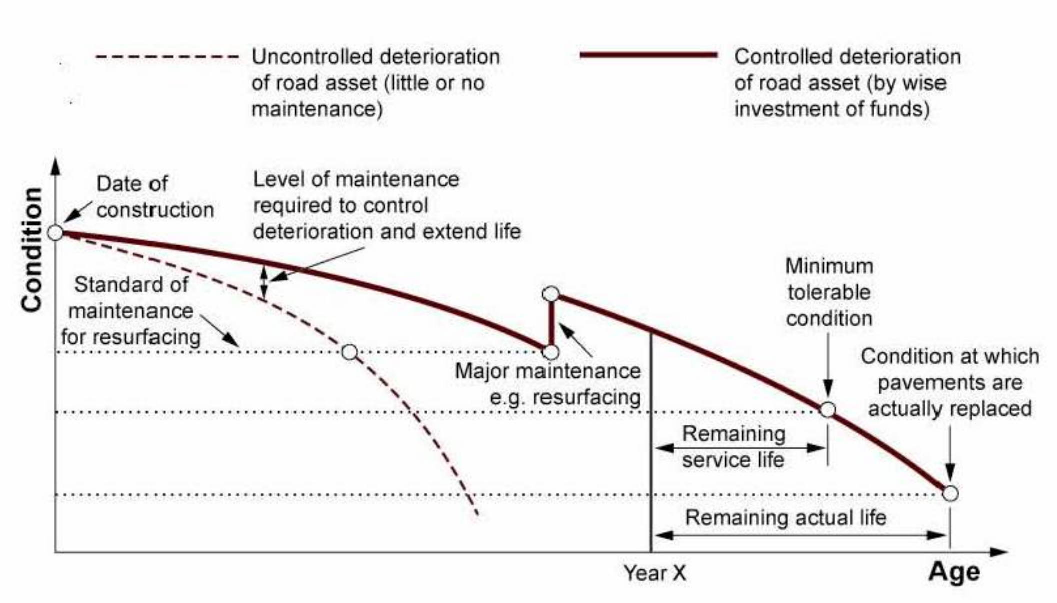

Figure 2.1 Life of pavement after construction
(Source Austroads 2009a)

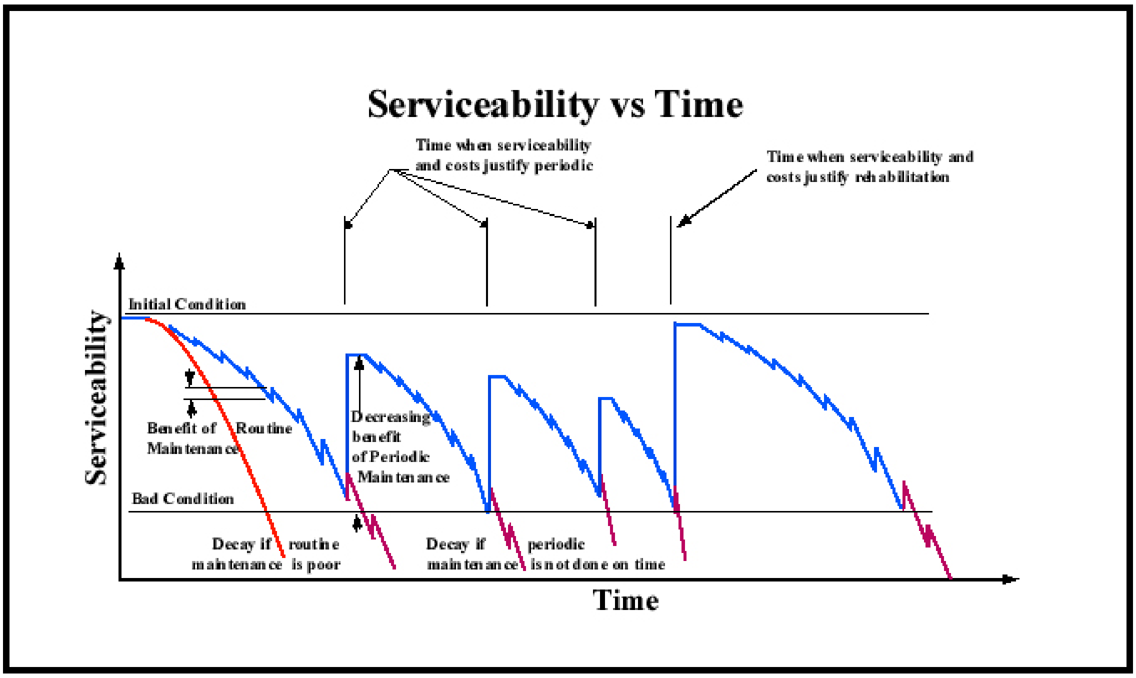

Figure 2.2 Life of pavement after construction as viewed by Cossens
(Source: Cossens 2010)

There are also different considerations when determining the life of a pavement. According to Terris, Roberts and Walker (2009), there are three types of pavement life relevant to pavement management include:

- Structural life which is the time interval remaining until there is no remaining structural capacity of the pavement. Remaining structural capacity is the ability of a pavement structure to carry repeated heavy vehicle axle loadings until the pavement shows signs of structural and surface distress that compromises its function.
- Surface life is the period of time until surface distress seriously compromises safe, reliable travel at the specified travel speed. Surface life is generally much shorter than structural life
- Service life is the period of time from the construction of the pavement to when the roads level of service is seriously compromised. The reason for the loss of service could be due to either end of structural life or end of surface life or a combination of both. The intended definition of end of service life is as a trigger for pavement rebuilding.

2.7 Asset Maintenance Responses

There are three types of responses used to keep an asset at an accepted level of service:

- Routine maintenance. This is generally reactive maintenance used to ensure the immediate safe operation of an asset and repair minor defects. In the case of pavements it includes activities such as pothole repair, obstacle removal and shoulder grading. Considerable evidence exists which shows that the rates of pavement deterioration are lower on pavements where routine maintenance is undertaken (Austroads 2009b).
- Periodic maintenance which consists of mainly pavement prevention activities designed to reduce future deterioration and manage safety issues such as skid resistance (Austroads 2009a). These activities include interventions such as resealing, crack sealing and heavy patching. The cost of this

type of work is a fraction of the cost of pavement rehabilitation. These activities are also considered highly effective.

- Rehabilitation or reconstruction is the rebuilding of the pavement when it has reached the end of its life.

One of the integrated strategies described by Austroads (Austroads 2009b) is an infrastructure preservation strategy or a strategic maintenance plan. This strategy translates performance objectives and policies into priorities to manage the condition of the asset. It identifies and prioritises appropriate asset maintenance and renewal actions to achieve and sustain the asset to meet the needs of the road user (Austroads 2009b). It also recognises and forecasts patterns of deterioration of the asset condition, the effectiveness of treatment regimes on life cycle costs and the effect of asset condition on the road user (Austroads 2009b).

2.8 Infrastructure Preservation Strategies

Austroads (Austroads 2009b) provides a detailed description of the components used in formulating a strategic maintenance plan. The components include:

- Road inventory and condition data must be collected.
- The minimum acceptable road conditions must be determined and translated into condition data and key performance indicators (KPIs).
- Condition trends over time must be modelled and analysed.
- Applicable treatment regimes and their effectiveness must be determined.
- The treatments and the optimum timing of these treatments must be determined. The timing and treatment choice need to minimise life cycle cost and achieve and sustain target conditions.
- Assessment of current and future maintenance requirements.

- Prioritisation or optimisation of maintenance activities using a decision support system.
- Measurement of success against key performance indicators.

These components are similar to those previously detailed when describing an asset management system. In the case of pavement management, a considerable part of this strategy could be considered a pavement preservation strategy. According to the Transportation Research Board (2011) pavement preservation is a long term strategy that enhances a pavements performance by using an integrated cost effective set of treatments to extend the pavement's life. These strategies improve safety and fulfil the expectation of road users. Pavement preservation is based on undertaking the lower cost routine maintenance and periodic maintenance activities rather than letting the pavement deteriorate to unacceptable levels and undertaking more expensive pavement reconstruction. A preventative maintenance treatment is a treatment that is used in a preventative manner and applied to a pavement in good condition (Peshkin & Hoerner 2005). Pavement preservation is based on the philosophy that good roads cost less to maintain resulting in road user costs being minimised (Peshkin & Hoerner 2005).

Literature from around the world claims that pavement preservation is the key for effective asset management of the pavement. This is demonstrated particularly in the United States of America (USA). The Federal Highway Administration (FHWA), American Association of State Highway and Transportation Officials (AASHTO) and state Departments of Transport (DoT) have introduced pavement preservation strategies across the USA.

Pavement preservation has been demonstrated to be effective. According to the AASHTO, spending one dollar on pavement preservation delays or eliminates spending between six and fourteen dollars on rehabilitation (American Association of State Highway and Transportation Officials 2009). This is shown in Figure 2.3.

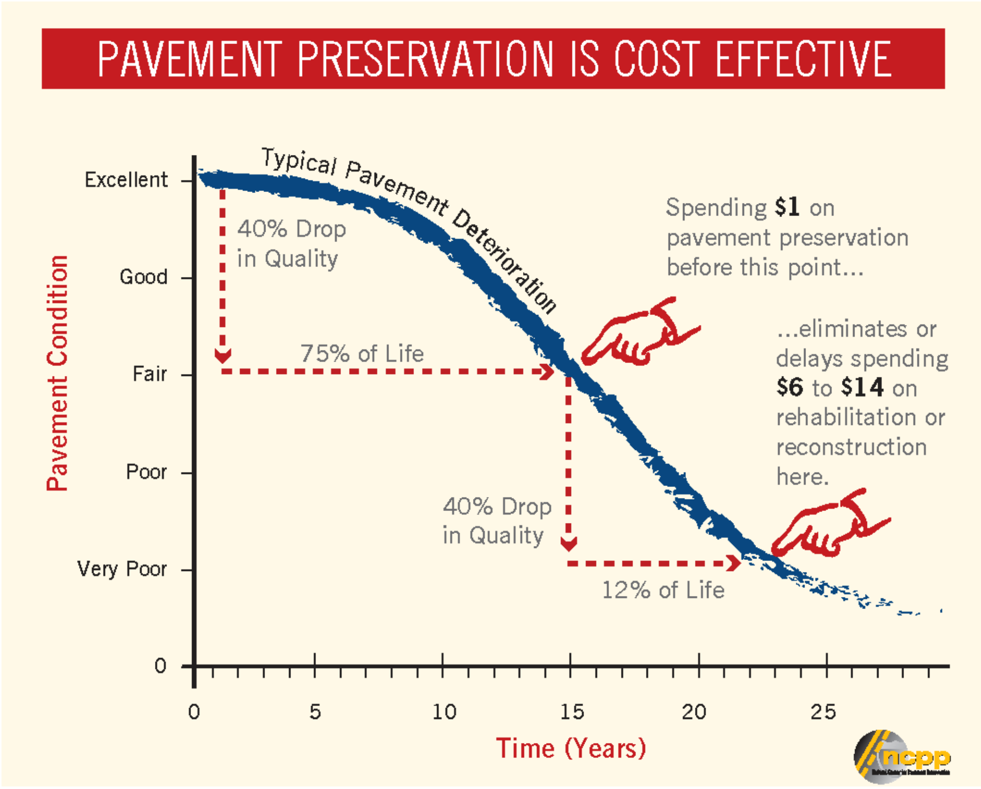

Figure 2.3 Graph showing cost effectiveness of pavement preservation
(Source: American Association of State Highway and Transportation Officials 2009 p 28)

The USA recognises that Australia and New Zealand are already world leaders in pavement preservation techniques. Studies of Australian and New Zealand pavement preservation practices, such as Federal Highway Administration (2002) have been undertaken by USA road authorities.

3 Literature Review – Implementation of a pavement management strategy

One of the key elements in formulating a strategic maintenance plan is the requirement for data about the system being managed. This data is required to provide sound factual evidence for decision making and planning (Austroads 2009c). Network wide maintenance planning requires data collected at the network level with this data usually collected on a large scale by automated means. Data is used in maintenance planning in the following ways (Austroads 2009c):

- Monitoring pavement performance and changes over time.
- Maintaining an inventory of pavement assets.
- Measuring performance of maintenance treatments to determine their effectiveness.

3.1.1 Road Inventory data

In terms of pavement management the inventory of a road refers to data describing the permanent features of that road's pavement (Haas, Hudson & Zaniewski 1994). Since there is a large amount of inventory data that could be captured, managers generally compromise between the level of detail they require and the cost of data capture (Haas, Hudson & Zaniewski 1994). Austroads (Austroads 2009c) recommends the following inventory data be established or collected:

- Road location referencing system. A road location referencing system is critical as it is used to locate the elements of the pavement. A simple referencing system is one using chainage along the road from a specific start point and offset from the centreline. More recently, referencing systems have been integrated as part of Geographical Information Systems. This is also supported by the ease of obtaining absolute position through the use of Global Navigation Satellite Systems such as the Global Positioning System (GPS).

- Segmentation of the network. For maintenance purposes roads are usually divided into segments. Segments are lengths of road considered to be homogenous in a chosen set of physical properties (Latimer et al. 2004). RMS has segmented roads based on the homogeneity of the pavement's construction materials with segments generally being around 1 km in length. A study undertaken by (Latimer et al. 2004) has recommended that the shorter the segment length used, such as 100 m, the better an optimised strategy can be implemented. However this must be traded against data requirements for these shorter segments. Also if there are many short segments, Ruck and Paine (2001) have shown that construction may not be efficient with lots of small projects occurring costing more than longer projects, due to losing cost efficiencies of scale.
- Road geometry. Geometry data defines the features of the pavement such as (Haas, Hudson & Zaniewski 1994):
    - Width of formation;
    - Grade;
    - Width of shoulders;
    - Curvature; and
    - Number of lanes.
- Pavement structure. This is a record of the structure and construction history of the pavement. Details collected may include:
    - Pavement type such as granular or concrete;
    - Wearing surface;
    - Base and sub-base details including materials and thicknesses; and
    - Year of construction and maintenance treatments applied.

- Environmental and drainage inventory data. The environment can have a significant effect on pavement conditions. Environmental data collected may include temperatures and rainfall or a combined measure such as the Thornthwaite moisture index (TMI). Drainage also has a significant impact on pavement performance so drainage data is often collected.
- Road use data. Pavement performance is a function of the amount of road usage (Austroads 2009c). Data collected usually includes:
    - Traffic volumes in terms of Annual Average Daily Traffic (AADT);
    - Axle load data as it is the heavier vehicles that consume the most of the life of a pavement; and
    - Traffic growth as it impacts on future pavement performance.
- Expenditure data including maintenance costs.

3.1.2 Road Condition Data

Road condition data is data used to describe the temporal physical properties of the pavement (Austroads 2009c). It is collected to describe the condition or performance of the pavement at a particular point in time and to predict future performance. Since road conditions change with time the condition of the road is only known at the time of the survey.

Condition data is a critical input into any pavement maintenance strategy. It describes the condition of the pavement and provides historical data that can be used for analysis such as for road deterioration forecasting or determining the effectiveness of maintenance treatments.

There are numerous decisions to be made about the capture of road condition data. Issues include data collection interval, measurement method, data aggregation methodologies and data capture frequencies. A more detailed description of these issues is reported in the "Austroads Guide to Asset Management Series". In terms of pavement maintenance planning, condition data generally measures the distress a pavement is undergoing. Distress is a term used to describe defects with the pavement.

Condition data needs to comprise three parts (Austroads 2009c):

- The name of the distress or parameter being measured.
- The severity or magnitude.
- The extent of the distress.

Pavement condition data can be classified as either functional or structural characteristics. Functional characteristics are the parameters that affect the safe and comfortable travel of road users (Austroads 2009c). Structural characteristics are concerned with the strength of the pavement (Austroads 2009c). Table 3.1 provides a summary of pavement condition data and distress types exhibited on granular pavements.

Table 3.1 Pavement condition data and distress types
(Source: Austroads 2009c, p14)

Evaluation Type	Pavement Function	Pavement Condition	Examples of pavement condition indicators and indexes
Functional Evaluation	Serviceability	Roughness	IRI
	Safety	Texture	Macrotexture
			Microtexture
		Skid resistance	SCRIM
Structural Evaluation	Structural capacity	Mechanical properties	Deflections
		Pavement distress	Cracking
			Rutting

3.1.2.1 Pavement roughness

Pavement roughness is simply a measure of how rough a road is. It is one of the most reported condition measures as it directly affects the ride of the road user. In addition, roughness also increases vehicle operating costs as it affects the amount of wear on vehicle parts, the handling of the vehicle and the dynamics of the vehicle (Paterson 1987). Roughness is the "measure of surface irregularities with wavelengths between 0.5 metres and 50 metres in the longitudinal profiles of either or both wheel paths in the traffic lane" (Austroads 2007a, p4).

Roughness has been measured using many different methods and reported using many indices over the years. Currently most road authorities measure roughness in terms of the International Roughness Index (IRI). It is based on the response of a generic motor vehicle to the road surface's roughness (Gillespie 1992). For network analysis IRI is generally obtained by measuring the road profile and processing this profile through an algorithm that simulates how a reference vehicle would respond to the roughness and summing the suspension travel (Gillespie 1992).

The IRI is expressed as the distance of suspension travel per lineal distance travelled along the road or metres per kilometre in SI units. Roughness is dependent on speed so IRI values are reported assuming the reference vehicle is travelling at 80 km/h. An IRI of zero metres per kilometre represents a true planar road surface with an IRI of six metres per kilometre representing a moderately rough paved road (Paterson 1987). Figure 3.1 shows the relationship between the IRI scale and road roughness.

The IRI was originally proposed by the World Bank as a worldwide standard for the following reasons (Paterson 1987):

- It is representative of vehicle responses and vehicle occupant comfort.
- It can be calculated from just road profile data.

- It is relevant to a wide range of vehicle types and correlates closely with vehicle speeds.
- It is a statistic easily obtained from less sophisticated measuring systems.
- It is time stable and reproducible as it is a mathematical summary statistic.

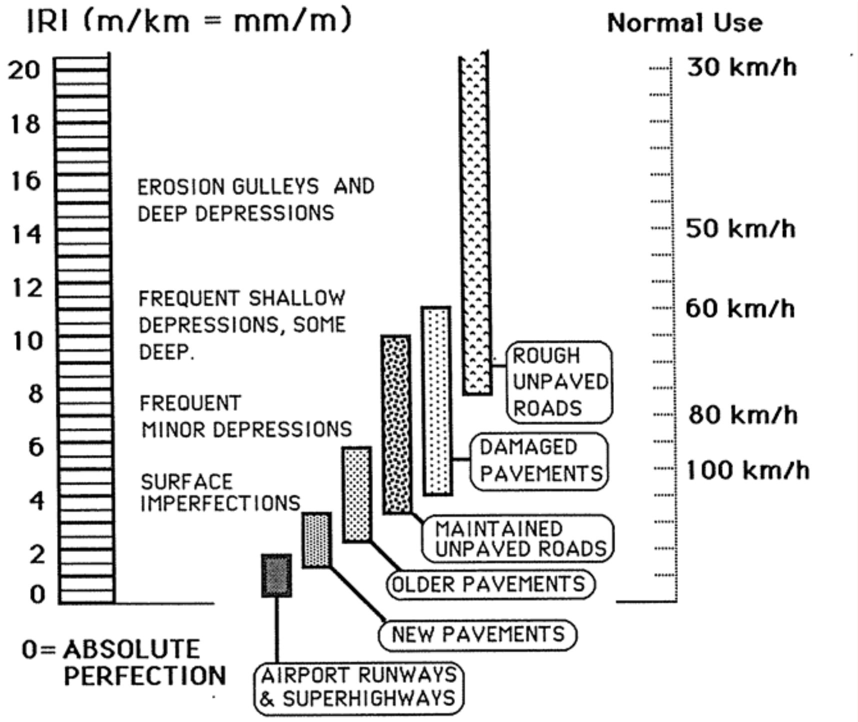

Figure 3.1 Relationship between road condition and International Roughness Index (IRI)

(Source: Paterson 1987, page 31)

Austroads have endorsed the use of IRI for the representation of roughness in Australia. It supersedes the older measure called the NAASRA (National Association of Australian State Road Authorities the precursor to Austroads) Roughness Meter (NRM). It is possible to accurately convert between IRI and NRM.

While roughness is an indication of ride quality and vehicle operating costs it is also used as an indicator for the level of pavement distress. It is an indicator of surface distress or pavement sub grade strength or a combination of both (Roberts & Martin 1996). However roughness alone is not an indicator of what the underlying problem is.

3.1.2.2 Rutting

A rut is a permanent traffic-associated longitudinal depression on the surface in the wheel path of a vehicle (Odoki & Kerali 2000). A rut is considered a pavement defect as it has performance implications such as (Austroads 2007b):

- Safety due to aquaplaning.
- Causing vehicle tracking in the lane.
- Dynamic loading due to surface profile variations.

Rutting is also used as an indication of pavement distress. It indicates that the pavement materials have undergone a permanent deformation due to a problem with the pavement structure.

At the network level, rutting is generally measured using automated methods such as a multi–laser profilometer. Rutting can be reported in many different ways however it is often reported in terms of its (Austroads 2007b):

- Severity. This involves reporting the mean rut depth and the standard deviation of the rut depth over a measurement interval of usually 100 metres. The standard deviation shows the variability of the rut depth over the measurement interval.
- Extent. This involves reporting the percentage of the measurement interval with maximum rut depths classified into bins such as:
    - Rut < 10mm
    - 10mm < rut< 20 mm etc.

3.1.2.3 Pavement strength

Pavement strength is an important characteristic of a pavement as it is a significant determinant of the functional performance of the pavement in terms of characteristics such as roughness, rutting and cracking (Austroads 2008a). According to Austroads (2008, p1) pavement strength is “the ability of a pavement structure to carry a cumulative repeated heavy axle loading before the pavement shows unacceptable signs of structural and surface distress which seriously compromise its function”

Most road authorities believe it is beneficial to know the strength of a pavement as it is the main determinant of the life remaining in a pavement (Roberts and Roper 1998). However, it is particularly costly and time consuming to collect pavement strength data at the network level. A pavement’s strength is related to its structure with the most direct method to determine strength being to undertake physical sampling. This is a destructive technique and is considered too destructive, slow and expensive for network level analysis.

The preferred method of assessing a pavement’s strength is using indirect, non destructive methods such as deflection testing. This method involves measuring the magnitude and shape of a pavement’s deflection bowl when a weight is dropped on the pavement. The deflection of a pavement is largely dependent on the pavements structure and composition. Figure 3.2 shows a typical deflection bowl. The values D_{xx} are the magnitudes of the deflection xx mm from the centre of the bowl. For example D_{1200} is the deflection 1200 mm from the centre of the bowl.

While deflection testing is the preferred method of measuring pavement strength it is still costly and time consuming to measure at the network level. The three main methods of measuring deflection, the deflectograph (DFG), Benkelman beam (BB) or falling weight deflectometer (FWD) are all time consuming methods of measuring pavement deflection. The fastest of these methods, the deflectograph, generally covers up to 30 km in a seven hour day. Thus it would take considerable time and expense to measure a road network of over 18,000 km.

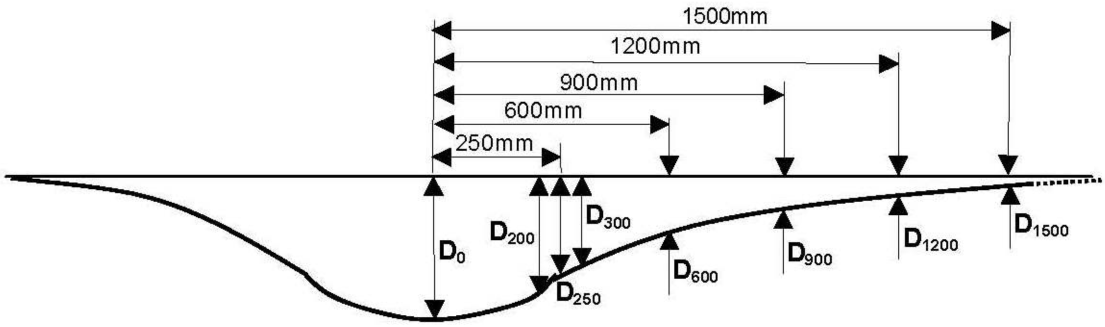

Figure 3.2 Typical pavement deflection bowl.
(Source: Austroads 2008a).

Recently RMS trailed a new deflection measuring device called the Traffic Speed Deflectometer (TSD). The TSD measures deflections at speeds of up to 80 km/h without disruption to traffic. The TSD uses Doppler lasers to measure the velocity of the pavement when a load is applied. A deflection can be calculated based on these measurements. Austroads (2012) provides more detail regarding the TSD. Figure 3.3 shows the TSD.

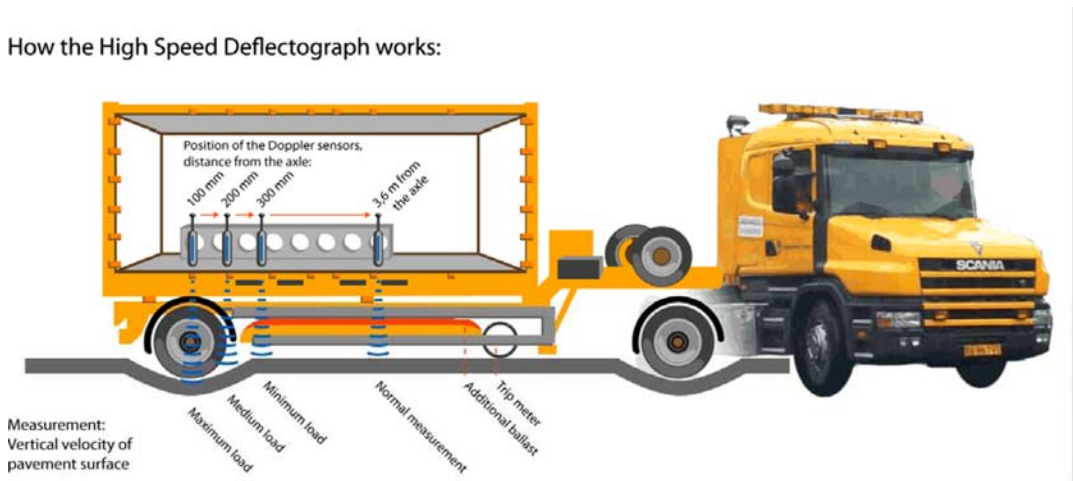

Figure 3.3 Illustration of the Traffic Speed Deflectometer.
(Source: Austroads 2012).

The use of the TSD makes it possible to economically and safely measure the structural condition of a road network. However at this time there is no reliable relationship between the TSD deflection values and other methods of measuring deflection. Research has shown that the deflections measured by the TSD are highly correlated with the deflections measured by DFG and FWD methods.

Rather than dealing with deflection values for representing pavement strength, these values are often converted into a structural number to represent the strength of the pavement. The structural number was intended to describe the structural capacity of a pavement in a simple way with only one number (Austroads 2003b). The assumption was that pavements made of different materials and different thicknesses with the same structural capacity would have the same structural number and expected performance characteristics (Martin, Choummanivong & Thoresen 2010). Since its introduction there have been the addition of different variables such as the modified structural number (SNC) and then the adjusted structural number (SNP) which are argued to represent the structural condition of a pavement more reliably than the original structural number. SNC considers the effect of sub grade strength while SNP allows for sub grades in deeper pavements. For pavements less than 700mm deep the SNC and SNP could be considered equal.

3.1.3 Road surfacing condition indicators

Road surface indicators describe the condition of the pavement surface. Knowledge of the condition of the pavement surface is required to manage safety issues and also indicate the overall condition and future performance of the pavement (Austroads 2006).

3.1.3.1 Cracking

Cracking as a road condition parameter is the measure of cracks appearing on the road surface. A crack is an unplanned break in the pavement surface (Austroads 2006). Cracking may or may not extend into the layers below the wearing surface. Thus while it is considered a surface defect it may indicate structural problems with the pavement structure. In addition the presence of cracking allows the ingress of water into the pavement structure. Water in the pavement structure accelerates its deterioration.

There are different types of cracking of pavements (Austroads 2006):

- Longitudinal cracking is linear cracks that run longitudinally along the pavement. Common causes include expansive sub grades or cyclical weakening of the pavement edge.
- Transverse cracking is unconnected linear cracks running across the pavement. These cracks are usually associated with bound flexible pavements and are reflections of a shrinkage crack in the base.
- Block cracking is interconnected cracks forming a series of blocks. This cracking is further categorised into blocks greater than 300mm in size and blocks less than 300mm in size. Block cracking less than 300 mm in size is known as crocodile cracking. There are various causes for this type of cracking including fatigue induced structural cracking, inadequate pavement thickness or aged bitumen surfacing.
- Irregular cracking which is random unconnected cracks. Causes may be due to loss of sub base or sub grade support, age hardening of bitumen or reflection cracks from bound base.

Cracking can be measured visually or using automated methods. For network analysis it is almost always measured using automated techniques using vehicles such as the RMS RoadCrack car. An issue with automated crack measurement is that the minimum crack size detected is around 1mm. Crack sizes less than 1 mm can still contribute to pavement deterioration and it is a problem that these are missed. Currently, the only method for reporting cracks less than 1 mm is by visual inspection which is prohibitive for network level data collection and analysis.

For cracking, Austroads (Austroads 2006) recommends the following be reported:

- Cracking type.
- Cracking severity, which is the average crack width.
- Cracking extent, which is the area affected by cracking as a percentage of the lane area.

3.1.3.2 Skid resistance and surface texture

Skid resistance and surface texture are conditions that relate to the wearing surface of the pavement. Skid resistance is a measure of friction between the vehicles tyres and the road wearing surface (Austroads 2008c). Surface texture is the deviation of the wearing surface from being a flat plane surface. In bituminous surfaced roads it is created by the aggregate used in the sealing. It is widely recognised that surface texture influences many different pavement-wheel interactions (Hall et al. 2009). Surface texture contributes significantly to the available level of friction between the tyres and the road surface.

Both skid resistance and surface texture are required for the safe use of a road. If the level of friction available at the contact between the tyre and surface is insufficient for the manoeuvre being attempted then the driver of the vehicle is likely to lose control of their vehicle (Austroads 2009d). Since both measures relate to the tyre-surface friction levels and have significant road safety implications, they are often considered together.

There are two main contributors to the level of friction at the tyre-surface interface (Austroads 2009d):

- Adhesion, which is reliant on the immediate surface of the aggregate (microtexture) that interfaces with the tyre.
- Hysteresis, which are the projections within the road surface (macrotexture) that deform the tyre. This is also known as the surface texture.

Skid resistance relies on both of these factors whereas surface texture is only influenced by hysteresis. On dry roads adhesion is the greatest contributor to the total available friction while in wet conditions the level of adhesion can be significantly reduced. Macrotexture is important in wet conditions as it allows the water to run off the road between the gaps in the sealing aggregate. Figure 3.4 shows a representation of microtexture and macrotexture.

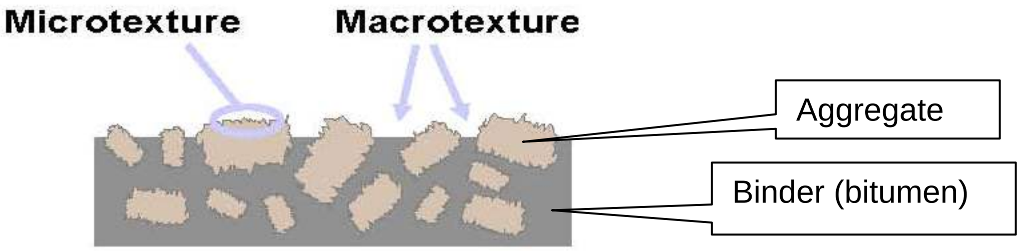

Figure 3.4 Diagram showing microtexture and macrotexture
Source (Austroads 2009d)

Due to the importance of skid resistance on road safety, considerable research has been undertaken to develop an understanding of the phenomenon and in measurement techniques (Haas, Hudson & Zaniewski 1994). Furthermore there are a considerable number of methods to measure skid resistance and surface texture. For the preparation of a road maintenance strategy, network level data is required. There are three common measurement systems used for automated skid resistance measurement in Australia (Austroads 2009d):

- Sideways-force Coefficient Routine Investigation Machine (SCRIM). This system, invented by the Transport Research Laboratory in the United Kingdom, is used in NSW, Victoria, Tasmania and New Zealand.
- Grip tester which is used in South Australia.
- Norsemeter Road Analyser and Recorder (ROAR) used in Queensland.

Each system of measurement produces a unique set of output data measured in different units. Correlation between the data from different machines is poor, largely because each device measures a different interaction between vehicle tyre and pavement (Haas, Hudson & Zaniewski 1994). This highlights the empirical nature of this measurement (Haas, Hudson & Zaniewski 1994).

In NSW the SCRIM reading (SR) is expressed as a positive unsigned integer equivalent to the sideways force coefficient (SFC) multiplied by 100 (Austroads 2009d). It is reported in 100 metre intervals. The SFC is the ratio of the sideways force to the vertical reaction on the SCRIM equipment and is reported for a theoretical speed of 50 km/h (Roads and Traffic Authority of New South Wales 1996).

Due to different manoeuvres vehicles undertake on different parts of the road network the SR value triggering investigation varies. Turning areas for vehicles requires an SR value below 55 for investigation while areas of undivided roads with an SR value below 45 require investigation.

There have been attempts to standardise skid resistance measurement, similar to the IRI used to measure roughness. In 1992 the World Road Association or Permanent International Association of Road Congresses (PIARC) undertook large experiments using 47 measuring systems from 16 countries measuring 33 texture parameters and 34 skid resistance parameters (Austroads 2009d). The aim of the study was to determine relationships to convert all the measurements to a common scale, the International Friction Index (IFI). However there has been concern of the accuracy of the derived conversion values and the IFI currently remains unused.

Network level capture of texture data is generally undertaken using mobile laser profiling. Austroads (2009e) provides more details on the capture of surface texture. Texture is reported in terms of:

- Mean profile depth (MPD).
- Sensor-Measured texture depth (SMTD).
- Historical volumetric methods such as the sand patch/sand circle test.

3.1.4 Pavement Performance

In general terms, performance is how well something fulfils its intended function. In relation to road asset management, pavement performance relates to the functionality of the pavement as viewed by the road user (Austroads 2009f). It could also be defined in terms of the level of service the pavement offers the road user (Austroads 2009f). The level of service offered to the road user depends on the structural and surface condition of the pavement. Therefore these conditions are measured in terms of their performance.

Pavement performance monitoring is critical for pavement maintenance. It is used to determine the current maintenance requirements, future maintenance requirements and in determining the effectiveness of the maintenance strategy. Pavement performance is monitored using performance indicators. Performance indicators have different names around the world such as key performance indicators (KPIs), key performance measures (KPMs) or just performance measures.

3.1.5 Key Performance Indicators

Key performance indicators are used to measure the performance of something in relation to an organisation's objectives or goals (Organisation for Economic Cooperation and Development 2001b). They can also be used to measure the effectiveness of an operation or of an organisation (Organisation for Economic Cooperation and Development 2001b). In pavement management, KPIs are used to measure a pavement's performance in relation to a road authority's strategic goals and objectives.

In determining KPIs the policy objectives of the road authority must be considered. The setting of performance indicators for road maintenance requires the road authority to decide what is necessary and affordable to meet the objectives of the organisation and the needs of its road users (Haas et. al. 2009). If too many resources are applied to meet a KPI that is set too high, this diminishes their availability to be used elsewhere (Finn and McDougall 2010).

The desirable attributes of a KPI should be that it is (Austroads 2003a and Kadar & Henning 2007):

- Objective.
- Repeatable. It is able to be repeatedly measured with appropriate accuracy.
- Representative. It must be clear and unambiguous leaving no doubt about its value and meaning.
- Manageable. The values of the indicator must be able to be influenced by the organisation.
- Predictable. It should be possible to predict changes using a model.
- Cost effective. Measurement must be able to be done in a cost effective manner.

The pavement condition parameters meet all of the above criteria resulting in their use as KPIs when measuring pavement performance and condition. The main issue with using these parameters is deciding the value of each parameter that makes the condition acceptable. If a value is set too high resources may be wasted and if set too low it may result in an unacceptable condition of the pavement.

When contemplating the organisation’s goals it is obvious that no one pavement performance indicator is capable of measuring the goals fully

(Kadar & Henning 2007). Therefore, usually a number of performance indicators may be used. Martin (1996) argues that road roughness alone is a suitable indicator as it has a low collection cost, relates directly to road user costs and is the most relevant measure of the long term functional behaviour of pavements. However VicRoads (Cossens 2010) who have used roughness as their main goal have recognised it alone cannot be used for setting pavement maintenance goals. This is further reinforced by Parkman (2008) who notes that roughness is an insensitive indicator with Transit New Zealand looking at other indicators to guide pavement maintenance planning. In some cases organisations choose to combine the measures to form a composite index (Fawcett et. al. 2001). While this may simplify performance reporting the condition indicators and any weighting applied to them must be chosen carefully otherwise the wrong goals may be targeted.

There are arguments for and against a single combined performance indicator. The first composite indicator was the Pavement Serviceability Index (PSI) which rated the ability of a pavement to serve traffic. It rated a pavement very poor (0) to very good (5) (Fawcett et. al. 2001). A number of composite indicators are used in the USA to define pavement condition such as the Pavement Condition Index created by the United States Army to rate airfields and roads. Composite indexes are considered useful to describe the overall condition of a pavement as it aggregates the complex descriptions of the distresses into one number (Fawcett et. al. 2001). This is particularly the case when communicating pavement condition to non-technical persons (Fawcett et. al. 2001).

Combined indices also simplify pavement deterioration and decision algorithms as only one variable has to be considered rather than multiple condition indicators (Fawcett et. al. 2001). However, caution needs to be used when using a combined index. Due to the aggregate nature of the index confusion with application and interpretation can occur (Haas, Hudson & Zaniewski 1994). This is generally due to the index masking specific information about the pavement condition (Haas, Hudson & Zaniewski 1994). In addition the combining of the indicators into one number requires subjective decisions be made about weighting the individual variables used to define the index.

3.1.6 Performance modelling

Performance modelling is the predicting of the performance of a pavement in the future. This future performance is modelled and assessed in terms of pavement condition data. Since pavement performance deteriorates with time, the modelling of a pavement is the modelling of its deterioration. Figure 3.5 illustrates how performance modelling can be applied to a pavement section to predict future deterioration. This forecast can then be used to determine which maintenance treatment should be applied and when it should be applied to ensure the pavement continues to meet its functional requirements.

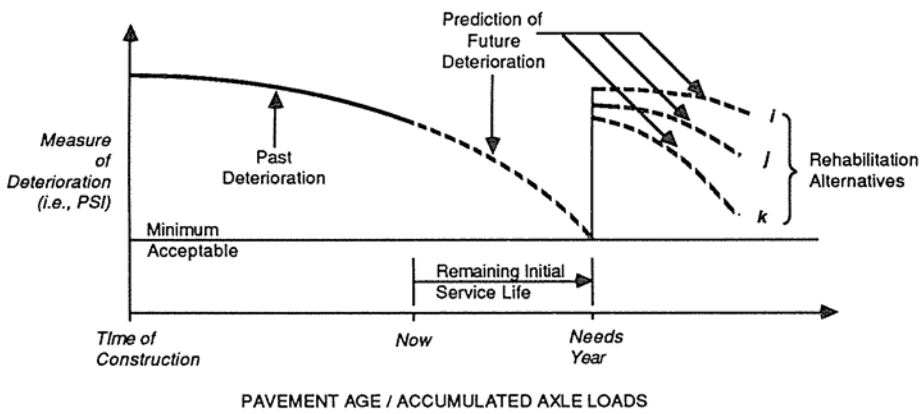

Figure 3.5 Pavement deterioration curve with performance modelling showing predicted performance
(Source: Haas, Hudson & Zaniewski 1994 p 192)

The accurate prediction of pavement performance plays a significant role in determining pavement management strategies (Austroads 2009f). Pavement preservation success is “based on selecting the right treatment for the right pavement at the right time” (Rathnakara & Veeratagavan 2011). Undertaking a treatment too late on a pavement with structural damage will result in poor performance because pavement preservation treatments are not designed to improve structural capacity (Rathnakara & Veeratagavan 2011). Applying a treatment too early will result in the use of unnecessary resources and may even cause additional problems (Rathnakara & Veeratagavan 2011). The optimal solution will maximise the return on the investment by allowing the most efficient use of resources to extend the life of a pavement (Rathnakara & Veeratagavan 2011).

3.1.7 Road deterioration models

Owing to their importance in pavement maintenance strategies and the high cost of maintenance, there has been considerable research into road deterioration models resulting in numerous models. The pavement deterioration model is the very essence of pavement management and used to determine key fundamentals such as the rate of asset degradation and road user costs.

Road deterioration is generally not based on a single model with individual models used to predict the deterioration of each pavement defect. In these models the defect is the dependent variable and it is based on independent input variables. Models can be classified into two categories (Austroads 2009f):

- Probabilistic models that recognise the uncertain nature of pavement performance by predicting variability in the outputs.
- Deterministic models which calculate a single value for each output indicator.

3.1.7.1 Probabilistic models

Probabilistic deterioration models recognise that the dependent variables cannot be represented in a deterministic relationship and there is also uncertainty associated with the independent variables (Martin 1996). Therefore a probabilistic model assigns various probabilities to the future condition modelled (Austroads 2009f). One advantage of probabilistic modelling is that it requires less data to create a model compared to deterministic models (Martin 1996). The output of a probabilistic model may be a probability distribution of the condition parameter at a certain time. (Austroads 2009f). An example of probabilistic modelling is a survivor or performance curve as shown in Figure 3.6. This type of curve is a graph of probability of a condition versus time.

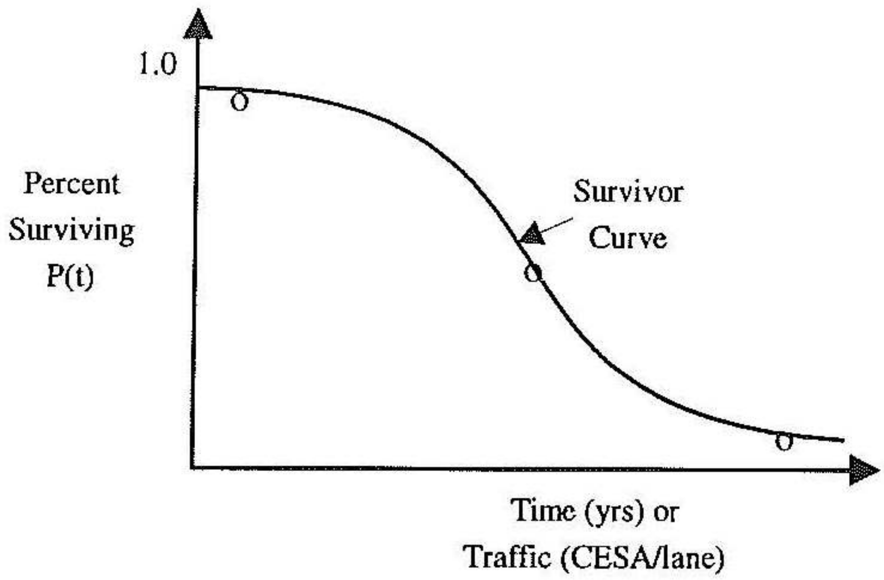

Figure 3.6 Survivor Curve
(Source: Martin 1996)

3.1.7.2 Deterministic models

Deterministic models can be further classified into how they were derived being (Haas, Hudson & Zaniewski 1994):

- Purely mechanistic with the dependent variables based on a response parameter such as stress, strain or deflection.
- Mechanistic-empirical where the dependent variable is related to a measured structural or functional condition such as roughness.
- Regression or empirical where the dependent variable is related to one or more of the independent variables.
- Subjective where experience is used in a structured way to develop deterioration models.

According to PIARC (Austroads 2009f) most deterministic models in use are either mechanistic-empirical or regression models. These models fulfil the requirements of natural performance models being based on observational data. Most functional road deterioration models used in Australia are deterministic and predict changes in the functional conditions of the pavement (Martin, Choummanivong & Thoresen 2010). When using these models Martin (1996) and Hajek (1985) have both shown that models based on local data appear to produce more reliable results.

3.1.7.3 Examples of deterioration models

It is impossible to describe all the models developed due to the large number of models available. Some examples of models considered relevant to the project are discussed below to provide an insight into the modelling process.

3.1.7.3.1 Highway Design and Maintenance Standards Model

Probably the best known and most used model is the Highway Design and Maintenance Standards Model (HDM) which was originally developed by the World Bank in the 1970's. The most current version is HDM-4 released in the mid 1990's. The HDM was initially developed to provide more effective road infrastructure in developing countries, however many industrialised countries have made use of the model (His & Sjögren 2003). The models for the HDM were developed by analysing considerable volumes of data from roads in mostly developing countries.

HDM-4 is more than a set of road deterioration models. It is a complete set of road appraisal models that can be used to prepare road investment programmes and to analyse network strategies. In addition computer software has been created using these road deterioration models that also has other functionality such as modelling traffic congestion, road safety, road user cost and environmental effects.

HDM-4 assumes that pavement deterioration manifests itself in different types of distresses which should be modelled separately (Odoki & Kerali 2000). Therefore the system predicts road deterioration through eight separate distress modes which can be divided into three categories as follows (His & Sjögren 2003):

- Surface distress based on:
  - cracking
  - ravelling
  - potholing
  - edge-break
- Deformation distress based on:
  - rutting
  - roughness
- Surface texture based on:
  - texture depth
  - skid resistance

Models created are either incremental or absolute models. Absolute models predict the distress at a particular instance as a function of the independent variables while incremental models calculate a change in condition from an initial state as a function of the independent variables (Odoki & Kerali 2000). These models have been developed as general models for world wide use and require calibration for use based on local factors.

While modelling all distresses, HDM-4 uses roughness as its main indicator when prioritising work. The other distress modes are used to determine the predicted roughness. Roughness is used as it can be related to road user costs when considering total costs of maintenance and operation.

Key (independent) variables affecting deterioration include (Odoki & Kerali 2000):

- Climate and environment.

- Traffic.
- Pavement history.
- Road geometry.
- Pavement structural characteristics.
- Material properties.

There has been considerable research on the application of these models for use in Australia. Martin (2004) investigated HDM-4 road deterioration models using data based on long term pavement monitoring sites. From these investigations it was found that the coefficients for rutting and roughness were significantly different from their default values. For strength, the model could not be calibrated with the recommendation that for sealed granular pavements the model may have to be altered. Further research based on data supplied by road authorities was undertaken by Austroads (2008b) with calibration of models for states which supplied data. Calibration values were successfully obtained however NSW data was not considered in this study.

3.1.7.3.2 Performance prediction for pavement management

Hajek et. Al. (1985) investigated different pavement deterioration models to determine the suitability of each model. While this report is old it highlights that models based on actual condition data produce more reliable results. These models included:

- Generic mechanistically based models.
- Generic empirical models.
- Empirical site specific models.

All models predicted a combined condition index. The empirical site specific models used a pavement's historical performance data to predict its future condition index while the generic models did not use any historical data relating to the site.

Prediction accuracy of the models was quantified in two ways (Hajek et. Al. 1985):

(i) By comparing the observed terminal pavement age with the predicted pavement terminal age; and

(ii) By comparing the terminal pavement condition index with the predicted pavement condition index calculated for the observed terminal pavement age.

Hajek noted that the prediction accuracy of the site specific models was better than the other types of models.

3.1.7.3.3 Interim network level functional deterioration models

Austroads undertook two related projects to determine network level road deterioration models. The first project (Austroads 2010a) aimed to predict the structural deterioration of pavements. The key output was a model that allows for the prediction of a structural number (and hence pavement strength) in the future based on a pavement's initial strength. This model also allowed for a pavement's initial strength to be calculated based on more recent deflections measured.

Variables used in the development of this model included pavement age, environmental data, traffic loading and SNC. A regression analysis was undertaken with the SNC used as the dependant variable. The final model determined that deterioration was related to the environment and pavement age only. The traffic loading parameter was found to have a relatively weak statistical relationship resulting in it being omitted from the model (Austroads 2010a). Austroads (2010a) note that pavements are designed conservatively to carry their expected traffic load during their design life possibly resulting in the variable not being statistically significant.

Experimental data highlighted an issue with the model. While the model predicts the continual weakening of a pavement over time during the observation period 70% of the pavement sections studies became stronger (Austroads 2010a). This is believed to be due to particularly dry conditions and it was observed that they did eventually deteriorate over time.

The second project determined road deterioration models for roughness, rutting and cracking for sealed granular pavements. Martin (2009) has developed mechanistic-empirical deterministic based pavement deterioration models for roughness, rutting and structural deterioration. Both absolute and incremental forms of models were developed.

According to Martin (2009) there are three phases of deterioration for flexible pavement being:

- Initial densification;
- Gradual permanent linear deterioration; and
- Rapid non linear permanent deterioration leading ultimately to catastrophic failure.

The models were developed for predicting deterioration of sealed granular pavements during the gradual deterioration phase (Martin 2009). They were derived using regression analysis. The data used in the analysis was obtained from 140 samples from long term pavement performance sites with additional cracking data supplied from South Australia (Martin 2009). Further details regarding these models can be found in Austroads (2010b) and Martin (2009). The roughness model has been compared against the HDM-4 model with no conclusive result.

In addition to deterioration models the project proposed a model to determine whether a pavement is undergoing gradual or rapid deterioration. This is significant as most road deterioration models, including these models, only predict the linear gradual deterioration phase of a pavement. Once a pavement undergoes rapid deterioration its deterioration is unpredictable. This equation was determined using a binary logistic regression analysis.

The models allow for maintenance effects for the rutting and roughness models however no allowance was made with the structural model. The maintenance effects are allowed for by inputting the dollar value of maintenance spent.

3.1.7.3.4 Deterioration models for local roads for NSW and the Australian Capital Territory (ACT) – Interim Report

In 2000 ARRB started a study with the aim of developing road deterioration models suitable for Australian conditions in terms of climate, environment and traffic. More than 200 organisations Australia wide have participated in the study with over 600 sites being monitored (Choummanivong & Martin 2010). In the ACT and NSW 125 sites were used for the analysis with changes to the structural and functional condition captured over a five year monitoring period. Performance data was collected including roughness, rutting, surface texture, deflections and bitumen samples.

Models were developed for strength, rutting, cracking and roughness. In their report Choummanivong & Martin (2010) provide equations for each model and show how the equations fit with observational data. Models were based on non-linear regression analysis of the data with their results reviewed for statistical significance and reasonableness before accepting a model (Choummanivong & Martin 2010). Choummanivong & Martin (2010) note that despite long structural and functional deterioration being observed the data did not show strong correlations with traffic data. Their final recommendations are that the models be used cautiously with appropriate engineering judgement (Choummanivong & Martin 2010).

3.1.7.3.5 Deterioration models for sealed local roads in Australia – Final Report

This project is the final determination based on the report described in the section above. The aim of the project was to produce a new set of road deterioration models for local Australian conditions in terms of climate, environment and traffic. The models were developed using data collected from 600 local sites around Australia. Data collected included roughness, rutting, texture, deflection, visual condition data and bitumen samples for laboratory analysis. In addition traffic volume data and pavement history was also obtained. It should be noted that these models were developed for local roads around Australia and generally not for major highways. However it was noted that some highways were used in the analysis.

The project mostly used regression analysis as the main tool for developing the models. The selection of each input parameter was based on the statistical significance of each independent variable and a best fit of the data to the model (Choummanivong and Martin 2011).

The output from the project included models for predicting rutting, roughness, cracking and structural life. Models were derived for both cumulative (absolute) distresses as well as incremental distresses. The incremental models allow for traffic growth.

The key inputs required for the models include:

- Structural number (SNC).
- Pavement design life.
- Environmental and climate data.
- Spray seal details.
- Traffic volumes and composition.
- Pavement age.

The authors note that the models are only valid for specific ranges of input data which is based on the range of observed data used to derive the models.

3.1.8 Maintenance Treatments and Works Effects

A strategic maintenance plan also needs to identify what maintenance treatments are available and how they improve the condition of the pavement. For strategic planning, treatments considered should be treatments used in periodic maintenance and rehabilitation. The use of periodic maintenance treatments enables the incorporation of pavement preservation into the maintenance strategy. There are two considerations when proposing a treatment:

- The timing of the treatment. Timing should be considered to ensure that the optimum time or intervention level is chosen to undertake the treatment to minimise the whole of life costs.
- Prediction of how the treatment impacts on the pavements performance in terms of pavement condition parameters. This is also known as works effects.

The determination of these works effects or reset rules is more difficult for preventative maintenance treatments than for a rehabilitation treatment (Zimmerman & Peshkin 2003). For rehabilitation treatments the pavement condition generally returns to near new however preventative maintenance treatments may not reduce any pavement condition parameter. For example a reseal may not reduce rutting or roughness but it still has positive effect on the pavement by slowing deterioration after its application (Zimmerman & Peshkin 2003). This was also shown in an Austroads study (Austroads 2007c).

As with road deterioration, there are numerous models for the prediction of works effects. Works effects modelling can be either deterministic or probabilistic and should be based on the change in pavement condition immediately before and after the treatment (Austroads 2009f). Deterministic models usually require calibration to apply for local conditions when they have been based on an area remote from where they are to be applied, such as HDM-4 models. Many organisations have created their own empirically based deterministic works effects models based on their own road condition data.

Austroads studies (Austroads 2009f) suggest that simple models using limited independent variables can be used for most works effect models. In 2007, Austroads developed some works effects models for selected treatments however these models only focussed on roughness and rutting. The study produced limited models applicable for granular pavements and recommended that each state should use different models. Unfortunately no models for NSW were produced due to limited data.

3.1.9 Treatments

When a pavement no longer provides a level of service or the surface is not fulfilling its function then some form of treatment is required. A treatment is a maintenance action used to rectify a defect in the pavements structure or surface. In terms of maintenance strategies the focus is on periodic maintenance and pavement rehabilitation. It is well documented that routine maintenance is generally effectively undertaken in Australia reacting to defects such as potholes in a timely manner which reduces further deterioration. RMS has a standard for intervention levels for this routine maintenance ensuring it is completed in a timely manner.

For effective maintenance, the engineer should evaluate a pavement like a doctor diagnosing a patient – each patient has different illnesses and the doctor applies a treatment to fit the individual (Galehouse 2002). Similarly, the engineer must choose a treatment that fits the unique condition of the pavement (Galehouse 2002). Key treatments used in pavement preservation are generally aimed at the surface of the road. Table 2 shows what treatment addresses each defect.

Table 3.2 Pavement Defects and related treatments.

-TREATMENT	Crack Sealing	Bitumen Rejuvenation	Resealing	Microsurfacing	Rehabilitation
DISTRESS					
Roughness				X	X
Rutting				X	X
Cracking	X	X	X	X	
Skid resistance			X	X	
Surface Texture			X	X	

3.1.9.1 Surface Treatments

3.1.9.1.1 Crack Sealing

Crack sealing could arguably be considered a routine maintenance activity however it is not undertaken reactively to a defect in the road that directly affects the function of the road in the same manner as potholes are fixed. It is a relatively low cost treatment to prevent moisture entering the pavement structure and compromising the base layers of the pavement (Cuelho, Mokwa & Akin 2006). While crack sealing is widely used it has a relatively short lifespan. In the USA it has been reported to have a life of around 2 to 3 years. This lifespan has been supported by Transport South Australia (Austroads 2008c).

While many publications recommend the use of crack sealing, clear qualitative assessments of whether crack sealing slows the deterioration of the pavement structure are rare (Cuelho, Mokwa & Akin 2006). Cuelho, Mokwa & Akin (2006) undertook a literature review of the effectiveness of crack sealing. Out of 100 references only four contained quantifiable data that addressed the effectiveness of crack sealing (Cuelho, Mokwa & Akin 2006). Their conclusion was that from their study they found little quantitative evidence that proves cost effectiveness of crack sealing. Like resealing, crack sealing would have a minimal immediate effect on rutting and roughness values. However if effective it should decrease the rate of deterioration of these indicators by stopping the ingress of water into the pavement.

3.1.9.1.2 Spray Sealing

A spray seal or chip seal is a thin layer of bituminous binder sprayed onto the surface of a pavement and into which a cover aggregate is spread and rolled (Austroads 2008c). This seal provides a hard wearing waterproof layer with good skid resistance that contributes to the overall performance of the pavement. A reseal is the addition of another spray seal layer over an older spray seal. There are numerous types of spray seals that can be applied with different types being used for different surfacing problems.

Spray seals can address surface defects such as the oxidisation of binder, ravelling, bleeding, minor cracking and skid resistance and texture problems. Work effects studies have shown that resealing does not address structural defects such as roughness and rutting.

There have been numerous studies on the life of spray seals. The life of spray seals is dependent on the volume of traffic and the environment with ultraviolet light from the sun causing bitumen to oxidise and become brittle. Cuelho, Mokwa & Akin (2006) report on surveys undertaken around the world to determine the life of spray seals. The ages reported vary from 1 year to 12 years with seals in Australia having a life of 10 years, New Zealand 7 years and South Africa 12 years. In another study VicRoads have reported they achieve a life of around 12 years for a spray seal (Cossens 2010). While the life of seals has been researched what is unclear is how long a reseal can extend a pavement’s life.

3.1.9.1.3 Shoulder sealing

Shoulder sealing is a pavement preservation technique that can significantly improve the safety of a road and the performance of a pavement (Austroads 2008c). By increasing the width of the seal the variation in moisture content in the pavement subgrade is minimised, reducing the likelihood of outer wheel path failure (Terris, Roberts & Walker 2009). In addition it is believed that shoulder widening reduces edge break and shoves. No qualitative data on the work effects of shoulder widening could be found however many reports such as Terris, Roberts & Walker (2009) recommend its use as a treatment.

3.1.9.1.4 Slurry seals and microsurfacing

A slurry seal is a mixture of bitumen emulsion, cement, water and aggregate and is applied in the form of a slurry (Austroads 2008c). Slurry seals can be used for correcting surface defects including rutting (Austroads 2008c). Microsurfacing is a form of slurry seal but is a mixture of polymer modified bitumen, aggregate, mineral filler and other additives, proportioned, mixed and placed on the wearing surface (Cuelho, Mokwa & Akin 2006). A single course of microsurfacing will retard bitumen oxidation and improve skid resistance (Michigan Department of Transportation 2010). Multiple courses of microsurfacing can be used to correct pavement deficiencies such as severe rutting, roughness, low skid resistance or moderate ravelling. As noted previously rutting is generally caused by weakness in the base or sub base layer. Microsurfacing just masks the rutting which would be expected to return as the cause has not been treated. This is highlighted in Cuelho, Mokwa & Akin (2006) who note that microsurfacing works well for immediate improvements in roughness and rutting however the effects may not last long enough to warrant the potential high cost of the treatment. Cuelho, Mokwa & Akin (2006) advise that microsurfacing pavements lasts 4 to 7 years and possibly extend the life of the pavement by 4 years. These results are based on over 10 different studies with the figures supported by the Michigan Department of Transportation (2010).

3.1.9.1.5 Bitumen Rejuvenation

Bitumen rejuvenation is a light application of cutback bitumen with the goal to increase the quality and quantity of the binder and to seal hairline cracks in an existing sealed surface (Austroads 2008c). This treatment is considered a short term fix as it generally lasts one to two years (Cuelho, Mokwa & Akin 2006).

3.1.9.2 Structural Treatments

3.1.9.2.1 Rehabilitation and reconstruction

Rehabilitation is the rebuilding of a road's structure with the aim to restore pavement condition or functionality to that of a new pavement. It is generally undertaken when a pavement has reached the end of its life. RMS defines rehabilitation as the rebuilding of the existing pavement with no widening of the formation. The rebuilding and widening of a pavement is considered reconstruction by RMS. In both cases rebuilding can be considered to be resetting the age of the pavement to zero years. Also assuming good construction techniques the condition parameters such as roughness, rutting and skid resistance should be reset to that of a new pavement.

3.2 Prioritisation or optimisation of treatments

While modelling of deterioration and work effects allows prediction of future pavement performance based on different maintenance treatments, the selection of the treatments to create an optimum maintenance program must be undertaken. The prioritisation or optimisation of treatments can be determined by many methods ranging from simple subjective ranking of treatments through to complex mathematical optimisation methods (Haas, Hudson & Zaniewski 1994). The optimisation of treatments is the selection of treatments that minimise or maximise a target for the network while prioritisation is the ranking of projects into an order for the work to be undertaken based on a criteria.

Haas, Hudson & Zaniewski (1994) state that the use of subjective ranking defeats the advantages of using the data and predictions obtained and they noted that they have found no research recommending this method. The size of a road network and the complexity of combinations of different treatments result in this type of prioritisation being impossible to cover all possibilities resulting in results being sub optimal. It can be seen that a system required to assess all the data is not simple.

One of the main aims of pavement maintenance system is to compare road maintenance alternatives within some funding constraint (Haas, Hudson & Zaniewski 1994). The result of these comparisons should be a network level priority program of maintenance and rebuilding using the most cost effective treatment for each maintenance segment.

One methodology that can be used to optimise the maintenance of a network is linear programming. Linear programming is a technique used in operations research. Operations research origins lie during World War II when a team of British scientists set out to make scientifically based decisions regarding the best utilisation of war resources (Taha 2001). Operations research, often called a management science frequently attempts to find an optimal solution for a problem subject to a set of constraints (Hillier & Lieberman 2001). The solving of these problems is used to assist organisations in decision making.

Linear programming is focussed on maximising or minimising an objective (Taha 2001). It is concerned with the problem of allocating limited resources among competing activities in the most optimal way. Linear programming requires the formulation of an objective function which is based on the parameters to be chosen. In the optimisation of road maintenance it may be desirable to minimise an objective such as maintenance cost or maximise an objective such as a pavement condition index where a higher number indicates a better pavement. The parameter needing to be chosen could be levels of different treatment applied.

Another tool of operations research is simulation. Simulation is the modelling of a real world system mathematically rather than using physical models (Hillier & Lieberman 2001). Simulation allows the properties and characteristics of a system to be studied using different scenarios. Decisions can then be made based on the outputs of these models. Simulation can also be used for prioritising maintenance activities by modelling different scenarios to observe the outcomes. From this the preferred outcome can be chosen.

Another optimising technique that is simpler than linear programming is that of near optimisation using heuristics. It is also known as the incremental benefit cost technique. Its aim is to determine the most incremental benefits per dollar invested (Ruck & Piane 2001). The incremental cost benefit ratio is the ratio between the increase in benefit and the increase in cost between successive strategies (Ruck & Piane 2001). According to Haas et. al. (1985) these near optimisation techniques are more simple and efficient than mathematical models such as linear programming. This technique has been tested and compared with the results of linear programming with the near optimal solution giving results between 93% and 99% of the optimal linear programming solution. Another advantage of this type of system is that it does not require complex models be developed which are required when using linear programming. This type of system is currently used in pavement management systems such as dTIMS Pavement Management System (PMS) and the United States Army system called PAVER.

While these types of systems may aid in decision making for maintenance activities their outputs are a function of the assumptions and models used. There are a multitude of models that could be used in a simulation or with linear programming with the model used having a significant effect on the outcome. These types of decision systems only provide optimal solutions for the model and not the real world. Hence any output from these types of models must be analysed using engineering judgement to ensure the desired result is obtained.

There are more advanced techniques for optimisation such as Artificial Neural Network, fuzzy logic or genetic algorithms. While these methods may provide a more optimised result they are computationally intensive and not always better. For example the use of genetic algorithms will not guarantee that the optimum solution is obtained (Simpson, Dandy & Murphy 1994). The use of these methods is considered beyond the scope for the creation of a simple pavement maintenance strategy.

3.3 Maintenance Strategies used by other road authorities in Australia and New Zealand

3.3.1 Queensland

The Queensland Department of Transport and Main Roads (QTMR) have produced Asset Maintenance Guidelines. The purpose of the guidelines is to provide guidance in key strategic areas of maintenance including pavement maintenance. The maintenance guidelines are based on QTMR's policies and visions. From these a maintenance vision has been created being to (Queensland Department of Transport and Main Roads 2002, p3):

> "Maintain roads so that:
> - Their whole of life performance is maximised, having regard to safety, user costs, community benefits and Main Roads outlays; and
> - Road maintenance is funded at levels consistent with this vision."

QTMR's maintenance strategy is similar in outline to the Infrastructure Preservation Strategy proposed by Austroads. In addition, the strategy promotes the use of pavement preservation practices instead of a rehabilitation approach. A rehabilitation approach allows the pavement to deteriorate to a poor condition including having structural damage and then the pavement is rehabilitated (Queensland Department of Transport and Main Roads 2002).

The guidelines recognise the importance of collecting pavement condition data with data collected on an annual basis. Data collected includes roughness, rutting, cracking, texture, edge break and potholes. This data is used for performance monitoring and for input into SCENARIO, QTMR's pavement management system. SCENARIO is a role based pavement management system where the user can apply different rules to develop a pavement maintenance program (Queensland Department of Transport and Main Roads 2002). The system has deterioration profiles for roughness, rutting, cracking and seal age. These profiles are based on HDM models and QTMR research. The system also contains rules which are the triggers for individual treatments with SCENARIO providing a specified treatment. The software also allows the user to apply a budget constraint when determining work.

The strategy also details performance reporting requirements. It states that performance reporting is to provide feedback to stakeholders about the condition of the network (Queensland Department of Transport and Main Roads 2002). Network condition measures reported include roughness, rutting, seal age and smooth travel exposure. Smooth travel exposure is a measure that relates the roughness of the network with the number of vehicles using the network. This allows for lower trafficked roads to have a higher roughness than roads with larger traffic volumes.

3.3.2 Victoria

VicRoads, the Victorian road authority has implemented a different type of strategy to Queensland. In 1994 VicRoads adopted "A Stitch in Time" pavement strategy. The stitch in time theme is based on an old English proverb that says "A stitch in time saves nine (stitches at a later date)"

(Cossens 2010). Thus it could be observed that VicRoads have formally stated they are adopting a pavement preservation strategy where cheaper timely repairs can prevent or delay major work (Cossens 2010).

The “Stitch in Time” strategy is based on strategic objectives which include (Cossens 2010):

- Better conditions of higher speed roads than lower speed roads.
- Suitable road conditions are maintained at least cost to the community.
- The right treatment is applied at the right time.

The original implementation of this strategy had not relied on a pavement management system software package or road deterioration modelling. Prioritisation for rehabilitation was based on a pseudo economic formula which mostly focussed on roughness. A roughness value of over IRI 4.2 m/km was the trigger for rehabilitation investigations. Resealing was undertaken on a cyclical interval based on VicRoads determination of the life of a seal. KPI’s have been used to monitor performance of the strategy.

Over time the strategy has been revised. Performance monitoring of the network has shown that roughness of the network has decreased due to a focus on roughness in the strategy. However the KPI’s have shown that the length of distressed pavement and the amount of rutting and cracking has been increasing on the network. Distressed pavement is pavement having at least 30% of a pavement segment with rutting more than 10mm and with at least 10% of the length having cracking.

Owing to this the strategy has been modified to also focus on these distresses. VicRoads believe that regulating shape on pavement with an IRI between 3.5 and 4.2 m/km may address this issue. Pavements in this category are known as Zone 2 pavements with VicRoads noting that these pavements are deteriorating with their roughness getting close to the rehabilitation trigger of IRI 4.2 m/km. VicRoads have modified their KPI’s to enable a more detailed analysis of these changes. KPI’s include (Cossens 2010):

- Percentage roughness > 4.2 m/km.
- Smooth travel exposure (< IRI 4.2 m/km).
- Percentage length of cracking (treated or untreated).
- Length of distressed pavement.
- Percentage of network with rutting > 10 mm.
- Amount of pavement in Zone 2 (IRI between 3.5 and 4.2 m/km).

3.3.3 New Zealand

The New Zealand Transport Agency has produced an asset management manual for pavement maintenance management. The manual describes a strategy similar to Queensland’s and the Austroads’ infrastructure preservation strategy. This strategy like the others promotes pavement preservation rather than rehabilitation.

The strategy requires the collection of network condition data. This data is collected for the preparation of maintenance programmes and for performance monitoring. In addition to the data collected by Queensland the strategy requires the collection of pavement strength data for use in modelling.

The strategy has set triggers or intervention levels for when a defect reaches a specified value. Interventions are specified for:

- Roughness;
- Rutting;
- Skid resistance; and
- Surface defects such as cracking.

The New Zealand Transport Agency undertakes pavement deterioration modelling using a combination of models including (Transit New Zealand 1996):

- World Bank's HDM-3 and HDM-4 models;
- South African experience with the HDM models; and
- New Zealand application of these models.

These deterioration models are implemented using the dTIMS pavement management system. The models allow for (Transit New Zealand 1996):

- The cost to road users of operating vehicles on the network at varying condition states;
- How the existing condition will deteriorate over time;
- Treatments available to correct this deterioration; and
- The impact these treatments will have on pavement condition.

From this analysis the pavement management system also optimises maintenance activities to formulate a treatment strategy. The optimisation process investigates the effect of different budget levels on future network condition and the effect of budget levels to the maintenance programme (Transit New Zealand 1996). Despite this modelling process Parkman (2008) believes that trends from historical performance data is of more value than the results of the deterioration models.

A performance monitoring programme is undertaken with the following objectives (Transit New Zealand 1996):

- To indicate whether investment levels are sustaining overall service needs;

- To monitor the effectiveness of specific treatments;
- To monitor the validity of the pavement deterioration models; and
- To monitor the effectiveness of the maintenance programme.

4 Methodology

4.1 Introduction

The methodology describes the procedures used to undertake the research for the development of a strategic maintenance plan. The methodology has generally followed the processes described in the previous chapters for the implementation of an infrastructure preservation strategy.

4.2 Background information

The first phase of the project involved research into pavement maintenance strategies. The study has focused on all elements required for the creation of a pavement maintenance strategy. The literature review has highlighted the vast body of knowledge and opinions regarding pavement maintenance strategies. In particular the literature review has identified that there is no one solution that could solve the problem. The review has identified that there are many systems in use and that modelling pavement deterioration and works effects is not a simple process with numerous models being developed to undertake these tasks. Furthermore it has been found that there are numerous methodologies to prioritise or optimise maintenance works.

4.3 Key Performance Indicators

An essential component of an infrastructure preservation strategy is KPIs. KPIs used in other strategies were researched and reviewed. From this KPIs were chosen and targets recommended. These were based on network condition data available.

4.4 Study area selection

Ideally a pavement maintenance strategy should consider all pavements that are managed by a road authority. This strategy could then determine the optimal allocation of resources over the whole network. However, this project has focussed on a few sites along one highway to provide a proof of concept which could then be implemented over the whole network. It was too difficult in the time frame allocated to undertake a strategy for 2600 km of road. RMS Northern Region manages roads of varying pavement construction with the majority being granular pavement construction with a spray seal surface. Therefore the project has focussed on these types of pavements. A road consisting of mostly this type of pavement is the Gwydir Highway. Therefore this road was chosen for the study. If the strategy is successful for this road it is believed it could be applied to the whole of RMS Northern Region roads.

The Gwydir Highway connects Grafton and Walgett and the towns in between including Glen Innes, Inverell and Moree. The total length of the highway is 568 km. RMS Northern Region is responsible for the maintenance of 326 km from Grafton to around 40 km east of Moree as shown in Figure 1.1.

Traffic volumes using the Gwydir Highway in 2011 are shown in Table 4.1. While the volumes may be considered low compared to most roads in urban areas, the Gwydir Highway is a key link in the NSW highway system. It is a major link in northern NSW between the coast and Pacific Highway in the east to the tablelands and primary production areas in the west of the state. It is the only road north of Newcastle (460 km south) that allows B-Doubles to travel between the coast and the tablelands. In addition it is soon to be opened to allow road trains to travel as far east as Inverell. The use of these larger vehicles creates considerable efficiencies when transporting freight.

Table 4.1 Gwydir Highway traffic volumes for 2011

Location	AADT (Vehicles)
Waterview	1800
Dandhara	460
Elsmore	1100
Warialda Creek	1000

The Gwydir Highway is a relatively new road being mostly constructed in the 1960's. The pavement for the majority of its length is constructed of granular road base and sealed with a thin bituminous surface (spray seal or chip seal). While the road is quite new, it is narrow with few shoulders and the more modern heavier vehicles currently using the highway were not considered during its design. Figures 4.1 and 4.2 show typical lengths of the Gwydir Highway.

Figure 4.1 Typical section of the Gwydir Highway east of Glen Innes

Figure 4.2 Typical section of the Gwydir Highway west of Inverell

4.4.1 Study sites

Four study sites were chosen along the length of the Gwydir Highway managed by RMS Northern Region. The sites chosen were representative of the different conditions on the road in terms of terrain and climate. At each of these sites five maintenance segments were analysed. The four sites are:

- Waterview, 3 km west of Grafton;
- Dandhara, 100 km west of Grafton;
- Elsmore, 20 km E of Inverell; and
- Warialda Creek, 3 km west of Warialda.

Figures 4.3 and 4.4 shows the location of the sites. Images of the sites are shown in Figures 4.5 to 4.8.

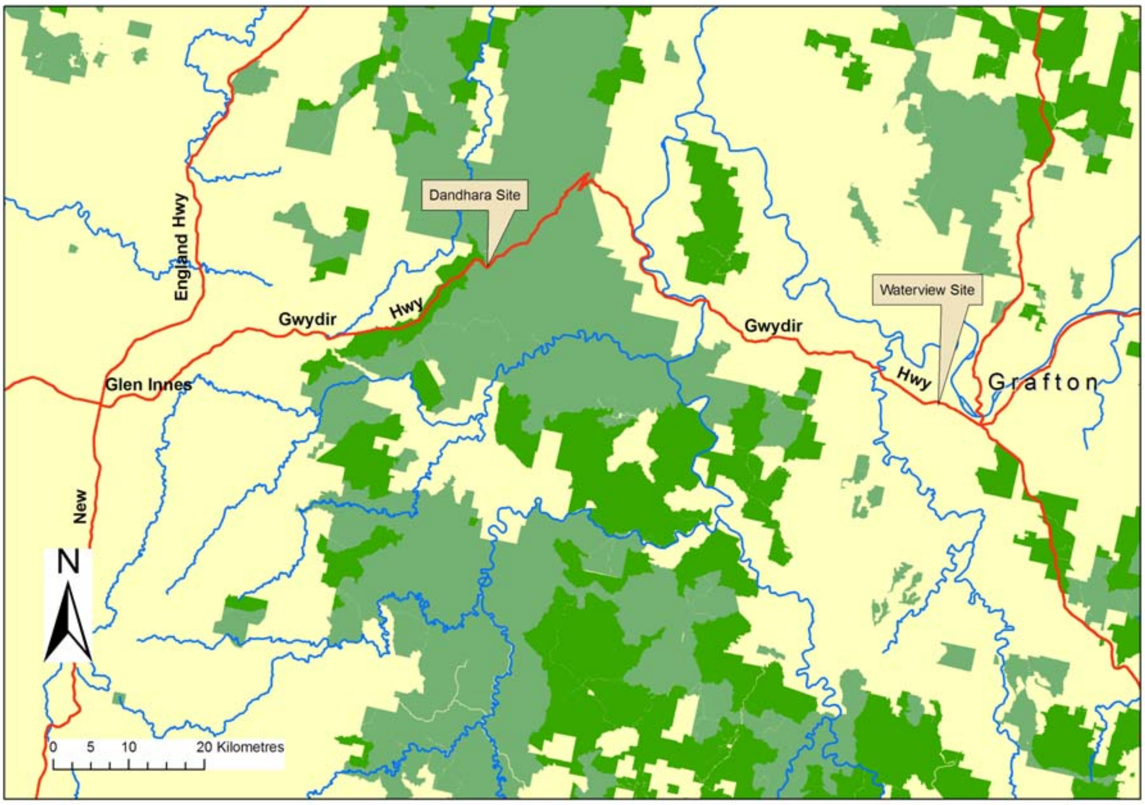

Figure 4.3 Location of Waterview and Dandhara sites

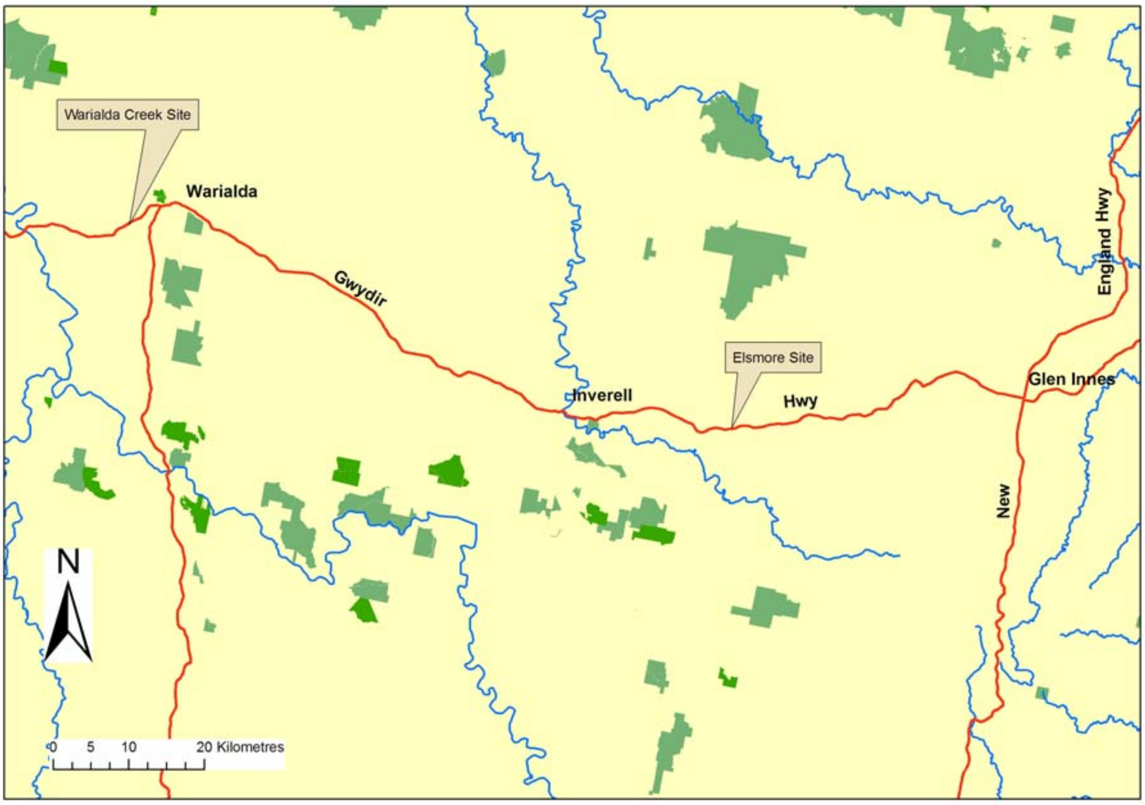

Figure 4.4 Location of Elsmore and Warialda Creek sites

Figure 4.5 Gwydir Highway at Waterview site

Figure 4.6 Gwydir Highway at Dandhara site

Figure 4.7 Gwydir Highway at Elsmore site

Figure 4.8 Gwydir Highway at Warialda Creek site

4.5 Road deterioration model selection

A suitable road deterioration model is an essential component of any road maintenance management system. The model allows for the prediction of the future deterioration of a pavement thus allowing asset managers to determine when intervention on a pavement is required. The aim of this part of the research project was to test two current road deterioration models with historical road condition data to assess their suitability for use on the Gwydir Highway and other RMS roads. The models were used to predict roughness, rutting and cracking for the years 2002 to 2012. The results were compared at the segment level.

The two models chosen were the latest two models proposed by Austroads and ARRB. These two models were chosen as they represent the latest knowledge and research in road deterioration modelling. Furthermore they have been proposed for Australian conditions based on Australian data. Most road deterioration models are based on the performance of overseas pavements and are therefore generally not suitable for Australian conditions.

The models chosen were:

- Interim network deterioration models proposed by Austroads (2010b).
- Deterioration models for sealed local roads in Australia proposed by Choummanivong and Martin (2011).

Both models are mechanistic deterministic empirical models. They are causal models which attempt to define the root cause of roughness (Hunt & Bunker 2001). The deterioration equations have been derived using statistical techniques to correlate these causative factors with roughness. Both models generally require the same inputs with the difference being the relationships between their inputs and the distresses. This is due to different observed data sets being used when determining these relationships. These models have been discussed earlier in this report.

4.6 Data collection

4.6.1 Road condition data

Road condition data such as roughness, rutting and cracking was required in order to compare the calculated distress with the actual distress. RMS collects data about its road network including road inventory data and road condition data. Road condition data is collected on an annual cycle with most data collected at 100 metre intervals for the entire Northern Region network. It is mainly captured using automated methods including the use of laser profilometers and the specialist RMS crack survey vehicle. In addition to roughness and rutting other data collected includes:

- Cracking;
- Skid resistance;
- Surface texture; and
- Historical treatment data.

This data is stored in a corporate database called the Road Asset Management System (RAMS). RAMS also stores inventory data such as segment number, segment length, seal type, pavement type and pavement width. Historical road condition data is also stored.

Data for this project was supplied by RMS Northern Region asset management staff in relational databases. The raw 100 metre interval data was supplied for the years 1996 to 2012. Summary data at the segment level was also supplied for the same years. A sample of these datasets is shown in Appendix B.

4.6.2 Pavement structure data

Pavement structure data such as resurfacing year and type of surfacing are required as an input into the deterioration models being tested. This data is also stored in RAMS with it being supplied in a relational database. The year of construction of the pavement and surfacing history was also supplied as part of this dataset.

4.6.3 Traffic volume data

A key input into most road deterioration models is the traffic loading applied to the pavement. The models being tested required the loading in terms of the millions of equivalent standard axles per year (MESA). An equivalent standard axle is a concept where the loads vehicles exert on the pavement are related to a standard axle load for design purposes .

Traffic volume data was obtained from a few different sources including the RMS corporate traffic volume database called the Vehicle Survey System (VSS) and from periodic traffic survey reports. For most of the sites investigated volumes are reported in AADT axle pairs. This is the number of axle pairs passing the site each day and does not allow for the classification of vehicle types. In fact an axle pair count does not provide a simple count of the number of vehicles passing a site. This is due to different types of vehicles having different numbers of axles. For example a car has one axle pair while a B-Double can have 4 axle pairs. Therefore to determine the AADT in terms of vehicles a conversion factor is needed to be calculated to convert axle pairs into vehicles. To calculate this factor, vehicle classification data was obtained where possible. From this it was possible to calculate the total number of vehicles and the composition of the vehicles. The composition of vehicles is required as only the volumes of heavy vehicles are used in the calculation of MESA.

Traffic growth trends were also calculated. For the Waterview and Dandhara sites it was observed that there has been no growth in traffic between 1995 and 2007. Therefore the volumes at these sites have been assumed to be constant in the future.

For the Elsmore and Warialda Creek sites, traffic growth has been observed. Linear regression models were created to allow for the calculation of volumes in years where no volumes were available. Details of traffic volume calculations are provided in Appendix C.

Once the volumes were calculated they were converted to MESA using equation 4.1 which is based on Austroads (2010c):

$$N_{DT} = 365 \times AADT \times DF \times \%HV \times LDF \times N_{HVAG} \qquad (4.1)$$

Where: N_{DT} = average number of axle groups per heavy vehicle (HVAG). Calculated from each dataset rather than assuming a value.

AADT = Annual Average Daily Traffic

DF = Direction factor: the proportion of AADT travelling in the lane. (Assumed 50%)

LDF = lane distribution factor: set to 1 as only one lane in each direction on the Gwydir Highway.

%HV = percentage heavy vehicles

From this MESA is calculated using equation 4.2:

$$MESA = N_{DT} \times HVAG/ESA \qquad (4.2)$$

where HVAG/ESA = 0.9 for major roads

The original form of the above equations also allow for traffic growth rates to be applied. However rather than use a growth rate, the calculation of MESA was done on a yearly basis using the current years AADT which had already had growth applied.

4.6.4 Climate data

Both models recognise the impact the environment has on the deterioration of pavements. The environment causes bitumen to oxidise resulting in cracking of the surface. This cracking then allows moisture into the pavement causing deterioration of the pavement. Both models use environmental data as inputs when predicting cracking, rutting and roughness.

The Thornthwaite Moisture Index (TMI) is often used to represent climatic impacts. It is the combination of the annual effects of precipitation, evapotranspiration, soil water storage, moisture deficit and runoff (Austroads 2010d). The data to calculate the TMI for the years required was not directly available from the Australian Bureau of Meteorology (BoM). However as part of an Austroads (2010d) study into climate change, a software tool that calculated the TMI was created. This tool allows the user to enter geographical coordinates (latitude, longitude) of a site to access a wide range of historical climate data from 1960 to 2007 and a range of simulated climate data from 2008 to 2099. A request was made to ARRB, the creator of the tool, who supplied the tool for use with this project.

By entering the geographical coordinates for each of the four sites, the tool provided a TMI from 1960 to 2099 with the TMI subsequently used in the models. A sample of TMI data is shown in Appendix D.

For the cracking model the time to crack initiation was required to be calculated. This equation required the minimum, maximum and average temperature at each of the four sites. This data was obtained from the BoM.

4.6.5 Pavement strength data

Another input to the models is the pavement and subgrade strength. The models tested required the modified structural number (SNC) to represent the pavement and subgrade strength. The most economical method of determining the SNC is to measure pavement deflections.

Studies dating back to the original HDM models have derived a relationship between SNC and deflection measurements. Therefore it was possible to calculate the SNC based on the FWD deflection d_0. At the start of the study FWD deflection data was only available between Glen Innes and west to the Northern Region boundary. This data was collected between 2009 and 2011 as part of a pavement evaluation project.

The FWD data was supplied in an Excel spreadsheet with deflections measured every 100 metres along the highway. Each deflection was located by chainage along the highway only. No offset from the road centreline was supplied which would have enabled more accurate positioning of the FWD test sites. By itself this data could not be used at the segment level. To relate this data to the maintenance segments it was loaded into ArcGIS, a Geographical Information System (GIS). Using the spatial analysis tools in ArcGIS the locations of the deflections were determined using the chainage and then related to each segment. From this the average deflection and standard deviation for each segment was calculated. Using the equation below, which was originally proposed by Paterson (1987), the SNC at the time of deflection measurement was calculated:

$$SNC = 3.2 \times D_0^{-0.63}$$

For the test sites east of Glen Innes, Waterview and Dandhara, no FWD deflections were originally available. However deflections from the Traffic Speed Deflectometer (TSD) project were available. The TSD project is detailed in Austroads (2012) with data for the Gwydir Highway collected in 2010. The TSD does not directly measure deflection but rather it measures the movement of the pavement when the vehicle carrying a load passes over it. From this deflections are derived. The magnitude of these deflections are not the same as other deflection measurements. The TSD project believed that it would be possible to derive a relationship between TSD and FWD deflections but this was not done as part of the TSD project. So before TSD deflections could be used a relationship between TSD and FWD deflections needed to be derived.

Since the TSD measures continuously, deflections were recorded at 10 metre intervals with the data supplied in a spreadsheet format. A sample of TSD data is contained in Appendix E. The TSD data was supplied with geographical coordinates but was not related to the maintenance segments. To relate the deflections to segments the data was imported into ArcGIS and related to segments.

4.6.6 Road condition data accuracy

The road condition data used to verify the model predictions has been measured using different methods. All measured data contains errors of some form so the quality of this data needs to be considered when using it to validate model predictions. Measured data contains three types of errors; random, systematic and/or gross errors. In addition measurement data is categorised in terms of its precision and accuracy. Accuracy refers to how close a measurement is to the true value while precision refers to the repeatability or spread of the measurements. Further discussion on the errors associated with road condition data measurement is detailed in Austroads (2006, 2007a and 2007b).

A description of the quality of the data supplied was not available but an analysis of the data for the segments analysed showed no large variations in either a temporal or spatial dimension. Furthermore the data supplied must be collected to RMS specifications and it has undergone a checking process before being supplied. Since no large variations were observed and that the data has been checked before supply it is believed that the data does not contain any gross errors. Random errors and systematic errors are harder to detect. The measurement method used has generally been the most accurate method which reduces the value of these types of errors. Furthermore the data has been averaged at the segment level which results in the reduction of random errors. Systematic errors are not considered a problem due to the measurement techniques. In addition since most of the models tested work on a relative system the difference between modelled and measured values due to systematic errors should be minimised.

4.6.7 Qualitative data

In addition to the literature review phone interviews were held with maintenance planning staff in other regions. The purpose of these interviews was to identify any suitable methodologies being used by these regions that could be implemented in RMS Northern Region. Also views on maintenance strategies, treatments and problems encountered were discussed. In addition staff from VicRoads were interviewed.

5 Results and analysis

5.1 Selection of key performance indicators

As discussed previously, KPIs can be used to measure the performance of a pavement. They can also be used as triggers for when a condition exceeds a specified value requiring maintenance to be undertaken. KPIs are also used in road deterioration forecasting to describe the future condition of the pavement.

The KPIs recommended have been selected from the network level condition data that is collected on an annual basis. They have been chosen to reflect current NSW Government policy regarding road condition and maintenance. One of the key decisions to be made was whether to use a composite index or to use individual indicators to describe the pavement condition. The problem with a composite index is the choice of its components and their relative weighting.

It was found that the Sydney Region of RMS uses a composite index, however, their network is primarily an urban network with mostly asphalt pavements. In addition, other combinations of distresses were considered but it was decided to focus on rutting and roughness for the KPIs. The KPIs recommended are

:

- Percentage of network with roughness less than IRI 4.2 m/km;
- Average roughness of network; and
- Length of network with rutting over a specified value;

Roughness was chosen for a number of reasons. A key reason was that one of the goals of NSW 2021, the NSW State Plan (NSW Department Of Premier and Cabinet 2011) is that of 93% of the state road network meeting the national smoothness standards by 2016. The national smoothness standard for a road is an IRI of less than 4.2 m/km (NSW Department of

Premier and Cabinet 2011). NSW 2021 is the NSW Government's "*10 year plan to guide policy and budget decision making and, in conjunction with the NSW Budget, to deliver on community priorities. It sets long–term goals and measurable targets, and outlines immediate actions that will help us (NSW) achieve these goals*" (NSW Department of Premier and Cabinet 2011, p3). Since this is a target of the NSW Government it should be a KPI for RMS Northern Region.

The NSW Government has also reinforced the policy that all government agencies have "*the customer at the heart of every decision*" (Transport for NSW 2012, p5). One of the main customers for RMS is the road user. A 1996 Coopers and Lybrand survey in the USA showed that pavement roughness is the primary concern of the travelling public (Hunt & Bunker 2001). Therefore the use of roughness as an indicator would assist with improving customer satisfaction when programming maintenance activities.

Roughness and rutting were chosen because they are relatively inexpensive to capture, they are an objective measure, they correlate well with road user costs and it is accepted as the most relevant long term measure of the functional behaviour of a pavement (Hunt & Bunker 2001, p6). Another reason that roughness was chosen is that most road deterioration models calculate road deterioration in terms of roughness. It was considered that the output of a model would be meaningless if they could not be compared against a KPI. The average roughness of the network was chosen to ensure the sustainability of the network. An average value of roughness is used to ensure that the whole network is not just sitting below an upper roughness threshold about to fail.

While roughness has been recommended it should be noted that VicRoads (Cossens 2010) found that using roughness alone as a target resulted in areas of maintenance being omitted. Since this may be an issue it is recommended that rutting also be measured as a KPI. While the indicator may not be required by the community, it is used to give the asset manager a different awareness of the network. In addition it is believed this KPI also assists with the future sustainability of the network (Cossens 2010).

5.2 Selection of targets for key performance indicators

While roughness and rutting have been chosen as performance indicators, values need to be set for targets. As discussed previously a target has been set for one KPI where 93% of the highway should have a roughness of less than an IRI of 4.2 m/km. Table 5.1 shows the percentage length of the Gwydir Highway with roughness less than 4.2 m/km over the last eleven years. It can be seen that this target has been met in nine of the past eleven years with the value oscillating near the target. Therefore based on the historical data this KPI is considered a realistic target for the Gwydir Highway and should be adopted.

Table 5.1 Percentage length of Gwydir Highway with roughness less than 4.2 m/km between 2002 and 2012

Year	% length with IRI less than 4.2 m/km
2002	94%
2003	94%
2004	93%
2005	92%
2006	94%
2007	95%
2008	94%
2009	95%
2010	95%
2011	92%
2012	93%

The average roughness of the road was another KPI proposed. Figure 5.1 shows the average roughness of the highway for the past eleven years. From this figure it can be seen that the average roughness has varied over the last eleven years. The figure also shows the expenditure (dollars based on year of work) for all maintenance activities related to pavement maintenance such as routine, resurfacing and reconstruction. From this figure it appears the average roughness is dependant on the value of pavement maintenance expenditure with the roughness decreasing a year after funding has increased. Based on the data, a possible value for the KPI to be tested is an IRI of 2.8 m/km. This value ensures the sustainability of the network ensuring that the highway is not all sitting just below 4.2 m/km and about to fail.

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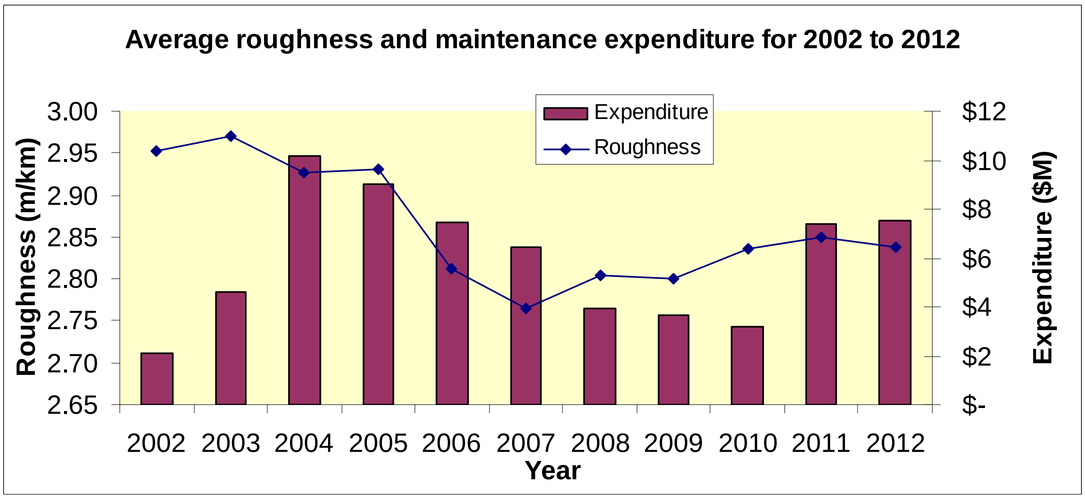

Figure 5.1 Graph of average roughness for the Gwydir Highway and maintenance expenditure for 2002 to 2012

Figure 5.2 shows the lengths of the Gwydir Highway with rut depths greater than 10 mm for the past 11 years. It also shows the maintenance expenditure. The value of 10mm was chosen as it is the smallest value of rut depth reported in terms of pavement lengths. Furthermore this value has been recommended by VicRoads. It can be seen in the figure that the length of the Gwydir Highway with rut depth greater than 10 mm quite variable between years. It ranges from 46 km in 2003 to 11 km in 2007. It is currently sitting at around 15 km. Therefore a recommended target is around 15 km of rut depth over 10 mm for the length of the highway.

The treatments to remove both roughness and rutting are generally the same however they may need to be applied at different locations. An optimisation algorithm would be required to determine which sites get treated to reduce these distresses as a whole.

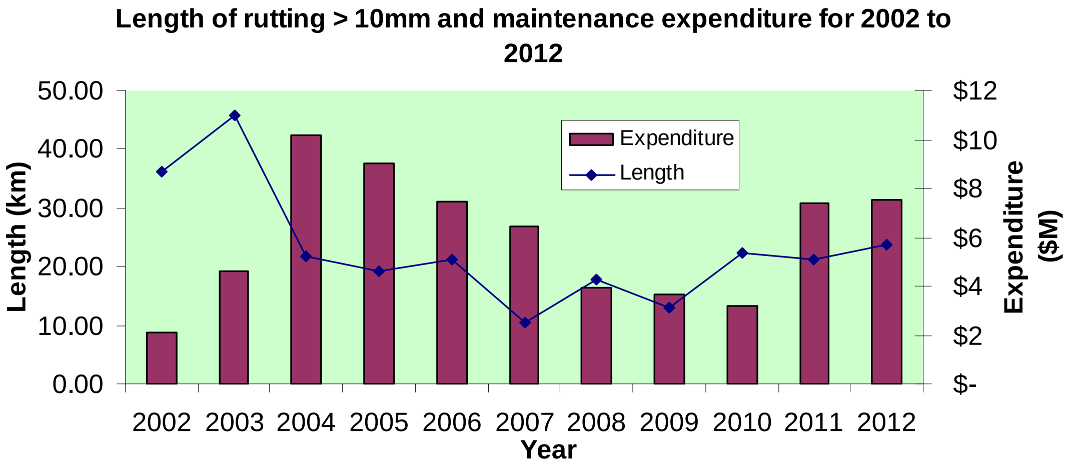

Figure 5.2 Graph of length of rutting greater than 10mm depth for the Gwydir Highway and maintenance expenditure for 2002 to 2012

5.3 Results of discussions with other RMS pavement maintenance planners

Telephone interviews were held with the pavement maintenance planners from the Southern, South-western and Sydney regions of RMS. In addition a senior maintenance planner from VicRoads was also interviewed. The aim of these interviews was to investigate what maintenance strategies are being used by other regions and if they could be used by RMS Northern Region. A questionnaire was used as a prompt for questioning however it was not always followed strictly. This allowed for flexibility in discussions. A copy of the questionnaire is shown in Appendix F.

It was discovered that the Southern and South-west Regions use a similar methodology to Northern Region for planning their maintenance activities. Neither has a written strategy detailing how they prioritise activities and neither appears to follow the methodology described by Austroads for the implementation of an infrastructure preservation strategy. They do have route standards documents which set standards for their network such as lane and shoulder widths and preferred pavement and surfacing types.

Similar to Northern Region these regions use condition data along with a network inspection to rate segments and determine priorities. Priorities are usually based on a worst first approach. It was also discovered that neither region uses any form of KPIs or deterioration prediction when determining priorities. Both regions recognised the importance of pavement preservation techniques and stressed the importance of their implementation.

In contrast Sydney Region currently uses a PMS for the planning of its pavement maintenance activities. The region has set a KPI based on a composite pavement condition index (PCI). This index is based on roughness, rutting, cracking and SCRIM values. The goal of the PMS is to select treatments within the available funding that optimise the overall PCI of the network. Sydney Region has determined deterioration curves, works effects and triggers for maintenance. These have been determined based on Sydney road network data. Sydney Region are also strong proponents of pavement preservation practices.

The Manager, Asset Strategies, VicRoads was also consulted regarding their maintenance strategy. Discussions confirmed that the “Stitch in Time” maintenance strategy was still in use. Advice was that all three forms of maintenance need to work together with routine maintenance still the key. In terms of prioritisation of works it appears the methodology is similar to the RMS Northern, Southern and South-Western Regions. VicRoads regions use network condition data and inspections to assist in prioritisation of works with a worst first strategy generally being adopted.

VicRoads set KPIs with their “Stitch in Time” strategy which were originally based mostly on roughness. A review of these KPIs has identified that roughness alone may not be the best KPI with VicRoads changing their KPIs to include other indicators. The current KPIs used by VicRoads are discussed in Section 3.3.2. VicRoads does not use road deterioration modelling. One reason for this is that according to the staff member interviewed “HDM models do not function the way VicRoads do”.

Table 5.2 Summary of Responses

ACTIVITY	Published maintenance strategy	Network condition data used to prioritise maintenance	Worst first strategy	KPIs determined	Road deterioration modelling used
RMS Northern		X	X		
VicRoads	X	X	X	X	
RMS Southern		X	X		
RMS Southwest	X	X	X		
RMS Sydney	X	X		X	X

5.4 Analysis of relationship between traffic speed deflectometer and falling weight deflectometer deflections

To determine a relationship between TSD and FWD deflections a linear regression analysis was performed. Before the regression could be undertaken the measured TSD deflections needed to be matched to their nearest FWD deflections. Figure 5.3 shows that for each FWD deflection measured there are many measured TSD deflections nearby. Using ArcGIS, the nearest TSD point was matched to the corresponding nearest FWD point. A criterion was set where points would only be matched if they were not more than 10 metres apart. It was considered that beyond 10 metres, the pavement strength between the points may start to differ due to being too far apart. Regression analysis was then undertaken between these data points for the Gwydir Highway, Fossickers Way and New England Highway.

Appendix G shows scatter plots of the TSD deflections versus FWD deflections for the Kamilaroi Highway and New England Highway. Figure 5.4 shows the scatter plot for the Gwydir Highway. These plots show the relationship between the 100 metre FWD deflections and the nearest corresponding TSD deflection (number of points, n ~ 3000 for all sites).

When looking at the scatter plots of all the sites no correlation between the data appears evident. Each plot also shows the line of best fit and the coefficient of determination R^2. In all cases the R^2 is a low value indicating that there does not appear to be a relationship between the variables.

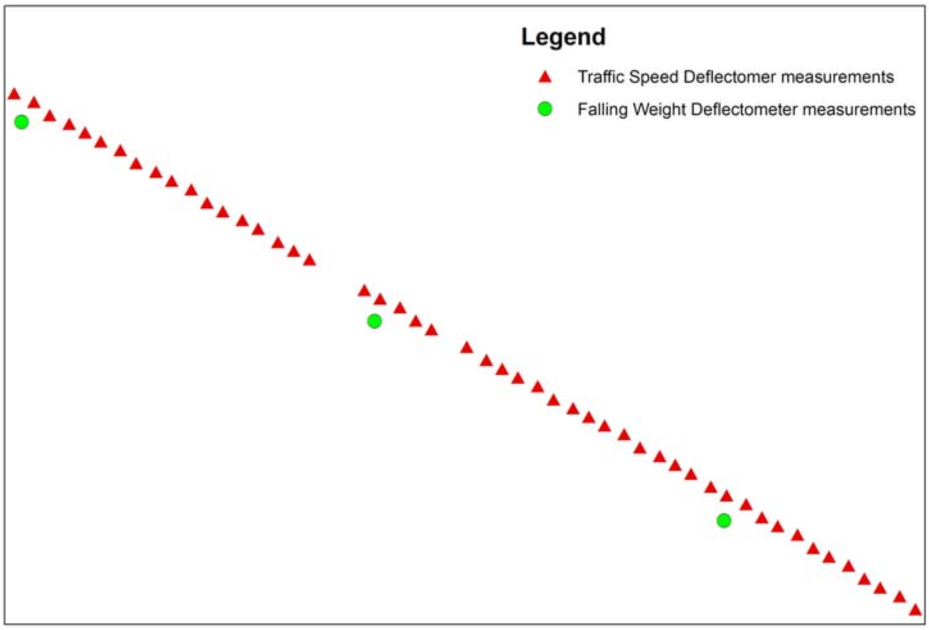

Figure 5.3 Plot showing spatial relationship between TSD and FWD points

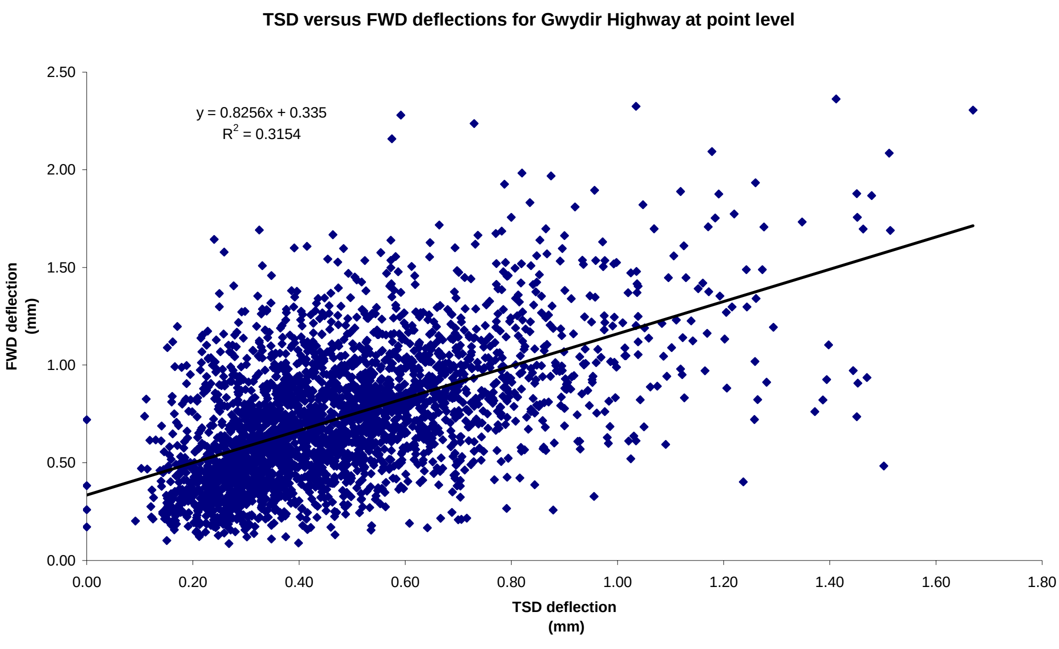

Figure 5.4 Scatter plot of TSD versus FWD deflections at the point level for the Gwydir Highway

There could be a few reasons for the lack of correlation between the variables. One reason is that in most cases there was up to a 1.5 year time gap between when the TSD deflections and the FWD deflections were measured. Over time the strength of the pavement may have changed resulting in the poor relationship between variables. The strength may have also changed due to maintenance undertaken, moisture in the pavement or due to wear of the pavement by vehicles using the road.

Another reason for the poor correlation may be due to positional inaccuracies. When testing the relationship it has been assumed that the pairs of points are within 10 metres of each other and the pavement/subgrade strength would be similar. However, this may not be the case as the FWD data only had a chainage to locate it. No offset from the centreline was supplied meaning that in some cases points compared may be further apart that assumed.

Also it is thought that different pavements respond differently to applied load (Austroads 2012). The analysis undertaken has not made any allowance for different pavement types. Nevertheless, roads such as the Fossickers Way and Gwydir Highway are nearly all of the same construction, a granular pavement with a thin spray seal. Therefore, it is believed that this should not be an issue in this case.

Figure 5.5 shows a profile of the different values of deflection along lengths of the Gwydir Highway. Plots of this type are also shown in Austroads (2012). While the plots in Austroads (2012) show that the deflections generally correspond with each other, this does not appear to be the case for the charts shown. It can be seen in this figure that in some areas when deflections are increasing for one device the other is decreasing and vice versa. These plots therefore support the regression analysis that no correlation can be found between the FWD and TSD deflections when comparing the deflection of individual points.

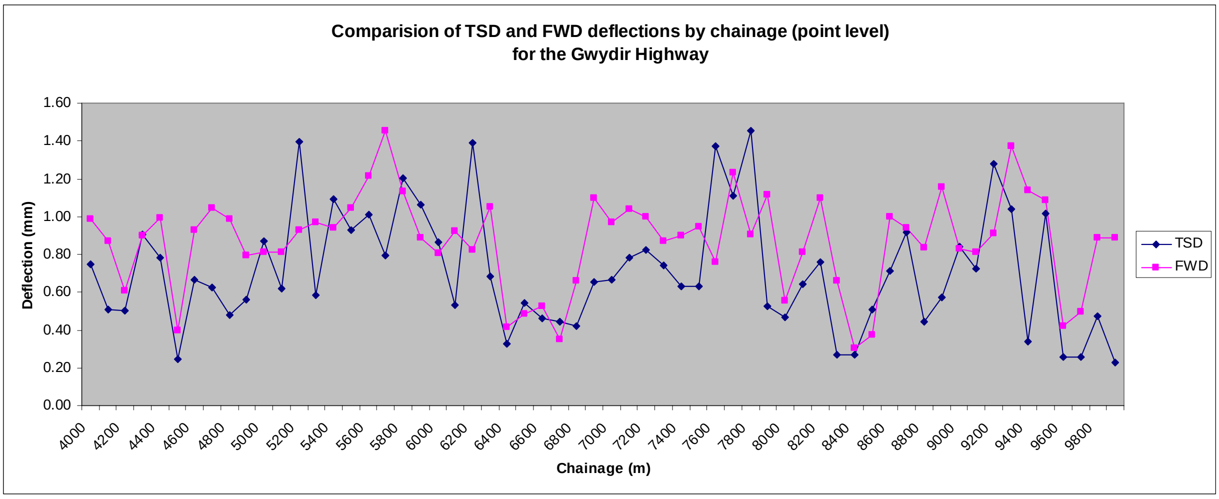

Figure 5.5 Comparison of TSD and FWD deflection by chainage (point level) for the Gwydir Highway

The correlation between TSD and FWD deflections was also investigated when these values were aggregated at the segment level. The average FWD and TSD deflections for each segment were calculated for the Gwydir Highway with a scatter plot shown in Figure 5.6. While there are fewer data points (n~300), the scatter plots show a more linear trend. This trend is supported by a higher R^2 of 0.6 indicating a closer relationship between the data. In addition Figure 5.7 shows the profile of deflections along the Gwydir Highway for a number of segments. This figure shows that the deflections follow the same trend closer than at the individual point level. Therefore this relationship could be used on the Gwydir Highway to calculate FWD deflections based on TSD deflections. While this relationship was found, it was not used due to FWD data being made available after these relationships were determined.

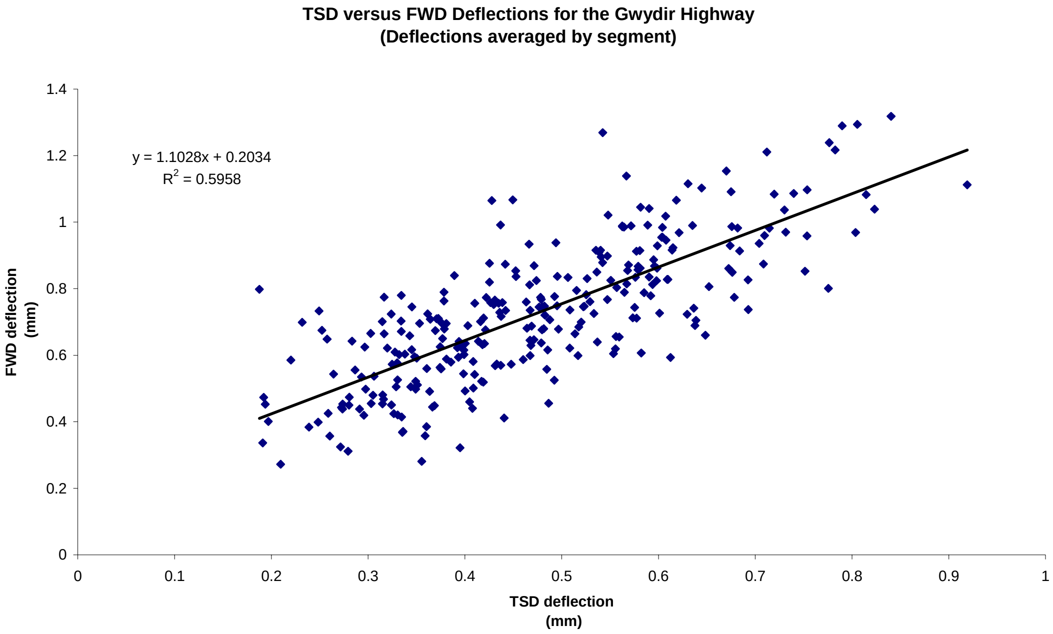

Figure 5.6 Scatter plot of TSD versus FWD deflections at the segment level for the Gwydir Highway

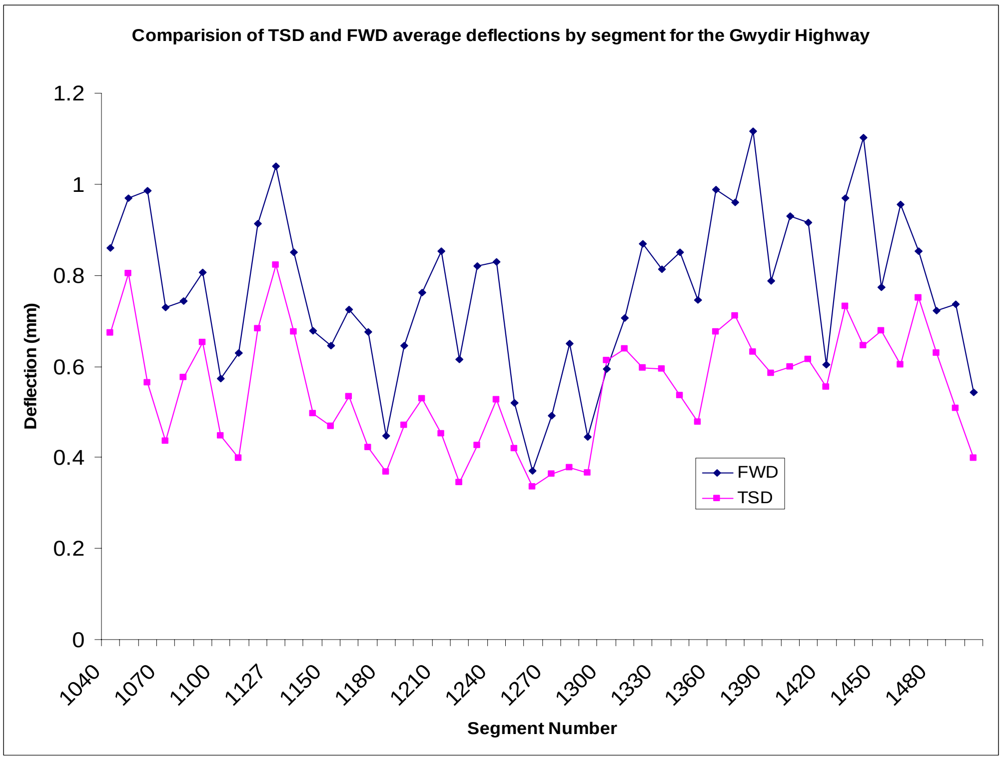

Figure 5.7 Comparison of TSD and FWD deflection by chainage (point level) for the Gwydir Highway

5.5 Deterioration models for sealed local roads

The road deterioration for sealed local roads model was implemented for the four sites using Microsoft Excel for the years 2002 to 2012. For the Waterview and Dandhara sites the cumulative model was used while for Elsmore and Warialda Creek the incremental model was used. This is due to Waterview and Elsmore having no traffic growth and Elsmore and Warialda Creek having traffic growth during the evaluation period.

5.5.1 Cumulative models for Waterview and Dandhara

Before discussing the results, some comments need to be made regarding the calculation of values used in the model. The cumulative models require the conditions of the pavement be known when it was built (Year 0). As these conditions are generally not known they must be calculated using more current condition data as a starting point. The key Year 0 conditions required were the initial structural number SNC_0, initial rutting (R_0) and initial roughness (IRI_0). To reverse calculate the Year 0 conditions the same deterioration models used for prediction were used to calculate SNC_0 and IRI_0. For the calculation of R_0 a different equation was used. When determining these Year 0 values the models assume that the road has deteriorated gradually from Year 0 to the current year. This may not always be a correct assumption as the models do not allow for the changes in pavement condition due to routine or preventative maintenance that may have occurred in the past.

When considering the IRI_0 values calculated for Waterview they appear unrealistic with all values below 1.5 m/km. Analysis of work effects for all pavement rehabilitation projects undertaken on the Gwydir Highway from 2001 to 2011 is shown in Figure 5.8. This figure shows that a roughness of 1.5 m/km would be an optimistic value for new pavement. It is believed these unrealistic values for Waterview are due to the current years having low roughness values probably due to effective routine maintenance. However the other Year 0 values of R_0 and SNC_0 for Waterview do appear realistic.

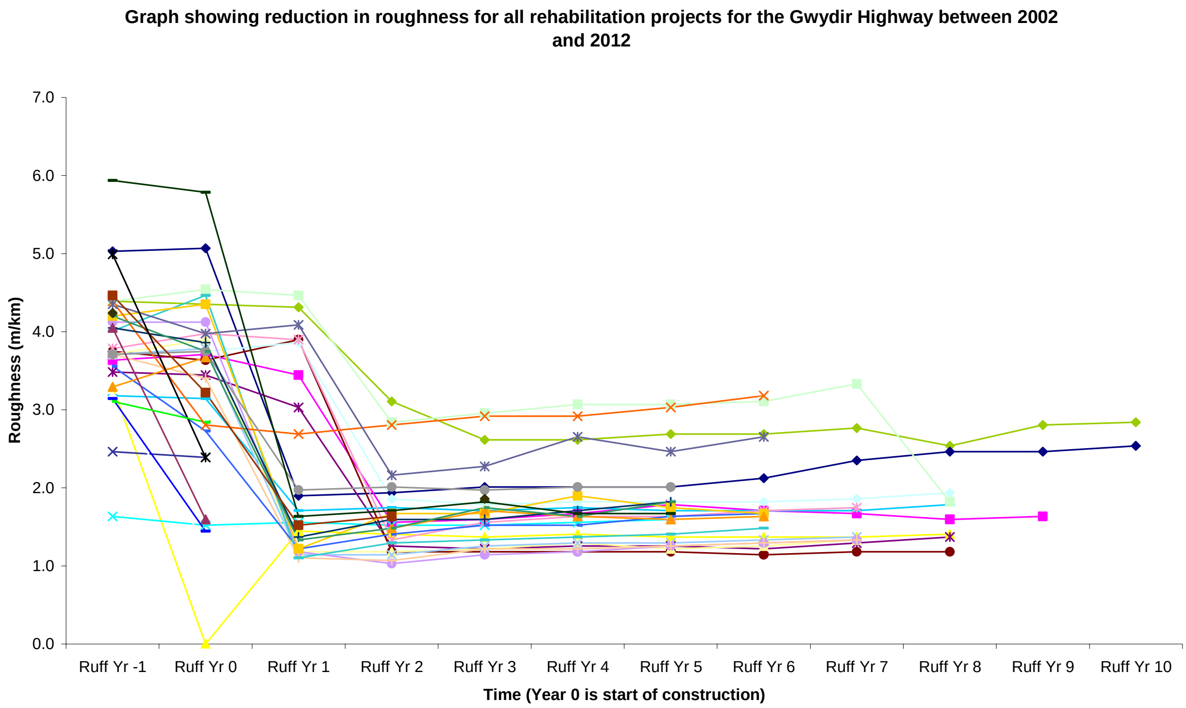

Figure 5.8 Graph showing works effects for pavement rehabilitation projects for the Gwydir Highway between 2002 and 2012

When considering the Year 0 values for Dandhara some of the IRI_0 values were calculated as being negative which is not possible. The age of the segments at Dandhara are around 50 years so again it is believed the routine maintenance activities have kept the roughness low. Therefore the values for IRI_0 at Dandhara were set to an assumed value of 1.5 m/km.

Figures 5.9 and 5.10 show selected graphs comparing the forecast roughness with the measured roughness for segments at Waterview and Dandhara. Appendix H provides more detail. At Waterview the model has generally underestimated the roughness by values up to 50% while at Dandhara the roughness has been overestimated by up to 160%. When looking at the residuals for Waterview no apparent trend can be observed. For Dandhara the values of the residuals are increasing with time indicating the models are diverging with the observed values.

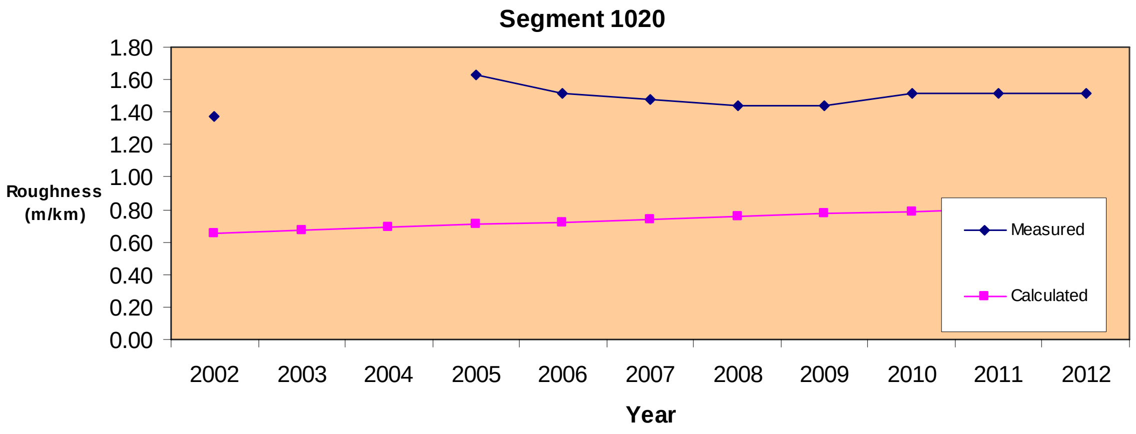

Figure 5.9 Comparison of predicted versus actual roughness for Segment 1020 at Waterview

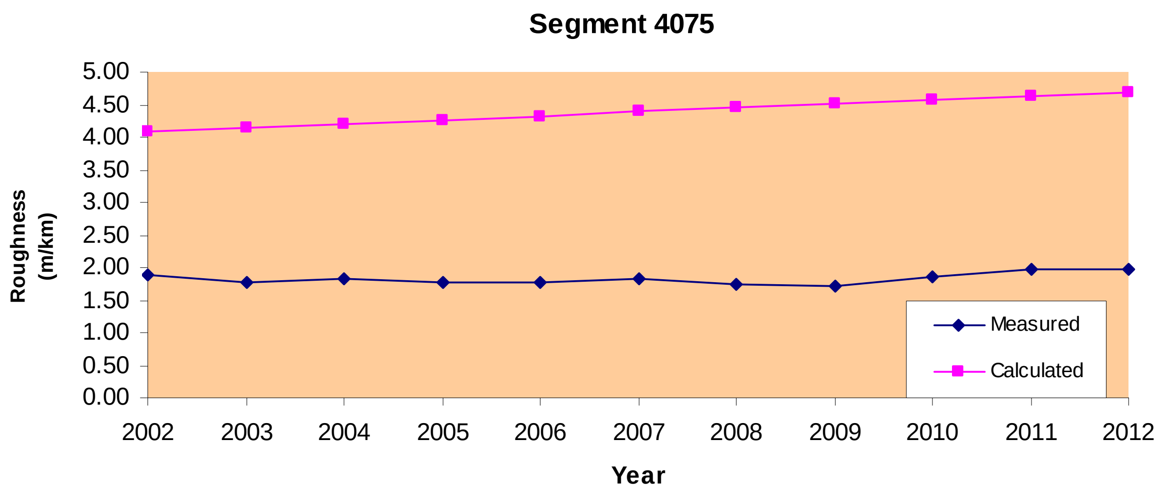

Figure 5.10 Comparison of predicted versus actual roughness for Segment 4075 at Dandhara

The roughness model contains a calibration factor that can be varied to adjust the model for local conditions. Since the predictions and measured values were so different, an attempt was made to adjust the forecasts using this calibration factor. This test was done for both sites. To adjust the factor, the residuals at each segment for each year were calculated. Then using Excel's solver function the sum of the squares of the residuals was minimised by varying the value of the calibration factor. As can be seen in Appendix H, Figure 5.11 and Figure 5.12 show that a calibration constant does provide an answer closer to the measured values with differences generally below 20% for roughness. While it appears that a calibration factor does allow for a better result, a different factor needs to be calculated for each site. The calibration factor appears to provide a much better agreement with the Dandhara segments compared to the Waterview segments.

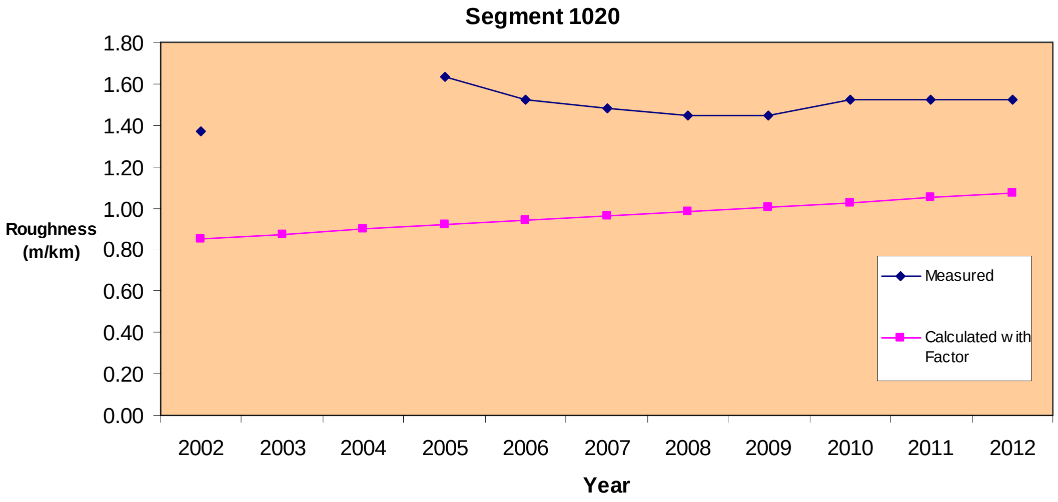

Figure 5.11 Comparison of predicted versus actual roughness for Segment 1020 at Waterview using calibration factor

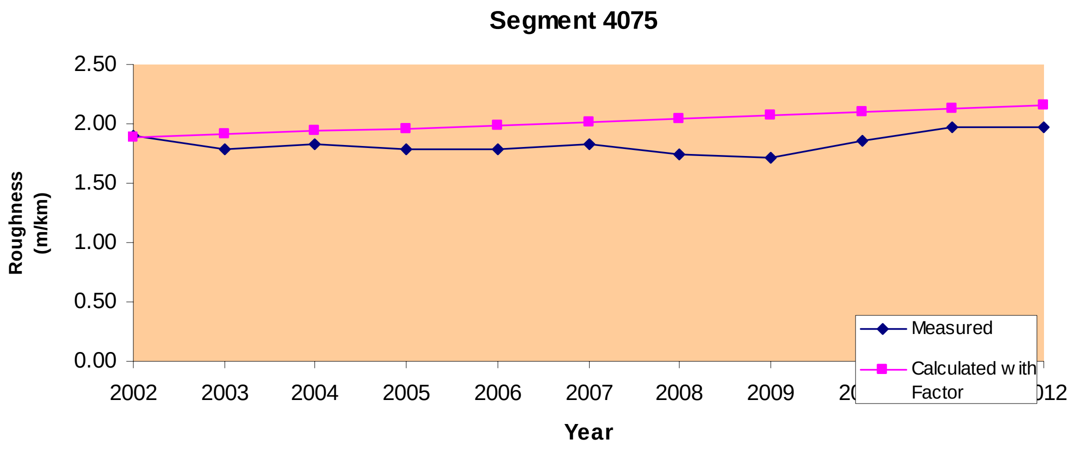

Figure 5.12 Comparison of predicted versus actual roughness for Segment 4075 at Dandhara using calibration factor

It is considered that the forecasts from the models not using the calibration factors are unsuitable due to their large differences with the measured values. If a calibration factor is used it has the computational overhead of requiring different values for different areas. However, if the measured 2002 value is adopted as the calculated or base value for 2002 and the annual difference previously calculated used, the results are more acceptable. This is in effect transforming the model into an incremental model. These values are shown in Figures 5.13 and 5.14 and detailed in Appendix H. It can be seen that for an 11year forecast period the predicted values are mostly within 20% of the measured values. This is considered acceptable as this modelling is trying to forecast an extremely complex interaction of factors. Also an advantage of this method is that no calibration factors are required.

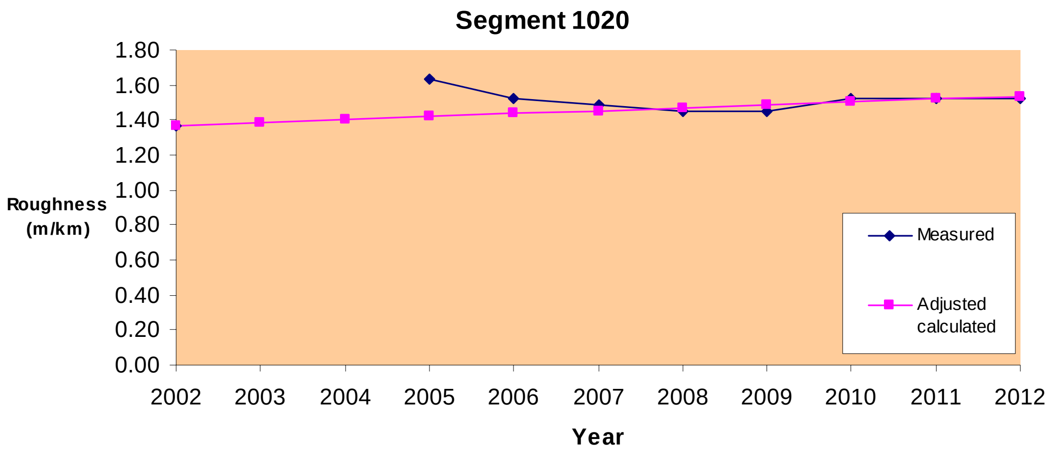

Figure 5.13 Comparison of predicted versus actual roughness for Segment 1020 at Waterview using annual difference and adoption of 2002 value

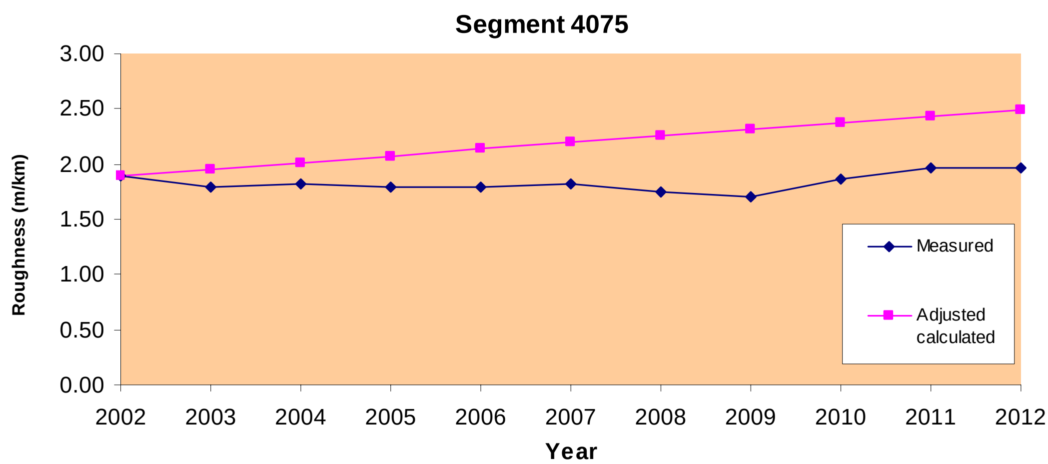

Figure 5.14 Comparison of predicted versus actual roughness for Segment 4075 at Dandhara using annual difference and adoption of 2002 value

Results for the prediction of rut depths for Waterview and Dandhara are detailed in Appendix H. Graphs comparing the actual versus predicted values are shown in Figures 5.15 and 5.16. It can be seen that the models do predict a gradual linear increase in rut depths over time. This is in contrast to the measured values which appear to vary over time. The variance in the actual rut values may be due to the effect of routine maintenance. As the road is a major highway rutting must be kept below specified levels to ensure safety for the road user. While there are differences in the calculated versus observed rutting values, the absolute difference is generally below 2mm which is a small amount. Therefore, it is considered that the rutting model is adequate.

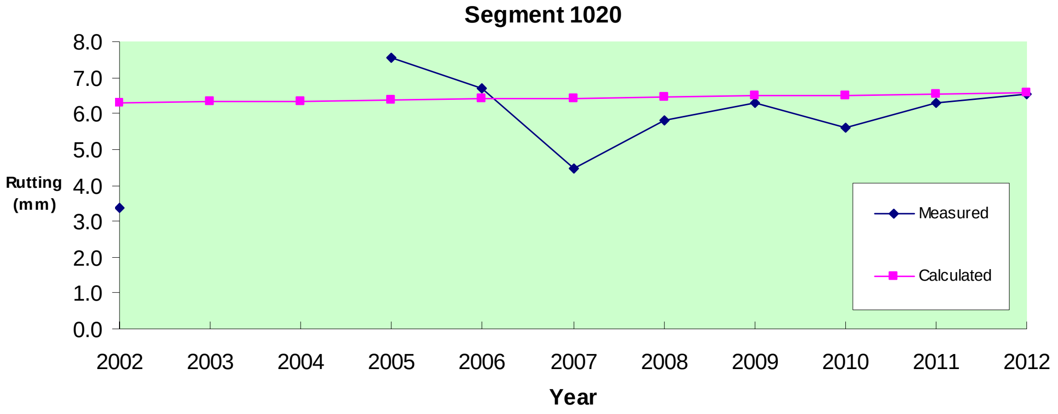

Figure 5.15 Comparison of predicted and measured rutting for segment 1020 at Waterview site

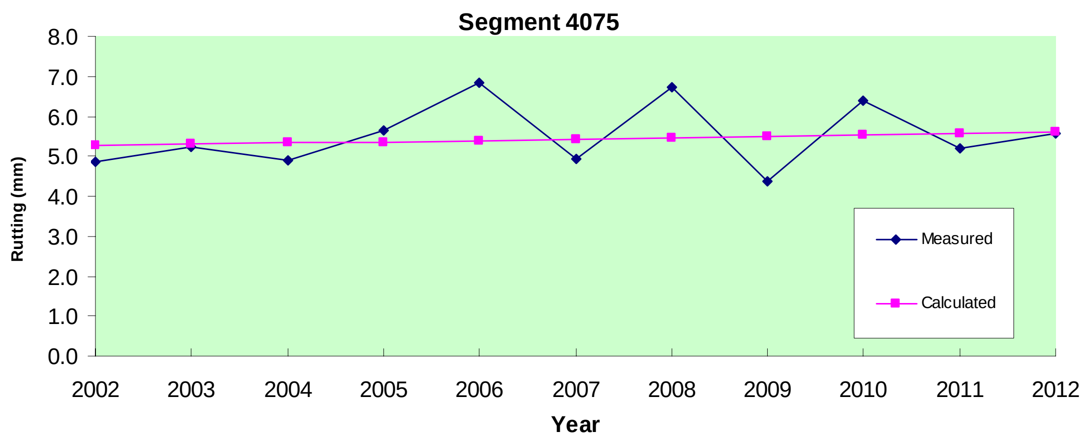

Figure 5.16 Comparison of predicted and measured rutting for segment 4075 at Dandhara site

The models also forecast the percentage of cracking for a segment. This is used as an input into the forecasting of roughness and rutting. In addition, a model exists to determine the age of a seal when cracking is first likely to occur. The model predicts when a seal starts cracking based on environmental data and seal characteristics. The models for Waterview and Dandhara have generally not used the cracking model as reseals were performed during the analysis period. Where predicted to occur the crack model results have been used. It can be seen from the existing condition data that cracking is generally measured as being at very low levels. This is due to the recent seals and due to maintenance interventions.

Cracking was only calculated for segment 1040 at the Waterview site with the cracking predicted to only occur during the last three years of analysis. The predicted value of cracking is higher than the measured value, however, both values are quite small, being less that 2%. Due to the current preventative maintenance practices of resealing and crack sealing it is believed that cracking contributes little to the deterioration of the pavement. Figures 5.17 and 5.18 show the measured time series cracking for the Waterview and Dandhara sites. No cracking was forecast at Dandhara due to the effect of resealing during the analysis period. The figures, especially Dandhara show how cracking varies due to maintenance activities.

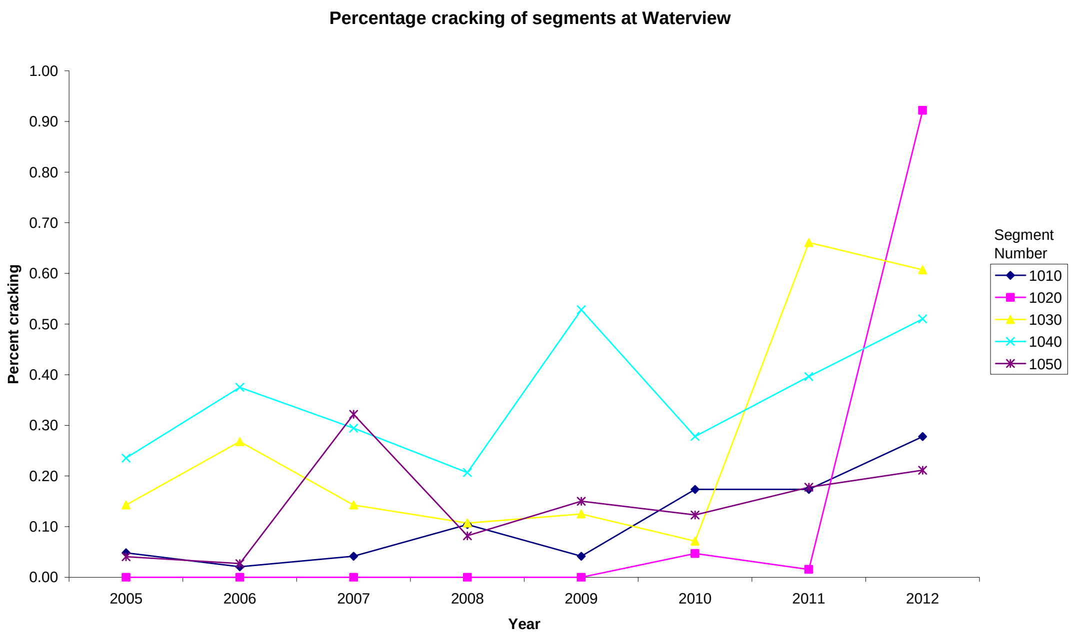

Figure 5.17 Measured cracking by segment at Waterview

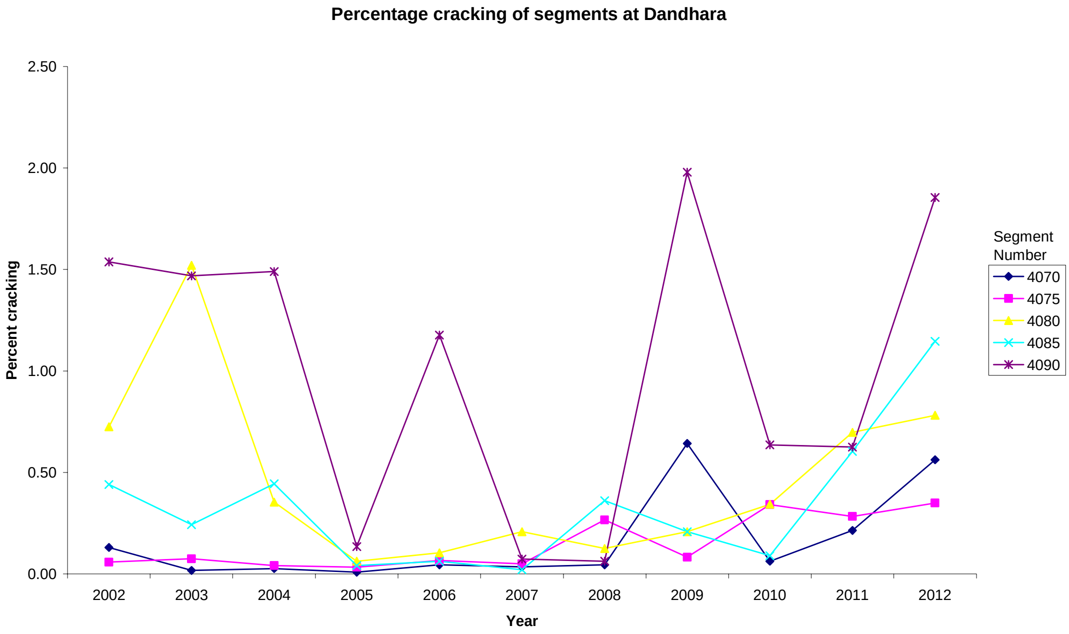

Figure 5.18 Measured cracking by segment at Dandhara

5.5.2 Incremental models for Elsmore and Warialda Creek

The incremental models for roughness, rutting and cracking were tested at the Elsmore and Warialda Creek sites. These incremental models calculate the current year's deterioration based on the previous year's deterioration, rather than from Year 0. Therefore these models used the values of roughness, rutting and cracking that were observed in 2002 as a base for the predictions. A value for SNC was calculated for 2002 by calculating annual changes back to 2002 from when it was observed. Subsequent year's distresses were calculated from these values.

The calculations for the predicted and actual roughness and rutting for Elsmore and Warialda Creek are detailed in Appendix I. Figures 5.19 and 5.20 show graphs of the predicted versus measured roughness for typical segments at Elsmore and Warialda Creek. The roughness values are generally within 15-20% of the measured values for the complete 11 year analysis period. It can also be seen that the difference between values increases as time increases which could indicate that the model is overestimating the increase in roughness per year. On the other hand it could mean that the increase in roughness of the segments is slowed by maintenance. This is most likely the case as roughness is generally forecast to increase gradually rather than stay constant.

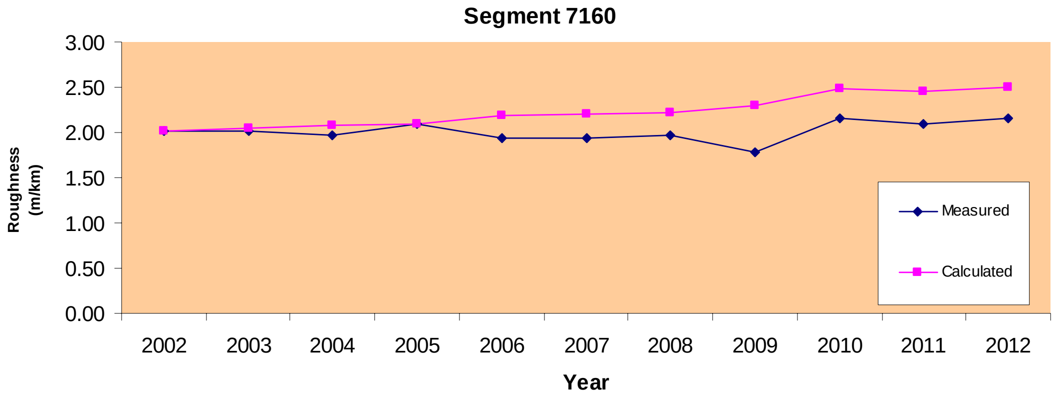

Figure 5.19 Comparison of predicted versus actual roughness for Segment 7160 at Elsmore

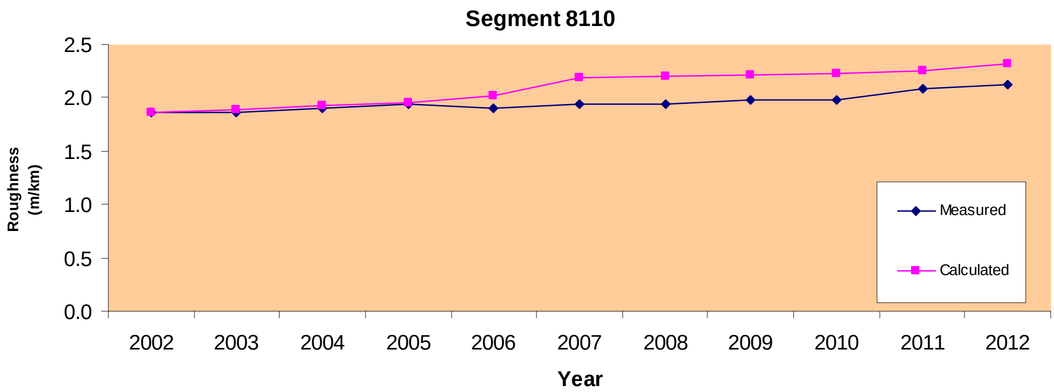

Figure 5.20 Comparison of predicted versus actual roughness for Segment 8110 at Warialda Creek

The predicted roughness values at Warialda Creek have a closer fit to the measured values compared to Elsmore. In this case both the actual and calculated roughness values are gradually increasing. Most values are within 10% of each other.

Similar to the cumulative models, an attempt was made to apply the local calibration factor to investigate if a better prediction could be made. The same process of minimising the square of the residuals was used to determine the local calibration factor. Figures 5.21 and 5.22 show plots of the actual and calibrated predicted values of roughness for selected segments. It can be seen from the plots that applying the calculated factor reduces the difference up to the year 2008. However, after 2008 the predicted values of roughness decrease over time. This is considered unrealistic as it is highly unlikely that the roughness would decrease over time. One possibility is that fitting the calculated value to the measured values is forcing the predictions to decrease due to the effect of maintenance activities on the measured values. This problem is observed for both Elsmore and Warialda Creek. Owing to this it is not recommended that these calibration factors be used.

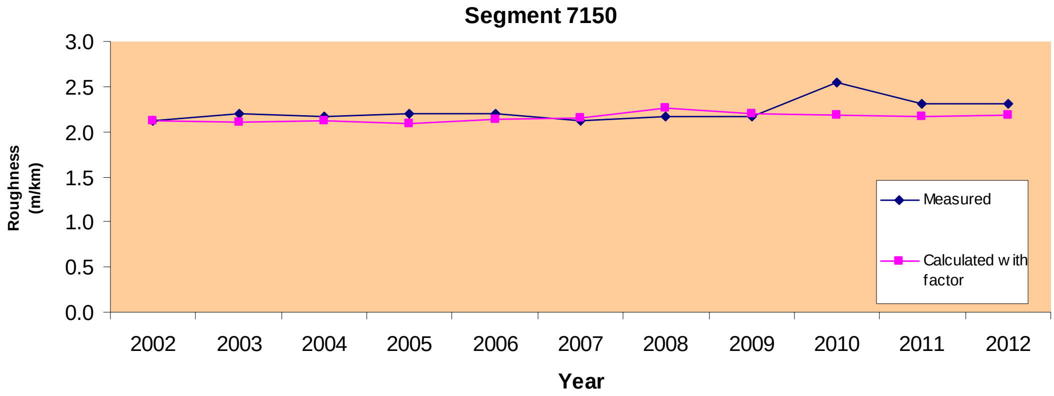

Figure 5.21 Comparison of predicted versus actual roughness for Segment 7150 at Elsmore

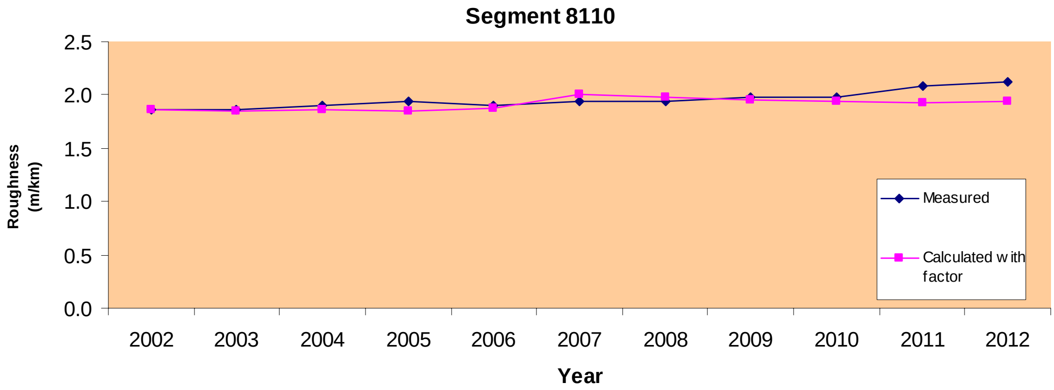

Figure 5.22 Comparison of predicted versus actual roughness for Segment 8110 at Warialda Creek

Using trial and error a constant could be found for Elsmore and Warialda Creek that produces results close to the measured values for the 11 year analysis period. This factor still allows the roughness to gradually increase. However, this value must be calculated for each site and requires trial and error for each site. Owing to this, use of this adjustment is not recommended considering the unadjusted models provide acceptable results.

Rut depth was also forecast at both sites with the actual rutting value for 2002 used as the base value for predictions. Comparisons of the predicted versus the measured values are detailed in Appendix I. Overall for both sites the model agrees closely with the measured values with nearly all differences below 2mm. Figures 5.23 and 5.24 show a comparison between calculated and measured rutting values for selected segments at both sites.

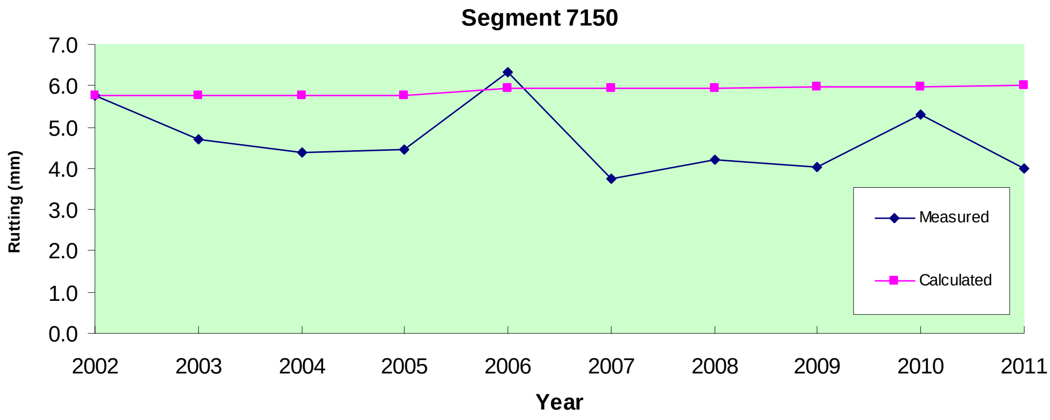

Figure 5.23 Comparison of predicted and measured rutting for segment 7150 at the Elsmore site

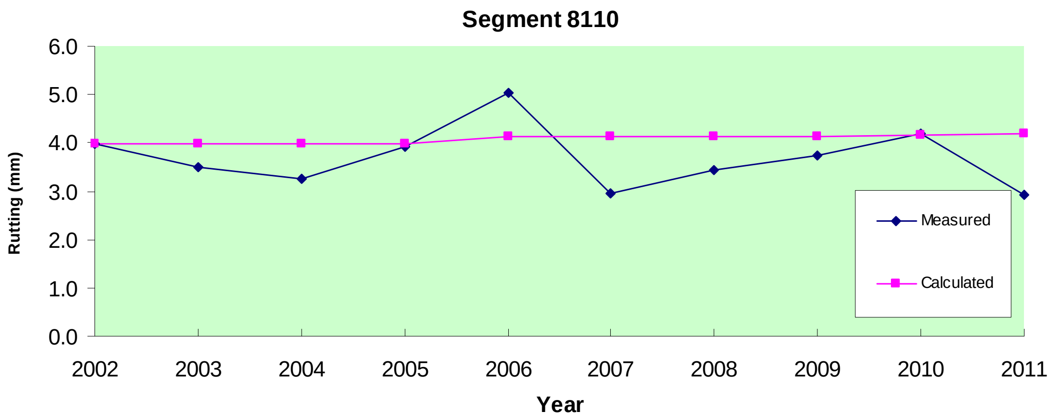

Figure 5.24 Comparison of predicted and measured rutting for segment 8110 at the Warialda Creek site

Figure 5.25 shows a graph of the predicted versus the measured cracking for a typical segment, Segment 7150. This segment was resealed in 2000. It can be seen that the model over predicts the amount of cracking. Whilst some of the difference may be due to measurement errors, it is considered that the main reason for the difference is due to RMS practices of crack sealing. Figure 5.26 shows typical crack sealing for part of the Elsmore Site. Crack sealing was also noticed at many of the other sites. This supports the assumption that maintenance activities are reducing the amount of cracking.

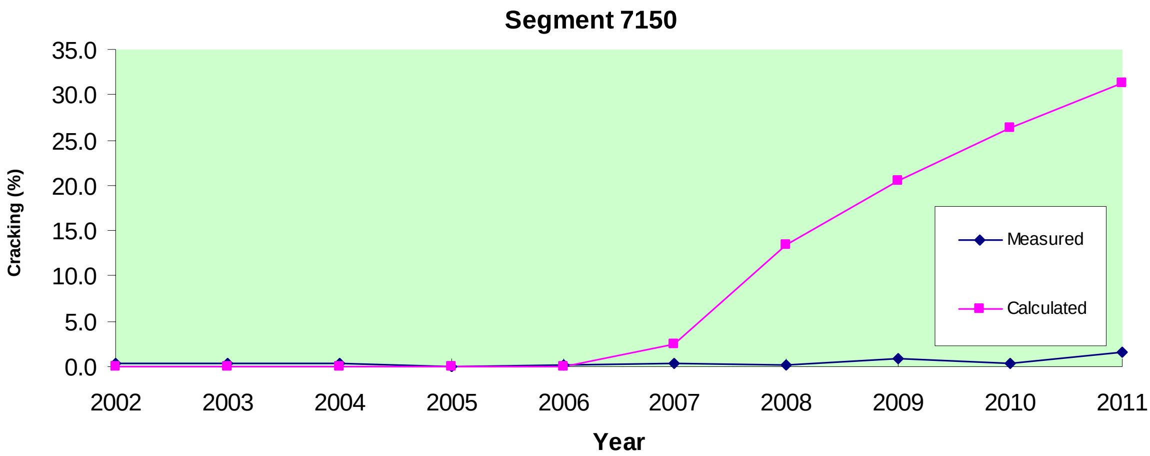

Figure 5.25 Comparison of predicted versus measured cracking for at Elsmore, Segment 7150.

5.6 Interim network level functional road deterioration models

The interim network level functional road deterioration model was implemented for the four sites using Microsoft Excel for the years 2002 to 2012. Similar to the previous test, Waterview and Dandhara were modelled using a cumulative model while Elsmore and Warialda Creek were modelled using an incremental model.

5.6.1 Cumulative models for Waterview and Dandhara

The models required determination of SNC_0, R_0 and IRI_0. SNC_0 and R_0 were calculated using different formula to the previous model resulting in different initial values. This model did not provide a specific method for deriving IRI_0.

Owing to the problems experienced calculating IRI_0 in the previous model, an initial IRI_0 of 1.5 m/km was assumed. The initial values calculated for SNC_0 and R_0 were considered acceptable.

Figure 5.26 Gwydir Highway at Elsmore showing crack sealing

This model made allowance for the dollar value of routine maintenance performed each year. The dollar value of maintenance performed was obtained from the RMS financial system. The value included all maintenance activities performed on the pavement and was converted into dollars for the year 2000.

The predictions for roughness for Waterview and Dandhara for typical segments are detailed in Figures 5.27 to 5.28. Complete details of the predictions are detailed in Appendix J. When comparing the forecasts with the measured values it can be seen that the residuals are increasing at both sites indicating that the models are overestimating the rate of increase in roughness. For the Waterview site the differences are variable with some segments having roughness over predicted by up to 100% with other segments under predicted. At Dandhara all roughness values are over predicted with some predictions being over by 130%. It is considered that these models are unsuitable in their current form. For the results to provide a closer approximation the initial roughness would have to be reduced. However the initial roughness was estimated at 1.5 m/km and it is believed that the initial roughness was unlikely to be lower than this value.

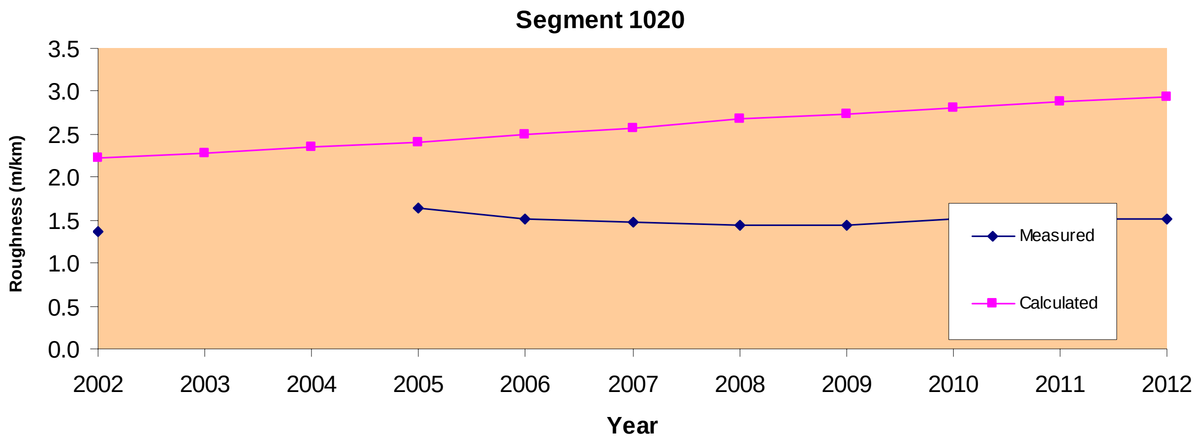

Figure 5.27 Comparison of predicted versus actual roughness for Segment 1020 at Waterview

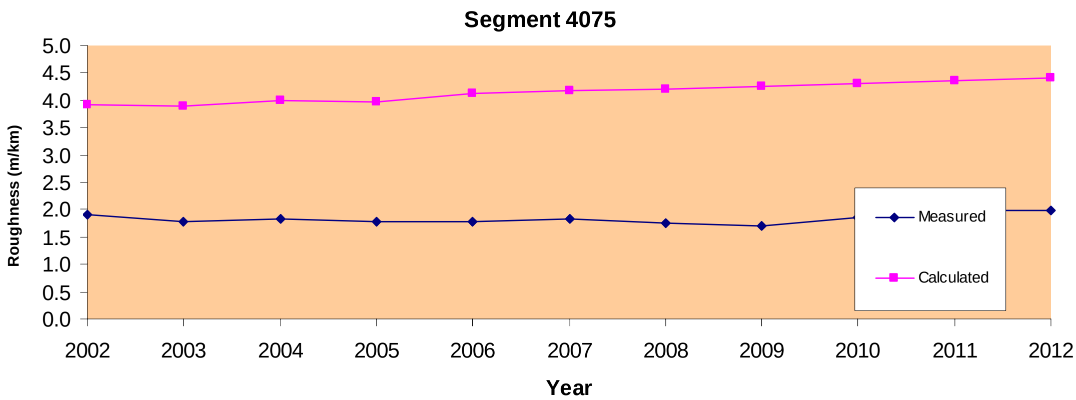

Figure 5.28 Comparison of predicted versus actual roughness for Segment 4075 at Dandhara

The roughness model contains a calibration factor but due to problems experienced with the local roads model it was not used. Furthermore it is believed that it would be difficult to scale results when the residuals are both positive and negative, with the calibration factor probably being close to unity.

When looking at the comparisons between calculated and observed values it was recognised that generally the roughness for 2002 was overestimated. This has resulted in subsequent year's roughness values also being overestimated. Therefore the measured 2002 roughness was adopted as the calculated value for 2002. The annual difference between the previously calculated roughness values were then used to calculate the subsequent year's roughness. This methodology is the same as what was done for the local roads cumulative models. In essence it is transforming the model into a form of incremental model. Figures 5.29 and 5.30 show plots of results for a segment each at Waterview and Dandhara using this method. The plots show that the predictions are closer to the actual values but could be considered unacceptable after five years where the difference is greater than 20%. Full details of the results are contained in Appendix J. It is quite evident when looking at the plots that the rate of roughness increase is much greater than the measured roughness which appears quite flat. As previously discussed the rate of roughness increase is probably influenced by maintenance to a certain degree. Therefore, it is considered that these models are only suitable for five years of prediction due to their over prediction of roughness after five years.

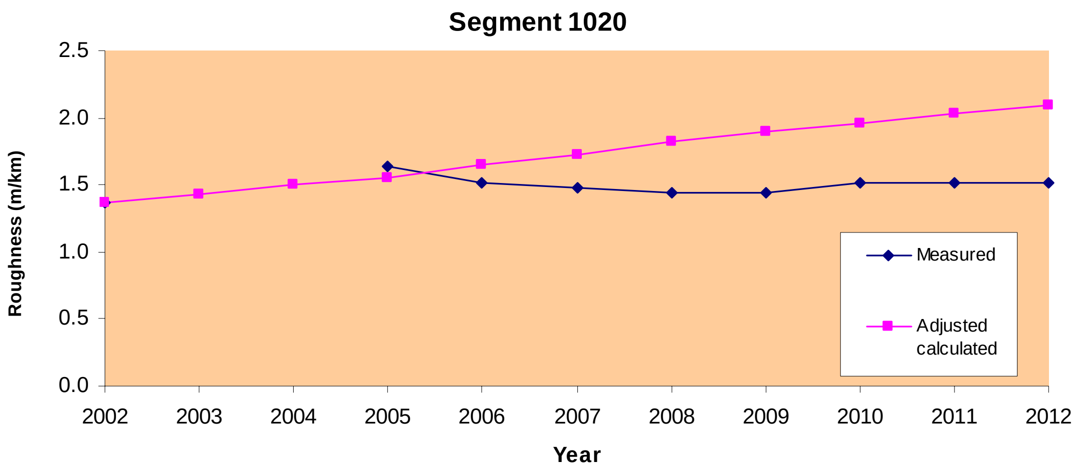

Figure 5.29 Comparison of predicted versus actual roughness for Segment 1020 at Waterview using the annual difference and adoption of the 2002 measured value as a base

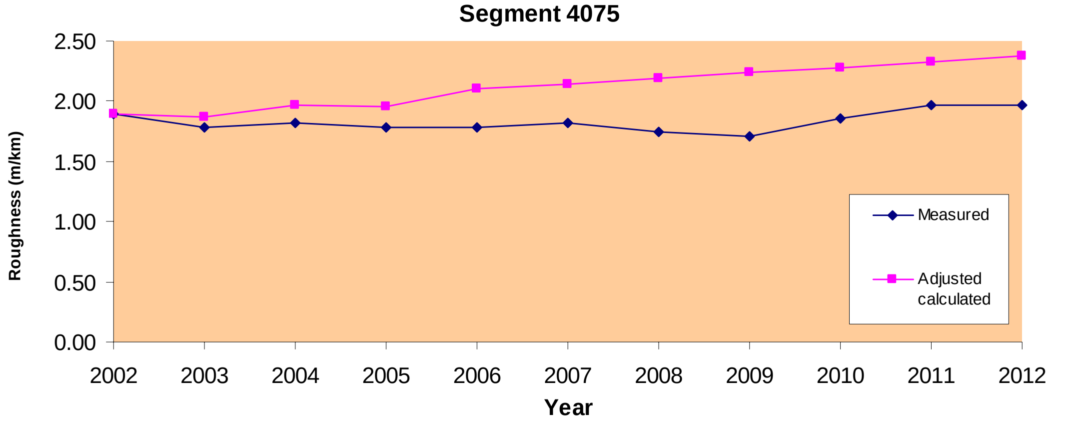

Figure 5.30 Comparison of predicted versus actual roughness for Segment 4075 at Dandhara using the annual difference and adoption of the 2002 measured value as a base

Rut depth was also forecast for Waterview and Dandhara. Detailed results can be found in Appendix J. Figures 5.31 and 5.32 show comparisons for a typical segments. The results show that the predicted rut depth is generally close to the measured rutting with most differences being below 2 mm. Therefore it is considered that the models adequately predict rutting over the analysis period.

Figure 5.31 Comparison of predicted versus actual rut depth for Segment 1020 at Waterview

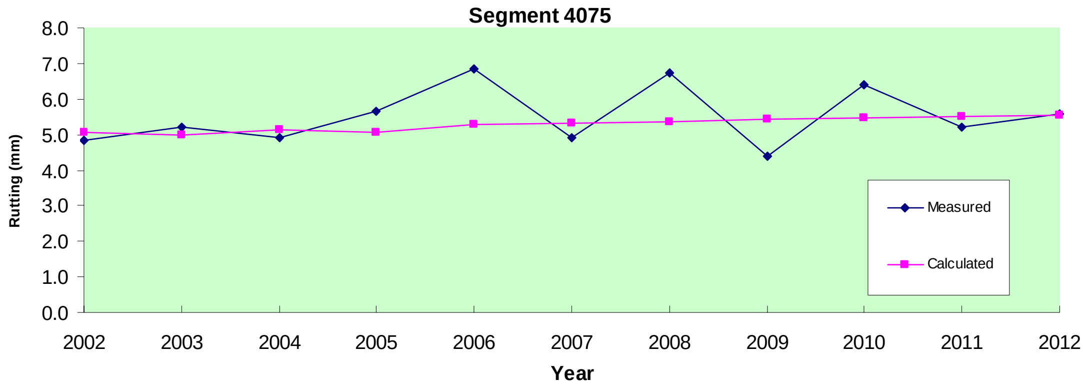

Figure 5.32 Comparison of predicted versus actual rut depth for Segment 4075 at Dandhara

The model also forecasts the percentage cracking for each segment following the same methodology as the local road deterioration model. First the age of the seal when cracking occurs is predicted. This value is then used to calculate the percentage cracking. The model used to calculate the percentage cracking is slightly different to the local roads cracking model with it using different constants. For most of the segments at Waterview and all the segments at Dandhara cracking is not predicted to occur due to recent resealing.

5.6.2 Incremental models for Elsmore and Warialda Creek

The incremental models for rutting, roughness and cracking were tested for the Elsmore and Warialda Creek sites. These models use the measured values for 2002 as a starting point. Despite being an incremental model the rutting model required the initial value SNC_0 as an input. This was calculated using the same methodology as for the cumulative models.

The calculated predictions for Elsmore and Warialda Creek are detailed in Appendix K. Figure 5.33 and 5.34 shows comparisons of measured versus predicted roughness of typical segments at these sites. It can be seen that the models for Elsmore have over predicted roughness by up to 30% while the models for Warialda Creek have predicted values close to the measured values with most of the differences below 10%. However, looking at a five year forecast period, both sites have differences below 20%. This is considered acceptable for a five year forecast period.

Figure 5.33 Comparison of predicted versus actual roughness for Segment 7160 at Elsmore

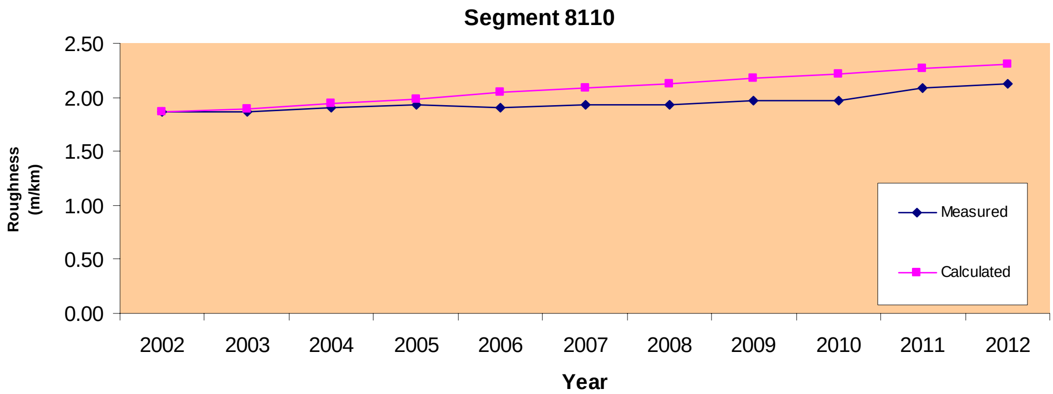

Figure 5.34 Comparison of predicted versus actual roughness for Segment 8110 at Warialda Creek

Rut depth was also forecast at both sites. For these incremental models the change in rutting for each year is calculated and added to the previous year. The actual measured rut depths for 2002 were adopted as a base for the calculation of future rut depths. A comparison of predicted versus measured rut depths is provided in Appendix K. Selected plots of these comparisons are shown in Figures 5.35 and 5.36. Overall for both sites the model agrees closely with the measured values with nearly all differences below 2mm over the analysis period.

Figure 5.35 Comparison of calculated and actual rut depth for Segment 7160 at Elsmore site

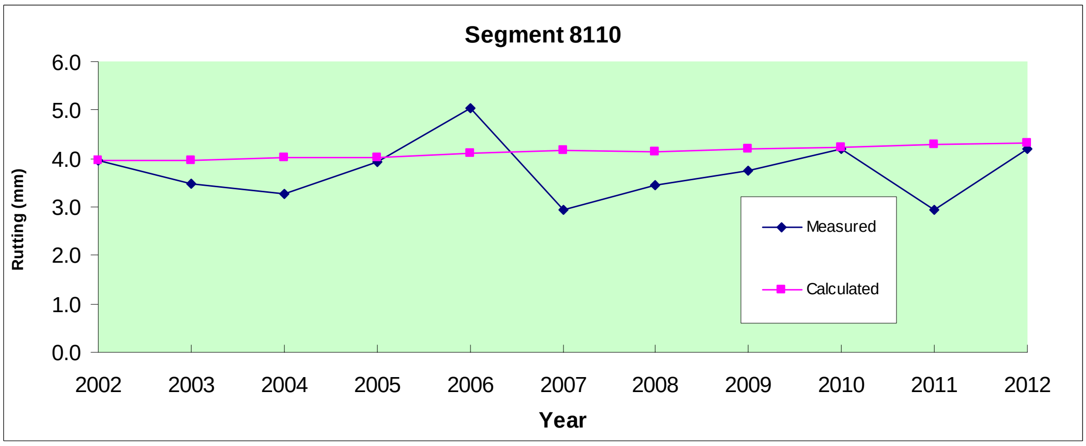

Figure 5.36 Comparison of calculated and actual rut depth for Segment 8110 at Warialda Creek site

Figure 5.37 shows a graph comparing measured versus predicted cracking for a typical segment. Owing to the differences between predicted cracking and measured cracking in previous models, the cracking model was not used. As discussed previously, due to reseal intervals and crack sealing it is believed that the cracking model is not valid for the Gwydir Highway. However, the roughness and rutting models required the change in cracking per year as an input. The predicted value for the annual increase in cracking was around 2% to 4% per annum which was considered too high. An assumed value of 0.5% annual increase in cracking has been used instead which was based on observation of cracking progression from the measured data. Even this value is considered conservative.

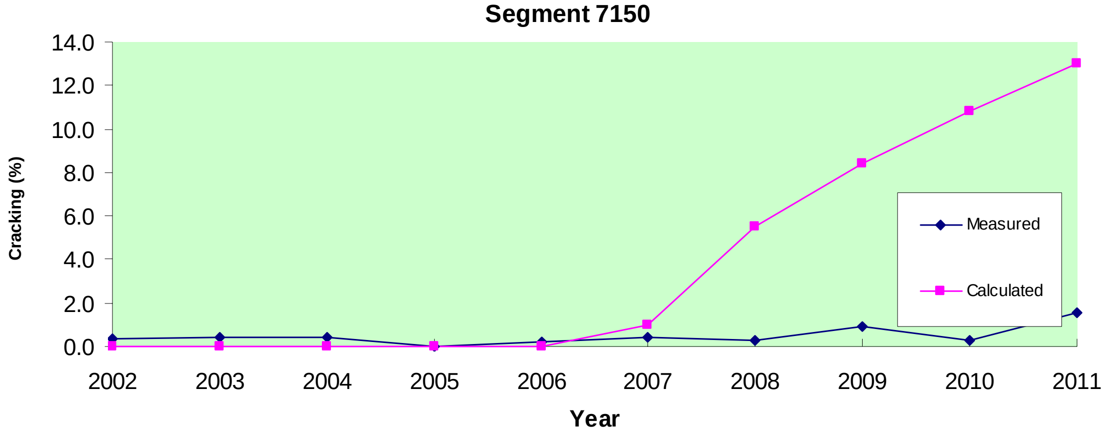

Figure 5.37 Comparison of predicted versus measured cracking for at Elsmore, Segment 7150.

5.6.3 Determination of point of rapid deterioration

One of the goals of pavement deterioration modelling is to predict the point when a pavement reaches the end of its life. In terms of deterioration this point is considered to occur when a pavement transitions from gradual linear deterioration to rapid deterioration. The deterioration models tested only model the gradual deterioration phase and are not able to determine the point when a pavement starts to undergo rapid deterioration. These models predict when a pavement reaches a particular condition in terms of distresses but not when the pavement will start rapid deterioration. Intervention to rebuild the pavement should occur at or just before the point of rapid deterioration. Therefore the point where rapid deterioration commences needs to be determined in terms of the distresses being predicted.

Through testing Martin (2009) proposed a model for determining the frontier between the gradual deterioration phase and the rapid deterioration phase.

The following formula was proposed:

$$Rut_{max} = 86.347 - 11.008 \times IRI$$

Figure 5.38 from Martin (2009) shows this relationship between rutting and roughness.

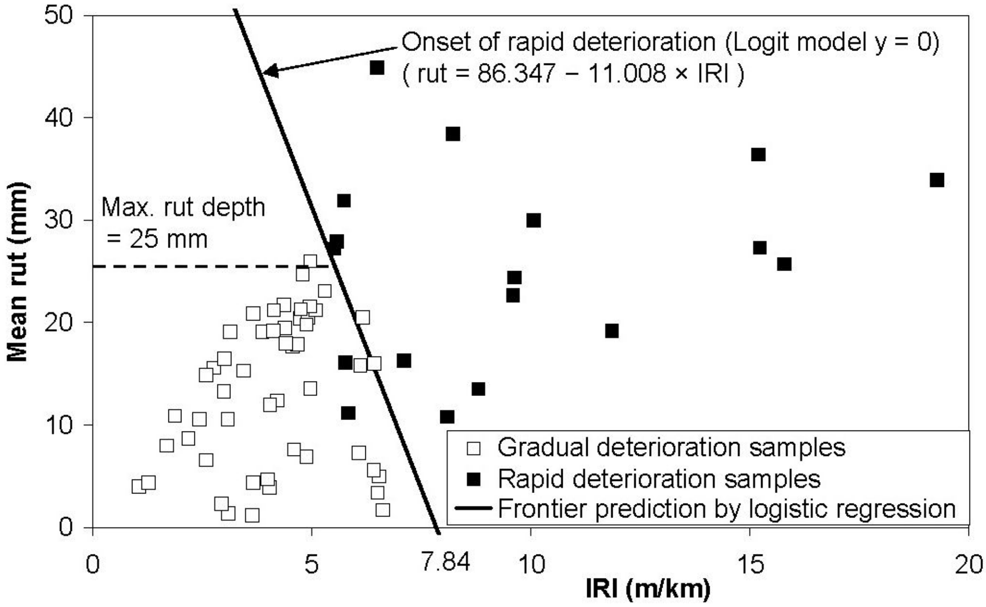

Figure 5.38 Chart showing Martin's method of determining the point of rapid deterioration
(Source: Martin (2009))

An attempt was made to use this model for the Gwydir Highway for determining which segments are undergoing rapid deterioration. However it was found that no segment fell into the zone of rapid deterioration as defined by this formula. This is most likely because maintenance activities either reduce the roughness or rutting or both. Therefore no segments fit the model proposed. This is despite some segments along the highway probably currently undergoing rapid deterioration. Therefore it was considered that the above equation was not applicable for the Gwydir Highway. It is also thought that the equation would not be applicable to any RMS Northern Region managed roads owing to the maintenance carried out to keep the roads safe.

Since Martin's model appeared invalid for the Gwydir Highway, an attempt to determine the point of rapid deterioration was made by looking at the segments on the Gwydir Highway that had undergone pavement rebuilding in the last 10 years. It was thought that where a pavement was rebuilt it had reached the end of its life. When looking at the roughness of these segments for the years preceding their rehabilitation, most had a roughness oscillating around 4.2 m/km. In most cases this magnitude of roughness existed for a considerable time before the road was rebuilt. Therefore the point of rapid deterioration in terms of roughness was not able to be determined from looking at these segments. However, what this analysis did highlight is that it appears that many segments are kept at around 4.2 m/km roughness for many years before being rehabilitated. It is also believed that considerable maintenance resources must be allocated to these segments to ensure the pavement is serviceable until it is rehabilitated. Unfortunately, maintenance data at the segment level was not available to confirm this. Figure 5.39 shows part of Segment 1040 at the Waterview site. Pavement patches can be seen where maintenance has been undertaken in order to improve safety. Roughness and rutting are also reduced as part of this work.

Figure 5.39 Gwydir Highway at Waterview showing patching

Another attempt to determine the point of transition to rapid deterioration was made by analysing the historical roughness data for the Gwydir Highway. To determine this point, it was assumed that the roughness would increase rapidly, even with maintenance being performed. It was thought that the roughness would be allowed to increase to around 4.2 m/km before maintenance is undertaken. Therefore to highlight segments where roughness had increased rapidly the difference in roughness between 2002 and 2012 was calculated. The segments with the largest increases in roughness were analysed.

Appendix L shows time series plots of roughness for selected segments between 2002 and 2012. Figures 5.40 and 5.41 show representative segments. These segments were either the segments that have undergone rehabilitation or have shown a larger than expected increase in roughness over the 11 years. These figures show that the roughness does increase sharply on some segments. It can be seen that the roughness is generally constant at around an IRI of 2.3 m/km for a few years before it increases rapidly. At first it was considered that a roughness of around 2.3 m/km may be the point of rapid deterioration. However, when looking at the 305 segments of the Gwydir Highway around 198 or 65% have a roughness in excess of this value and would therefore be considered to be rapidly deteriorating. Furthermore, if this was the case it would not be feasible to rehabilitate all these segments. It could also be seen that a few segments appear to rapidly deteriorate at around 2.9 m/km. Even if this value was adopted it would recommend that 41% of the segments undergo rehabilitation. This number is also considered unrealistic.

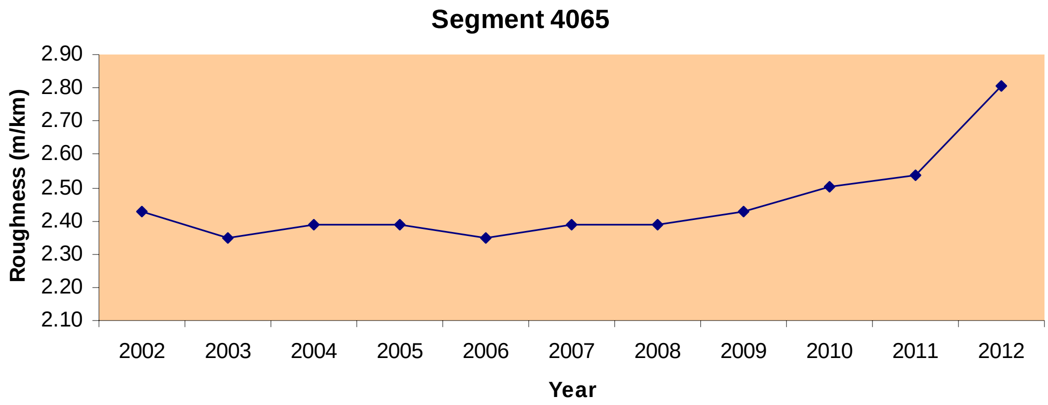

Figure 5.40 Sample time series plots of roughness for segments with larger than the average change in roughness between 2002 and 2012

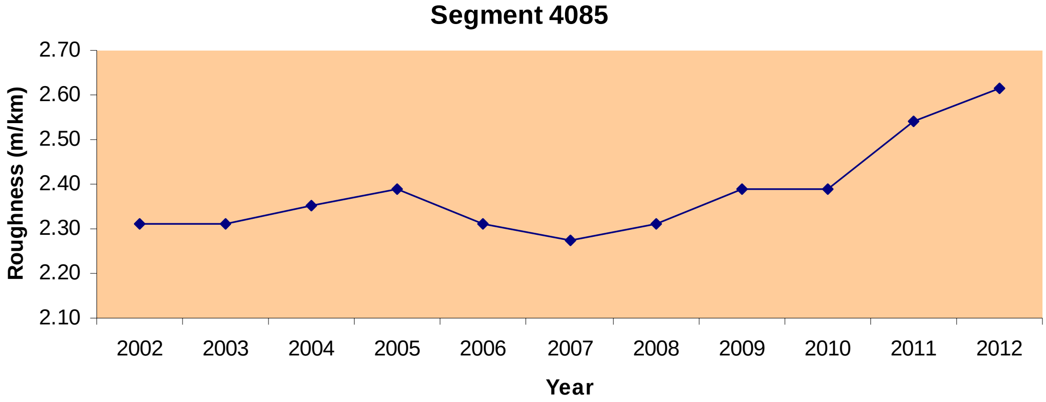

Figure 5.41 Sample time series plots of roughness for segments with larger than the average change in roughness between 2002 and 2012

A search for maintenance records at the segment level was undertaken to see if maintenance was distorting the rate of deterioration. Unfortunately RMS has only been recording maintenance activities at the segment level electronically since 2010 with the previous paper based records not available. Subsequently, this research could not be investigated further.

5.6.4 Summary of results

The study has proposed three KPIs for RMS Northern Region to use as target for guiding the selecting of road maintenance activities and sites. In addition, a relationship between FWD and TSD deflections has been found. Discussions with other RMS regions has also highlighted that RMS Northern Region is following a similar procedure to these regions.

Analysis has shown it is possible to model road deterioration in terms of roughness and rutting. However, the predictions for cracking were considered unsatisfactory. This is due to regular maintenance being undertaken to reduce cracking. It was found that the models using a cumulative methodology had poor forecasts due to their reliance on the initial condition data of the road just after construction was completed. By applying a slight change to these models resulted in the models producing reasonable results.

When comparing both models the local roads model gives results that could forecast an 11 year period whereas the interim network road deterioration model could only provide a suitable forecast for a five year timeframe. In terms of data input requirements and computational effort both models could be considered equivalent.

The point where a pavement transitions from gradual linear deterioration to rapid deterioration was investigated. A model proposed by Martin (2009) was tested and found to be unsuitable for the Gwydir Highway. Analysing condition data this transition point was investigated with the result that more data needs to be obtained.

5.6.5 Applicability of extending the results for use on the remainder of the network managed by RMS Northern Region and for RMS roads as a whole

The KPIs proposed could be used for driving maintenance activities on the rest of the RMS road network as a whole for pavements of similar construction to what was tested. For the RMS Northern Region the KPIs could be used on all roads except for the Pacific Highway which is mostly constructed of concrete and asphalt. The KPIs would also probably not be relevant for the Sydney Region. Urban roads are generally of different construction and they have different requirements. For example roughness, which is speed dependant, is less important as the speed vehicles travel at is lower. For the KPIs proposed to work, it is recommended that the targets are reviewed on a regular basis.

While a relationship between FWD and TSD deflections has been found, more research needs to be done on roads other than the ones where the analysis was performed. At this stage a relationship has only been investigated for three roads and is considered only suitable for the roads studied. Use on the whole RMS network could be considered an extrapolation from a very small sample resulting in uncertain results. The study has shown that it is possible to get a relationship however more work needs to be done before a NSW wide relationship is found.

The testing of the models has shown that they are applicable for deterioration modelling on the Gwydir Highway for at least a five year forecast period. The models have not relied on any local calibration factor with the only modification to the original models being to adopt a more recent year as a base when using the cumulative versions of the models. The testing has been undertaken on different areas along the Gwydir Highway which has different climates, traffic volumes and maintenance providers. Therefore it is considered that both models could be used for the prediction of roughness and rutting for roads of similar construction within the RMS Northern Region. Since most roads, with the exception of the Pacific Highway, within Northern Region are of similar construction the model should be suitable for these roads.

Extrapolating the results it is also believed that the models tested could be used to predict road deterioration for roads of similar construction on all roads managed by RMS throughout NSW. Further testing is recommended to validate this.

In summary the results have shown that the work could be used by RMS as a whole where pavements are of a similar construction. Additional work needs to be done to complete the strategy. Once this additional work is complete a development system could be constructed. If the strategy is adopted it is recommended that a computerised pavement management system should be used to undertake this work from forecasting through to optimising the final recommended program. The results this system produces should be recognised as only an aid in the programming of maintenance. An experienced maintenance engineer should still make the final decisions based on engineering judgement.

6 Conclusion

This project has recognised the importance of efficient and effective pavement maintenance. With maintenance funding being constantly scrutinised, the optimal delivery of this maintenance is even more critical. The project has undertaken an extensive literature review into pavement maintenance strategies and their implementation. This review has highlighted the need for RMS Northern Region to implement a pavement maintenance strategy to ensure it allocates its limited maintenance resources in the most effective manner.

It is recommended that a pavement maintenance strategy based on the Austroads infrastructure preservation strategy be implemented. This project has started to provide a proof of concept for the implementation of this strategy based on testing for the Gwydir Highway. It has investigated the initial elements of the strategy including the setting of KPIs and investigating road deterioration models.

The study has recommended KPIs for use as targets for prioritising maintenance, assessing the effectiveness of maintenance and for providing an indicator of the overall condition of the network. It is recognised that these KPIs are preliminary and they should be subject to review in terms of both the indicators and the targets set.

Investigation of the suitability of road deterioration modelling for the prediction of road deterioration has been undertaken. Most of the data required for modelling is already collected by RMS Northern Region on an annual basis. Testing has shown this data to be suitable for use as inputs into the models and for validating the models. The data not regularly collected is that of pavement strength, or pavement deflection data. In the past this data has been expensive to collect. However, this project has shown that is it possible to use data from new, more efficient technology, such as the TSD. A relationship between TSD and FWD data was found at the segment level. It is also believed that with further studies a relationship between TSD and FWD deflections could be determined at the point level. However, as an input in road deterioration models the relationship found was considered suitable for the section of road analysed. This is due to the models usually forecasting road deterioration at the segment level.

The ability of two road deterioration models to forecast roughness, rut depth and cracking were tested; the deterioration model for local sealed roads proposed by ARRB and the interim network level road deterioration model proposed by Austroads. The study has shown that in their original forms, the cumulative methodology used in both models gives poor predictions for roughness and rut depth while the incremental methodology gives acceptable predictions for roughness and rut depth. If the cumulative methodology is modified to use current measured values as a base for calculations, more acceptable results are possible.

Testing of the models showed that the interim network level functional deterioration model predicted roughness and rut depths consistent with the measured values for a five year period. The road deterioration model for local roads predicted roughness and rut depths consistent with the measured values for the full eleven year period tested. Neither model satisfactorily predicted cracking. Based on these results it is considered that the models could be used by RMS Northern Region to forecast deterioration of roads of similar construction material within the Region. It is also believed that the models could be used by RMS as a whole to predict deterioration of similar roads for the whole RMS network.

Therefore, it could be said it is possible to get acceptable results using either model when modelling roughness and rutting for a five year forecast period. Both models poorly predicted cracking which is probably due to maintenance interventions reducing cracking.

In terms of data input requirements and computational effort, both models could be considered equivalent. While both models give acceptable values for roughness over a five year period, the deterioration model for local roads gives slightly better results compared to the interim network road deterioration models. Furthermore, the local roads models could be used for a 10 year forecast period if desired.

The knowledge of when a pavement transitions from gradual linear deterioration to rapid deterioration in terms of the distresses modelled is essential. The transition was investigated by analysing the segments of the Gwydir Highway that were rehabilitated in the last 12 years. In addition, segments that had large increases in roughness over a 12 year period were also investigated. The aim was to see if a roughness value could be found where the pavement transitioned from gradual to rapid deterioration. Unfortunately a value could not be found due to maintenance activities masking the point of rapid deterioration. This is because the highway must be maintained to a safe standard at all times. It is recommended that maintenance records be kept at the segment level. This may identify when excessive maintenance is being undertaken to reduce the roughness. The point when this excessive maintenance starts could be considered the start of rapid deterioration.

It should be noted that while this research has shown that a strategy could provide a more optimum maintenance program, the strategy is only another tool to assist the maintenance engineer in maintenance planning. The final decisions still need to be made by an experienced engineer using sound engineering judgement.

6.1 Further Work

The study has established a foundation for the proof of concept for an infrastructure preservation strategy. So far the study has not identified any barriers to the implementation of this strategy. Therefore, it is recommended that further study be undertaken.

Further research to be undertaken might include:

- Further investigation into the use of TSD deflections as an input for road deterioration models. A relationship between FWD and TSD deflections was found, however, more testing needs to be undertaken. At this stage a relationship has only been investigated for three roads and is considered only suitable for the roads studied. Use on the whole RMS network could be considered an extrapolation from a very small sample resulting in uncertain results. In addition the measurements were taken at different locations and different dates. FWD deflections and TSD deflections should be measured at the same time and the exact same location so that a more accurate relationship between these deflections could be found. The relationship also needs to be studied at more sites to determine if one relationship for a type of pavement can be found or whether the relationship is more site dependant resulting in a number of different relationships.
- Further testing of the models should be undertaken. An analysis of the sensitivity of the input variables should be performed. In addition, further investigation into the differences in cracking should be undertaken.
- When sufficient data is available, analysis of maintenance records should be undertaken to determine if excessive maintenance could be used to identify the transition from gradual linear deterioration to rapid deterioration.
- Determining works effects and how treatments reduce the level of deterioration.
- Testing of optimisation techniques. Optimisation techniques such as linear programming or simpler methods such as near optimisation using heuristics could be tested to determine their suitability for prioritising works based on the KPIs selected.
- Extension of this research to other highways managed by RMS Northern Region and the RMS network as a whole. This may

include the review of the KPIs selected. This would be to determine their suitability for use on other roads in the RMS network.

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Appendix A Project Specification

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/2 Research Project

Project Specification

Student: **Scott Smith**

Topic: Determination of a Strategic Planning Approach for the Maintenance Management of a Major Road Network

Supervisor: Professor Ron Ayers

Sponsor: Adam Cameron, Roads and Maritime Services

Aim: To investigate a strategic maintenance strategy for the road network administered by NSW Roads and Maritime Services (RMS) Northern region. The maintenance strategy aims to determine the optimum maintenance solution with the funding available. This is achieved in part by setting performance criteria, predicting road deterioration and determining the point of rapid deterioration of a pavement.

Program: **Version B, 05 Sep 2012**

1. Research literature and background material relating to:

    - strategic maintenance planning;
    - performance criteria used to set targets in road maintenance;
    - methodologies used to determine pavement condition, optimum condition intervention levels and predict deterioration; and
    - maintenance strategies of Australian and international road agencies.

2. Determine key performance indicators and targets that could be used to guide the selection of maintenance treatments and determine the effectiveness of the strategy.

3. Consult with other RMS staff around the state regarding other systems in use.

4. Using the Gwydir Highway as a prototype:

    - Determine the suitability of road deterioration modelling in predicting deterioration of the Gwydir Highway.
    - Suggest possible improvements to models that may produce more suitable results.

5. Determine the suitability of Traffic Speed Deflectometer data for use in road deterioration modelling.

6. Determine the point where a pavement transitions from gradual linear deterioration to rapid deterioration

7. Critically review the outcomes of the work for the Gwydir Highway and analyse if the system developed can be extended to the remainder of the road network administered in the RMS Northern Region.

8. Report findings in the required written and oral formats.

If time permits:

Either Test the strategy on other roads in the RMS Northern Region, *or*, if the Gwydir Highway work is not extendable to other roads, develop the system to a higher degree of effectiveness.

Student: ______________________ 15/10/2012

Supervisor R. Ayers. 15 /10/2012

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Appendix B Sample RAMS data

HW12																						
UNIQ	SEGN	LONG	RUFF	L50	L70	L90	L110	TRI	RUTWO_A	RUTWI_A	SPTDC	SPTDO	RUTM	RUTH	RUTX	RUT%	RUTI	CRCA	CRCB	CRCC	CRCD	YEAR
R0012037002.010AU	7260	1.6	41	1.19	1.5				2.253125	1.579999E-02	2.334875	1.930812		0	0	1	1	0.59375	0.15625	0.09375	0.8125	200
R0012056009.510AU	8140	0.76	63	9.999943E-02	0.5700006	9.000015E-02			3.205265	1.090004E-02	2.539342	2.243421		3.000011E-03	0	2	3	0	0	0	0.1973684	200
R0012037010.780AU	7320	0.67	55	0.3000002	0.5				4.022389	1.280005E-02	2.438656	2.27582		0	0	2	3	1.044776	7.462686E-02	0.2238806	0.8955224	200
R0012037009.450AU	7310	1.33	85		0.25	0.39999996	0.1000004		6.556388	0.1406997	2.107219	1.646015		7.999954E-03	0	11	17	0.7518797	1.090226	0.1879699	1.503759	200
R0012037008.160AU	7300	1.29	87		0.1499996	0.5399999	3.999996E-02		9.868217	0.5518999	2.177984	1.904341		2.579996E-02	0	45	66	2.054264	2.093023	0.503876	0.6589147	200
R0012037006.390AU	7290	1.77	101	0.1100001	0.3100004	1.26	0.7599998		8.199433	0.4955999	1.88322	1.861582		9.319995E-02	0	33	54	1.666667	0.7062147	0.4237288	0.8757062	200
R0012038001.330AU	7340	0.42	90			0.21999999	4.999995E-02		9.966665	0.1773	1.370238	1.405476		1.639999E-02	0	46	70	6.071429	1.904762	2.976191	1.309524	200

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Appendix C Traffic volume data and calculations

STATE HIGHWAY NO.12 - GWYDIR HIGHWAY

CLARENCE VALLEY LGA

STATION	LOCATION	MAP	Km	1980 AADT	1982 AADT	1984 AADT	1986 AADT	1988 AADT	1990 AADT	1992 AADT	1995 AADT	1998 AADT	2001 AADT	2004 AADT
04.276	GRAFTON-W OF MR83,BENT ST	TOWN	0.6	--	5880	--	5296	--	7276	--	7006	6968	--	8405
04.152	GRAFTON-25M W OF HAY ST	TOWN	2.7	--	3170	--	3188	--	4341	--	--	--	--	--
04.153	W OF EATONSVILLE RD	15	6.1	--	1480	--	1488	--	1730	--	2160	1972	1990	1925
04.277	AT ORARA RIVER BR	15	16.1	--	730	--	753	--	--	--	930	839	808	777
04.278	JACKADGERY-AT MANN RIVER BR	12	43.5	--	590	--	601	--	687	--	--	--	--	--

GLEN INNES SEVERN LGA

STATION	LOCATION	MAP	Km	1980 AADT	1982 AADT	1984 AADT	1986 AADT	1988 AADT	1990 AADT	1992 AADT	1995 AADT	1998 AADT	2001 AADT	2004 AADT
*91.003	GIBRALTAR RANGE-AT TICK GATE	12	83.0	460	515	490	523	524	583	586	586	582	580	572
91.194	BALD NOB-E OF DUNDEE RD	14	132.1	610	--	600	--	715	--	764	--	--	--	--
91.444	GLEN INNES-S OF ROBINSON AV	TOWN	156.9	1190	--	730	--	932	--	1440	1237	924	791	1217
91.445	GLEN INNES-E OF SH9,CHURCH ST	TOWN	158.7	3170	--	2620	--	2819	--	3979	--	--	--	--
91.446	GLEN INNES-W OF SH9,CHURCH ST	TOWN	158.8	2460	--	2760	--	2707	--	3103	--	--	--	--
91.447	GLEN INNES-E OF LAMBETH ST	TOWN	159.6	4340	--	4160	--	--	--	4674	4598	--	4271	4272
91.449	GLEN INNES-W OF CORONATION AV,RR7706	TOWN	160.1	1900	--	2090	--	--	--	2451	--	--	--	--
91.068	GLEN INNES-AT FURRACABAD CK BR	TOWN	161.4	1370	--	1110	--	1347	--	1079	1315	1654	1406	1512
91.196	MATHESON-E OF KINGS PLAINS RD	11	177.0	840	--	860	--	--	--	--	--	--	--	--
91.195	MATHESON-W OF KINGS PLAINS RD	11	177.2	720	--	820	--	--	--	--	--	--	--	--

RTA Vehicle Survey System
Traffic Composition Report
For the Year: 2004

State -
Region -
LGA -
Road - 0000012 - GWYDIR HIGHWAY

Station	Instl. No	Description	Directn	No Survey Days	No Survey Vehicles	% Cars	% Rigid Trucks	% Artic Trucks
91.444	1670036	SH12 (Gwydir Hwy), Glen Innes - S of Taylor St	3	9	3644	87.0	8.8	4.2
91.444	1670037	SH12 (Gwydir Hwy), Glen Innes - S of Taylor St	4	9	3760	87.3	8.8	3.9
91.447	1670049	SH12 (Ferguson St), Glen Innes - at railway level crossin	3	9	13608	92.9	4.2	2.9
91.447	1670050	SH12 (Ferguson St), Glen Innes - at railway level crossin	4	9	13354	92.5	4.1	3.4
91.594	2180002	SH12 (Gwydir Hwy), at Swan Brook Ck	3	300	104146	83.6	7.1	9.3
91.594	2180003	SH12 (Gwydir Hwy), at Swan Brook Ck	4	300	105885	82.4	7.2	10.3
91.259	2180017	SH12 (Gwydir Hwy), Rob Roy - 0.5km W of Rob Roy School	4	362	244065	85.6	6.4	8.0
91.259	2180018	SH12 (Gwydir Hwy), Rob Roy - 0.5km W of Rob Roy School	3	362	235957	87.9	5.9	6.2
91.341	2910167	SH12 (Gwydir Hwy), W of Biniguy Rd	3	366	160025	87.9	4.8	7.3
91.341	2910168	SH12 (Gwydir Hwy), W of Biniguy Rd	4	366	162564	83.8	8.6	7.6
04.153	3320022	SH12 (Charles St), W of Batonsville Rd	3	10	8053	90.5	5.2	4.3
04.153	3320023	SH12 (Charles St), W of Batonsville Rd	4	10	8150	90.6	6.1	3.3
04.277	3320030	SH12 (Charles St), at Orara River	3	10	2964	86.5	6.4	7.0
04.277	3320031	SH12 (Charles St), at Orara River	4	10	3160	85.7	8.4	5.9
91.003	4000007	SH12 (Gwydir Hwy), Gibraltar Range - at Dandahra Ck North	3	276	62789	85.5	5.6	8.9
91.003	4000008	SH12 (Gwydir Hwy), Gibraltar Range - at Dandahra Ck North	4	276	63233	85.1	7.5	7.4
91.068	4000044	SH12 (Ferguson St), Glen Innes - at Furracabad Creek	3	6	3243	86.2	7.2	6.5
91.068	4000045	SH12 (Ferguson St), Glen Innes - at Furracabad Creek	4	6	3416	84.5	7.3	8.2
96.550	4710103	SH12 (Gwydir Hwy), Collarenebri - E of MR329 (???)	3	42	5859	65.9	5.2	28.9
96.550	4710104	SH12 (Gwydir Hwy), Collarenebri - E of MR329 (???)	4	42	5769	66.8	4.6	28.6
91.078	5120039	SH12 (Moree Rd), Warialda - E of MR63 (Bingara Rd)	3	9	4761	86.9	6.2	6.8
91.078	5120040	SH12 (Moree Rd), Warialda - E of MR63 (Bingara Rd)	4	9	4828	87.2	6.4	6.5
91.428	5120045	SH12 (Inverell Rd), Warialda - 0.5km E of East St	3	9	2824	81.3	8.1	10.6
91.428	5120046	SH12 (Inverell Rd), Warialda - 0.5km E of East St	4	9	3303	82.7	7.3	9.9
91.605	5120051	SH12 (Gwydir Hwy), Delungra - at Yallaroi LGA boundary	3	9	2959	84.3	6.8	9.0
91.605	5120052	SH12 (Gwydir Hwy), Delungra - at Yallaroi LGA boundary	4	9	2888	84.5	6.6	8.9

NOTE: The Description for the Installation Direction Codes are

1 - Northbound	2 - Southbound	3 - Eastbound	4 - Westbound
5 - North and south	6 - East and west	10 - Unknown direction	20 - Two unknown direc
31 - Northern approach	32 - Southern approach	33 - Eastern approach	34 - Western approach
39 - All approaches	99 - Unknown	9999999 - Unknown	

Calculation of design traffic - Waterview

STN	**4.153**	Waterview

Observed Volumes (axle pairs)

Year	1995	1998	2001	2004
Volume	2160	1972	1990	1925

Type	**% Type**	**No axle pairs**
Car	92.0%	1
Rigid	4.0%	1.5
Artic	4.0%	3.75

Total axle pairs (2005)	Vehicles	Cars	Rigid	Artic
1925	1704	1567	68	68

Axle pair to vehicle ratio	0.884956

Observed Volumes (vehicles)

Year	1995	1998	2004		**AADT veh**
Volume	1912	1745	1704		**1745**
				%HV	**8.0%**

Nhvag	2.6	
Df	0.5	
LDF	1	
CGF	1	(1 yr)
Year	ALL	
AADT	1800	
N_{DT}	68985	
DESA	62086.5	0.0620865
MESA	0.062087	
ESA/HVAG	0.9	

Calculation of design traffic -Dandhara

STN	**91.003**	Gibraltar Range

Observed Volumes (axle pairs)

Year	1992	1995	1998	2001	2004	2007 (V)
Volume	586	586	582	580	572	451

Type	**% Type**	**No axle pairs**
Car	85.0%	1
Rigid	6.5%	1.5
Artic	8.5%	3.75

Total axle pairs (2004)	Vehicles	Cars	Rigid	Artic
572	451.7275	383.9684107	29.36229	38.39684

Axle pair to vehicle ratio	**0.789733**

Observed Volumes (vehicles)

Year	1992	1995	1998	2001	2004	2007 (V)		AADT veh	Growth
Volume	463	463	460	458	452	451		460	0%
						%HV	15%		

Nhvag	2.8	
Df	0.5	
LDF	1	
CGF	1	(1 yr)

N_{DT}	34915.69	
ESA/HVAG	0.9	
DESA	31424.12	year
MESA	0.031424	

Calculation of design traffic -Elsmore

STN **91.594** Swan Brook Ck

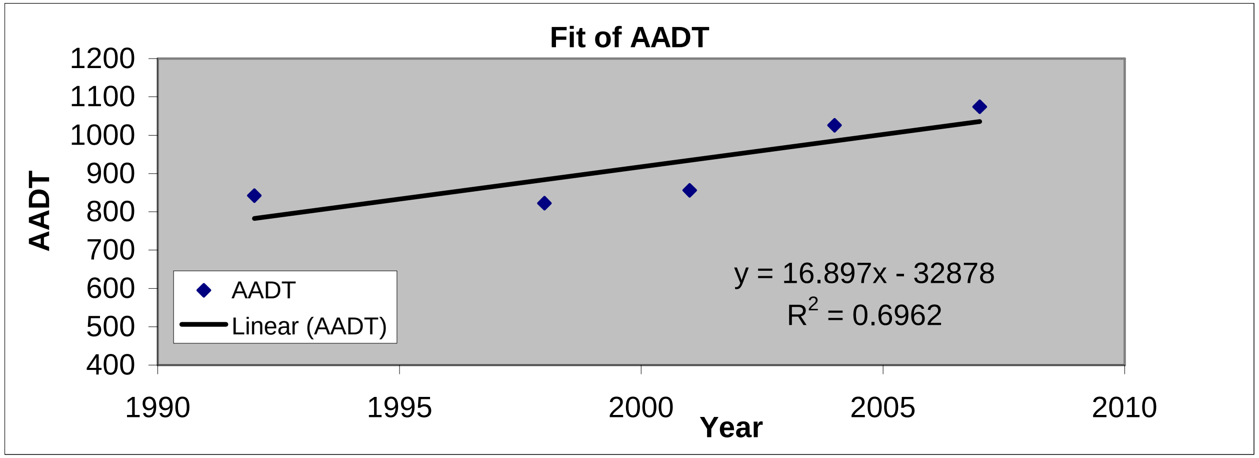
Observed Volumes (axle pairs)

Year	1992	1995	1998	2001	2004	2007
Volume	1066	954	1041	1084	1299	1360

Type	**% Type**	**No axle pairs**
Car	85.0%	1
Rigid	6.5%	1.5
Artic	8.5%	3.75

Total axle pairs (2004)	Vehicles	Cars	Rigid	Artic
1299	1025.864	871.9842053	66.68115	87.19842

Axle pair to vehicle ratio **0.789733**



Observed Volumes (vehicles)

Year	1992		1998	2001	2004	2007		AADT veh		Growth	
Volume	842		822	856	1026	1074		822		17	veh/year
						%HV	15%		2%		

Nhvag	2.8	
Df	0.5	
LDF	1	
CGF	1	(1 yr)

Calculated Volumes

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AADT	932.897	949.794	966.691	983.588	1000.485	1017.382	1034.279	1051.176	1068.073	1084.97	1101.867	1118.764	1135.661	1152.558	1169.455
N_{DT}	70868.1	72151.69483	73435.29	74718.88	76002.47	77286.06	78569.65	79853.24	81136.83	82420.42	83704.02	84987.61	86271.2	87554.79	88838.38
DESA	63781.29	64936.52535	66091.76	67246.99	68402.22	69557.45	70712.69	71867.92	73023.15	74178.38	75333.61	76488.85	77644.08	78799.31	79954.54

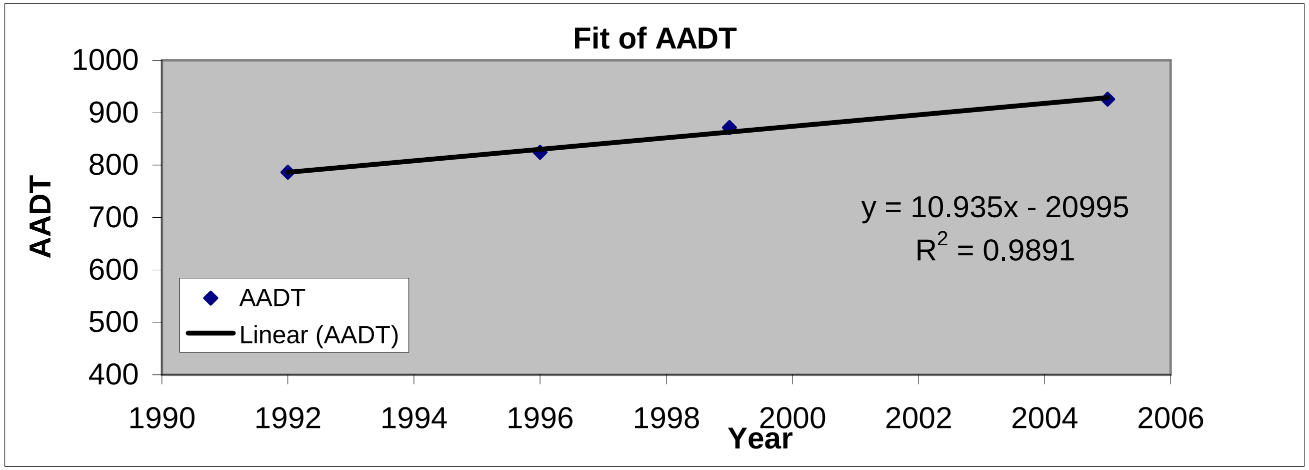
ESA/HVAG 0.9

Calculation of design traffic Warialda Creek

STN **91.341** Biniguy

Observed Volumes (axle pairs)

Year	1992	1996	1999	2002	2005	2007
Volume	965	1012	1070	1652	1136	1080



Type	**% Type**	**No axle pairs**
Car	85.0%	1
Rigid	6.5%	1.5
Artic	8.5%	3.75

Total axle pairs (2005)	Vehicles	Cars	Rigid	Artic
1136	925.4582485	795.8940937	64.78208	64.78208

Axle pair to vehicle ratio **0.814663951**

Observed Volumes (vehicles)

Year	1992	1996	1999		2005	2007		AADT veh
Volume	786	824	872		925	880		872
						%HV	15%	

Nhvag	2.6	
Df	0.5	
LDF	1	
CGF	1	(1 yr)

Calculated Volumes

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AADT	885.935	896.87	907.805	918.74	929.675	940.61	951.545	962.48	973.415	984.35	995.285	1006.22	1017.155	1028.09	1039.025
N_{DT}	59418.55303	60151.94981	60885.35	61618.74	62352.14	63085.54	63818.93	64552.33	65285.73	66019.12	66752.52	67485.92	68219.31	68952.71	69686.11
DESA	53476.69773	54136.75483	54796.81	55456.87	56116.93	56776.98	57437.04	58097.1	58757.15	59417.21	60077.27	60737.33	61397.38	62057.44	62717.5

.

Appendix D Sample Thornthwaite Moisture Index data

			Station ID	**Waterview**	**Dandhara**	**Elsmore**	**Warialda Creek**
			Longitude	152.887459	152.26304	151.35033	150.4051
			Latitude	-29.684548	-29.54441	-29.78419	-29.57263
Data Type	Year	Month	Data				
	1992			57.6	32.22857143	24.342857	2.971429
	1993			56.76	31.37	26.39	5.73
	1994			49.21	29.37	23.93	5.20
	1995			48.37	30.39	25.21	9.39
	1996			57.80	36.31	25.31	11.27
	1997			56.76	35.50	27.31	12.10
	1998			57.16	40.27	32.11	15.40
	1999			52.64	35.57	27.79	11.80
	2000			44.49	30.00	23.79	7.60
	2001			43.14	29.39	25.56	8.29
	2002			43.14	28.51	20.53	2.93
	2003			38.20	24.11	18.16	-0.59
	2004			38.86	26.71	17.77	-0.76
	2005			35.01	23.67	13.54	-3.03
	2006			39.07	28.55	17.07	-0.65
	2007			39.48	28.42	15.16	-1.36
Lower	2008			42.975	28.075	12	-4.125
	2009			42.7	27.9	11.8	-4.2
	2010			42.4	27.6	11.7	-4.4
	2011			42.1	27.5	11.5	-4.5
	2012			41.8	27.3	11.3	-4.6

.

Appendix E Sample Traffic Speed Deflectometer Data

RoadNo	RoadName	AdminUnitCode	ItemStartDate	BeginOffset(km)	EndOffset(km)	ItemLength(km)	LcUnique	SurveyYear	CrossSectiona	Vd(100)(mm/s)	Vd(200)(mm/s)	Vd(300)(mm/s)	Slope(100)(um/m)	Slope(200)(um/m)	Slope(300)(um/m)	Deflection-Maximum(mm)	SCI300(um)	Curvature	Speed(Km/Hr)	AirTemperature	RoadTemperature	SurveyDate	SurveyTime	Latitude	Longitude	Altitude(m)
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.007	0.002	-0.005	0000012,0100,A1	2010	C	30.41200	26.79500	18.07500	1.98100	1.74500	1.17700	0.551	468.39427	36.246	55	26	27.7	25-Mar-2010	09:42:53	-29.706680000000	152.93678	50.308
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.012	0.007	-0.005	0000012,0100,A1	2010	C	27.49700	25.42900	16.73700	1.78200	1.64800	1.08500	0.513	430.24657	32.606	56	26	26.2	25-Mar-2010	09:42:53	-29.706650000000	152.93673	50.794
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.017	0.012	-0.005	0000012,0100,A1	2010	C	27.18300	24.11700	16.86000	1.75400	1.55700	1.08800	0.499	417.89225	31.572	56	26	26.8	25-Mar-2010	09:42:53	-29.706630000000	152.93669	51.280
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.022	0.017	-0.005	0000012,0100,A1	2010	C	29.26700	25.45100	18.66000	1.88300	1.63800	1.20100	0.537	446.64145	33.332	56	26	30.0	25-Mar-2010	09:42:52	-29.706600000000	152.93664	51.545
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.027	0.022	-0.005	0000012,0100,A1	2010	C	28.08300	25.76800	17.39800	1.80300	1.65400	1.11700	0.520	434.68413	32.680	56	26	26.7	25-Mar-2010	09:42:52	-29.706580000000	152.93660	51.738
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.032	0.027	-0.005	0000012,0100,A1	2010	C	27.69800	25.65400	17.91100	1.77100	1.64100	1.14500	0.523	430.67372	31.592	56	26	26.0	25-Mar-2010	09:42:52	-29.706560000000	152.93656	51.930
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.037	0.032	-0.005	0000012,0100,A1	2010	C	28.17700	26.14600	18.43500	1.79300	1.66400	1.17300	0.533	436.85345	31.829	57	26	26.3	25-Mar-2010	09:42:51	-29.706530000000	152.93651	52.141
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.042	0.037	-0.005	0000012,0100,A1	2010	C	26.28700	25.80300	18.45200	1.66800	1.63700	1.17100	0.527	418.55874	29.102	57	26	26.2	25-Mar-2010	09:42:51	-29.706510000000	152.93647	52.364
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.047	0.042	-0.005	0000012,0100,A1	2010	C	25.33300	25.01000	16.95900	1.60600	1.58600	1.07500	0.497	401.80563	28.678	57	26	26.6	25-Mar-2010	09:42:51	-29.706480000000	152.93642	52.586
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.052	0.047	-0.005	0000012,0100,A1	2010	C	23.79500	22.46700	15.37500	1.50700	1.42300	0.97400	0.449	369.14896	27.021	57	26	27.8	25-Mar-2010	09:42:50	-29.706460000000	152.93638	52.777
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.057	0.052	-0.005	0000012,0100,A1	2010	C	22.07500	20.76200	14.19200	1.39300	1.31100	0.89600	0.414	340.55495	25.004	57	26	27.0	25-Mar-2010	09:42:50	-29.706430000000	152.93633	52.935
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.062	0.057	-0.005	0000012,0100,A1	2010	C	20.49800	17.60300	11.00300	1.28700	1.10600	0.69100	0.341	298.51212	24.433	57	26	27.6	25-Mar-2010	09:42:50	-29.706410000000	152.93629	53.092
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.067	0.062	-0.005	0000012,0100,A1	2010	C	20.78900	17.26800	11.68000	1.29900	1.07900	0.73000	0.344	299.07703	24.100	58	26	30.0	25-Mar-2010	09:42:49	-29.706390000000	152.93624	53.220
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.072	0.067	-0.005	0000012,0100,A1	2010	C	23.74800	18.02600	10.14100	1.47800	1.12200	0.63100	0.347	321.46064	30.079	58	26	31.6	25-Mar-2010	09:42:49	-29.706360000000	152.93620	53.282
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.077	0.072	-0.005	0000012,0100,A1	2010	C	25.61000	18.83700	10.83400	1.58800	1.16800	0.67200	0.366	341.48004	32.382	58	26	31.5	25-Mar-2010	09:42:49	-29.706340000000	152.93616	53.344
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.082	0.077	-0.005	0000012,0100,A1	2010	C	24.40900	19.40000	11.06400	1.50800	1.19900	0.68400	0.367	334.90026	30.160	58	26	29.6	25-Mar-2010	09:42:48	-29.706320000000	152.93611	53.388
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.087	0.082	-0.005	0000012,0100,A1	2010	C	23.92300	19.51700	10.94600	1.47200	1.20100	0.67400	0.363	330.21873	29.414	59	26	27.4	25-Mar-2010	09:42:48	-29.706290000000	152.93607	53.264
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.092	0.087	-0.005	0000012,0100,A1	2010	C	25.80400	20.10500	11.25500	1.58100	1.23200	0.69000	0.377	347.60741	31.997	59	26	26.6	25-Mar-2010	09:42:48	-29.706270000000	152.93602	53.142
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.097	0.092	-0.005	0000012,0100,A1	2010	C	29.27900	22.34300	13.20600	1.78700	1.36400	0.80600	0.426	391.17312	35.713	59	26	27.4	25-Mar-2010	09:42:48	-29.706250000000	152.93598	53.020
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.102	0.097	-0.005	0000012,0100,A1	2010	C	26.79200	19.08600	10.20100	1.62900	1.16000	0.62000	0.362	343.78516	34.341	59	26	27.2	25-Mar-2010	09:42:47	-29.706220000000	152.93594	53.384
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.107	0.102	-0.005	0000012,0100,A1	2010	C	26.72500	22.03800	11.59100	1.62100	1.33700	0.70300	0.397	363.38451	32.975	59	26	26.7	25-Mar-2010	09:42:47	-29.706200000000	152.93589	53.838
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.112	0.107	-0.005	0000012,0100,A1	2010	C	39.25600	29.29900	17.28400	2.38400	1.77900	1.05000	0.559	516.89209	47.986	59	26	27.7	25-Mar-2010	09:42:47	-29.706170000000	152.93585	54.294
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.117	0.112	-0.005	0000012,0100,A1	2010	C	41.57400	29.86500	17.32500	2.53300	1.82000	1.05600	0.577	539.98672	51.909	59	26	29.2	25-Mar-2010	09:42:46	-29.706150000000	152.93580	54.417
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.122	0.117	-0.005	0000012,0100,A1	2010	C	41.79800	30.88200	18.15900	2.55700	1.88900	1.11100	0.595	552.0028	51.699	59	26	27.1	25-Mar-2010	09:42:46	-29.706120000000	152.93576	54.264
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.127	0.122	-0.005	0000012,0100,A1	2010	C	39.23200	27.45000	17.69900	2.41000	1.68600	1.08700	0.553	512.74088	48.007	59	26	28.8	25-Mar-2010	09:42:46	-29.706100000000	152.93571	54.111
0000012	GWYDIR HIGHWAY	850	25-Mar-2010	0.132	0.127	-0.005	0000012,0100,A1	2010	C	34.93300	25.82000	16.62300	2.15300	1.59200	1.02500	0.513	468.66219	42.142	58	26	27.6	25-Mar-2010	09:42:45	-29.706070000000	152.93567	54.077

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Appendix F Sample question list

Developing a maintenance strategy for a major road network

Questions for RMS Staff

Background – I am looking at establishing a maintenance strategy for the Gwydir Highway looking at issues such as intervention levels, KPI's treatments and works effects.

1. Does your region have a maintenance strategy?
    a. If so can I have a copy for information please?

2. Are your maintenance treatments based on a pavement preservation strategy? I.e. trying to extend the life of the pavement using cheaper treatments?
3. How do you determine maintenance priorities? Do you use any KPM's from network level condition data?
4. How do you use the network level condition data to determine maintenance needs?
5. How do you determine when to intervene on a segment? How do you determine what treatment to use?
6. What treatments do you use for your granular pavements:
    a. Resealing
    b. Heavy patching
    c. Rehabilitation
    d. Reconstruction
    e. Slurry seals
    f. AC overlays on granular pavements
    g. Crack sealing
    h. Other?

7. Have you ever undertaken determined how different treatments affect the work effects?
8. Have you investigated the supplementary activities of the RMAP program as to how they affect pavement performance? Things such as drainage works, shoulder grading?
9. How do you manage resealing – is it a cyclical program or done on a needs basis?

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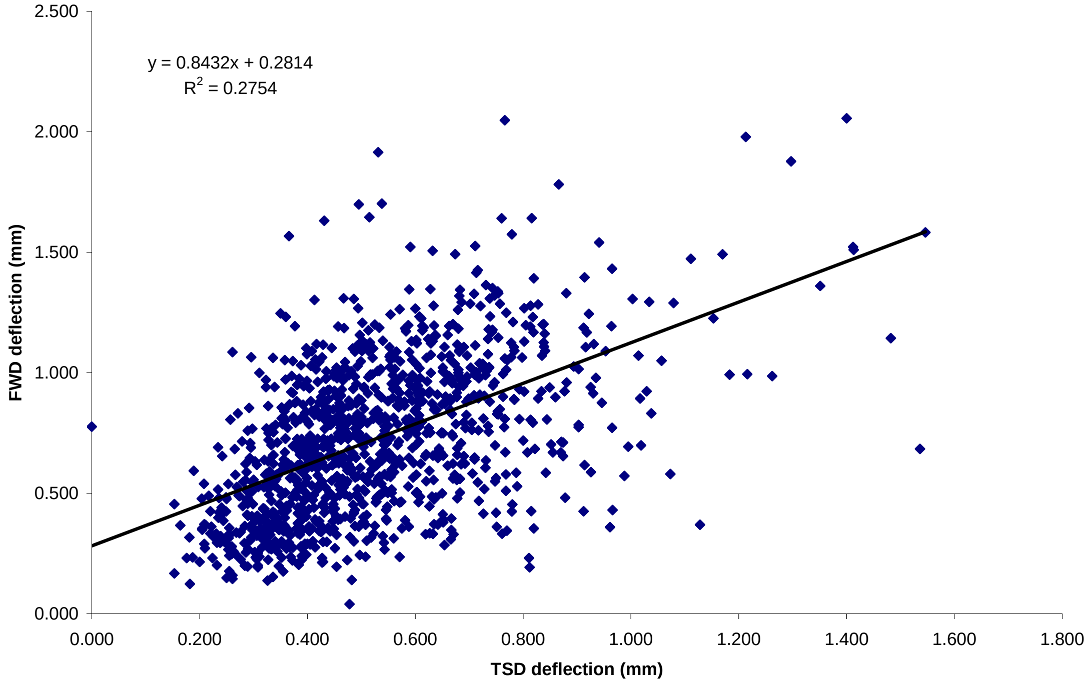
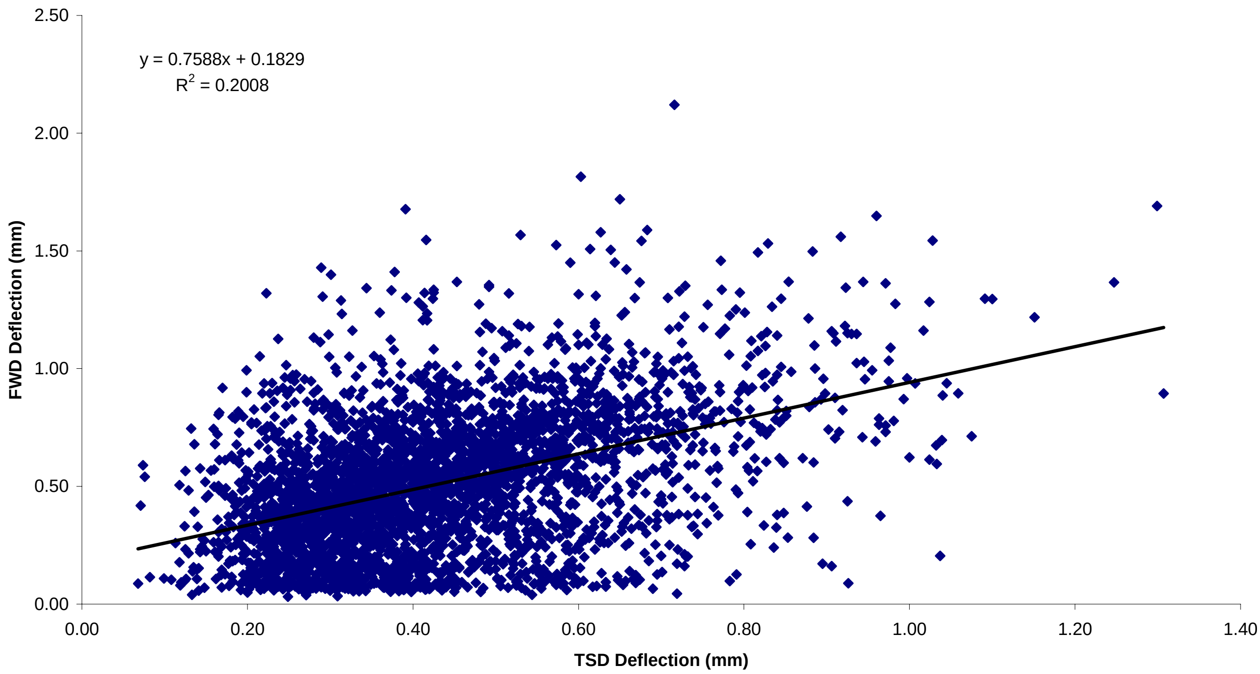
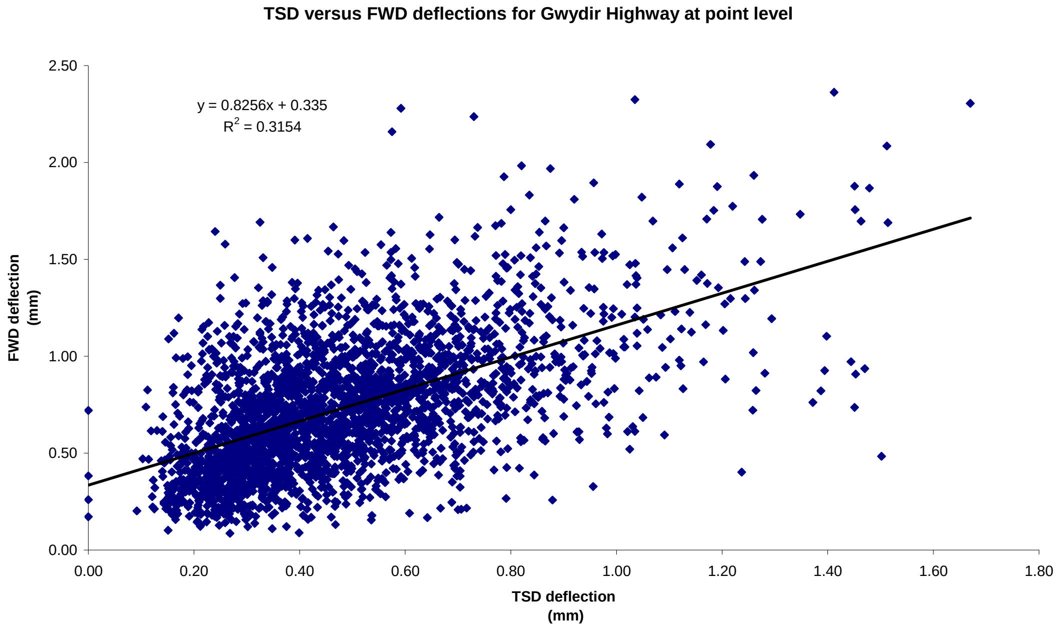
Appendix G Scatter plots for Traffic Speed Deflectometer and Falling Weight Deflectometer analysis

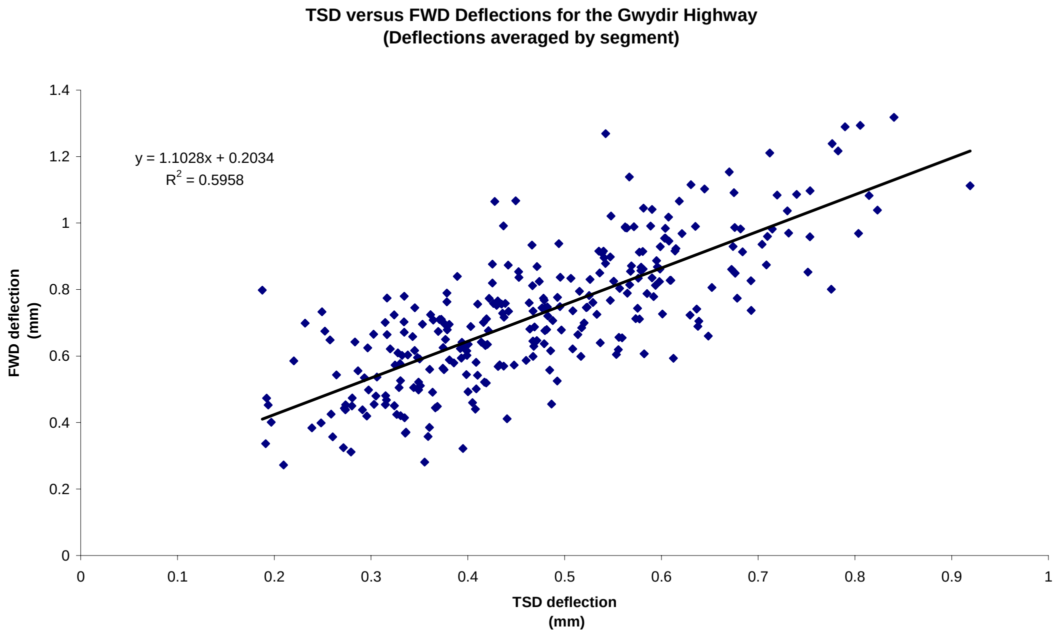
TSD versus FWD deflections for the Kamilaroi Highway at the point level



TSD versus FWD deflections for the New England Highway at the point level




TSD versus FWD deflections for Gwydir Highway at point level
y = 0.8256x + 0.335
R^2 = 0.3154
FWD deflection
(mm)
TSD deflection
(mm)
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80


TSD versus FWD Deflections for the Gwydir Highway
(Deflections averaged by segment)
y = 1.1028x + 0.2034
R^2 = 0.5958
FWD deflection
(mm)
TSD deflection
(mm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

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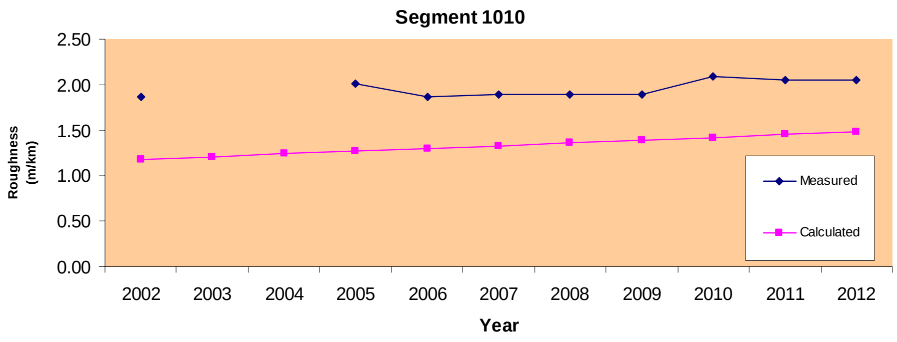
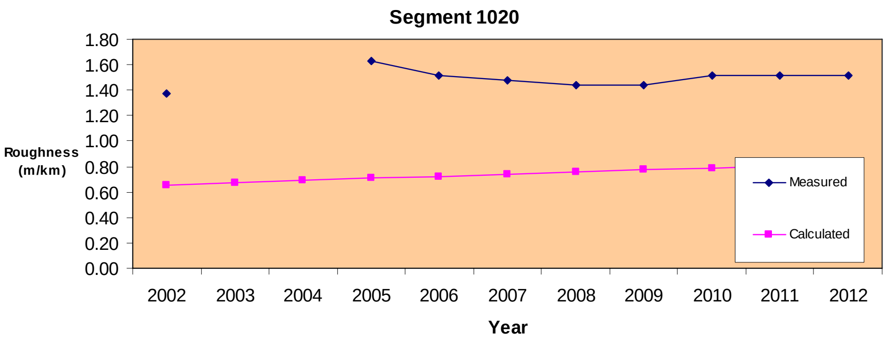
Appendix H Results for Deterioration Models for Sealed Local Roads - Waterview and Dandhara sites

Roughness for Waterview Site based on unmodified local roads model

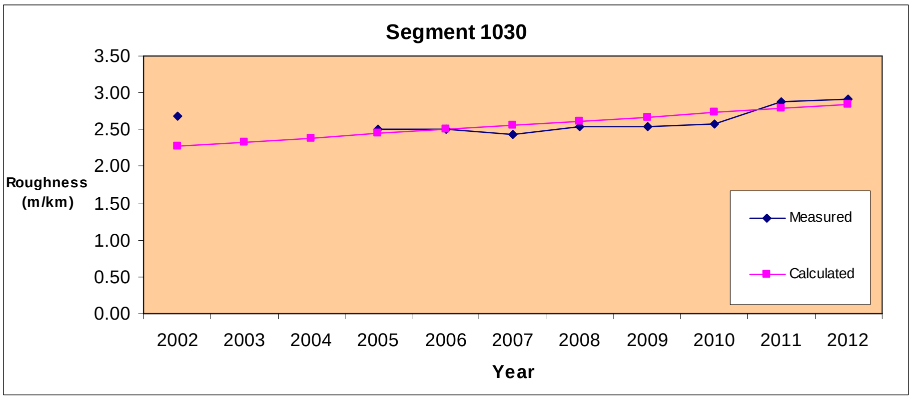
Segment 1010				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.86	1.18	0.68	37%
2003		1.21		
2004		1.24		
2005	2.01	1.27	0.74	37%
2006	1.86	1.30	0.56	30%
2007	1.90	1.33	0.57	30%
2008	1.90	1.36	0.54	28%
2009	1.90	1.39	0.51	27%
2010	2.09	1.42	0.67	32%
2011	2.05	1.45	0.60	29%
2012	2.05	1.48	0.57	28%



Segment 1020				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.37	0.66	0.71	52%
2003		0.67		
2004		0.69		
2005	1.63	0.71	0.93	57%
2006	1.52	0.72	0.80	52%
2007	1.48	0.74	0.74	50%
2008	1.44	0.76	0.69	48%
2009	1.44	0.77	0.67	46%
2010	1.52	0.79	0.73	48%
2011	1.52	0.81	0.71	47%
2012	1.52	0.82	0.70	46%

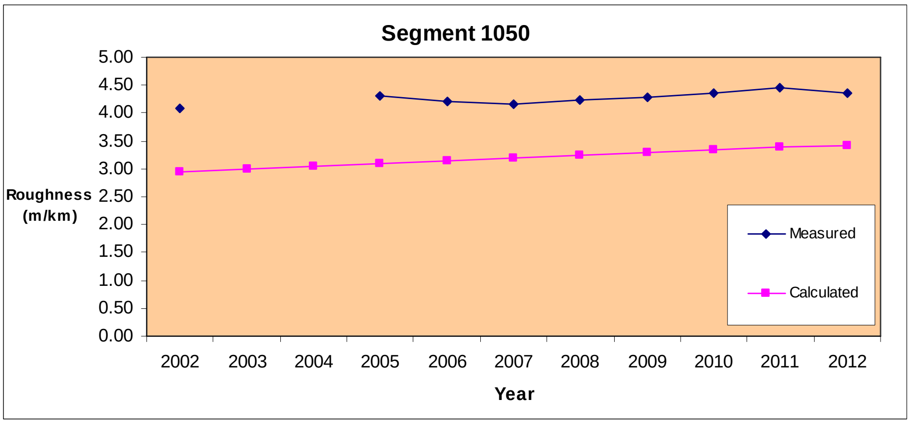


Segment 1030				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.69	2.27	0.42	15%
2003		2.33		
2004		2.39		
2005	2.50	2.44	0.06	2%
2006	2.50	2.50	0.00	0%
2007	2.43	2.56	-0.13	-5%
2008	2.54	2.61	-0.08	-3%
2009	2.54	2.67	-0.13	-5%
2010	2.58	2.73	-0.15	-6%
2011	2.88	2.79	0.09	3%
2012	2.92	2.84	0.07	3%



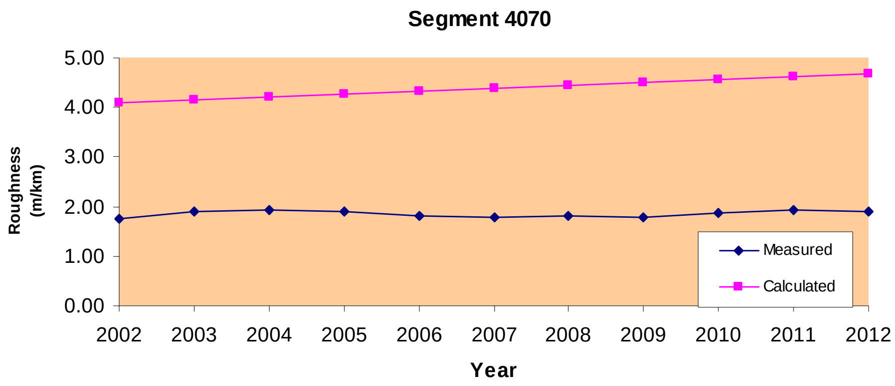
Segment 1040				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	3.79	1.36	2.42	64%
2003		1.38		
2004		1.40		
2005	3.60	1.42	2.17	60%
2006	3.52	1.45	2.08	59%
2007	3.41	1.47	1.94	57%
2008	3.41	1.49	1.92	56%
2009	3.48	1.51	1.97	57%
2010	3.45	1.53	1.91	56%
2011	3.60	1.55	2.04	57%
2012	3.71	1.57	2.14	58%

Segment 1050				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	4.09	2.96	1.13	28%
2003		3.00		
2004		3.05		
2005	4.31	3.10	1.22	28%
2006	4.20	3.14	1.06	25%
2007	4.16	3.19	0.97	23%
2008	4.24	3.24	1.00	24%
2009	4.28	3.29	0.99	23%
2010	4.35	3.33	1.02	23%
2011	4.46	3.38	1.08	24%
2012	4.35	3.43	0.92	21%

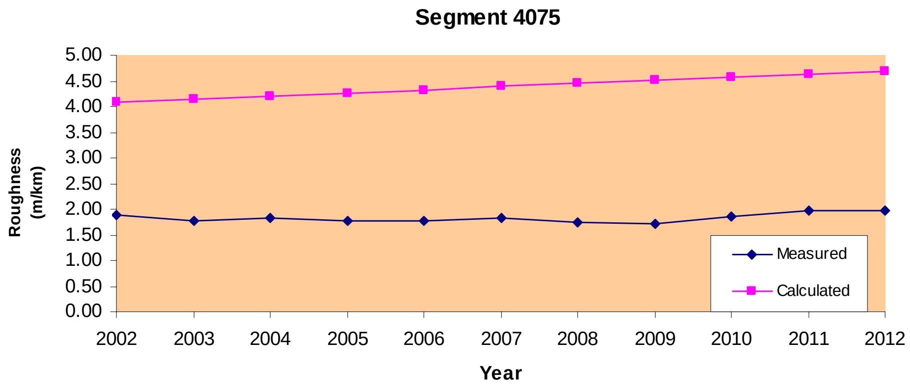


Roughness for Dandhara Site based on unmodified local roads model

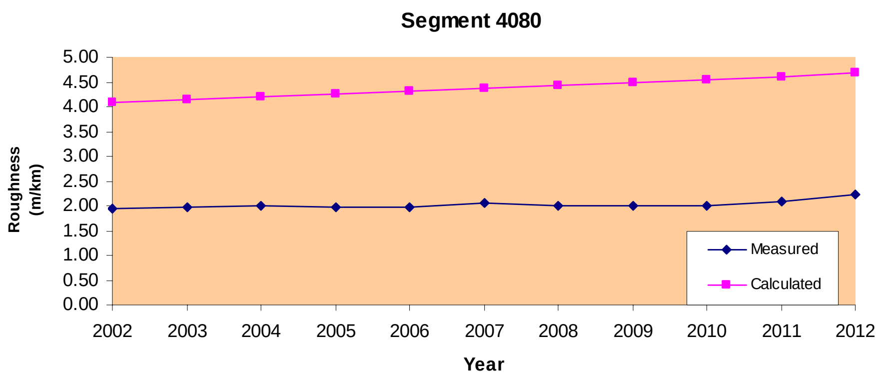
Segment 4070				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.75	4.08	-2.34	-134%
2003	1.90	4.14	-2.24	-118%
2004	1.94	4.20	-2.27	-117%
2005	1.90	4.26	-2.36	-124%
2006	1.82	4.32	-2.50	-137%
2007	1.78	4.38	-2.59	-145%
2008	1.82	4.44	-2.62	-144%
2009	1.78	4.50	-2.71	-152%
2010	1.86	4.56	-2.70	-145%
2011	1.94	4.62	-2.68	-138%
2012	1.90	4.67	-2.78	-146%



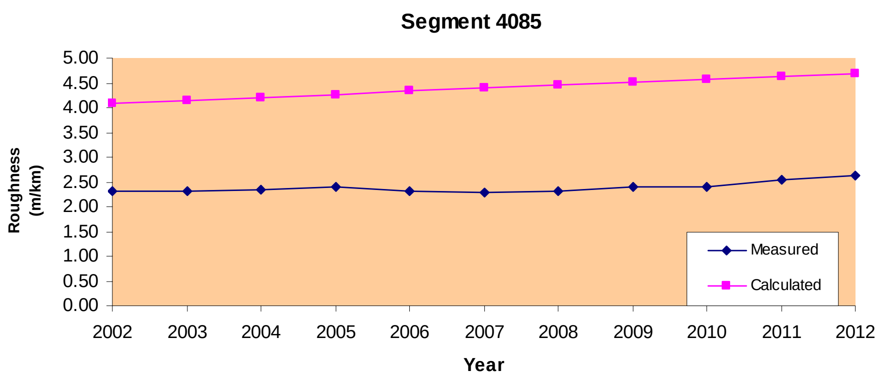
Segment 4075				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.90	4.09	-2.19	-116%
2003	1.78	4.15	-2.37	-133%
2004	1.82	4.21	-2.39	-131%
2005	1.78	4.27	-2.48	-139%
2006	1.78	4.33	-2.54	-143%
2007	1.82	4.39	-2.56	-141%
2008	1.75	4.45	-2.70	-155%
2009	1.71	4.50	-2.80	-164%
2010	1.86	4.56	-2.70	-145%
2011	1.97	4.62	-2.65	-134%
2012	1.97	4.68	-2.71	-137%



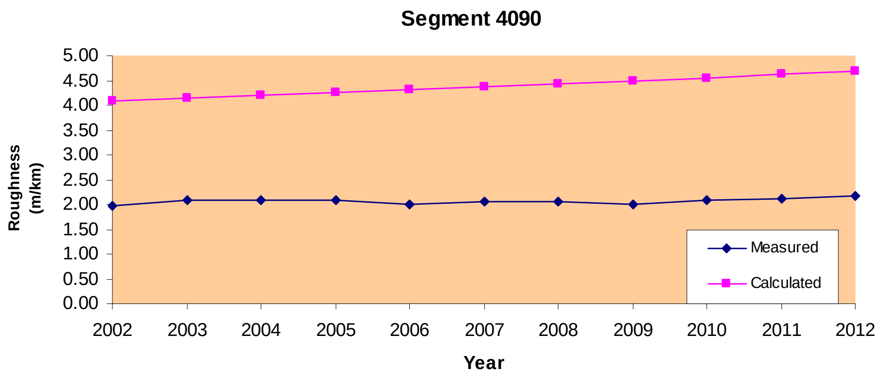
Segment 4080				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.94	4.08	-2.15	-111%
2003	1.97	4.14	-2.17	-110%
2004	2.01	4.20	-2.19	-109%
2005	1.97	4.26	-2.29	-116%
2006	1.97	4.32	-2.34	-119%
2007	2.05	4.38	-2.33	-114%
2008	2.01	4.44	-2.43	-121%
2009	2.01	4.50	-2.48	-124%
2010	2.01	4.55	-2.54	-126%
2011	2.09	4.61	-2.53	-121%
2012	2.24	4.67	-2.44	-109%



Segment 4085				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.31	4.09	-1.78	-77%
2003	2.31	4.15	-1.84	-80%
2004	2.35	4.21	-1.86	-79%
2005	2.39	4.27	-1.88	-79%
2006	2.31	4.33	-2.02	-87%
2007	2.28	4.39	-2.11	-93%
2008	2.31	4.45	-2.13	-92%
2009	2.39	4.51	-2.12	-89%
2010	2.39	4.57	-2.18	-91%
2011	2.54	4.63	-2.09	-82%
2012	2.61	4.69	-2.07	-79%

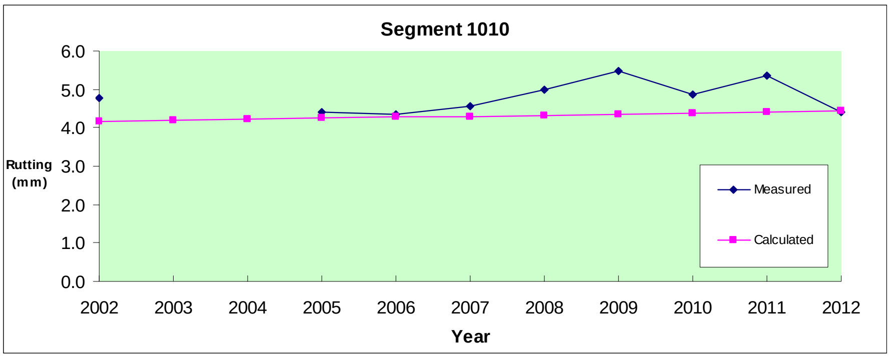


Segment 4090				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.97	4.08	-2.11	-107%
2003	2.09	4.14	-2.06	-99%
2004	2.09	4.20	-2.12	-101%
2005	2.09	4.26	-2.17	-104%
2006	2.01	4.32	-2.31	-115%
2007	2.05	4.38	-2.33	-114%
2008	2.05	4.44	-2.39	-117%
2009	2.01	4.50	-2.49	-124%
2010	2.09	4.56	-2.47	-118%
2011	2.12	4.62	-2.49	-117%
2012	2.16	4.68	-2.51	-116%

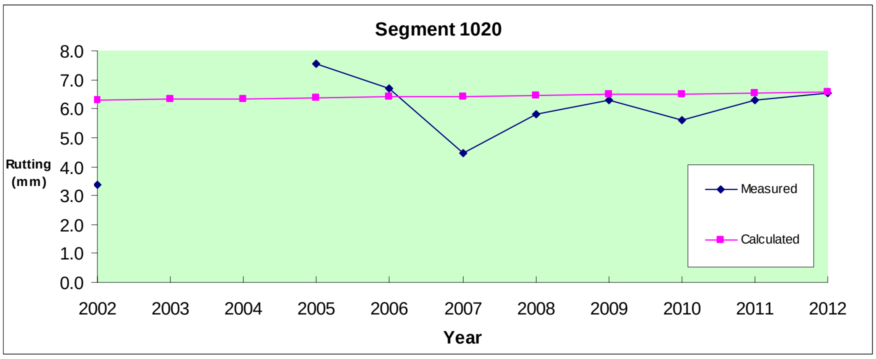


Rutting for Waterview Site based on unmodified local roads model

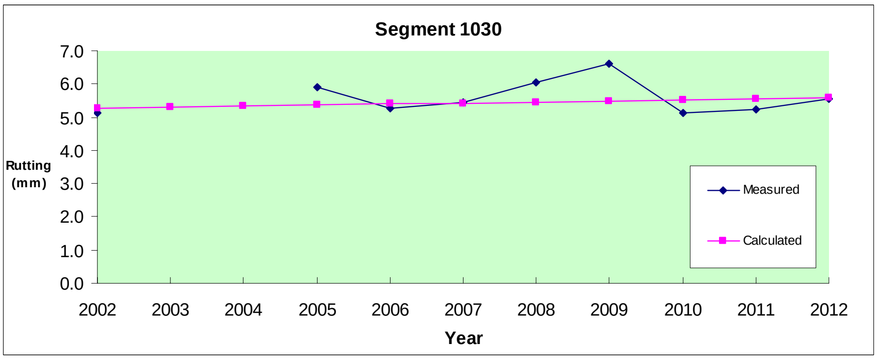
Segment 1010				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.8	4.2	0.6	13%
2003		4.2		
2004		4.2		
2005	4.4	4.2	0.1	3%
2006	4.3	4.3	0.1	2%
2007	4.6	4.3	0.3	6%
2008	5.0	4.3	0.7	13%
2009	5.5	4.4	1.1	21%
2010	4.9	4.4	0.5	10%
2011	5.4	4.4	1.0	18%
2012	4.4	4.4	0.0	-1%



Segment 1020				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	3.4	6.3	-2.9	-88%
2003		6.3		
2004		6.3		
2005	7.6	6.4	1.2	16%
2006	6.7	6.4	0.3	4%
2007	4.5	6.4	-2.0	-44%
2008	5.8	6.5	-0.6	-11%
2009	6.3	6.5	-0.2	-3%
2010	5.6	6.5	-0.9	-16%
2011	6.3	6.5	-0.2	-4%
2012	6.5	6.6	0.0	0%

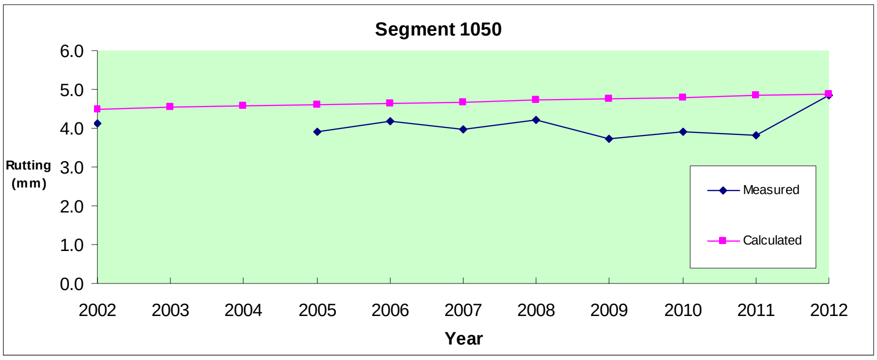


Segment 1030				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	5.1	5.3	-0.1	-3%
2003		5.3		
2004		5.3		
2005	5.9	5.4	0.5	9%
2006	5.3	5.4	-0.1	-2%
2007	5.5	5.4	0.0	1%
2008	6.1	5.5	0.6	10%
2009	6.6	5.5	1.1	17%
2010	5.1	5.5	-0.4	-7%
2011	5.2	5.5	-0.3	-6%
2012	5.5	5.6	0.0	-1%



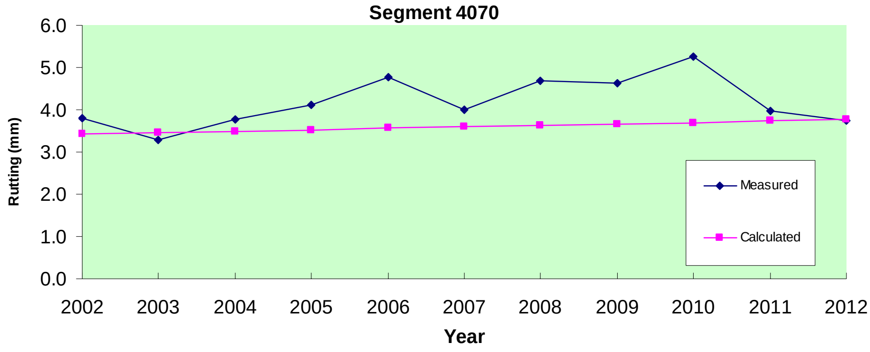
Segment 1040				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	6.5	6.7	-0.2	-4%
2003		6.7		
2004		6.8		
2005	6.2	6.8	-0.6	-10%
2006	7.8	6.8	1.0	12%
2007	6.0	6.9	-0.8	-14%
2008	6.8	6.9	-0.2	-2%
2009	5.9	7.0	-1.1	-18%
2010	5.8	7.0	-1.2	-21%
2011	6.5	7.0	-0.5	-8%
2012	7.0	7.1	0.0	-1%

Segment 1050				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.1	4.5	-0.4	-9%
2003		4.5		
2004		4.6		
2005	3.9	4.6	-0.7	-18%
2006	4.2	4.6	-0.5	-11%
2007	4.0	4.7	-0.7	-18%
2008	4.2	4.7	-0.5	-12%
2009	3.7	4.8	-1.0	-27%
2010	3.9	4.8	-0.9	-22%
2011	3.8	4.8	-1.0	-26%
2012	4.8	4.9	0.0	-1%



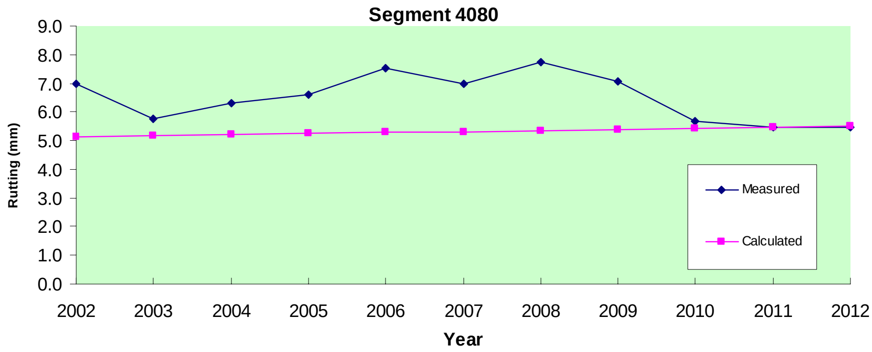
Rutting for Dandhara Site based on unmodified local roads model

Segment 4070				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	3.8	3.4	0.4	10%
2003	3.3	3.5	-0.2	-5%
2004	3.8	3.5	0.3	7%
2005	4.1	3.5	0.6	14%
2006	4.8	3.6	1.2	25%
2007	4.0	3.6	0.4	10%
2008	4.7	3.6	1.0	22%
2009	4.6	3.7	1.0	21%
2010	5.3	3.7	1.6	30%
2011	4.0	3.7	0.2	6%
2012	3.7	3.8	0.0	-1%

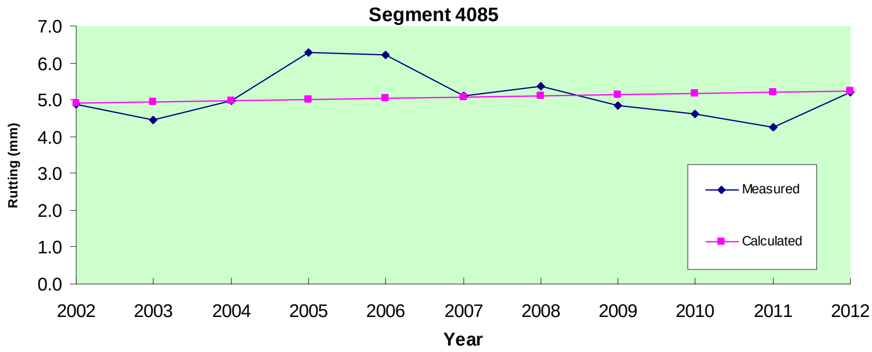


Segment 4075				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.9	5.3	-0.4	-8%
2003	5.2	5.3	-0.1	-1%
2004	4.9	5.3	-0.4	-9%
2005	5.7	5.4	0.3	5%
2006	6.8	5.4	1.4	21%
2007	4.9	5.4	-0.5	-10%
2008	6.7	5.5	1.3	19%
2009	4.4	5.5	-1.1	-25%
2010	6.4	5.5	0.9	14%
2011	5.2	5.6	-0.4	-7%
2012	5.6	5.6	0.0	-1%

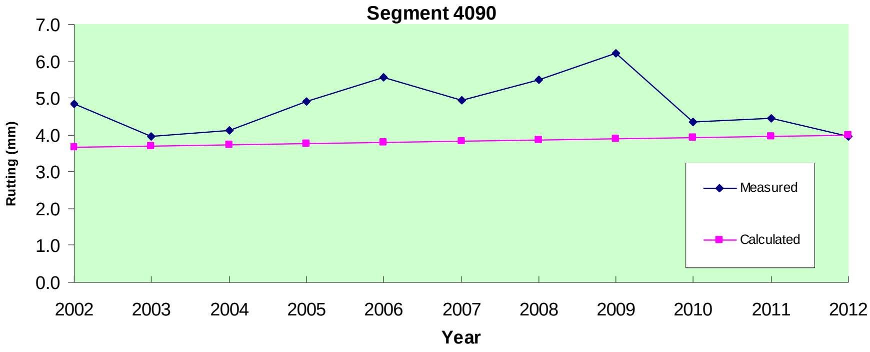
Segment 4080				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	7.0	5.2	1.8	26%
2003	5.8	5.2	0.6	10%
2004	6.3	5.2	1.1	18%
2005	6.6	5.2	1.4	20%
2006	7.5	5.3	2.2	30%
2007	7.0	5.3	1.7	24%
2008	7.7	5.3	2.4	31%
2009	7.1	5.4	1.7	24%
2010	5.7	5.4	0.2	4%
2011	5.5	5.5	0.0	0%
2012	5.5	5.5	0.0	-1%



Segment 4085				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.9	4.9	0.0	0%
2003	4.4	4.9	-0.5	-11%
2004	5.0	5.0	0.0	0%
2005	6.3	5.0	1.3	20%
2006	6.2	5.0	1.2	19%
2007	5.1	5.1	0.0	1%
2008	5.4	5.1	0.3	5%
2009	4.8	5.1	-0.3	-6%
2010	4.6	5.2	-0.6	-12%
2011	4.3	5.2	-1.0	-22%
2012	5.2	5.2	0.0	-1%

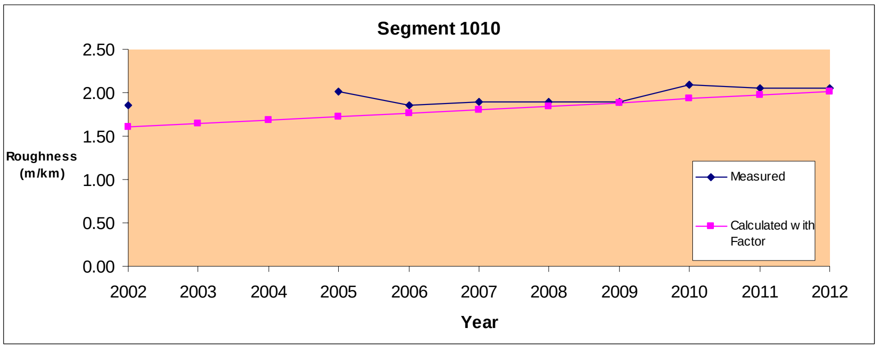


Segment 4090				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.8	3.7	1.2	24%
2003	4.0	3.7	0.3	6%
2004	4.1	3.7	0.4	10%
2005	4.9	3.8	1.1	23%
2006	5.6	3.8	1.8	32%
2007	5.0	3.8	1.1	23%
2008	5.5	3.9	1.6	30%
2009	6.2	3.9	2.3	37%
2010	4.3	3.9	0.4	9%
2011	4.4	4.0	0.5	11%
2012	4.0	4.0	0.0	-1%

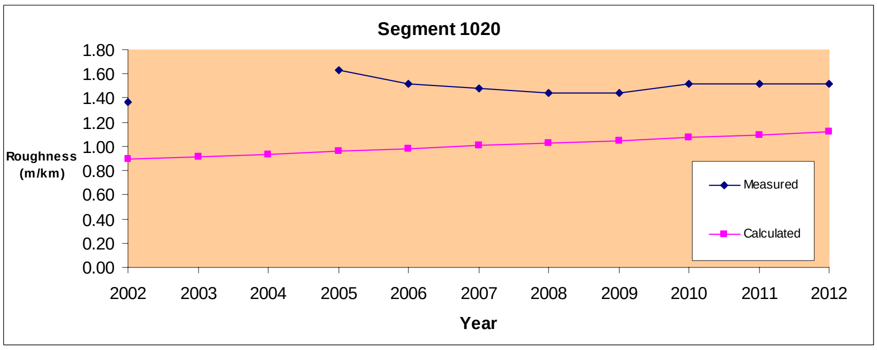


Roughness for Waterview site calculated with calibration factor determined by least squares

Segment 1010				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.86	1.60	0.26	14%
2003		1.64		
2004		1.68		
2005	2.01	1.72	0.29	14%
2006	1.86	1.76	0.10	5%
2007	1.90	1.81	0.09	5%
2008	1.90	1.85	0.05	3%
2009	1.90	1.89	0.01	1%
2010	2.09	1.93	0.16	8%
2011	2.05	1.97	0.08	4%
2012	2.05	2.01	0.04	2%



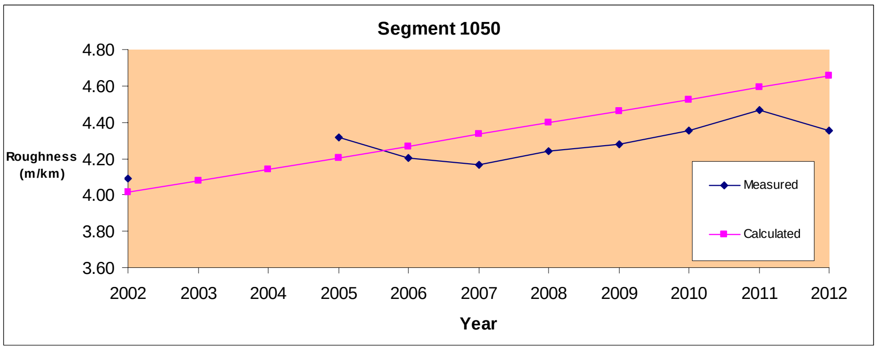
Segment 1020				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.37	0.89	0.48	35%
2003		0.91		
2004		0.94		
2005	1.63	0.96	0.67	41%
2006	1.52	0.98	0.54	35%
2007	1.48	1.01	0.48	32%
2008	1.44	1.03	0.42	29%
2009	1.44	1.05	0.39	27%
2010	1.52	1.07	0.45	29%
2011	1.52	1.10	0.42	28%
2012	1.52	1.12	0.40	26%



Segment 1030				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.69	3.09	-0.40	-15%
2003		3.16		
2004		3.24		
2005	2.50	3.32	-0.82	-33%
2006	2.50	3.40	-0.89	-36%
2007	2.43	3.47	-1.05	-43%
2008	2.54	3.55	-1.01	-40%
2009	2.54	3.63	-1.09	-43%
2010	2.58	3.71	-1.13	-44%
2011	2.88	3.78	-0.90	-31%
2012	2.92	3.86	-0.94	-32%

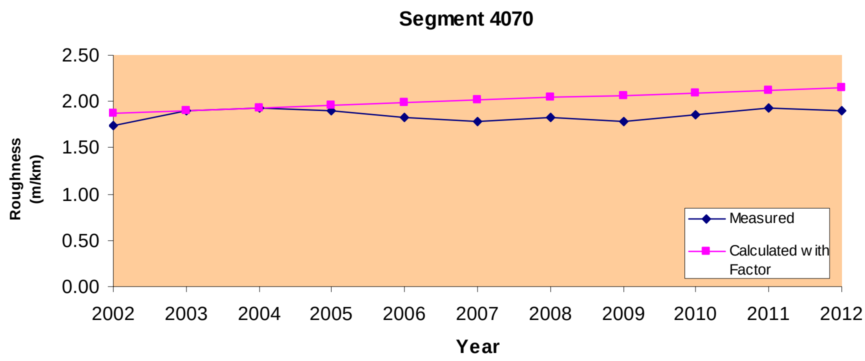
Segment 1040				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	3.79	1.85	1.94	51%
2003		1.88		
2004		1.91		
2005	3.60	1.93	1.66	46%
2006	3.52	1.96	1.56	44%
2007	3.41	1.99	1.42	42%
2008	3.41	2.02	1.39	41%
2009	3.48	2.05	1.43	41%
2010	3.45	2.08	1.37	40%
2011	3.60	2.11	1.49	41%
2012	3.71	2.14	1.57	42%

Segment 1050				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	4.09	4.01	0.07	2%
2003		4.08		
2004		4.14		
2005	4.31	4.20	0.11	3%
2006	4.20	4.27	-0.07	-2%
2007	4.16	4.33	-0.17	-4%
2008	4.24	4.40	-0.16	-4%
2009	4.28	4.46	-0.19	-4%
2010	4.35	4.53	-0.17	-4%
2011	4.46	4.59	-0.13	-3%
2012	4.35	4.65	-0.30	-7%

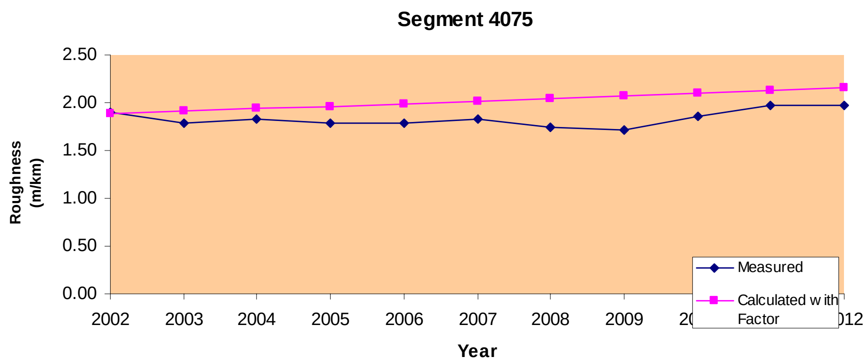


Roughness for Dandhara site calculated with calibration factor determined by least squares

Segment 4070				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.75	1.88	-0.13	-8%
2003	1.90	1.91	-0.01	0%
2004	1.94	1.93	0.00	0%
2005	1.90	1.96	-0.06	-3%
2006	1.82	1.99	-0.16	-9%
2007	1.78	2.01	-0.23	-13%
2008	1.82	2.04	-0.22	-12%
2009	1.78	2.07	-0.28	-16%
2010	1.86	2.10	-0.24	-13%
2011	1.94	2.12	-0.19	-10%
2012	1.90	2.15	-0.25	-13%

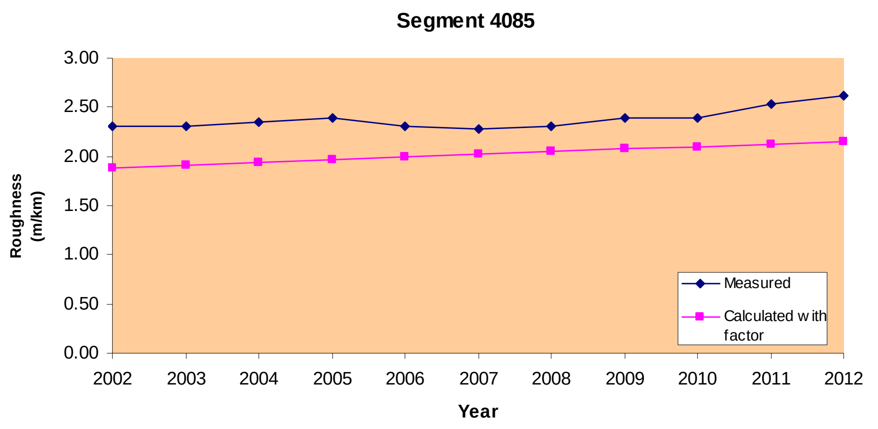


Segment 4075				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.90	1.88	0.02	1%
2003	1.78	1.91	-0.12	-7%
2004	1.82	1.94	-0.11	-6%
2005	1.78	1.96	-0.18	-10%
2006	1.78	1.99	-0.21	-12%
2007	1.82	2.02	-0.20	-11%
2008	1.75	2.04	-0.30	-17%
2009	1.71	2.07	-0.36	-21%
2010	1.86	2.10	-0.24	-13%
2011	1.97	2.13	-0.15	-8%
2012	1.97	2.15	-0.18	-9%

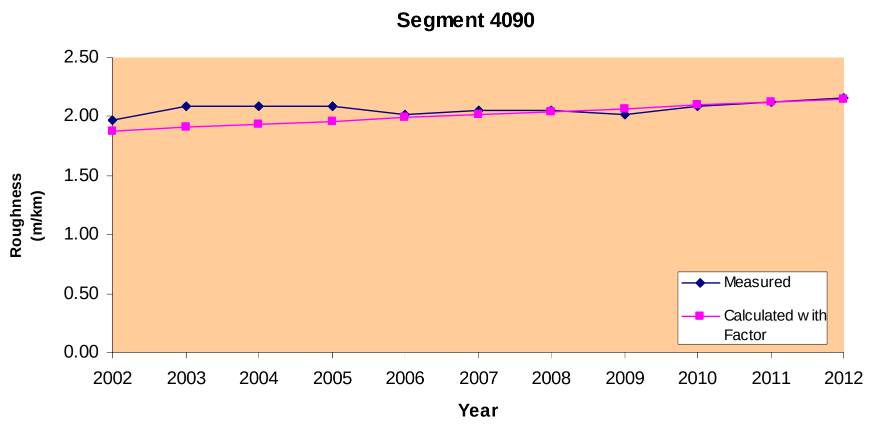


Segment 4080				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.94	1.88	0.06	3%
2003	1.97	1.90	0.07	3%
2004	2.01	1.93	0.08	4%
2005	1.97	1.96	0.01	1%
2006	1.97	1.99	-0.01	-1%
2007	2.05	2.01	0.04	2%
2008	2.01	2.04	-0.03	-1%
2009	2.01	2.07	-0.06	-3%
2010	2.01	2.10	-0.08	-4%
2011	2.09	2.12	-0.04	-2%
2012	2.24	2.15	0.09	4%

Segment 4085				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.31	1.88	0.43	19%
2003	2.31	1.91	0.40	17%
2004	2.35	1.94	0.41	18%
2005	2.39	1.96	0.42	18%
2006	2.31	1.99	0.32	14%
2007	2.28	2.02	0.26	11%
2008	2.31	2.05	0.27	12%
2009	2.39	2.07	0.32	13%
2010	2.39	2.10	0.29	12%
2011	2.54	2.13	0.41	16%
2012	2.61	2.16	0.46	18%

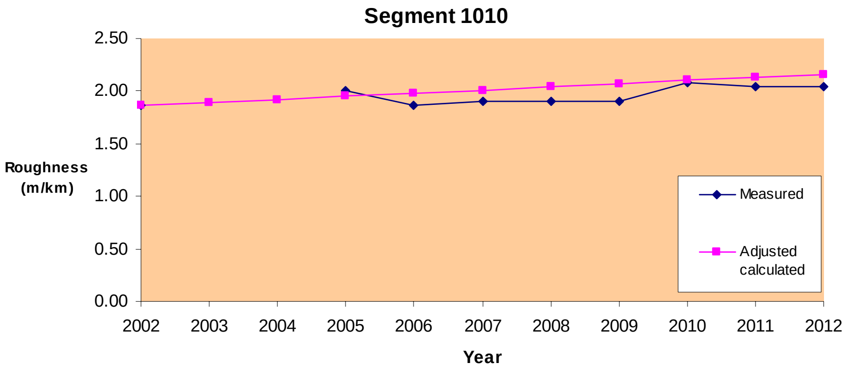


Segment 4090				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.97	1.88	0.09	5%
2003	2.09	1.91	0.18	9%
2004	2.09	1.93	0.15	7%
2005	2.09	1.96	0.13	6%
2006	2.01	1.99	0.02	1%
2007	2.05	2.01	0.03	2%
2008	2.05	2.04	0.01	0%
2009	2.01	2.07	-0.06	-3%
2010	2.09	2.10	-0.01	0%
2011	2.12	2.12	0.00	0%
2012	2.16	2.15	0.01	1%

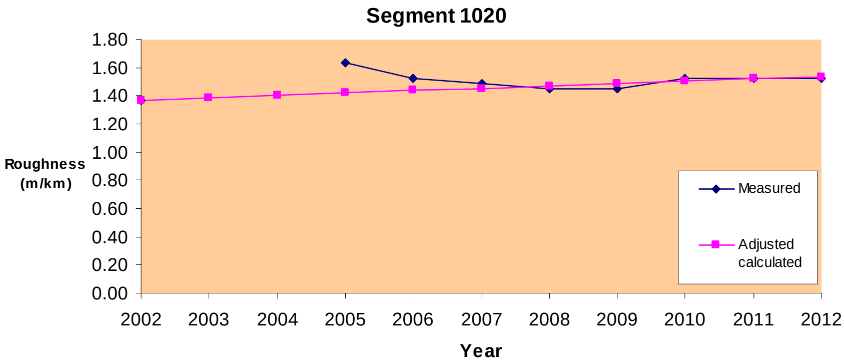


Roughness for Waterview site calculated with adjusted initial roughness

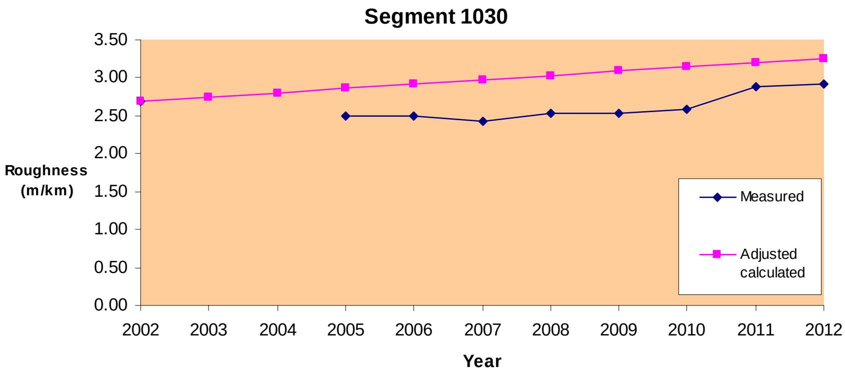
Segment 1010					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.86	1.18	1.86	0.00	0%
2003		1.21	1.89		
2004		1.24	1.92		
2005	2.01	1.27	1.95	0.06	3%
2006	1.86	1.30	1.98	-0.12	-7%
2007	1.90	1.33	2.01	-0.11	-6%
2008	1.90	1.36	2.04	-0.14	-8%
2009	1.90	1.39	2.07	-0.17	-9%
2010	2.09	1.42	2.10	-0.02	-1%
2011	2.05	1.45	2.13	-0.08	-4%
2012	2.05	1.48	2.16	-0.11	-6%



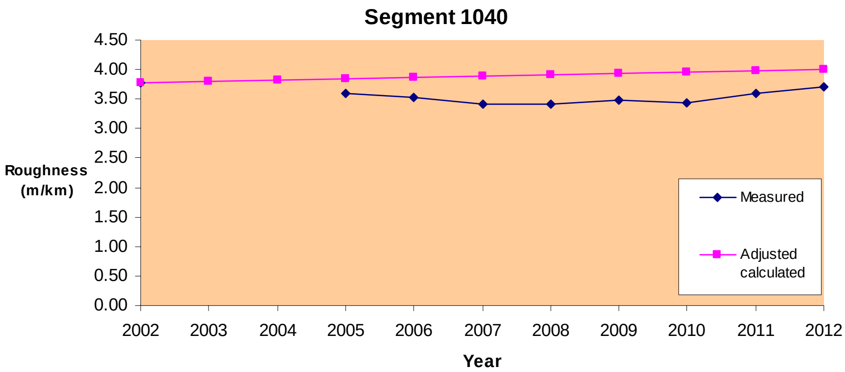
Segment 1020					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.37	0.66	1.37	0.00	0%
2003		0.67	1.39		
2004		0.69	1.40		
2005	1.63	0.71	1.42	0.21	13%
2006	1.52	0.72	1.44	0.08	6%
2007	1.48	0.74	1.45	0.03	2%
2008	1.44	0.76	1.47	-0.02	-2%
2009	1.44	0.77	1.49	-0.04	-3%
2010	1.52	0.79	1.50	0.02	1%
2011	1.52	0.81	1.52	0.00	0%
2012	1.52	0.82	1.54	-0.02	-1%



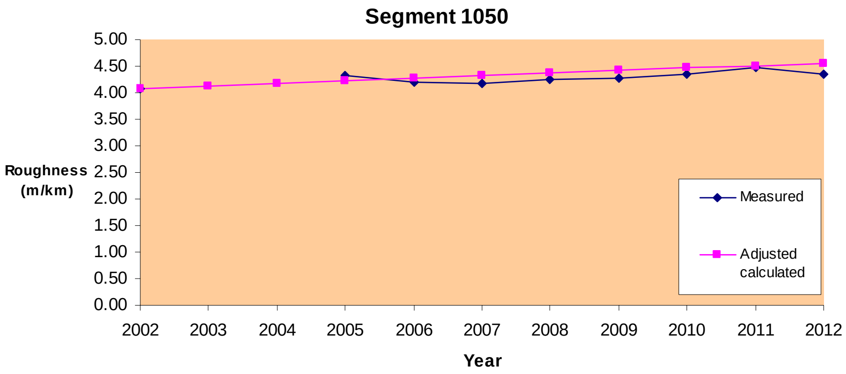
Segment 1030					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	2.69	2.27	2.69	0.00	0%
2003		2.33	2.75		
2004		2.39	2.80		
2005	2.50	2.44	2.86	-0.36	-14%
2006	2.50	2.50	2.92	-0.42	-17%
2007	2.43	2.56	2.97	-0.55	-23%
2008	2.54	2.61	3.03	-0.49	-19%
2009	2.54	2.67	3.09	-0.55	-22%
2010	2.58	2.73	3.15	-0.57	-22%
2011	2.88	2.79	3.20	-0.32	-11%
2012	2.92	2.84	3.26	-0.34	-12%



Segment 1040					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	3.79	1.36	3.79	0.00	0%
2003		1.38	3.81		
2004		1.40	3.83		
2005	3.60	1.42	3.85	-0.25	-7%
2006	3.52	1.45	3.87	-0.35	-10%
2007	3.41	1.47	3.89	-0.48	-14%
2008	3.41	1.49	3.91	-0.51	-15%
2009	3.48	1.51	3.93	-0.45	-13%
2010	3.45	1.53	3.96	-0.51	-15%
2011	3.60	1.55	3.98	-0.38	-11%
2012	3.71	1.57	4.00	-0.29	-8%

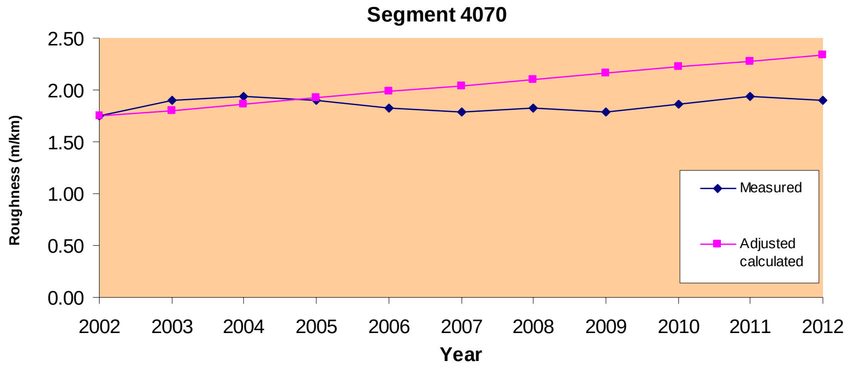


Segment 1050					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	4.09	2.96	4.09	0.00	0%
2003		3.00	4.13		
2004		3.05	4.18		
2005	4.31	3.10	4.23	0.09	2%
2006	4.20	3.14	4.28	-0.07	-2%
2007	4.16	3.19	4.32	-0.16	-4%
2008	4.24	3.24	4.37	-0.13	-3%
2009	4.28	3.29	4.42	-0.14	-3%
2010	4.35	3.33	4.46	-0.11	-3%
2011	4.46	3.38	4.51	-0.05	-1%
2012	4.35	3.43	4.56	-0.21	-5%

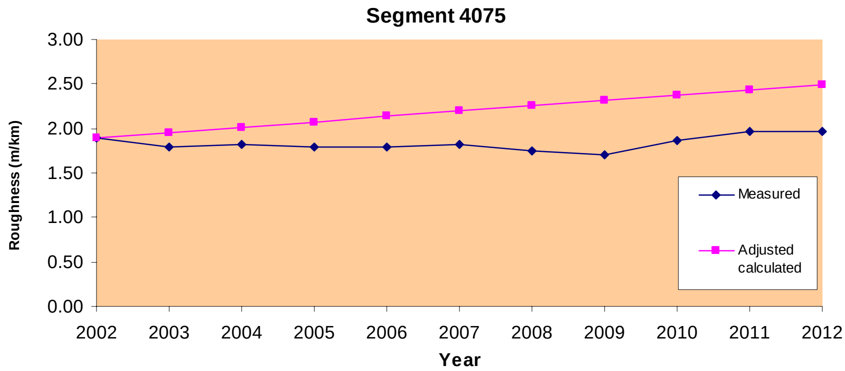


Roughness for Dandhara site calculated with adjusted initial roughness

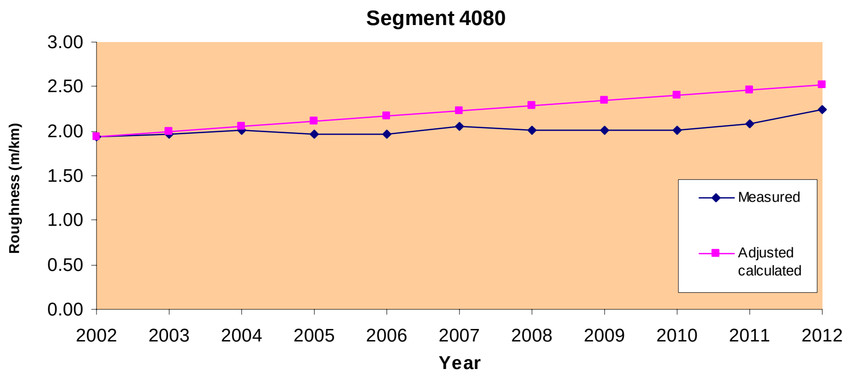
Segment 4070					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.75	4.08	1.75	0.00	0%
2003	1.90	4.14	1.81	0.09	5%
2004	1.94	4.20	1.86	0.07	4%
2005	1.90	4.26	1.92	-0.03	-1%
2006	1.82	4.32	1.98	-0.16	-9%
2007	1.78	4.38	2.04	-0.26	-14%
2008	1.82	4.44	2.10	-0.28	-15%
2009	1.78	4.50	2.16	-0.38	-21%
2010	1.86	4.56	2.22	-0.36	-19%
2011	1.94	4.62	2.28	-0.34	-18%
2012	1.90	4.67	2.34	-0.44	-23%



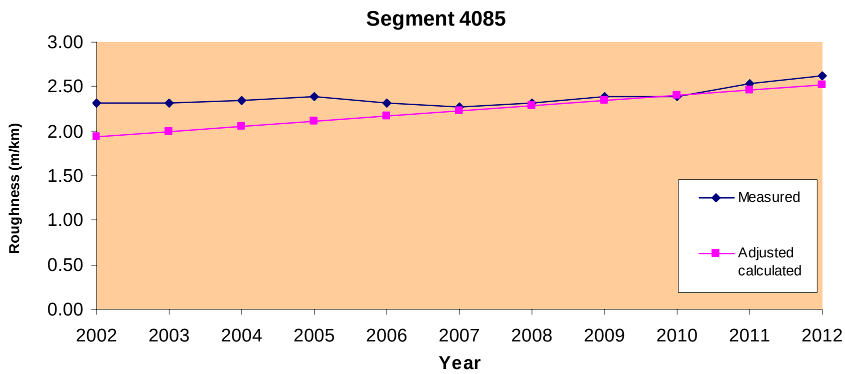
Segment 4075					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.90	4.09	1.90	0.00	0%
2003	1.78	4.15	1.96	-0.17	-10%
2004	1.82	4.21	2.02	-0.19	-11%
2005	1.78	4.27	2.07	-0.29	-16%
2006	1.78	4.33	2.13	-0.35	-20%
2007	1.82	4.39	2.19	-0.37	-20%
2008	1.75	4.45	2.25	-0.51	-29%
2009	1.71	4.50	2.31	-0.60	-35%
2010	1.86	4.56	2.37	-0.51	-27%
2011	1.97	4.62	2.43	-0.46	-23%
2012	1.97	4.68	2.49	-0.52	-26%



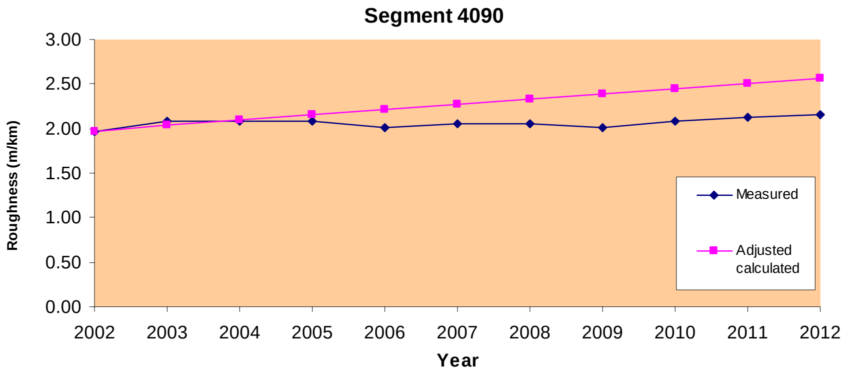
Segment 4080					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.94	4.08	1.94	0.00	0%
2003	1.97	4.14	1.99	-0.02	-1%
2004	2.01	4.20	2.05	-0.04	-2%
2005	1.97	4.26	2.11	-0.14	-7%
2006	1.97	4.32	2.17	-0.20	-10%
2007	2.05	4.38	2.23	-0.18	-9%
2008	2.01	4.44	2.29	-0.28	-14%
2009	2.01	4.50	2.35	-0.34	-17%
2010	2.01	4.55	2.41	-0.40	-20%
2011	2.09	4.61	2.47	-0.38	-18%
2012	2.24	4.67	2.53	-0.29	-13%



Segment 4085					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	2.31	4.09	2.31	0.00	0%
2003	2.31	4.15	2.37	-0.06	-3%
2004	2.35	4.21	2.43	-0.08	-3%
2005	2.39	4.27	2.49	-0.10	-4%
2006	2.31	4.33	2.55	-0.24	-10%
2007	2.28	4.39	2.61	-0.33	-15%
2008	2.31	4.45	2.67	-0.35	-15%
2009	2.39	4.51	2.73	-0.34	-14%
2010	2.39	4.57	2.79	-0.40	-17%
2011	2.54	4.63	2.85	-0.31	-12%
2012	2.61	4.69	2.90	-0.29	-11%



Segment 4090					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.97	4.08	1.97	0.00	0%
2003	2.09	4.14	2.03	0.05	3%
2004	2.09	4.20	2.09	0.00	0%
2005	2.09	4.26	2.15	-0.06	-3%
2006	2.01	4.32	2.21	-0.20	-10%
2007	2.05	4.38	2.27	-0.22	-11%
2008	2.05	4.44	2.33	-0.28	-14%
2009	2.01	4.50	2.39	-0.38	-19%
2010	2.09	4.56	2.45	-0.36	-17%
2011	2.12	4.62	2.50	-0.38	-18%
2012	2.16	4.68	2.56	-0.40	-19%



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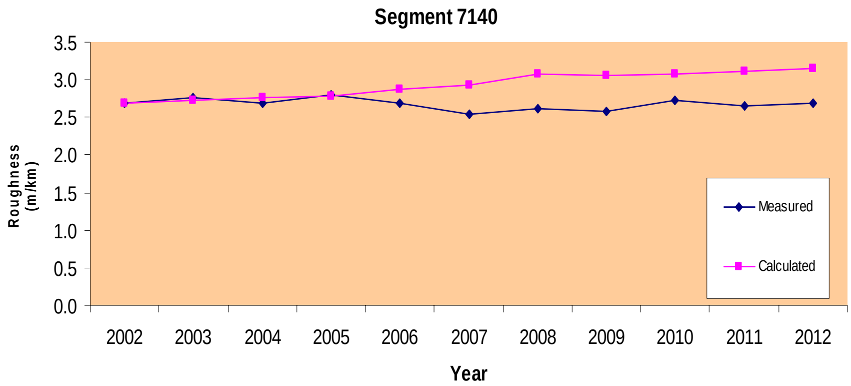
Appendix I Results for Deterioration Models for Sealed Local Roads – Elsmore and Warialda Creek sites

Roughness for Elsmore site

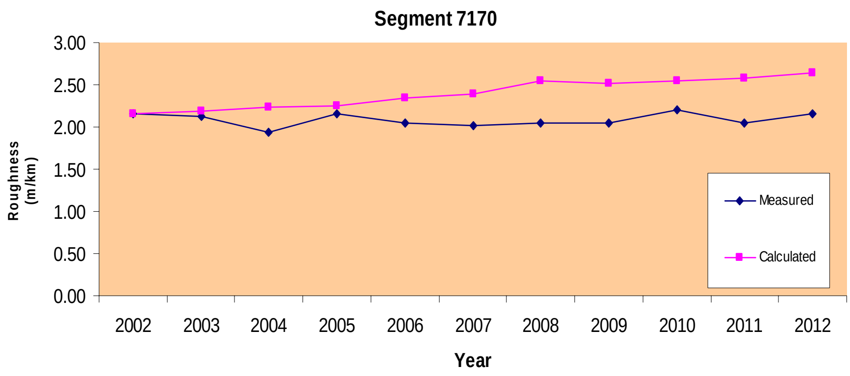
Segment 7140				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.7	2.7	0.0	0%
2003	2.8	2.7	0.0	2%
2004	2.7	2.8	-0.1	-3%
2005	2.8	2.8	0.0	1%
2006	2.7	2.9	-0.2	-7%
2007	2.5	2.9	-0.4	-15%
2008	2.6	3.1	-0.5	-18%
2009	2.6	3.1	-0.5	-19%
2010	2.7	3.1	-0.4	-13%
2011	2.7	3.1	-0.5	-17%
2012	2.7	3.1	-0.5	-17%



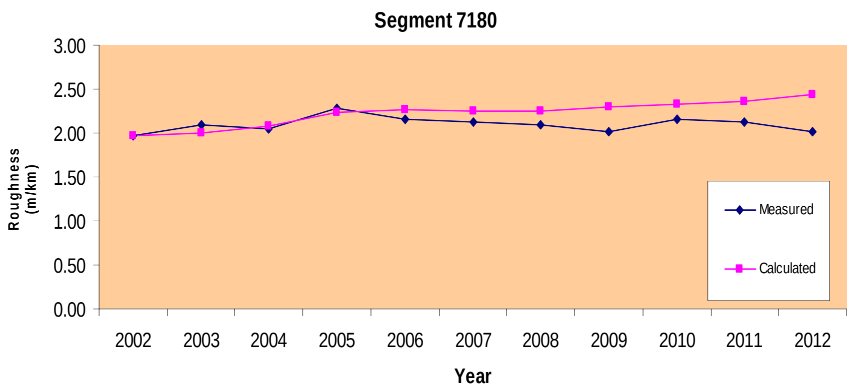
Segment7150				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.1	2.1	0.0	0%
2003	2.2	2.2	0.0	2%
2004	2.2	2.2	0.0	-2%
2005	2.2	2.2	0.0	0%
2006	2.2	2.3	-0.1	-5%
2007	2.1	2.4	-0.2	-11%
2008	2.2	2.5	-0.3	-16%
2009	2.2	2.5	-0.3	-15%
2010	2.5	2.5	0.0	1%
2011	2.3	2.5	-0.2	-10%
2012	2.3	2.6	-0.3	-12%

Segment 7160				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.01	2.01	0.00	0%
2003	2.01	2.04	-0.03	-1%
2004	1.97	2.08	-0.11	-6%
2005	2.09	2.09	-0.01	0%
2006	1.94	2.19	-0.25	-13%
2007	1.94	2.20	-0.26	-14%
2008	1.97	2.21	-0.24	-12%
2009	1.78	2.30	-0.51	-29%
2010	2.16	2.48	-0.32	-15%
2011	2.09	2.46	-0.37	-18%
2012	2.16	2.50	-0.34	-16%

Segment 7170				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.16	2.16	0.00	0%
2003	2.12	2.19	-0.07	-3%
2004	1.94	2.24	-0.30	-15%
2005	2.16	2.24	-0.08	-4%
2006	2.05	2.34	-0.29	-14%
2007	2.01	2.39	-0.38	-19%
2008	2.05	2.54	-0.49	-24%
2009	2.05	2.52	-0.47	-23%
2010	2.20	2.55	-0.35	-16%
2011	2.05	2.58	-0.53	-26%
2012	2.16	2.63	-0.47	-22%

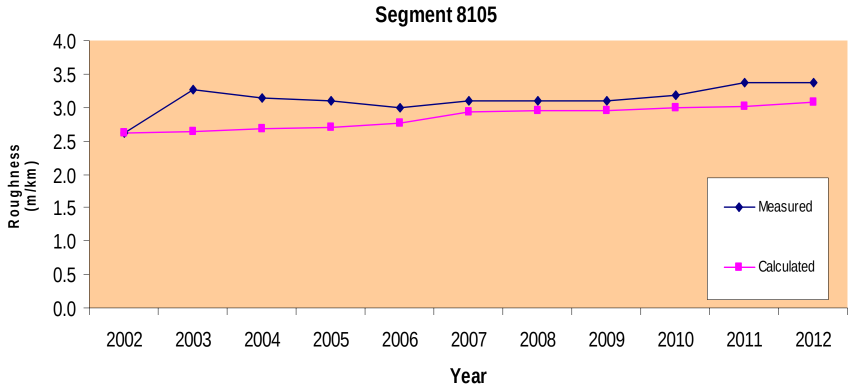


Segment 7180				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.97	1.97	0.00	0%
2003	2.09	2.00	0.08	4%
2004	2.05	2.09	-0.04	-2%
2005	2.28	2.23	0.04	2%
2006	2.16	2.26	-0.10	-5%
2007	2.12	2.25	-0.13	-6%
2008	2.09	2.26	-0.17	-8%
2009	2.01	2.29	-0.28	-14%
2010	2.16	2.33	-0.17	-8%
2011	2.12	2.37	-0.24	-11%
2012	2.01	2.43	-0.42	-21%

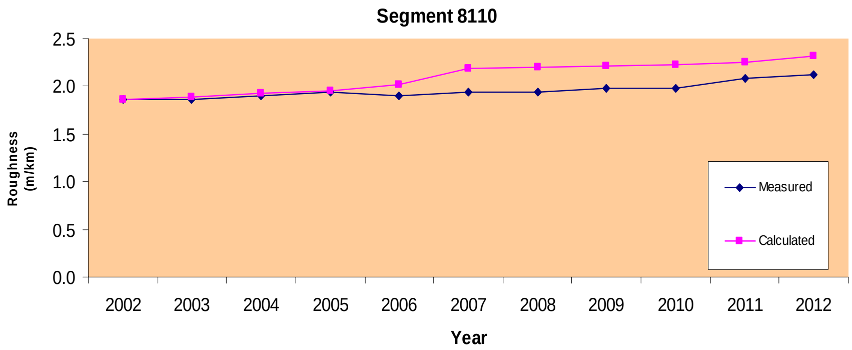


Roughness for Warialda Creek site

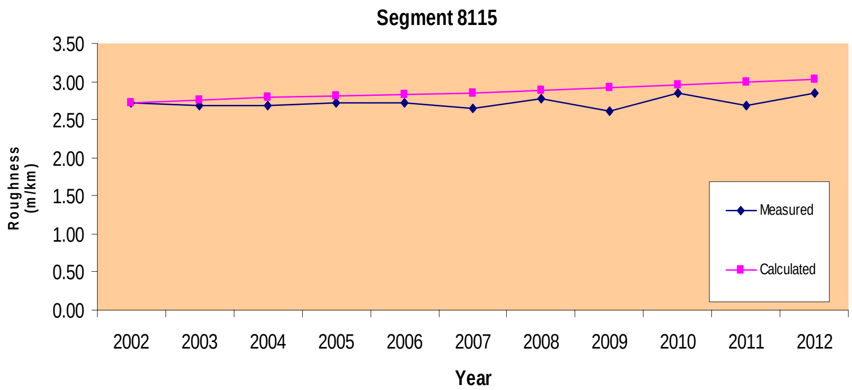
Segment 8105				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.6	2.6	0.0	0%
2003	3.3	2.6	0.6	19%
2004	3.1	2.7	0.5	15%
2005	3.1	2.7	0.4	13%
2006	3.0	2.8	0.2	7%
2007	3.1	2.9	0.2	5%
2008	3.1	3.0	0.2	5%
2009	3.1	3.0	0.1	5%
2010	3.2	3.0	0.2	6%
2011	3.4	3.0	0.4	11%
2012	3.4	3.1	0.3	9%



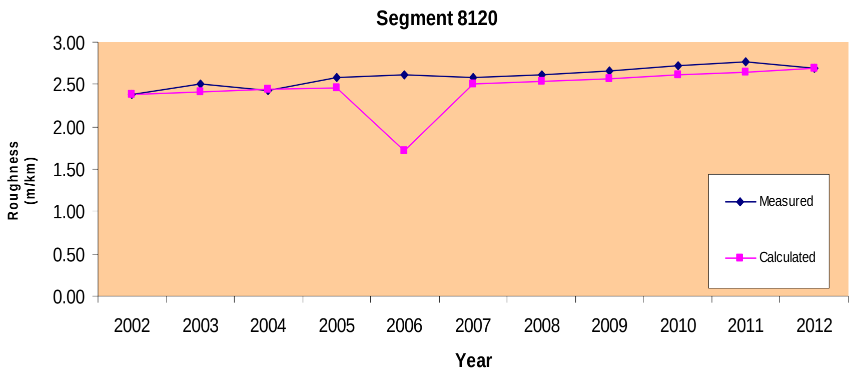
Segment 8110				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.9	1.9	0.0	0%
2003	1.9	1.9	0.0	-1%
2004	1.9	1.9	0.0	-2%
2005	1.9	2.0	0.0	-1%
2006	1.9	2.0	-0.1	-6%
2007	1.9	2.2	-0.3	-13%
2008	1.9	2.2	-0.3	-14%
2009	2.0	2.2	-0.2	-12%
2010	2.0	2.2	-0.3	-13%
2011	2.1	2.3	-0.2	-8%
2012	2.1	2.3	-0.2	-9%



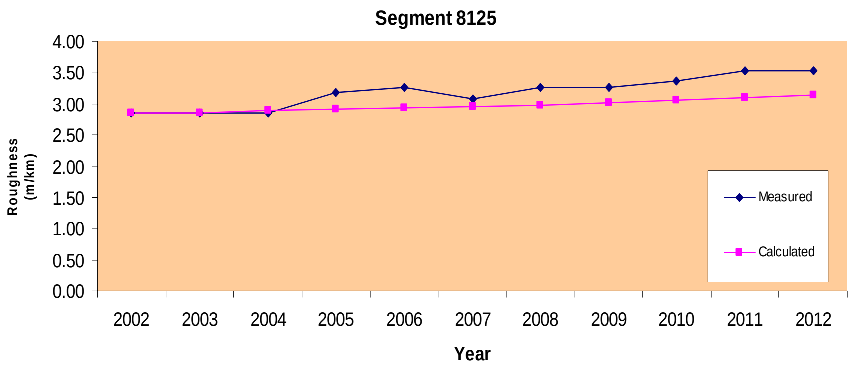
Segment 8115				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.73	2.73	0.00	0%
2003	2.69	2.75	-0.06	-2%
2004	2.69	2.79	-0.10	-4%
2005	2.73	2.81	-0.08	-3%
2006	2.73	2.83	-0.10	-4%
2007	2.65	2.85	-0.20	-8%
2008	2.77	2.88	-0.11	-4%
2009	2.61	2.92	-0.30	-11%
2010	2.84	2.95	-0.11	-4%
2011	2.69	2.99	-0.30	-11%
2012	2.84	3.03	-0.19	-7%



Segment 8120				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.39	2.39	0.00	0%
2003	2.50	2.41	0.09	4%
2004	2.43	2.44	-0.02	-1%
2005	2.58	2.47	0.11	4%
2006	2.61	1.71	0.90	34%
2007	2.58	2.51	0.07	3%
2008	2.61	2.53	0.09	3%
2009	2.65	2.57	0.08	3%
2010	2.73	2.61	0.12	4%
2011	2.77	2.65	0.12	4%
2012	2.69	2.69	0.00	0%



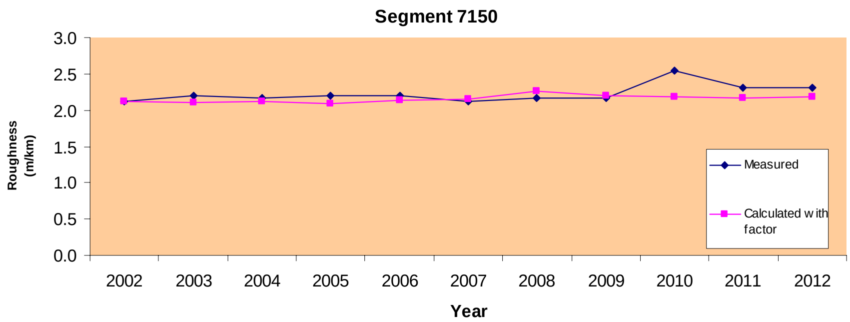
Segment 8125				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.84	2.84	0.00	0%
2003	2.84	2.86	-0.02	-1%
2004	2.84	2.90	-0.06	-2%
2005	3.18	2.92	0.26	8%
2006	3.26	2.93	0.32	10%
2007	3.07	2.96	0.11	4%
2008	3.26	2.98	0.27	8%
2009	3.26	3.02	0.23	7%
2010	3.37	3.06	0.31	9%
2011	3.52	3.10	0.42	12%
2012	3.52	3.14	0.38	11%



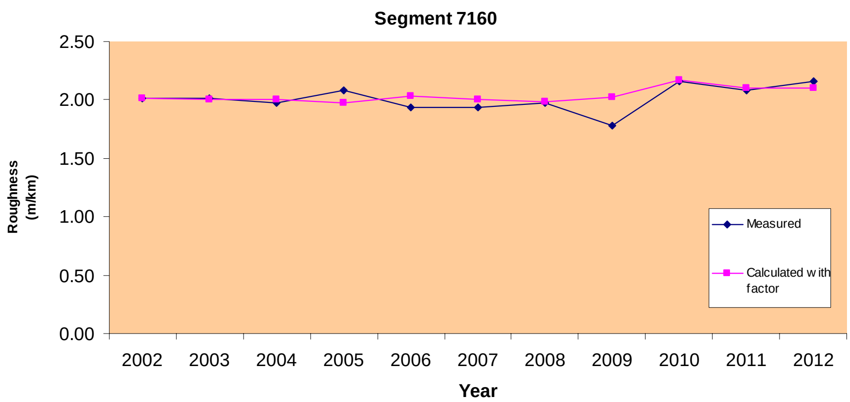
Roughness for Elsmore site using calibration factor

Segment 7140				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.7	2.7	0.0	0%
2003	2.8	2.7	0.1	4%
2004	2.7	2.7	0.0	1%
2005	2.8	2.6	0.2	7%
2006	2.7	2.7	0.0	1%
2007	2.5	2.7	-0.1	-5%
2008	2.6	2.8	-0.2	-6%
2009	2.6	2.7	-0.1	-5%
2010	2.7	2.7	0.1	2%
2011	2.7	2.6	0.0	0%
2012	2.7	2.6	0.1	2%

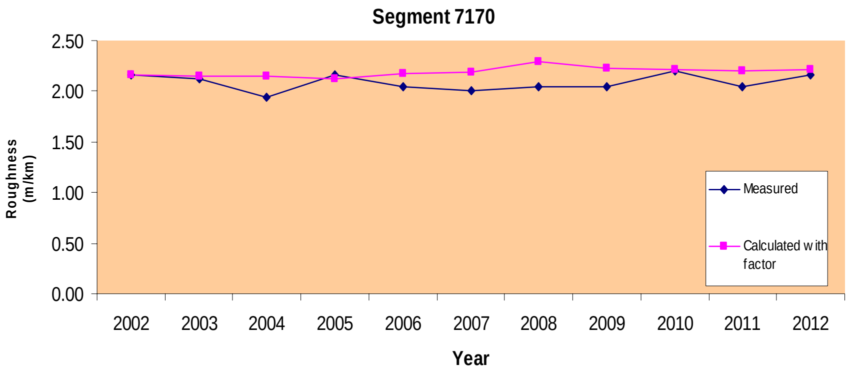
Segment7150				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.12	2.12	0.00	0%
2003	2.20	2.11	0.09	4%
2004	2.16	2.12	0.05	2%
2005	2.20	2.08	0.11	5%
2006	2.20	2.14	0.06	3%
2007	2.12	2.15	-0.02	-1%
2008	2.16	2.26	-0.10	-4%
2009	2.16	2.20	-0.03	-2%
2010	2.54	2.18	0.36	14%
2011	2.31	2.17	0.15	6%
2012	2.31	2.18	0.13	6%



Segment 7160				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.01	2.01	0.00	0%
2003	2.01	2.00	0.01	0%
2004	1.97	2.01	-0.03	-2%
2005	2.09	1.98	0.11	5%
2006	1.94	2.03	-0.10	-5%
2007	1.94	2.01	-0.07	-4%
2008	1.97	1.98	-0.01	-1%
2009	1.78	2.03	-0.24	-14%
2010	2.16	2.17	-0.01	0%
2011	2.09	2.11	-0.02	-1%
2012	2.16	2.11	0.06	3%



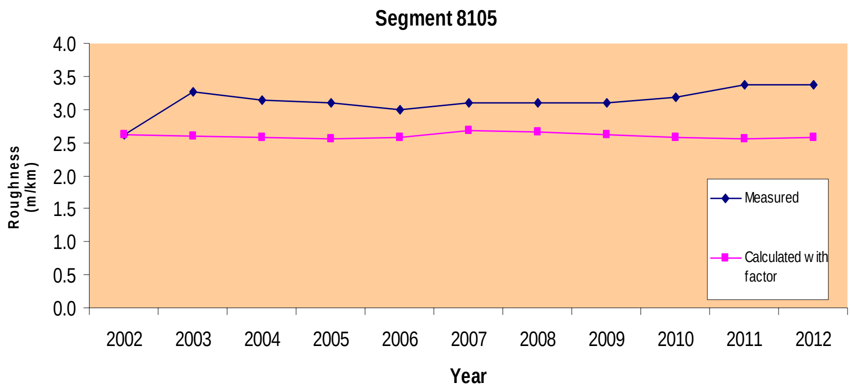
Segment 7170				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.16	2.16	0.00	0%
2003	2.12	2.15	-0.02	-1%
2004	1.94	2.15	-0.22	-11%
2005	2.16	2.12	0.04	2%
2006	2.05	2.17	-0.12	-6%
2007	2.01	2.18	-0.17	-8%
2008	2.05	2.29	-0.24	-12%
2009	2.05	2.23	-0.18	-9%
2010	2.20	2.21	-0.01	0%
2011	2.05	2.20	-0.15	-7%
2012	2.16	2.21	-0.05	-2%



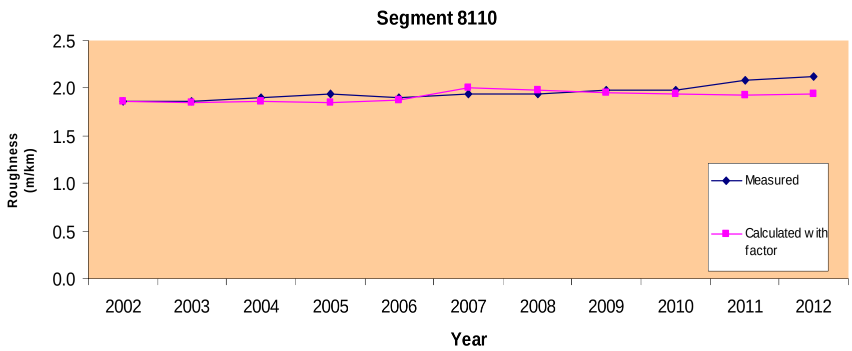
Segment 7180				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.97	1.97	0.00	0%
2003	2.09	1.96	0.12	6%
2004	2.05	2.01	0.04	2%
2005	2.28	2.12	0.16	7%
2006	2.16	2.10	0.06	3%
2007	2.12	2.06	0.07	3%
2008	2.09	2.02	0.07	3%
2009	2.01	2.02	-0.01	0%
2010	2.16	2.02	0.15	7%
2011	2.12	2.01	0.11	5%
2012	2.01	2.04	-0.03	-1%

Roughness for Warialda Creek site using calibration factor

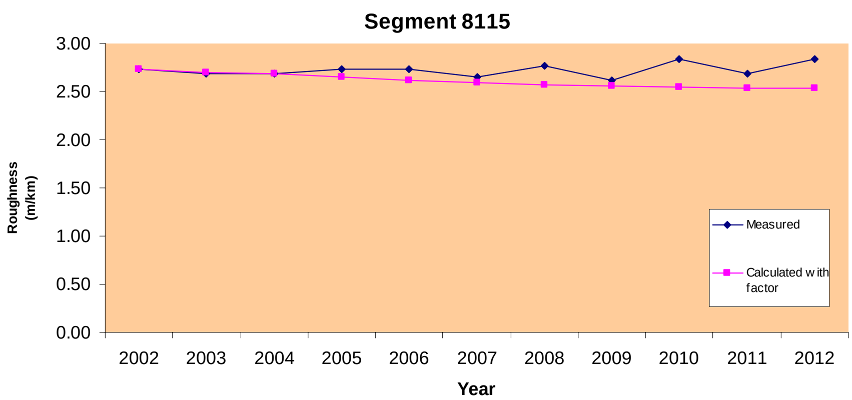
Segment 8105				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.6	2.6	0.0	0%
2003	3.3	2.6	0.7	20%
2004	3.1	2.6	0.6	18%
2005	3.1	2.6	0.5	18%
2006	3.0	2.6	0.4	14%
2007	3.1	2.7	0.4	13%
2008	3.1	2.6	0.5	15%
2009	3.1	2.6	0.5	16%
2010	3.2	2.6	0.6	19%
2011	3.4	2.6	0.8	24%
2012	3.4	2.6	0.8	24%



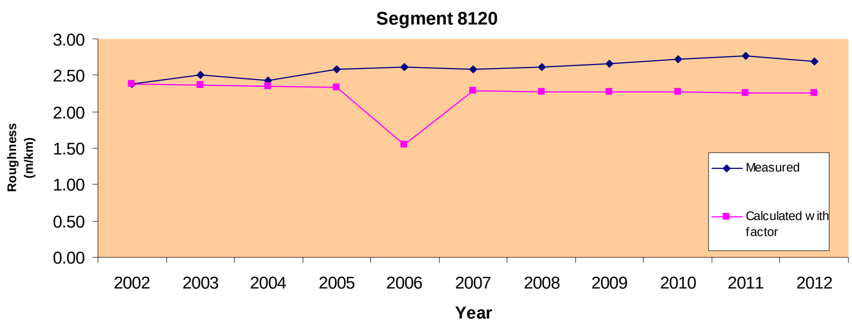
Segment 8110				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.86	1.86	0.00	0%
2003	1.86	1.85	0.01	1%
2004	1.90	1.86	0.04	2%
2005	1.94	1.85	0.09	5%
2006	1.90	1.88	0.02	1%
2007	1.94	2.01	-0.07	-4%
2008	1.94	1.98	-0.04	-2%
2009	1.97	1.95	0.02	1%
2010	1.97	1.94	0.04	2%
2011	2.09	1.93	0.16	8%
2012	2.12	1.94	0.18	9%



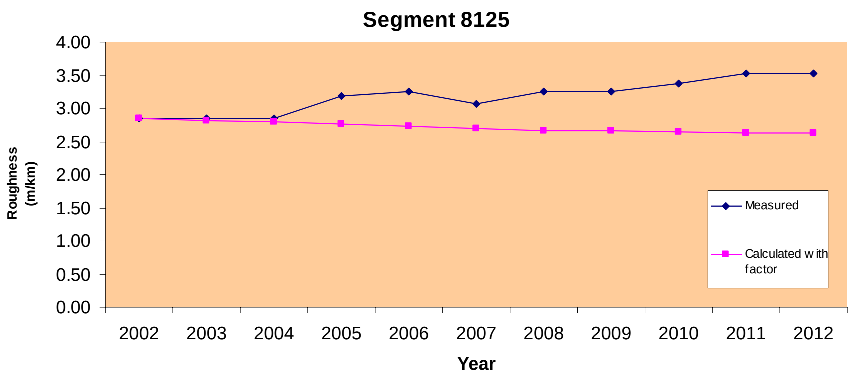
Segment 8115				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.73	2.73	0.00	0%
2003	2.69	2.70	-0.01	0%
2004	2.69	2.68	0.01	0%
2005	2.73	2.65	0.07	3%
2006	2.73	2.62	0.11	4%
2007	2.65	2.60	0.06	2%
2008	2.77	2.57	0.20	7%
2009	2.61	2.56	0.05	2%
2010	2.84	2.55	0.29	10%
2011	2.69	2.54	0.15	6%
2012	2.84	2.53	0.31	11%



Segment 8120				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.39	2.39	0.00	0%
2003	2.50	2.36	0.14	6%
2004	2.43	2.35	0.07	3%
2005	2.58	2.33	0.25	10%
2006	2.61	1.55	1.07	41%
2007	2.58	2.30	0.28	11%
2008	2.61	2.28	0.34	13%
2009	2.65	2.27	0.38	14%
2010	2.73	2.27	0.46	17%
2011	2.77	2.26	0.50	18%
2012	2.69	2.26	0.43	16%

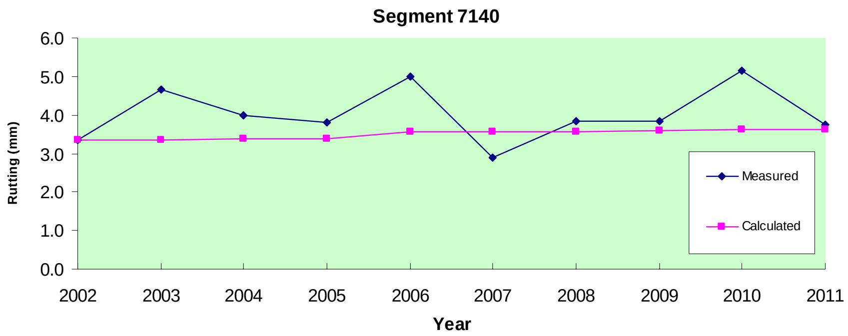


Segment 8125				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.84	2.84	0.00	0%
2003	2.84	2.81	0.04	1%
2004	2.84	2.79	0.05	2%
2005	3.18	2.76	0.42	13%
2006	3.26	2.72	0.54	16%
2007	3.07	2.69	0.37	12%
2008	3.26	2.67	0.59	18%
2009	3.26	2.65	0.60	18%
2010	3.37	2.64	0.73	22%
2011	3.52	2.63	0.89	25%
2012	3.52	2.62	0.90	26%

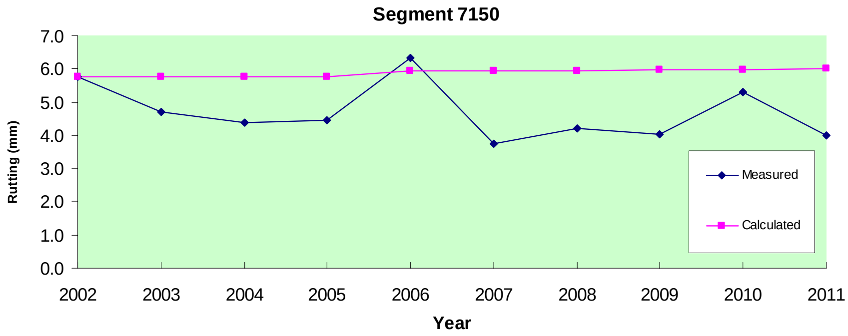


Rut depth comparison for Elsmore site

Segment 7140				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	3.4	3.4	0.0	0%
2003	4.7	3.4	1.3	28%
2004	4.0	3.4	0.6	16%
2005	3.8	3.4	0.4	11%
2006	5.0	3.6	1.4	29%
2007	2.9	3.6	-0.7	-23%
2008	3.9	3.6	0.3	8%
2009	3.8	3.6	0.3	7%
2010	5.1	3.6	1.5	30%
2011	3.8	3.6	0.1	3%

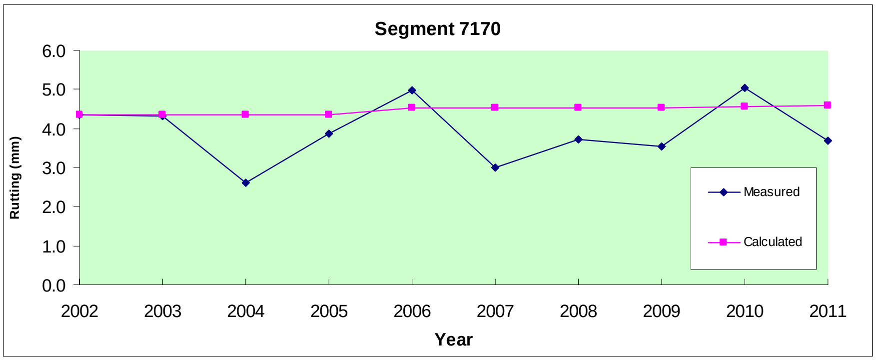


Segment 7150				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	5.8	5.8	0.0	0%
2003	4.7	5.8	-1.1	-23%
2004	4.4	5.8	-1.4	-32%
2005	4.5	5.8	-1.3	-30%
2006	6.3	5.9	0.4	6%
2007	3.8	5.9	-2.2	-58%
2008	4.2	5.9	-1.7	-41%
2009	4.0	6.0	-1.9	-48%
2010	5.3	6.0	-0.7	-13%
2011	4.0	6.0	-2.0	-50%

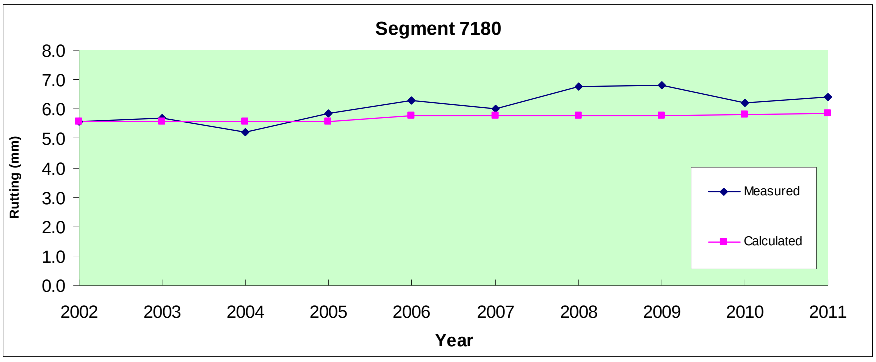


Segment 7160				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.0	4.0	0.0	0%
2003	3.9	4.0	-0.1	-2%
2004	3.5	4.0	-0.5	-14%
2005	3.7	4.0	-0.3	-8%
2006	5.6	4.1	1.4	25%
2007	3.1	4.1	-1.0	-32%
2008	4.0	4.1	-0.2	-4%
2009	4.1	4.2	-0.1	-1%
2010	4.4	4.2	0.2	4%
2011	4.1	4.2	-0.1	-1%

Segment 7170				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.3	4.3	0.0	0%
2003	4.3	4.3	0.0	-1%
2004	2.6	4.4	-1.7	-66%
2005	3.9	4.4	-0.5	-13%
2006	5.0	4.5	0.5	9%
2007	3.0	4.5	-1.5	-51%
2008	3.7	4.5	-0.8	-22%
2009	3.5	4.5	-1.0	-29%
2010	5.1	4.6	0.5	10%
2011	3.7	4.6	-0.9	-24%

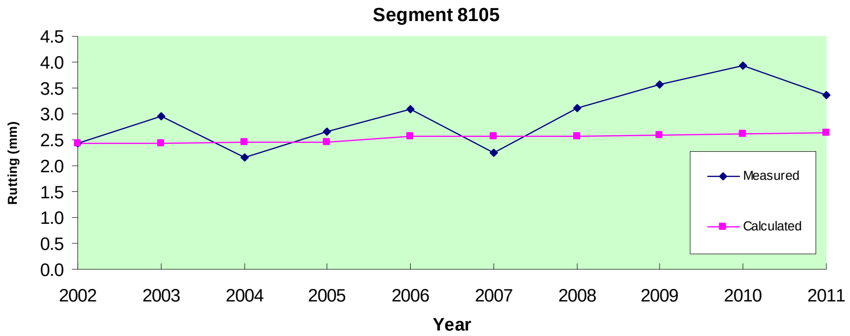


Segment 7180				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	5.6	5.6	0.00	0%
2003	5.7	5.6	0.13	2%
2004	5.2	5.6	-0.39	-7%
2005	5.9	5.6	0.26	4%
2006	6.3	5.8	0.54	9%
2007	6.0	5.8	0.24	4%
2008	6.8	5.8	1.01	15%
2009	6.8	5.8	1.04	15%
2010	6.2	5.8	0.39	6%
2011	6.4	5.8	0.58	9%

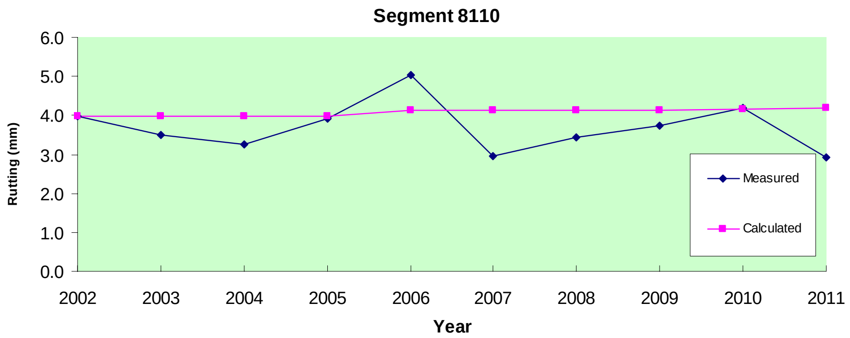


Rut depth comparison for Warialda Creek site

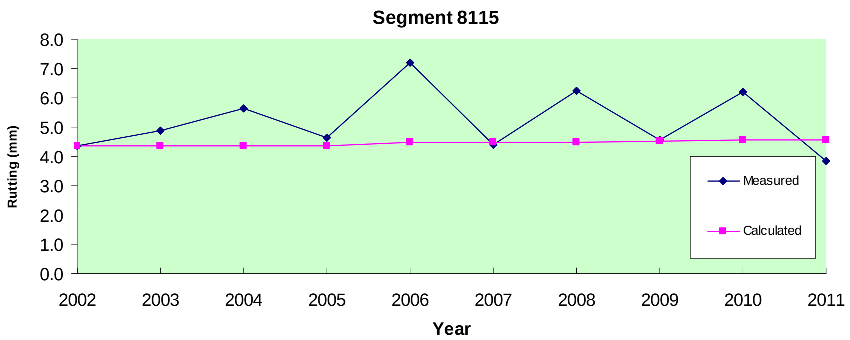
Segment 8105				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	2.4	2.4	0.0	0%
2003	3.0	2.4	0.5	18%
2004	2.2	2.4	-0.3	-13%
2005	2.7	2.4	0.2	8%
2006	3.1	2.6	0.5	16%
2007	2.3	2.6	-0.3	-14%
2008	3.1	2.6	0.5	18%
2009	3.6	2.6	1.0	27%
2010	3.9	2.6	1.3	33%
2011	3.4	2.6	0.7	21%



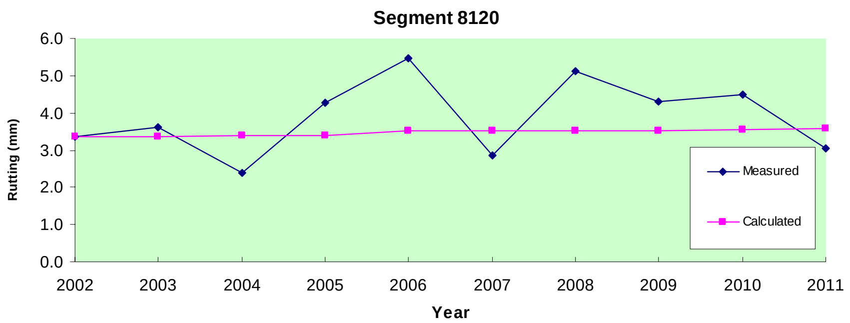
Segment 8110				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Differenc %
2002	4.0	4.0	0.0	0%
2003	3.5	4.0	-0.5	-14%
2004	3.3	4.0	-0.7	-23%
2005	3.9	4.0	-0.1	-2%
2006	5.1	4.1	0.9	18%
2007	3.0	4.1	-1.2	-40%
2008	3.4	4.1	-0.7	-20%
2009	3.8	4.1	-0.4	-10%
2010	4.2	4.2	0.0	1%
2011	2.9	4.2	-1.3	-43%



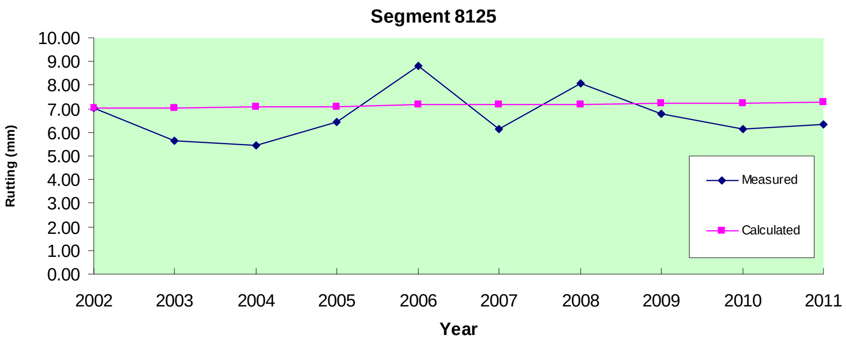
Segment 8115				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.3	4.3	0.0	0%
2003	4.9	4.3	0.5	11%
2004	5.6	4.4	1.3	23%
2005	4.6	4.4	0.3	6%
2006	7.2	4.5	2.7	38%
2007	4.4	4.5	-0.1	-2%
2008	6.2	4.5	1.7	28%
2009	4.6	4.5	0.0	1%
2010	6.2	4.5	1.6	27%
2011	3.9	4.6	-0.7	-19%



Segment 8120				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	3.4	3.4	0.0	0%
2003	3.6	3.4	0.3	7%
2004	2.4	3.4	-1.0	-41%
2005	4.3	3.4	0.9	21%
2006	5.5	3.5	2.0	36%
2007	2.9	3.5	-0.7	-23%
2008	5.1	3.5	1.6	31%
2009	4.3	3.5	0.8	18%
2010	4.5	3.5	0.9	21%
2011	3.1	3.6	-0.5	-17%



Segment 8125				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	7.04	7.04	0.00	0%
2003	5.65	7.04	-1.39	-25%
2004	5.45	7.06	-1.61	-30%
2005	6.46	7.06	-0.60	-9%
2006	8.80	7.19	1.61	18%
2007	6.14	7.19	-1.05	-17%
2008	8.08	7.19	0.89	11%
2009	6.77	7.22	-0.45	-7%
2010	6.14	7.24	-1.10	-18%
2011	6.34	7.27	-0.92	-15%



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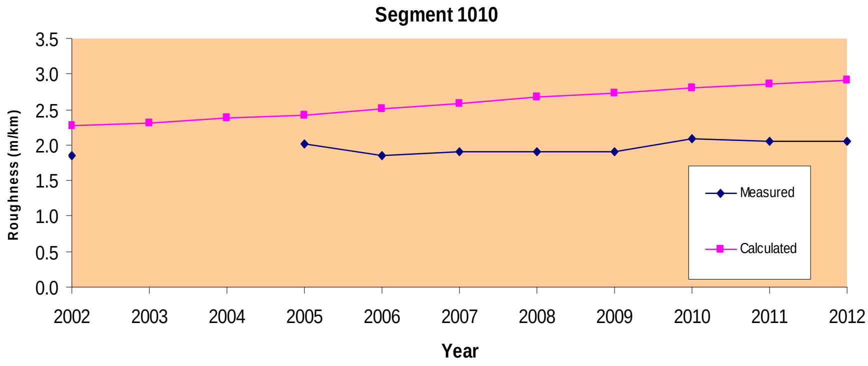
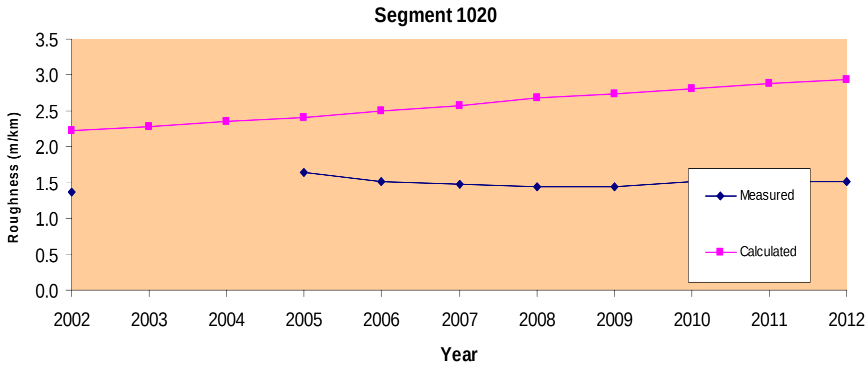
Appendix J Results for Interim Network Level Functional Road Deterioration Models – Waterview and Dandhara sites

Roughness for Waterview Site

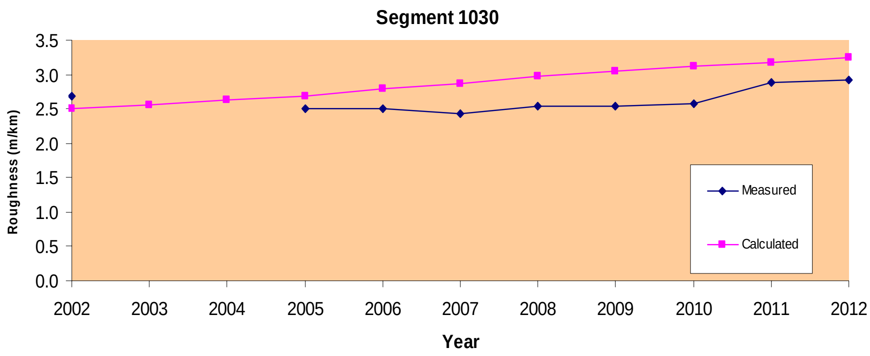
Segment 1010				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.9	2.3	-0.4	-22%
2003		2.3		
2004		2.4		
2005	2.0	2.4	-0.4	-21%
2006	1.9	2.5	-0.7	-35%
2007	1.9	2.6	-0.7	-36%
2008	1.9	2.7	-0.8	-41%
2009	1.9	2.7	-0.8	-44%
2010	2.1	2.8	-0.7	-34%
2011	2.0	2.9	-0.8	-40%
2012	2.0	2.9	-0.9	-42%



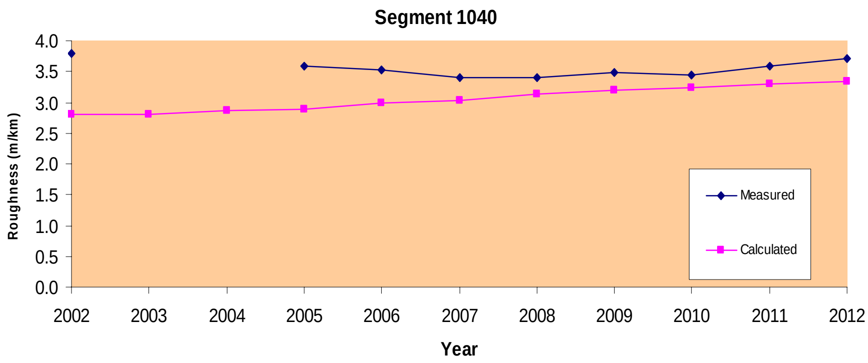
Segment 1020				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.4	2.2	-0.8	-62%
2003		2.3		
2004		2.3		
2005	1.6	2.4	-0.8	-47%
2006	1.5	2.5	-1.0	-64%
2007	1.5	2.6	-1.1	-74%
2008	1.4	2.7	-1.2	-85%
2009	1.4	2.7	-1.3	-90%
2010	1.5	2.8	-1.3	-85%
2011	1.5	2.9	-1.4	-89%
2012	1.5	2.9	-1.4	-93%



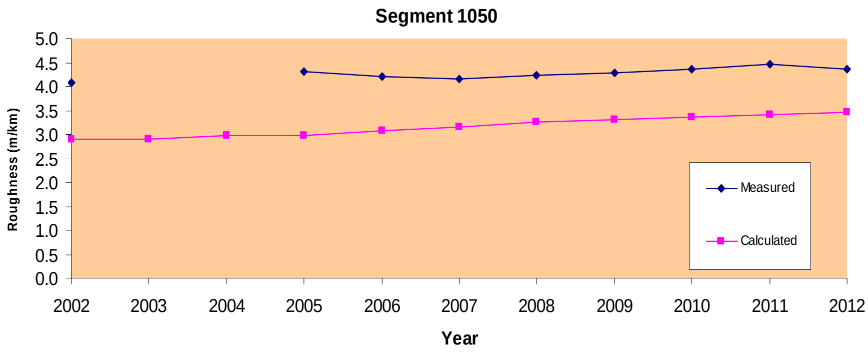
Segment 1030				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.7	2.5	0.2	7%
2003		2.6		
2004		2.6		
2005	2.5	2.7	-0.2	-7%
2006	2.5	2.8	-0.3	-11%
2007	2.4	2.9	-0.4	-18%
2008	2.5	3.0	-0.4	-17%
2009	2.5	3.0	-0.5	-20%
2010	2.6	3.1	-0.5	-21%
2011	2.9	3.2	-0.3	-11%
2012	2.9	3.3	-0.3	-11%



Segment 1040				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	3.8	2.8	1.0	26%
2003		2.8		
2004		2.9		
2005	3.6	2.9	0.7	20%
2006	3.5	3.0	0.5	15%
2007	3.4	3.0	0.4	11%
2008	3.4	3.1	0.3	8%
2009	3.5	3.2	0.3	8%
2010	3.4	3.2	0.2	6%
2011	3.6	3.3	0.3	9%
2012	3.7	3.3	0.4	10%

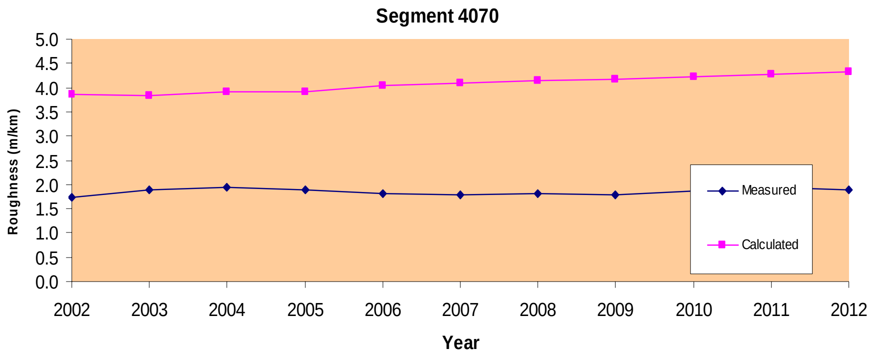


Segment 1050				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	4.1	2.9	1.2	29%
2003		2.9		
2004		3.0		
2005	4.3	3.0	1.3	31%
2006	4.2	3.1	1.1	27%
2007	4.2	3.1	1.0	24%
2008	4.2	3.2	1.0	23%
2009	4.3	3.3	1.0	23%
2010	4.4	3.4	1.0	23%
2011	4.5	3.4	1.1	24%
2012	4.4	3.5	0.9	21%

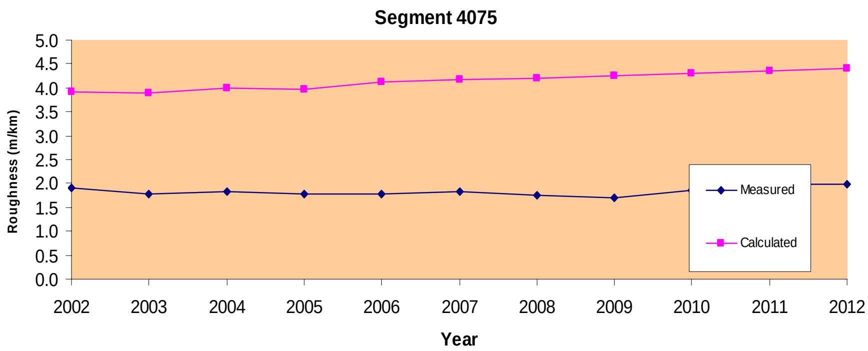


Roughness for Dandhara Site

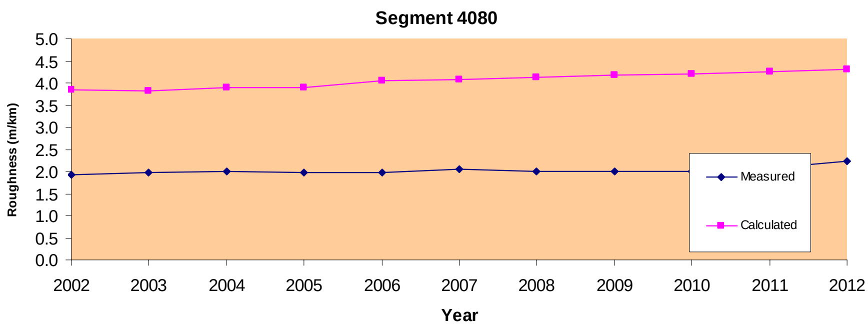
Segment 4070				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.7	3.9	-2.1	-121%
2003	1.9	3.8	-1.9	-101%
2004	1.9	3.9	-2.0	-102%
2005	1.9	3.9	-2.0	-106%
2006	1.8	4.0	-2.2	-122%
2007	1.8	4.1	-2.3	-130%
2008	1.8	4.1	-2.3	-127%
2009	1.8	4.2	-2.4	-134%
2010	1.9	4.2	-2.4	-127%
2011	1.9	4.3	-2.3	-121%
2012	1.9	4.3	-2.4	-127%



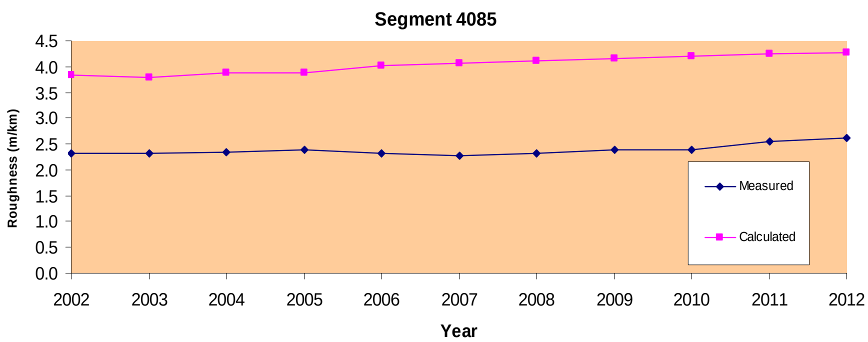
Segment 4075				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.9	3.9	-2.0	-107%
2003	1.8	3.9	-2.1	-118%
2004	1.8	4.0	-2.2	-119%
2005	1.8	4.0	-2.2	-123%
2006	1.8	4.1	-2.3	-131%
2007	1.8	4.2	-2.3	-129%
2008	1.7	4.2	-2.5	-141%
2009	1.7	4.3	-2.6	-149%
2010	1.9	4.3	-2.4	-131%
2011	2.0	4.4	-2.4	-120%
2012	2.0	4.4	-2.4	-123%



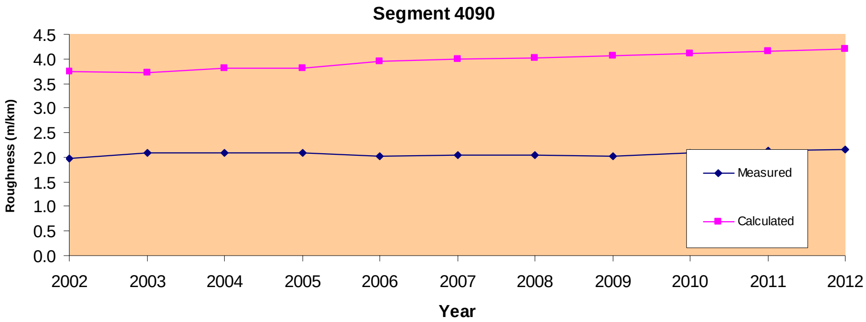
Segment 4080				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.9	3.8	-1.9	-99%
2003	2.0	3.8	-1.8	-93%
2004	2.0	3.9	-1.9	-94%
2005	2.0	3.9	-1.9	-98%
2006	2.0	4.0	-2.1	-105%
2007	2.0	4.1	-2.0	-99%
2008	2.0	4.1	-2.1	-105%
2009	2.0	4.2	-2.2	-107%
2010	2.0	4.2	-2.2	-110%
2011	2.1	4.3	-2.2	-104%
2012	2.2	4.3	-2.1	-92%



Segment 4085				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.3	3.8	-1.5	-65%
2003	2.3	3.8	-1.5	-64%
2004	2.4	3.9	-1.5	-65%
2005	2.4	3.9	-1.5	-62%
2006	2.3	4.0	-1.7	-74%
2007	2.3	4.1	-1.8	-79%
2008	2.3	4.1	-1.8	-77%
2009	2.4	4.1	-1.8	-74%
2010	2.4	4.2	-1.8	-75%
2011	2.5	4.2	-1.7	-67%
2012	2.6	4.3	-1.7	-64%

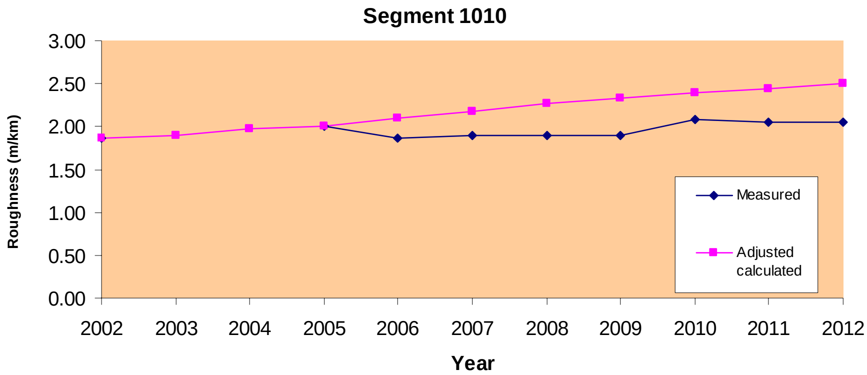


Segment 4090				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.0	3.8	-1.8	-90%
2003	2.1	3.7	-1.6	-79%
2004	2.1	3.8	-1.7	-83%
2005	2.1	3.8	-1.7	-82%
2006	2.0	3.9	-1.9	-96%
2007	2.0	4.0	-1.9	-95%
2008	2.0	4.0	-2.0	-97%
2009	2.0	4.1	-2.1	-102%
2010	2.1	4.1	-2.0	-97%
2011	2.1	4.2	-2.0	-96%
2012	2.2	4.2	-2.0	-94%

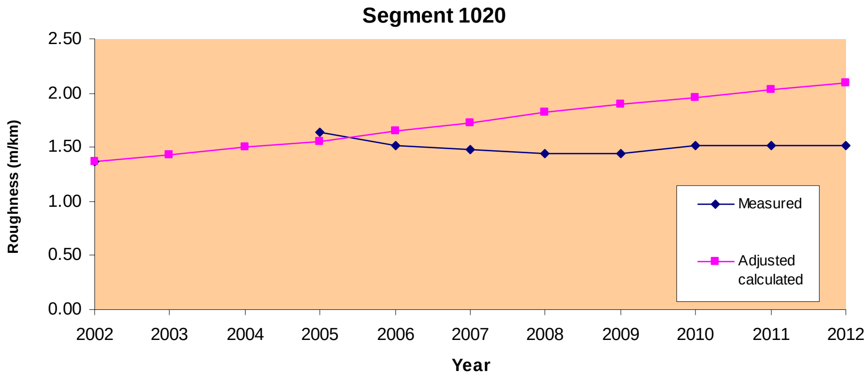


Roughness for Waterview site calculated with adjusted initial roughness

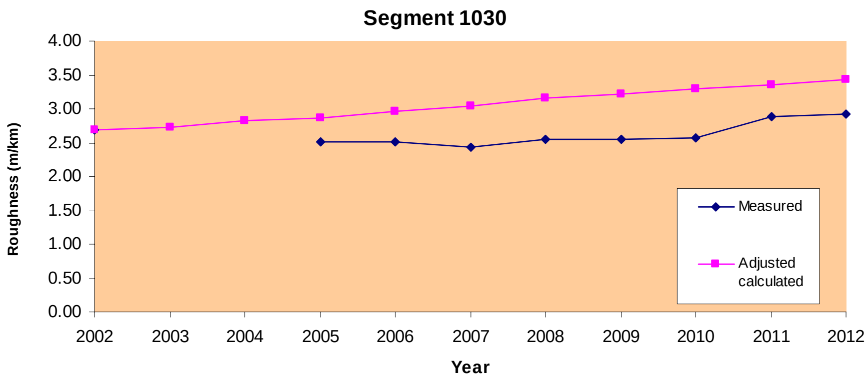
Segment 1010					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.86	2.27	1.86	0.00	0%
2003		2.32	1.90		
2004		2.39	1.97		
2005	2.01	2.43	2.01	0.00	0%
2006	1.86	2.52	2.10	-0.24	-13%
2007	1.90	2.59	2.17	-0.27	-14%
2008	1.90	2.68	2.26	-0.37	-19%
2009	1.90	2.74	2.32	-0.43	-23%
2010	2.09	2.80	2.39	-0.30	-14%
2011	2.05	2.86	2.45	-0.40	-19%
2012	2.05	2.92	2.50	-0.46	-22%



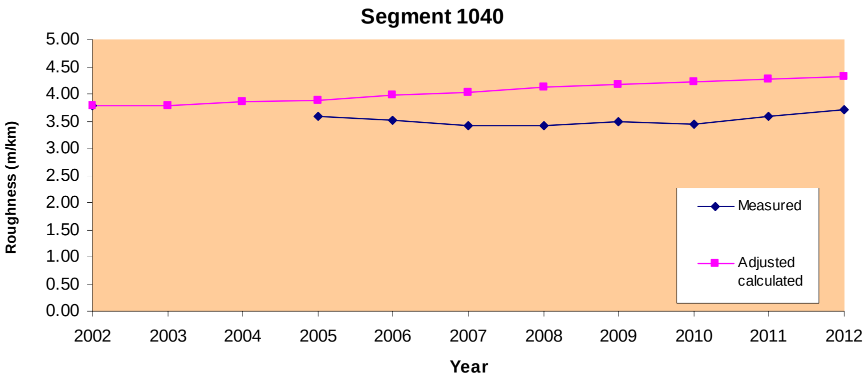
Segment 1020					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.37	2.21	1.37	0.00	0%
2003		2.27	1.42		
2004		2.35	1.50		
2005	1.63	2.40	1.55	0.08	5%
2006	1.52	2.50	1.65	-0.13	-9%
2007	1.48	2.57	1.73	-0.24	-16%
2008	1.44	2.67	1.83	-0.38	-26%
2009	1.44	2.74	1.89	-0.45	-31%
2010	1.52	2.81	1.96	-0.44	-29%
2011	1.52	2.87	2.03	-0.51	-33%
2012	1.52	2.94	2.09	-0.57	-38%



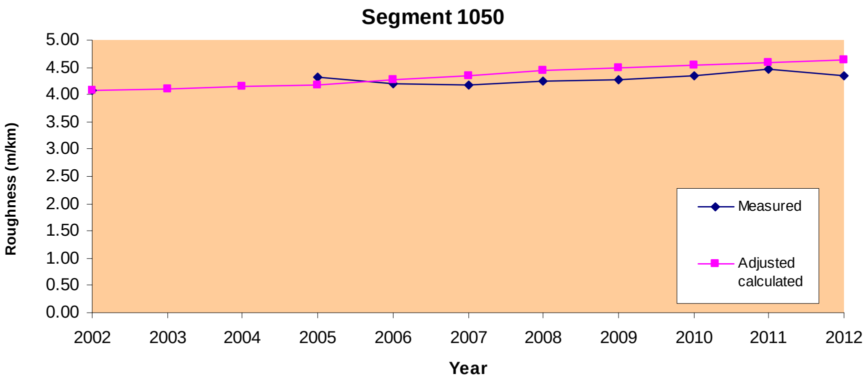
Segment 1030					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	2.69	2.51	2.69	0.00	0%
2003		2.55	2.73		
2004		2.63	2.81		
2005	2.50	2.68	2.86	-0.36	-14%
2006	2.50	2.79	2.97	-0.46	-19%
2007	2.43	2.86	3.04	-0.62	-25%
2008	2.54	2.97	3.15	-0.61	-24%
2009	2.54	3.04	3.22	-0.68	-27%
2010	2.58	3.11	3.29	-0.72	-28%
2011	2.88	3.18	3.36	-0.48	-17%
2012	2.92	3.25	3.43	-0.51	-18%



Segment 1040					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	3.79	2.80	3.79	0.00	0%
2003		2.81	3.79		
2004		2.87	3.85		
2005	3.60	2.88	3.87	-0.27	-7%
2006	3.52	2.98	3.96	-0.44	-13%
2007	3.41	3.04	4.02	-0.62	-18%
2008	3.41	3.14	4.12	-0.71	-21%
2009	3.48	3.19	4.17	-0.69	-20%
2010	3.45	3.24	4.22	-0.78	-23%
2011	3.60	3.29	4.27	-0.68	-19%
2012	3.71	3.34	4.32	-0.61	-16%

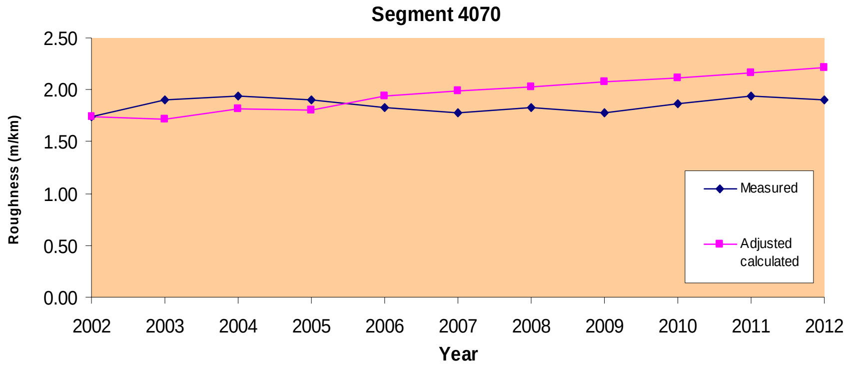


Segment 1050					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	4.09	2.90	4.09	0.00	0%
2003		2.91	4.09		
2004		2.97	4.16		
2005	4.31	2.98	4.17	0.14	3%
2006	4.20	3.08	4.27	-0.07	-2%
2007	4.16	3.15	4.33	-0.17	-4%
2008	4.24	3.25	4.43	-0.20	-5%
2009	4.28	3.30	4.49	-0.21	-5%
2010	4.35	3.35	4.54	-0.19	-4%
2011	4.46	3.41	4.59	-0.13	-3%
2012	4.35	3.46	4.65	-0.29	-7%

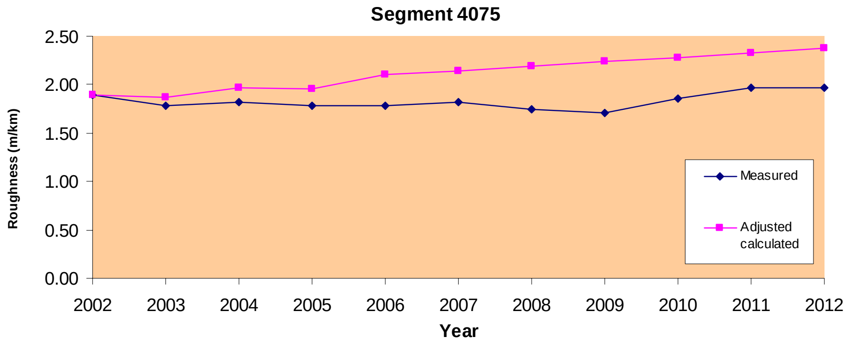


Roughness for Dandhara site calculated with adjusted initial roughness

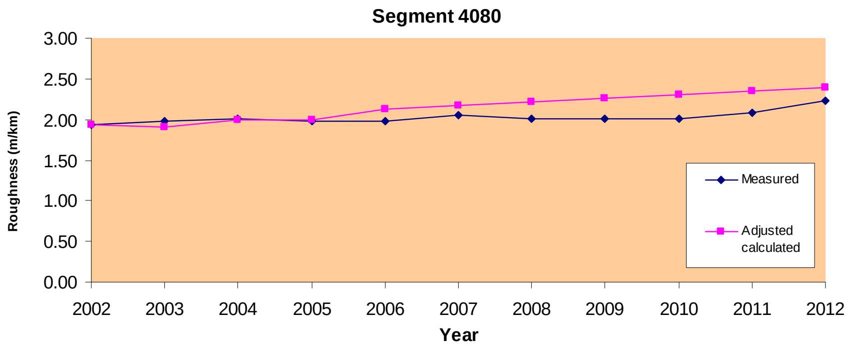
Segment 4070					
	Roughness				
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.75	3.85	1.75	0.00	0%
2003	1.90	3.82	1.72	0.18	10%
2004	1.94	3.92	1.81	0.12	6%
2005	1.90	3.91	1.80	0.10	5%
2006	1.82	4.05	1.94	-0.12	-7%
2007	1.78	4.10	1.99	-0.20	-11%
2008	1.82	4.14	2.03	-0.21	-11%
2009	1.78	4.18	2.08	-0.29	-16%
2010	1.86	4.22	2.12	-0.26	-14%
2011	1.94	4.27	2.16	-0.23	-12%
2012	1.90	4.31	2.21	-0.31	-16%



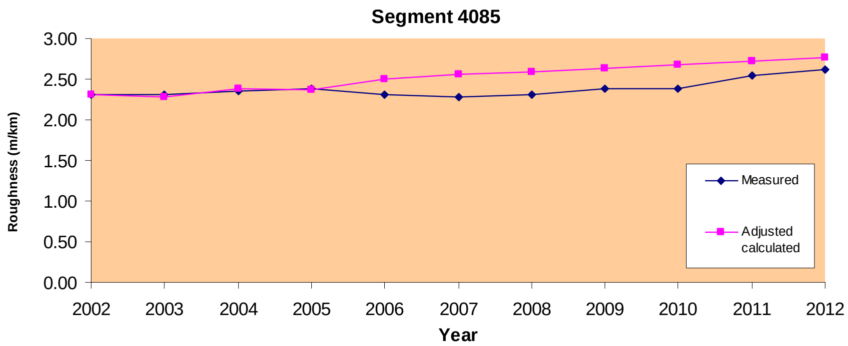
Segment 4075					
	Roughness				
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.90	3.92	1.90	0.00	0%
2003	1.78	3.89	1.87	-0.08	-5%
2004	1.82	3.99	1.96	-0.14	-8%
2005	1.78	3.98	1.95	-0.17	-10%
2006	1.78	4.12	2.10	-0.31	-18%
2007	1.82	4.17	2.15	-0.32	-18%
2008	1.75	4.21	2.19	-0.44	-25%
2009	1.71	4.26	2.24	-0.53	-31%
2010	1.86	4.30	2.28	-0.42	-23%
2011	1.97	4.35	2.33	-0.35	-18%
2012	1.97	4.40	2.37	-0.40	-20%



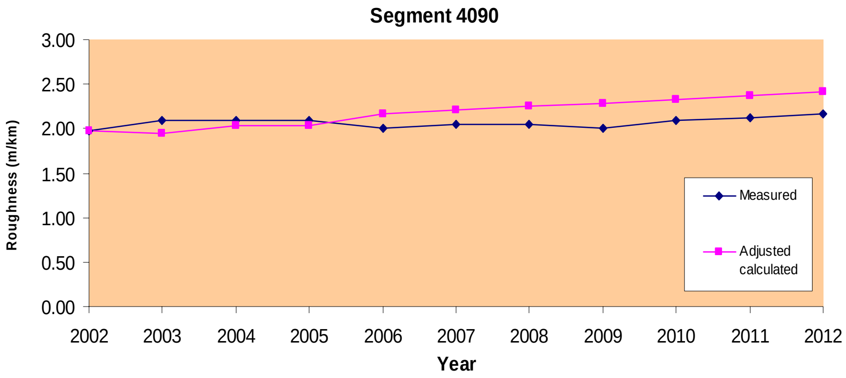
Segment 4080					
	Roughness				
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.94	3.84	1.94	0.00	0%
2003	1.97	3.81	1.90	0.07	3%
2004	2.01	3.91	2.00	0.01	1%
2005	1.97	3.90	1.99	-0.02	-1%
2006	1.97	4.04	2.13	-0.16	-8%
2007	2.05	4.08	2.18	-0.13	-6%
2008	2.01	4.13	2.22	-0.21	-10%
2009	2.01	4.17	2.26	-0.25	-13%
2010	2.01	4.21	2.31	-0.29	-15%
2011	2.09	4.26	2.35	-0.26	-13%
2012	2.24	4.30	2.39	-0.16	-7%



Segment 4085					
	Roughness				
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	2.31	3.82	2.31	0.00	0%
2003	2.31	3.79	2.28	0.03	1%
2004	2.35	3.89	2.38	-0.03	-1%
2005	2.39	3.88	2.37	0.02	1%
2006	2.31	4.02	2.51	-0.19	-8%
2007	2.28	4.06	2.55	-0.28	-12%
2008	2.31	4.10	2.59	-0.28	-12%
2009	2.39	4.15	2.64	-0.25	-10%
2010	2.39	4.19	2.68	-0.29	-12%
2011	2.54	4.24	2.73	-0.19	-7%
2012	2.61	4.28	2.77	-0.15	-6%



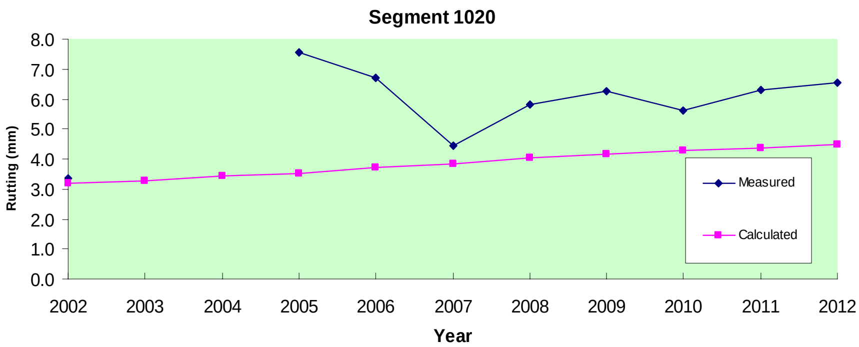
Segment 4090					
Roughness					
Year	Measured (m/km)	Calculated (m/km)	Adjusted calculated (m/km)	Difference (m/km)	Difference %
2002	1.97	3.75	1.97	0.00	0%
2003	2.09	3.72	1.94	0.14	7%
2004	2.09	3.82	2.04	0.05	2%
2005	2.09	3.81	2.03	0.06	3%
2006	2.01	3.94	2.16	-0.15	-8%
2007	2.05	3.99	2.21	-0.16	-8%
2008	2.05	4.03	2.25	-0.20	-10%
2009	2.01	4.07	2.29	-0.28	-14%
2010	2.09	4.11	2.33	-0.24	-12%
2011	2.12	4.16	2.38	-0.25	-12%
2012	2.16	4.20	2.42	-0.26	-12%



Rut depth comparison for Waterview site

Segment 1010				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.8	3.3	1.5	32%
2003		3.3		
2004		3.4		
2005	4.4	3.5	0.9	21%
2006	4.3	3.7	0.7	16%
2007	4.6	3.8	0.8	17%
2008	5.0	3.9	1.1	21%
2009	5.5	4.0	1.5	27%
2010	4.9	4.1	0.7	15%
2011	5.4	4.2	1.2	22%
2012	4.4	4.3	0.1	3%

Segment 1020				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	3.4	3.2	0.2	5%
2003		3.3		
2004		3.4		
2005	7.6	3.5	4.0	53%
2006	6.7	3.7	3.0	44%
2007	4.5	3.9	0.6	14%
2008	5.8	4.0	1.8	31%
2009	6.3	4.2	2.1	34%
2010	5.6	4.3	1.4	24%
2011	6.3	4.4	1.9	30%
2012	6.5	4.5	2.1	31%



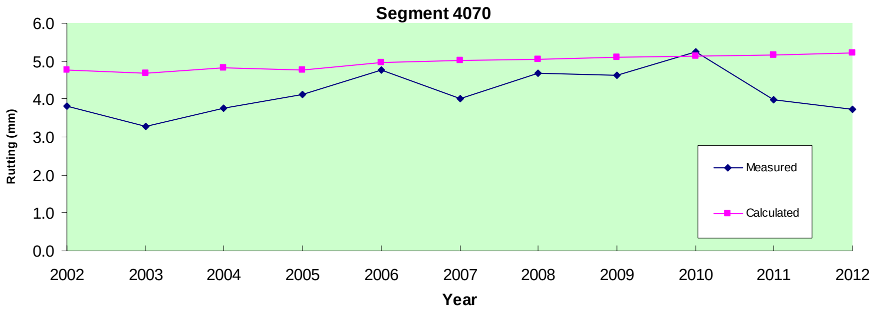
Segment 1030				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	5.1	4.5	0.6	12%
2003		4.6		
2004		4.7		
2005	5.9	4.8	1.2	20%
2006	5.3	5.0	0.3	6%
2007	5.5	5.1	0.3	6%
2008	6.1	5.3	0.7	12%
2009	6.6	5.4	1.2	18%
2010	5.1	5.6	-0.4	-8%
2011	5.2	5.7	-0.4	-9%
2012	5.5	5.8	-0.2	-4%

Segment 1040				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	6.5	5.1	1.3	21%
2003		5.0		
2004		5.1		
2005	6.2	5.1	1.2	19%
2006	7.8	5.2	2.6	33%
2007	6.0	5.3	0.7	12%
2008	6.8	5.5	1.3	19%
2009	5.9	5.5	0.4	6%
2010	5.8	5.6	0.2	4%
2011	6.5	5.6	0.9	14%
2012	7.0	5.7	1.4	20%

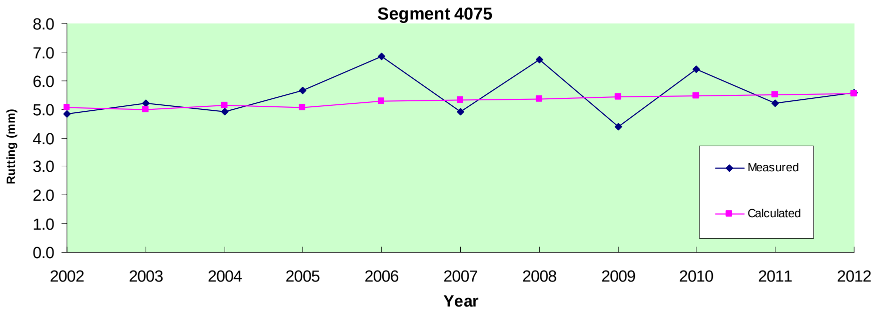
Segment 1050				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.1	5.5	-1.4	-34%
2003		5.4		
2004		5.5		
2005	3.9	5.5	-1.5	-40%
2006	4.2	5.7	-1.5	-35%
2007	4.0	5.7	-1.8	-45%
2008	4.2	5.9	-1.7	-41%
2009	3.7	6.0	-2.2	-60%
2010	3.9	6.0	-2.1	-54%
2011	3.8	6.1	-2.2	-58%
2012	4.8	6.1	-1.3	-26%

Rut depth comparison for Dandhara site

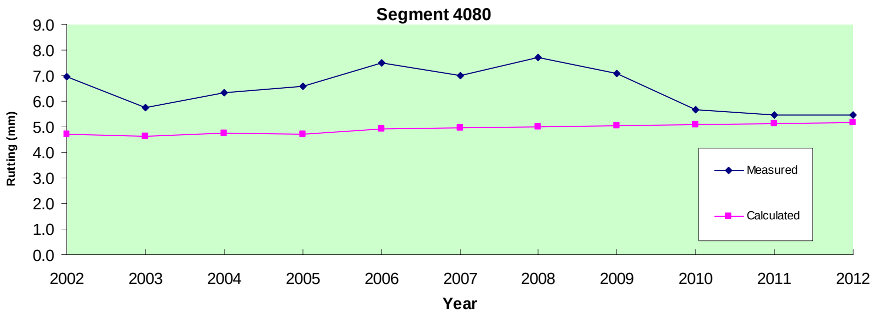
Segment 4070				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	3.8	4.8	-1.0	-25%
2003	3.3	4.7	-1.4	-42%
2004	3.8	4.8	-1.0	-28%
2005	4.1	4.8	-0.6	-16%
2006	4.8	5.0	-0.2	-5%
2007	4.0	5.0	-1.0	-25%
2008	4.7	5.1	-0.4	-8%
2009	4.6	5.1	-0.5	-10%
2010	5.3	5.1	0.1	2%
2011	4.0	5.2	-1.2	-30%
2012	3.7	5.2	-1.5	-40%



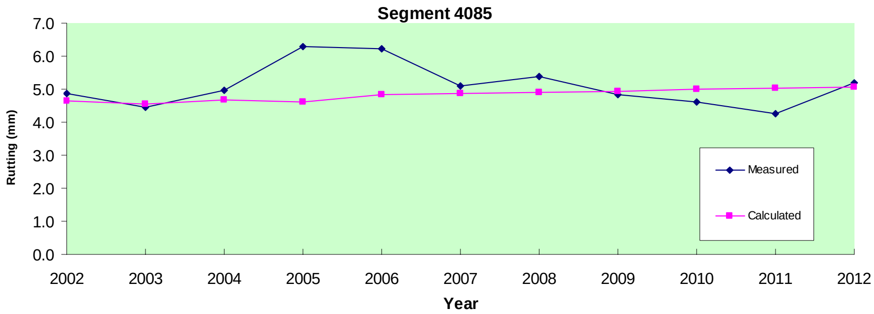
Segment 4075				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.9	5.1	-0.2	-5%
2003	5.2	5.0	0.2	5%
2004	4.9	5.1	-0.2	-5%
2005	5.7	5.1	0.6	10%
2006	6.8	5.3	1.5	23%
2007	4.9	5.3	-0.4	-8%
2008	6.7	5.4	1.4	20%
2009	4.4	5.4	-1.0	-24%
2010	6.4	5.5	0.9	15%
2011	5.2	5.5	-0.3	-6%
2012	5.6	5.5	0.0	0%



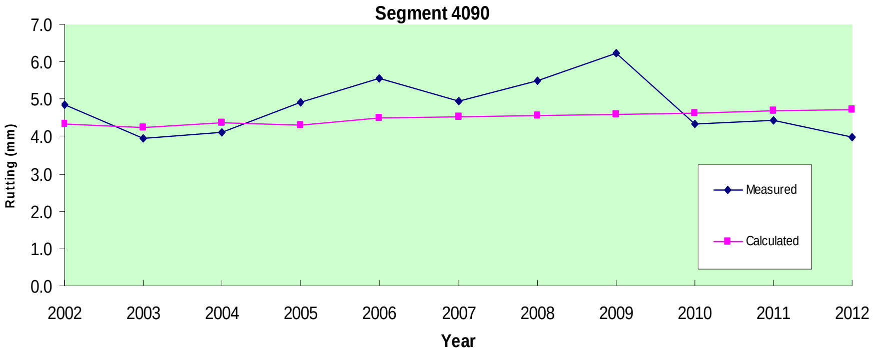
Segment 4080				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	7.0	4.7	2.2	32%
2003	5.8	4.6	1.1	19%
2004	6.3	4.8	1.6	25%
2005	6.6	4.7	1.9	29%
2006	7.5	4.9	2.6	34%
2007	7.0	5.0	2.0	29%
2008	7.7	5.0	2.7	35%
2009	7.1	5.0	2.0	29%
2010	5.7	5.1	0.6	10%
2011	5.5	5.1	0.3	6%
2012	5.5	5.2	0.3	5%



Segment 4085				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.9	4.6	0.2	5%
2003	4.4	4.5	-0.1	-2%
2004	5.0	4.7	0.3	6%
2005	6.3	4.6	1.7	26%
2006	6.2	4.8	1.4	22%
2007	5.1	4.9	0.2	4%
2008	5.4	4.9	0.5	9%
2009	4.8	4.9	-0.1	-2%
2010	4.6	5.0	-0.4	-8%
2011	4.3	5.0	-0.8	-18%
2012	5.2	5.1	0.1	3%



Segment 4090				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.8	4.3	0.5	11%
2003	4.0	4.2	-0.3	-7%
2004	4.1	4.4	-0.2	-6%
2005	4.9	4.3	0.6	12%
2006	5.6	4.5	1.1	19%
2007	5.0	4.5	0.4	8%
2008	5.5	4.6	0.9	17%
2009	6.2	4.6	1.6	26%
2010	4.3	4.6	-0.3	-7%
2011	4.4	4.7	-0.2	-5%
2012	4.0	4.7	-0.7	-19%



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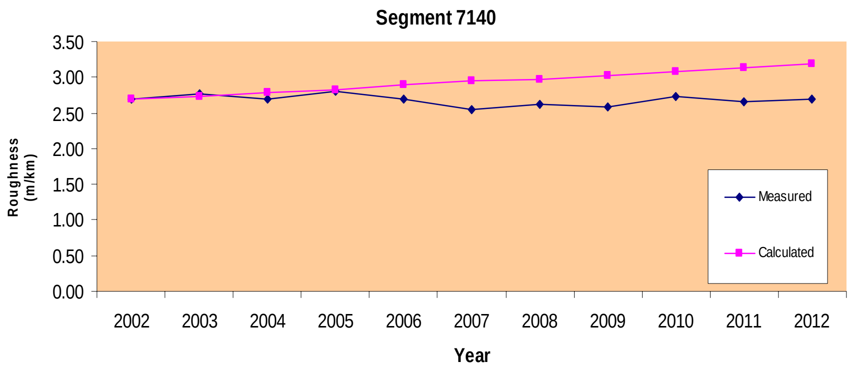
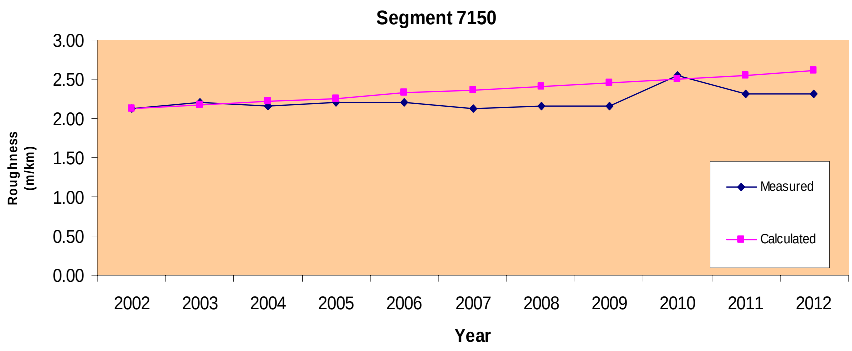
Appendix K Results for Interim Network Level Functional Road Deterioration Models – Elsmore and Warialda Creek sites

Roughness comparison for Elsmore site

Segment 7140				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.69	2.69	0.00	0%
2003	2.77	2.73	0.03	1%
2004	2.69	2.79	-0.10	-4%
2005	2.80	2.82	-0.01	0%
2006	2.69	2.90	-0.21	-8%
2007	2.54	2.94	-0.40	-16%
2008	2.61	2.98	-0.36	-14%
2009	2.58	3.03	-0.45	-18%
2010	2.73	3.08	-0.36	-13%
2011	2.65	3.14	-0.48	-18%
2012	2.69	3.19	-0.50	-19%

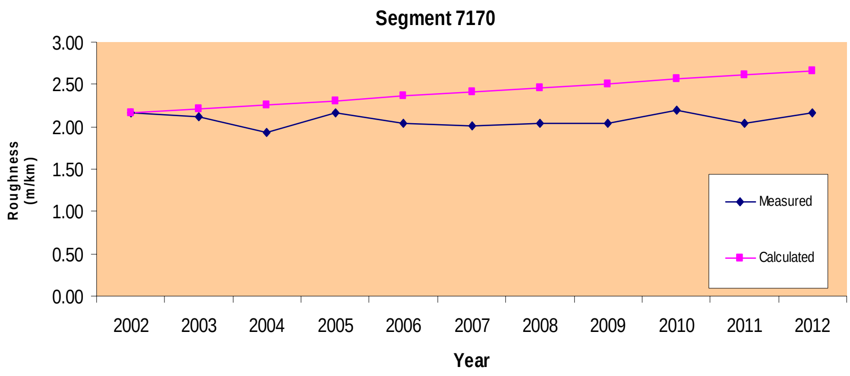


Segment 7150				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.12	2.12	0.00	0%
2003	2.20	2.17	0.03	1%
2004	2.16	2.22	-0.06	-3%
2005	2.20	2.25	-0.05	-2%
2006	2.20	2.32	-0.12	-6%
2007	2.12	2.37	-0.24	-11%
2008	2.16	2.40	-0.24	-11%
2009	2.16	2.45	-0.29	-13%
2010	2.54	2.50	0.04	1%
2011	2.31	2.55	-0.24	-10%
2012	2.31	2.61	-0.29	-13%



Segment 7160				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.01	2.01	0.00	0%
2003	2.01	2.06	-0.05	-2%
2004	1.97	2.11	-0.14	-7%
2005	2.09	2.15	-0.06	-3%
2006	1.94	2.22	-0.28	-15%
2007	1.94	2.26	-0.33	-17%
2008	1.97	2.30	-0.33	-17%
2009	1.78	2.35	-0.57	-32%
2010	2.16	2.40	-0.24	-11%
2011	2.09	2.46	-0.37	-18%
2012	2.16	2.51	-0.34	-16%

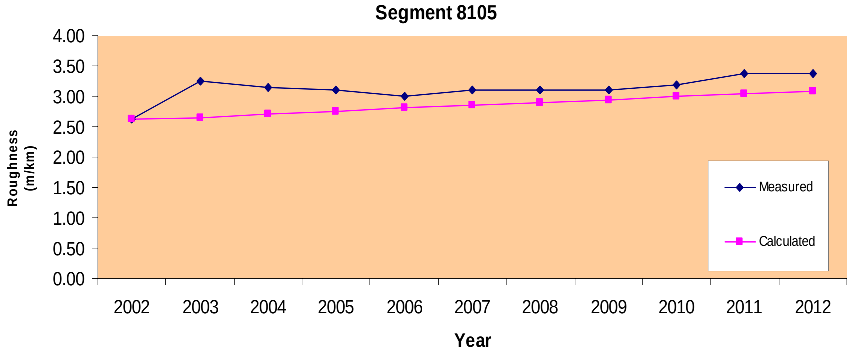
Segment 7170				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.16	2.16	0.00	0%
2003	2.12	2.21	-0.08	-4%
2004	1.94	2.26	-0.33	-17%
2005	2.16	2.30	-0.14	-6%
2006	2.05	2.37	-0.32	-16%
2007	2.01	2.42	-0.41	-20%
2008	2.05	2.45	-0.41	-20%
2009	2.05	2.51	-0.46	-22%
2010	2.20	2.56	-0.36	-16%
2011	2.05	2.61	-0.56	-28%
2012	2.16	2.67	-0.50	-23%



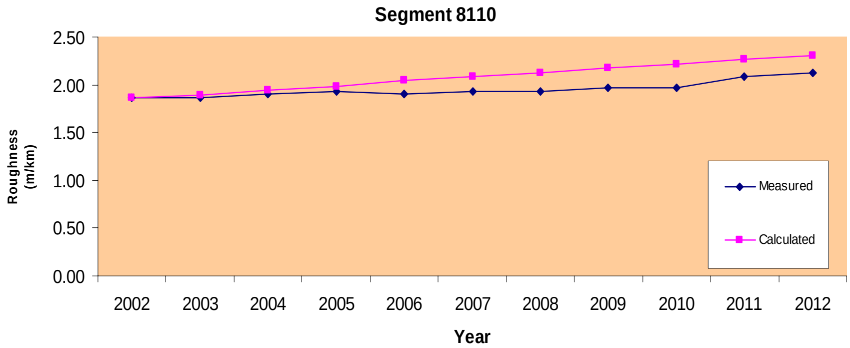
Segment 7180				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.97	1.97	0.00	0%
2003	2.09	2.02	0.06	3%
2004	2.05	2.08	-0.03	-2%
2005	2.28	2.12	0.16	7%
2006	2.16	2.20	-0.04	-2%
2007	2.12	2.25	-0.12	-6%
2008	2.09	2.28	-0.20	-9%
2009	2.01	2.34	-0.33	-16%
2010	2.16	2.40	-0.24	-11%
2011	2.12	2.45	-0.33	-16%
2012	2.01	2.51	-0.50	-25%

Roughness comparison for Warialda Creek site

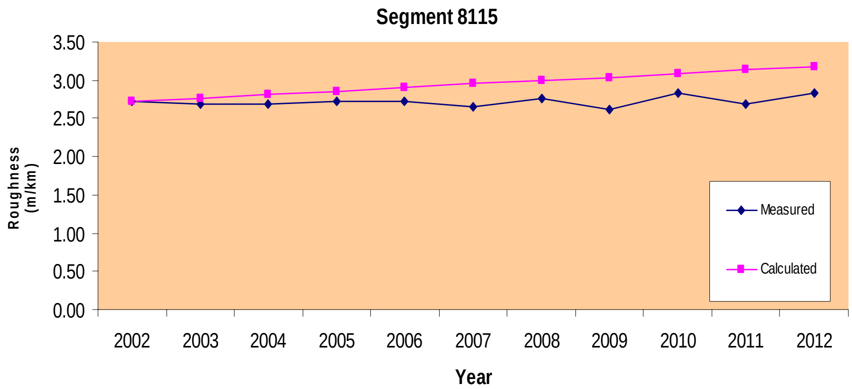
Segment 8105				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.61	2.61	0.00	0%
2003	3.26	2.65	0.60	19%
2004	3.14	2.70	0.44	14%
2005	3.11	2.74	0.36	12%
2006	2.99	2.81	0.18	6%
2007	3.11	2.86	0.25	8%
2008	3.11	2.89	0.21	7%
2009	3.11	2.94	0.16	5%
2010	3.18	2.99	0.19	6%
2011	3.37	3.04	0.33	10%
2012	3.37	3.09	0.28	8%



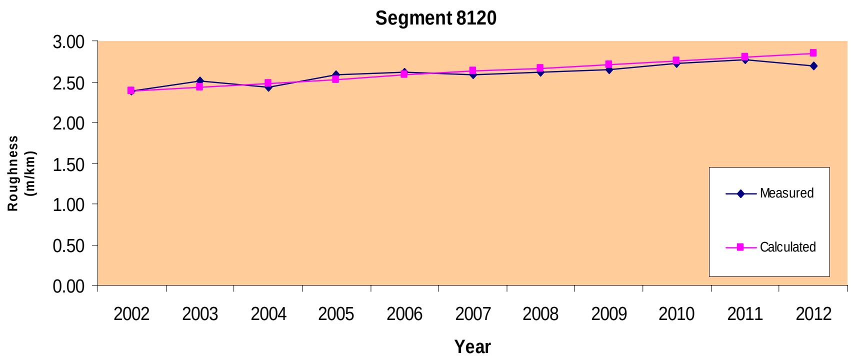
Segment 8110				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	1.86	1.86	0.00	0%
2003	1.86	1.90	-0.04	-2%
2004	1.90	1.95	-0.05	-3%
2005	1.94	1.98	-0.05	-3%
2006	1.90	2.04	-0.15	-8%
2007	1.94	2.09	-0.15	-8%
2008	1.94	2.12	-0.19	-10%
2009	1.97	2.17	-0.20	-10%
2010	1.97	2.22	-0.24	-12%
2011	2.09	2.26	-0.18	-8%
2012	2.12	2.31	-0.18	-9%



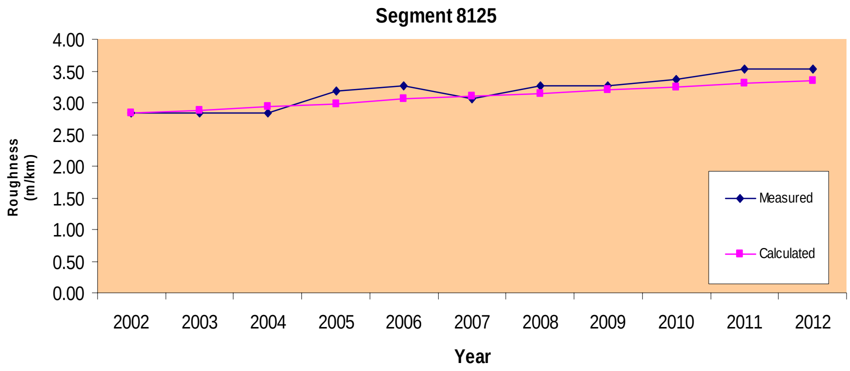
Segment 8115				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.73	2.73	0.00	0%
2003	2.69	2.77	-0.07	-3%
2004	2.69	2.81	-0.12	-5%
2005	2.73	2.85	-0.13	-5%
2006	2.73	2.91	-0.18	-7%
2007	2.65	2.96	-0.30	-11%
2008	2.77	2.99	-0.23	-8%
2009	2.61	3.04	-0.42	-16%
2010	2.84	3.09	-0.24	-9%
2011	2.69	3.13	-0.44	-16%
2012	2.84	3.18	-0.34	-12%



Segment 8120				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.39	2.39	0.00	0%
2003	2.50	2.43	0.07	3%
2004	2.43	2.48	-0.05	-2%
2005	2.58	2.52	0.06	2%
2006	2.61	2.58	0.04	1%
2007	2.58	2.63	-0.05	-2%
2008	2.61	2.66	-0.05	-2%
2009	2.65	2.71	-0.06	-2%
2010	2.73	2.76	-0.03	-1%
2011	2.77	2.80	-0.04	-1%
2012	2.69	2.85	-0.16	-6%



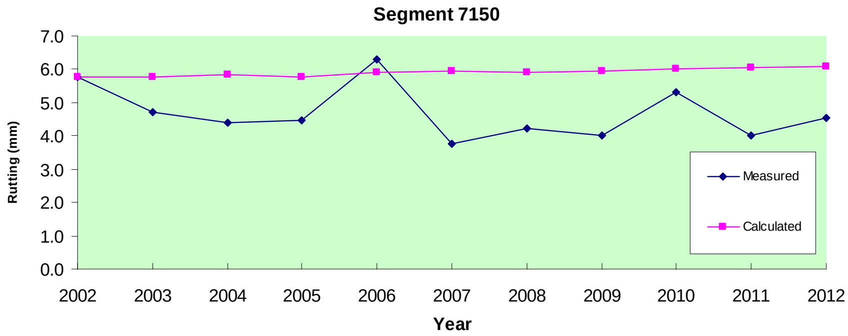
Segment 8125				
Roughness				
Year	Measured (m/km)	Calculated (m/km)	Difference (m/km)	Difference %
2002	2.84	2.84	0.00	0%
2003	2.84	2.89	-0.04	-2%
2004	2.84	2.94	-0.10	-4%
2005	3.18	2.99	0.19	6%
2006	3.26	3.05	0.20	6%
2007	3.07	3.11	-0.04	-1%
2008	3.26	3.15	0.11	3%
2009	3.26	3.20	0.06	2%
2010	3.37	3.25	0.12	4%
2011	3.52	3.30	0.22	6%
2012	3.52	3.35	0.17	5%



Rut depth comparison for Elsmore site

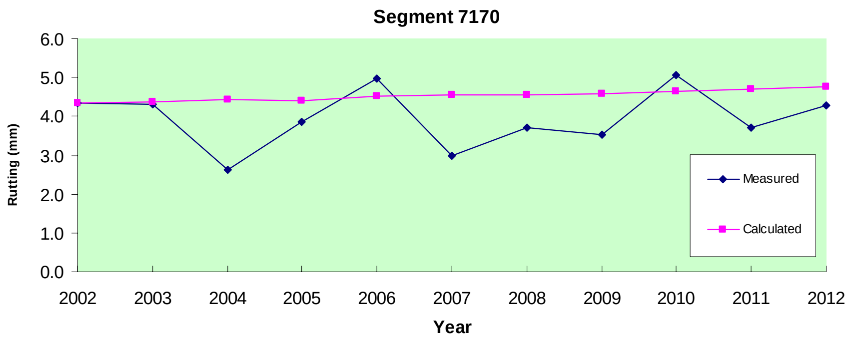
Segment 7140				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	3.4	3.4	0.0	0%
2003	4.7	3.4	1.3	27%
2004	4.0	3.4	0.6	14%
2005	3.8	3.4	0.4	11%
2006	5.0	3.6	1.4	29%
2007	2.9	3.6	-0.7	-23%
2008	3.9	3.5	0.3	8%
2009	3.8	3.6	0.2	6%
2010	5.1	3.7	1.5	29%
2011	3.8	3.7	0.0	1%
2012	4.1	3.8	0.3	8%

Segment 7150				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	5.8	5.8	0.0	0%
2003	4.7	5.8	-1.1	-23%
2004	4.4	5.8	-1.4	-33%
2005	4.5	5.8	-1.3	-30%
2006	6.3	5.9	0.4	6%
2007	3.8	5.9	-2.2	-58%
2008	4.2	5.9	-1.7	-40%
2009	4.0	6.0	-1.9	-48%
2010	5.3	6.0	-0.7	-13%
2011	4.0	6.0	-2.1	-51%
2012	4.5	6.1	-1.5	-34%



Segment 7160				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.0	4.0	0.0	0%
2003	3.9	4.0	-0.1	-2%
2004	3.5	4.0	-0.6	-16%
2005	3.7	4.0	-0.3	-9%
2006	5.6	4.1	1.4	25%
2007	3.1	4.2	-1.0	-33%
2008	4.0	4.2	-0.2	-4%
2009	4.1	4.2	-0.1	-2%
2010	4.4	4.3	0.1	2%
2011	4.1	4.3	-0.2	-4%
2012	4.2	4.4	-0.1	-3%

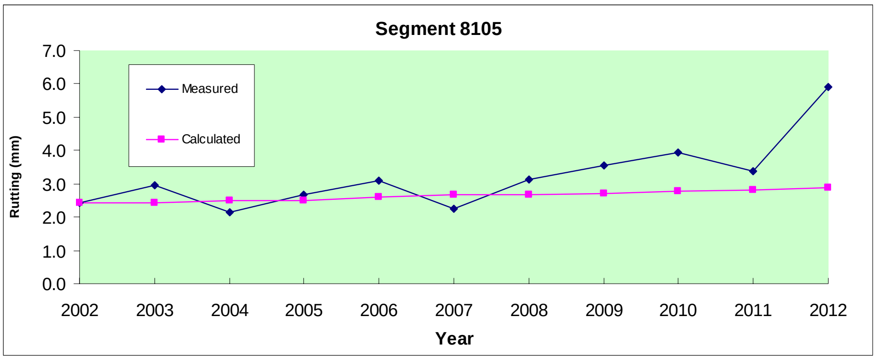
Segment 7170				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.3	4.3	0.0	0%
2003	4.3	4.4	0.0	-1%
2004	2.6	4.4	-1.8	-69%
2005	3.9	4.4	-0.5	-14%
2006	5.0	4.5	0.5	9%
2007	3.0	4.6	-1.6	-52%
2008	3.7	4.5	-0.8	-22%
2009	3.5	4.6	-1.1	-30%
2010	5.1	4.7	0.4	8%
2011	3.7	4.7	-1.0	-27%
2012	4.3	4.8	-0.5	-11%



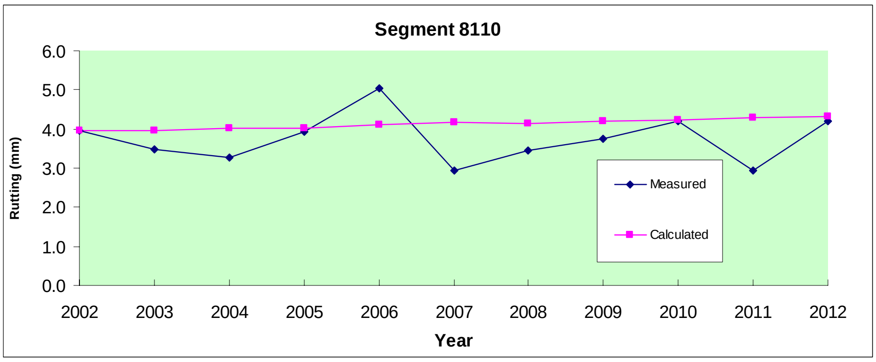
Segment 7180				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	5.6	5.6	0.0	0%
2003	5.7	5.6	0.1	2%
2004	5.2	5.7	-0.5	-9%
2005	5.9	5.7	0.2	3%
2006	6.3	5.8	0.5	8%
2007	6.0	5.9	0.1	2%
2008	6.8	5.8	0.9	14%
2009	6.8	5.9	0.9	13%
2010	6.2	6.0	0.2	3%
2011	6.4	6.1	0.4	6%
2012	7.0	6.1	0.9	12%

Rut depth comparison for Warialda Creek site

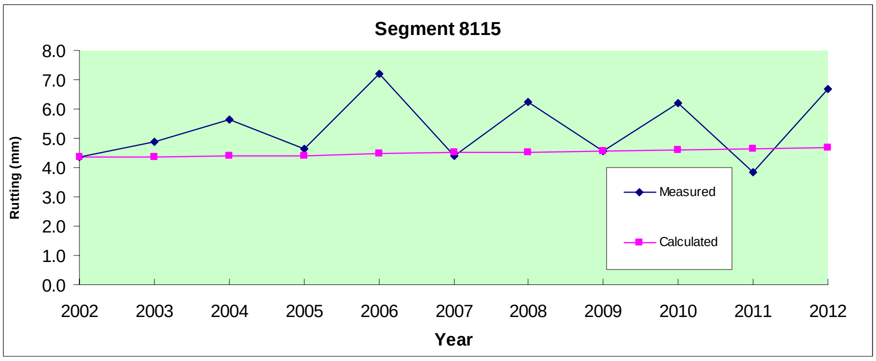
Segment 8105				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	2.4	2.4	0.0	0%
2003	3.0	2.4	0.5	18%
2004	2.2	2.5	-0.3	-15%
2005	2.7	2.5	0.2	6%
2006	3.1	2.6	0.5	15%
2007	2.3	2.7	-0.4	-18%
2008	3.1	2.7	0.5	15%
2009	3.6	2.7	0.8	24%
2010	3.9	2.8	1.2	30%
2011	3.4	2.8	0.5	16%
2012	5.9	2.9	3.0	51%



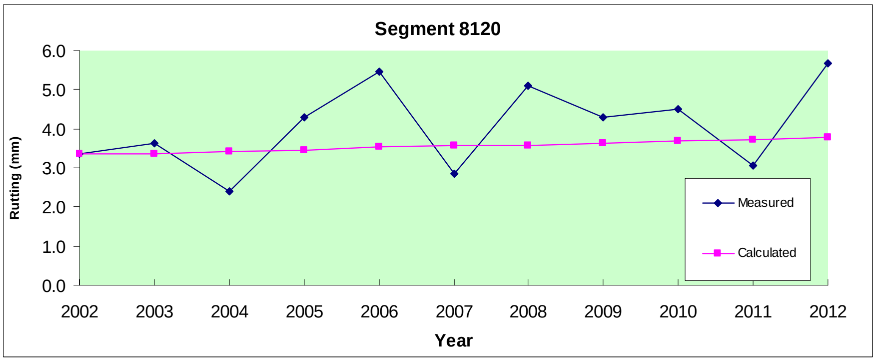
Segment 8110				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.0	4.0	0.0	0%
2003	3.5	4.0	-0.5	-14%
2004	3.3	4.0	-0.8	-23%
2005	3.9	4.0	-0.1	-3%
2006	5.1	4.1	0.9	18%
2007	3.0	4.2	-1.2	-41%
2008	3.4	4.2	-0.7	-21%
2009	3.8	4.2	-0.4	-12%
2010	4.2	4.2	0.0	-1%
2011	2.9	4.3	-1.4	-46%
2012	4.2	4.3	-0.1	-3%



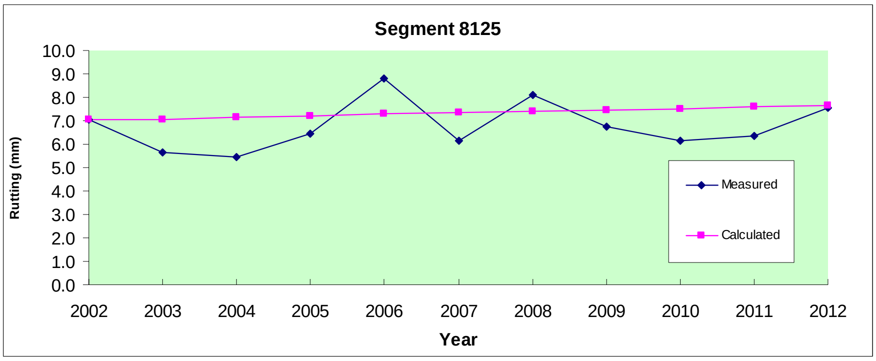
Segment 8115				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	4.3	4.3	0.0	0%
2003	4.9	4.3	0.5	11%
2004	5.6	4.4	1.2	22%
2005	4.6	4.4	0.2	5%
2006	7.2	4.5	2.7	38%
2007	4.4	4.5	-0.1	-3%
2008	6.2	4.5	1.7	27%
2009	4.6	4.6	0.0	0%
2010	6.2	4.6	1.6	25%
2011	3.9	4.7	-0.8	-21%
2012	6.7	4.7	2.0	30%



Segment 8120				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	3.4	3.4	0.0	0%
2003	3.6	3.4	0.3	7%
2004	2.4	3.4	-1.0	-43%
2005	4.3	3.4	0.8	20%
2006	5.5	3.5	1.9	35%
2007	2.9	3.6	-0.7	-26%
2008	5.1	3.6	1.5	30%
2009	4.3	3.6	0.7	16%
2010	4.5	3.7	0.8	18%
2011	3.1	3.7	-0.7	-22%
2012	5.7	3.8	1.9	33%



Segment 8125				
Rutting				
Year	Measured (mm)	Calculated (mm)	Difference (mm)	Difference %
2002	7.0	7.0	0.00	0%
2003	5.7	7.1	-1.42	-25%
2004	5.5	7.1	-1.70	-31%
2005	6.5	7.2	-0.73	-11%
2006	8.8	7.3	1.49	17%
2007	6.1	7.4	-1.23	-20%
2008	8.1	7.4	0.70	9%
2009	6.8	7.4	-0.68	-10%
2010	6.1	7.5	-1.37	-22%
2011	6.3	7.6	-1.23	-19%
2012	7.5	7.6	-0.11	-1%



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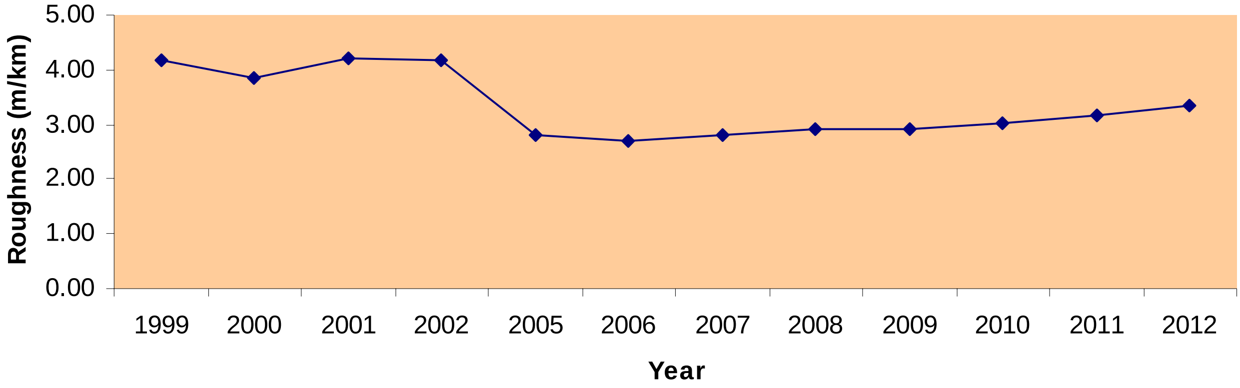
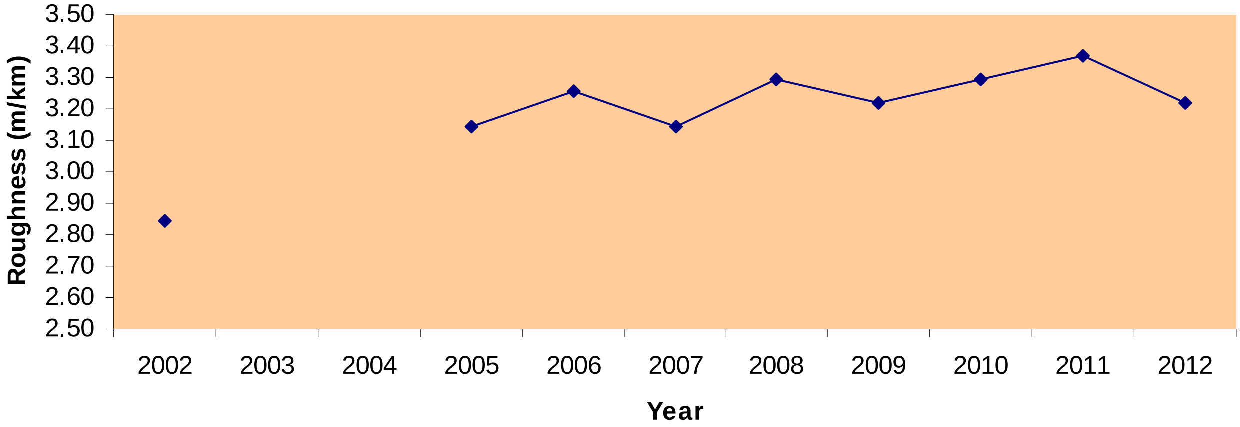
Appendix L Time series plot of roughness progression used for determining the point of rapid deterioration

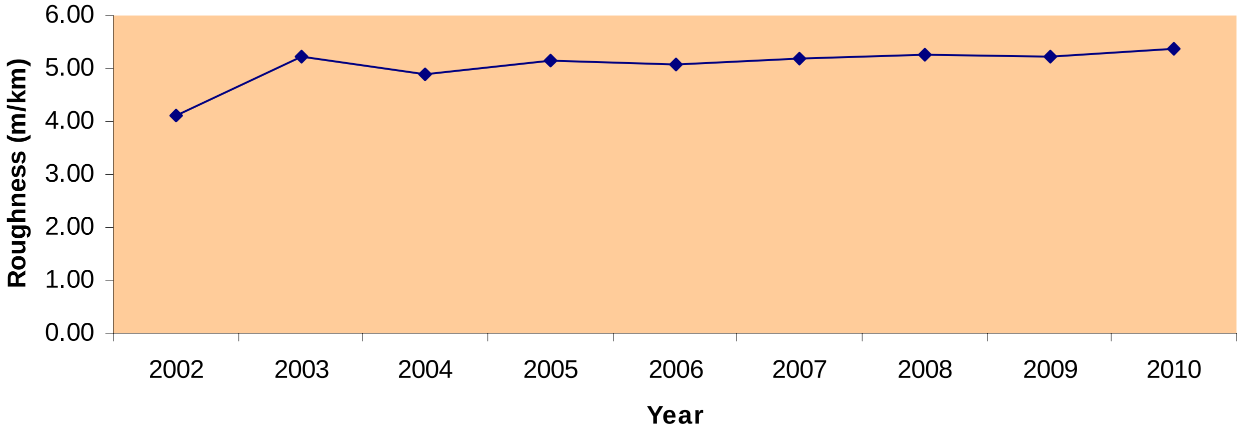
Segment 1170

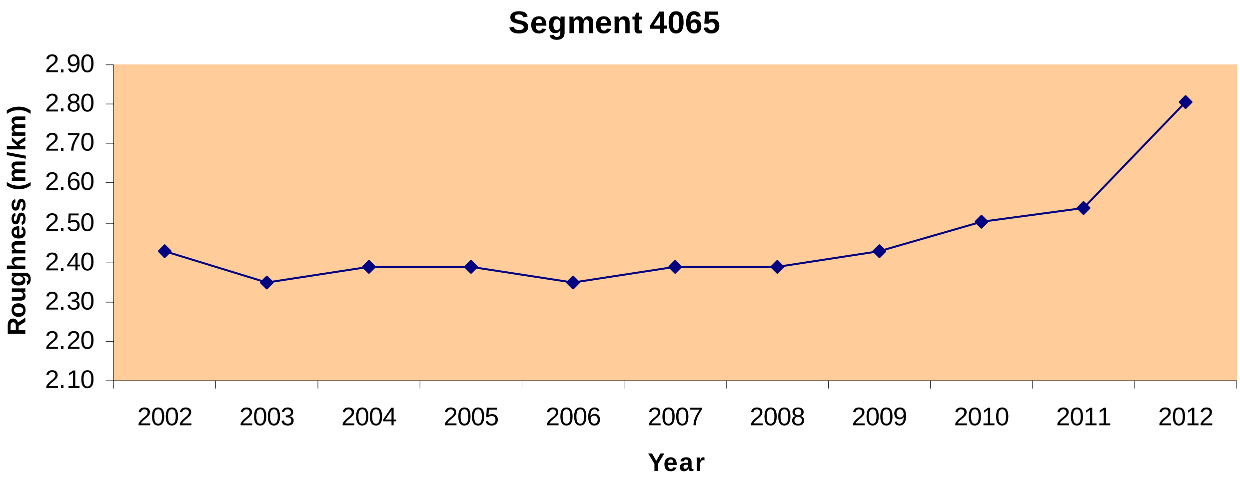


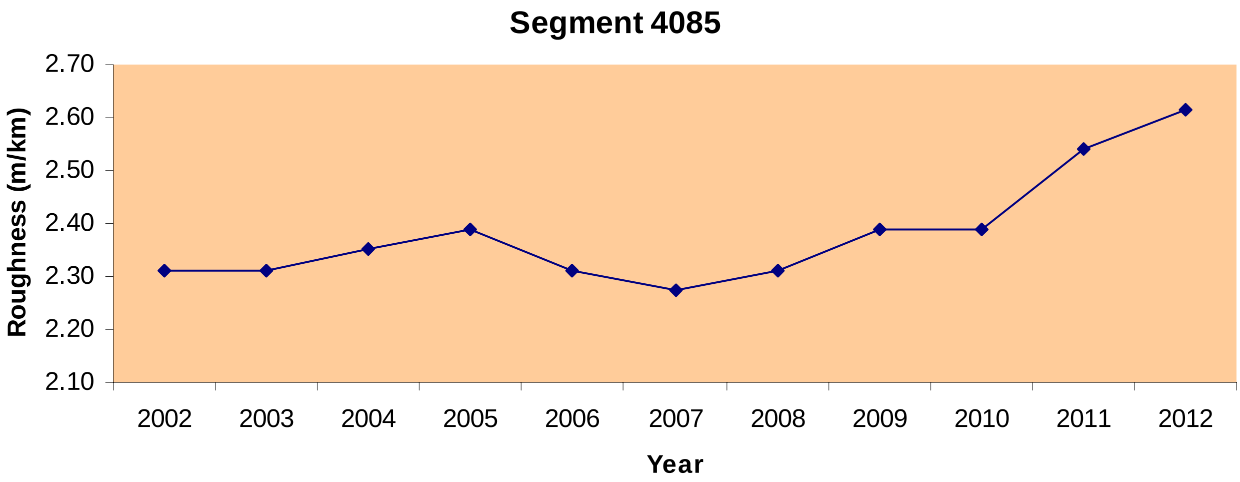
Segment 1280

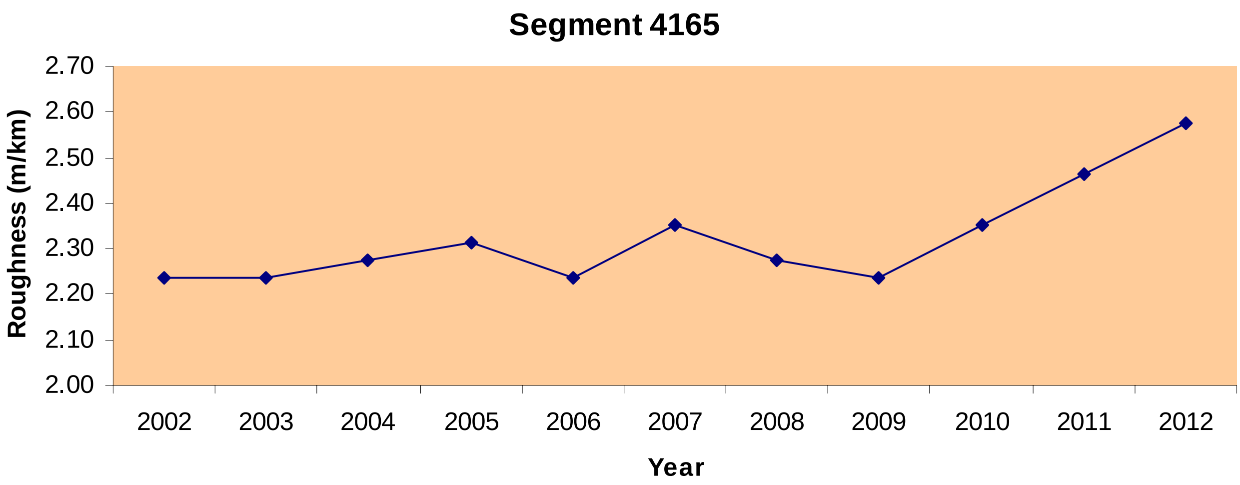


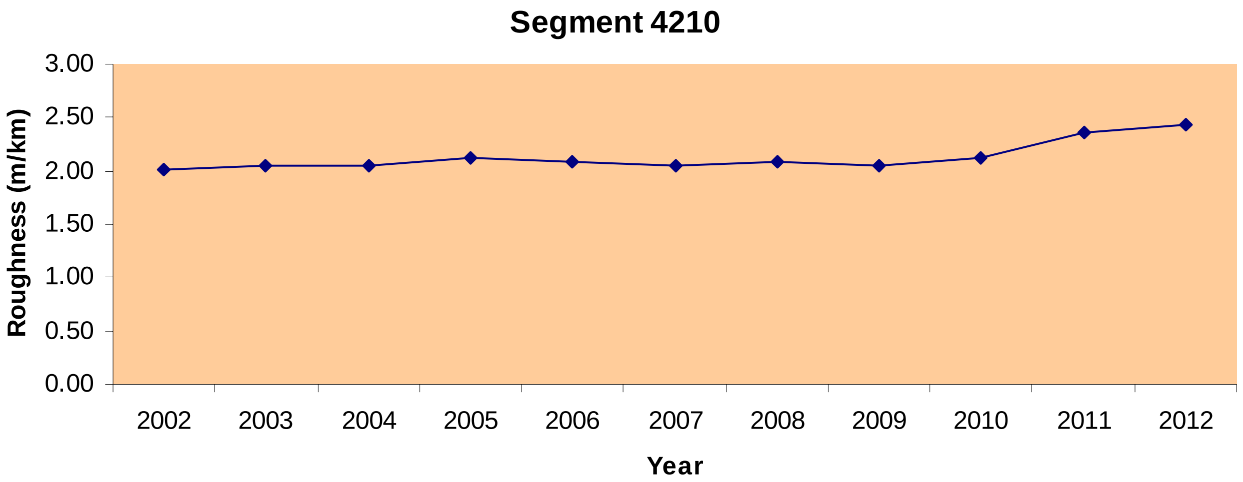
Segment 1335

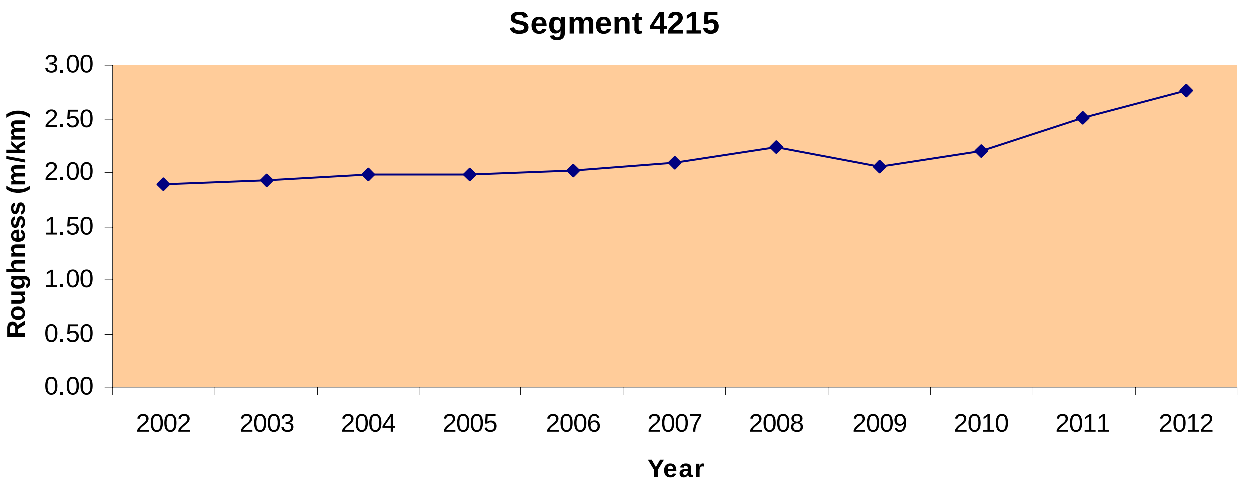


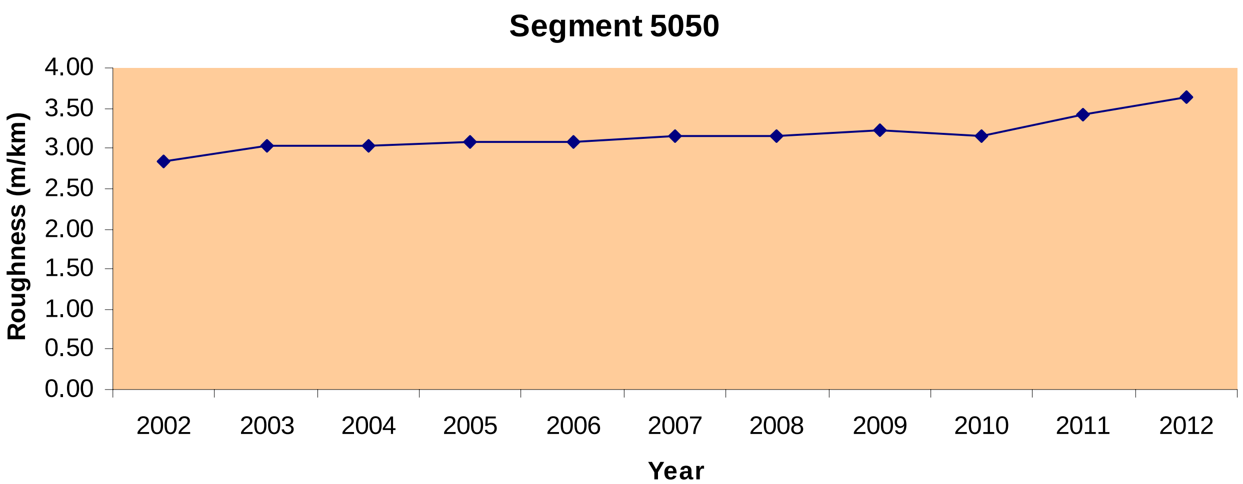

Segment 4065
Roughness (m/km)
2.90
2.80
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

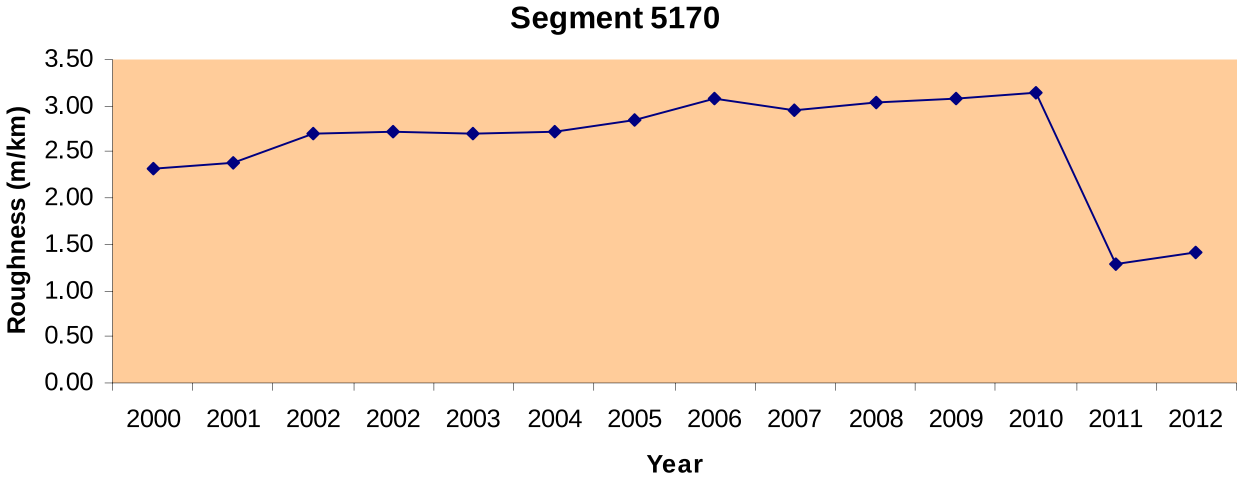

Segment 4085
Roughness (m/km)
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

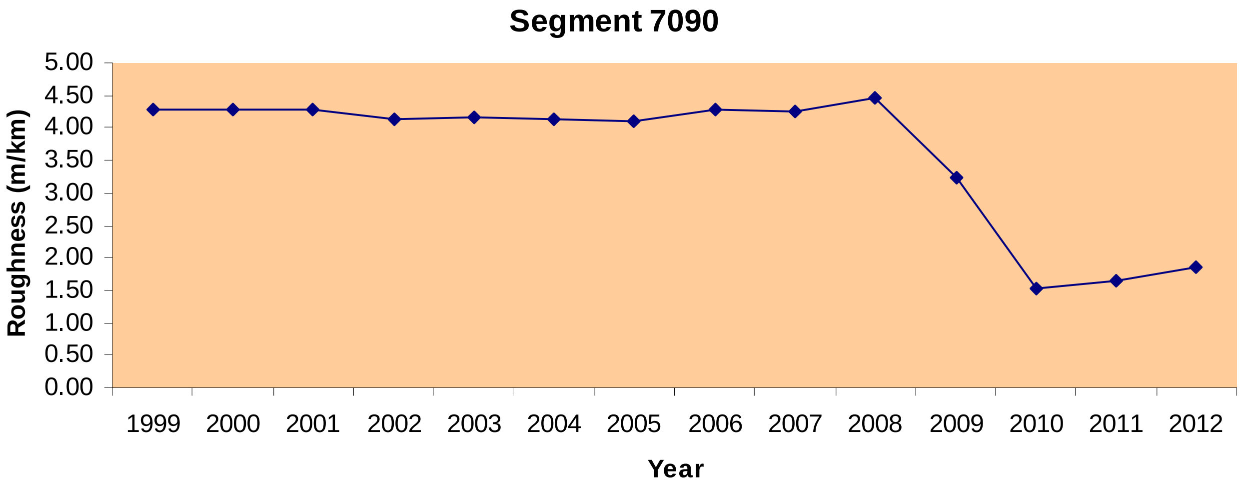

Segment 4165
Roughness (m/km)
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

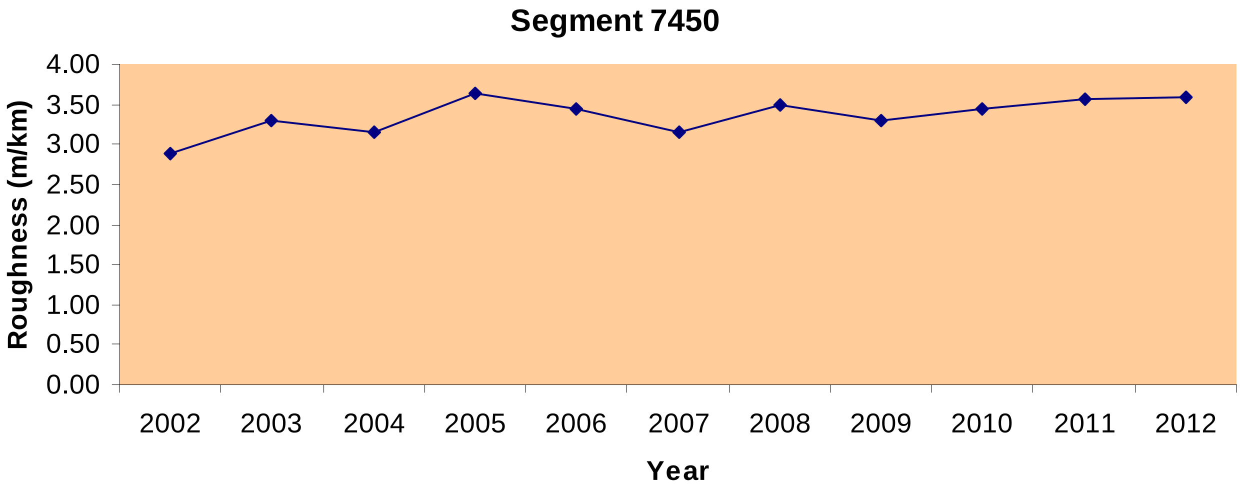

Segment 4210
Roughness (m/km)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

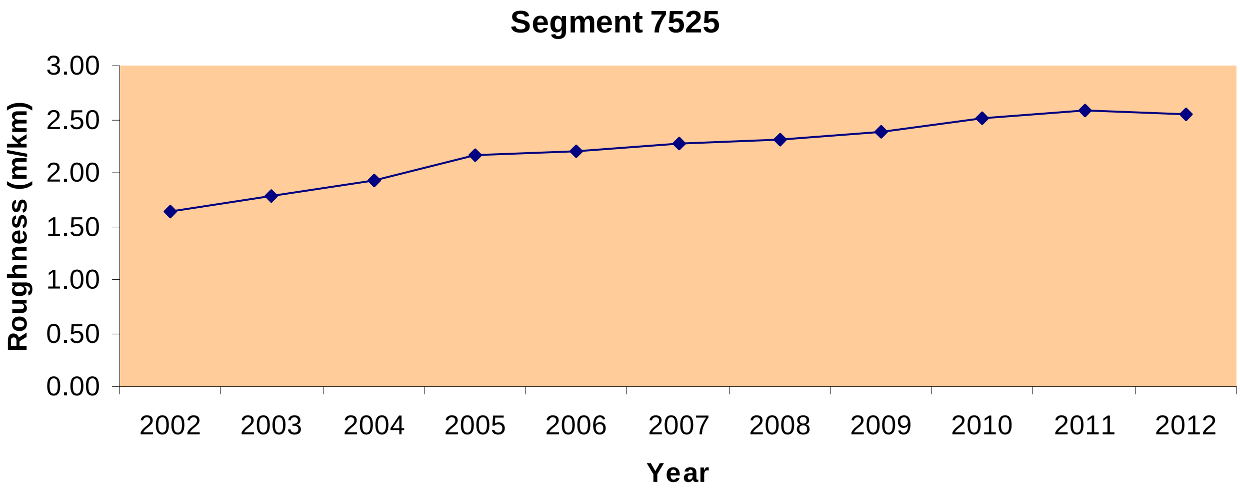

Segment 4215
Roughness (m/km)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

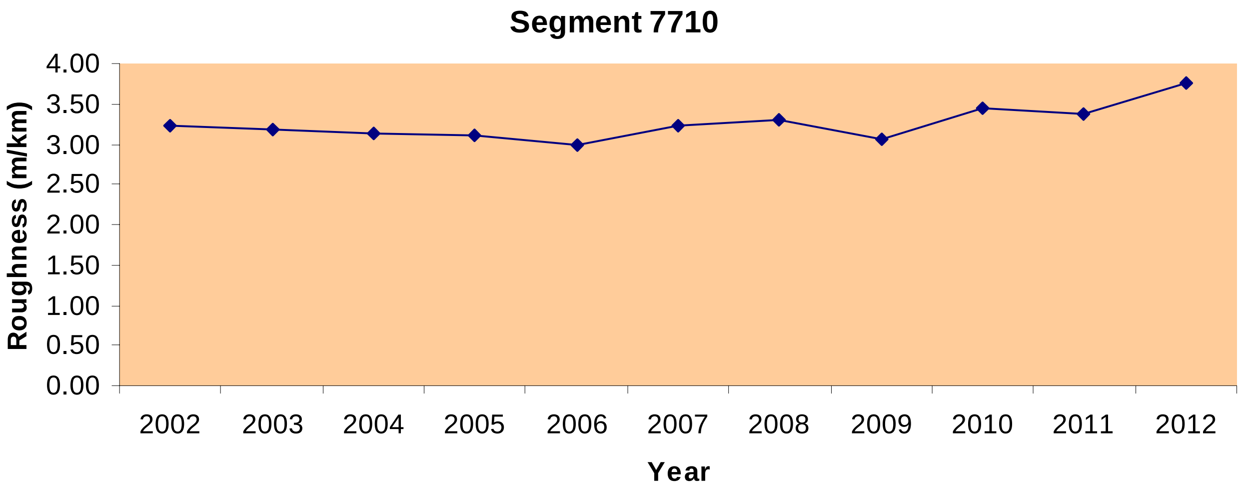

Segment 5050
Roughness (m/km)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

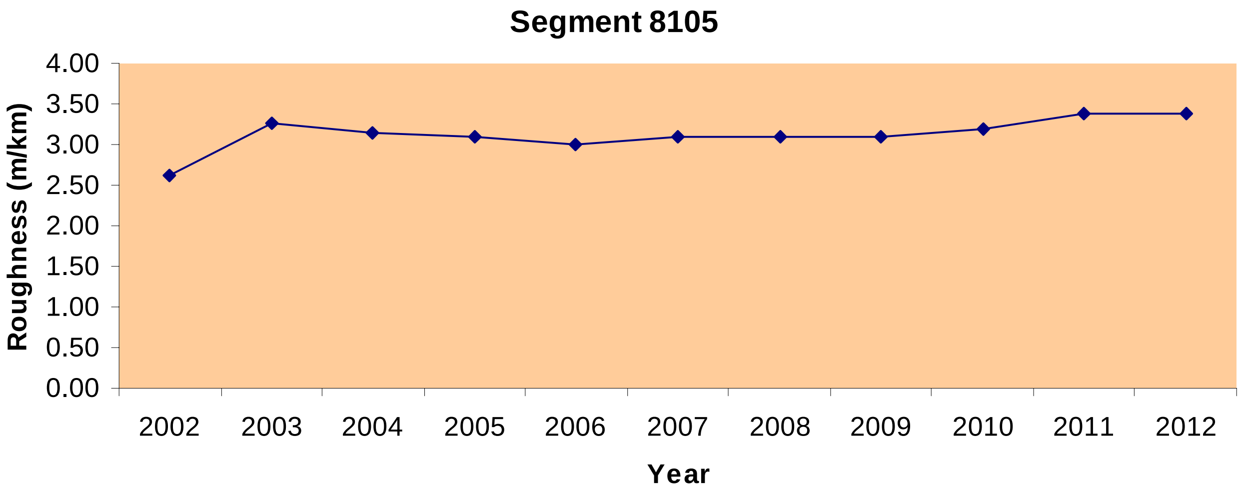

Segment 5170
Roughness (m/km)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2000 2001 2002 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Year

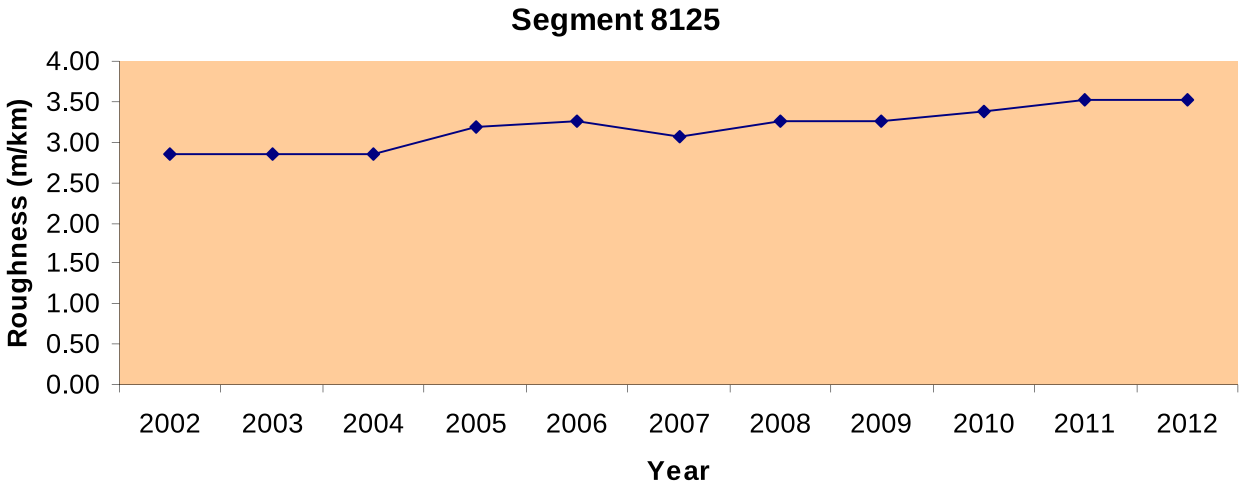

Segment 7090
Roughness (m/km)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Year

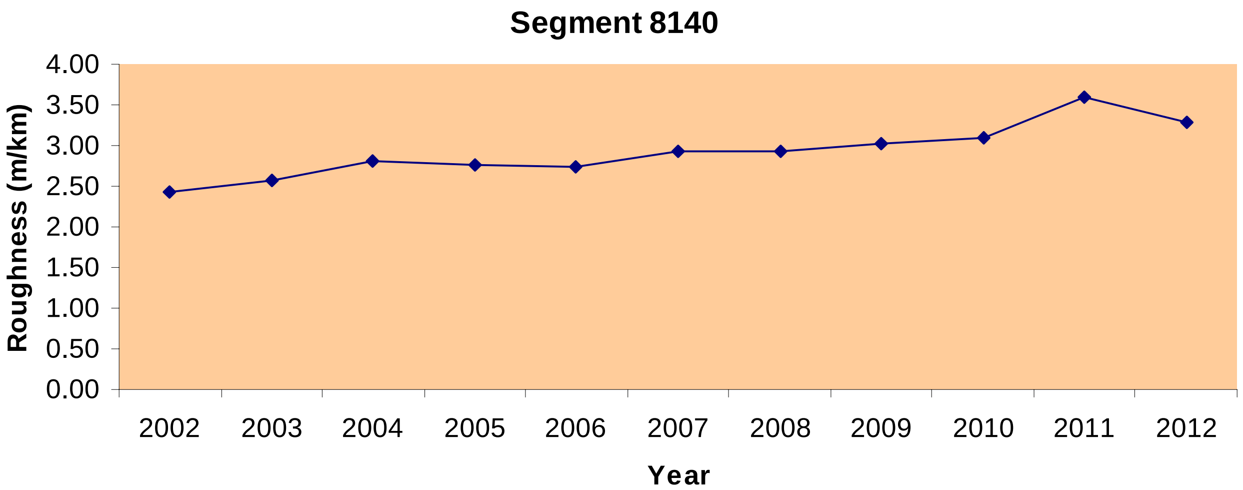

Segment 7450
Roughness (m/km)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Year

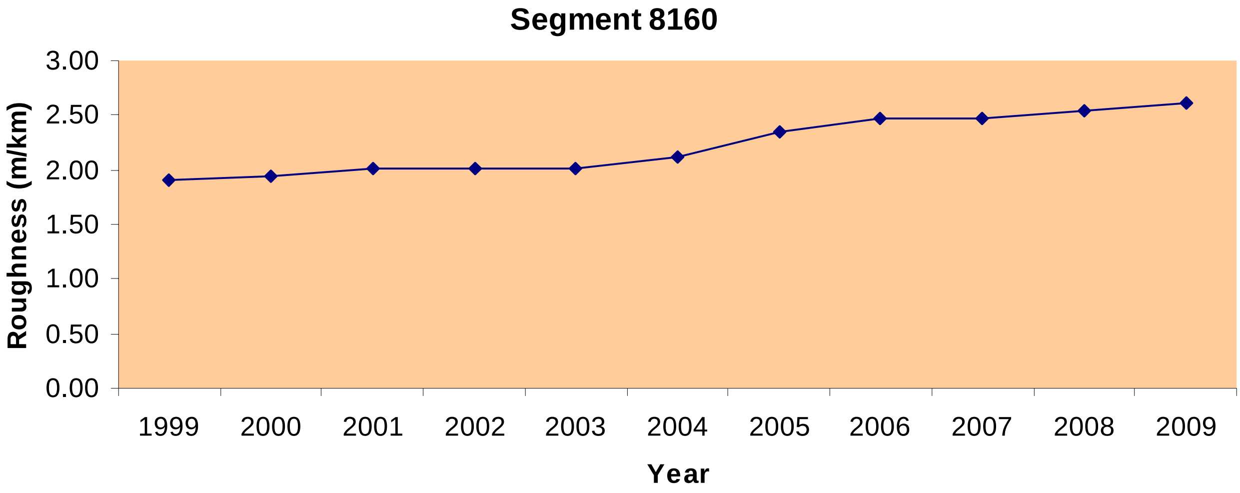

Segment 7525
Roughness (m/km)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

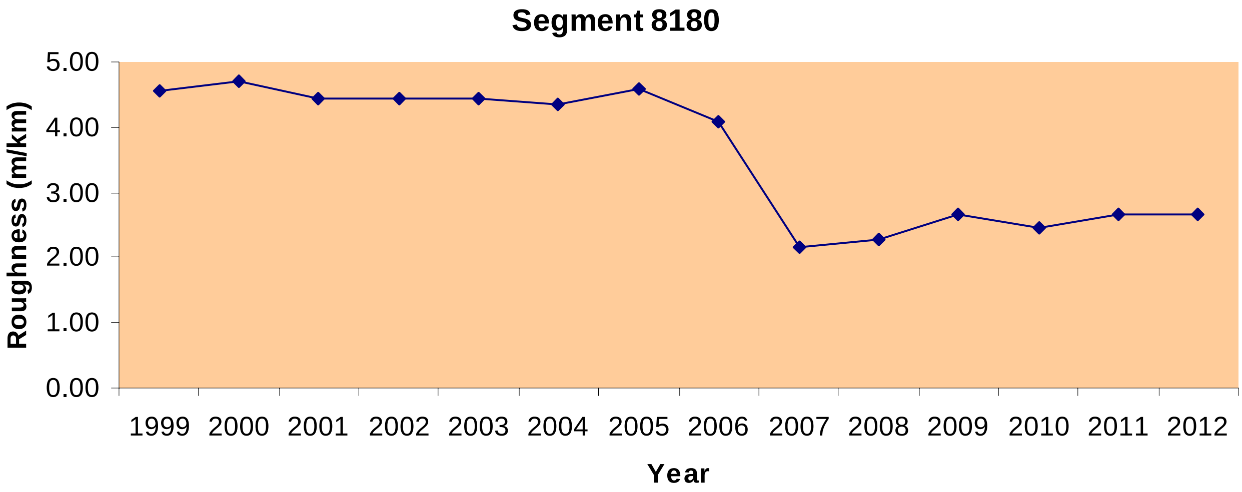

Segment 7710
Roughness (m/km)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

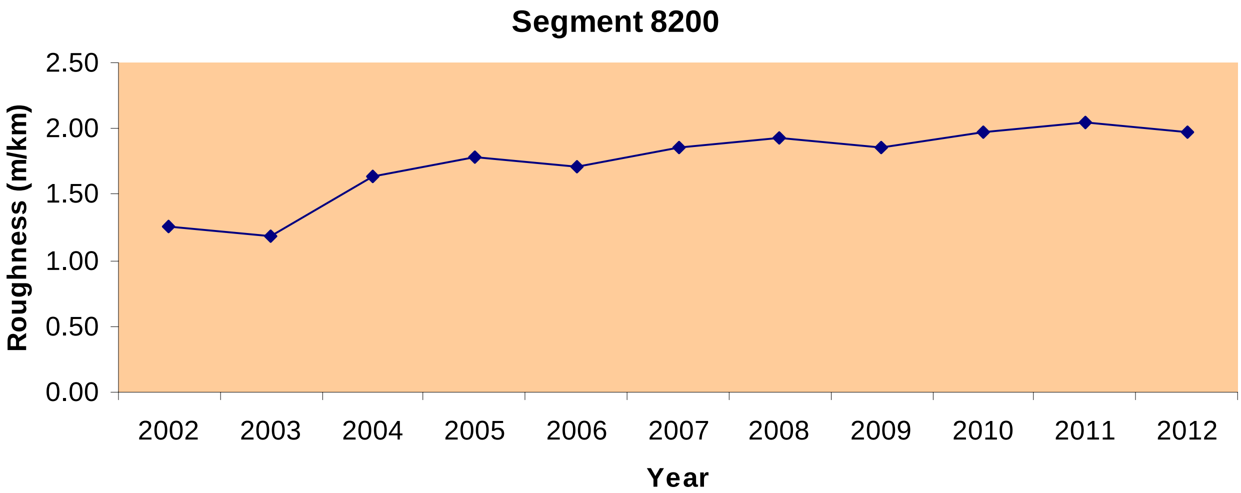

Segment 8105
Roughness (m/km)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

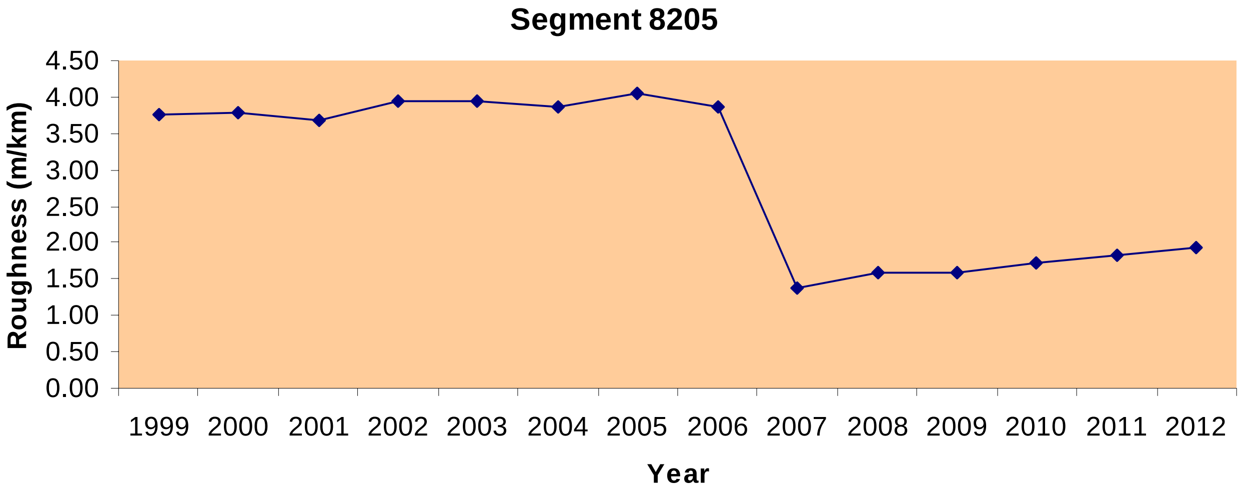

Segment 8125
Roughness (m/km)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

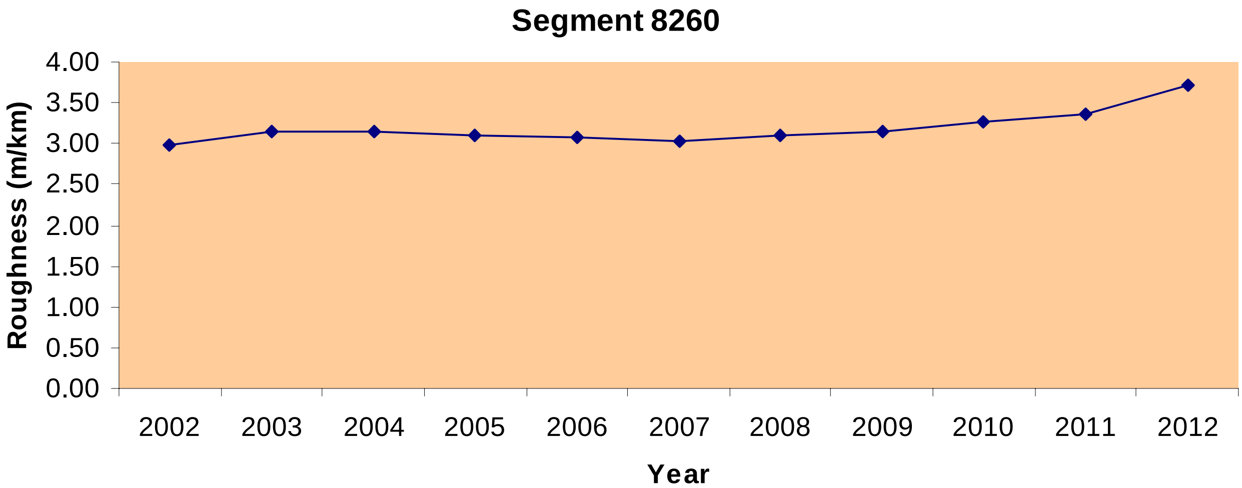

Segment 8140
Roughness (m/km)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year


Segment 8160
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Roughness (m/km)
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year


Segment 8180
5.00
4.00
3.00
2.00
1.00
0.00
Roughness (m/km)
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year


Segment 8200
2.50
2.00
1.50
1.00
0.50
0.00
Roughness (m/km)
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year


Segment 8205
Roughness (m/km)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year


Segment 8260
Roughness (m/km)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year